PRELIMINARY TECHNICAL SUPPORT DOCUMENT: ENERGY EFFICIENCY PROGRAM FOR CONSUMER PRODUCTS AND COMMERCIAL AND INDUSTRIAL EQUIPMENT:

GENERAL SERVICE LAMPS

December 1, 2014

U.S. Department of Energy
Assistant Secretary
Office of Energy Efficiency and Renewable Energy
Building Technologies Program
Appliances and Commercial Equipment Standards
Washington, DC 20585

This document was prepared for the U.S. Department of Energy
by staff members of
Navigant Consulting, Inc.
and
Lawrence Berkeley National Laboratory

EXECUTIVE SUMMARY

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

ES.1 OVERVIEW OF PRELIMINARY ANALYSIS ACTIVITIES

Section 6295(o)(3)(B) of 42 U.S.C. requires the U.S. Department of Energy (DOE) to establish energy conservation standards (ECS) that achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified. Pursuant to Energy Policy and Conservation Act (EPCA), DOE has the discretion to issue energy conservation standards for general service lamps (GSLs). (42 U.S.C. 6295(i)(6)(A)-(B)) DOE is currently conducting an ECS rulemaking for GSLs. This technical support document presents preliminary analyses in support of that rulemaking. This executive summary presents key results of those analyses and delineates issues on which DOE seeks comment.

Figure ES.1.1 presents a summary of the analytical components of the standards-setting process and illustrates how key results are generated. The focal point of the figure is the center column, labeled “Analyses.” The columns labeled “Key Inputs” and “Key Outputs” show how the analyses fit into the process and how they relate to each other. Key inputs are the types of data and other information that the analyses require. Some key information is obtained from public databases; DOE collects other inputs from interested parties or persons having special knowledge and expertise. Key outputs are analytical results that feed directly into the standards-setting process. The issues on which DOE seeks comment from interested parties derive from the key results that are generated by the preliminary analysis. Arrows connecting analyses show the types of information that feed from one analysis to another.

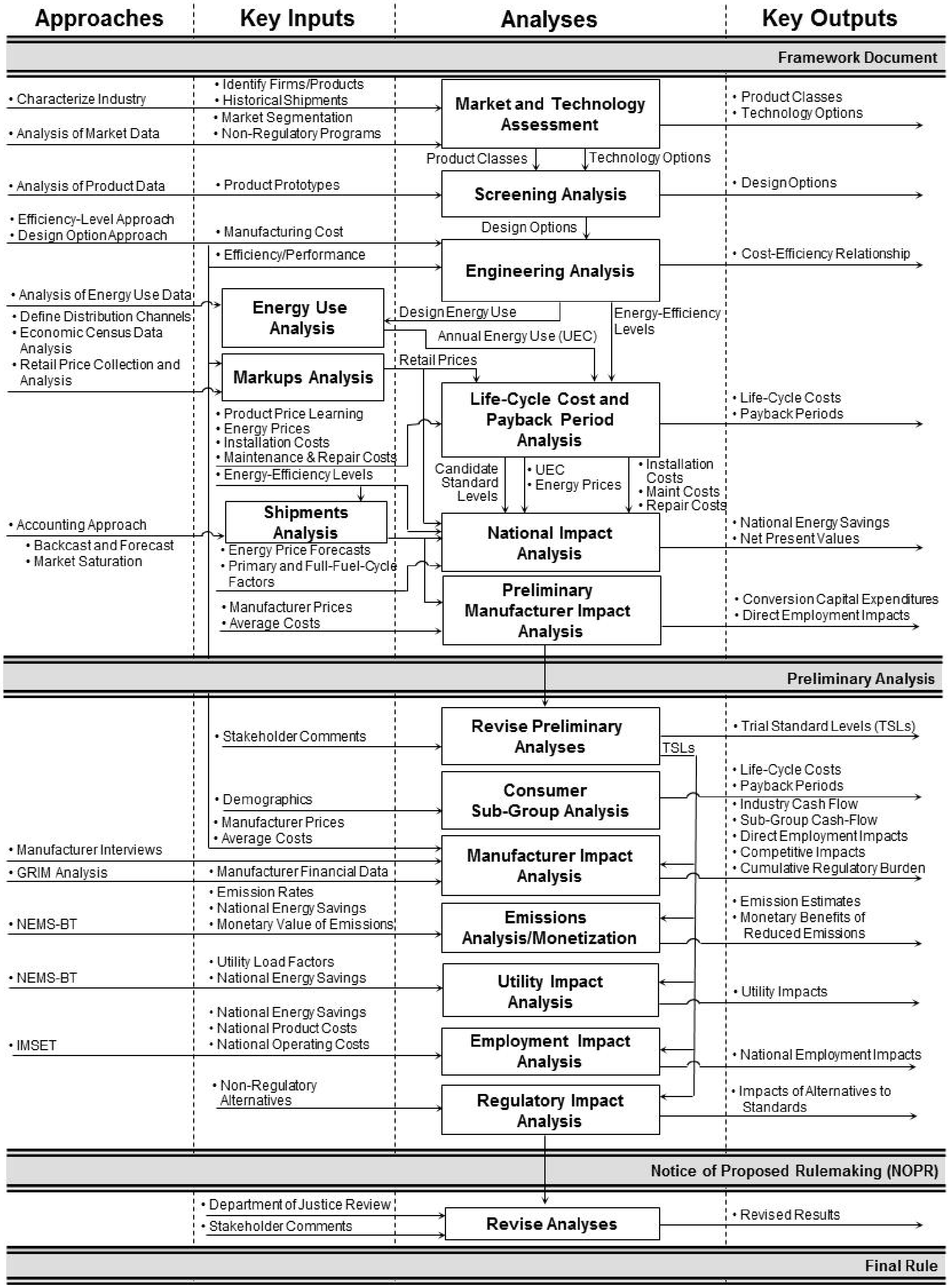

Figure ES.1.1 Flow Diagram of Analyses for the GSL Rulemaking Process

ES.2 KEY RESULTS OF THE ANALYSIS

ES.2.1 Determination of Scope

The Energy Policy and Conservation Act definition of “general service lamp” includes general service incandescent lamps (GSILs), compact fluorescent lamps (CFLs), general service lighting-emitting diode (LED) lamps, organic light-emitting diode (OLED) lamps, and any other lamps that the Secretary determines are used to satisfy lighting applications traditionally served by general service incandescent lamps. However, the term general service lamp does not include any GSIL excluded from the “general service incandescent lamp” definition, or any general service fluorescent lamp or incandescent reflector lamp. 10 CFR 430.2 Chapter 2 of this technical support document (TSD) discusses each of the lamp types included in the definition of general service lamp in more detail.

In summary, DOE is considering establishing standards in this rulemaking for the following lamps:

- Integrated, non-reflector, medium screw base lamps with a lumen output between 310 and 2,600 lumens;
- GU24 base, non-reflector lamps with a lumen output between 310 and 2,600 lumens; and
- Non-integrated, non-reflector, pin base, CFLs with a lumen output between 310 and 2,600 lumens.

Standards would not apply to the follow lamp types:

- OLED lamps
- Mercury vapor lamps
- Incandescent reflector lamps
- General service fluorescent lamps
- Light fixtures
- Appliance lamps
- Black light lamps
- Bug lamps
- Colored lamps
- Infrared lamps
- Marine signal lamps
- Mine service lamps
- Plant light lamps
- Sign service lamps
- Silver bowl lamps
- Showcase lamps
- Traffic signal lamps
- General service incandescent lamps that are:
    - A left-hand thread lamp
    - A marine lamp

- A reflector lamp
- A rough service lamp
- A shatter-resistant lamp (including a shatter-proof lamp and a shatter-protected lamp)
- A 3-way incandescent lamp
- A vibration service lamp
- A G shape lamp (as defined in ANSI C78.20) (incorporated by reference; see §430.3) and ANSI C79.1-2002 (incorporated by reference; see §430.3) with a diameter of 5 inches or more
- A T shape lamp (as defined in ANSI C78.20) (incorporated by reference; see §430.3) and ANSI C79.1-2002 (incorporated by reference; see §430.3) and that uses not more than 40 watts or has a length of more than 10 inches
- A B, BA, CA, F, G16-1/2, G-25, G30, S, or M-14 lamp (as defined in ANSI C79.1-2002) (incorporated by reference; see §430.3) and ANSI C78.20 (incorporated by reference; see §430.3) of 40 watts or less.

ES.2.2 Market and Technology Assessment

A market and technology assessment characterizes the relevant markets and technology options. DOE addresses (1) manufacturer market share and characteristics, (2) existing regulatory and non-regulatory initiatives for improving product efficacy, and (3) trends in product characteristics and retail markets. This information provides data and resource material throughout the analysis.

In its market assessment, which is described in chapter 3 of this TSD, DOE qualitatively and quantitatively characterizes the structure of the GSL market. DOE reviewed existing literature and spoke with manufacturers to gain an understanding of the GSL industry in the United States. Industry publications (*e.g.*, manufacturer catalogs, trade journals), government agencies, and trade organizations provided the bulk of the information. Using this information, DOE assessed the overall state of the industry, GSL manufacturing and market shares, shipments by lamp type, general technical information on GSLs, and industry trends.

The technology assessment centers on understanding how energy is used by the product, and what changes are possible that would reduce energy consumption. Measures that improve the energy efficiency of the products are called technology options, and they are based on existing technologies, as well as working prototypes. DOE develops a list of technology options, which are then considered against four screening criteria discussed in the following section. Those technology options that pass the four screening criteria are called design options and will be considered as ways to improve the efficacy of the products in the engineering analysis and will assist DOE in determining the maximum technologically feasible design.

DOE reviewed manufacturer catalogs, recent trade publications, technical journals, and patent filings to determine technology options. In chapter 3 of this TSD, DOE presents the technology options and applicable lamp types that DOE has preliminarily identified to improve the efficacy of general service lamps.

DOE generally divides covered products into product classes by the type of energy used, capacity, or other performance-related features that affect efficacy. Different energy conservation standards may apply to different product classes. (42 U.S.C. 6295(q)) In this preliminary analysis, DOE is considering ballast location and lumen package as product class setting factors for GSLs. DOE is considering establishing the three product classes shown in Table ES.2.1. See chapter 3 of this TSD for further discussion.

Table ES.2.1 Product Classes for GSLs

Lamp Type	Lumen Output
Integrated GSLs (*e.g.*, self-ballasted CFL, integrated LED lamp)	310-1,999
	2,000-2,600
Non-Integrated GSLs (*e.g.*, externally ballasted CFL)	310-2,600

ES.2.3 Screening Analysis

DOE developed technology options for enhancing efficacy of lamps used in GSLs in the technology assessment. In consultation with interested parties, DOE reviewed the options to assess whether the options are technologically feasible; practicable to manufacture, install, and service; would adversely impact product utility or availability; or would have adverse impacts on health and safety. See chapter 4 of this TSD for details.

ES.2.4 Engineering Analysis

In the engineering analysis, DOE chose certain product classes as representative and concentrated its analytical effort on those classes. Generally, DOE selected representative product classes based on the highest shipment volumes, although it also considered unique performance characteristics as appropriate. DOE then chose appropriate baseline models and identified more efficacious replacements. A baseline model is typically the most common, least efficacious product sold in a given product class. See chapter 5 of this TSD for details. Candidate standard levels (CSLs) were developed using catalog data and were analyzed against publicly available compliance and testing verification databases when available.

DOE is considering an equation-based standard for efficacy that varies based on lumen output. DOE is considering the following equation form to develop CSLs for the integrated GSLs product classes:

$$Efficacy = A - 29.42 * 0.9983^{Lumens}$$

Equation ES.2.1

Where:
Efficacy = minimum efficacy requirement,
Lumens = measured lumen output, and
A = an adjustment variable defined for each CSL.

DOE is considering the following equation form to develop CSLs for the non-integrated GSLs product class:

$$Efficacy = A - 25.00 * 0.9989^{Lumens}$$

Equation ES.2.2

Where:
Efficacy = minimum efficacy requirement,
Lumens = measured lumen output, and
A = an adjustment variable defined for each CSL.

Table ES.2.2 presents the CSLs identified in the engineering analysis for the integrated and non-integrated product classes.

Table ES.2.2 Candidate Standard Levels for GSL Representative Product Classes

Representative Product Class	Candidate Standard Level	Efficacy
		lm/W
Integrated Low Lumen (310 – 1,999 lumens)	Baseline (<15 W)*	45 lm/W
	CSL 1	67.6-29.42*0.9983^Lumens
	CSL 2	74.2-29.42*0.9983^Lumens
	CSL 3	80.2-29.42*0.9983^Lumens
	CSL 4	87.5-29.42*0.9983^Lumens
	CSL 5	90.8-29.42*0.9983^Lumens
Integrated High Lumen (2,000 – 2,600 lumens)	Baseline (≥15 W)**	60 lm/W
	CSL 1	67.6-29.42*0.9983^Lumens
	CSL 2	74.2-29.42*0.9983^Lumens
Non-Integrated (310 – 2,600 lumens)	Baseline†	45 lm/W
	CSL 1	72.6-25.00*0.9989^Lumens

* Baseline corresponds to the highest existing standard for medium base CFLs with wattage less than 15 W.

** Baseline corresponds to the highest existing standard for medium base CFLs with wattage greater than or equal to 15 W.

† Baseline corresponds to the backstop requirement of 45 lumens per watt for GSLs because no existing standards apply for the non-integrated product class. (*See* 42 U.S.C. 6295(i)(6)(A)(ii) and (i)(6)(A)(v))

ES.2.5 Product Price Determination

For this rulemaking, DOE estimated the end-user price of GSLs directly, rather than develop manufacturer selling prices (MSPs) from a bill of materials and manufacturer markup analysis. DOE selected this methodology because it is difficult to reverse-engineer GSLs, which are not easily disassembled.

Because blue book price data were not available for all GSLs, DOE was unable to utilize blue book prices to develop end-user prices in the preliminary analysis. Therefore, DOE reviewed and used publicly available retail prices for GSLs to develop end-user prices for each CSL. In its review of price data, DOE observed a range of end-user prices paid for a lamp, depending on the distribution channel through which the lamp is purchased. DOE identified four main distribution channels (large consumer-based distributors [*e.g.*, home centers], small consumer-based distributors [*e.g.*, drug stores], electrical distributors, and state procurement).

DOE then developed an average weighted end-user price using estimated percentage of shipments that go through each distribution channel obtained in interviews with manufacturers. Additionally, DOE assessed and accounted for the general price trends in relation to efficacy for all GSLs. Once DOE calculates end-user prices, DOE adds sales tax and, if appropriate, installation costs to derive the total, installed end-user cost. See chapter 6 of this TSD for details.

ES.2.6 Energy Use Analysis

The purpose of the energy use analysis is to determine the annual energy consumption of GSLs and to assess the energy savings potential of increased lamp efficiency. The energy use analysis provides the basis for developing the energy savings used in the life-cycle cost (LCC) analysis and subsequent analyses. DOE's test procedures provide standardized results that can serve as the basis for comparing the performance of different products used under the same conditions, but actual usage in the field may differ from usage estimated by the test procedure.

To determine the energy use for GSLs in residential and commercial installations, DOE combined information on power consumption of the representative lamps from the engineering analysis (chapter 5 of this TSD) with information on operating hours of those lamp types. For the residential sector, DOE used metered data of daily hours of use for regions where the data were available; for all other regions, DOE used daily hours of use values based on the metered data from adjacent regions. For the commercial sector, DOE used average daily hours of use data from a survey of commercial lighting energy use. For both the residential and commercial sectors, DOE included the impact of lighting controls, such as dimmers, timers, or occupancy sensors (hereafter referred to simply as "controls"), in the energy use calculation for the fraction of GSLs installed in locations with controls. To illustrate the impact that controls have on energy use, Chapter 7 also provides energy use results assuming that no GSLs are used with controls.

Table ES.2.3, Table ES.2.4, and Table ES.2.5 show the average annual energy use of GSLs in each of the product classes at each CSL that DOE considered in this rulemaking and the annual energy savings with respect to the baseline (CSL 0). All values are in units of kilowatt-hours (kWh) per year. Chapter 7 provides more details on the methods, data sources, and assumptions used for the energy use analysis.

Table ES.2.3 Average Annual Energy Use and Savings per Unit for Integrated Low Lumen (< 2,000 lm) GSLs

CSL	Residential		Commercial	
	Energy Use (kWh/yr)	**Savings (kWh/yr)**	**Energy Use (kWh/yr)**	**Savings (kWh/yr)**
0	11.6	0.0	46.3	0.0
1	10.8	0.8	43.0	3.3
2	8.9	2.7	39.7	6.6
3	8.2	3.4	36.4	9.9
4	7.4	4.2	33.1	13.2
5	7.1	4.6	31.4	14.9

Table ES.2.4 Average Annual Energy Use and Savings per Unit for Integrated High Lumen (≥ 2,000 lm) GSLs

CSL	Residential		Commercial	
	Energy Use (kWh/yr)	Savings (kWh/yr)	Energy Use (kWh/yr)	Savings (kWh/yr)
0	26.6	0	106.0	0.0
1	24.9	1.7	99.2	6.6
2	24.1	2.5	95.9	9.9

Table ES.2.5 Average Annual Energy Use and Savings per Unit for Non-Integrated GSLs

CSL	Residential		Commercial	
	Energy Use (kWh/yr)	Savings (kWh/yr)	Energy Use (kWh/yr)	Savings (kWh/yr)
0	24.9	0	99.2	0.0
1	24.9	0	99.2	0.0
	20.3	4.6	80.7	18.4

ES.2.7 Life-Cycle Cost and Payback Period Analyses

The impacts of energy conservation standards on consumers often include a change in operating expense (usually decreased energy expenses) and a change in purchase price (usually increased). The LCC of a product is the cost it incurs over its lifetime, taking into account both purchase price and operating expenses. The payback period (PBP) represents the time it takes to recover the additional installed cost of the more-efficient products through operating expense savings.

DOE analyzed the net effect on consumers by calculating the LCC and PBP using inputs from the engineering performance data, the product price determination, and the energy use and shipments analyses. Inputs to the LCC calculation include the installed cost to the consumer, operating expenses, lifetime of the product, discount rates. In addition, it uses base case and standards case efficiency distributions derived in the shipments analysis using a consumer choice model.

For the integrated low-lumen product class (the only product class that includes LEDs), the LCC and PBP analysis samples GSLs from four lumen bins according to their market distribution, because of the high variability in LED prices across lumen ranges. The prices and efficacies from the 60 W-equivalent lamps in the engineering analysis results were used to project prices and efficacies for the other lumen bins using online retailer data and the efficacy-to-lumen relationship developed in the engineering analysis.

DOE accounted for variability in operating hours in the residential sector by generating distributions for daily hours of use derived from a residential metering study. For the commercial sector, DOE developed triangular daily hours of use distributions corresponding to ±20 percent of the average daily hours of use derived in the energy use analysis. Lamp lifetime was based on the sampled hours of use, considering the lamp's rated lifetime, renovation/retrofit rates, and the effects of on-cycle length on CFL lifetimes. To account for differences in the lifetime of lamps at different efficiency levels, DOE incorporated a residual value in the LCC calculation. Chapter 8 of this TSD provides a detailed description of the LCC and PBP inputs, analysis, and results.

Table ES.2.6 shows the base case efficiency distribution used for each product class in the compliance year.

Table ES.2.6 Market Share of each Candidate Standard Level in the Base Case

	Residential			**Commercial**		
CSL	**Integrated**		**Non-Integrated**	**Integrated**		**Non-Integrated**
	Low Lumen (< 2,000 lm)	**High Lumen (≥ 2,000 lm)**		**Low Lumen (< 2,000 lm)**	**High Lumen (≥ 2,000 lm)**	
0	1.1%	21.4%	65.4%	0.1%	21.4%	65.4%
1	48.5%	31.8%	30.5%	53.8%	31.8%	30.5%
			4.1%			4.1%
2	0.5%	46.8%		0.0%	46.8%	
3	1.7%			0.1%		
4	21.0%			17.5%		
5	27.1%			28.4%		

Table ES.2.7 through Table ES.2.12 present the key findings from the analyses. These findings include, for the compliance year: (1) the average LCC of each CSL, (2) the average PBP relative to the baseline product (CSL 0), (3) average LCC savings that result from a standard set at a given CSL, based on the base-case and standards-case efficiency distributions, and (4) the share of consumers that would experience a net cost (*i.e.*, negative LCC savings). Because the lighting market is in the process of undergoing significant transformation, DOE also calculated LCC results for 2025, five years after the compliance year. Details and results of this calculation can be found in Chapter 8 of this TSD.[a]

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[a] Chapter 8 also provides LCC savings estimates relative to the base case efficiency distribution for a "roll-up" scenario, in which all consumers who purchased a lamp in the base case that is less efficient than the minimum allowable efficiency in the standards case purchase the least efficient lamp available in the standards case.

Table ES.2.7 LCC and PBP Results by Efficiency Level for Integrated Low Lumen (< 2,000 lm) GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	6.2	1.6	5.6	11.8	---	8.8
1	4.0	1.5	5.2	8.8	0	9.8
2	34.9	1.3	4.6	23.1	99.6	17.9
3	22.2	1.2	4.2	16.0	40.5	17.9
4	7.5	1.1	3.8	8.5	2.6	17.9
5	7.2	1.0	3.6	8.1	1.7	17.9
Commercial Sector						
0	7.0	6.9	17.7	24.8	---	2.2
1	4.4	6.4	16.5	20.2	0	2.8
2	45.7	6.0	15.3	37.9	40.0	6.3
3	29.1	5.5	14.0	28.4	15.3	6.3
4	7.7	5.0	12.8	17.2	0.4	6.3
5	7.3	4.8	12.2	16.4	0.2	6.3

Note: The LCC results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the baseline product.

Table ES.2.8 Average LCC Savings for Integrated Low Lumen (< 2,000 lm) GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	0%	0.0
2	27%	-0.1
3	27%	0.0
4	25%	0.3
5	22%	0.5
Commercial Sector		
0	0.0%	0.0
1	0.0%	0.0
2	1.1%	1.7
3	1.1%	1.7
4	0.8%	1.7
5	0.3%	2.1

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

Table ES.2.9 LCC and PBP Results by CSL for Integrated High Lumen (≥ 2,000 lm) GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	9.7	3.6	12.8	22.5	---	8.8
1	10.1	3.4	12.0	22.1	1.5	8.8
2	10.8	3.3	11.6	21.3	3.1	9.8
Commercial Sector						
0	9.7	12.4	31.6	41.5	---	2.2
1	10.1	11.6	29.7	39.8	0.4	2.2
2	10.8	11.2	28.7	37.6	0.9	2.8

Note: The LCC results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the baseline product.

Table ES.2.10 Average LCC Savings for Integrated High Lumen (≥ 2,000 lm) GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	6%	0.2
2	13%	0.5
Commercial Sector		
0	0.0%	0.0
1	0.2%	0.5
2	1.2%	1.7

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

Table ES.2.11 LCC and PBP Results by CSL for Non-Integrated GSLs

CSL	Average Costs 2014$				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	13.2	3.4	11.9	25.2	---	8.8
1	14.2	3.4	11.9	22.8	N/A	11.6
	15.7	2.8	9.7	21.1	4.0	12.5
Commercial Sector						
0	13.2	11.6	29.6	42.9	---	2.2
1	14.2	11.6	29.6	39.0	N/A	4.1
	15.7	9.4	24.1	33.3	1.2	5.0

Note: The LCC results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the baseline product.

Table ES.2.12 Average LCC Savings for Non-Integrated GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	**Average Savings (2014$)**
Residential Sector		
0	0%	0.0
1	12%	1.6
Commercial Sector		
0	0.0%	0.0
1	5.4%	2.6

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

ES.2.8 Shipments Analysis

Shipments projections are used to calculate the national impacts of standards on energy use, net present value (NPV), and future manufacturer cash flows. The shipments model has three main interacting elements: (1) a lamp demand module, which estimates total shipments of GSLs for each year of the analysis period; (2) a price learning module, which projects future prices based on historic price trends; and (3) a consumer choice module, which assigns shipments to product classes and efficacy levels based on sector-specific consumer sensitivities to lamp price, energy consumption, lifetime, and mercury content. Details of the model DOE used to estimate shipments in this rulemaking, including the consumer-choice model, are described in chapter 9 of this TSD.

For the reference scenario, which reflects DOE’s best estimate of all variables, DOE estimated that integral LED luminaires would grow into the market for traditional GSL luminaires according to a Bass diffusion curve, resulting in the displacement of 15 percent of the market for traditional GSL luminaires at the end of the analysis period. To determine GSL price trends, DOE used a learning curve approach, in which the learning rate is defined as the percentage drop in price with each doubling in cumulative production. DOE estimated that LED GSLs will experience learning at the historic CFL-GSL learning rate during the analysis period, for reasons detailed in Appendix 9A of this TSD. The reference scenario assumes that rare earth oxide prices remain constant at their current price. Lamp lifetime distributions in the reference scenario were developed from the rated lifetimes of lamps, considering sector-specific hours of use distributions, renovation/retrofit rates, and the effects of on-cycle length on CFL lifetimes.

DOE also developed alternative shipments scenarios in addition to the reference scenario, to reflect uncertainties in certain parameters and to determine the impact of key variables on the rulemaking. DOE analyzed a scenario in which there was no incursion of integral LEDs by the end of the analysis period, and a scenario in which 50 percent of the market for traditional GSL luminaires was displaced at the end of the analysis period. To capture uncertainty in the rate of price decline for LED-GSLs, DOE analyzed two additional scenarios: a scenario where LED GSLs decline in price at the historic LED-GSL learning rate, and a scenario where LED and CFL GSL prices remain constant throughout the analysis period. Given the uncertainty in the future trajectory of rare earth oxide prices, DOE also analyzed a scenario in which rare earth oxide prices are significantly higher. Additionally, DOE analyzed two alternative lifetime scenarios: one in which lamp lifetime was based only on a lamp's rated lifetime and the effects of on-cycle length on CFL lifetimes, without consideration of renovations or retrofits, and another in which LED GSLs were treated like consumer electronics devices and retired much sooner than their rated lifetime. Alternative scenarios are discussed in more detail in appendix 8B and Chapter 9 of this TSD.

Figure ES.2.1 shows the projected total (*i.e.*, residential and commercial) base case shipments by technology type for integrated low lumen GSLs over the analysis period. There is a spike in shipments in 2020 as a result of the backstop prescribed by amendments to EPCA in the Energy Independence and Security Act of 2007 (EISA 2007). Because GSILs are not included in the scope of this rulemaking, DOE assumed that a potential GSL final rule would not yield sufficient energy savings to avoid triggering the EISA 2007 backstop. Therefore, DOE assumed that the EISA 2007 backstop will go into effect concurrently with a potential GSL standard at the compliance date of this rulemaking. (*See* 42 U.S.C. 6295(i)(6)(A)(ii) and (i)(6)(A)(v))

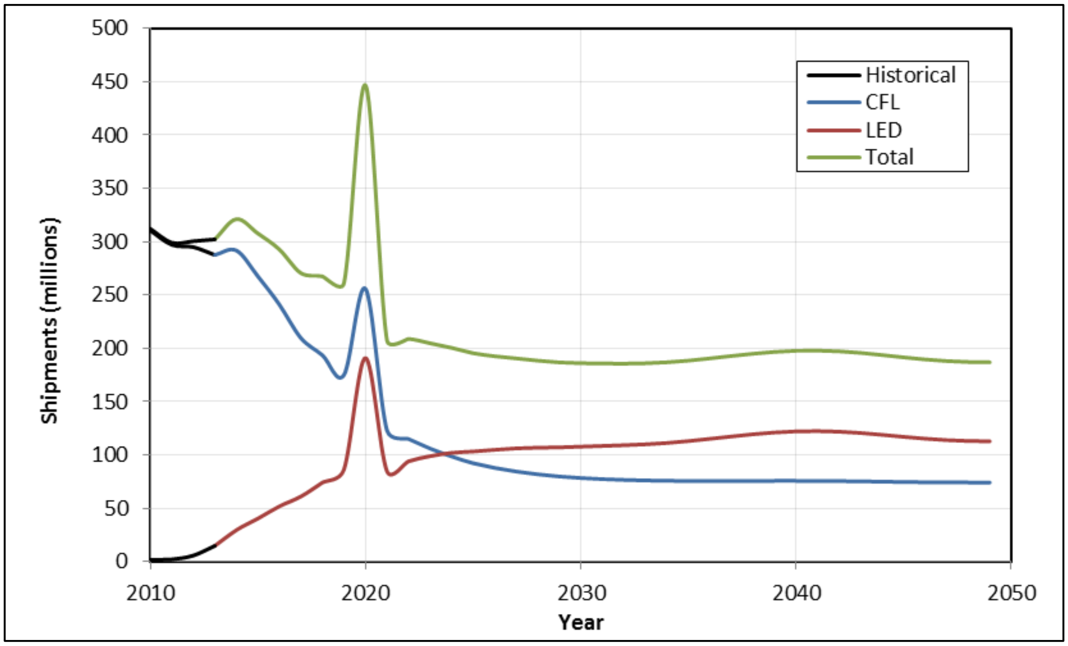

Figure ES.2.1 Projected Total Base Case Shipments by Technology Type for Integrated Low Lumen GSLs (< 2,000 lm)

Figure ES.2.2, Figure ES.2.3, and Figure ES.2.4 show projected total shipments by candidate standard case for integrated low lumen GSLs, integrated high lumen GSLs, and non-integrated GSLs, respectively, over the analysis period.

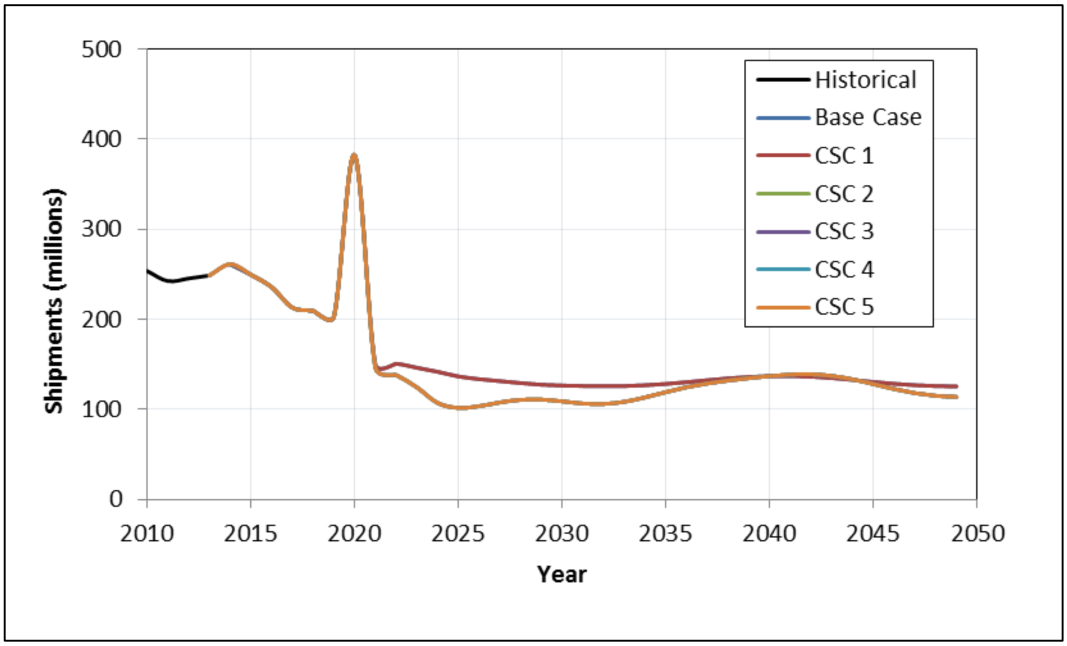

Figure ES.2.2 **Projected Total Shipments by Candidate Standard Case for Integrated Low Lumen GSLs (< 2,000 lm)**

Note: In some cases, the change in shipments between a candidate standards case and the base case or between two candidate standards cases is so small that it is indistinguishable on the figure. In these cases, the higher standard level overwrites the lower.

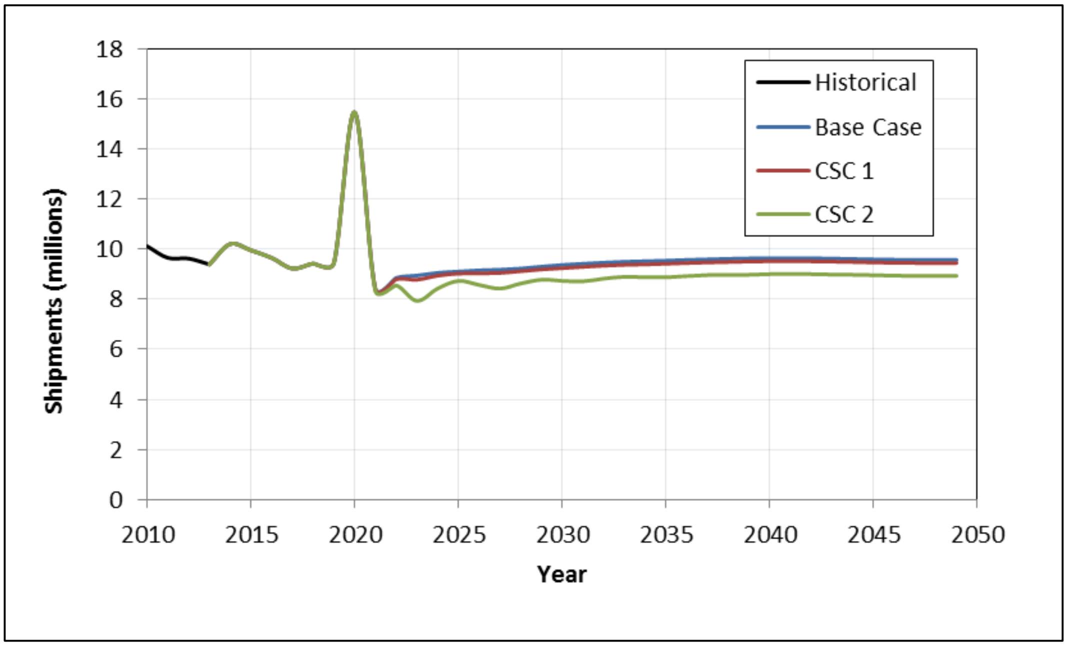

Figure ES.2.3 **Projected Total Shipments by Candidate Standard Case for Integrated High Lumen GSLs (≥ 2,000 lm)**

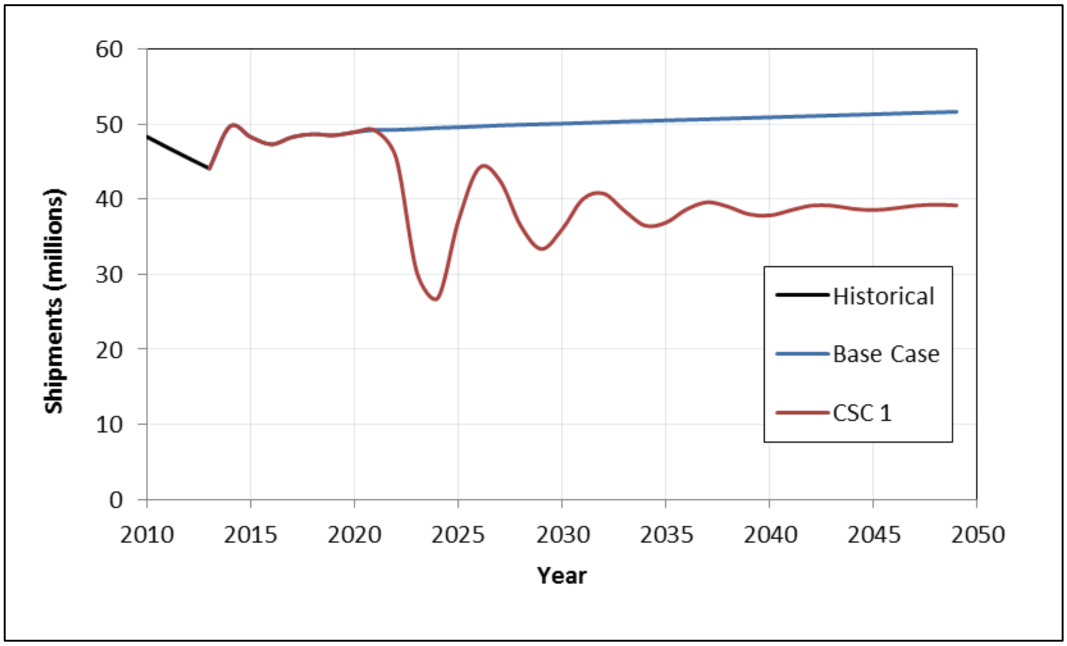

**Figure ES.2.4	Projected Total Shipments by Candidate Standard Case for Non-Integrated GSLs**

ES.2.9 National Impact Analysis

The national impact analysis (NIA) estimates the following national impacts from possible efficiency levels for GSLs: (1) national energy savings; (2) monetary value of the energy savings due to standards; (3) increased total installed costs of the considered products due to standards; and (4) the NPV of the difference between the value of energy savings and increased total installed costs. DOE prepared a spreadsheet model to estimate energy savings and national consumer economic costs and savings resulting from potential standards. In contrast to the LCC and PBP analyses, which use probability distributions for the inputs, the NIA uses average or typical values for inputs.

A key component of DOE's estimates of national energy savings (NES) and NPV is the trend in energy efficiency projected for the base case (without new standards) and each of the standards cases (with new standards). DOE developed a consumer-choice model to estimate the base-case efficiency distribution based on consumer sensitivity to lamp price, energy consumption, lifetime, and mercury content. For its determination of standards-case efficiency distributions, DOE recalculated market shares for efficiency levels using only those efficiency levels that meet or exceed a standard in the year a standard comes into effect and subsequent years.

Several alternative scenarios were analyzed by DOE in the NIA, including alternative scenarios for electricity price projections, the fraction of LED shipments that operate in standby mode, the fraction of GSL shipments with controls in the commercial sector, and rebound effect. DOE assumed no rebound effect in the reference scenario. Chapter 10 of this TSD provides additional details on these scenarios and other aspects of the NIA analysis.

ES.2.9.1 National Energy Savings

DOE calculated annual NES as the difference between national energy consumption in the base case (without new efficiency standards) and under each CSL. Cumulative energy savings are the sum of the annual NES over the period in which products shipped in 2020-2049 are in operation. The NES results shown in Table ES.2.13 are expressed as full-fuel cycle energy savings in quads (quadrillion Btu).

Table ES.2.13 Estimates of Cumulative Full-Fuel Cycle National Energy Savings (quads)

CSL	Integrated		Non-Integrated
	Low Lumen (< 2,000 lm)	High Lumen (≥ 2,000 lm)	
1	0.00	0.01	0.00
2	0.34	0.02	
3	0.34		
4	0.35		
5	0.47		

ES.2.9.1 Net Present Value of Consumer Benefits

DOE calculated net monetary savings in each year as the difference between total savings in operating costs and increases in total equipment costs in the base case and standards cases. DOE calculated savings over the life of the products purchased in the forecast period. The NPV is the difference between the present value of operating cost savings and the present value of increased total installed costs. DOE used discount rates of 7 percent and 3 percent to discount future costs and savings to the present. The NPV results are shown in Table ES.2.14 and Table ES.2.15.

Table ES.2.14 Cumulative Net Present Value of Consumer Benefits at 3% in billion 2014$

EL	Integrated		Non-Integrated
	Low Lumen (< 2,000 lm)	High Lumen (≥ 2,000 lm)	
1	0.02	0.04	1.95
2	1.21	0.09	
3	1.44		
4	1.90		
5	2.52		

Table ES.2.15 Cumulative Net Present Value of Consumer Benefits at 7% in billion 2014$

EL	Integrated		Non-Integrated
	Low Lumen (< 2,000 lm)	High Lumen (≥ 2,000 lm)	
1	0.02	0.02	0.96
2	0.54	0.04	
3	0.67		
4	0.96		
5	1.28		

ES.2.10 Preliminary Manufacturer Impact Analysis

The manufacturer impact analysis (MIA) assesses the potential impacts of energy conservation standards on manufacturers, including effects on expenditures for capital conversion, marketing costs, shipments, and research and development costs. Impacts to direct employment are also addressed in the MIA. Potential impacts might lead to changes in manufacturing practices for GSLs. DOE identified potential impacts through interviews with manufacturers and other interested parties. See chapter 12 of this TSD for details.

ES.2.11 Other Analyses

The remaining chapters of this preliminary TSD address the following analyses, which will be performed for any NOPR issued for GSLs:

- The consumer subgroup analysis evaluates the effects of energy conservation standards on various consumer subgroups (chapter 11).
- The emissions analysis examines the effects of energy conservation standards on various airborne emissions (chapter 13).
- The monetization of emissions analysis estimates the economic impacts of reduced emissions as a result of energy conservation standards (chapter 14).
- The utility impact analysis examines impacts of energy conservation standards on the generation capacity of electric utilities (chapter 15).
- The employment impact analysis examines the indirect effects of energy conservation standards on national employment (chapter 16).
- The regulatory impact analysis examines the national impacts of non-regulatory alternatives to mandatory energy conservation standards (chapter 17).

ES.3 ISSUES ON WHICH DOE SEEKS PUBLIC COMMENT

DOE is interested in receiving comment on all aspects of this preliminary analysis. DOE especially invites comment or data to improve DOE's analyses, including information that will respond to the following questions and concerns raised in the development of this preliminary TSD.

ES.3.1 GSL Definitions

DOE developed definitions for several terms in support of the scope of the rulemaking. DOE requests comment on the definitions under consideration including "integrated lamp," "non-integrated lamp," "general service LED lamp," "OLED lamp," "colored lamp," "reflector lamp," "non-reflector lamp," "light fixture," "pin base lamp," and "GU24 base."

ES.3.2 Specialty Application MBCFLs and LED Lamps

DOE identified MBCFLs and LED lamps that are designed for specialty applications and are not able to provide overall illumination including: black light lamps, bug lamps, colored lamps, plant light lamps, and silver bowl lamps. DOE is considering providing exemptions for these specialty applications. DOE requests comment on the MBCFLs identified for specialty applications that cannot provide overall illumination and if there are other MBCFLs that should be considered. DOE requests comment on the LED lamps identified for specialty applications that cannot provide overall illumination and if there are other LED lamps that should be considered.

ES.3.3 GSL Exemptions

DOE assessed the full list of exemptions that apply to GSILs to determine if the lamp types provide overall illumination and therefore can be used in general lighting applications. Of the exemptions provided for GSILs, DOE has preliminarily determined that appliance lamps, black lights, bug lamps, colored lamps, infrared lamps, marine signal lamps, mine service lamps, plant lights, sign service lamps, silver bowl lamps, showcase lamps, and traffic signal lamps cannot provide overall illumination and therefore cannot be used in general lighting applications. DOE is considering not establishing standards for these lamp types under the GSL rulemaking because the lamps are intended for use in non-general applications. DOE requests comment on the exemptions that DOE is considering providing for GSLs based on its assessment that the lamp types are intended for non-general applications.

DOE has preliminarily determined that 3-way lamps, vibration service lamps, rough service lamps, and shatter-resistant lamps are able to provide overall illumination and therefore can be used in general lighting applications. For these reasons, DOE believes that 3-way lamps, vibration service lamps, rough service lamps, and shatter-resistant lamps are general service lamps and do not require an exemption from standards. DOE requests comment on this decision.

ES.3.4 OLED Lamps

DOE requests comment on its consideration to continue to not establish standards for OLED lamps in this rulemaking.

ES.3.5 Lamps Addressed in Other Rulemakings

DOE has the authority to consider additional lamp types that it determines are used to satisfy lighting applications traditionally served by GSILs. To limit the probability that one lamp type might be subject to two different standards, DOE is not considering including self-ballasted mercury vapor lamps in the scope of this rulemaking. DOE requests comment on its consideration to exclude from the scope of the GSL rulemaking lamps that are addressed in other rulemakings.

ES.3.6 Other Integrated Lamps

DOE does not believe that LED technology is currently able to provide the same utility as halogen technology in the MR16 lamp shape. Because more efficient replacements that maintain the same utility are not currently available, DOE has tentatively decided to not establish energy conservation standards for reflector pin base integrated lamps at this time. DOE requests comment on whether LED MR16 lamps are suitable replacements for incandescent/halogen reflector integrated MR16 lamps.

DOE also requests comment on whether there are any integrated lamps with other bases than screw bases that have a significant market share.

ES.3.7 Other Non-Integrated Lamps

Due to low market share and to avoid stifling innovation with LED non-reflector pin base non-integrated lamps, DOE is not considering establishing standards for these products. DOE requests comment on the market share and technological feasibility of increasing the efficacy of non-reflector pin base non-integrated lamps.

DOE identified screw base and pin base non-integrated lamps that meet the definition of GSL. DOE requests comment on whether there are any non-integrated lamps with other bases that meet the definition of GSL and the market share of these lamps.

ES.3.8 MBCFL Metrics

DOE has the authority to revise the existing metrics and consider additional metrics for MBCFLs in this rulemaking and requests comment on several topics related to this. Regarding metrics that DOE is not considering revising, DOE requests comment on maintaining the current lumen maintenance requirements. Regarding metrics that DOE is considering revising, DOE requests comment on the rapid cycle stress performance of commercially available MBCFLs and the appropriateness of requiring an increased lifetime of 10,000 hours for MBCFLs. Regarding metrics that DOE is considering adding, DOE requests comment on adding a requirement for power factor and its consideration of a standard for power factor of 0.5 or greater; CRI and its consideration of a standard for CRI of 80 or greater; and the start time of MBCFLs and its consideration to require a start time of within one second of the application of electrical power. Regarding metrics that DOE is not considering adding, DOE requests comment on the consideration to not set a separate requirement for THD; the consideration to not set a CCT requirement for MBCFLs; and the consideration to not set requirements for operating frequency.

ES.3.9 GSL Technology Options

DOE requests comment on the technology options under consideration for GSLs. Specifically, DOE also requests comment on the addition of reduced current density as a technology option.

ES.3.10 GSL Product Classes

DOE is considering establishing three product classes for this rulemaking. DOE welcomes comments on the product class divisions it is considering for GSLs in this preliminary analysis. Further, DOE specifically requests comments on a product class division based on lumen package for the integrated GSLs. DOE also requests comments on its preliminary determination that energy consumed in standby mode will be negligible and therefore a product class division based on standby mode operation for integrated GSLs is not warranted.

ES.3.11 GSL Design Options

DOE requests comments on the design options it is considering for GSLs.

ES.3.12 GSL Data Approach

DOE welcomes comment on the data approach including any additional databases that should be considered.

ES.3.13 GSL Baseline Selection

DOE is directly analyzing all product classes and has selected one baseline lamp for each product class. DOE requests comment on its analysis of one baseline lamp for each product class. DOE also requests comment on the baseline units selected for each product class.

ES.3.14 More Efficacious Substitutes

DOE requests comment on the criteria used in selecting more efficacious substitute lamps in the integrated product class, as well as the characteristics of the lamps selected. In particular, DOE requests comment on its assumptions that more efficacious substitutes must have lumen output within 10 percent of the baseline lamp and must be omnidirectional light sources.

Similarly, DOE requests comment on the criteria used in selecting more efficacious substitute lamps in the non-integrated product class, as well as the characteristics of the lamps selected. In particular, DOE requests comment on its assumptions that more efficacious substitutes must have lumen output within 10 percent of the baseline lamp-and-ballast system. DOE also requests comment on its assumption that the base type of the baseline lamp in the non-integrated product class must be maintained for more efficacious substitutes.

ES.3.15 Non-Integrated Ballast Pairing

DOE pairs non-integrated GSLs with representative ballasts because the non-integrated GSLs analyzed in this preliminary analysis operate on a ballast in practice. DOE requests comment on the lamp-and-ballast systems selected for the non-integrated product class.

ES.3.16 Candidate Standard Levels

DOE requests comment on the CSLs under consideration for the integrated and non-integrated product classes, including the max tech levels.

ES.3.17 CSL Equation Methodology

DOE requests comment on the methodology used to develop the CSLs equations. In particular, DOE requests comment on the use of a lumens-based equation and the equation form itself.

ES.3.18 Non-Integrated GSL Replacement Assumptions

DOE found that the fixtures frequently used with the non-integrated GSLs analyzed were available in configurations for several different lamp types, and therefore assumed that fixture compatibility would not be an issue for the vast majority of consumers. DOE requests comment on its assumption that fixture compatibility would not be a common issue for non-integrated GSL replacements.

DOE evaluated the impacts of CSL 1 on the individual base types in the non-integrated product class. DOE confirmed that the vast majority of base types were still available at CSL 1, and therefore consumers will not be forced to switch between lamps with differing base types. DOE also requests comment on its assumption that consumer utility will not be lost with the base types that remain at CSL 1.

ES.3.19 Product Price Determination

DOE invites comment on the methodology and results for estimating end-user prices for GSLs in this preliminary analysis. DOE also requests comment on the appropriateness of the distribution channels and estimated percentage shipments through each channel used in this preliminary analysis.

ES.3.20 GSL Hours of Use

DOE requests comment on the data and methodology used to estimate operating hours for GSLs, particularly in the residential sector. Also, DOE seeks comment on its assumption that GSL operating hours will not vary by light source technology during the analysis period.

ES.3.21 EISA 2007 Backstop Criteria

DOE requests any data suggesting that the EISA 2007 backstop criteria will not be met.

ES.3.22 Fraction of Dimmable GSLs in the Residential Sector

For the residential sector, DOE estimated that at the compliance year five percent of CFL GSLs will be dimmable based on manufacturer interviews, whereas no such limit was placed on LED GSLs (though they may not be installed in fixtures that employ dimmers). DOE requests comment on this approach.

ES.3.23 Energy Savings from Lighting Controls

For this preliminary analysis, DOE estimated 30 percent energy savings for any GSL operated with lighting controls, including dimmers and controls integrated into smart LED lamps. DOE requests data and information to help compare the energy use implications of using dimmers as opposed to other lighting controls.

ES.3.24 Integrated Low Lumen GSL Market Distribution Estimates

DOE seeks comment on the market distribution estimates for the four lumen ranges analyzed as part of the integrated low lumen product class.

ES.3.25 Consumer Purchases in Standards Case Analyses

In each of the 10,000 sampled purchases used to determine the average LCC savings, DOE assumes that in the standards case consumers purchase lamps that are at least as efficient as the ones they would purchase in the absence of standards. DOE seeks comment on this assumption.

ES.3.26 Commercial Hours of Use Variability

DOE invites comments and data on its approach to account for variability in hours of use in the commercial sector.

ES.3.27 GSL Service Life Scenarios

DOE is analyzing three GSL service life scenarios in its analyses. DOE invites comment on the lifetime scenarios considered in the LCC, PBP, and subsequent analyses.

ES.3.28 Lifetime Distribution Modeling

DOE invites comments and data on the assumptions and methodology used to calculate GSL survival probabilities as a function of GSL age.

ES.3.29 Installation Costs

For this preliminary analysis, DOE assumed that the installation costs for GSLs are identical for all CSLs and product classes in the residential sector as well as the commercial sector (though they may differ by sector). Therefore, DOE did not include installation costs. DOE welcomes comment on this approach.

ES.3.30 LCC and Consumer Impacts from Potential Standards

For a potential standard at each CSL, DOE presents the resulting average LCC savings and the percent of consumers affected by the standard using the base-case and standards-case efficiency distributions calculated in the shipments analysis. DOE seeks comment on this approach.

ES.3.31 GSL Disposal Costs

DOE requests comment and relevant data on the disposal cost assumptions used in its analyses.

ES.3.32 LCC and PBP Methodologies

DOE requests comment on the overall methodology and results of the LCC and PBP analyses.

ES.3.33 GSL Shipments Data

DOE requests any representative data on GSL shipments as they become available in order to improve the accuracy of the shipments analysis.

ES.3.34 Residential Integrated High Lumen GSLs

DOE requests comment on its assumption that approximately 3 percent of all residential-sector GSLs with integrated ballasts or drivers are brighter than 2,000 lumens.

ES.3.35 Integrated LED Fixture Penetration

DOE assumed that integrated LED fixtures will capture 0 percent, 15 percent, and 50 percent of the fixture market by 2049 in the low-penetration, reference, and high-penetration scenarios, respectively. DOE invites comment and data on these scenarios.

ES.3.36 Non-Integrated CFL GSLs

DOE assumed that non-integrated CFL GSLs will remain a constant fraction of the installed GSL stock in the commercial sector, after accounting for the incursion from integrated LED fixtures into the commercial building stock. DOE seeks comment and data on this assumption.

ES.3.37 Rare Earth Price Scenarios

DOE invites comment on the two rare earth materials price scenarios considered in its analyses.

ES.3.38 Electricity Price Scenarios

DOE invites comment on the electricity price projection scenarios considered in its analyses.

ES.3.39 LED Learning Rate Scenarios

In its reference scenario for this preliminary analysis, DOE assumed that the LED GSL learning rate will slow in the near future to equal the historical learning rate for CFL GSLs. In an alternative scenario, DOE assumed that the LED GSL learning rate will remain at the faster value observed in recent years. DOE invites comment on these scenarios.

ES.3.40 Incremental Price of Brighter LED GSLs

DOE is assuming that both the price of LED GSLs and the incremental price of brighter LED GSLs are falling. DOE requests comment and data on this assumption.

ES.3.41 Pre-Compliance Year Shift Away from Incandescent GSLs

DOE assumed in its shipments projections that some fraction of the market for GSILs shifts to CFL or LED GSLs in each year prior to 2020, with the remainder shifting to CFL or LED GSLs in 2020. DOE assumed that the remaining market for GSILs in the commercial sector is already negligible, so this shift was assumed to occur entirely within the residential market. DOE requests comment and data on this assumption.

ES.3.42 GSL Market Data

DOE requests comment and data on current market shares and market trends for GSLs in the commercial sector.

ES.3.43 GSL Rebound Effect Scenarios

DOE analyzed three rebound effect scenarios in the NIA: 1) 0 percent rebound for both the residential and commercial sectors (the reference scenario), 2) 8.5 percent rebound and 1 percent rebound for the residential and commercial sectors, respectively, and 3) 15 percent rebound for both the residential and commercial sectors. DOE requests data that can be used to further refine the rebound effect assumptions used in the NIA.

ES.3.44 Penetration of LED GSLs with Standby Functionality

DOE assumed that residential LED GSLs with standby functionality will represent 0 percent, 50 percent, and 100 percent of residential LED GSLs in the market by 2049 in the low-penetration, reference, and high-penetration scenarios, respectively. DOE invites comment and data on these assumptions.

ES.3.45 Penetration of Commercial GSLs with Controls

DOE analyzed two scenarios to account for the fraction of GSL shipments with controls in the commercial sector: 1) The current fraction of GSLs with controls remains constant over the analysis period, and 2) The fraction of commercial floor space utilizing various types of controls grows from 30 percent today to a projected value of 80 percent by the end of the analysis period (the reference scenario). DOE invites comment and data on these scenarios.

ES.3.46 Shipments Analysis and NIA Scenarios

DOE is considering a number of scenarios in its shipments and NIA analyses. DOE asks for comment on whether there are other scenarios which should be considered.

ES.3.47 Consumer Subgroup Analysis

DOE welcomes input regarding which, if any, consumer subgroups should be considered when developing potential energy conservation standards for GSLs.

ES.3.48 Emissions Analysis

DOE requests comment on its approach to conducting the emissions analysis for GSLs.

ES.3.49 Monetization of Emissions Reductions Benefits

DOE invites input on the proposed approach for estimating monetary benefits associated with emissions reductions.

ES.3.50 Utility Impact Analysis

DOE seeks comment on the planned approach to conduct the utility impact analysis.

ES.3.51 Employment Impact Analysis

DOE welcomes input on its proposed approach for assessing national employment impacts.

ES.3.52 Regulatory Impact Analysis

DOE requests any available data or reports that would contribute to the analysis of alternatives to standards for GSLs. In particular, DOE seeks information on the effectiveness of existing or past efficiency improvement programs for these products.

CHAPTER 1. INTRODUCTION

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1. INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This preliminary technical support document (TSD) provides the analytical approaches, inputs, and results associated with the U.S. Department of Energy's (DOE's) study of energy conservation standards for general service lamps (GSLs). The preliminary TSD also serves to provide technical detail and is a compendium to the life-cycle cost (LCC) and payback period (PBP) and national impact analysis (NIA) spreadsheets that are available on regulations.gov, docket number EERE–2013–BT–STD–0051 for the preliminary analysis at http://www.regulations.gov/#!docketDetail;D=EERE-2013-BT-STD-0051.[a]

1.2 OVERVIEW OF THE APPLIANCES AND COMMERCIAL EQUIPMENT STANDARDS PROGRAM

Title III of the Energy Policy and Conservation Act of 1975 (EPCA; 42 U.S.C. 6291–6317), as amended, established the "Energy Conservation Program for Consumer Products Other Than Automobiles," which includes major household appliances.[b] Subsequent amendments expanded Title III of EPCA to include additional consumer products, including general service lamps—the products that are the focus of this rulemaking. Before DOE determines whether to adopt a proposed energy conservation standard, it first solicits comments on the proposed standard. DOE designs any new or amended standard to achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)) To determine whether a standard is economically justified, DOE must review comments on the proposal and determine that the benefits of the proposed standard exceed its burdens to the greatest extent practicable, weighing the following seven factors:

(1) the economic impact of the standard on the manufacturers and consumers of the products subject to the standard;

(2) the savings in operating costs throughout the estimated average life of the products compared to any increases in the price, initial charges, or maintenance expenses for the products that are likely to result from the imposition of the standard;

(3) the total projected amount of energy savings likely to result directly from imposition of the standard;

(4) any lessening of the utility or the performance of the products likely to result from imposition of the standard;

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[a] Information regarding the preliminary analysis can also be found here: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/83.

[b] Part B was re-designated Part A on codification in the U.S. Code for editorial reasons.

(5) the impact of any lessening of competition, as determined in writing by the Attorney General, likely to result from imposition of the standard;

(6) the need for national energy conservation; and

(7) other factors the Secretary considers relevant.

(42 U.S.C. 6295(o)(2)(B)(i))

1.3 OVERVIEW OF GSL STANDARDS

As mentioned in the previous section, Part B of Title III (42 U.S.C. 6291-6309), as amended, established the “Energy Conservation Program for Consumer Products Other Than Automobiles,” which includes the GSLs that are the subject of this rulemaking. In particular, amendments to EPCA in the Energy Independence and Security Act of 2007 (EISA) directed DOE to conduct two rulemaking cycles to evaluate energy conservation standards for GSLs. (42 U.S.C. 6295(i)(6)(A)-(B))

For the first rulemaking cycle, EPCA, as amended by EISA, directs DOE to initiate a rulemaking no later than January 1, 2014, to evaluate standards for GSLs and determine whether exemptions for certain incandescent lamps should be maintained or discontinued. (42 U.S.C. 6295(i)(6)(A)(i)) The scope of the rulemaking is not limited to incandescent lamp technologies. (42 U.S.C. 6295(i)(6)(A)(ii)) Further, for this first rulemaking cycle, the EISA amendments provide that DOE must consider a minimum standard of 45 lumens per watt (lm/W). (42 U.S.C. 6295(i)(6)(A)(ii)) If DOE fails to meet the requirements of 42 U.S.C. 6295(i)(6)(A)(i)-(iv) or the final rule from the first rulemaking cycle does not produce savings greater than or equal to the savings from a minimum efficacy standard of 45 lm/W, sales of GSLs that do not meet the minimum 45 lm/W standard will be prohibited beginning on January 1, 2020. (42 U.S.C. 6295(i)(6)(A)(v))

The EISA-prescribed amendments direct DOE to initiate a second rulemaking cycle by January 1, 2020 to determine whether standards in effect for general service incandescent lamps (GSILs) should be amended with more stringent requirements and if the exemptions for certain incandescent lamps should be maintained or discontinued. (42 U.S.C. 6295(i)(6)(B)(i)) For this second review of energy conservation standards, the scope is again not limited to incandescent lamp technologies. (42 U.S.C. 6295(i)(6)(B)(ii))

This preliminary analysis is part of DOE’s first cycle of review to evaluate standards for GSLs and whether the standards should apply to additional GSL types. (42 U.S.C. 6295(i)(A) Additionally, this rulemaking satisfies the requirements under 42 U.S.C 6295(m)(1) for DOE to review the existing standards for medium base compact fluorescent lamps (MBCFLs), as compact fluorescent lamps (CFLs) are included in the definition of GSL. It also addresses 42 U.S.C. 6295(gg)(3) in which DOE is directed to incorporate standby mode and off mode energy use in any amended (or new) standard adopted after July 1, 2010, pursuant to 42 U.S.C. 6295(o).

1.4 PROCESS FOR SETTING ENERGY CONSERVATION STANDARDS

DOE considers stakeholder participation a very important part of the standards-setting process. DOE encourages the participation of all stakeholders during the comment period of each rulemaking stage. Beginning with the rulemaking framework document for GSLs (hereafter the "framework document") and during subsequent comment periods, interactions among stakeholders provide a balanced discussion of the information that is required for the standards rulemaking.

In conducting test procedure and the energy conservation standard rulemakings, DOE involves interested parties through formal public notifications (*i.e.*, *Federal Register* notices). For this GSL energy conservation standards rulemaking, DOE will employ the procedures set forth in DOE's Process Rule (Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products, 61 FR 36974, July 15, 1996, 10 CFR Part 430, Subpart C, Appendix A) to the extent they are appropriate for developing energy conservation standards for the lamps covered under this rulemaking.

Before DOE determines whether to amend energy conservation standards for GSLs, it must first solicit comments on a proposed standard. (42 U.S.C. 6295(o)(2)(B)(i)) DOE must design new standards for these products to achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified, and would result in significant energy savings. (42 U.S.C. 6295(o)(2)(A) and (3)) To determine whether a proposed standard complies with these requirements, DOE must, after receiving comments on the proposed standard, determine whether the benefits of the standard exceed its burdens to the greatest extent practicable, weighing the seven factors previously described.

Subsequent to the publication of the framework document, the standards rulemaking process involves preliminary analyses followed by two additional formal, major public notices, which are published in the *Federal Register*. The preliminary analyses are designed to publicly vet the models and tools used in the rulemaking and to facilitate public participation before the proposed rule stage. After the preliminary analyses are vetted, DOE issues the first major notice, the notice of proposed rulemaking (NOPR), which presents a discussion of comments received in response to the preliminary analyses of the impacts of standards on consumers, manufacturers, and the nation; DOE's weighing of the impacts; and the proposed standards. The second notice is the final rule, which presents a discussion of comments received in response to the NOPR; the revised analysis of the impacts of standards; DOE's weighing of the impacts; the standards adopted by DOE; and the compliance dates of the standards.

Table 1.4.1 Analyses Under the Process Rule

Preliminary Analysis	NOPR	Final Rule*
Market and Technology Assessment	Revised Preliminary Analyses	Revised Analyses
Screening Analysis	Consumer Subgroup Analysis	
Engineering Analysis	Manufacturer Impact Analysis	
Energy Use Characterization	Emissions Analysis	
Product Price Determination	Monetizing CO_2 and Other Emissions	
Life-Cycle Cost and Payback Period Analysis	Utility Impact Analysis	
Shipments Analysis	Employment Impact Analysis	
National Impact Analysis	Regulatory Impact Analysis	
Preliminary Manufacturer Impact Analysis		

* During the final rule phase, DOE considers the comments submitted by the U.S. Department of Justice concerning the impact of any lessening of competition that is likely to result from the imposition of the standard. (42 U.S.C. 6295(o)(2)(B)(v))

On December 9, 2013, DOE published a notice announcing the availability of the framework document and a public meeting to discuss the proposed analytical framework for the rulemaking. 78 FR 73737. DOE also posted the framework document on its website: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/83.

DOE held the public meeting on January 14, 2014 to discuss procedural and analytical approaches to the rulemaking and to inform and facilitate stakeholders' involvement in the rulemaking process. The analytical framework presented at the public meeting described rulemaking analyses, such as the engineering analysis and the LCC and PBP analysis, the methods proposed for conducting them, and the relationships among the various analyses. See Table 1.4.1 for all the analyses discussed at the public meeting and the stage at which the analyses are undertaken. PDF copies of the slides and other material associated with the public meeting are available at: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx/ruleid/83.

During the public meeting and the framework document comment period,[c] DOE received several comments about the GSL rulemaking from stakeholders, including manufacturers, trade associations, environmental advocates, and other interested parties. The major issues discussed were: scope of coverage, scope of metrics, product classes, efficacy level approach, shipment forecasts, and the backstop analysis. A detailed discussion of stakeholder comments is available in chapter 2 of this TSD.

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[c] The National Electrical Manufacturers Association (NEMA) requested that DOE extend the comment deadline by two weeks from the original January 23, 2014 deadline. DOE agreed and moved the comment deadline to February 7, 2014. The notice extending the framework comment period is available at: http://www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0051-0009.

As part of the information gathering and sharing process, DOE organized and held interviews with GSL manufacturers who operate in the U.S. market. DOE had five objectives for these interviews: (1) solicit feedback on the scope of coverage for the rulemaking; (2) solicit feedback on the engineering analysis; (3) solicit feedback on topics related to the preliminary manufacturer impact analysis; (4) provide an opportunity early in the rulemaking process to express specific concerns to DOE; and (5) foster cooperation between manufacturers and DOE. During the manufacturer interviews, DOE discussed these and other issues regarding market data, distribution channels, anticipated consumer responses to standards, production and equipment mix, conversion costs, and cumulative regulatory burden. Appendix 12A of this TSD contains a complete copy of the interview guide.

DOE incorporated the information gathered at the meetings into its market and technology assessment (chapter 3 of this TSD), engineering analysis (chapter 5 of this TSD), product price determination (chapter 6 of this TSD), and the preliminary manufacturer impact analysis (chapter 12 of this TSD). Following the publication of the preliminary analysis, DOE intends to hold additional meetings with manufacturers as part of the consultative process for the manufacturer impact analysis conducted during the NOPR phase.

For the LCC, PBP, and NIA, DOE developed spreadsheets using Microsoft Excel®. The LCC and PBP spreadsheets calculate the economic impacts of replacing GSLs with more efficacious lamps. The NIA spreadsheet calculates the national energy savings (NES) and national net present value (NPV) at various candidate standard levels and includes a model that forecasts the impacts of energy conservation standards at various levels on product shipments. These spreadsheets are available on regulations.gov, docket number EERE–2013–BT–STD–0051 at http://www.regulations.gov/#!docketDetail;D=EERE-2013-BT-STD-0051.

1.5 STRUCTURE OF THE DOCUMENT

This preliminary TSD outlines the analytical approaches used in this rulemaking. The TSD consists of 17 chapters and 11 appendices.

Chapter 1	Introduction: provides an overview of the appliance standards program and how it applies to the rulemaking for GSLs, and outlines the structure of the document
Chapter 2	Analytical Framework: describes the rulemaking process, and provides an overview of each analysis including rationale for preliminary determinations
Chapter 3	Market and Technology Assessment: characterizes the GSL market and the technologies available for increasing efficacy, and outlines product classes
Chapter 4	Screening Analysis: determines which technology options are viable for consideration in the engineering analysis

Chapter 5	Engineering Analysis: describes DOE’s approach to the engineering analysis, and establishes candidate standard levels based on lamp efficacy
Chapter 6	Product Price Determination: describes DOE’s approach to determining the end-user prices for GSLs
Chapter 7	Energy Use Characterization: discusses the sources and methods for developing energy use estimates for GSLs
Chapter 8	Life-Cycle Cost and Payback Period Analysis: discusses the economic effects of standards on individual consumers and calculates the LCC and PBP of GSLs
Chapter 9	Shipments Analysis: discusses the methods used for forecasting shipments with and without higher energy conservation standards
Chapter 10	National Impacts Analysis: discusses the methods used for forecasting national energy consumption and national economic impacts based on annual product shipments and estimates of future product efficiency distributions in the absence and presence of higher efficiency standards
Chapter 11	Consumer Subgroup Analysis: discusses the methods to be used to study the impacts of standards on a subgroup of GSL consumers and compares the LCC and PBP of products with and without higher efficiency standards
Chapter 12	Preliminary Manufacturer Impact Analysis: discusses the methods to be used to study the impacts of standards on the finances and profitability of GSL manufacturers, and presents preliminary manufacturer impact analysis results
Chapter 13	Emissions Analysis: discusses the methods to be used to study the effects of standards on sulfur dioxide (SO2), nitrogen oxides (NOx), mercury (Hg), and carbon dioxide (CO2) emissions
Chapter 14	Monetization of Emission Reductions Benefits: discusses the methods to be used to study the effects of standards on monetary benefits likely to result from the reduced emissions of CO2 and NOX
Chapter 15	Utility Impact Analysis: discusses the methods to be used to study the effects of standards on the installed generation capacity of electric utilities
Chapter 16	Employment Impact Analysis: discusses the methods to be used to analyze the effects of standards on national employment

Chapter 17	Regulatory Impact Analysis: discusses present regulatory actions and the methods to be used to determine the impact of non-regulatory alternatives to energy conservation standards
Appendix AA	Acronyms and Abbreviations: provides a set of acronyms and abbreviations used throughout the TSD
Appendix 8A	User Instructions for LCC and PBP Spreadsheet: provides basic instructions for operating the LCC and PBP workbook, as well as descriptions of each worksheet included in the workbook
Appendix 8B	Uncertainty and Variability: describes how uncertainty and variability were incorporated into the analyses and presents LCC and PBP analysis results for alternative scenarios DOE considered
Appendix 8C	Discount Rate Distributions: provides the probability distributions used with real interest rates to develop residential and commercial discount rates
Appendix 8D	Modeling of Rare Earth Price Impacts: reflects the findings of DOE's analysis of the rare earth phosphor market
Appendix 8E	Lifetime Modeling: describes the methodology DOE used to model GSL survival probability as a function of GSL age
Appendix 10A	User Instructions for National Impact Analysis Spreadsheet Model: provides basic instructions for operating the NIA workbook, as well as descriptions of each worksheet included
Appendix 10B	Full-Fuel-Cycle Multipliers: summarizes the methods used to calculate full-fuel-cycle (FFC) energy savings expected to result from potential standards
Appendix 10C	Lighting Controls Market Penetration Projection: describes the assumptions and analysis DOE used to project changes in the penetration of lighting controls
Appendix 10D	Rebound Effect: describes the direct rebound effect and the analysis DOE used to establish its baseline rebound rate
Appendix 12A	Manufacturer Impact Analysis Interview Guide

CHAPTER 2. ANALYTICAL FRAMEWORK

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 2. ANALYTICAL FRAMEWORK

2.1 INTRODUCTION

The Energy Policy and Conservation Act of 1975 (EPCA; 42 U.S.C. 6291 *et seq.*), as amended, requires that energy conservation standards set by the U.S. Department of Energy (DOE) be technologically feasible and economically justified, and achieve the maximum possible improvement in energy efficiency. (42 U.S.C. 6295(o)(2)(A) and (3)) This chapter provides a description of the general analytical framework that DOE uses in developing such standards, and in particular, standards for general service lamps (GSLs). It includes a description of the methodology, the analytical tools, and relationships among the various analyses that are part of this rulemaking. Chapter 2 also provides an overview of the preliminary activities DOE has conducted and discusses the comments it received in response to the framework document. Finally, chapter 2 provides cross-references to the other chapters of this technical support document (TSD) that address DOE's analytical approach, inputs, and findings.

The analyses presented in this TSD include:

- a market and technology assessment to characterize the relevant GSL market; to identify technology options that improve efficacy; and to develop product classes;

- a screening analysis to review each technology option and determine if it is technologically feasible; is practicable to manufacture, install, and service; would adversely impact lamp utility or lamp availability; or would have adverse impacts on health and safety;

- an engineering analysis to study representative lamp systems and, as appropriate, lamp-and-ballast systems used as substitutes for baseline lamps, to select candidate standard levels (CSLs), and to determine lamp system power ratings;

- a product price determination that develops end-user product prices for the representative lamps identified in the engineering analysis;

- an energy-use characterization that generates energy-use estimates for covered GSLs;

- a life-cycle cost (LCC) analysis that calculates, at the consumer level, the discounted savings in operating costs throughout the estimated average life of the lamp, compared to any increase in the installed costs likely to result directly from imposition of the standard;

- a payback period (PBP) analysis to estimate the amount of time it takes consumers to recover the higher purchase expense of more efficacious lamps through lower operating costs;

- a shipments analysis that estimates shipments of GSLs over the time period examined in the analysis;

- a national impact analysis (NIA) that assesses the aggregate impacts at the national level of potential energy conservation standards as measured by the net present value (NPV) of total consumer economic impacts and national energy savings (NES); and

- a preliminary manufacturer impact analysis (MIA) that begins to evaluate the effects on manufacturers that may result from an amended efficacy standard.

DOE may revise any of its analyses based on comments and new information received on this preliminary analysis before publishing any subsequent notice of proposed rulemaking (NOPR). The analyses DOE performs in any NOPR stage include the following:

- a consumer subgroup analysis that evaluates the economic impacts on identifiable groups of consumers of GSLs, including various categories of lamp purchasers or owners who may experience disproportionate impacts from a national energy conservation standard;

- an MIA that estimates the financial impact of standards on lamp manufacturers and calculates impacts on competition, employment at the manufacturing plant, and manufacturing capacity;

- a utility impact analysis that estimates the effects of proposed standards on the installed capacity and the generating base of electric utilities;

- an employment impact analysis that estimates the impacts of standards on net jobs eliminated or created in the general economy as a consequence of increased spending on the installed price of GSLs and reduced consumer spending on energy;

- an emissions analysis to provide estimates of the effects of amended energy conservation standards on emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_X), and mercury (Hg);

- a monetization of the reduced emissions from the proposed standard levels; and

- a regulatory impact analysis (RIA) that presents major alternatives to proposed standards that may achieve comparable energy savings at a reasonable cost.

DOE developed this analytical framework and documented its findings in the Energy Conservation Standards Rulemaking Framework Document for General Service Lamps (December 9, 2013).[1] DOE presented the analytical approach to interested parties during a public meeting held on January 14, 2014 (hereafter the “framework public meeting”).

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[1] The framework document is available at: www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0051-0006.

In response to the publication of the framework document and the framework public meeting, DOE received comments from interested parties on its analytical approach. Based on the timing of the release of the framework document, the National Electrical Manufacturers Association (NEMA) requested that DOE extend the comment deadline by two weeks. (NEMA, Public Meeting Transcript, No. 19 at p. 13)[2] DOE agreed and extended the comment deadline from January 23, 2014 until February 7, 2014.[3] This chapter summarizes the key comments DOE received, describes DOE's responses, and summarizes the analytical approach taken in this preliminary analysis. In the executive summary of this TSD, DOE identifies issues on which it seeks public comment, which are also discussed in the following sections.

2.2 BACKGROUND

2.2.1 Regulatory Authority and History of Standards Rulemakings for GSLs

Title III of EPCA sets forth a variety of provisions designed to improve energy efficiency. Part B of Title III (42 U.S.C. 6291-6309) established the "Energy Conservation Program for Consumer Products Other Than Automobiles," which includes major household appliances.[4] Subsequent amendments expanded Title III of EPCA to include additional consumer products, including GSLs—the products that are the focus of this preliminary analysis. In particular, amendments to EPCA in the Energy Independence and Security Act of 2007 (EISA) directed DOE to conduct two rulemaking cycles to evaluate energy conservation standards for GSLs. (42 U.S.C. 6295(i)(6)(A)-(B))

For the first rulemaking cycle, EPCA, as amended by EISA, directs DOE to initiate a rulemaking no later than January 1, 2014, to evaluate standards for GSLs and determine whether exemptions for certain incandescent lamps should be maintained or discontinued. (42 U.S.C. 6295(i)(6)(A)(i)) The scope of the rulemaking is not limited to incandescent lamp technologies. (42 U.S.C. 6295(i)(6)(A)(ii)) Further, for this first cycle of rulemaking, the EISA amendments provide that DOE must consider a minimum standard of 45 lumens per watt (lm/W). (42 U.S.C. 6295(i)(6)(A)(ii)) If DOE fails to meet the requirements of 42 U.S.C. 6295(i)(6)(A)(i)-(iv) or the final rule from the first rulemaking cycle does not produce savings greater than or equal to the savings from a minimum efficacy standard of 45 lm/W, sales of GSLs that do not meet the minimum 45 lm/W standard beginning on January 1, 2020, will be prohibited. (42 U.S.C. 6295(i)(6)(A)(v))

The EISA-prescribed amendments direct DOE to initiate a second rulemaking cycle by January 1, 2020, to determine whether standards in effect for general service incandescent lamps

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[2] A notation in this form provides a reference for information that is in the docket of DOE's rulemaking to develop energy conservation standards for GSLs (Docket No. EERE–2013–BT–STD– 51), which is maintained at www.regulations.gov. This notation indicates that the statement preceding the reference is document number 19 in the docket for the GSL energy conservation standards rulemaking, and appears at page 13 of that document.

[3] The notice extending the framework comment period is available at www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0051-0009.

[4] Part B was re-designated Part A on codification in the U.S. Code for editorial reasons.

(GSILs) should be amended with more stringent requirements and if the exemptions for certain incandescent lamps should be maintained or discontinued. (42 U.S.C. 6295(i)(6)(B)(i)) For this second review of energy conservation standards, the scope is not limited to incandescent lamp technologies. (42 U.S.C. 6295(i)(6)(B)(ii))

This preliminary analysis is part of DOE's first cycle of review to evaluate standards for GSLs and whether the standards should apply to additional GSL types. (42 U.S.C. 6295(i)(A) Additionally, this rulemaking satisfies the requirements under 42 U.S.C 6295(m)(1) for DOE to review the existing standards for medium base compact fluorescent lamps (MBCFLs), as compact fluorescent lamps (CFLs) are included in the definition of GSL. It also addresses 42 U.S.C. 6295(gg)(3) in which DOE is directed to incorporate standby mode and off mode energy use in any amended (or new) standard adopted after July 1, 2010, pursuant to 42 U.S.C. 6295(o).

2.2.2 Rulemaking Schedule

In the schedule presented in the framework document, this preliminary analysis was scheduled to be published in November 2014, the NOPR in December 2015, and the final rule in December 2016. DOE received no comments regarding the proposed rulemaking schedule; however, DOE received comments on the general timing and initiation of this rulemaking. NEMA commented that the recent implementation of EISA—which requires the phase-out of 60 W screw-based bulbs as of January 1, 2014—will affect the market in ways that surveys will be unable to adequately characterize until late 2014. NEMA therefore encouraged DOE to make every effort to gather data after the effects of the EISA implementation have run their course. (NEMA, No. 15 at p. 15) Additionally, NEMA indicated that it is difficult to comment on the standards rulemaking when a test procedure (TP) rulemaking is happening concurrently, because it is largely unknown how the products will be tested. (NEMA, Public Meeting Transcript, No. 19 at p. 77)

DOE acknowledges that implementation of the latest phase of EISA will have market implications that will take time to be fully realized. Accordingly, DOE intends to collect and use the most recent available market data to inform its analyses. For this preliminary analysis, DOE has used the latest relevant market information available, including the 2010 U.S. Lighting Market Characterization (LMC);[5] recent versions of the U.S. Energy Information Administration's (EIA's) Commercial Building Energy Consumption Survey (CBECS);[6] and Residential Energy Consumption Survey (RECS);[7] NEMA lamp indices;[8] KEMA shelf survey

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[5] U.S. Department of Energy. *2010 U.S. Lighting Market Characterization*. January 2012. Available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf.

[6] U.S. Department of Energy–Energy Information Administration. *Commercial Building Energy Consumption Survey. Micro-level data: File 1 General Building Information and Energy End Uses*. 2003. Washington, D.C. (Last Accessed September 15, 2014) http://www.eia.gov/consumption/commercial/data/2003/index.cfm?view=microdata.

[7] U.S. Department of Energy–Energy Information Administration. Residential Energy Consumption Survey. 2009 RECS Survey Data. 2011. Washington, D.C. (Last Accessed September 15, 2014) http://www.eia.gov/consumption/residential/data/2009/.

[8] National Electrical Manufacturers Association. *Lamp Indices.* (Last Accessed August 4, 2014.) http://www.nema.org/news/Pages/NEMA-News.aspx.

data;[9] and shipments and GSL lumen bin data provided by the Cadeo Group.[10] DOE requests any recent information or data on market shipments data for GSLs that can be used to provide a representative baseline for the NOPR analyses.

The People's Republic of China (P.R. China) judged the existing GSL standards and test procedures as adequate, given current energy efficiency goals, and stated that this rulemaking adds nothing new. For that reason, P.R. China considered it unnecessary to complete the rulemaking and suggested withdrawal. (P.R. China, No. 21 at p. 3)

As stated in section 2.2.1, DOE is required by EPCA, as amended by EISA, to initiate a rulemaking no later than January 1, 2014, to evaluate standards for GSLs and to publish a final rule by January 1, 2017, if standards are to be established. (42 U.S.C. 6295(i)(6)(A)(i) and (iii)) Additionally, this rulemaking also satisfies the requirements under 42 U.S.C 6295(m)(1) for DOE to review the existing standards for MBCFLs. When DOE evaluates any new or amended energy conservation standard for "covered products," EPCA, as amended, specifies that any standard DOE prescribes for consumer products must be designed to achieve the maximum improvement in energy efficiency that is technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)(A)) Moreover, the Secretary of Energy (Secretary) may not establish a new or amended standard if such standard would not result in a significant conservation of energy. (42 U.S.C. 6295(o)(3)(B)) Therefore, DOE must evaluate GSLs to determine if standards are technologically feasible and economically justified.

2.2.3 Test Procedure

EPCA sets forth generally applicable criteria and procedures for DOE's adoption and amendment of test procedures. (42 U.S.C. 6293) Manufacturers of covered products must use these test procedures to certify to DOE that their product complies with EPCA energy conservation standards and to quantify the efficiency of their product. DOE is considering developing and amending test procedures for products included in the definition of GSLs. The term GSL includes GSILs, CFLs, general service light-emitting diode (LED) lamps, organic light-emitting diode (OLED) lamps, and any other lamps that the Secretary determines are used to satisfy lighting applications traditionally served by general service incandescent lamps. 10 Code of Federal Regulations (CFR) 430.2

DOE's test procedures for GSILs are set forth at 10 CFR 430, subpart B, appendix R. These test procedures provide instructions for measuring GSIL performance largely by incorporating industry standards. These test procedures were updated in a final rule published in January 2012. 77 FR 4203 (January 27, 2012). The rule updated citations and references to the industry standards currently referenced in DOE's test procedures for GSILs and established a new test procedure for determining the rated lifetime of GSILs.

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[9] DNV GL Sustainable Energy Use. California Retail Lighting Shelf Survey Online Tool. (Last Accessed September 15, 2014.) https://websafe.kemainc.com/projects62/crlss/Home.aspx.

[10] Carmichael, R. GSL shipments and lumen bin distribution data. 2014. Washington, DC. Cadeo Group. Contract 7094760-T2D.

In the preliminary analysis of the general service fluorescent lamp (GSFL) and incandescent reflector lamp (IRL) energy conservation standards rulemaking[11] (hereafter "GSFL and IRL Standards Rulemaking"), DOE determined that the term "compact fluorescent lamps" includes both pin base and medium base CFLs (see section 2.3 for further discussion). DOE's current test procedures for MBCFLs are set forth at 10 CFR 430, subpart B, appendix W. These test procedures provide instructions for measuring MBCFL performance by referencing the August 9, 2001, ENERGY STAR® Program Requirements for CFLs Version 2.0. Currently there is no DOE test procedure for non-integrated CFLs (also referred to as pin base CFLs); however, DOE has initiated a CFL TP rulemaking to amend existing test procedures for MBCFLs at appendix W and to include test procedures for additional CFL metrics and CFL types, including non-integrated CFLs.

DOE is also currently developing test procedures for LED lamps. DOE published a supplemental notice of proposed rulemaking (SNOPR) on August 4, 2014, to propose test procedures for integrated LED lamps. 79 FR at 32019. The rulemaking does not include test procedures for non-integrated LED lamps or OLED lamps. However, as discussed in section 2.3.5, DOE is not considering establishing standards for non-integrated LED lamps at this time. Further, DOE is not considering establishing standards for OLED lamps at this time. See section 2.3.4 for more information. Therefore, DOE does not believe test procedures for non-integrated LED lamps and OLED lamps are necessary in advance of prescribing standards for this rulemaking.

DOE has the authority to consider additional lamps that it determines are used to satisfy lighting applications traditionally served by GSILs. (42 U.S.C. 6291(30)(BB)) In the framework document, DOE stated that it would consider establishing test procedures for additional lamp types, including hybrid lamps and self-ballasted mercury vapor (SBMV) lamps. As discussed in section 2.3.5.5, DOE determined that the hybrid lamps identified fall within the definition of MBCFL and therefore will address test procedures for hybrid lamps in the CFL TP rulemaking. DOE is no longer considering establishing standards for SBMV lamps in the scope of this rulemaking (see section 2.3.5.1 for more detail). DOE did not identify any additional lamp types covered by this rulemaking that would need test procedures to be established prior to an energy conservation standard being prescribed for these lamps.

DOE received comments regarding test procedures for the products included in the scope of this rulemaking. The California Energy Commission (CEC) stated that DOE should attempt to use the same testing methodology for all lamps within the scope of the rulemaking, particularly where lamps serve the same utility and are direct substitutes for one another. (CEC, No. 11 at p. 7)

While DOE is maintaining a technology neutral approach to this rulemaking, there are inherent mechanical and electrical differences between lamp types that require separate testing methods. Additionally, DOE test procedures frequently incorporate references to industry-

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[11] The preliminary analysis technical support document for the GSFL and IRL Standards Rulemaking is available at www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0006-0022.

approved test methods. The Illuminating Engineering Society of North America (IES) has developed separate standards for solid-state lighting products (*i.e.*, LEDs and OLEDs) and CFLs. Although DOE is not considering establishing one test procedure for all GSLs, DOE intends to coordinate the test procedures in development for CFLs and integrated LED lamps and prescribe consistent testing methodologies when possible.

NEMA urged DOE not to develop test procedures that make the testing and qualification process overly complicated and burdensome. NEMA also requested that DOE take into account any existing test procedures in place for these products developed by other agencies or groups, so as not to be redundant. (NEMA, No. 15 at p. 7)

EPCA provides, in relevant part, that any test procedures prescribed or amended under 42 U.S.C. 6293 shall not be unduly burdensome to conduct. (42 U.S.C. 6293(b)(3)) Therefore, in developing test procedures, DOE makes significant efforts to prevent the adoption of test methods that are overly burdensome for manufacturers. DOE weighs burden in the development of test procedures, and solicits feedback from manufacturers and other stakeholders during the test procedure rulemaking process to ensure its test procedures are not overly burdensome. To reduce testing burden and redundancy, DOE incorporates industry standard test procedures, thus aligning with industry practice. DOE also considers voluntary testing methods, such as ENERGY STAR, when developing its test procedures. See section 2.4 for more information.

DOE also received comments on the impact of establishing new test procedures on the timing of this GSL rulemaking. NEMA commented that as more lamp types without existing test procedures are added to the scope of this GSL rulemaking, the longer it would take to accomplish the rulemaking. NEMA further noted that it is difficult to comment on a standards rulemaking when the test procedure rulemaking for the product is happening concurrently. (NEMA, Public Meeting Transcript, No. 19 at pp. 74, 77) NEMA specifically noted that there are currently no test procedures for pin base CFLs and self-ballasted mercury vapor lamps, and that development of these new test procedures could delay the rulemaking. (NEMA, No. 15 at p. 7) Natural Resources Defense Council (NRDC), Appliance Standard Awareness Project (ASAP), Alliance to Save Energy, American Council for an Energy-Efficient Economy, Consumer Federation of America, Northeast Energy Efficiency Partnerships, and Northwest Energy Efficiency Alliance (NRDC, ASAP, *et al.*) commented that if issues related to test methods for pin base CFLs or hybrid lamps are difficult to resolve, DOE should not set standards for these lamp types to prevent delaying the GSL rulemaking. (NRDC, ASAP, *et al.*, No. 17 at p. 10)

DOE understands the concerns of stakeholders regarding the timing of establishing test procedures for products that are included in the scope of the rulemaking but do not currently have DOE test procedures. DOE acknowledges the importance of having a test procedure in place prior to the standards being finalized and thus has already initiated rulemakings for these products. Regarding pin base CFLs, DOE is considering developing test procedures for additional CFL types including non-integrated CFLs in the ongoing CFL TP rulemaking. DOE is also planning to develop test procedures for hybrid lamps in the CFL TP rulemaking. As mentioned previously, DOE is not considering establishing standards for SBMV lamps in the scope of this rulemaking and therefore does not believe a test procedure is necessary at this time (see section 2.3.5.1 for more detail).

DOE received comments on suggested test methods for CFLs. NRDC requested that the sample size of five used in the existing DOE MBCFL test procedure for several metrics be updated to a sample size of ten to align with the current ENERGY STAR specification so the data can be used for future enforcement. (NRDC, Public Meeting Transcript, No. 19 at pp. 79-80) NRDC, ASAP, *et al.* also commented that DOE would need to review test methods and make adjustments as necessary to accommodate hybrid lamps as their power consumption during warm-up periods differs greatly from steady state operation. To account for this, NRDC, ASAP, *et al.* suggested that DOE establish an alternate time to take the power and light output measurements. (NRDC, ASAP, *et al.*, No. 17 at p. 10)

DOE recognizes that the sampling requirements of the existing MBCFL Test Procedure do not align with the current ENERGY STAR specifications, *ENERGY STAR Program Requirements Product Specification for Lamps (Light Bulbs) Eligibility Criteria Version 1.1* (hereafter "ENERGY STAR Lamps Specification V1.1"). DOE will address potential amendments to the sampling requirements in the upcoming CFL TP rulemaking. Regarding hybrid lamps, DOE will address the testing of these lamp types in the CFL TP rulemaking.

NEMA commented that the CFL test procedure must address the differences in operation between externally ballasted CFLs and self-ballasted CFLs and determine how to best accommodate the discrepancy. NEMA further noted that reference ballast specifications do not exist at this time. (NEMA, Public Meeting Transcript, No. 19 at p. 75)

DOE acknowledges the differences in operation between self-ballasted and externally ballasted CFLs. Subsequently, DOE will consider test procedures specific to integrated (*i.e.*, self-ballasted) and non-integrated (*i.e.*, externally ballasted) CFLs in the CFL TP rulemaking. DOE will also address reference ballast specifications for non-integrated CFLs in the CFL TP rulemaking. Further, DOE is considering separate product classes for integrated and non-integrated GSLs, with the inherent difference in their efficacies as one of the factors in the decision. See section 2.5.3 for more information.

NRDC, ASAP, *et al.* commented that DOE should work with the Federal Trade Commission (FTC) to require labels on all lamps indicating the date of manufacture or import. Such labeling would make it possible to determine if a given lamp has been manufactured or imported after the effective date of the rulemaking. NRDC, ASAP, *et al.* also suggested that DOE establish lumen equivalency tables that manufacturers would be required to adhere to when making equivalency claims, thus discouraging exaggerated claims. (NRDC, ASAP, *et al.*, No. 17 at pp. 13-14) DOE understands concerns regarding the manufacture date and potentially inflated lumen equivalency claims of covered products, and DOE will continue to work with FTC on labeling issues.

2.2.4 Standby and Off Mode Energy Consumption

EPCA requires energy conservation standards adopted for a covered product after July 1, 2010, to address standby mode and off mode energy use. (42 U.S.C. 6295(gg)(3)) EPCA defines active mode as the condition in which an energy-using piece of equipment is connected to a main power source, has been activated, and provides one or more main functions. (42 U.S.C. 6295(gg)(1)(A)) Standby mode is defined as the condition in which an energy-using piece of equipment is connected to a main power source and offers one or more of the following user-oriented or protective functions: facilitating the activation or deactivation of other functions (including active mode) by remote switch (including remote control), internal sensor, or timer; or providing continuous functions, including information or status displays (including clocks) or sensor-based functions. *Id*. Off mode is defined as the condition in which an energy-using piece of equipment is connected to a main power source, and is not providing any standby or active mode function. *Id*.

To satisfy the EPCA definitions of standby mode and off mode (42 U.S.C. 6295(gg)(1)), the lamp must not be providing any active mode function (*i.e.*, emitting light). DOE determined that it is not possible for GSLs included in the scope of this rulemaking to meet the off-mode criteria because there is no condition in which a GSL is connected to main power is not already in a mode accounted for in either active or standby mode. DOE notes the existence of a small number of commercially available GSLs that operate in standby mode. DOE discusses GSLs that operate in standby mode in further detail in sections 2.3.5.4, 2.5.3.9, and 2.11.

2.3 SCOPE OF LAMPS

In this section, DOE discusses specific issues and comments related to the scope of lamps included in this rulemaking. The term, general service lamp, includes general service incandescent lamps, compact fluorescent lamps, general service light-emitting diode lamps, organic light-emitting diode lamps, and any other lamps that the Secretary determines are used to satisfy lighting applications traditionally served by general service incandescent lamps; however, this definition does not apply to any lighting application or bulb shape excluded from the “general service incandescent lamp” definition, or any general service fluorescent lamp or incandescent reflector lamp. (*See* 42 U.S.C. 6291(30)(BB)) In the following sections, DOE discusses each part of this definition to clearly define the scope of this rulemaking.

2.3.1 General Service Incandescent Lamps

As stated previously, GSILs are included in the definition of GSL. The definition of “general service incandescent lamp” is as follows:

> *General service incandescent lamp* means a standard incandescent or halogen type lamp that is intended for general service applications; has a medium screw base; has a lumen range of not less than 310 lumens and not more than 2,600 lumens or, in the case of a modified spectrum lamp, not less than 232 lumens and not more than 1,950 lumens; and is capable of being operated at a voltage range at least partially within 110 and 130 volts; however this definition does not apply to the following incandescent lamps—
>
> (1) An appliance lamp;
> (2) A black light lamp;
> (3) A bug lamp;

(4) A colored lamp;
(5) An infrared lamp;
(6) A left-hand thread lamp;
(7) A marine lamp;
(8) A marine signal service lamp;
(9) A mine service lamp;
(10) A plant light lamp;
(11) A reflector lamp;
(12) A rough service lamp;
(13) A shatter-resistant lamp (including a shatter-proof lamp and a shatter-protected lamp);
(14) A sign service lamp;
(15) A silver bowl lamp;
(16) A showcase lamp;
(17) A 3-way incandescent lamp;
(18) A traffic signal lamp;
(19) A vibration service lamp;
(20) A G shape lamp (as defined in ANSI C78.20) (incorporated by reference; see § 430.3) and ANSI C79.1-2002 (incorporated by reference; see § 430.3) with a diameter of 5 inches or more;
(21) A T shape lamp (as defined in ANSI C78.20) (incorporated by reference; see § 430.3) and ANSI C79.1-2002 (incorporated by reference; see § 430.3) and that uses not more than 40 watts or has a length of more than 10 inches; and
(22) A B, BA, CA, F, G16-1/2, G-25, G30, S, or M-14 lamp (as defined in ANSI C79.1-2002) (incorporated by reference; see § 430.3) and ANSI C78.20 (incorporated by reference; see § 430.3) of 40 watts or less.

10 CFR 430.2

The Consolidated Appropriations Act, 2014 (Public Law 113-76, January 17, 2014; hereafter referred to as the “Appropriations Rider”), in relevant part, restricts the use of appropriated funds in connection with several aspects of DOE’s incandescent lamps energy conservation standards program. Specifically, section 322 states that none of the funds made available by the Act may be used to implement or enforce standards for GSILs, intermediate base incandescent lamps and candelabra base incandescent lamps. Thus, DOE is not considering GSILs, intermediate base incandescent lamps or candelabra base incandescent lamps in this rulemaking. DOE received several comments on the inclusion of GSILs in the scope of this rulemaking.

2.3.1.1 Appropriations Rider

DOE received comments on its interpretation of the Appropriations Rider. NEMA and ASAP requested for DOE to elaborate on its conclusion to not include lamps that meet the definition of GSIL in the GSL rulemaking due to the Appropriations Rider. NEMA and ASAP asked for more background information on this decision process because the current interpretation of the Appropriations Rider will reduce DOE’s flexibility and become a hindrance to the best outcomes for manufacturers, consumers, and the environment. (NEMA, Public

Meeting Transcript, No. 19 at pp. 14-15; ASAP, Public Meeting Transcript, No. 19 at pp. 16-17, 19-20)

California Investor-Owned Utilities (CA IOUs), CEC, and Earthjustice and the Northwest Energy Efficiency Alliance (NEEA) commented that GSILs should be included within the rulemaking and cited sections of 42 U.S.C. 6295(i)(6) as support. Specifically, CA IOUs, CEC, Earthjustice, and NEEA commented that per section 42 U.S.C. 6295(i)(6)(A)(i)(I), DOE must determine whether the standards for GSLs should be amended to become more stringent than the GSIL standards specified in paragraph (1)(A). CA IOUs, CEC, Earthjustice, and NEEA cited 42 U.S.C. 6295(i)(6)(A)(ii)(I), which states that the GSL rulemaking shall not be limited to GSILs, thereby including GSILs in the rulemaking. (CA IOUs, No. 18 at p. 2; CEC, No. 11 at pp. 7-12; Earthjustice and NEEA, No. 12 at p. 2) CA IOUs and CEC further noted that 42 U.S.C. 6295(i)(6)(A)(ii)(II) states that the rulemaking shall include a minimum 45 lm/W standard for all GSLs, which includes GSILs by definition. (CA IOUs, No. 18 at p. 2; CEC, No. 11 at pp. 7-12) CEC and Earthjustice and NEEA commented that GSLs are defined in 42 U.S.C. 6291(30)(BB)(i)(I) as including GSILs, thus making DOE obligated to evaluate amended standards for the lamps. (CEC, No. 11 at pp. 7-12; Earthjustice and NEEA, No. 12 at p. 2) CEC concluded that legal precedent requires that if the plain language of a statute is clear, effect must be given to the intent of that statute, which in this case requires DOE to consider GSILs. (CEC, No. 11 at p. 8)

DOE acknowledges that 42 U.S.C. 6295(i)(6) authorizes DOE to evaluate energy conservation standards for GSLs, which, by definition, includes GSILs. However, DOE is restricted currently by the Appropriations Rider from using appropriated funds to implement or enforce standards for GSILs and therefore is not including GSILs in the GSL rulemaking. If the limitation on DOE's use of appropriated funds regarding new standards for GSILs is removed during the course of this rulemaking, DOE can at that point consider revising the scope of the rulemaking to include GSILs.

NEMA commented that excluding GSILs from the rulemaking is not the most obvious interpretation of the Appropriations Rider because NEMA does not believe it prevents the Secretary from making a decision for each of the lamp types included in the scope of the rulemaking, therefore satisfying all obligations of 42 U.S.C. 6295(i)(6)(A)(i-iv). NEMA commented that the Secretary can decide not to amend standards in 10 CFR 430.32(x) but promulgate or amend standards for other GSLs without constituting as implementing 10 CFR 430.32(x). (NEMA, No. 15 at p. 7) Earthjustice and NEEA commented that adopting new, more stringent standards for GSILs would not render the Appropriations Rider meaningless, as it would still apply to existing GSIL standards. (Earthjustice and NEEA, No. 12 at p. 3) CA IOUs commented that the current rulemaking would neither implement, nor enforce the previous standard but rather propose and adopt new standards for a newly defined group of lamps. CA IOUs noted that if Congress's intent were to prevent DOE from developing new standards for GSLs, it would have said that DOE could not use funds to carry out EISA requirements or amend existing GSIL standards in any way. (CA IOUs, No. 18 at p. 2)

As noted previously, DOE is restricted by the Appropriations Rider from including GSILs in its analysis at this time.

CA IOUs also stated that even if setting new standards for GSLs were considered to be implementing existing standards, this would not be an issue until a final rule adopted the standards and set an effective date. CA IOUs commented that DOE should include GSILs in the rulemaking throughout the analysis period and revisit the issue in three years when the final rule is expected to be published. If at the end of the rulemaking DOE determines it is not able to adopt new standards for GSILs, DOE could remove them from the scope at that time. (CA IOUs, No. 18 at p. 2) Earthjustice and NEEA also jointly commented that DOE must at a minimum begin to conduct analysis necessary to ensure that DOE is prepared for the expiration of the Appropriations Rider. They stated that there is no reason that DOE cannot conduct analyses of the impact of a more stringent standard and the Appropriations Rider is due to expire before DOE must complete this rulemaking. (Earthjustice and NEEA, No. 12 at p. 3)

As stated, because section 322 of the Appropriations Rider prohibits the expenditure of appropriated funds to implement or enforce GSILs, DOE is not including GSILs in the scope of the GSL rulemaking at this time.

DOE received comments on the importance of analyzing GSILs as part of the market. NRDC, ASAP, *et al.* urged DOE to carry out EPCA's intended more expansive view of lamps that serve general service lighting applications, thus enabling evaluation of standards on a technology neutral basis. NRDC, ASAP, *et al.* suggested that DOE has taken an inappropriately restrictive view of the Appropriations Rider and that GSILs should be included. (NRDC, ASAP, *et al.*, No. 17 at p. 2) CEC was also concerned that DOE was not including all lamps that are direct substitutes within the rulemaking, such as GSILs, noting that it is impossible to set a meaningful technology-neutral standard as these lamps will gain a unique market advantage by not having the same standards apply. (CEC, No. 11 at pp. 6-7)

NRDC, ASAP, *et al.* commented that even if DOE is forbidden from working on new GSIL standards, it must evaluate GSIL technology in order to carry out its statutory obligations with respect to other GSLs. NRDC, ASAP, *et al.* commented that carrying out an evaluation of the GSIL market and technologies does not further the implementation or enforcement of GSIL standards and is completely outside the scope of the Appropriations Rider. NRDC, ASAP, *et al.* also stated that GSILs represent the lowest efficacy product in the GSL market and therefore must be used as the baseline technology against which all improvements are measured. (NRDC, ASAP, *et al.*, No. 17 at pp. 2-3) NRDC, ASAP, *et al.* commented that in order to develop a standard that meets the statutory criteria of section 325(o), DOE must evaluate a range of efficacy improvements from the baseline to the maximum technologically feasible (max-tech) design, which includes improved incandescent technologies. NRDC, ASAP, *et al.* concluded that even if the Appropriations Rider is interpreted to prevent application of a new standard for GSILs, GSIL technology might still provide the technical basis for the selected standard level. (NRDC, ASAP, *et al.*, No. 17 at p. 3)

DOE understands concerns regarding the analysis of standards on a technology neutral basis and therefore is not considering technology specific standards. However, as discussed previously, DOE is restricted by the Appropriations Rider from including GSILs in the analysis at this time. For more information on technology options DOE is considering, see section 2.5.2. For more information on the baseline lamps that DOE is considering, see section 2.7.3.

2.3.1.2 Exempted Incandescent Lamps

DOE is also directed by 42 U.S.C. 6295(i)(6)(A)(i)(II) to determine whether the exemptions for certain incandescent lamps should be maintained or discontinued based, in part, on exempted lamp sales collected from manufacturers. In March 2013, DOE reviewed the 2012 sales of rough service lamps, vibration service lamps, 3-way incandescent lamps, 2,601-3,300 lumen general service incandescent lamps, and shatter-resistant lamps. DOE published a notice of data availability regarding the data collection and estimated future unit sales in which it concluded that these five types of incandescent lamps have not experienced significant growth since their exemption from federal efficiency standards. 78 FR 15891 (March 13, 2013). Because this assessment indicated no further action is necessary regarding these lamp types, DOE concluded in the framework document that they would not be included in the GSL rulemaking.

CA IOUs, CEC, Earthjustice and NEEA, and NRDC, ASAP, *et al.* commented that DOE has not followed its obligations under 42 U.S.C. 6295(i)(6)(A)(i)(II), which requires the exemptions for certain lamps to be re-evaluated based in part on exempted lamp sales data, thus indicating that DOE is required to consider factors other than lamp sales. Further, CEC and NRDC, ASAP, *et al.* stated that DOE is separately required to track the sales of rough service, vibration service, 3-way, 2,601-3,300 lumen output, and shatter resistant under 42 U.S.C. 6295(1)(4)(b)(1) but must consider all 22 exemptions in this rulemaking. (CA IOUs, No. 18 at p. 5; CEC, No. 11 at p. 15; Earthjustice and NEEA, No. 12 at pp. 3-5; NRDC, ASAP, *et al.*, No. 17 at p. 3) CEC also noted that DOE’s assessment in the framework document is legally invalid because DOE is not permitted to exclude exempted lamps from consideration at this stage and must address the exemptions as part of the rulemaking process. (CEC, No. 11 at p. 15)

DOE agrees that 42 U.S.C. 6295(i)(6)(A)(i)(II) authorizes DOE to evaluate whether the 22 exemptions for incandescent lamps should be maintained or discontinued based in part on exempted lamp sales data. DOE further acknowledges that it is authorized to consider factors beyond sales data in its assessment of the exemptions. As stated previously, DOE is prohibited by the Appropriations Rider from using appropriated funds to implement or enforce standards for GSILs and thus cannot modify the existing exemptions for GSILs in the rulemaking. If the limitations imposed by the Appropriations Rider are lifted, DOE can evaluate whether the 22 exemptions for incandescent lamps should be maintained based on sales data and other factors.

Soraa recommended that rough service lamps, vibration service lamps, 3-way incandescent lamps, 2,601-3,300 lumen general service incandescent lamps, and shatter-resistant lamps be included in the scope of the GSL rulemaking. (Soraa, No. 10 at p. 1) NRDC, ASAP, *et al.* noted that many of the exempted incandescent lamps are already being designed, labeled, and marketed as substitutes for incandescent lamps that are no longer compliant with standards. NRDC, ASAP, *et al.* provided examples of three exempted lamp types that demonstrate circumvention of standards. NRDC identified a multipack of vibration service lamps at a significantly lower price than the least costly compliant lamps and that are also lower efficacy than conventional incandescent lamps. Another example they noted were 3-way lamps which can be marketed as replacements to traditional incandescent lamps for a similarly low price. Lastly, NRDC, ASAP, *et al.* commented that lamps just outside the lumen range (*e.g.*, 2,601 lumens) are allowed to be sold without any efficacy improvements. NRDC urged DOE to consider extending the maximum lumen output range. (NRDC, ASAP, *et al.*, No. 17 at pp. 4-5; NRDC, Public Meeting Transcript, No. 19 at pp. 71-72) ASAP also expressed concern over DOE's decision not to thoroughly examine exempted lamps (*i.e.*, three-way, rough service, high-output lamps). While these lamps all meet a particular market niche and need, which is the reason they are exempted, they do not deliver energy savings like lamps compliant with the standards promulgated by EISA do. ASAP further noted the potential risk for a loophole and also an opportunity to improve the efficacy of these lamps, and therefore ASAP requested DOE further evaluate these lamp types. (ASAP, Public Meeting Transcript, No. 19 at pp. 21-22)

CA IOUs shared NRDC's sentiments for DOE to strongly consider standards for the exempted incandescent lamp types, as they have seen a huge amount of shelf space become available to exempted lamp types. CA IOUs noted that DOE must consider other factors besides its assessment that there were not sufficient sales. CA IOUs commented that as the EISA Phase 1 standards require compliance, the pressure on the niche market will increase and more of these lamps will be produced and sold. (CA IOUs, Public Meeting Transcript, No. 19 at pp. 45-46) ASAP concurred with this comment and predicted that in all likelihood, sales of some of these exempted lamps are significantly larger than those of the additional categories DOE is considering, such as hybrid lamps and mercury vapor lamps. General Electric (GE) replied that 3-way and higher lumen lamps are included in their annual surveys, so DOE has the ability to evaluate those to see if they are exempted lamp types of concern or not. (ASAP, Public Meeting Transcript, No. 19 at pp. 72-73; GE, Public Meeting Transcript, No. 19 at p. 73)

DOE recognizes the possibility that exempted incandescent/halogen lamps could be used in general service applications. DOE notes that the sales volume of rough service, vibration service, 3-way incandescent/halogen, 2,601 – 3,300 lumen output, and shatter-resistant lamps is continuing to be monitored. Therefore, if sales of these lamp types increase substantially and the established threshold is crossed, a separate rulemaking will be initiated as authorized by 42 U.S.C. 6295(l)(4). DOE further notes that it cannot modify exemptions as they pertain to GSILs. However, DOE has preliminarily determined that several of the exemptions for GSILs describe lamps that do not serve in general lighting applications and therefore has not included those lamps, regardless of the technology used, in the scope of this rulemaking.

DOE discusses its assessment of exemptions in the following relevant subsections.

ASAP asked whether all NEMA manufacturers participate in the EISA-required survey of exempted lamp types and if any non-NEMA manufacturers participate. GE responded that all NEMA manufacturers participate in the survey and that it was unlikely that non-NEMA manufacturers participate in the survey. ASAP expressed concern that the non-NEMA portion of the market is the area likely to see exploitation of potential loopholes regarding exempted lamps. ASAP noted that once one manufacturer exploits a loophole and starts getting a cost advantage and market share, it creates pressure for others to follow suit. ASAP also noted that it may make sense to develop standards for these products not only for loophole prevention but because many of these lamps are sold now and are a significant portion of residential energy consumption. (ASAP, Public Meeting Transcript, No. 19 at pp. 48-51; GE, Public Meeting Transcript, No. 19

at p. 49) NRDC, ASAP, *et al.* commented that included in the statute is the implication that sales data should only be part of the evaluation process for whether an exemption should be continued in this rulemaking and that the sales data should not only utilize NEMA members. Although it is appreciated that NEMA provided their sales data, NRDC, ASAP, *et al.* stated that NEMA does not cover all U.S. lamp sales and most attempts to circumvent the standards would occur with offshore brands and thus not appear in NEMA data. NRDC, ASAP, *et al.* suggested that DOE supplement the currently gathered data with sales data from utilities or market research firms. (NRDC, ASAP, *et al.*, No. 17 at pp. 3,13)

NEMA and GE commented that they are required to monitor the five exempted lamp types, and they will continue to honor their responsibility to the federal government to track and report on the sales figures of the exempted lamp types. GE noted that when one of the lamp types' sales volume crosses the EISA-prescribed threshold, then it would be an appropriate time for DOE to consider standards. NEMA commented that until there is statistical proof that the five exempted lamp types are being exploited as loopholes, there is no cause to consider them for efficacy standards. (NEMA, Public Meeting Transcript, No. 19 at pp. 46-47; NEMA, No. 15 at p. 21; GE, Public Meeting Transcript, No. 19 at p. 54) NRDC asked for further clarity on if the NEMA survey includes sales of private label lamps. For example, many lamps sold at Home Depot or Wal-Mart are not labeled as Philips or GE but are made by those manufacturers and sold under a private label. NEMA responded that if NEMA manufacturers make it, regardless of the name on it, it is included in the survey. NRDC also noted that many small manufacturers who were previously small but now have increasing sales (*e.g.*, Cree) need to be included in the NEMA dataset if they are not already. (NRDC, Public Meeting Transcript, No. 19 at pp. 51-52; NEMA, Public Meeting Transcript, No. 19 at p. 52)

Regarding the data included in DOE's monitoring of exempted lamp types, DOE notes that the manufacturers that participate in NEMA's collection of shipment data each year are listed in the spreadsheet model comparing actual lamp sales with benchmark unit sales, which is published along with the notice of data availability.[12] Additionally, as noted in the spreadsheet model, NEMA aggregates and adjusts company data using market share estimates in order to represent the entire U.S. market. Due to the restrictions imposed by the Appropriations Rider preventing DOE from using appropriated funds to implement or enforce the standards for GSILs, DOE is unable to modify exemptions for GSILs in this rulemaking. As stated previously, DOE will continue to monitor sales of the five exempted lamp types on an annual basis and will initiate an accelerated rulemaking as required by 42 U.S.C. 6295(l)(4) if the threshold is exceeded.

DOE also received several comments suggesting that DOE project sales trends of the exempted incandescent/halogen lamp types. CA IOUs suggested that for each exempted lamp type, DOE should model future sales in 2020 to determine whether to set standards for them, rather than only looking retrospectively at lamp sales patterns. CA IOUs noted there would be significantly more pressure on the exempted lamp types in 2020 due to pressure from the backstop or standards. To do this, CA IOUs commented that DOE should assess whether the

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[12] The historical spreadsheets showing comparisons of anticipated versus actual sales is available online at: http://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/63.

lamp could be utilized in the same sockets as covered GSLs, and whether the exempted lamp could be cost competitive with regulated GSLs if manufactured in bulk. If an exempted lamp type could meet these two requirements, DOE should forecast the expected increase in market share for this lamp when the efficacy standard for covered lamps becomes more stringent. CA IOUs concluded that DOE could then assess whether there is any energy savings potential for these exempted lamps, and whether to set standards for them. (CA IOUs, No. 18 at pp. 5-6; CA IOUs, Public Meeting Transcript, No. 19 at pp. 53-54) NRDC urged caution to not make assumptions about the specialty or exempted lamps because inexpensive 60 W incandescent lamps are still available, so there is currently less motivation for manufacturers and consumers to shift to niche lamps that have low sales, but that market trend could escalate in the future. (NRDC, Public Meeting Transcript, No. 19 at pp. 25-26) CEC also commented that DOE failed to consider the effect of the phase out of 60 W and 40 W incandescent lamps on exempted lamp sales. (CEC, No. 11 at p. 15)

As discussed previously in this section, DOE is prohibited by the Appropriations Rider from using appropriated funds to implement or enforce the standards for GSILs and therefore is not including GSILs in the scope of this rulemaking at this time. As such, DOE is unable to model the effect of standards for GSILs prescribed by EISA or project future trends of certain exempted incandescent/halogen lamps.

2.3.2 Compact Fluorescent Lamps

CFLs are also included in the definition of GSL, however the term “compact fluorescent lamp” is not currently defined in the CFR. CFLs can be integrated (*e.g.*, medium base CFLs) or non-integrated (*e.g.*, pin base CFLs). The Energy Policy Act of 2005 (EPAct 2005; Pub. L. 109–58) amended EPCA by setting energy conservation standards for MBCFLs. DOE’s existing energy conservation standards apply only to integrally ballasted (also referred to as self-ballasted) MBCFLs. 10 CFR 430.32(u) The definition for “medium base compact fluorescent lamp” is as follows:

> *Medium base compact fluorescent lamp* means an integrally ballasted fluorescent lamp with a medium screw base, a rated input voltage range of 115 to 130 volts and which is designed as a direct replacement for a general service incandescent lamp; however, the term does not include—
>
> (1) Any lamp that is—
> (i) Specifically designed to be used for special purpose applications; and
> (ii) Unlikely to be used in general purpose applications, such as the applications described in the definition of “General Service Incandescent Lamp” in this section; or
> (2) Any lamp not described in the definition of “General Service Incandescent Lamp” in this section that is excluded by the Secretary, by rule, because the lamp is—
> (i) Designed for special applications; and
> (ii) Unlikely to be used in general purpose applications.
>
> 10 CFR 430.2

As stated previously, the term “compact fluorescent lamp” is not currently defined but was determined to apply to both integrated and non-integrated CFLs in the preliminary analysis of the GSFL and IRL Standards Rulemaking.[13] NRDC agreed that both screw-based and pin base CFLs should be included in the analysis. (NRDC, Public Meeting Transcript, No. 19 at pp. 64-65) NEMA suggested a definition of “compact fluorescent lamp” adapted from the current definition of “medium base compact fluorescent lamp” in 10 CFR 430.2 to accommodate both integrated and non-integrated CFLs. NEMA suggested the definition to be “compact fluorescent lamp means an integrally or externally ballasted fluorescent lamp with a medium screw base or a pin base, a rated input voltage range of 115 to 130 volts and which is used in general lighting applications” and maintained the exemptions for lamps used in specialty applications from the MBCFL definition. (NEMA, No. 15 at p. 8)

DOE is considering a definition for “compact fluorescent lamp” in the CFL TP rulemaking. Similar to NEMA’s proposed definition, DOE is considering defining the term “compact fluorescent lamp” to include both integrated and non-integrated CFLs. The definition that DOE is considering is as follows:

> *Compact fluorescent lamp* means an integrated or non-integrated single-ended, low pressure mercury electric-discharge source in which a fluorescing coating transforms some of the ultraviolet energy generated by the mercury discharge into light; however, the term does not include circline or U-shaped fluorescent lamps.

DOE is also considering defining the terms “integrated” and “non-integrated” to further support the scope of this rulemaking. DOE developed technology neutral definitions that can be used to describe the various lamp technologies covered by this rulemaking. The definitions that DOE is considering are as follows:

> *Integrated lamp* means a lamp that contains all components necessary for the starting and stable operation of the lamp, does not include any replaceable or interchangeable parts, and is connected directly to a branch circuit through an ANSI base and corresponding ANSI standard lamp-holder (socket).
>
> *Non-integrated lamp* means a lamp that is not an integrated lamp.

DOE requests comment on the definitions under consideration for integrated lamp and non-integrated lamp.

In the framework document, DOE proposed including in this rulemaking all lamps that met the definition of “medium base compact fluorescent lamp” stated in 10 CFR 430.2. DOE noted that, as stated in the definition, MBCFLs designed for special purpose applications and unlikely to be used in general purpose applications are exempted from standards. For determining such non-general applications, the definition specifically references the GSIL definition, which lists several lamp types, such as reflector lamps, not considered for use in

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[13] The preliminary analysis technical support document for the GSFL and IRL Standards Rulemaking is available at www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0006-0022.

general service applications. Thus, in the framework document DOE interpreted the GSIL exemptions as also applying to MBCFLs.

In this preliminary analysis, DOE reassessed its interpretation of the exemptions from the MBCFL definition for MBCFLs used in specialty applications. Upon further consideration, DOE believes that because the definition of GSL in 42 USC §6291(30)(BB)(i) explicitly states that the term includes CFLs, and is not in any way limited to a particular base type of CFL, the intent of the definition was to consider all CFLs to be GSLs. Thus, DOE preliminarily concluded that the exemptions for the lamp types listed in the GSIL definition at 42 USC §6291(30)(D)(ii), referred to in the GSL definition, do not automatically apply to the MBCFLs included in the GSL rulemaking. Otherwise, the inclusion of CFLs in the definition of GSL would be a nullity. DOE conducted a separate assessment to determine if there are MBCFLs that are designed for specialty use and therefore cannot provide overall illumination. DOE identified MBCFLs that were designed for specialty applications and are not able to provide overall illumination, including black light lamps, bug lamps, colored lamps, plant light lamps, and silver bowl lamps. DOE is considering providing exemptions for these specialty applications, which are discussed further in section 2.3.5. DOE requests comment on the MBCFLs identified for specialty applications that cannot provide overall illumination and if there are other MBCFLs that should be considered.

As described previously, DOE determined that the term “compact fluorescent lamps” is not limited to MBCFLs. DOE therefore concluded that both integrated and non-integrated CFLs could be considered in the GSL rulemaking. Section 2.3.5 discusses additional CFLs for which DOE is considering establishing standards.

2.3.3 General Service LED Lamps

General service LED lamps are included in the definition of GSL. LED means a p-n junction solid state device of which the radiated output, either in the infrared region, the visible region, or the ultraviolet region, is a function of the physical construction, material used, and exciting current of the device. 10 CFR 430.2 Similar to CFLs, LED lamps can be integrated or non-integrated. DOE proposed a definition for “integrated LED lamp” in a test procedure SNOPR for LED lamps (hereafter “LED TP SNOPR”). 79 FR 32048 (June 3, 2014). The proposed definition is as follows:

> *Integrated light-emitting diode lamp* means an integrated LED lamp as defined in ANSI/IESNA RP–16 (incorporated by reference; see § 430.3).

As stated in the LED TP SNOPR, the ANSI/IESNA standard defines integrated LED lamps as comprising the LED source (the LED packages [components] or LED arrays [modules]), LED driver, ANSI standard base, and other optical, thermal, mechanical and electrical components such as phosphor layers, insulating materials, fasteners to hold components within the lamp together, and electrical wiring. The LED lamp is intended to connect directly to a branch circuit through a corresponding ANSI standard socket. 79 FR at 32021-22 (June 3, 2014).

Although 10 CFR 430.2 defines the term "light-emitting diode or LED" and DOE has proposed a definition for "integrated light-emitting diode lamp," DOE does not currently have a definition for "general service LED lamp." NEMA proposed definitions for LED lamps included in the scope of this rulemaking based on adapting definitions from ENERGY STAR Lamps Specification V1.1. NEMA proposed defining integral screw base LED lamp as an "integrated assembly comprised of LED packages (components) or LED arrays (modules), LED driver, medium screw base and other optical, thermal, mechanical, and electrical components. The device is intended to connect directly to the branch circuit through a corresponding screw based lamp-holder (socket)." NEMA also proposed a definition for integral pin base LED lamp as "an integrated assembly comprised of LED packages (components) or LED arrays (modules), LED driver, pin base, and other optical, thermal, mechanical, and electrical components. The device is intended to connect directly to the branch circuit through a corresponding GU pin base lamp holder (socket)." (NEMA, No. 15 at p. 8)

DOE appreciates NEMA's proposals for definitions to support the LED lamps covered in this rulemaking. As stated previously, DOE has tentatively determined that the term general service LED lamp includes both integrated and non-integrated LED lamps. Therefore, DOE has decided to propose a more general definition similar to the definition proposed for "compact fluorescent lamp" discussed in section 2.3.2 to clearly explain this determination. DOE is proposing the following definition for general service LED lamp:

> *General service light-emitting diode (LED) lamp* means an integrated or non-integrated LED lamp designed for use in general lighting applications (as defined in 430.2).

As stated in the definition, general service LED lamps are used in general lighting applications. In the framework document, DOE considered including in this rulemaking all LEDs that serve general lighting applications and are not the lamp types or shapes excluded from the GSIL definition in 42 USC §6291(30)(D)(ii). As discussed in section 2.3.2, DOE reassessed its interpretation of the exemptions from the GSIL definition, referred to in the GSL definition, and determined that because the definition of GSL in 42 USC §6291(30)(BB)(i) explicitly states that the term includes general service LEDs, the intent of the definition was to consider all general service LEDs to be GSLs. DOE determined that the exemptions for certain bulb shapes and lighting applications in the GSIL definition do not generally apply to the other lamp types included in the definition of GSL. Otherwise all LED lamps would be considered exempt, rendering the inclusion of LED lamps in the GSL definition a nullity. In this preliminary analysis, DOE assessed whether LED lamps exist that are designed for specialty applications and therefore cannot provide overall illumination. DOE identified LED lamps that were designed for specialty applications and are not able to provide overall illumination, including black light lamps, bug lamps, colored lamps, plant light lamps, and silver bowl lamps. DOE is considering providing exemptions for these specialty applications, which are discussed further in section 2.3.5. DOE requests comment on the LED lamps identified for specialty applications that cannot provide overall illumination and if there are other LED lamps that should be considered. DOE also requests comment on its proposed definition for general service LED lamp.

As described previously, DOE determined that the term "general service LED lamp" is not limited to integrated LED lamps. DOE therefore concluded that both integrated and non-integrated LED lamps could be considered in the GSL rulemaking. Section 2.3.5 discusses LED lamps for which DOE is considering establishing standards.

2.3.4 OLED Lamps

OLED lamps are included in the definition of GSL. OLED means a thin-film light-emitting device that typically consists of a series of organic layers between two electrical contacts (electrodes). 10 CFR 430.2 OLEDs are diffuse light sources made of thin layers of carbon-based semiconductor material. The layer-based construction tends to support development of large, flat surfaces rather than traditional lamp shapes. Because OLEDs are an emerging technology, the commercial availability of OLEDs is very limited. Further, products that are available are not used in general lighting applications due to their size and shape. The OLEDs that are available are marketed for accent lighting, interior design, or are sold integrated into fixtures. In addition, due to the emerging nature of the technology and the limited commercial availability of OLEDs, it is unclear whether the efficacy of existing OLED products can be improved. For these reasons, in the framework document DOE considered not establishing standards for OLED lamps in this rulemaking.

DOE received comments on its consideration to not establish standards for OLED lamps at this time. NRDC, ASAP, *et al.* commented that they would not oppose DOE leaving out OLED lamps from this rulemaking and phase of review of GSL energy conservation standards. (NRDC, ASAP, *et al.*, No. 17 at p. 10) NEMA agreed that it is too early to set standards for OLEDs. NEMA noted that the market is just beginning to see the earliest applications of this technology and is expected to rapidly evolve. NEMA concluded that there is insufficient experience, technology evolution, and commercial availability to justify including them in the scope of the rulemaking. (NEMA, No. 15 at p. 8; GE, Public Meeting Transcript, No. 19 at p. 67)

DOE agrees that it would be premature to establish standards for OLED lamps at this time. As noted in the framework document and by NEMA, OLED lamps are an emerging technology with limited commercial availability. Further, DOE notes that it remains unclear if the efficacy of existing OLED product can be improved. For these reasons, DOE is maintaining its decision to not consider establishing standards for OLED lamps in this preliminary analysis.

NRDC commented that a definition for OLED lamp is necessary to distinguish between LED lamps and OLED lamps, especially if no standard will be set for OLED lamps. (NRDC, Public Meeting Transcript, No. 19 at p. 68) DOE agrees that a definition for OLED lamp is necessary to clearly define the scope of this rulemaking. DOE is considering defining OLED lamps as follows:

> *Organic light-emitting diode or OLED lamp* means an integrated or non-integrated lamp that uses OLEDs as the primary source as light.

DOE requests comment on its consideration to continue to not establish standards for OLED lamps in this rulemaking. DOE also requests comment on its proposed definition for OLED lamp.

2.3.5 Other Lamps

Pursuant to the definition of GSL, DOE has the authority to consider additional lamps that it determines are used to satisfy lighting applications traditionally served by GSILs. In the framework document, DOE stated that the definition of GSIL indicates that GSLs are: (1) typically intended for general service applications; (2) have a medium screw base; (3) emit between 310 and 2,600 lumens; and (4) are capable of being operated at a voltage range at least partially within 110 and 130 V. DOE defines the term “general lighting application” as follows:

> *General lighting application* means lighting that provides an interior or exterior area with overall illumination.
>
> 10 CFR 430.2

Thus, in the framework document, lamps that met the four criteria outlined in the definition of GSIL were proposed to be included in the scope of coverage, regardless of the technology used to produce light. DOE received comments regarding the scope of coverage of this rulemaking.

CEC commented that DOE should include lamps within the rulemaking, regardless of socket type, because the application is to provide general, omnidirectional illumination. CEC cited that the definition of GSLs includes any lamp that can satisfy lighting applications traditionally served by GSILs and does not preclude certain lamps based on their socket type. CEC noted that there are already several socket types other than medium screw bases, including candelabra, intermediate, pin, and GU24 bases, which are currently serving the same purpose as GSLs, have significant sales volumes, and therefore should be included in this rulemaking. (CEC, No. 11 at p. 17) Soraa also recommended that DOE not limit the GSL definition by base type, as there are many base types that can be used in general service applications. (Soraa, No. 10 at p. 2)

DOE agrees with CEC and Soraa that a socket or base type does not preclude the use of a lamp in general service applications and recognizes that lamps with base types other than medium screw bases can provide overall illumination. Therefore, DOE has revised its criteria for lamps meeting the definition of GSL stated in the framework, including the requirement for a GSL to have a medium screw base.

In this preliminary analysis, DOE has taken a broad interpretation for what can be considered a GSL. In this broad interpretation, GSLs are lamps intended to serve in general lighting applications. As noted previously, a general lighting application is defined in 10 CFR 430.2 as lighting that provides an interior or exterior area with overall illumination.

DOE believes that several different base types can be used in general lighting applications, and that GSLs utilize an ANSI base to ensure they can be used in sockets commonly found in residential, commercial, and industrial fixtures. Therefore, DOE considers GSLs to have an ANSI base. DOE also believes that lumen output can restrict a lamp’s use in general lighting applications. DOE does not believe that lamps with lumen outputs below 310 lumens are intended for use in general lighting applications because their low lumen output is not sufficient for overall illumination. Thus, DOE considers GSLs to have a lumen output of at least 310 lumens. Additionally, DOE believes that lamps with operating voltage outside the range of 110 to 130 V can be used in general lighting applications. Specifically, DOE believes that both lamps operating on line voltage (*i.e.*, connects directly to a branch circuit) and lamps operating on low voltage (*i.e.*, requires the use of a transformer) can provide overall illumination. Therefore, DOE does not consider GSLs to have a specific voltage range.

DOE also considered whether lamps designed or labeled for specific applications could provide overall illumination and therefore met the definition of general service lamp. DOE determined that the exemptions for specialty applications listed in 42 U.S.C. 6291(30)(D)(ii) are only applicable to GSILs. However, DOE is considering in this rulemaking whether any exemptions for specialty applications are needed for other GSLs. DOE received several comments on if exemptions for specialty applications were necessary.

NRDC, ASAP, *et al.* and CA IOUs commented that if more energy efficient lamps can provide the same services as the exempted lamps, then those exemptions should be discontinued and the lamps should be included in the scope. (NRDC, ASAP, *et al.*, No. 17 at p. 6; CA IOUs, No. 18 at p. 6) NRDC, ASAP, *et al.* commented that DOE should also consider the risk of lamps circumventing standards, specifically whether exempted lamps can be used for general service illumination and whether lamps, if exempted, could be sold at prices lower than compliant lamps. NRDC, ASAP, *et al.* noted that sales data could be useful in the assessment of circumvention but should not be the only consideration. In situations where an exempted product has a risk of circumvention, but cannot feasibly become more efficient, NRDC, ASAP, *et al.* recommended that DOE consider creating a separate product class or narrowing the definitions of the exempted lamp categories. (NRDC, ASAP, *et al.*, No. 17 at p. 4)

DOE agrees that factors, including the technological feasibility of offering the exempted lamp's utility at a higher level of efficacy and potential circumvention of standards, are important considerations for this rulemaking. When determining whether an exemption for a specialty application is necessary, DOE assessed whether the lamp types could provide overall illumination and therefore could be used in general lighting applications. If DOE determined that the lamp could be used to provide overall illumination, but also offered a separate feature that was valued by consumers, DOE ensured that the utility provided by the lamp was offered at the highest efficacy levels.

Although the exemptions that apply to GSILs do not automatically apply to other lamp technologies, DOE considered whether these exemptions should be continued. DOE assessed whether each specified lamp type provides overall illumination and therefore can be used in general lighting applications. DOE has preliminarily determined that appliance lamps, black lights, bug lamps, colored lamps, infrared lamps, marine signal lamps, mine service lamps, plant lights, sign service lamps, silver bowl lamps, showcase lamps, and traffic signal lamps cannot provide overall illumination and therefore cannot be used in general lighting applications. DOE found the lumen output of these lamps, when provided by manufacturers, was insufficient to provide overall illumination. DOE notes that for many of the lamp types listed, such as colored lamps and bug lamps, the lumen output is not stated in manufacturer catalogs as providing lumen output is not the primary application. Therefore, DOE is considering not establishing standards for these lamp types under the GSL rulemaking because the lamps are intended for use in non-general applications. DOE requests comment on this decision.

DOE also reviewed left-hand thread lamps, marine lamps, reflector lamps, rough service lamps, shatter-resistant lamps, 3-way lamps, vibration service lamps, and lamps of several specific shapes (such as G, T, B, BA, CA, F, G16.5, G25, G30, S, and M14, as defined in ANSI C79.1-2002 and ANSI C78.20). Based on its assessment, DOE has preliminarily determined that these lamp types provide overall illumination and therefore can serve in general lighting applications and do not require an exemption from standards.

DOE received specific comments on several of the lamp types that DOE is considering establishing standards for in this rulemaking. NRDC, ASAP, *et al.* noted that 3-way lamps are offered in more efficient halogen, CFL, and LED technologies and therefore the exemption is no longer warranted. NRDC, ASAP, *et al.* also commented that LED lamps are a filament-less technology and therefore can serve as vibration service and rough service lamps. NRDC, ASAP, *et al.* further noted that halogen, CFL, and LED lamps can use shatter-resistant coatings similar to traditional incandescent/halogen lamps. NRDC, ASAP, *et al.* concluded that if shatter resistant coatings affect efficacy, a separate product class may be warranted, rather than an exemption. (NRDC, ASAP, *et al.*, No. 17 at p. 6)

As stated previously, DOE has preliminarily determined that 3-way lamps, vibration service lamps, rough service lamps, and shatter-resistant lamps are able to provide overall illumination and therefore can be used in general lighting applications. DOE also assessed whether the utility offered by these lamp types is available at higher levels of efficacy, which would indicate that there is no technological reason the utility could not be maintained in the future. DOE found that 3-way CFLs and LED lamps are available. Further, DOE found that one of the most efficacious GSLs currently available on the market is a 3-way LED lamp. Vibration service lamps and rough service lamps are defined specifically in the context of incandescent/halogen technology. However, DOE believes the utility of these lamp types, as well as shatter-resistant lamps, is their service in applications where vibrations occur (such as in a ceiling fan) or in applications where broken glass due to shattering would be a safety hazard (such as a food preparation area). DOE believes that LED lamps are inherently durable and resistant to shattering and thus can provide the necessary utility to serve in these applications. DOE also confirmed that shatter-resistant CFLs exist. DOE requests comment on the lamp types that DOE is considering not providing exemptions for in this GSL rulemaking.

CEC commented that the current list of exemptions exists from a perceived need for specialty lamps that provide a distinct utility and cannot meet efficacy standards. CEC noted that because the scope of the rulemaking is limited to medium screw bases, the specialty purpose lamps could continue to be distributed and sold in other base types without having to maintain the exemptions. CEC concluded that if DOE continues to limit the rulemaking to medium screw bases, it should remove all exemptions and define GSL to cover products in direct competition for general purpose lighting and include primary features, such as omnidirectional light, white light, and medium screw bases. (CEC, No. 11 at pp. 16-17)

As stated previously, DOE has taken a broad interpretation of GSL and is considering lamps with base types other than medium screw bases to be general service lamps because lamps with other base types, such as candelabra and GU24, are frequently used in general lighting applications.

Soraa commented that the scope of lamps should be broadened to include all lamp types that are used in general service lighting applications today, such as reflector lamps. (Soraa, No. 10 at p. 1) Soraa commented that DOE's Lighting Market Characterization[14] indicates that reflector (R), parabolic aluminum reflector (PAR), bulged reflector (BR), and multifaceted reflector (MR) shaped lamps are used for general service lighting and make up a significant component of the energy consumption of the general lighting market. Soraa noted that if these lamps types are not included, there may be as much energy consumed by the remaining halogen reflector and low voltage display lamps as the regulated GSLs. (Soraa, No. 10 at p. 2)

DOE agrees with Soraa that reflector lamps provide overall illumination and therefore can serve in general lighting applications. In this preliminary analysis, DOE has determined that reflector lamps are included in the broad interpretation of the scope of coverage of the GSL rulemaking. DOE notes, however, that the definition of GSL explicitly states that IRLs are not included. DOE addresses other reflector lamps that are included in the scope of this rulemaking in more detail in the subsections that follow.

DOE is considering defining terms in support of the scope of coverage. To further explain lamp types DOE identified for use in non-general applications, DOE is considering defining the term "colored lamp" as follows:

> *Colored lamp* means a colored fluorescent lamp, a colored incandescent lamp, or a lamp designed and marketed as a colored lamp and not designed or marketed for general lighting applications with either of the following characteristics (if multiple modes of operation are possible [such as variable CCT], either of the below characteristics must be maintained throughout all modes of operation):
>
> > (1) A CRI less than 40, as determined according to the method set forth in CIE Publication 13.3 (incorporated by reference; see §430.3); or
> > (2) A correlated color temperature less than 2,200 K or greater than 7,000 K as determined according to the method set forth in IES LM-66 or IES LM-79 as appropriate (incorporated by reference; see §430.3).

DOE is also considering defining terms related to the lamp types that can serve in general lighting applications. Specifically, DOE is considering defining "reflector lamp" and "non-reflector" lamp as follows:

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[14] U.S. Department of Energy. *2010 U.S. Lighting Market Characterization*. January 2012. Available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf.

> *Reflector lamp* means a lamp that has an R, PAR, BPAR, BR, ER, MR, or similar bulb shape as defined in ANSI C78.20 (incorporated by reference; see §430.3) and ANSI C79.1 (incorporated by reference; see §430.3) and is used to direct light.
>
> *Non-reflector lamp* means a lamp that is not a reflector lamp.

To ensure that complete light fixtures with ANSI bases (*e.g.*, certain retrofit kits) are not included in the scope of this rulemaking, DOE is considering defining the term light fixture. DOE is considering defining the term based on the definition in the industry standard, ANSI/IESNA RP-16. The definition DOE is considering for light fixture is as follows:

> *Light Fixture* means a complete lighting unit consisting of lamp(s) and ballast(s) (when applicable) together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamp(s) to the power supply.

DOE requests comment on the definitions under consideration in support of the scope of coverage of the GSL rulemaking.

Thus, for the purposes of this rulemaking, DOE considered lamps which are not or could not be considered in another rulemaking proceeding, have a lumen output of 310 lumens or greater, have an ANSI base, are not a light fixture, and are not designed and labeled for use in the following non-general applications, as meeting the definition of GSL: appliance lamps, black light lamps, bug lamps, colored lamps, infrared lamps, marine signal lamps, mine service lamps, plant light lamps, sign service lamps, silver bowl lamps, showcase lamps, and traffic signal lamps.

Although many lamp types meet the definition, DOE has tentatively decided to not set standards for several of these lamp types at this time. When evaluating GSLs, DOE considered standards for lamps when it concluded that standards were technologically feasible, economically justified, and would result in significant energy savings. DOE conducted a two-phase review of specific lamp types to define which lamps would be analyzed in this rulemaking. DOE began by analyzing the potential for energy savings and technological feasibility. For the GSLs that passed those criteria, DOE conducted a full economic analysis in the LCC analysis and NIA. The following sections evaluate several lamp types and summarize which lamp types DOE is considering setting standards for at this time.

2.3.5.1 Lamps Addressed In Other Rulemakings

As discussed previously, DOE has the authority to consider additional lamp types that it determines are used to satisfy lighting applications traditionally served by GSILs. To limit the probability that one lamp type might be subject to two different standards, DOE did not consider adding lamp types that are or could be addressed in a separate rulemaking proceeding. For example, the general service fluorescent lamp rulemaking considered establishing standards for additional types of fluorescent lamps (such as 2-foot linear fluorescent lamps). While that rulemaking ultimately concluded that additional lamps should not be subject to standards, DOE did not consider the additional lamps evaluated as GSFLs to be candidates for coverage in the GSL rulemaking.

In the framework document, DOE stated that it identified self-ballasted mercury vapor (SBMV) lamps that were marketed as GSIL replacements and determined that SBMV lamps were intended for general service applications. DOE received comments on including SBMV lamps in the scope of the GSL rulemaking.

NEMA commented that SBMV lamps should not be included in the scope of this rulemaking, as 10 CFR 431.282 defines a mercury vapor lamp as a high-intensity discharge (HID) lamp, which means it is covered by a different rulemaking. NEMA also stated that self-ballasted mercury vapor lamps are not used in high volume and have very little energy savings potential. NEMA noted that the high prices and lumen output of these lamps make them an unlikely substitute for covered GSLs or potential loophole. NEMA further questioned the plausibility of consumers purchasing SBMV lamps considering existing public concern regarding the 2 milligrams of mercury in a CFL. (NEMA, No. 15 at pp. 7, 9; NEMA, Public Meeting Transcript, No. 19 at p. 71)

As stated previously, to limit the probability that one lamp type may be subject to two different standards, DOE is not considering lamp types in this preliminary analysis that are or could be addressed in a separate rulemaking proceeding. As noted by NEMA, mercury vapor lamps are defined as HID lamps. Because SBMV lamps could be addressed in a separate rulemaking, DOE is not considering including SBMV lamps in the scope of this GSL rulemaking.

CEC commented that SBMV lamps should not be included in the scope of this rulemaking because EISA prohibited the sale of mercury vapor ballasts after January 1, 2008, which are used in SBMV lamps, thereby making the sale of SBMV lamps in the United States illegal. Furthermore, CEC commented that sockets that are compatible with mercury vapor lamps are also compatible with other, higher-efficacy lighting technologies, so there would not be any loss in utility by removing these lamps from the market. However, CEC allowed that if evidence suggests that SBMV lamps do not use mercury vapor ballasts, or that there would be a significant utility loss, then they should be included in the scope of the rulemaking. (CEC, No. 11 at p. 18)

While mercury vapor ballasts, other than specialty application mercury vapor ballasts, have been banned from import or production in the United States since January 1, 2008, the sale of SBMV lamps is not prohibited in the United States. (*See* 42 U.S.C. 6295(ee)) Notably, 42 U.S.C. 6291(47) defines the term mercury vapor lamp as including self-ballasted screw base lamps. Mercury vapor ballast is later defined in 42 U.S.C. 6291(48) as a device that is designed and marketed to start and operate mercury vapor lamps intended for general illumination. Thus, a SBMV lamp is a separately defined covered product and the energy conservation standards prescribed by EISA prohibiting the sale of mercury vapor ballasts does not apply to SBMV lamps. However, because SBMV lamps can be considered under the HID lamp rulemaking, as mentioned previously, DOE is not considering SBMV lamps in the scope of this GSL rulemaking.

DOE is considering defining the term mercury vapor lamp in support of the scope of coverage of this rulemaking. DOE is considering using the definition in 42 U.S.C. 6291(47) for mercury vapor lamp which is defined as follows:

> *Mercury vapor lamp* means a high intensity discharge lamp, including clear, phosphor-coated, and self-ballasted screw base lamps, in which the major portion of the light is produced by radiation from mercury typically operating at a partial vapor pressure in excess of 100,000 Pa (approximately 1 atm).

DOE requests comment on its consideration to exclude from the scope of the GSL rulemaking lamps that are addressed in other rulemakings.

2.3.5.2 Lamps without an ANSI Base

In the framework document, DOE considered general service lamps to have a medium screw base. In this preliminary analysis, DOE has taken a broader interpretation of the definition of general service lamp. As noted previously, DOE believes that GSLs use an ANSI base to ensure they can be used in sockets commonly found in residential, commercial, and industrial fixtures. Thus, DOE considers general service lamps to have an ANSI base.

The Edison Electrical Institute (EEI) suggested that DOE include gas lamps within the scope of the GSL rulemaking as they provide overall illumination. EEI commented that although gas lamps have a small market share, they are competitive products and use a significant amount of energy. EEI noted that many gas lamps use continuously burning pilot lights and therefore use energy usage at all times, even when the fixture is producing no light. (EEI, No. 16 at pp. 4-5) DOE conducted a survey of the market and was unable to identify any gas lamps with ANSI bases. Based on the criteria established in this preliminary analysis, DOE does not believe gas lamps meet the definition of general service lamp.

2.3.5.3 High Lumen Lamps (>2,600 Lumens)

DOE is considering lamps with a lumen output of at least 310 lumens as meeting the definition of a GSL. In the framework document, DOE considered including lamps with lumen output between 310 and 2,600 lumens. DOE maintains this lower bound in the preliminary analysis because lamps with lumen output less than 310 lumens do not provide sufficient overall illumination. However, DOE does not believe there is an upper bound on lumen output that can provide overall illumination.

DOE received a comment on the lumen output range considered in the framework document. NRDC, ASAP, *et al.* commented that incandescent/halogen lamps and CFLs can provide high lumen outputs, and therefore lamps with lumen output in the range of 2,601 – 3,300 lumens should be included in the scope of this rulemaking. (NRDC, ASAP, *et al.*, No. 17 at p. 6)

Regarding lamps with a lumen output greater than 2,600 lumens, DOE believes that these lamps can be used in overall illumination and therefore meet the definition of GSL. DOE also agrees that higher lumen output lamps exist in more efficient technologies (*e.g.*, integrated and non-integrated CFLs). DOE notes that, as discussed in section 2.3.1, due to the restrictions of the

Appropriations Rider, DOE is unable to consider modifying existing exemptions for GSILs and therefore is not currently including GSILs with lumen output greater than 2,600 lumens in the scope of the rulemaking. DOE believes that establishing energy conservation standards for higher lumen lamps, while not also addressing higher lumen incandescent lamps, may ultimately increase national energy consumption. More efficient products typically have lower operating costs but higher initial costs relative to the baseline products available on the market. Because the GSILs with lumen outputs greater than 2,600 lumens are exempt from standards, consumers may choose to purchase incandescent lamps rather than more expensive CFL and LED lamps. Therefore, DOE is considering not establishing standards for GSLs with lumen outputs greater than 2,600 lumens at this time.

2.3.5.4 General Service Lamps that Operate in Standby Mode

DOE identified lamps that meet the definition of GSL and can operate in standby mode. See section 2.2.4 for more information on standby mode. Feedback from manufacturers during interviews indicated that few GSLs provide standby mode functionality. Manufacturers noted that only a handful of such lamps exist, and it is a niche market at this time. DOE also found, based on manufacturer feedback, that GSLs that operate in standby mode use a variety of methods to achieve the desired functionality (*e.g.*, remotely turn the lamp on or off, changing lamp color, dimming the lamp), which results in differing power consumption and utility provided. DOE believes that while such GSLs currently represent a very small fraction of the GSL market, the market share for GSLs that can operate in standby mode will increase over the analysis period. Thus, due to the increasing market share of these products, DOE is considering establishing standards for GSLs with standby mode power at this time.

2.3.5.5 Integrated Lamps

As described in section 2.3.2, integrated lamps (also referred to as self-ballasted lamps) contain all components necessary to start and operate a lamp and directly connect to a branch circuit via an ANSI base. DOE considered integrated lamps that are not or could not be considered in another rulemaking proceeding, have a lumen output of 310 lumens or greater, have an ANSI base, are not a light fixture, and are not designed and labeled for use in the non-general applications described in section 2.3.5, to meet the definition of general service lamp. The following sections discuss these general service integrated lamps by base type and identify lamps for which DOE is considering establishing standards at this time.

Medium Screw Base

Medium screw base integrated lamps are offered in a variety of technologies and are also offered with or without a reflector. Medium screw base lamps are the most common lamps on the market, given the proliferation of the medium screw base socket. While most of these lamps are omnidirectional, many are also offered with reflectors, which are used to direct the light. Reflector lamps are commonly used in track lighting and recessed can light fixtures. Medium screw base integrated lamps provide overall illumination and are commonly found in residential, commercial, and industrial locations.

Non-reflector medium screw base integrated lamps exist primarily in three technologies: incandescent/halogen, compact fluorescent, and LED.[15] General service incandescent/halogen lamps that have a medium screw base are addressed in section 2.3.1; DOE is not considering GSILs in this rulemaking due to the Appropriations Rider. MBCFLs are addressed in section 2.3.2. As standards already exist for these products, this rulemaking considers whether to amend standards for MBCFLs. In the framework document, DOE stated that it identified lamps that can serve in general lighting applications that use a CFL as the primary lighting source and also contain either a halogen capsule or an LED. The hybrid lamps that DOE identified meet the definition of MBCFL, though the term "hybrid CFL" is not currently defined. DOE received comments on hybrid lamps.

NEMA proposed the definition of a hybrid lamp to be "a lamp utilizing two or more lighting technologies to provide two or more different lighting functions." (NEMA, No. 15 at p. 9)

DOE is considering a similar definition as proposed by NEMA for "hybrid CFL." The definition under consideration in the CFL TP rulemaking is as follows:

> *Hybrid compact fluorescent lamp* means a compact fluorescent lamp that incorporates one or more supplemental light sources of different technology.

NRDC, ASAP, *et al.* commented that hybrid lamps should be included in the scope of the rulemaking, noting that that certain halogen-CFL hybrid lamps address the consumer complaint of long warm-up periods for CFLs. (NRDC, ASAP, *et al.*, No. 17 at p. 10) On the other hand, NEMA commented that hybrid lamps are not used in sufficient volumes to warrant including these lamps under this rulemaking. (NEMA, No. 15 at p. 7) As noted, DOE has determined that the hybrid lamps identified meet the definition of MBCFL. Because MBCFLs are included in the scope of this rulemaking, as discussed in section 2.3.2, hybrid lamps are also included in the scope.

Medium screw base integrated LED lamps are rapidly increasing their market share relative to incandescent/halogen and compact fluorescent technology. In the most recent lamp indices data published by NEMA for the fourth quarter of 2013, the market share of LED A-shape replacement lamps increased 42.3 percent over the previous quarter.[16] Given their nontrivial market share, DOE has tentatively concluded that standards for medium screw base integrated LED lamps would result in significant energy savings. Technology for these lamps is rapidly changing, such that new generations of LED products have improved performance relative to products that entered the market six months before. In its Multi-Year Program Plan for solid state lighting, DOE published a target LED package efficacy for the year 2020 and identified areas that could potentially be improved to achieve the targeted efficacy, such as

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[15] In addition, DOE identified non-reflector medium screw base integrated lamps available in mercury vapor technology. These lamps are discussed in more detail in section 2.3.5.1.

[16] NEMA. *Halogen A-line Lamp Shipments Continue to Rise During Fourth Quarter*. March 27, 2014. Available at: http://www.nema.org/news/Pages/Halogen-A-line-Lamp-Shipments-Continue-to-Rise-During-Fourth-Quarter.aspx.

package efficiency, electrical efficiency, and power and phosphor conversion efficiency.[17] Because further efficacy improvements are possible, DOE has tentatively concluded that standards for these lamps are technologically feasible. For these reasons, DOE conducted a full economic analysis for medium screw base integrated LED lamps in the LCC analysis and NIA. See chapters 8 and 10 of this TSD for more information.

Reflector medium screw base integrated lamps are also typically offered with incandescent/halogen, compact fluorescent, or LED technology. As discussed in section 2.3.5, IRLs are specifically excluded from the definition of GSL and therefore will not be considered in this rulemaking. Based on data from the 2010 LMC, DOE determined that reflector CFLs compose less than 2 percent of the total inventory of lamps in the United States. The LED lamp data is not given by lamp shape, however LED lamps compose less than 1 percent of the total inventory of lamps in the United States, of which reflector LED lamps would be an even smaller portion. Although DOE believes that LED reflector lamps may compose a growing portion of the reflector lamp market, DOE believes that establishing energy conservation standards for these lamps may ultimately increase national energy consumption. As noted previously, more efficient products typically have lower operating costs but higher initial costs relative to the baseline products available on the market. Because IRLs are not considered in this rulemaking and would be subject to separate, less stringent efficacy requirements, consumers may choose to purchase IRLs rather than more expensive CFL and LED reflector lamps. Because IRLs are less efficacious, they require more energy to produce the same amount of light as CFLs and LED lamps and thus any shift to these products could increase overall energy consumption. For these reasons, DOE has tentatively decided to not establish energy conservation standards for reflector medium screw base integrated lamps at this time.

Candelabra and Intermediate Base

Candelabra and intermediate base integrated lamps are offered with incandescent/halogen, compact fluorescent, and LED technology. The candelabra base is the more common of the two base types – about 5 percent of product offerings compared to less than 1 percent for the intermediate base. Candelabra and intermediate base integrated lamps provide overall illumination and are found primarily in residential locations.

Non-reflector candelabra and intermediate base integrated lamps exist primarily in three technologies: incandescent/halogen, compact fluorescent, and LED. Incandescent/halogen lamps that have a candelabra or intermediate screw base are addressed in section 2.3.1; DOE is not considering these lamps in this rulemaking due to the Appropriations Rider. A review of compact fluorescent and LED product offerings indicates that few products are offered in these technologies compared to the number offered with incandescent/halogen technology. After reviewing the available product information, DOE does not believe it is appropriate to establish energy conservation standards for these lamps at this time. DOE found that a large number of CFL and LED candelabra and intermediate base lamps do not have standard ANSI shape designations. DOE believes these non-standard form factors could prevent the CFL and LED

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[17] U.S. Department of Energy. *Solid State Lighting Research and Development Multi-Year Program Plan.* May 2014. Available at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2014_web.pdf.

lamps from serving in the same applications as lamps with incandescent/halogen technology, and thus these lamp types may not be available at higher levels of efficacy. For these reasons, DOE has tentatively decided to not establish energy conservation standards for non-reflector candelabra and intermediate base integrated lamps at this time.

At the time of this analysis, the vast majority of candelabra and intermediate base integrated lamps were omnidirectional. DOE identified one incandescent/halogen reflector candelabra base integrated lamp and a limited number of incandescent/halogen reflector intermediate base integrated lamps. However, as stated previously, DOE is not considering these lamp types due to the Appropriations Rider. DOE was unable to identify reflector candelabra base or intermediate base integrated lamps in CFL or LED technology. For these reasons, DOE does not believe that standards for reflector candelabra and intermediate base integrated lamps would result in significant energy savings. Therefore, DOE has tentatively decided not to establish energy conservation standards for these lamps at this time.

Pin Base

DOE considers pin base integrated lamps to be integrally ballasted (if applicable) lamps with plug-in lamp bases that operate on line voltage (*i.e.*, connect directly to the branch circuit without the use of a transformer). Pin base integrated lamps are offered in a variety of technologies and are also offered with or without a reflector. Common pin base integrated lamps are tubular quartz halogen lamps, GU24 base lamps, and GU10 base lamps with a MR shape. Pin base integrated lamps provide overall illumination and are found predominately in residential and commercial locations. DOE is considering defining terms related to pin base lamps in support of the scope of this rulemaking. The terms DOE is considering are as follows:

> *Pin base lamp* means a lamp that uses a base type designated as a single pin base or multiple pin base system in Table 1 of ANSI C81.61, Specifications for Electrics Bases (incorporated by reference; see §430.3).
>
> *GU24 base* means the GU24 base standardized in ANSI C81.61 (incorporated by reference; see §430.3).

DOE requests comment on the definitions under consideration for pin base lamp and GU24 base.

Non-reflector pin base integrated lamps are available with multiple pin bases and exist with incandescent/halogen, CFL, and LED technology. The incandescent/halogen non-reflector pin base integrated lamps (*e.g.*, G8 and G9 base tubular halogen quartz lamps) have few products available on the market. CFL and LED non-reflector pin base integrated lamps commonly use GU24 bases. Of the integrated pin bases considered, lamps with GU24 bases compose the vast majority of the market. The GU24 base was created as a substitute to the medium screw base to prevent the use of incandescent/halogen lamps. While GU24 lamps may not currently be sold in the same volume as medium screw base lamps, DOE expects their sales to increase considerably as a result of regulations and voluntary program specifications. For example, California’s Building Code Standards Title 24 requires high efficiency lighting to be installed, thus prohibiting screw base sockets.[18] Similarly, the *ENERGY STAR Program Requirements Product Specification for Luminaires (Light Fixtures) Eligibility Criteria Version 1.2* specification prohibits the use of screw bases (*e.g.*, E26) in luminaires in order to achieve ENERGY STAR certification.[19] Given their expected market share, DOE has tentatively concluded that standards for non-reflector GU24 base integrated lamps would result in significant energy savings. Furthermore, because these lamps exist in varying levels of efficacy (*i.e.*, CFL and LED technology), DOE has concluded that standards for these lamps would be technologically feasible. For these reasons, DOE conducted a full economic analysis for non-reflector GU24 base integrated lamps in the NIA. See chapters 8 and 10 of this TSD for more information.

Reflector pin base integrated lamps are also offered with multiple pin bases, but in contrast to non-reflector lamps, the GU10 base is the most common base for reflector lamps. Although products are offered with incandescent/halogen, CFL, and LED technology, there are very few CFL products and halogen and LED lamp options dominate the market. Although DOE believes these lamps compose a sizeable portion of the reflector lamp market, DOE does not believe it is appropriate to establish energy conservation standards for these lamps at this time. DOE does not believe that LED technology is currently able to provide the same utility as halogen technology in the MR16 lamp shape. MR lamps are used in recessed downlights and track lighting, typically in retail, hospitality, residential, and museum applications.[20] As noted by DOE's CALiPER program, halogen MR16 lamps deliver focused illumination from their small (2 inch) diameter, have desirable color quality, are easy to use with controls, and are available with a range of different options (*e.g.*, beam angle and intensity) and accessories (*e.g.*, spread lenses). Given this combination of features, the conventional halogen MR16 lamp is one of the most difficult lamps for LED technology to successfully replicate.[21] A recent report by DOE's CALiPER program found that every LED MR16 that claimed to be a replacement for a halogen MR16 produced fewer lumens and had lower center beam intensity than would be predicted using the ENERGY STAR center beam intensity tool. While new products continue to enter the market, LED MR16s still do not offer the same lumen packages as available halogen MR16s (particularly above 500 lumens). This difference is likely because LED lamps must incorporate a driver into an already small form factor and struggle to efficiently dissipate heat to achieve optimal performance. Because more efficient replacements that maintain the same utility are not currently available, DOE has tentatively decided to not establish energy conservation standards for reflector pin base integrated lamps at this time. DOE requests comment on whether LED MR16 lamps are suitable replacements for incandescent/halogen reflector integrated MR16 lamps.

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[18] California Energy Commission's Building Code Standards are available at: http://www.energy.ca.gov/title24/.

[19] *ENERGY STAR® Program Requirements for Luminaires (Light Fixtures) Eligibility Criteria Version 1.2*. December 21, 2012. Washington, DC.

[20] U.S. Department of Energy. *CALiPER Application Summary Report 22: LED MR16 Lamps*. June 2014. Available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_22_summary.pdf.

[21] Ibid.

Other Bases

Additional base types exist for integrated lamps, including other screw bases, however DOE identified very few integrated non-reflector and reflector lamps with these base types. DOE has tentatively concluded that given their low market share, standards for non-reflector and reflector lamps with other bases such as mogul bases and bayonet bases would not result in significant energy savings. DOE requests comment on whether there are any integrated lamps with other bases that have a significant market share.

2.3.5.6 Non-Integrated

As described in section 2.3.2, non-integrated lamps (also referred to as externally ballasted lamps) are lamps that do not contain all components necessary for the starting and stable operation of the lamp. Non-integrated lamps require an external component, such as a ballast, driver, or transformer to operate on a branch circuit. DOE considered non-integrated lamps that are not or could not be considered in another rulemaking proceeding, have a lumen output equal to or greater than 310 lumens, have an ANSI base, are not a light fixture, and are not designed and labeled for use in the non-general applications described in section 2.3.5, to meet the definition of general service lamp. The following sections discuss general service non-integrated lamps by base type and identify lamps for which DOE is considering establishing standards at this time.

Screw Base

Non-reflector and reflector screw base non-integrated lamps are very uncommon and are available in a limited range of technologies. DOE identified one non-reflector medium screw base non-integrated lamp that may meet the definition of GSL. The non-reflector screw base non-integrated lamp is a CFL intended to be used in marine applications and operates using a battery. Similarly, DOE identified few reflector screw base non-integrated lamps. The reflector screw base non-integrated lamp type it did identify is used for providing illumination in pool and spa applications. DOE has tentatively concluded that given their extremely low market share, standards for non-reflector and reflector screw base non-integrated lamps would not result in significant energy savings and is therefore not considering establishing standards for these products at this time.

Pin Base

DOE considers pin base non-integrated lamps to be lamps that use a single pin base or multiple pin base system (as defined by ANSI 81.61) and operate using an external ballast, driver, or transformer. Pin base non-integrated lamps are offered in a variety of technologies and are also offered with or without a reflector. Pin base non-integrated lamps provide overall illumination and are found in residential, commercial, and industrial locations. Common lamp types considered pin base non-integrated lamps are pin base CFLs and low voltage incandescent/halogen lamps with or without a reflector.

Although non-reflector pin base non-integrated lamps are available in incandescent/halogen, CFL, and LED technologies, CFLs are by far the most common type. As stated in the framework document, DOE determined that the term compact fluorescent includes both integrated and non-integrated CFLs and therefore stated that it was considering including non-integrated, or pin base, CFLs in the scope of this rulemaking. Pin base CFLs are available in a variety of pin bases including 2-pin and 4-pin configurations such as the G24d-3 and G24q-3 bases, respectively. For more detail on common base types of pin base CFLs, see section 2.7. DOE received comments regarding the inclusion of pin base CFLs in the scope of this rulemaking.

NEMA advised DOE to reconsider whether to include pin base CFLs in this rulemaking. (NEMA, No. 15 at p. 7) NEMA commented that pin base CFLs are not a direct replacement for millions of incandescent screw base products and would require a consumer to purchase a new luminaire. NEMA stated that while the pin base CFL market is noticeable, it is minor and its growth comes from consumers purchasing new fixtures. (NEMA, Public Meeting Transcript, No. 19 at p. 76) NEMA further commented that pin base CFLs are already at max-tech efficiency, and therefore there is no justification for including them in this rulemaking. NEMA noted that if DOE does include them in the rulemaking, the standard should be set at the current max-tech levels and should take into account the increased burden on the industry of the additional reporting and testing requirements for pin base CFLs. (NEMA, No. 15 at p. 9)

DOE agrees with NEMA that the market share of pin base CFLs is not insignificant given the vast number of product offerings and common use in commercial applications. Given their nontrivial market share, DOE has tentatively concluded that standards for pin base CFLs could result in significant energy savings. As discussed in section 2.7, DOE identified some variation in levels of efficacy for non-integrated lamps and therefore believes standards are technologically feasible. For these reasons, DOE assessed whether standards for these lamps are economically justified. See chapter 10 of this TSD for more information.

Incandescent/halogen non-reflector pin base non-integrated lamps include quartz halogen lamps that operate on low voltage and thus require the use of a transformer. Common base types for these lamps include G4 and GY6.35 bases. Incandescent/halogen non-reflector pin base non-integrated lamps have few products available on the market. A very limited number of LED non-reflector pin base non-integrated lamps with the same base types, and thus intended to replace the incandescent/halogen versions, are available on the market currently. DOE has tentatively concluded that given their low market share, standards for non-reflector pin base non-integrated lamps would not result in significant energy savings. Further, because LED technology is changing rapidly, DOE believes that establishing standards for these products may slow innovation in a market that appears to be developing. DOE requests comment on the market share and technological feasibility of increasing the efficacy of non-reflector pin base non-integrated lamps.

Reflector pin base non-integrated lamps are also offered with multiple pin bases, but in contrast to non-reflector lamps, the GU5.3 base is the most common base and corresponds to the MR16 lamp shape. Although products are offered with incandescent/halogen, CFL, and LED technology, incandescent/halogen and LED lamp options dominate the market and there are very few CFL products. DOE received a comment on reflector pin base non-integrated lamps. Soraa recommended that lamps that are driven by transformers, such as low voltage LED MR16 lamps, should be included in the scope. Soraa commented that while this lamp was initially only used for projectors, it is now widely used in restaurants, hotels, and residential settings. (Soraa, No. 10 at p. 2)

DOE agrees that MR16 lamps can be used in general lighting applications. Although DOE believes these lamps provide overall illumination and compose a sizeable portion of the reflector lamp market, DOE does not believe it is appropriate to establish energy conservation standards for these lamps at this time. For the same reasons described for reflector pin base integrated lamps in section 2.3.5.5, DOE does not believe that LED technology is currently able to provide the same utility as halogen technology in the MR16 lamp shape. Additionally, LED reflector pin base non-integrated lamps have the added complexity of needing to be compatible with an existing transformer. Because replacements that are more efficient and yet maintain the same utility are not currently available, DOE has tentatively decided not to establish energy conservation standards for reflector pin base integrated lamps at this time. DOE requests comment on whether LED MR16 lamps are suitable replacements for incandescent/halogen reflector non-integrated MR16 lamps.

Other Bases

DOE did not identify any additional base types for non-integrated lamps that meet the definition of GSL. DOE requests comment on whether there are any non-integrated lamps with other bases that meet the definition of GSL and the market share of these lamps.

2.3.5.7 Summary of Lamps

In summary, while many different lamp types meet the definition of GSL, DOE is only considering establishing standards in this rulemaking for the following lamps:

- Integrated, non-reflector, medium screw base lamps with a lumen output between 310 and 2,600 lumens;
- GU24 base, non-reflector lamps with a lumen output between 310 and 2,600 lumens; and
- Non-integrated, non-reflector, pin base, CFLs with a lumen output between 310 and 2,600 lumens.

Standards would not apply to the follow lamp types:

- OLED lamps
- Mercury vapor lamps
- IRLs
- GSFLs
- Light fixtures
- Appliance lamps
- Black light lamps
- Bug lamps
- Colored lamps
- Infrared lamps

- Marine signal lamps
- Mine service lamps
- Plant light lamps
- Sign service lamps
- Silver bowl lamps
- Showcase lamps
- Traffic signal lamps
- GSILs that are:
    - A left-hand thread lamp
    - A marine lamp
    - A reflector lamp
    - A rough service lamp
    - A shatter-resistant lamp (including a shatter-proof lamp and a shatter-protected lamp)
    - A 3-way incandescent lamp
    - A vibration service lamp
    - A G shape lamp (as defined in ANSI C78.20) (incorporated by reference; see §430.3) and ANSI C79.1-2002 (incorporated by reference; see §430.3) with a diameter of 5 inches or more
    - A T shape lamp (as defined in ANSI C78.20) (incorporated by reference; see §430.3) and ANSI C79.1-2002 (incorporated by reference; see §430.3) and that uses not more than 40 watts or has a length of more than 10 inches
    - A B, BA, CA, F, G16-1/2, G-25, G30, S, or M-14 lamp (as defined in ANSI C79.1-2002) (incorporated by reference; see §430.3) and ANSI C78.20 (incorporated by reference; see §430.3) of 40 watts or less.

2.3.5.8 Summary of Definitions

In summary, DOE is considering defining the following terms in this rulemaking to support the scope of coverage:

- Integrated lamp (discussed in section 2.3.2)
- Non-integrated lamp (discussed in section 2.3.2)
- General service LED lamp (discussed in section 2.3.3)
- OLED lamp (discussed in section 2.3.4)
- Colored lamp (discussed in section 2.3.5)
- Reflector lamp (discussed in section 2.3.5)
- Non-reflector lamp (discussed in section 2.3.5)
- Light fixture (discussed in section 2.3.5)
- Mercury vapor lamp (discussed in section 2.3.5.1)
- Pin base lamp (discussed in section 2.3.5.5)
- GU24 base (discussed in section 2.3.5.5)

2.4 SCOPE OF METRICS

In this section, DOE discusses specific issues and comments related to the scope of metrics included in this rulemaking. The topics of discussion include revising existing metrics for MBCFLs and additional metrics under consideration for MBCFLs.

As stated in section 2.2.1, this rulemaking satisfies the requirements under 42 U.S.C 6295(m)(1) to review existing standards for MBCFLs, as CFLs are included in the definition of a GSL. EPAct 2005 amended EPCA by establishing energy conservation standards for MBCFLs. Performance requirements were specified for five metrics: (1) minimum initial efficacy; (2) lumen maintenance at 1,000 hours; (3) lumen maintenance at 40 percent of lifetime; (4) rapid cycle stress; and (5) lamp life. (42 U.S.C. 6295(bb)(1)) DOE received several comments on the authority to revise the existing metrics and consider additional metrics for lamp types included in the scope of this rulemaking.

ASAP noted that DOE intends to treat this rulemaking as the six-year review for the EPAct CFL standards and that as such, DOE is authorized by EPAct 2005 to consider revising existing quality specifications, such as the rapid cycle test, and adding new quality elements, such as power factor. ASAP asked whether DOE intends to evaluate these other elements of the CFL standard and if not, why they are not under consideration. (ASAP, Public Meeting Transcript, No. 19 at p. 24) Earthjustice and NEEA also suggested that DOE consider adopting additional requirements for MBCFLs. Earthjustice and NEEA added that under EPCA section 325(bb) paragraph (2), DOE is authorized to adopt requirements for color rendering index (CRI), power factor, frequency, and start time using the August 9, 2001, ENERGY STAR® Program Requirements for CFLs Version 2.0, but they have failed to do so. (Earthjustice and NEEA, No. 12 at p. 7)

In addition to revising the existing requirements for MBCFLs, DOE has the authority to establish requirements for additional metrics including CRI, power factor, operating frequency, and maximum allowable start time based on the requirements prescribed by the August 9, 2001, ENERGY STAR® Program Requirements for CFLs Version 2.0, or establish other requirements after considering energy savings, cost effectiveness, and consumer satisfaction. (42 U.S.C. 6295(bb)(2)-(3)) Therefore, as part of this rulemaking, DOE is reviewing whether all five existing metrics for MBCFLs should be amended and if additional performance requirements, including CRI, power factor, frequency, and start time, among others, should be added.

NRDC commented that current CFL standards regulate performance characteristics, in addition to the efficacy of the product, and asked if DOE is open to including other metrics besides efficacy (*e.g.*, power factor, stress test) for the other lamp types covered by the new standard. (NRDC, Public Meeting Transcript, No. 19 at p. 179)

As discussed in section 2.2.1, DOE is directed to evaluate energy conservation standards for GSLs. (42 U.S.C. 6295(i)(6)(A)-(B)) The term "energy conservation standard" is defined, in relevant part, as a performance standard that prescribes a minimum level of energy efficiency or a maximum quantity of energy used. (42 U.S.C. 6291(6)(A)) Further, under 42 U.S.C. 6293, EPCA sets forth the criteria and procedures DOE must follow when prescribing or amending test procedures for covered products. EPCA provides that any test procedures prescribed or amended under this section shall be reasonably designed to produce test results, which measure energy efficiency, energy use, or estimated annual operating cost of a covered product during a representative average use cycle or period of use and shall not be unduly burdensome to conduct. (42 U.S.C. 6293(b)(3)) Therefore, when considering energy conservation standards and test procedures, DOE is only authorized to evaluate performance standards and prescribe test procedures directly related to energy efficiency or energy used. DOE may consider other performance metrics related to quality if given explicit authority to do so for a covered product, as is the case with MBCFLs. Thus, for this rulemaking, DOE will not be evaluating performance metrics for covered lamp types other than MBCFLs.

2.4.1 Existing Metrics for MBCFLs

DOE received several comments suggesting revisions to the existing metrics and recommendations for new metric requirements. NRDC, ASAP, *et al*. suggested that DOE adopt the latest ENERGY STAR specifications and test methods for each of the existing parameters, and added that this approach will likely not meet a great deal of opposition as most CFLs in today's market already meet ENERGY STAR requirements. NRDC, ASAP, *et al.* further stated that a standard based on the latest ENERGY STAR specifications would set a minimum floor for CFLs, thus providing energy savings from the minimum efficacy and performance requirements that are designed to prevent consumers from reverting to less efficient technologies due to premature failure or removal by unsatisfied customers. (NRDC, ASAP, *et al.*, No. 17 at p. 11) ASAP agreed, noting that it would make sense to update the existing, outdated quality specifications copied from August 9, 2001, ENERGY STAR® Program Requirements for CFLs Version 2.0 to reflect current ENERGY STAR specifications. (ASAP, Public Meeting Transcript, No. 19 at pp. 56-57)

DOE is considering revising existing metrics and incorporating new metrics that improve the quality of MBCFLs. As stated previously, standards currently exist for initial lamp efficacy, lumen maintenance at 1,000 hours, lumen maintenance at 40 percent of lifetime, rapid cycle stress, and lamp lifetime. The current standards are based on August 9, 2001, ENERGY STAR® Program Requirements for CFLs Version 2.0. ENERGY STAR has since released several updates to the specification, the latest of which was finalized in August 2014, ENERGY STAR Lamps Specification V1.1. DOE assessed the revisions in the ENERGY STAR specification for the five existing metrics required by DOE and also surveyed the specifications of commercially available MBCFLs to determine current product performance for the five existing metrics.

The current energy conservation standards for efficacy of MBCFLs vary based on wattage and whether the lamp has a cover. The ENERGY STAR Lamps Specification V1.1 revised the wattage and covering divisions and increased the minimum lamp efficacy requirements. Based on an assessment of commercially available products, DOE determined that MBCFLs are performing above DOE's current efficacy standard. DOE is evaluating revised efficacy requirements for GSLs, which includes MBCFLs, as part of this rulemaking. For more information on the levels of efficacy under consideration, see section 2.7.5.

DOE also has minimum requirements for lumen maintenance. For lumen maintenance at 1,000 hours, DOE requires that the average of at least five lamps be a minimum of 90 percent of initial lumen output at 1,000 hours. The ENERGY STAR Lamps Specification V1.1 maintained this requirement with the added specification that all units must be surviving at 1,000 hours. For lumen maintenance at 40 percent of lifetime, DOE requires that 80 percent of the initial lumens must be achieved at 40 percent of lifetime. The ENERGY STAR Lamps Specification V1.1 also maintained this requirement with the added specification that no more than three units may be less than 75 percent of the initial lumen rating. DOE found that manufacturers do not publish information in catalogs on lumen maintenance at 1,000 hours and 40 percent of lifetime for MBCFLs. DOE assessed data submitted for the compliance certification management system (CCMS) reporting requirements and found that the majority of lamps certified exceeded the minimum lumen maintenance standards. DOE believes that the current requirements for lumen maintenance adequately address potential issues with lumen depreciation that could lead to consumer dissatisfaction and is therefore considering maintaining the existing requirements for lumen maintenance at 1,000 hours and lumen maintenance at 40 percent of lifetime. DOE requests comment on maintaining the current lumen maintenance requirements.

Additionally, there is a minimum requirement for rapid cycle stress for MBCFLs. DOE requires that at least five lamps must survive cycling once per every two hours of rated life. The ENERGY STAR Lamps Specification V1.1 changed the cycling requirement to once per hour of rated lifetime or a maximum of 15,000 cycles. The ENERGY STAR Lamps Specification V1.1 added an exception for instant start CFLs with a start time less than or equal to 100 milliseconds (ms), which are only required to survive cycling once per every two hours of rated life. For MBCFLs other than instant start CFLs, the increased requirement for rapid cycle stress provides consumer satisfaction by ensuring that MBCFLs are able to survive frequent switching and preventing premature failure. DOE found that manufacturers do not publish information on rapid cycle stress or starting method for MBCFLs. Further, manufacturers simply report the number of surviving units for DOE CCMS reporting requirements. However, DOE has received feedback from manufacturers that the market shifts in response to ENERGY STAR specifications and so DOE believes that MBCFLs are likely already achieving this level of product performance for rapid cycle stress. Therefore, DOE is considering increasing the number of cycles required for non-instant start lamps (*i.e.*, lamps with start times greater than 100 ms) to once per every hour of rated life with a maximum of 15,000 cycles to reduce testing burden. DOE requests comment on the rapid cycle stress performance of commercially available MBCFLs.

DOE currently requires a minimum lifetime of 6,000 hours for MBCFLs. The ENERGY STAR Lamps Specification V1.1 revised the minimum lifetime requirement to be 10,000 hours. Lifetime impacts consumer satisfaction as a longer life requires less frequent changes. Based on an assessment of commercially available lamps in manufacturer catalogs, DOE found that the majority of MBCFLs on the market have lifetimes of at least 10,000 hours. Further, of the MBCFLs for which data was submitted to DOE for CCMS reporting, 73 percent have a lifetime of at least 10,000 hours. The ENERGY STAR Certified Light Bulbs database also supports an increased lifetime with 79 percent of certified products having a lifetime of at least 10,000 hours.[22] Because DOE found that commercially available MBCFLs are already achieving this higher level of performance, DOE is considering revising the lifetime standard for MBCFLs to

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[22] *ENERGY STAR Program Requirements Product Specification for Lamps (Light Bulbs) Eligibility Criteria Version 1.0* becomes effective September 30, 2014, at which time the updated lifetime of 10,000 hours will be required.

be a minimum of 10,000 hours. DOE requests comment on the appropriateness of requiring an increased lifetime of 10,000 hours for MBCFLs.

2.4.2 Additional Metrics for MBCFLs

DOE received comments on additional metrics that should be considered in this rulemaking. EEI recommended adding requirements for power factor and total harmonic distortion (THD). EEI commented that lamps with low power factors increase demand for power and related transmission and distribution losses, which undermines the purposes of DOE's energy conservation standards program. (EEI, No. 16 at p. 2)

DOE does not currently have a standard for power factor, however, DOE has explicit authority to consider power factor for MBCFLs. (42 U.S.C. 6295(bb)(2)) Power factor is the ratio of active input power to apparent input power. A low power factor product is inefficient and requires an increase in electric utility's generation and transmission capacity.[23] Because a minimum power factor requirement could decrease energy use, DOE is considering power factor in this rulemaking. Total harmonic distortion is defined as the ratio of the root mean square (rms) values of the harmonic content to that of the fundamental current, expressed as a percentage. Because THD is directly related to power factor, setting a minimum power factor requirement will effectively set a standard for THD and therefore DOE is not considering a setting a separate requirement for THD.

DOE reviewed industry specifications for MBCFLs and found that the ENERGY STAR Lamps Specification V1.1 requires that CFLs have a power factor of 0.5 or greater. ENERGY STAR does not have a separate requirement for THD. The industry standard ANSI C82.77 Harmonic Emission Limits – Related Power Quality Requirements for Lighting Equipment suggests a power factor of 0.5 for integrally ballasted medium screw base compact light sources with input power less than or equal to 35 watts. Based on an assessment of commercially available lamps in manufacturer catalogs, DOE determined that the majority of MBCFLs have a power factor in the range of 0.5 to 0.6 and a limited number of MBCFLs have a power factor greater than 0.6. The ENERGY STAR Certified Light Bulbs database supported this distribution with about 77 percent of MBCFLs with a power factor in the range of 0.5 to 0.6.

EEI commented that power factor should be the highest possible value and harmonic distortion should be the lowest possible value that all lamps included in the scope of this rulemaking are able to achieve. EEI added that the requirements should be technology and market neutral, and noted that CFLs and LED lamps exist with power factors greater than 0.8. EEI concluded that these metrics should be considered for all technologies under this rulemaking and stated that 42 U.S.C 6295(bb)(2) gives DOE the authority to set minimum power factors for CFLs. (EEI, No. 16 at pp. 2-4)

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[23] U.S. Department of Energy. *Reducing Power Factor Cost*. https://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/mc60405.pdf.

As stated previously, DOE has explicit authority to consider additional metrics, including power factor, for MBCFLs. (42 U.S.C. 6295(bb)(2)) However, DOE does not have authority to consider additional metrics for LED lamps and therefore is not considering setting power factor requirements for LED lamps in this rulemaking. DOE agrees that MBCFLs exist with a power factor greater than 0.8 but found these lamps to be extremely uncommon. Based on the ENERGY STAR Certified Light Bulbs database, approximately two percent of MBCFLs had a power factor greater than 0.8. As noted, the majority of the market reports power factor in the range of 0.5 to 0.6. Thus, DOE believes that requiring a minimum power factor of 0.5 is achievable for MBCFLs while supporting improved overall efficacy. It is also consistent with ENERGY STAR requirements and recommendations in industry standards. DOE is considering adding the requirement for MBCFLs to have a power factor of 0.5 or greater and no separate requirement for THD. DOE requests comment on adding a requirement for power factor and its consideration of a standard for power factor of 0.5 or greater. DOE also requests comment on its consideration not to set a standard for THD.

DOE is also considering standards for other metrics as discussed previously in this section. DOE does not currently have a standard for CRI, however, DOE has explicit authority to consider CRI for MBCFLs. (42 U.S.C. 6295(bb)(2)) CRI is a measure of the color rendering properties of a light source, or the ability of a light source to show the “true” color of an object as compared to a reference source.[24] A standard for CRI ensures consumer satisfaction because high CRI light sources render colors well. The ENERGY STAR Lamps Specification V1.1 requires that CFLs have a CRI of at least 80. It also requires that no more than 3 units included in the average have a CRI less than 77 and no units have a CRI less than 75. Based on an assessment of commercially available lamps in manufacturer catalogs, DOE found that over 99 percent of MBCFLs on the market have a CRI of at least 80. DOE identified only a few MBCFLs with a CRI of less than 80. Because a minimum CRI requirement would increase consumer satisfaction and DOE found that nearly all commercially available MBCFLs are already achieving a CRI of at least 80, DOE is considering requiring MBCFLs to have a CRI of 80 or greater. DOE requests comment on adding a requirement for CRI and its consideration of a standard for CRI of 80 or greater.

DOE does not have a standard for correlated color temperature (CCT). CCT is a measure of the perceived color of the white light emitted from a lamp.[25] Lower CCT values correspond to warmer light, with more red content in the spectrum, and higher CCTs correspond to cooler light, with more blue content. The ENERGY STAR Lamps Specification V1.1 requires CCT to correspond to one of six nominal CCTs and fall within a prescribed chromaticity space. DOE believes that different CCTs are desirable depending on the application and therefore is not considering setting a requirement for CCT. DOE requests comment on its consideration not to set a CCT requirement for MBCFLs.

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[24] Illuminating Engineering Society of North America. *The IESNA Lighting Handbook: Reference and Applications*. Ninth Edition. 2000. p. G-7.

[25] Illuminating Engineering Society of North America. *The IESNA Lighting Handbook: Reference and Applications*. Ninth Edition. 2000. p. G-8.

Currently, DOE does not have a standard for operating frequency. Operating frequency is the frequency of the current measured in hertz supplied by the ballast to the lamp during operation. The ENERGY STAR Lamps Specification V1.1 requires that CFLs have a frequency within 20 to 33 kHz or at least 40 kHz. Requiring an operating frequency within a specified range ensures that lamps do not interfere with other electrical products, such as television remotes. Because operating frequency does not directly impact consumer satisfaction, DOE is not considering setting standards for operating frequency at this time. DOE requests comment on the consideration to not set requirements for operating frequency.

DOE does not currently have a standard for start time. The ENERGY STAR Lamps Specification V1.1 requires that the time needed for a lamp to become fully illuminated must be within one second of application of electrical power. DOE believes that start time impacts consumer satisfaction because a delay in starting is undesirable and can affect acceptance of a more efficient lamp technology. DOE reviewed manufacturer catalogs and the ENERGY STAR Certified Light Bulbs database and found that neither start time nor starting method is typically reported. DOE is considering requiring a start time of within one second of the application of electrical power because the market likely finds one second an acceptable start time since it has been the ENERGY STAR specification for several years. DOE requests comment on the start time of MBCFLs and its consideration to require a start time of within one second of the application of electrical power.

2.4.3 Summary

Table 2.4.1 summarizes the metrics and corresponding requirements that DOE is considering for MBCFLs.

Table 2.4.1 Performance Metrics for Medium Base Compact Fluorescent Lamps

Metric	Minimum Standard Considered
Efficacy	See section 2.7.5 for more information on candidate standard levels under consideration.
Lumen maintenance at 1,000 hours	90 percent of initial lumen output at 1,000 hours
Lumen maintenance at 40 percent of lifetime	80 percent of initial lumen output at 40 percent of lifetime
Rapid cycle stress	MBCFL with start time > 100 ms: survive one cycle per hour of rated lifetime or a maximum of 15,000 cycles MBCFLs with a start time of ≤ 100 ms: survive one cycle per every two hours of rated lifetime
Lifetime	10,000 hours
Power factor	0.5
CRI	80
Start time	The time needed for a MBCFL to become fully illuminated must be within one second of application of electrical power

2.5 MARKET AND TECHNOLOGY ASSESSMENT

In the initial stages of an energy conservation standards rulemaking, DOE gathers information that provides an overall picture of the market for the products concerned, including the nature and market characteristics of the products and the industry structure. This activity consists of both quantitative and qualitative analysis, based primarily on publicly available information. The subjects addressed in the market and technology assessment for the preliminary analysis include the major manufacturers, product classes, retail market trends, shipments of covered products, regulatory and non-regulatory programs, and technologies that could be used to improve the efficacy of GSLs. This information serves as a resource throughout the rulemaking.

DOE reviewed existing literature and spoke with manufacturers to gain an understanding of the GSL industry in the United States. Industry publications (*e.g.*, manufacturer catalogs, trade journals), government agencies, and trade organizations provided the bulk of the information. Using this information, DOE assessed the overall state of the industry, GSL manufacturing and market shares, shipments by lamp type, general technical information on GSLs, and industry trends.

The discussion below summarizes the analytical approach and the comments DOE received in response to the framework document. A more detailed discussion on DOE's approach can be found in the market and technology assessment (chapter 3 of this TSD).

2.5.1 Market Assessment

2.5.1.1 Manufacturers of GSLs

The GSL industry is characterized by both domestic and international manufacturers. The majority of covered GSLs are manufactured by four large companies. The four manufacturers that hold the majority of the domestic market share of GSLs are listed below.

- GE Consumer and Industrial of General Electric, Inc. (GE)
- OSRAM SYLVANIA of Siemens AG (OSI)
- Philips Lighting Company of Philips Electronics North America Corporation (Philips)
- Cree, Inc. (Cree)

In addition to lamps listed under this rulemaking, the lighting divisions of GE, OSI, and Philips manufacture other products, such as lamp ballasts, high intensity discharge lamps, GSFLs, and IRLs.

All four companies are members of NEMA, a trade association that represents manufacturers of electrical equipment, including GSLs. NEMA provides an organizational framework for manufacturers of lighting products to work together on projects that affect their industry and businesses.

Although the GSL market is predominantly supplied by large manufacturers, DOE intends to conduct a study of small businesses that manufacture GSLs for the NOPR stage of this rulemaking analysis. The Regulatory Flexibility Act (5 U.S.C. 601 *et seq.*) requires preparation of an initial regulatory flexibility analysis for every rule that by law must be proposed for public comment, unless the agency certifies that the rule, if promulgated, will not have a significant economic impact on a substantial number of small entities. A regulatory flexibility analysis examines the impact of the rule on small entities and considers alternative ways of reducing negative impacts. The Small Business Administration defines small business manufacturing enterprises for GSLs under the North American Industry Classification System product code 335110, "Electric Lamp Bulb and Part Manufacturing," which has a size standard of 1,000 employees or fewer. This includes the total number of employees in the parent company, not only those in the divisions that produce GSLs. DOE invites interested parties to provide information for any small businesses that manufacture GSLs and should be consulted before DOE publishes a NOPR.

2.5.2 Technology Assessment

In the technology assessment, DOE identifies technology options that appear to be feasible means of improving lamp efficacy. This assessment provides the technical background and structure on which DOE bases its screening and engineering analyses. To develop a list of technology options, DOE reviewed manufacturer catalogs, recent trade publications and technical journals, and consulted with technical experts.

In the framework document, DOE included a list of technology options to analyze for GSLs. Recognizing that GSLs comprise of more than one lamp type, each with their own mechanisms for improving efficacy DOE identified technology options by lamp type. Specifically, DOE presented technology options for GSIL, CFL, and LED lamp types and also identified a change in technology (*e.g.,* moving from CFLs to LED lamps) as a technology option. DOE received several comments on these options.

NRDC, ASAP, *et al.* and CA IOUs commented on the omission of halogen infrared (HIR) from the list of technology options. NRDC, ASAP, *et al.* encouraged DOE to look further into this technology and contact coating companies since the technology can lead to a significant efficacy improvement for GSILs. CA IOUs noted that HIR is one of the best technology options to improve incandescent filament technology. (NRDC, ASAP, *et al.*, No. 17 at pp. 10-11; CA IOUs, Public Meeting Transcript, No. 19 at p. 100) NEMA stated that their comments regarding incandescent reflector lamps made in response to the rulemaking that constitutes the second review of GSFL and IRL standards[26] also apply to this rulemaking. Specifically, they stated that the technology options presented are already being used or are not technically feasible to produce a practical product. Further, NEMA recalled DOE's first review of IRL standards which resulted in amended IRL standards published in a final rule in July 2009 (hereafter the "2009 Lamps Rule"). 74 FR 34080 (July 14, 2009). NEMA noted that in the 2009 Lamps Rule DOE had determined the max-tech level was possible with the use of the highest-efficiency technologically feasible reflector, halogen IR coating, and filament design and because this would require the use

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[26] DOE initiated a rulemaking to conduct a second review of existing general service fluorescent lamps (GSFLs) and IRL. At the time of this analysis, DOE had published a notice of proposed rulemaking (NOPR) and held an associated public meeting May 1, 2014. 79 FR 24067 (April 29, 2014). Further information on the rulemaking including comments received at the preliminary analysis and NOPR phase can be found under Docket No. EERE–2011–BT–STD–0006), which is maintained at www.regulations.gov.

of proprietary technology, DOE could not consider this level further in its analyses. 74 FR 34080, 34096 (July 14, 2009).[27] (NEMA, No. 15 at pp. 11-12)

As stated previously, DOE is restricted by the Appropriations Rider from using appropriated funds to implement or enforce standards for GSILs and therefore is not considering GSILs in this rulemaking at this time. See section 2.2.1 for further details.

2.5.2.1 CFL Technology Options

Regarding the technology options for CFLs, NEMA reiterated that their comments pertaining to GSFLs made in the second review of GSFL and IRL standards remain equally applicable here as nothing regarding the feasibility for these technologies has changed. NEMA noted that several of the technology options considered by DOE have reached their limit in currently available products. Specifically, NEMA noted that with regards to highly emissive electrode coatings, existing emitters are already designed for energy conservation and long life. According to NEMA, further changes could shorten lamp life and any potential improvements would be minimal, as electrode losses have been reduced significantly with high frequency operation. NEMA also stated that based on current technologies, the limits of gas fill technology and high efficiency phosphor technology have been reached by manufacturers and a breakthrough is needed to make further improvements. (NEMA, No. 15 at pp. 11-13)

In the framework document, DOE presented highly emissive electrode coatings, higher efficiency lamp fill gas composition, and higher efficiency phosphors as a technology options that can improve CFL efficacy. Based on DOE’s research there are various combinations of highly emissive electrode coatings; various weights and mixes of phosphors; and various types and ratios of fill gases that can be used to improve lamp efficacy. Because CFLs are present on the market at more than one level of efficacy, each of these technology options can be used to improve the efficacy of less efficient products. Therefore, DOE continues to consider these technology options.

Further, DOE recognizes that certain technology options may require a trade-off between increasing efficacy and maintaining long lifetimes. DOE screens out technology options that have an adverse impact on consumer utility including a shortened lifetime product. See section 2.6 and chapter 4 of this TSD for more details on technology options screened out in this preliminary analysis.

2.5.2.2 LED Lamp Technology Options

NEMA noted several technical challenges for each of the LED lamp technology options presented in the framework document. Based on a review of research efforts in this field, patents, prototypes, and commercially available products DOE has found that the LED lamp technology

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[27] In the 2009 Lamps Rule, the highest level analyzed for IRLs was based on a commercially available lamp that employed a silver reflector, an improved IR coating, and a filament design that resulted in a lifetime of 4,200 hours, and did not require proprietary technology. In its second review of IRL standards, DOE was able to identify even more efficacious IRLs, which also did not require proprietary technology. 74 FR 24068, 24110-11 (April 29, 2014).

options presented in the framework have met or have the potential to meet the technical issues outlined by NEMA.

Regarding efficient down converters NEMA commented that these are not in use today due to technical challenges surrounding the narrow-band phosphors that enable high spectral efficiency and include robust packaging for lumen maintenance, while still achieving high quantum efficiency under high temperature and flux. (NEMA, No. 15 at pp. 13-14)

In the framework document, DOE presented efficient down converters as a technology option that uses high-efficiency wavelength conversion materials such as nano-phosphors and quantum dot phosphors. DOE has identified research efforts that have made progress in addressing the technical issues associated with these technologies. For example, DOE-funded SUNY/Buffalo program developed quantum dot phosphor down converters with 80 percent efficiency in the green through red wavelengths with only a five percent loss in efficiency at 150 °C, and have minimal losses at fluxes up to 38,000 W/cm^2.[28] Further, although no longer commercially available, a R30 LED lamp utilizing quantum dot phosphors was introduced by Nexxus Lighting, Inc. and QD Vision in 2010.[29] Therefore, DOE continues to consider efficient down converters as a viable means of increasing LED lamp efficacy.

NEMA noted the following challenges with the improved package architectures technology option: unreliable die attachment methods; development of polymer optical encapsulants to improve color stability and emitter lifetime; development of high index encapsulants to increase photon extraction; and ability to reduce down converting layer temperatures using high thermal conductivity.

In the framework document, DOE presented improved package architecture as a technology option, noting examples of architecture enhancements such as RGB+, hybrid color, and bonding the chip directly on to the heat sink. Manufacturer feedback and DOE research indicates that these and various other ways for improving package architecture are being utilized in products and are the subject of further R&D. Cree, for example, produced an LED in its lab with an efficacy of 276 lm/W in 2013 owing the improvement in part to advances in LED package architecture.[30] Cree has since improved its lab LED performance to over 300 lm/W as of March 2014.[31] Therefore, DOE continues to consider improved package architecture as a viable means of improving LED lamp efficacy.

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[28] U.S. Department of Energy. *SUNY/Buffalo Developing High-Efficiency Colloidal Quantum Dot Phosphors.* July 11, 2013. (Last Accessed September 15, 2013) http://www1.eere.energy.gov/buildings/ssl/suny_quantum_dots.html.

[29] Nexxus Lighting. *NEXXUS LIGHTING DELIVERS FIRST COMMERCIALLY-AVAILABLE QUANTUM DOT.LED REPLACEMENT LIGHT BULBS.* (Last Accessed September 15, 2014) http://www.nexxuslighting.com/news/pressReleases/news_030810.php#.

[30] Cree. *Cree Sets New R&D performance Record with 276 Lumen-Per-Watt Power LED.* February 13, 2013. (Last Accessed September 15, 2014) http://www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/~/link.aspx?_id=2F008013AEF14FAAA42C2A9686F5F865&_z=z.

[31] Cree. *Cree Sets New R&D performance Record with 276 Lumen-Per-Watt Power LED.* February 13, 2013. (Last Accessed September 15, 2014) http://www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/300LPW-LED-barrier.

Regarding improved emitter materials, NEMA commented that there is no clear path toward development of green and yellow emitters. NEMA added that multi-color modules require more advanced drivers to handle color stability since different color LED chips will degrade at different rates. (NEMA, No. 15 at p. 13)

In the framework document, DOE presented improved emitter material as a technology option; specifically, non-blue LED emitters (*i.e.*, red, green, or amber) that allow for optimization of spectral efficiency. The primary issue with developing non-blue emitters is the efficiency droop caused by Auger recombination, a process in which electrons collide and product heat rather than emit light. Researchers have identified methods to mitigate Augur recombination. (See chapter 3 of this TSD for further details.) Therefore, DOE believes there are pathways to develop improved emitters including green and yellow. Further, demonstrated products such as the Philips L Prize LED lamp with different color LEDs (*i.e.*, blue and red) indicate that the issue of controlling color stability over lamp life for multi-color modules can be addressed by manufacturers. [32] Therefore, DOE continues to consider improved emitter materials as a technology option to improve LED lamp efficacy.

NEMA also commented on the alternative substrate materials technology option stating that silicon (Si) and gallium nitride (GaN)-on-Si devices do not perform significantly better than sapphire devices. (NEMA, No. 15 at p. 13)

In the framework document, DOE presented alternative substrate material as a technology option. While, sapphire is the most commonly used substrate in LEDs, alternative substrate materials such as gallium nitride (GaN), GaN-on-Si, and silicon carbide (SiC) have lattice mismatch that is absent or minimal, reducing likelihood of defects and thereby device quality and efficiency.[33] Soraa manufactures lamps using GaN on GaN LEDs and recently announced a new LED package reaching 75 percent wall-plug-efficiency.[34] Hence, DOE continues to consider use of substrates other than sapphire as a technology option to improve LED lamp efficacy.

Regarding improved thermal interface material (TIM) technology, NEMA remarked that there are challenges in developing such materials to enable high efficiency thermal transfer for long-term reliability and high performance. (NEMA, No. 15 at p. 13)

In the framework document, DOE presented improved TIMs as a technology option that allows for higher efficiency thermal transfer, which can improve LED efficacy by lowering LED junction temperature.[35] DOE's research indicates that there are commercially available high

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[32] U.S. Department of Energy. *Lab Testing for Philips Entry*. July 1, 2013. (Last Accessed September 15, 2014) http://www.lightingprize.org/60watttest.stm.

[33] Solid State Technology. *Beyond sapphire: LED substrates from GaN to ZnO, SiC, and Si*. May 14, 2012. (Last Accessed September 15, 2014) http://electroiq.com/blog/2012/05/beyond-sapphire-led-substrates-gan-zno-sic-si/.

[34] Soraa. Soraa develops the world's most efficient LED; begins integration into large lamp line. February 24, 2014. (Last Accessed September 15, 2014) http://www.soraa.com/news/soraa-large-lamp-gen3-022414.

[35] RPI. *Junction temperature in light-emitting diodes assessed by different methods*. (Last Accessed September 15, 2014) http://www.ecse.rpiscrews.us/~schubert/Reprints/2005%20Chhajed%20et%20al%20%28SPIE%20Photonics%20West%29%20Junction%20temperature%20in%20LEDs.pdf.

performing TIMs. There are also research efforts targeting reliable high efficiency thermal transfer materials such as chemical vapor deposition (CVD) diamond which provides high thermal conductivity while allowing for standard methods of attachment (*e.g.*, solders and epoxies).[36] Therefore, DOE continues to consider improved TIM as a viable means for improving LED lamp efficacy.

With regard to optimized heat sinks, NEMA commented that performance is generally compromised by form factor constraints. (NEMA, No. 15 at p. 13) NEMA also noted that reliability is a concern with active thermal management systems. (NEMA, No. 15 at p. 13)

In the framework document, DOE presented optimized heat sinks and active thermal management systems as technology options that improve thermal conductivity and heat dissipation, lowering the temperature at the LED junction and increasing lamp efficacy. DOE determined that geometrical constraints can be addressed in optimized heat sink designs. For example, finned designs made out of materials with high thermal transfer coefficients have been utilized in commercially available A-shape lamps. Further, there are existing patents on optimized heat sinks for LEDs indicating this is an area of ongoing research.[37] [38] Additionally as active thermal management systems are being used in commercially available lamps, such as Philips MASTER LEDspot MR16s, and DOE believes any reliability concerns can be addressed by manufacturers.[39] Therefore, DOE continues to consider optimized heat sinks and active thermal management systems as a technology options that can increase the efficacy of LED lamps.

NEMA commented on the device level optics technology option, stating that the package size limits the extent of beam shaping that can be done with reasonable extraction efficiency and that it adds system complexity. (NEMA, No. 15 at p. 14)

In the framework document, DOE presented device level optics as a technology option that involves optimizing optics at the chip level or the primary optic, so that the outer secondary optic can be removed, thereby eliminating losses due to absorption. DOE has found that there are research efforts addressing issues of optimizing extraction efficiency for small package sizes as well as improving beamshaping. An existing patent presents primary optic configurations that achieve more controlled beam shapes while allowing for a more simplified and efficient

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[36] Aidala, Dwain A. *CVD Diamond Solves Thermal Challenges*. Solid State Technology. (Last Accessed September 15, 2014) http://electroiq.com/blog/2006/10/cvd-diamond-solves-thermal-challenges/.

[37] Ashfaqul Chowdhury and Gary Allen. GE Lighting Solutions, LLC. (2014) *U.S. Patent No. 8,672,516.* Washington DC: US Patent and Trademark Office.

[38] Timothy Chen and George Uhler. Technical Consumer Products, Inc. (2013) *U.S. Patent Application No.20130294097 A1.* Washington DC: US Patent and Trademark Office.

[39] Philips. *Technical application guide: Philips MASTER LEDspot LV D 7-35W or 10-50W MR16.* (Last Accessed September 15, 2014) http://www.lighting.philips.com/pwc_li/main/shared/led/portal/pdf/Technical-Application-Guide-MASTER-LEDspot-LV-D-7-35W-10-50W-MR16.pdf.

secondary optic.[40] Therefore, DOE continues to consider device level optics as a viable means of increase LED lamp efficacy.

Regarding improved driver designs, NEMA commented that the functional requirements of the driver (*e.g.*, power quality, flicker, dimmability, isolation, line regulation, and transient/surge protection) often limit its efficiency. (NEMA, No. 15 at p. 14)

In the framework document, DOE presented improved driver design as a technology option that can increase driver efficiency through advanced circuit designs. Manufacturer feedback and DOE's review of catalogs indicate a range of efficiencies associated with drivers. The existence of this range, coupled with historical increases in driver efficiency in commercially available lamps, demonstrates the potential for improvement in driver design while meeting the functional specifications of the product. Therefore, DOE continues to consider improved driver design as a technology option for improving LED lamp efficacy.

With regard to AC LEDs, NEMA noted that these often need external components to mitigate inherent issues like flicker and operate with 50 percent utilization or less. NEMA added that high voltage AC LEDs include losses due to die segmentation and have other complexity issues. (NEMA, No. 15 at p. 14)

DOE presented AC LEDs as a technology option in the framework document. By reducing conventional driver size or removing the driver component, complexity, and efficiency losses AC-powered LEDs can increase performance of the LED lamp. Seoul Semiconductor has a number of high voltage AC LED modules commercially available for integration into lamps. In July 2014, Seoul Semiconductor announced a new line of AC LED modules with improved AC drivers designed specifically for the omnidirectional lamps.[41] The new AC driver improves compatibility with TRIAC dimmers and is designed to mitigate flicker issues that can arise during dimming of AC LEDs. [42] [43] Additionally, improvements in circuit design can increase LED utilization. For example, Texas Instruments' (TI's) TPS92411 MOSFET switch allows a small capacitor to be placed across each LED segment on a circuit to store energy keeping all LEDs lit even when the AC line voltage is too low, thereby increasing LED utilization.[44] Therefore, DOE continues to consider AC LEDs as a viable means of improving LED lamp efficacy.

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[40] Eric Tars, Bernd Kellerm Peter Guschl, and Gerald Negley. (2011) *U.S. Patent No. 8,564,004.* Washington DC: US Patent and Trademark Office.

[41] Seoul Semiconductor. *Seoul Semiconductor Introduces a New Acrich-based Module for Omnidirectional Lamps*. July 29, 2014. (Last Accessed September 15, 2014) http://www.seoulsemicon.com/en/html/company/press_view.asp?Idx=265.

[42] Seoul Semiconductor. *Seoul Semiconductor Launches the Next Generation of Smart Lighting LED Technology _ Acrich3.* July 29, 2014. (Last Accessed September 15, 2014) http://www.seoulsemicon.com/en/html/company/press_view.asp?Idx=264.

[43] LED Magazine. *Seoul Semiconductor announces Acrich3 AC-LED driver, new MJT LEDs.* June 4, 2014. (Last Accessed September 15, 2014) http://www.ledsmagazine.com/articles/2014/06/seoul-semiconductor-announces-acrich3-ac-led-driver-new-mjt-leds.html.

[44] LED Magazine, *TI launches AC-driver technology for LED-based lighting*. (Last Accessed September 15,2014) http://www.ledsmagazine.com/articles/2013/11/ti-launches-ac-driver-technology-for-led-based-lighting.html.

NEMA cited costs issues for the following technology options presented in the framework document: improved package architecture involving mixed color configurations requiring additional controls; use of alternative substrates such as GaN; active thermal management systems, and increased light utilization technology which involves a trade-off with optical losses and cost. (NEMA, No. 15 at pp. 13-14)

DOE does not take cost into consideration when identifying technology options. DOE considers costs in determining the economic justification of any standard levels developed using these technologies.

In addition to the technology options detailed in the framework document, DOE is considering reduced current density as a technology option for improving LED lamp efficacy. DOE notes that increasing current results in a commensurate decrease in LED efficacy.[45] DOE's research and manufacturer feedback have shown that reducing current density within reason will increase LED lamp efficacy while maintaining practical levels of lumen output per unit area. Therefore, DOE is considering reduced current density, which involves increasing the number of LEDs, as a technology option that can increase the efficacy LED lamps. See chapter 3 of this TSD for further details. DOE requests comment on the addition of reduced current density as a technology option.

Further, based on manufacturer feedback and research conducted in this preliminary analysis, DOE is considering clarifying certain technology options for LED lamps. For the efficient down converter technology, DOE is noting that efficient down converters also include optimized phosphor conversion resulting from either advanced phosphor compositions or placement of phosphors (*i.e.*, remote phosphor technology). Phosphor-coated LEDs is the most common down converter mechanism for converting shorter wavelengths to longer wavelengths to produce white light in LEDs. DOE has found there are research efforts and existing patents on optimized phosphor coating for LEDs.[46] [47] Further, Cree, for example, produced an LED in its lab with an efficacy of 276 lm/W in 2013 owing the improvement in part to advancements in phosphors.[48]

In the framework document, DOE defined device level optics as integrating a specific lens into the primary optic to allow for the removal of the secondary optic. DOE research indicates that in addition to a lens, there are other methods for optimizing the primary optic and further that even the simplification of the secondary optic due to such enhancements can eliminate losses due to absorption at interfaces. Therefore, DOE is considering clarifying that

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[45] U.S. Department of Energy. *Energy Efficiency of LEDs.* March, 2013. (Last Accessed September 15, 2014) http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led_energy_efficiency.pdf.

[46] Anant Setlur. *Phosphors for LED-based Solid-State Lighting.* 2009. (Last Accessed September 15, 2014) http://www.electrochem.org/dl/interface/wtr/wtr09/wtr09_p032-036.pdf.

[47] William Winder Beers, Jon Bennett Jansma,Fangming Du, William Erwin COHEN, Alok Mani Srivastava, Samuel Joseph Camardello, Holly Ann Comanzo. (2013) *U.S. Patent Application No. 201301140978.* Washington DC: US Patent and Trademark Office.

[48] Cree. *Cree Sets New R&D performance Record with 276 Lumen-Per-Watt Power LED.* February 13, 2013. (Last Accessed September 15, 2014) http://www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/March/~/link.aspx?_id=2F008013AEF14FAAA42C2A9686F5F865&_z=z

this technology option encompasses any enhancements to the primary optic of the LED package that would simplify or remove entirely the secondary optic, and thereby reduce losses due to absorption at interfaces.

To conduct the technology assessment, DOE reviewed manufacturer catalogs, recent trade publications, technical journals, and patent filings; and consulted with technical experts and manufacturers to ensure it identified all possible technology options that can increase the efficacy of GSLs. In summary, DOE is considering the technology options as shown in Table 2.5.1 in this preliminary analysis. For further information on all technology options considered in this TSD see chapter 3. DOE requests comment on the technology options under consideration for GSLs.

Table 2.5.1 GSL Technology Options

Lamp Type	Name of Technology Option	Description
CFL	**Highly Emissive Electrode Coatings**	Improved electrode coatings allow electrons to be more easily removed from electrodes, reducing lamp power and increasing overall efficacy.
	Higher Efficiency Lamp Fill Gas Composition	Fill gas compositions improve cathode thermionic emission or increase mobility of ions and electrons in the lamp plasma.
	Higher Efficiency Phosphors	Techniques to increase the conversion of ultraviolet (UV) light into visible light.
	Glass Coatings	Coatings on inside of bulb enable the phosphors to absorb more UV energy, so that they emit more visible light.
	Multi-Photon Phosphors	Emitting more than one visible photon for each incident UV photon.
	Cold Spot Optimization	Improve cold spot design to maintain optimal temperature and improve light output.
	Improved Ballast Components	Use of higher-grade components to improve efficiency of integrated ballasts.
	Improved Ballast Circuit Design	Better circuit design to improve efficiency of integrated ballasts.
	Change in Technology	Replace CFL with LED technology.

Lamp Type	Name of Technology Option	Description
LED	**Efficient Down Converters**	New high-efficiency wavelength conversion materials, including optimized phosphor conversion, quantum-dots and nano-phosphors, have the potential for creating warm-white LEDs with improved spectral efficiency, high color quality, and improved thermal stability.
	Improved Package Architectures	Novel package architectures such as RGB+, system-in-package, hybrid color, and chip-on-heat-sink have the potential to improve thermal management, color-efficiency, optical distribution, as well as electrical integration to greatly improve overall lamp and luminaire efficacy.
	Improved Emitter Materials	The development of efficient red, green, or amber LED emitters, will allow for optimization of spectral efficiency with high color quality over a range of correlated color temperatures (CCT) and which also exhibit color and efficiency stability with respect to operating temperature.
	Alternative Substrate Materials	Alternative substrates such as gallium nitride (GaN), silicon (Si), GaN-on-Si, and silicon carbide to enable high-quality epitaxy for improved device quality and efficacy.
	Improved Thermal Interface Materials	Develop TIMs that enable high efficiency thermal transfer for long-term reliability and performance optimization of the LED device and overall lamp product.
	Optimized Heat Sink Design	Improve thermal conductivity and heat dissipation from the LED chip thus reducing efficacy loss from rises in junction temperature.
	Active Thermal Management Systems	Devices such as internal fans, vibrating membranes, and circulated liquid cooling systems to improve thermal dissipation from the LED chip.
	Device Level Optics	Enhancements to the primary optic of the LED package that would simplify or remove entirely the secondary optic, and thereby reduce losses due to absorption at interfaces.
	Increased Light Utilization	Reduce optical losses from the lamp housing, diffusion, beam shaping and color-mixing to increase the efficacy of the LED lamp.
	Improved Driver Design	Increase driver efficiency through novel and intelligent circuit design.
	AC LEDs	Reduce or eliminate the requirements of a driver and therefore the effect of driver efficiency on lamp efficacy.
	Reduced Current Density	Increase the number of LEDs in a lamp to reduce current density while maintaining lumen output. This reduces the efficiency losses associated with higher current density.

2.5.3 Product Classes

DOE divides covered products into classes by: (a) the type of energy used; (b) the capacity of the product; or (c) other performance-related features that justify different standard levels, considering the consumer utility of the feature and other relevant factors. (42 U.S.C. 6295(q)) In the framework document, DOE considered establishing product classes for GSLs based on the following three factors: (1) ballast location; (2) dimmability; and (3) cover.

CEC proposed that DOE should start with a single product class and add product classes only if significant cost or technical challenges arise based on the stringency of the standard.

(CEC, No. 11 at p. 14) CA IOUs stated that while the product classes presented in the framework impact consumer utility, it is questionable whether they have any correlation with efficacy, and recommended DOE consider only one product class for GSLs in the preliminary analysis. However, CA IOUs noted that should any of the product classes in the framework document be maintained, DOE should make them more self-explanatory, well-defined, and less subject to interpretation. (CA IOUs, No. 18 at pp. 7-8) ASAP added that the product class structure should be robust so that it can accommodate technologies not yet on the market. (ASAP, Public Meeting Transcript, No. 19 at pp. 94-95)

In evaluating product class setting factors, DOE considers their impact on both efficacy and consumer utility. In this preliminary analysis, DOE has reevaluated the product class setting factors considered in the framework document and also considered additional class setting factors. The following sections discuss the comments received on potential product class setting factors and whether DOE is establishing a separate product class division for them.

2.5.3.1 Covering

Some lamps incorporate an added glass or silicone cover over the main light source, which can reduce the lumen output of the lamp. Covered lamps may offer utility to consumers as they more closely resemble traditional lighting technologies and are frequently utilized where a lamp is visible. For this reason, DOE considered establishing a separate product class for covered lamps in the framework document.

Soraa recommended eliminating this product class stating that a cover provides no real value or distinction over the other product class-setting factors of ballast location and dimmability. (Soraa, No. 10 at p. 2) CEC also supported the removal of the product class division based on lamp cover and commented that if a 45 lm/W standard is adopted, a product class based on lamp cover should not exist since a large number of lamps in this category currently exceed 45 lm/W. (CEC, No. 11 at pp. 13-15)

CA IOUs stated that the cover versus bare distinction for lamps is based on CFLs, which with an external cover look more like a traditional lamp but have decreased efficacy. However, CA IOUs noted that because there are LED lamps with a cover that have a higher efficacy and incandescent lamps with a cover that have a lower efficacy than CFLs that are covered and bare, there is no apparent correlation between efficacy and this product attribute across all GSLs. NRDC, ASAP, *et al.* agreed that the covered versus uncovered terms apply only to CFLs and that considering a frosted lamp to be covered did not make sense. (NRDC, ASAP, *et al.*, No. 17 at pp. 7-8)

However, NEMA and GE supported a covered and bare product class division for integrated CFLs and a diffuse and clear coated product class division for LED lamps. (NEMA, No. 15 at p. 10; GE, Public Meeting Transcript, No. 19 at pp. 111-112) NEMA also provided definitions for “covered compact fluorescent lamp” and “covered light-emitting diode lamp” which specified that these lamps have a glass or plastic housing that can either be clear or diffuse. NEMA recommended that “diffuse cover” be defined as a cover that scatters light transmitted through the cover such that the source of the light is not discernable. (NEMA, No. 15 at p. 11)

In the framework document, DOE considered a cover to be something added to the lamp such that the main light source is not distinguishable. For the preliminary analysis, DOE conducted additional research on covered versus bare lamps and the applicability of this distinction across different lamp technologies. DOE found that while a cover generally decreased efficacy, particularly in CFLs, a cover could also result in increased efficacy, such as when it has a phosphor coating and transforms light emitted from LEDs into visible light. As described later in this section, DOE is considering technology neutral product classes in the preliminary analysis. DOE notes that many LED lamps that have covers also have high efficacies. Thus, covered products will still be available at the highest levels of efficacy analyzed. For these reasons, DOE is no longer considering establishing a product class for covered versus bare products.

2.5.3.2 Dimmability

In the framework document, DOE noted that dimmable lamps could have a lower efficacy than lamps with otherwise similar characteristics because of the added circuitry necessary for dimming functionality and the inclusion of cathode heat. For certain technologies, such as CFLs and LED lamps, not all products are marketed as capable of being dimmed. Thus a lamp that can be dimmed may offer unique performance characteristics and provide a utility to consumers. For these reasons, in the framework document DOE considered establishing a separate product class based on dimmability.

NEMA noted that while dimmability is a consumer utility, it is not included in all lamp designs, and further that the ability to dim varies by lamp type and brand. NEMA recommended that dimmable products should be tested at full power and should not be subject to different requirements. (NEMA, No. 15 at p. 10) NRDC, ASAP, *et al.* commented that a product class based on dimmability is unnecessary since dimming products exist at a range of levels of efficacy. (NRDC, ASAP, *et al.*, No. 17 at pp. 7-8) CEC again noted that if a 45 lm/W standard is adopted, a dimmable product class should not exist since a large number of lamps in that category currently exceed 45 lm/W. (CEC, No. 11 at pp. 13-15)

CEC and CA IOUs stated they could not find a correlation between dimmability and efficacy. (CEC, No. 11 at pp. 13-15; CA IOUs, No. 18 at pp. 7-8) According to CEC’s analysis of ENERGY STAR lamps, the average efficacy of medium screw base, non-reflector lamps was 66 lm/W for those that were dimmable and 64 lm/W for those that were not dimmable. (CEC, No. 11 at pp. 13-15) CA IOUs further noted that should this product class be maintained, DOE should clarify what qualifies as a minimum level of dimmability as dimmable lamps have different capacities to dim (*e.g.*, some lamps dim smoothly down to 1-2 percent of light output while others only dim to 50 percent). CA IOUs also directed DOE to a dimmability standards proposal and test procedure for LED replacement lamps submitted to CEC in 2013 by PG&E and SDG&E. (CA IOUs, No. 18 at pp. 7-8)

Several stakeholders commented on the applicability of such a product class setting factor across different lamp technologies. GE remarked that for externally ballasted lamps it is the ballast rather than the lamp that is designed to be dimmed or not dimmed. Therefore, GE stated that the dimmable product class distinction is not applicable to the externally ballasted lamps.

(GE, Public Meeting Transcript, No. 19 at pp. 90-91) CEC noted that a dimmable distinction does not apply to incandescent lamps, as they are all dimmable. (CEC, No. 11 at pp. 13-15)

In the framework document DOE determined that a lamp that could be dimmed offers a consumer utility but this ability could also result in reduced efficacy due to added circuitry. Upon further review of catalog data and feedback from stakeholders, DOE determined that dimmable lamps are available across a range of efficacies and further confirmed that the ability to dim has a negligible impact on efficacy. Therefore, because there is no discernable impact on efficacy in relation to dimmability, DOE is no longer considering establishing separate product classes for lamps that are dimmable and those that are not.

2.5.3.3 Ballast Location

Ballast location refers to the use of integrated ballasts (*i.e.*, self-ballasted) or non-integrated ballasts (*i.e.*, externally ballasted). DOE notes that self-ballasted lamps may have lower inherent efficacy compared to lamps that utilize external ballasts due to the additional components and circuitry integrated into a self-ballasted lamp. The use of a self-ballasted lamp can be advantageous in that a consumer need only replace one lamp unit rather than two separate components. Self-ballasted lamps are also generally more compact and thus can be used in applications with size constraints. For these reasons, in the framework document DOE considered establishing separate product classes based on ballast location.

CA IOUs recommended eliminating the externally ballasted product class as they have a low market share, may not be easily adopted as they require special fixtures, and do not pose a low-efficacy loophole. (CA IOUs, No. 18 at pp. 7-8) NRDC, ASAP, *et al.* commented that the same standards should apply to self-ballasted lamps as externally ballasted lamps, as the latter would require a reference ballast for purposes of testing. (NRDC, ASAP, *et al.*, No. 17 at pp. 7-8)

DOE does not consider market share when identifying product class setting factors but rather focuses primarily on the impact on consumer utility and efficacy. DOE determined that the location of a ballast, specifically whether it is external and replaceable or permanently enclosed in the lamp can impact consumer utility and efficacy. The difference in size and physical configuration (*i.e.*, one lamp component versus two lamp components) offer different utility to consumers. Further based on DOE research, lamps that incorporate a ballast include additional components and circuitry and therefore are likely to have a lower inherent efficacy compared to lamps that utilize external ballasts. Additionally, the testing of externally ballasted lamps on a reference ballast would still not account for the additional circuitry that would be reflected in the measured efficacy of a self-ballasted lamp. Therefore, DOE continues to consider ballast location to be a product class-setting factor.

Regarding the terminology used to describe a product class division based on ballast location, GE pointed out that "driver" is a more accurate term when referring to LED lamps. (GE, Public Meeting Transcript, No. 19 at p. 93) CA IOUs agreed that it would be confusing to use the term 'ballast' when referring to LED drivers. ASAP suggested that the product classes be revised to reduce ambiguity and conform with industry terminology to avoid confusion (*e.g.*, not using the term "ballast" interchangeably with "driver"). (ASAP, Public Meeting Transcript, No.

19 at pp. 94-95) CA IOUs also requested that if DOE was going to consider product classes based on ballast location, that it clarify how an incandescent lamp, which has no ballast, would be categorized. (CA IOUs, No. 18 at p. 8)

The impact on efficacy and utility for this product class division is based on the lamp having all its components enclosed within it as opposed to requiring an external, replaceable component. Therefore, to provide a clearer description of the product class that is applicable across all GSL technology types, DOE is considering using the terms ‘integrated’ and ‘non-integrated’ rather than ‘self-ballasted’ and ‘externally ballasted.’ Integrated GSLs would comprise lamps that contain all components necessary for the starting and stable operation of the lamp, do not include any replaceable or interchangeable parts, and are connected directly to a branch circuit through an ANSI base and corresponding ANSI standard lamp-holder (socket). Non-integrated GSLs would comprise any lamp that is not an integrated lamp.

2.5.3.4 Lamp Technology

In the framework document, DOE did not consider establishing separate product classes based on lamp technology. Rather, multiple lamp technologies could be present in a single product class. CEC agreed with DOE’s decision not to establish product classes by lamp technology, noting that otherwise more efficient technologies would be unfairly impacted as they would be subject to higher standards while less efficient technologies would likely have lower first costs and remain competitive in the market. (CEC, No. 11 at p. 6) NRDC, ASAP, *et al.* also endorsed a technology-neutral approach. (NRDC, ASAP, *et al.*, No. 17 at pp. 7-8; ASAP, Public Meeting Transcript, No. 19 at p. 22)

NEMA, however, proposed product class divisions that are specific to lamp technology. Specifically, NEMA recommended the following product classes: 1) medium screw base (MSB) filament lamps (*i.e.*, halogen incandescent), 2) MSB and pin base self-ballasted CFL (covered and bare/clear cover, two categories), 3) MSB and pin base LED lamp with integral driver (clear coated and diffuse coatings, two categories). (NEMA, No. 15 at p. 10).

In evaluating GSLs, DOE determined that different lamp technologies do not offer consumers different utility. DOE believes that for use in a general service application, a CFL and LED lamp offer similar functionality. Therefore, DOE is not considering product class divisions based on lamp technology. In the product class structure under consideration, medium base CFLs fall into the integrated GSL product class. DOE accounts for the existing standards for medium base CFLs in the analysis of this product class to ensure there is no backsliding.[49]

2.5.3.5 Base Type

In the framework document, DOE did not consider establishing separate product classes based on base type. CEC commented that if smaller base types, such as candelabra, are included in the scope of coverage, those may warrant a separate product class because of space constraints

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[49] EPCA’s anti-backsliding provision mandates that the Secretary not prescribe any amended standard that either increases the maximum allowable energy use or decreases the minimum required energy efficiency of a covered product. (42 U.S.C. 6295(o)(1))

of certain products. (CEC, Public Meeting Transcript, No. 19 at pp. 95-96) As discussed in section 2.3.5.5, DOE is not considering setting standards for GSLs with candelabra bases in this rulemaking.

2.5.3.6 Lamp Spectrum

DOE received comments on establishing a product class division based on lamp spectrum. ASAP commented that DOE did not address how it planned to include modified spectrum lamps in the analysis which have a lower standard than conventional lamps. (ASAP, Public Meeting Transcript, No. 19 at pp. 22-23) NEMA recommended that DOE develop a definition based on the color point defined in the current definition for incandescent modified spectrum lamps per 10 CFR 430.2 and then develop derating factors for CFL and LED lamps as appropriate. (NEMA, No. 15 at pp. 10-11)

NRDC, ASAP, et al and CA IOUs disagreed, recommending that DOE not include an allowance for modified spectrum lamps allowing them to meet weaker standards. (NRDC, ASAP, *et al.*, No. 17 at p. 8; CA IOUs, No. 18 at p. 9) NRDC, ASAP, et al noted that the current EISA standards already provide a 25 percent allowance for modified spectrum GSILs and as a result these lamps are no more efficient than conventional inefficient incandescent lamps. They cited an example of a GE 72 W Reveal incandescent lamp that claims to be a 100 W replacement but produces lumen output equivalent to a 75 W and a GE 13 W Reveal CFL that claims to be a 60 W replacement but produces 30 percent less light than a standard 60 W incandescent lamp. (NRDC, ASAP, *et al.*, No. 17 at pp. 8-10) Further CA IOUs commented that they have been able to show in the past that modified spectrum incandescent lamps can be manufactured with only a 10 percent reduction in light output compared to standard spectrum lamps. Additionally, CA IOUs emphasized that in considering all types of GSLs, an efficacy allowance for modified spectrum lamps is inappropriate because fluorescent and LED technologies can offer a modified spectrum without reducing efficacy. (CA IOUs, No. 18 at p. 9)

DOE is not considering a separate product class for modified spectrum lamps in this preliminary analysis. Modified spectrum lamps provide a unique spectral power distribution (SPD) that increases the contrast between reds and greens, resulting in a type of light different from a standard spectrum. DOE’s research indicates that are various ways to manipulate SPDs to achieve a modified spectrum such as neodymium coating, phosphor mixes and LED color mixing or a combination thereof. DOE has found that certain methods do not require a decrease in efficacy. For example the Philips L Prize lamp and Cree’s existing product line of True White® color mixed LED modules are able to achieve a modified spectrum at high efficacies. Because efficacy is impacted in different ways based on the method used to achieve modified spectrum GSLs, DOE is not considering a product class division for modified spectrum GSLs.

2.5.3.7 Correlated Color Temperature

NEMA also suggested that DOE consider derating factors for high CCT CFLs (> 4,500 K) and low CCT LED lamps (< 3,200 K).

DOE understands that CCT is a measure of the perceived color of the white light emitted from the lamp. The perception of light affords consumers a different utility for lamps with different CCT values. DOE found that while there is a reduction in efficacy for fluorescent technology at higher CCTs, LED technology experiences an increase. For CFLs at higher CCTs, more light is converted to shorter wavelengths (*i.e.*, blue, violet) to which human eyes are less sensitive, thereby resulting in a decline in efficacy. In LED lamps, the LED emits blue light (*i.e.*, shorter wavelengths) which is partially down converted to longer wavelengths. While this process results in longer wavelengths to which human eyes are more sensitive, there is a decrease in lumen output due to losses from phosphor conversion and a larger Stokes' shift.[50] To achieve lower CCTs in LED lamps more down conversion and a larger Stokes' shift is required, resulting in lower efficacy. Due to these underlying differences in technology, the efficacy trends associated with CCT differ for CFLs and LED lamps. Therefore, a consistent correlation between efficacy and CCT cannot be established for all GSLs. Hence, DOE is not considering such a product class division based on CCT.

2.5.3.8 Lumen Package

In this preliminary analysis, DOE is also considering lumen package as a product class setting factor for integrated GSLs. After further analysis, DOE determined that higher lumen output products cannot achieve the same levels of efficacy as lower lumen output products. DOE believes that higher lumen packages offer a consumer utility. After evaluating manufacturer catalogs and other sources,[51] DOE determined that a general service high lumen application would have light output in the range of 2,000 – 2,600 lumens. DOE was unable to identify LED lamp replacements for incandescent lamps of wattages higher than 100 W. Therefore, DOE examined lumen ranges of CFLs marketed as being equivalent to a 125 W incandescent lamp, the next common incandescent wattage after the 100 W. Additionally, ENERGY STAR Lamps Specification V1.1[52] defines a 125 W incandescent equivalent lamp to have a lumen range of 2,000 – 2,549. The upper lumen limit of the high lumen package product class under consideration is maintained at 2,600 in accordance with the scope of this rulemaking, which covers products in the lumen range of 310 – 2,600. Because of the impact on both efficacy and utility, DOE is considering establishing separate product classes for integrated GSLs with lumen outputs between 310 and 1999 and integrated GSLs with lumen outputs between 2,000 and 2,600. DOE is not establishing a product class division based on lumen package for non-integrated GSLs, as DOE found lumen packages across a range of efficacies for these products. DOE requests comments on a product class division based on lumen package for the integrated GSLs.

2.5.3.9 Standby Mode Operation

In this preliminary analysis, DOE is also considering a division based on the ability for a lamp to operate in standby mode. As stated in section 2.3.5.4, DOE identified integrated lamps that meet the definition of GSL and operate in standby mode. DOE believes that standby mode operation offers a consumer utility because these lamps have the ability to be remotely turned

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[50] Stokes' shift is the difference, in nanometres, between the peak excitation and the peak emission wavelengths. Stokes' law states that radiation emitted must be of the longer wavelength than that absorbed.

[51] ENERGY STAR Lamps Specification V1.1, available at http://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Lamps%20V1%201_Specification.pdf.

[52] Ibid.

off, turned on, dimmed, or other functionality. DOE evaluated whether operation in standby mode impacts lamp efficacy. Based on commercially available products, DOE found that standby power consumption can vary based on the technology used to facilitate standby functionality. DOE assumes that the market will shift to the lowest energy consuming method available, such as Bluetooth or smart controls that are external to the lamp, over the course of the analysis period and therefore believes that the energy consumed in standby mode is negligible. Because DOE believes that the energy consumed while operating standby mode will be negligible for GSLs, DOE does not believe there is a difference in efficacy for lamps that can operate in standby mode compared to lamps that cannot operate in standby mode. Therefore, DOE is not considering a product class division based on standby mode operation. DOE requests comments on its preliminary determination that energy consumed in standby mode will be negligible and therefore a product class division based on standby mode operation for integrated GSLs is not warranted.

2.5.3.10 Summary

In summary, DOE is considering establishing the three product classes shown in Table 2.5.2. See chapter 3 of this TSD for further discussion. DOE welcomes comments on the product class divisions it is considering for GSLs in this preliminary analysis.

Table 2.5.2 GSL Product Classes

Lamp Type	Lumen Output
Integrated GSLs (*e.g.*, self-ballasted CFL, integrated LED lamp)	310-1,999
	2,000-2,600
Non-Integrated GSLs (*e.g.*, externally ballasted CFL)	310-2,600

2.6 SCREENING ANALYSIS

After DOE identifies the technologies that improve the efficacy of GSLs, DOE conducts the screening analysis. The purpose of the screening analysis is to determine which options to consider further and which options to screen out. DOE consults with industry, technical experts, and other interested parties in developing a list of technology options. DOE then applies the following set of screening criteria to determine which options are unsuitable for further consideration in the rulemaking (10 CFR Part 430, subpart C, appendix A at 4(a)(4) and 5(b)):

- *Technological Feasibility:* DOE will consider technologies incorporated in commercially available products or in working prototypes to be technologically feasible.

- *Practicability to Manufacture, Install, and Service:* If mass production of a technology and reliable installation and servicing of the technology could be achieved on the scale necessary to serve the relevant market at the time the standard comes into effect, then DOE will consider that technology practicable to manufacture, install, and service.

- *Adverse Impacts on Product Utility or Product Availability:* If DOE determines a technology to have significant adverse impact on the utility of the product to significant subgroups of consumers, or to result in the unavailability of any covered product type with performance characteristics (including reliability), features, sizes, capacities, and volumes that are substantially the same as products generally available in the United States at the time, it will not further consider this technology.

- *Adverse Impacts on Health or Safety:* If DOE determines that a technology will have significant adverse impacts on health or safety, it will not further consider this technology.

Those technology options not screened out by the above four criteria are called "design options" and are considered as possible methods of improving efficacy in the engineering analysis.

NEMA agreed with the four screening criteria, but stated that it is essential that performance enhancements meet a maximum three-year payback for consumer acceptance. NEMA also noted their concern regarding determining technological feasible technology options which have not been mass produced and met the litmus test of commercial offering. Additionally, NEMA stated that DOE assess whether combination of technology options are technologically feasible together before determining them as technologically feasible for a given lamp type. (NEMA, No. 15 at p. 14)

As noted, DOE screens out technology options that will have an adverse impact on product utility to ensure that the functionality consumers are receiving will be preserved in higher efficacy products. Therefore, a period to determine consumer acceptance is unnecessary. DOE will consider technology options in prototype lamps or model lamps only when the lamp can be produced with commercially available technologies and information is available indicating that the lamp can be manufactured on a commercial scale at the time any final standards require compliance.

Soraa commented that the technology options for GSILs and CFLs come with considerable detriment of lifetime, small efficacy gains, or both. Soraa recommended that the only technology options for improving the efficacy of GSILs and CFLs should be switching to a more efficient lamp technology. (Soraa, No. 10 at p. 2)

DOE recognizes that certain technology options result in an inverse relationship between efficacy and lifetime. However, DOE believes that the technology options under consideration can be adjusted to produce an optimal combination of efficacy and lifetime. Further, the impacts of lamp lifetime are considered in the cost assessment of this analysis.

Soraa noted that all technology options for CFLs retain mercury, which is both poisonous, a threat to human safety, and a waste hazard. (Soraa, No. 10 at p. 2) Private citizen, Thomas Duchesneau commented that he hoped incandescent bulbs will still be available for residential use in the future, as CFLs bring on eye strain and headaches. (Duchesneau, No. 3 at p. 1)

DOE screens out any technology option that would have an adverse impact on health or safety. DOE is not aware of any reports or documentation regarding safety and health concerns resulting for the technology options under consideration for CFLs. Therefore, DOE is not considering screening out any CFL technology option due to adverse impact on health or safety.

Regarding the higher efficiency phosphor technology option for CFLs, NEMA stated that given rare earth phosphor availability and cost issues, all coating resources used in the implementation of higher efficiency phosphors are being used to reduce losses and optimize current technology performance rather than attain further improvements in lamp efficacy. (NEMA, No. 15 at p. 13) DOE has found lamps which utilize higher efficiency phosphors to be commercially available and of varying efficacies. DOE understands there are concerns regarding a limited supply of rare earth phosphors that may impact the application of this technology option. However, DOE considers this technology option as means of improving lamp efficacy to be practicable to manufacture, install, and service. Therefore, DOE finds that higher efficiency phosphors meet the screening criteria and is considering it as a design option.

NEMA reiterated its comment made in the second review of the GSFL and IRL rulemaking that it is still appropriate to screen out the multi-photon phosphor technology because cost effective, improved performance phosphors have not been identified. (NEMA, No. 15 at p. 12) In this preliminary analysis, DOE is considering screening out multi-photon phosphor technology based on the first criterion, technological feasibility, because the technology is still in the research phase and DOE is unaware of any prototypes or commercially available products that incorporate the technology. See chapter 4 of this TSD for further details.

In this preliminary analysis, of the GSL technology options identified for improving CFL efficacy, DOE is considering screening out the following:

<u>CFL Technology Options</u>

- Multi-photon phosphors because they could not be proven to be technologically feasible;

<u>LED Technology Options</u>

- Quantum dot and nanophosphor technologies because they could not be proven to be technologically feasible;
- Improved emitter materials because they could not be proven to be technologically feasible and/or practicable to manufacture, install and service;
- AC LEDs because they could not be proven to be practicable to manufacture, install and service

The following are GSL technologies that DOE has not screened out and is still considering as design options:

<u>CFL Design Options</u>

- Highly Emissive Electrode Coatings
- Higher Efficiency Lamp Fill Gas Composition
- Higher Efficiency Phosphors
- Glass Coatings

- Cold Spot Optimization
- Improved Ballast Components
- Improved Ballast Circuit Design
- Change in Technology

LED Design Options

- Efficient Down Converters (with the exception of quantum dots and nanophosphor technologies)
- Improved Package Architectures
- Alternative Substrate Materials
- Improved Thermal Interface Materials
- Optimized Heat Sink Design
- Active Thermal Management Systems
- Device Level Optics
- Increased Light Utilization
- Improved Driver Design
- Reduced Current Density

For further details on the screening out of GSL technology options, see chapter 4 of this TSD. DOE requests comments on the design options it is considering for GSLs.

2.7 ENGINEERING ANALYSIS

In the engineering analysis, DOE first selects representative product classes to analyze. It then selects baseline lamps within those representative product classes, and identifies more efficacious substitutes for the baseline lamps. DOE uses these more efficacious lamps to develop CSLs.

For this rulemaking, DOE derives CSLs in the engineering analysis and end-user prices in the product price determination. DOE estimates the end-user price of GSLs directly because reverse-engineering a lamp is impractical as the lamps are not easily disassembled. By combining the results of the engineering analysis and the product price determination, DOE derives typical inputs for use in the LCC and NIA. Section 2.8 discusses the product price determination (see chapter 6 of this TSD for further detail).

2.7.1 Approach

The following is a summary of the steps taken in the engineering analysis:

- Step 1: Select Representative Product Classes
- Step 2: Select Baseline Lamps
- Step 3: Identify More Efficacious Substitutes
- Step 4: Develop CSLs

A more detailed discussion of the methodology DOE followed to perform the engineering analysis can be found in chapter 5 of this TSD. The following discussion summarizes the general steps of the engineering analysis:

Representative product classes: DOE first reviews covered lamps and the associated product classes. When a product has multiple product classes, DOE selects certain classes as "representative" and concentrates its analytical effort on these classes. DOE selects representative product classes primarily because of their high market volumes. For those product classes that are not directly analyzed, DOE extrapolates the CSLs from representative product classes.

Baseline lamps: For each representative product class, DOE selects a baseline lamp as a reference point against which to measure changes resulting from energy conservation standards. Typically, a baseline model is the most common, least efficacious lamp sold in a given product class. For this preliminary analysis, DOE uses performance data presented in manufacturer catalogs to determine lamp efficacy. DOE also considers other lamp characteristics in choosing the most appropriate baseline for each product class such as lumen output, wattage, CCT, shape, and lifetime.

More efficacious substitutes: DOE selects higher efficacy lamps as replacements for each of the baseline models considered. When selecting higher efficacy lamps, DOE considers only design options that meet the criteria outlined in the screening analysis (see section 2.6 or chapter 4 of this TSD). DOE also sought to maintain the baseline lamp's characteristics, such as base type, CCT, and CRI among other specifications, for substitute lamps. For non-integrated GSLs, DOE pairs each representative lamp with an appropriate ballast because non-integrated GSLs are a component of a system, and their performance is related to the ballast on which they operate.

Candidate standard levels: After identifying the more efficacious substitutes for each baseline lamp, DOE develops CSLs. DOE bases its analysis on three factors: (1) the design options associated with the specific lamps studied; (2) the ability of lamps across the lumen range to comply with the standard level of a given product class;[53] and (3) the maximum technologically feasible CSL.

DOE received several comments on the general approach to the engineering analysis presented in the framework document. Regarding the data approach, CEC requested that DOE, when determining performance characteristics of lamps on the market, use DOE certification data, the LED Lighting Facts Database, CEC certification data, the Federal Trade Commission labeling data, and the ENERGY STAR qualified list. (CEC, No. 11 at p. 21)

On the topic of using certification data and verification testing data when establishing efficacy levels, NEMA commented that DOE must be careful in evaluating apparent outliers and filter out data that may be the result of misunderstood reporting requirements or mistakes in reporting. NEMA cautioned DOE to give careful consideration to any data, including

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[53] CSLs span multiple lamps of different lumen outputs and wattages. In selecting CSLs, DOE considered whether these multiple lamps can meet the standard levels.

manufacturer catalogs, that is used in order to ensure that values reported are measured using the same test methods used in this rulemaking. (NEMA, No. 15 at p. 16) Westinghouse also made note of the possibility of data entry errors arising from confusion when entering lamps into the certification database. Westinghouse thus requested that DOE consider potential outliers in the database and to ignore those in any baseline establishment to avoid potentially creating a disruption in the market. (Westinghouse, Public Meeting Transcript, No. 19 at pp. 122-123)

For the preliminary analysis, DOE used performance data of commercially available GSLs presented in manufacturer catalogs to identify potential baseline lamps and develop CSLs. DOE used catalog data as the basis of its engineering analysis because it is the largest and most comprehensive dataset. However, DOE also used publicly available test data from the CEC Appliance Efficiency Certified Light Bulbs Database,[54] DOE's LED Lighting Facts Product List,[55] ENERGY STAR Certified Light Bulbs database,[56] and DOE's CCMS database[57] when possible to verify efficacies calculated from catalog values and to ensure lamps can comply with CSLs based on test data. Regarding outliers, DOE identified data outliers in both its collection of lamp performance data from manufacturer catalogs and in its review of efficacy values from the compliance and verification testing databases. DOE identified both on the high and low end outliers, and in cases where DOE was unable to verify the value using third-party data or manufacturer confirmation, did not consider the lamp in the engineering analysis. DOE welcomes comment on the data approach including any additional databases that should be considered.

Although certain products included in the scope of this rulemaking do not currently have DOE test procedures (*e.g.*, LED lamps), industry standards for testing efficacy have been in place for several years for these products. Therefore, DOE believes that manufacturers and the organizations conducting verification testing are likely using existing industry standard test methods to determine performance values. As stated in section 2.2.3, EPCA directs DOE to establish test procedures for covered products in advance of prescribing an energy conservation standard. (42 U.S.C. 6295(o)(3)(A)) Thus, DOE plans to finalize test procedures for GSLs for which DOE is considering establishing standards prior to the completion of this rulemaking.

2.7.2 Representative Product Classes

In the case where a covered product has multiple product classes, DOE identifies and selects certain product classes as "representative" and concentrates its analytical effort on those classes. DOE chooses product classes as representative primarily because of their high market volumes. In the framework document, DOE identified its methodology for selecting representative product classes and discussed its preliminary findings on the highest volume GSLs. DOE received several comments on the methodology of selecting representative product

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[54] Certification data is publicly available on CEC's Appliance Efficiency Database available here: http://www.appliances.energy.ca.gov/Default.aspx.

[55] DOE's LED Lighting Facts Product List is publicly available here: http://www.lightingfacts.com/products.

[56] The ENERGY STAR Certified Light Bulbs database is publicly available here: http://www.energystar.gov/productfinder/product/certified-light-bulbs/results.

[57] DOE's Compliance Certification Database is publicly available here: www.regulations.doe.gov/certification-data/.

classes as well as the product classes from the framework document that should be directly analyzed.

NEEA suggested that DOE consider more than shipment volume when selecting representative product classes, reasoning that there are many other factors that affect the economics of the analysis (*e.g.*, lifetime of the product, predicted number of on/off cycles, etc.). (NEEA, Public Meeting Transcript, No. 19 at pp. 106-108) DOE typically chooses representative product classes based on the highest shipment volume and then scales its analytical findings for those representative product classes to other product classes that are not directly analyzed. However in this preliminary analysis, DOE is considering directly analyzing all product classes for GSLs. As stated in section 2.5.3.3, DOE is considering product class divisions based on ballast location. DOE is considering directly analyzing both the integrated and non-integrated product classes because of technological differences that would preclude scaling from the high volume integrated product class. Specifically, DOE observed different efficacy trends and maximum technologically feasible levels between the two classes. Further, manufacturer feedback indicated that scaling between the integrated and non-integrated product classes is not appropriate. DOE is also considering a product class division based on lumen package for the integrated product class as discussed in section 2.5.3.8. DOE is considering directly analyzing both the low lumen and high lumen integrated product classes. DOE has found that there are technological limitations to producing high lumen (*i.e.*, 2,000 lumens or greater) GSLs using LED technology and therefore CSLs for this product class cannot be scaled from the low lumen output integrated product class.

Noting that standard CFLs are non-dimmable and comprise the majority of the market because LED lamps are an emerging product, NEMA questioned DOE’s determination that dimmable products are more common than non-dimmable products. (NEMA, Public Meeting Transcript, No. 19 at pp. 104-105) GE noted that for medium screw bases, more sockets have dimmable lamps because incandescent/halogen lamps are all dimmable. However, GE agreed that most sockets with CFLs or LED lamps are not currently dimmable. (GE, Public Meeting Transcript, No. 19 at pp. 105-106)

In the framework document, DOE determined the commonality of dimmable GSLs by evaluating product offerings in catalogs of dimmable CFLs and LED lamps, which cumulatively resulted in a majority of dimmable products. However, in this preliminary analysis, DOE is no longer considering dimmability as a product class division. See section 2.5.3 and chapter 3 of this TSD for further discussion of product classes.

In summary, DOE is considering analyzing all product classes as representative as shown (in gray) in Table 2.7.1. See chapter 5 of this TSD for further discussion.

Table 2.7.1 GSL Representative Product Classes

Lamp Type	Lumen Package
Integrated GSLs	310-1,999
	2,000-2,600
Non-Integrated GSLs	310-2,600

2.7.3 Baseline Lamps

Once DOE identified the representative product classes for analysis, it selected baseline lamps to analyze in each class. Typically, a baseline lamp is the most common, least efficacious lamp that meets existing energy conservation standards. Specific lamp characteristics are used to characterize the most common lamps purchased by consumers today (*e.g.*, wattage, CCT, CRI, and light output). Because certain products within the scope of this rulemaking have existing standards, GSLs that fall within the same product class as these lamps must meet the existing standard in order to prevent backsliding. (*See* 42 U.S.C. 6295(o)(1))
Thus, DOE is only considering baseline lamps in the integrated product classes that meet the existing standards for bare MBCFLs. The non-integrated product class does not have any applicable existing standards.

DOE received general comments regarding baseline lamps. NEMA and GE noted that although the most common lamp is not always the least efficacious, the least efficacious lamp for each product class is the most appropriate baseline. (NEMA, No. 15 at p. 15; GE, Public Meeting Transcript, No. 19 at pp. 114-115) CA IOUs agreed that efficacy should be the most important metric to consider when establishing the baseline. (CA IOUs, Public Meeting Transcript, No. 19 at p. 116)

As noted, DOE considers both commonality and efficacy when selecting baseline lamps and thus selects the most common, least efficacious lamp that just meets existing standards (when applicable). DOE determines the most common product characteristics such as lumen output range, CCT, and CRI. Among lamps with those characteristics, DOE selects the least efficacious product as the baseline.

CEC asked for clarification on whether incandescent technology would be considered as a baseline. (CEC, Public Meeting Transcript, No. 19 at pp. 120-121) NRDC urged caution to not prematurely or incorrectly lock down a baseline because the full impact of the first phase of the EISA standards for GSILs has not been seen yet, and the final phase of standards for 60 W and 40 W lamps just became effective this year. NRDC noted that there is lag time in the impact of standards due to warehousing and stockpiling by manufacturers and retailers of lamps that were legal at the time of their production. (NRDC, Public Meeting Transcript, No. 19 at pp. 24-25)

As discussed in section 2.3.1, DOE is unable to analyze incandescent/halogen lamps in the rulemaking at this time. Therefore, DOE is considering CFLs and LED lamps when selecting the most common, least efficacious lamp to serve as the baseline. Further, DOE must only consider lamps that meet the most stringent existing standard for applicable product classes to ensure backsliding does not occur.

NRDC expressed concern regarding light output as a criterion for the baseline lamp stating that it could lead to a comparison of brighter lamps versus less bright. For example, a 40 W lamp and its alternatives might be very different from 100 W lamps in terms of pricing and availability. NRDC suggested that multiple baseline lamps might be needed. (NRDC, Public Meeting Transcript, No. 19 at pp. 113-114)

DOE considered light output, or lumen package, when selecting baseline lamps in each product class to ensure that the most common lamp was analyzed. As discussed in section 2.5.3.8, DOE found differences in available technology between high lumen (2,000-2,600 lumen) integrated lamps and low lumen (310-1,999 lumen) integrated lamps and thus created a product class division based on lumen package. DOE directly analyzes all product classes and has selected a baseline lamp in both the low lumen and high lumen integrated product classes. DOE does not believe that there would be substantial differences in consumer economics within each product class and therefore analyzed one baseline lamp for each product class. DOE requests comment on its analysis of one baseline lamp for each product class.

2.7.3.1 Integrated Lamps

In this preliminary analysis, DOE identified baseline lamps in the integrated product classes as the most common, least efficacious lamps that meet existing standards for MBCFLs. For integrated GSLs, the most common lamps were determined based on characteristics such as lumen output, lifetime, CRI, and CCT. Based on a review of lamps that had the most common characteristics, DOE determined that the baseline lamp for the integrated low lumen product class is a 14 W, 750 lumen (*i.e.*, 60 W equivalent) A-shape CFL with a lifetime of 10,000 hours, a CRI of 80, and a CCT of 2,700 K. Feedback collected during manufacturer interviews confirmed the 60 W equivalent lamps to be the highest volume GSL. For the integrated high lumen product class, DOE determined the baseline to be a 32 W, 2,000 lumen (*i.e.*, greater than 100 W equivalent) spiral CFL with a lifetime of 10,000 hours, a CRI of 80, and a CCT of 2,700 K.

The characteristics of the baseline lamps in the integrated product classes that DOE is considering in this preliminary analysis are summarized in Table 2.7.2. See chapter 5 of this TSD for additional detail on the baseline selection process. DOE requests comment on the baseline units selected for the integrated product classes.

Table 2.7.2 Integrated Product Classes Baseline Lamps

Product Class	Lamp Shape	Base Type	Lamp Type	Nominal Wattage	Initial Lumens	Rated Efficacy	Lifetime	CCT	CRI
				W	*lm*	*lm/W*	*hr*	*K*	
Integrated Low Lumen (310-1,999 Lumens)	A-Shape	E26	CFL	14	750	53.6	10,000	2,700	80
Integrated High Lumen (2,000-2,600 Lumens)	Spiral	E26	CFL	32	2,000	62.5	10,000	2,700	80

2.7.3.2 Non-Integrated Lamps

In the preliminary analysis, DOE identified the baseline lamp in the non-integrated product class as the most common, least efficacious lamp. The non-integrated product class does not have applicable existing standards and therefore the lowest efficacy lamps on the market were considered. For non-integrated GSLs, the most common lamps were determined based on characteristics such as wattage, lumen output, shape, base type, lifetime, and CCT. DOE found that the base types of non-integrated CFLs typically correspond to certain wattages and lumen outputs, and thus DOE concentrated on a common wattage and its associated base type. Based on a review of lamps that had the most common characteristics, DOE determined that the baseline lamp for the non-integrated product class is a 26 W, 1,710 lumen double tube[58] G24q-3 base CFL with a lifetime of 10,000 hours and a CCT of 4,100 K. Feedback collected during manufacturer interviews confirmed the 26 W CFL to be the highest volume non-integrated GSL.

The characteristics of the baseline lamp in the non-integrated product class that DOE is considering in this preliminary analysis are summarized in Table 2.7.3. See chapter 5 of this TSD for additional detail on the baseline selection process. DOE requests comment on the baseline unit selected for the non-integrated product class.

Table 2.7.3 Non-Integrated Product Class Baseline Lamp

Lamp Shape	**Base Type**	**Lamp Type**	**Nominal Wattage**	**Rated Wattage**	**Initial Lumens**	**Mean Lumens**	**Rated Efficacy**	**Lifetime**	**CCT**	**CRI**
			W	*W*	*lm*	*lm*	*lm/W*	*hr*	K	
Double Tube	G24q-3	CFL	26	26	1,710	1,450	65.8	10,000	4,100	82

2.7.4 More Efficacious Substitutes

DOE selects a series of more efficacious replacements for the baseline lamps considered within each representative product class. DOE considered only technologies that met all four criteria in the screening analysis. These selections were made such that potential substitutions maintained light output within 10 percent of the baseline lamp's light output with similar characteristics when possible. In identifying the more efficacious substitutes, DOE utilized a database of commercially available lamps.

DOE received a general comment on the methodology used to identify more efficacious substitutes. NEMA urged caution regarding the use of modeling to identify higher-efficacy products. NEMA asserted that the list of design options must come from a commercially available, proven product and that only commercially available solutions can be fairly used to set efficacy levels. NEMA additionally cited its disagreements from other rulemakings that proposed inclusion of proprietary, laboratory-only, or prototypical technology options. (NEMA, No. 15 at p. 16)

When evaluating higher efficacy substitutes, DOE only considers lamps that incorporate technology options that meet the screening criteria described in section 2.6. DOE considers technologies incorporated in commercially available products or in working prototypes to be technologically feasible. The technology must also be practicable to manufacture, install, and

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[58] The double tube shape for CFLs, that is, a CFL with two U-shaped glass tubes, is also sometimes referred to as quad tube in industry.

service, have no adverse impacts on product utility or product availability, and have no adverse impacts on health or safety. There is no requirement that an analyzed product be commercially available. However, in this preliminary analysis, DOE did not model any lamps and therefore the more efficacious substitute lamps under consideration are, in fact, commercially available products.

Further details specific to the more efficacious substitutes of the integrated and non-integrated product classes are discussed in the following sections.

2.7.4.1 Integrated Lamps

For integrated GSLs, DOE identified more efficacious substitute lamps that saved energy and had light output within 10 percent of the baseline lamp's light output. DOE selected more efficacious substitutes with same base type as the baseline lamp since replacing an integrated lamp with a lamp of a different base type would potentially require a fixture or socket change and thus is considered an unlikely replacement. In this preliminary analysis, DOE also ensured that the more efficacious substitutes were marketed as omnidirectional,[59] thus maintaining the even light distribution of the baseline lamp. DOE found several lamp types marketed as semi-omnidirectional. However, to ensure that the more efficacious substitutes could be used in the same applications as the baseline lamps, DOE only considered marketed as omnidirectional in this preliminary analysis. See chapter 5 of this TSD for additional details of the more efficacious substitutes selected. DOE requests comment on the criteria used in selecting more efficacious substitute lamps in the integrated product class, as well as the characteristics of the lamps selected. In particular, DOE requests comment on its assumptions that more efficacious substitutes must have lumen output within 10 percent of the baseline lamp and must be omnidirectional light sources.

2.7.4.2 Non-Integrated Lamps

For non-integrated GSLs, DOE considered more efficacious lamps that did not increase energy consumption relative to the baseline and had light output within 10 percent of the baseline lamp-and-ballast system when possible. Due to potential physical and electrical constraints associated with switching base types, DOE selected substitute lamps that had the same base type as the baseline lamp. DOE identified substitute lamps that were the same wattage as the baseline but produced more light and were therefore more efficacious or lamps that were lower wattage than the baseline but produced similar light and were therefore more efficacious. For further detail, see chapter 5 of this TSD. DOE requests comment on the criteria used in selecting more efficacious substitute lamps in the non-integrated product class, as well as the characteristics of the lamps selected. In particular, DOE requests comment on its assumptions that more efficacious substitutes must have lumen output within 10 percent of the baseline lamp-and-ballast system. DOE also requests comment on its assumption that the base type of the

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[59] ENERGY STAR Lamps Specification V1.1 specifies luminous intensity distribution requirements for omnidirectional light sources and is available here: http://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Lamps%20V1%201_Specification.pdf.

baseline lamp in the non-integrated product class must be maintained for more efficacious substitutes.

DOE received a comment pertaining to the methodology outlined in the framework document for selecting more efficacious substitutes for the non-integrated product class. NRDC asked if pin base CFLs will be analyzed with an assumed ballast because non-integrated lamps operate as part of a system. (NRDC, Public Meeting Transcript, No. 19 at pp. 64-65)

DOE pairs non-integrated GSLs with representative ballasts because the non-integrated GSLs analyzed in this preliminary analysis operate on a ballast in practice. To develop representative lamp-and-ballast system pairings, DOE determined the most common non-integrated CFL ballasts based on manufacturer feedback and a survey of the market. Specifically in this rulemaking, DOE chose to pair the non-integrated GSLs with a one-lamp electronic ballast with programmed start starting method to represent the lamp-and-ballast combinations present in the market. See chapter 5 of this TSD for additional details. DOE requests comment on the lamp-and-ballast systems selected for the non-integrated product class.

2.7.5 Candidate Standard Levels

After identifying more efficacious substitutes for each of the baseline lamps, DOE develops CSLs based on the consideration of several factors, including: (1) the design options associated with the specific lamps being studied (*e.g.*, grades of phosphor for CFLs, improved package architecture for LEDs); (2) the ability of lamps across the applicable lumen range to comply with the standard level of a given product class;[60] and (3) the max-tech level. DOE received comments specific to the general methodology for selecting CSLs presented in the framework document.

The NRDC and ASAP joint comment, CEC, and CA IOUs urged DOE to establish smooth, continuous efficacy levels as opposed to step functions because step functions encourage manufacturers to design products at the lowest efficacy requirements thus resulting in dimmer lamps. (NRDC, ASAP, *et al.*, No. 17 at pp. 6-7; CEC, No. 11 at p. 13; CA IOUs, No. 18 at pp. 9-10) ASAP stated that equation-based standards generally result in fewer discontinuities and reduced potential for gaming opportunities. (ASAP, Public Meeting Transcript, No. 19 at p. 21) The NRDC and ASAP joint comment also noted that this approach is widely accepted and has been used by the European Union, its member countries, and other countries around the world. (NRDC, ASAP, *et al.*, No. 17 at p. 7)

NEMA agreed with the application of an equation-based approach to efficacy standards but noted that other approaches such as a step function and efficacy bins have been successful for certain technologies in the past. NEMA urged DOE to evaluate which approach would be best for the technology being regulated and reserved final comment until review of DOE's preliminary analysis. (NEMA, No. 15 at p. 16) GE also suggested that a tiered or stepped

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[60] ELs span multiple lamps of different lumen output and wattages. In selecting CSLs, DOE considered whether these multiple lamps can meet the ELs.

approach could be considered in addition to an equation-based approach in this rulemaking. GE noted that the step approach was very successful in the previous incandescent rulemaking and noted that an equation-based approach is not always the best approach. (GE, Public Meeting Transcript, No. 19 at pp. 117-118)

CA IOUs commented on the step-based approach mentioned by DOE noting that Phase 1 of the EISA standards caused manufacturers to introduce many products at the least efficacious part of the step function. Consequently, consumers ended up with products that may not have been as bright as what they thought they were getting. CA IOUs noted that a step-based approach creates a disincentive in the design process by giving an advantage to products that are less efficacious. (CA IOUs, Public Meeting Transcript, No. 19 at pp. 118-119) GE disagreed with CA IOUs regarding the success of the step function saying that the step function had the effect of manufacturers ending up at common wattages thus avoiding massive consumer confusion. GE noted that there are marketing, consumer education, and other industry benefits associated with a step function including consumer understanding of replacement wattages. (GE, Public Meeting Transcript, No. 19 at p. 119) NRDC, ASAP, *et al.* commented that it is inaccurate to state that the existing binned standards for incandescent lamps restricted wattages to four values, noting that 60 W incandescent lamps have been replaced with 43 W halogen lamps, CFLs between 13 W and 15 W, and LED lamps between 9 W and 13 W. NRDC, ASAP, *et al.* further stated that more efficient incandescent lamps that use 50 percent less power for the same light are also expected to enter the market this year thus potentially introducing more wattage options. (NRDC, ASAP, *et al.*, No. 17 at pp. 6-7)

DOE is considering an equation-based approach in this rulemaking. DOE is considering a continuous function based on its assessment that a step function, where efficacy rises significantly at certain increments in lumen output or wattage, is not representative of the technology used in the products covered by this rulemaking. DOE also recognizes that a step function increases the potential for products to be introduced at the lowest possible efficacy point in each step. While this could potentially encourage the development of similar-wattage products across the industry, DOE believes that a wide variety of replacement wattages are already available to consumers, and a wide variety will continue to be available in the future as new, more efficacious products are introduced. For these reasons, DOE believes that the limitations of a step function outweigh its benefits and is therefore considering a standard based on a smooth, continuous equation. See chapter 5 for more detail on CSLs and the equation-based approach.

Regarding whether standards should be based on lumen output or wattage, Philips suggested DOE group products by lumens instead of wattage because that is how the lamps will be bought for applications. Philips further noted that there are such large variations in the wattages for lamps used in the same application that it no longer makes any sense to group products by wattage. (Philips, Public Meeting Transcript, No. 19 at p. 117) NRDC agreed that future standards should be focused on lumen output and suggested setting minimum efficacy standards as a function of light output. (NRDC, Public Meeting Transcript, No. 19 at p. 122) CA IOUs also agreed that standards and equations should be a function of lumen output rather than wattage because lumens identify the product utility. CA IOUs noted that there is a wide range of wattages that offer the same utility and thus wattage is no longer an indicator of the product's core function, to produce light. CA IOUs noted that lamps that provide the same lumen output provide the same utility and therefore should have to meet the same performance standard. (CA IOUs, No. 18 at pp. 9-10; Public Meeting Transcript, No. 19 at p. 118)

ACEEE commented that manufacturers, the advocacy community, and others have spent a lot of time and effort recently in educating the consumer about the importance of shopping based on lumens. ACEEE noted that as more products enter the market with very different wattages for delivering the same lumen package, the market will move away from purchasing based on wattage. ACEEE further commented that while the step function may have served the purpose of minimizing confusion for consumers in the past, hopefully consumers will have shifted to lumen-based purchasing before the standard takes effect. (ACEEE, Public Meeting Transcript, No. 19 at pp. 119-120) NRDC, ASAP, *et al.* also commented that manufacturers, retailers, DOE, FTC, EPA, utilities, and others have been working to educate consumers to buy lamps based on light output rather than wattage, and DOE should avoid setting a standard that encourages consumer reliance on energy use rather than light output as a measure of performance. (NRDC, ASAP, *et al.*, No. 17 at p. 7)

DOE is considering a lumens-based approach in this preliminary analysis. Because the lamps covered by the scope of this rulemaking span different lighting technologies, GSLs designed to satisfy the same applications are available in a variety of wattages. DOE agrees that the primary utility provided by a lamp is lumen output, which can be achieved through a wide range of wattages depending on the lamp technology. For these reasons, DOE believes that lamps providing equivalent lumen output and therefore intended for the same applications should be subject to the same minimum efficacy requirements. Thus, DOE is considering an equation-based approach to establish CSLs for GSLs reflecting the relationship between efficacy and lumen output.

The following sections discuss the CSLs developed in the preliminary analysis for the integrated and non-integrated product classes in more detail.

2.7.5.1 Integrated Lamps

For this preliminary analysis, DOE analyzed CSLs for each of the integrated product classes. DOE used commercially available lamps and their associated efficacies to determine the design options required to meet each CSL. For the integrated product classes, DOE used the catalog initial lumen output and the catalog wattage of the lamp to calculate efficacy. To establish final minimum efficacy requirements for each CSL, DOE evaluated whether any adjustments were necessary to the initial CSLs to ensure lamps were available across the entire lumen range represented by the product class. DOE determined that adjustments to CSLs were necessary to ensure lamps were available across the entire lumen range. As discussed in section 2.7.1, DOE also evaluated publicly available compliance and testing verification databases to ensure the CSLs were achievable. DOE determined that no adjustments to CSLs were necessary based on additional compliance and testing data. See chapter 5 of this TSD for more detail. The CSLs and characteristics of the representative lamp units for the integrated product classes are summarized in the table below.

Table 2.7.4 Integrated Product Class' Representative Lamp Units

Product Class	CSL	Lamp Shape	Base Type	Lamp Type	Nominal Wattage	Initial Lumens	Rated Efficacy	Lifetime	CCT	CRI
					W	*lm*	*lm/W*	*hr*	*K*	
Integrated Low Lumen (310-1,999 lumens)	Baseline	A-Shape	E26	CFL	14	750	53.6	10,000	2,700	80
	CSL 1	Spiral	E26	CFL	13	800	61.5	12,000	2,700	82
	CSL 2	A-Shape	E26	LED	12	800	66.7	25,000	2,700	82
	CSL 3	A-Shape	E26	LED	11	800	72.7	25,000	2,700	81
	CSL 4	A-Shape	E26	LED	10	800	80.0	25,000	2,700	82
	CSL 5	A-Shape	E26	LED	9.5	800	84.2	25,000	2,700	80
Integrated High Lumen (2,000-2,600 lumens)	Baseline	Spiral	E26	CFL	32	2,000	62.5	10,000	2,700	80
	CSL 1	Spiral	E26	CFL	30	2,000	66.7	10,000	2,700	82
	CSL 2	Spiral	E26	CFL	29	2,200	75.9	12,000	2,700	82

For the integrated low lumen representative product class, five CSLs are being considered. The baseline represents a basic CFL with an efficacy near the existing MBCFL standard level. CSL 1 represents an improved CFL with more efficient phosphors and improved ballast components. CSL 2 represents a basic LED lamp with an efficacy near the lowest performing LED lamps currently available on the market. CSL 3 represents an improved LED lamp with improved package architecture, high efficiency driver, and improved optics. CSL 4 represents an advanced LED lamp with further improved package architecture, high efficiency driver, and improved optics. CSL 5 is the maximum technologically feasible level and represents an LED lamp with the most efficacious combination of package architecture, driver, and optics available on the market today.

For the integrated high lumen representative product class, two CSLs are being considered. The baseline represents a basic CFL with an efficacy near the existing MBCFL standard level. CSL 1 represents an improved CFL with more efficient phosphors and improved ballast components. CSL 2 is the maximum technologically feasible level and represents the most efficacious combination of phosphors and ballast components.

DOE utilized a database of commercially available lamps to evaluate efficacy trends of integrated GSLs across a range of lumen outputs[61] in order to fit the curve. DOE confirmed the curve fit matched product performance, particularly in the low and high ends of the GSL lumen range. As stated previously, DOE is considering establishing CSLs based on an equation for efficacy using lumens as the input. DOE requests comment on the methodology used to develop the CSLs equations. In particular, DOE requests comment on the use of a lumens-based equation and the equation form itself. DOE is considering the following equation form for integrated GSLs:

$$Efficacy = A - 29.42 * 0.9983^{Lumens}$$

Eq. 2.1

Where:

Efficacy = minimum efficacy requirement,
Lumens = measured lumen output, and
A = an adjustment variable.

Because the equations account for changes in efficacy due to lumen output, they can also account for market shifts to new lumen packages. For each representative lamp unit, DOE calculated the "A-value" of the equation. The A-value is an adjustment variable that shifts the equation in a vertical direction and is calculated to represent certain levels of efficacy. DOE evaluated the equation against lamps with the same design options as the representative lamp unit for each CSL and made slight adjustments to capture the efficacy of lamps with those design options across the entire lumen output range. This allowed for continuous CSLs across product classes. DOE also reviewed test data as discussed in section 2.7.1 and found that compliance and verification testing data supported the CSLs under consideration. DOE did not make any adjustments to CSLs based on this additional data. See chapter 5 of this TSD for further detail.

DOE received a comment pertaining to the CSLs of the integrated product classes. Earthjustice and NEEA commented that MBCFLs have existing standards ranging from 40 to 60 lm/W, and therefore DOE cannot set standards for GSLs that apply to MBCFLs lower than these existing standards because DOE is prohibited from backsliding under 42 U.S.C. 6295(o)(1). Earthjustice and NEEA also noted the provision in section 325(i)(7)(B) that creates a limited exception for certain lamps including MBCFLs from the anti-backsliding provision, but further noted that Congress did not intend to lower standards for MBCFLs and therefore MBCFLs remain subject to existing standards that exceed 45 lm/W. (Earthjustice, NEEA, No. 12 at pp. 6-7) DOE agrees that the anti-backsliding provision in 42 U.S.C. 6295(o)(1) applies and thus any standard prescribed for GSLs that is applicable to MBCFLs cannot be lower than the existing MBCFL standards. Therefore, DOE only considered CSLs for the integrated product classes that would not decrease the existing minimum efficacy requirements for MBCFLs in this preliminary analysis.

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[61] DOE included lamps that meet the definition of GSL but were outside the lumen range of 310 – 2,600 lumens because it believes this would result in a curve that better represents the relationship between efficacy and lumen output for the technologies analyzed.

Table 2.7.5 summarizes the efficacy requirements at each CSL for the integrated product classes. DOE requests comment on the CSLs under consideration for the integrated product classes, including the max-tech levels.

Table 2.7.5 Summary of CSLs for GSL Integrated Representative Product Classes

Representative Product Class	Candidate Standard Level	Efficacy
		lm/W
Integrated Low Lumen (310 – 1,999 lumens)	CSL 1	67.6-29.42*0.9983^Lumens
	CSL 2	74.2-29.42*0.9983^Lumens
	CSL 3	80.2-29.42*0.9983^Lumens
	CSL 4	87.5-29.42*0.9983^Lumens
	CSL 5	90.8-29.42*0.9983^Lumens
Integrated High Lumen (2,000 – 2,600 lumens)	CSL 1	67.6-29.42*0.9983^Lumens
	CSL 2	74.2-29.42*0.9983^Lumens

2.7.5.2 Non-Integrated Lamps

For this preliminary analysis, DOE analyzed CSLs for the non-integrated product class. DOE used commercially available lamps and their associated rated efficacies to determine the design options required to meet each CSL. For the non-integrated product class, DOE used the catalog initial lumen output and the ANSI rated wattage of the lamp, or nominal wattage if the ANSI rated wattage was not available, to calculate efficacy. The CSL and characteristics of the representative lamp units for the non-integrated product class are summarized in Table 2.7.6.

Table 2.7.6 Non-Integrated Product Class Design Representative Lamp Units

CSL	Lamp Shape	Base Type	Lamp Type	Nominal Wattage	Rated Wattage	Initial Lumens	Mean Lumens	Rated Efficacy	Lifetime	CCT	CRI
				W	*W*	*lm*	*lm*	*lm/W*	*hr*	K	
Baseline	Double Tube	G24q-3	CFL	26	26	1,710	1,450	65.8	10,000	4,100	82
CSL 1	Double Tube	G24q-3	CFL	26	26	1,800	1,530	69.2	17,000	4,100	82
CSL 1	Double Tube	G24q-3	CFL	21	21	1,525	1,310	72.6	20,000	4,100	82

For the non-integrated representative product class, one CSL is being considered. The baseline represents a basic CFL with an efficacy near the lowest performing non-integrated GSLs currently available on the market. DOE is considering two representative lamp units at CSL 1, consisting of a full wattage, improved CFL with more efficient phosphors and therefore more light output and a more efficient reduced wattage CFL that produces similar lumen output as the baseline unit. The full wattage representative lamp unit is used to set the minimum efficacy requirements of CSL 1 because it represents the maximum technologically feasible level that applies across all lumen packages within this product class. DOE added a second representative unit, the reduced wattage CFL, which gives consumers the option to replace their current full wattage lamp with one that saves energy.

For this preliminary analysis, DOE evaluated whether replacing the baseline lamp with more efficacious substitutes at the higher CSL would require a fixture change. However, based on an assessment of commonly available fixtures on the market, DOE found that the fixtures frequently used with the non-integrated GSLs analyzed were available in configurations for several different lamp types. Therefore, DOE assumed that fixture compatibility would not be an issue for the vast majority of consumers. Similarly, DOE evaluated the impacts of CSL 1 on the individual base types in the non-integrated product class. DOE confirmed that the vast majority of base types were still available at CSL 1, and therefore consumers will not be forced to switch between lamps with differing base types.[62] Further, because the different bases are maintained at CSL 1 and base type dictates the required ballast, consumers will not be required to change ballasts with CSL 1. DOE also ensured that the impacts of CSL 1 are consistent across the lumen output range of the entire product class. See chapter 5 of this TSD for more detail. DOE requests comment on its assumption that fixture compatibility would not be a common issue for non-integrated GSL replacements. DOE also requests comment on its assumption that consumer utility will not be lost with the base types that remain at CSL 1.

DOE utilized a similar methodology as the integrated product classes to develop the CSL equation. DOE again analyzed products outside of the GSL lumen range in order to create the best curve fit possible for the product class, and confirmed the curve fit matched product performance. DOE is considering the following equation form for non-integrated GSLs:

$$Efficacy = A - 25.00 * 0.9989^{Lumens}$$

Eq. 2.2

Where:

Efficacy = minimum efficacy requirement,
Lumens = measured lumen output, and
A = an adjustment variable.

DOE calculated the "A-value" for the representative lamp unit used to set the minimum efficacy requirements of CSL 1. DOE then evaluated the equation against lamps with the same design options as the representative lamp unit and made slight adjustments to capture the efficacy of lamps with those design options across the entire lumen output range. In particular, DOE ensured that lamps of different base types were represented at the CSL. See chapter 5 of this TSD for further detail. Table 2.7.7 summarizes the efficacy requirement of CSL 1 for the non-integrated GSLs. DOE requests comment on the CSL under consideration for the non-integrated product class.

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[62] DOE identified three base types that are potentially unable to meet CSL 1 out of an original 26 base types. Based on consultation with manufacturers and electrical distributors, DOE believes these base types are discontinued or are used in applications (*e.g.*, desk lamps) that have already transitioned to higher efficiency technologies.

Table 2.7.7 Summary of CSLs for GSL Non-Integrated Representative Product Class

Representative Product Class	Candidate Standard Level	Efficacy *lm/W*
Non-Integrated (310 – 2,600 lumens)	CSL 1	72.6-25.00*0.9989^Lumens

2.7.6 Scaling to Other Product Classes

DOE identifies and selects certain product classes as representative and analyzes these product classes directly. DOE determines certain product classes to be representative due to high market volumes and/or distinct characteristics. CSLs for product classes that are not directly analyzed ("non-representative product classes") are then determined by scaling from the CSLs of the representative product classes. However, DOE chose to directly analyze all product classes as representative in this preliminary analysis. Thus, no scaling was required.

2.8 PRODUCT PRICE DETERMINATION

Typically, DOE develops manufacturing selling prices (MSPs) for covered products and applies markups to create end-user prices to use as inputs to the LCC analysis and NIA. Because GSLs are difficult to reverse-engineer (*i.e.*, not easily disassembled), DOE directly derives end-user prices for the lamps covered in this rulemaking. In the framework document, DOE proposed estimating end-user prices for lamps by establishing discounts from manufacturer suggested price lists (hereafter "blue-book prices"). DOE received several comments on pricing methodology presented in the framework document.

CA IOUs and ASAP questioned DOE's approach specifically asking how DOE would estimate prices of any new products or technologies that are not commercially available without a developing a cost efficiency curve. (CA IOUs, Public Meeting Transcript, No. 19 at pp. 139-140; ASAP, Public Meeting Transcript, No. 19 at p. 23) NRDC, ASAP, *et al.* suggested that to develop prices for products that are not commercially available or sold in low quantities, DOE should supplement its retail price data with the engineering analysis. (NRDC, ASAP, *et al.*, No. 17 at p. 11)

If DOE analyzes prototype lamps or model lamps, DOE will determine pricing for these lamps based on information available at the time of the analysis – such as the cost-efficiency relationship of other analyzed lamps, the cost of commercially available lamps that utilize similar technology or components, manufacturer-provided data, and any other relevant sources. However, in this preliminary analysis DOE is not considering any lamps that are not commercially available.

CEC pointed out lamp prices are impacted by non-efficiency factors including lamp characteristics such as CRI and lifetime, as well as warrantees, brand value, packaging quality, inventory cost, and profit margin. CEC noted that DOE's analysis would include both high-end products marketed to consumers not sensitive to prices as well as products that are marketed to consumers sensitive to price, rendering the comparison invalid. CEC suggested that DOE should disaggregate the cost of non-efficiency features and normalize to profit margins. CEC also suggested that to account for the wide variation in product lifetimes DOE should normalize prices based on dollars per lumen-year. (CEC, No. 11 at p. 19; CEC, Public Meeting Transcript, No. 19 at pp 144-145)

In the product price determination, DOE develops end-user prices for each representative lamp. These representative lamps reflect the common characteristics (*e.g.,* CCT, CRI, lifetime) of lamps being purchased by consumers within a product class. With regards to these non-efficiency factors and factors related to how the lamp is being sold (*e.g.,* warranties, packaging, profit margins), DOE notes that the end-user price is inclusive of these costs – such as the manufacturer's cost to offer a specific warranty, use certain packaging, and earn a desired profit. The final product available on shelves reflects a combination of features as determined by the manufacturer - consumers cannot pick and choose among them. Therefore, DOE has not disaggregated the cost of these features and instead presents only the end-user price. Further, product lifetimes are considered in the life-cycle cost analysis of the lamp. See section 2.10.

NRDC, ASAP, *et al.* noted actual retail prices can vary greatly and are frequently well below blue book prices and encouraged DOE to supplement its analysis with a range of retail outlet data that accounts for different types of retailers (*e.g.,* high volume versus low volume) and package sizes in which bulbs are sold. They further suggested DOE weight its pricing data according to the percentage of sales associated with each type of retailer. (NRDC, ASAP, *et al.,* No. 17 at p. 7; NRDC, Public Meeting Transcript, No. 19 at pp. 129-134) NRDC also urged DOE not to make the assumption that a less efficient lamp, costs less as future LED lamps might not only be more efficient, but also cost less. (NRDC, Public Meeting Transcript, No. 19 at pp. 129-130)

Because blue book price data was not available for all GSLs, DOE was unable to utilize blue book prices to develop end-user prices in the preliminary analysis. Therefore, DOE reviewed and used publicly available retail prices for GSLs to develop end-user prices for each CSL. In its review of price data, DOE observed a range of end-user prices paid for a lamp, depending on the distribution channel through which the lamp is purchased. DOE identified four main distribution channels (large consumer-based distributors [*e.g.,* home centers], small consumer-based distributors [*e.g.,* drug stores], electrical distributors, and state procurement). DOE then developed an average weighted end-user price using the estimated percentage of shipments that go through each distribution channel based on feedback from interviews with manufacturers. Additionally, DOE assessed and accounted for the general price trends in relation to efficacy for all GSLs. For example, DOE noted that available data indicated that LED lamp prices decreased with increased lamp efficacy and confirmed that calculated end-user prices reflected this trend. Once DOE calculated end-user prices, DOE added sales tax and, if appropriate, installation costs to derive the total, installed end-user cost. See chapter 6 of this TSD for further details. DOE invites comment on the methodology and results for estimating end-user prices for GSLs in this preliminary analysis.

GE noted that the distribution of GSLs is broader than for commercial products, and suggested DOE expand its list of distribution channels presented in framework document to consumer channels such as mass merchants, drug stores, and grocery stores. (GE, Public Meeting Transcript, No. 19 at pp. 132-133) ALA noted that new retailers such as battery stores and consumer-oriented lighting showrooms are beginning to enter the CFL and LED lamp market. (ALA, Public Meeting Transcript, No. 19 at pp. 133-134) NEMA asserted that because screw-based products target the same end-user/socket distribution channels for these products do not vary by technology. NEMA noted, however, that smaller distribution channels may tend to feature less expensive technologies, and therefore, may not carry LED lamps. NEMA also stated that remotely ballasted pin base CFLs tend to be distributed through commercial channels. (NEMA, No. 15 at p. 18)

In the framework document, DOE had noted the following potential distribution channels for the pricing analysis: State procurement contracts, large electrical supply distributors, home improvement/hardware stores, and other sources of publicly available end-user prices, such as Internet retailers. Based on further research and feedback from manufacturers, DOE identified other channels from which consumers commonly purchase GSLs. Therefore, in this preliminary analysis, in addition to the channels mentioned in the framework document, DOE also gathered prices from mass merchants (*e.g.*, Walmart), grocery stores (*e.g.*, Safeway), and drug stores (*e.g.*, CVS). DOE did not include battery stores and lighting showrooms in its analysis as DOE research and feedback from manufacturers indicate they are not considered common channels through which consumers purchase GSLs.

Further, based on feedback from manufacturer interviews and an assessment of lamp price data and trends, DOE determined that certain GSL distribution channels should be grouped together. DOE determined that home centers, hardware stores, and mass merchants could be appropriately grouped into one distribution channel based on their similarity in price and target market. DOE also determined that Internet retailers, grocery stores, and drug stores could be grouped into one distribution channel because they all offer consumers a more convenient purchasing option at a typically increased cost. In summary, DOE identified the following four main distribution channels for GSLs in this preliminary analysis:

- Large consumer-based distributors: Home Centers, Hardware Stores, and Mass Merchants
- Small consumer-based distributors: Internet Retailers, Grocery Stores, and Drug Stores
- Electrical Distributors
- State Procurement

Further, as NEMA noted and as is reflected by DOE research and feedback in manufacturer interviews, distribution channels do not generally vary by technology type. Therefore, DOE considers the four main distribution channels identified above for all GSLs. However, based on stakeholder comments and feedback from manufacturer interviews, DOE acknowledges that a larger volume of non-integrated GSLs go through commercial distribution channels than integrated GSLs. Therefore, DOE applied different percentage weightings to each distribution channel for integrated versus non-integrated GSLs. For the integrated GSLs, large consumer-based distributors were estimated at 75 percent, small-consumer-based distributors at 10 percent, electrical distributors at 10 percent, and State procurement at 5 percent. For non-integrated GSLs, large consumer-based distributors were estimated at 10 percent, small-consumer-based distributors at 5 percent, electrical distributors at 75 percent, and State procurement at 10 percent. See chapter 6 of this TSD for further details. DOE requests comment on the appropriateness of the distribution channels and estimated percentage shipments through each channel used in this preliminary analysis.

2.9 ENERGY-USE CHARACTERIZATION

The purpose of the energy use analysis is to identify how products are used by consumers, and thereby determine the energy savings potential of energy efficiency improvements. DOE determines the energy consumption of lamps using estimates of a lamp's power consumption (*i.e.*, the rate of energy consumed, in watts) and estimates of the way consumers use the lamp (*i.e.*, operating hours per year and the impact of controls such as dimmers). This analysis, which is meant to represent typical energy consumption in the field, is an input to both the LCC and PBP analyses and the NIA.

In the framework document, DOE indicated that it would derive annual energy consumption of lamps by multiplying the power rating by the number of hours of operation per year. DOE further stated that it would use the LMC and recent versions of EIA's CBECS, RECS, and the Manufacturing Energy Consumption Survey (MECS)[63] to determine operating hours by building type and Census Division. DOE received several comments on the methodology presented in the framework document.

NEMA agreed with the proposed methodology, but suggested that DOE consider establishing separate operating hours by technology. (NEMA, No. 15 at p. 17) For the preliminary analysis, DOE did not use separate operating hours by technology, but instead assumed that the operating hours for lamps considered by this rulemaking are the same as the current operating hours for all GSLs.

Because GSILs are not included in the scope of this rulemaking, DOE assumed that any GSL final rule would not yield sufficient energy savings to avoid triggering the EISA 2007 45 lm/W backstop. Therefore, DOE assumed that the backstop will go into effect on January 1, 2020, per statutory requirement. Given the statutory requirement to publish a GSL final rule by January 1, 2017, and the requirement for the compliance date to be at least three years after the publication of a GSL final rule, DOE assumed that the compliance date for any final GSL rule would be concurrent with the compliance date for the EISA 2007 backstop. (*See* 42 U.S.C. 6295(i)(6)(A)(ii), (i)(6)(A)(iii) and (i)(6)(A)(v)) Thus, during the analysis period, DOE assumes that CFL and LED GSLs will be filling all sockets currently filled by GSLs. Although some metering studies have observed higher hours of operation for CFL GSLs compared to incandescent/halogen GSLs—such as NMR Group, Inc.'s Northeast Residential Lighting Hours-

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[63] Administration., U.S. Department of Energy–Energy Information Manufacturing Energy Consumption Survey. 2010 MECS Survey Data. 2013. Washington, D.C. (Last Accessed September 15, 2014.) http://www.eia.gov/consumption/manufacturing/data/2010/.

of-Use Study[64] —DOE assumed that the higher hours of use found for CFL GSLs is based on those lamps currently disproportionately filling sockets with higher hours of use. This would not be the case during the analysis period, when CFL and LED GSLs are expected to fill all GSL sockets. This assumption is equivalent to assuming no rebound in operating hours as a result of more efficacious technologies filling sockets currently filled by less efficacious technologies prior to, or as a result of, the EISA 2007 backstop. Additionally, operating hours were assumed to be equivalent for CFL and LED GSLs in the reference scenario. In other words, the reference scenario assumed no rebound as a result of a potential GSL energy conservation standard. Additional rebound scenarios are discussed in section 2.12 and in chapter 10.

NRDC, ASAP, *et al.* encouraged DOE to collect hours of use data from a variety of sources and suggested that the daily hours of use results from the Residential Lighting End-Use Consumption Study: Estimation Framework and Initial Estimates (RLEUCS)[65] are potentially too low. (NRDC, ASAP, *et al.*, No. 17 at p. 12) NEEA pointed out that an online database would be made available containing GSL socket metering data by fixture, room, and lamp type. (NEEA, Public Meeting Transcript, No. 19 at pp. 91-92)

In addition to drawing information from LMC, CBECS, and RECS, DOE collected data from a number of sources in order to characterize GSL energy use. For the residential sector, DOE used hours of use data from metering studies in California,[66] Georgia,[67] North Carolina,[68]

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[64] NMR Group, DNV GL. Northeast Residential Lighting Hours-of-Use Study. May 5, 2014. Prepared for Connecticut Energy Efficiency Board, Cape Light Compact, Massachusetts Energy Efficiency Advisory Council, National Grid Massachusetts, National Grid Rhode Island, New York State Energy Research and Development Authority. (Last Accessed August 22, 2014.)

[65] DNV KEMA Energy and Sustainability, Pacific Northwest Laboratory. Residential Lighting End-Use Consumption Study: Estimation Framework and Baseline Estimates. December 2012. (Last Accessed September 15, 2014) http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2012_residential-lighting-study.pdf.

[66] DNV KEMA Energy and Sustainability, Pacific Northwest Laboratory. *Residential Lighting End-Use Consumption Study: Estimation Framework and Baseline Estimates*. December 2012. (Last Accessed September 15, 2014) http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2012_residential-lighting-study.pdf.

[67] Nexant, Inc., and Apex Analytics, LLC. *Georgia Power Company Residential Lighting Saturation and Metering Study*. October 4, 2013. Prepared for Georgia Power Company. (Last Accessed August 22, 2014.)

[68] Navigant Consulting, Cadmus Group, Inc, and Apex Analytics LLC. *EM&V Report for the 2010-2011 Residential Energy Star Lighting Program*. June 27, 2012. Prepared for Duke / Progress Energy Carolinas (Last Accessed August 22, 2014.)

South Carolina,[69] Maryland,[70] Ohio,[71] Illinois,[72] the Northwest,[73] and the Northeast.[74] Some of the metering studies separately reported daily hours of use for all GSLs and for the subset of CFL GSLs. Others studies only reported operating hours for CFL GSLs. If daily operating hours for all GSLs were not reported in a particular metering study, a correction factor (based on the average fractional difference in operating hours between all GSLs and CFL GSLs from recent metering studies that reported both) was used to estimate daily operating hours for all GSLs.

NEMA stated that DOE should pay attention to specific location and time of use and whether an application is residential or commercial/industrial. (NEMA, No. 15 at p. 17) DOE characterized GSL energy use separately for the residential and commercial sectors. In determining energy use in the residential sector, DOE used daily hours of use metered data for regions where the data were available; for all other regions, DOE used daily hours of use values based on the metered data from adjacent regions (see chapter 7 of this TSD for more detail). For the commercial sector, DOE used average daily hours of use data by building type from LMC. DOE notes that the installed stock of GSLs in the industrial sector is less than 1 percent of the installed stock in the commercial sector according to LMC; furthermore, DOE assumes that the hours of operation for GSLs in the industrial sector (*e.g.*, in offices) are approximately equal to the hours of operation for GSLs in the commercial sector. Therefore, DOE analyzed these two sectors together (using data specific to the commercial sector), and refers to the combined sector as the commercial sector.

During the framework public meeting, stakeholders commented on DOE's analysis of dimmable GSLs. Philips inquired as to how DOE will account for the amount of time dimmable GSLs are dimmed and also noted that DOE cannot use a uniform dimming factor across technology types, because some technologies cannot be dimmed. (Philips, Public Meeting Transcript, No. 19 at pp. 148-149) NRDC suggested DOE collect data on the percentage of dimmable GSLs in the market, noting that dimmable GSLs likely represent a small part of the market and therefore should be treated separately from the non-dimmable lamps in terms of

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[69] TecMarket Works and Building Metrics. *Duke Energy Residential Smart $aver CFL Program in North Carolina and South Carolina: Results of a Process and Impact Evaluation.* February 15, 2011. (Last Accessed August 22, 2014.)

[70] Navigant Consulting, and Cadmus Group, Inc. *EmPOWER Maryland 2010 Interim Evaluation Report*. January 15, 2011. Prepared for Baltimore Gas and Electric, Potomac Electric Power Company, Delmarva Power and Light (DPL), Southern Maryland Electric Cooperative (SMECO), and Allegheny Power (AP). (Last Accessed August 22, 2014.)

[71] Vermont Energy Investment Corporation. *State of Ohio Energy Efficiency Technical Reference Manual*. August 6, 2010. Prepared for the Public Utilities Commission of Ohio.

[72] Cadmus Group, Inc. *Lighting and Appliance Evaluation—PY 2*. December 2010. Prepared for Ameren Illinois. (Last Accessed August 22, 2014.)

[73] Northwest Energy Efficiency Alliance. *Residential Building Stock Assessment Metering Study*. April 28, 2014. Seattle, WA. Report #E14-283. (Last Accessed June 20, 2014)

[74] NMR Group, DNV GL. *Northeast Residential Lighting Hours-of-Use Study*. May 5, 2014. Prepared for Connecticut Energy Efficiency Board, Cape Light Compact, Massachusetts Energy Efficiency Advisory Council, National Grid Massachusetts, National Grid Rhode Island, New York State Energy Research and Development Authority. (Last Accessed August 22, 2014.)

energy use. (NRDC, Public Meeting Transcript, No. 19 at p. 150) An independent stakeholder also noted the importance of considering lighting controls—specifically dimming and sensors—stating that controls are an easy way to limit wattage use and prolong lamp life. (Madden, No. 4 at p. 1)

DOE acknowledges that dimmability and lighting controls are important factors in estimating energy consumption of GSLs. Rather than estimating the amount of time dimmable GSLs are dimmed, DOE estimated a 30 percent decrease in energy use for all installation locations with controls (whether dimming or other types of controls) in both the residential and commercial sectors, based on a meta-analysis of field measurements of energy savings from commercial lighting controls by Williams *et al.*[75] DOE estimated that five percent of CFL GSLs can be dimmed, whereas no such limit was placed on LED GSLs (though they may not be installed in fixtures which are dimmable).

In analyzing the commercial sector, DOE used LMC data to determine that, in 2010, 30 percent of commercial buildings employ some means of lighting control (3 percent dimming, 27 percent switching-based controls or a combination of switching and dimming). DOE then used a model to estimate the commercial floor area incorporating controls, accounting for the current variation in standards adopted by the States, the relevant floor area in each State, the breakdown of floor area by application, and the code requirements for each floor area application. By the end of the analysis period (2049), DOE estimates that approximately 80 percent of commercial buildings employ some means of lighting control.

In analyzing the residential sector, DOE assumed the same energy use reductions from employing dimmers or other controls as in the commercial sector. DOE used LMC data to determine that 14 percent of residential fixtures employed some form of lighting control (12 percent dimming, 2 percent switching-based controls) in 2010, and DOE assumed that the fraction of residential fixtures employing controls remained constant over the analysis period. The limit of five percent of CFL GSLs being dimmable resulted in the estimation of more than 14 percent of LED GSLs being installed in fixtures with controls in the LCC savings, shipments and national impact analyses.

DOE also estimated that the market share of "smart" LED GSLs, with controls integrated into the lamp, would grow according to a Bass diffusion curve over the course of the analysis period. DOE assumed that the energy saving associated with these integrated controls would be the same as the energy savings for GSLs used with fixtures employing controls. See chapter 10 of this TSD for more discussion of the modeling of the market share of smart LED GSLs and the national impact of such lamps.

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[75] Williams, A., B. Atkinson, K. Garbesi, E. Page, and F. Rubinstein. *Lighting controls in commercial buildings*. 2012. Leukos 8(3) pp. 161-180. (Last Accessed August 8, 2014.) http://ies.tandfonline.com/doi/pdf/10.1582/LEUKOS.2012.08.03.001#.VH9IAzHF-UY.

2.10 LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

The impacts of amended energy conservation standards on consumers often include a change in operating expense (usually decreased energy costs) and a change in purchase price (usually increased). The life-cycle cost (LCC) of a product is the cost it incurs over its lifetime, taking into account both purchase price and operating expenses. The payback period (PBP) represents the time it takes to recover the additional installed cost of the more efficient products through annual operating-cost savings. DOE analyzes the net effect on consumers by calculating the LCC and PBP using the engineering performance data, the product price determined in chapter 6, the product price learning rate developed in the shipments analysis, and the energy use results. Inputs to the LCC calculation include the installed cost to the consumer (purchase price plus installation cost), operating expenses, the lifetime of the product or another defined period of analysis, and a discount rate. Inputs to the PBP calculation include the installed cost to the consumer and first-year operating costs.

The engineering analysis presents representative lamp data for lamps at a specific lumen level. Because of the high variability in LED lamp prices across lumen ranges, DOE analyzed the LCC and PBP across four lumen bins (310-749 lm, 750-1,049 lm, 1,050-1,489 lm, and 1,490-1,999 lm) for the integrated low-lumen product class, which is the only product class that includes LED lamps. DOE used online retailer data, market share data of each lumen bin, and the efficacy-to-lumen relationship developed in the engineering analysis to generate representative lamp data for all lumen bins, across all CSLs for the integrated low-lumen product class.

Recognizing that several inputs to the determination of consumer LCC and PBP are either variable or uncertain, DOE conducted the LCC and PBP analyses by modeling the variability in the inputs using Monte Carlo simulation and probability distributions. Each Monte Carlo simulation consists of 10,000 LCC and PBP calculations. The model performs each calculation using input values that are either sampled from probability distributions and building or household samples or characterized with single point values. For example, DOE accounted for variation in residential and commercial daily hours of use by generating distributions. For the residential sector, DOE derived hours of use distributions by room type from the database associated with the NEEA Residential Building Stock Assessment Metering (RBSAM) Study.[76] For the commercial sector, DOE mapped the daily hours of use values for each LMC building type to the CBECS building types. DOE then developed triangular daily hours of use distributions for each CBECS building type, with the mean of each distribution corresponding to the respective building type's average daily hours of use.

DOE used a "simple" PBP for this rulemaking, which is the ratio of the increase in purchase cost (*i.e.*, from a less efficient design to a more efficient design) to the decrease in annual operating expenditures. The "simple" PBP does not take into account other changes in operating expenses over time or the time value of money.

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[76] Northwest Energy Efficiency Alliance Residential Building Stock Assessment Metering Study. April 28, 2014. Seattle, WA. Report #E14-283. (Last Accessed June 20, 2014)

In regard to the PBP, NEMA stated that consumers demand a short payback period, and recommended DOE use a maximum of three years. (NEMA, No. 15 at p. 18) DOE acknowledges consumer sensitivity to PBP. DOE conducts a PBP analysis on each of the selected CSLs, and those PBP results help inform the selection of a potential energy conservation standard.

DOE received a number of written comments as well as statements from stakeholders at the public meeting relating to the LCC analysis. CEC suggested DOE use the average number of operating hours of all GSLs today for its LCC analysis, treating every lamp as an equal competitor for any given GSL socket in the market. (CEC, No. 11 at p. 20) DOE agrees with CEC and has used the average operating hours of all GSLs in the analyses.

DOE received a number of comments of the lifetimes of GSLs. NRDC, ASAP, *et al.*, GE, and ASAP recommended DOE account for different product lifetimes in its analysis, with GE specifically indicating that different lamp technologies offer different levels of convenience to the consumer by way of frequency of replacement. (NRDC, ASAP, *et al.*, No. 17 at p. 12; GE, Public Meeting Transcript, No. 19 at pp. 148-149; ASAP, Public Meeting Transcript, No. 19 at pp. 158-159) NRDC also recommended DOE use residual value calculations to account for the different GSL lifetimes. (NRDC, No. 17 at pp. 12-13)

To account for differences in the lifetime of lamps at different levels of efficacy, DOE incorporated a residual value in the LCC calculation. The residual value is an estimate of the product's value to the consumer at the end of the LCC analysis period. For this rulemaking, the LCC analysis period is the lifetime of the product within a product class with the shortest lifetime. The residual value recognizes that some lamps have a longer lifetime and may continue to function beyond the end of the LCC analysis period. Thus, consumers of longer-lived lamps do not have to incur the purchase of another lamp at the end of the LCC analysis period. The residual value calculation conducted for this preliminary analysis took into account the time-value of money and the decline in lamp prices over time. Details of the LCC calculation can be found in chapter 8 of this TSD.

NEEA commented that the energy savings depend on the lifetime of the product, hours of use and, in some cases, how many times it is switched on and off. (NEEA, Public Meeting Transcript, No. 19 at pp. 107-108) DOE used data from a CFL Laboratory Testing Report submitted to the California Public Utilities Commission[77] for information regarding the effect of on-cycle switching time on CFL life. DOE assumed that the lifetime of LED GSLs was not affected by on/off switching.

For the LCC, PBP, and subsequent analyses, the relevant GSL lifetime is the service lifetime of the GSL (*i.e.*, the age at which the GSL is retired from service), and not the technical lifetime of the GSL. To characterize the uncertainty in GSL lifetime, DOE conducted three separate GSL survival probability (lifetime) scenarios:

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[77] James J. Hirsch and Associates, Erik Page & Associates, Inc. *CFL Laboratory Testing Report: Preliminary Results from a CFL Switching Cycle and Photometric Laboratory Study*. Submitted to the California Public Utilities Commission Energy Division on May 21, 2012.

Scenario 1: The probability of survival as a function of the analysis year is a distribution of lamp lifetimes considering the lamp's rated lifetime (in hours), sector-specific hours-of-use distributions, and effects of on-cycle length on CFL lifetimes;

Scenario 2: This scenario (the reference scenario) uses the probability of survival used in Scenario 1, truncated by a Weibull distribution with a median of 20 years to account for lamp turnover when a renovation or retrofit occurs; and

Scenario 3: For LED GSLs, this scenario uses the probability of survival in Scenario 1, truncated by a Weibull distribution with a median of 5 years, to account for the possibility of the service lifetime of LED GSLs being similar to those of consumer electronic devices. The probability of survival for CFL GSLs is identical to Scenario 2.

DOE also received comments regarding its intention to assume the residential GSL installation cost is zero. Philips, Westinghouse, and ASAP all recommended that DOE consider residential installation costs in the LCC and PBP calculations. (Philips, Public Meeting Transcript, No. 19 at p. 155; Westinghouse, Public Meeting Transcript, No. 19 at pp. 155-156; ASAP, Public Meeting Transcript, No. 19 at pp. 158-159) In particular, ASAP requested DOE account for the benefit to a consumer in a long-lived lamp from avoided installation time and effort, both in the residential and commercial sectors. (ASAP, Public Meeting Transcript, No. 19 at pp. 158-159) NEMA suggested that installation costs need to be included in the analyses in cases where an externally ballasted GSL is replacing an integrally ballasted GSL and requires a new fixture. (NEMA, Public Meeting Transcript, No. 19 at pp. 82-83)

DOE acknowledges the convenience provided to consumers of not having to replace longer-life GSLs as often as comparatively short-lived GSLs, but DOE has assumed no product class switching for this preliminary analysis and notes that installation time is negligible under this assumption. Additionally, installation costs will be equivalent across the various levels of efficacy under consideration for a given product class and building sector, and lifetime is taken into account in the LCC calculation. Therefore, DOE did not include installation costs.

NRDC suggested DOE consider new, longer-lifetime incandescent lamps in its LCC and PBP analyses. (NRDC, Public Meeting Transcript, No. 19 at p. 157) DOE assumes that the EISA 2007 backstop will go into effect concurrently with the compliance date of this rulemaking. Therefore, DOE assumed that there will be no shipments of incandescent lamps (for the general service applications covered by this rulemaking) during the analysis period.

2.11 SHIPMENTS ANALYSIS

DOE uses projections of product shipments to calculate the national impacts of standards on energy use, NPV, and future manufacturer cash flows. Details of the shipments analysis are provided in chapter 9 of this TSD. This section highlights key changes in the shipments modeling approach from the approach presented in the framework document, and responds to comments by stakeholders regarding how DOE projects shipments.

DOE adopted a consumer-choice-based shipments model to estimate lamp shipments for this rulemaking. The shipments model has three main interacting elements: (1) a demand module, which estimates the demand for new GSL shipments in each lamp category for each year of the shipments projection period; (2) a price projection module, which projects future lamp prices based on historic price trends and projected future shipments; and (3) a consumer choice module, which assigns shipments to lamps at different efficiencies based on consumer sensitivities to lamp price, energy consumption, lifetime, and mercury content. Because the product classes considered here are typically used in dissimilar applications, the model did not consider the possibility that standards could drive consumers to switch between product classes.

The lamp demand module estimates the demand for GSLs, both as replacements for failed lamps and for new luminaire installations. The demand calculation assumes that the sector-specific density and lumen distribution of installed GSLs remains fixed per square foot of floor space, and that floor space changes over the analysis period according to the EIA's sector-specific *Annual Energy Outlook (AEO)* 2014[78] projections. While lamp demand per square foot remains fixed, annual lighting energy consumption per square foot is allowed to vary according to the fraction of the floor space implementing lighting system controls. A lamp turnover calculation estimates demand for lamps in each year given the initial stock, the expected lifetimes of the lamps, and sector-specific assumptions about operating hours.

The price learning module estimates lamp prices in each year of the analysis period. Separate experience curves were utilized for CFLs and LED GSLs, based on fits to historic price and sales data for GSLs utilizing each technology. For LED lamps, DOE also assumed that the incremental price of increased lumens will decline exponentially with time, based on fits to historical price data, so that the current large price premium for 1,600 lm lamps, relative to 500 lm lamps, will decrease over time and eventually become negligible. For CFLs, DOE assumed that experience-curve price declines do not apply to the portion of the price that is attributable to the cost of rare-earth oxides for use in the lamp phosphors. Finally, DOE assumed that the prices of integrated, low-lumen GSLs at CSLs 0, 2, and 3 will not experience price declines due to experience curves. DOE assumes that these technologies are becoming obsolete as the market has shifted to more efficacious CFLs and LED lamps.

The consumer-choice module assigns shipments to the available lamp options, determined in the engineering analysis and the LCC analysis, based on sector-specific consumer sensitivities to lamp price, energy consumption, lifetime, and mercury content. In the base case, all lamp options are available. In each possible standards case only those lamp options at or above the CSL are considered to be available. Where appropriate, the consumer choice module also accounts for observed deviations from the explicitly modeled consumer sensitivities mentioned previously using an acceptance factor that limits the maximum market share of certain product options.

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[78] Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040*. Report No. DOE/EIA-03832014. Washington, D.C. http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

Numerous stakeholders provided comments regarding DOE's forecasting of GSL shipments. NEMA and NRDC pointed out that regulations are still taking effect that make it difficult to estimate future GSL shipments. (NEMA, No. 15 at p. 18; NRDC, Public Meeting Transcript, No. 19, pp. 24-25) NEMA also noted that there are programs in place encouraging the use of more efficient lighting technologies. (NEMA, No. 15 at p. 18) GE agreed with NEMA, indicating that it is difficult to start a rulemaking soon after another rulemaking has gone into effect due to the lack of available data on the effect of the past rulemaking. (GE, Public Meeting Transcript, No. 19 at p. 164). NRDC also pointed out that DOE needs to be careful not to assume that niche bulbs that currently have low sales will automatically continue to have low sales (NRDC, Public Meeting Transcript, No. 19 at pp. 25-26) Philips, NRDC, ASAP, *et al.*, and NEEA all recommended DOE analyze multiple forecast scenarios due to the inherent uncertainty in forecasting and the rapid market adoption of LED lamps. (Philips, Public Meeting Transcript, No. 19 at p. 166; NRDC, ASAP, *et al.*, No. 17 at p. 12; NEEA, Public Meeting Transcript, No. 19 at pp. 166-167)

DOE recognizes the inherent uncertainty in projecting GSL shipments in the face of proposed energy conservation standards as well as in the base case scenario. Furthermore, DOE acknowledges that there are a number of programs and statutes currently in place that affect the GSL market, not least of which is the January 1, 2014 compliance date for the latest phase of EISA standards for GSILs.[79] DOE requests any representative data on GSL shipments as they become available in order to improve the accuracy of the shipments analysis. DOE will also continue to monitor sales of certain lamps exempted from GSIL standards to assess if they are no longer niche products.

In light of the uncertainty in the future GSL market, DOE conducted shipments projections for a number of scenarios, with alternative assumptions (described in chapter 8B) for each of the following: (1) Incursion of integral LED luminaires into the market for traditional GSL luminaires at the end of the analysis period; (2) Lamp service lifetime; (3) LED price learning rate; and (4) Rare earth material prices. Uncertainty was also addressed via additional scenarios considered in the national impact analysis, with alternative assumptions for each of the following: (1) Fraction of LED shipments that have standby functionality at the end of the analysis period (residential sector only); (2) Standby power consumption; (3) Rebound; (4) Fraction of GSL shipments with controls (for commercial sector); and (5) Electricity price projection (also described in appendix 8B).

Regarding the fraction of LED shipments that have standby functionality, as stated in section 2.3.5.4, DOE believes that while “smart” LED GSLs, which have standby functionality, currently represent a very small fraction of the GSL market, the market share for such GSLs will increase over the course of the analysis period. Therefore, DOE included GSLs with standby functionality in its analyses. In the reference scenario, DOE assumed that the proportion of GSLs shipped with standby functionality would increase over time according to a Bass diffusion curve, with 50 percent of GSLs shipped including standby functionality by the end of the analysis period. DOE also considered low- and high-standby scenarios, where 0 percent and 100 percent of GSLs shipped, respectively, include standby functionality by the end of the analysis period.

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[79] *See* 10 CFR 430.32(x).

As stated in section 2.9, DOE has assumed that the integrated controls associated with these smart LEDs result in a similar reduction in energy consumption compared to lamps used with fixtures employing controls.

A number of stakeholders commented on the uncertainty in future LED lamp prices. NRDC, ASAP, *et al.* expect LED GSL prices to continue dropping, but they do not anticipate significant price changes for CFL GSLs. (NRDC, ASAP, *et al.*, No. 17 at p. 11) Lutron inquired into how DOE intends to project the prices of LEDs (Lutron, Public Meeting Transcript, No. 19 at pp. 128-129) In response to DOE's planned consideration of experience curves, CA IOUs recommend that DOE consider experience curves separately for each GSL technology type. (CA IOUs, Public Meeting Transcript, No. 19 at pp. 135-136)

To account for expected changes in the price of GSLs over the analysis period, DOE used a learning curve (also referred to as experience curve) approach. Learning curves relate a product's cumulative production (production since the product's introduction to the market) to the product's price. Product price generally decreases as a function of increasing cumulative production, with a learning rate equal to the percentage drop in price for each doubling in cumulative production. LED GSLs are currently in a very early phase of their market adoption, and their learning rate currently appears to be higher than the historic learning rate for the more mature CFL technology (see chapter 9 of this TSD). Given the very early-market nature of LED GSLs and associated uncertainty in the LED-GSL learning rate, DOE analyzed three scenarios for LED-GSL learning rates: (1) a scenario where LED GSLs experience price learning at the historic LED-GSL learning rate; (2) a scenario where LED GSLs experience price learning at the historic CFL-GSL learning rate; and (3) for reference to gauge the impact of price learning, a scenario where LED and CFL GSLs experience no price learning (*i.e.*, prices stay at constant real prices throughout the analysis period). As discussed in chapter 9 of this TSD, DOE is using the historic CFL-GSL learning rate as the reference price learning scenario. In this scenario, the prices of LED GSLs will still decrease faster than the prices of CFL GSLs on an annual basis, because LED GSLs are still in a relatively early phase of their market adoption and cumulative production will double more rapidly than for CFL GSLs. Details of the experience curve methodology and calculations are discussed in chapter 9 of this TSD.

Lutron Electronics indicated that it may be useful for DOE to determine the relative weight of the purchase price compared to the remainder of the life-cycle cost when characterizing the behavior of GSL consumers. (Lutron Electronics, Public Meeting Transcript, No. 19 at p. 156) DOE agrees with Lutron Electronics' suggestion and accounted for consumer sensitivity to lamp price, energy consumption, lifetime, and mercury content in the consumer choice model.

NEMA suggested that a GSL socket that contains an incandescent GSL will not necessarily always contain an incandescent GSL, and that eventually a longer-life, higher-efficacy GSL will replace it. (NEMA, Public Meeting Transcript, No. 19 at p. 85) GE added that, over time, CFL and LED GSLs will reduce the market for incandescent GSLs. (GE, Public Meeting Transcript, No. 19 at pp. 85-86) DOE agrees that there may be voluntary conversions to more efficient light technologies over time, and is using a consumer-choice approach to modeling shipments to capture this effect. DOE also notes that the EISA 2007 backstop is assumed to go into effect concurrently with the compliance date of this rulemaking. Therefore, DOE assumed that there will be no shipments of incandescent lamps (for the general service applications covered by this rulemaking) during the analysis period.

2.12 NATIONAL IMPACT ANALYSIS

The NIA provides DOE's assessment of the aggregate impacts of potential efficacy standards at the national level. Measures of impact that DOE will report include future NES from a standard set at each CSL (*i.e.*, the cumulative energy savings from a potential energy conservation standard relative to a base case that assumes no change in the standard over a specific forecast period), and the NPV for consumers in the aggregate from a standard set at each CSL.

DOE accounts for the direct rebound effect in its NES analyses. Direct rebound is the concept that as appliances become more efficient, consumers use more of their service because their operating cost is reduced. In the case of lighting, the rebound could be manifested in increased hours of use or in increased lighting density (fixtures per square foot).

Lutron Electronics suggested DOE consider that consumers will use their lamps more as the lamps become more efficacious, and NEMA encouraged DOE to consider studies that indicate longer operating hours for more efficient CFL or LED GSLs. (NEMA, No. 15 at p. 17; Lutron Electronics, Public Meeting Transcript, No. 19 at p. 147)

A publication by Greening *et al.* (2000)[80] looked at lighting rebound estimates from earlier studies conducted in the 1990s. They found that the studies for residential lighting rebound are inconclusive due to the methods used. A more recent study of residential lighting in 369 homes in California showed no difference in the hours of use of CFLs with respect to other lamps,[81] which suggests a low degree of rebound from efficacy improvement. A comparison of the 2001[82] and 2010[83] LMC reports show no evidence of rebound of residential or commercial lighting. Given the information from the above sources, DOE assumed no rebound for the residential or commercial lighting in its reference scenario for this preliminary analysis.

In addition to the reference scenario, DOE conducted an analysis for two alternative scenarios, which account for increased GSL usage stemming from the use of more efficacious lamps: a scenario with an 8.5 percent rebound rate for residential lighting, based on the average of

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[80] Greening, Lorna, David Green, and Carmen Difiglio. "Energy efficiency and consumption - the rebound effect - a survey." *Energy Policy*. 2000. Vol. 28, pp. 389-401 (Last Accessed September 15, 2014.) www.elsevier.com/locate/enpol.

[81] KEMA. *CFL Metering Study Final Report*. Oakland, CA. (Last Accessed September 11, 2014.) http://www.calmac.org/publications/2005_Res_CFL_Metering_Study_Final_ReportES.pdf.

[82] Navigant Consulting. *U.S. Lighting Market Characterization, Volume I: National Lighting Inventory and Energy Consumption Estimate*. September 2002. (Last Accessed September 15, 2014.) http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/lmc_vol1.pdf.

[83] U.S. Department of Energy. *2010 U.S. Lighting Market Characterization*. January 2012. (Last Accessed September 15, 2014.) http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf.

two hours-of-use studies cited by Greening *et al.* (2000), and a one percent rebound rate for commercial and industrial lighting, also derived from Greening *et al.* (2000); and a scenario where both the residential and commercial rebound rates were assumed to be 15 percent, based on an estimate of the average rebound rate for a suite of appliances from the National Energy Modeling System (NEMS). DOE requests data that can be used to further refine the rebound assumptions used in the NIA.

DOE received a large number of comments regarding the relationship between the 45 lm/W backstop provision in EISA and the NIA for this rulemaking. CEC provided analysis results indicating that it is only feasible to adopt a regulation for GSLs that achieve greater savings than the backstop if GSILs are included in the scope. (CEC, No. 11 at p. 10) CA IOUs indicated that DOE should forecast business-as-usual energy use in the GSL market and quantify the savings that would result from the backstop, stating that this is an important part of the rulemaking, and that DOE needs to consider future GSIL efficacy, cost, lifetime, performance, supply chains, and market share in conducting this analysis. (CA IOUs, No. 18 at p. 3) During the framework public meeting, ASAP commented that it is reasonable for DOE to analyze the backstop as an option in the GSL rulemaking. (ASAP, Public Meeting Transcript, No. 19 at p. 37) CEC also noted that even if the final rule from this rulemaking achieves less energy savings than the backstop, the final rule would still be beneficial because it would achieve incremental energy savings for GSLs beyond the energy savings from the backstop. (CEC, No. 11 at p. 12)

The Appropriations Rider, in relevant part, restricts the use of appropriated funds in connection with several aspects of DOE’s incandescent lamps program. Specifically, section 322 states that none of the funds made available by the Act may be used to implement or enforce standards for GSILs, intermediate base incandescent lamps and candelabra base incandescent lamps. Because section 322 appears to curtail any further activity to implement or enforce standards for GSILs, DOE will not be considering GSILs in its analyses. Furthermore, because GSILs are not included in the scope of this rulemaking, DOE assumed that a potential GSL final rule would not yield sufficient energy savings to avoid triggering the EISA 2007 backstop. Therefore, as discussed in section 2.9, DOE assumes that the EISA 2007 backstop will go into effect concurrently with a potential GSL standard at the compliance date of this rulemaking, eliminating the need to characterize the effect of the backstop for this rulemaking’s analyses. Thus, as noted previously, DOE has assumed that there will be no shipments of incandescent lamps for general service applications during the analysis period.

A discussion took place during the public meeting that indicated a difference in interpretation among key stakeholders regarding the 45 lm/W backstop provision in EISA. (*See* 42 U.S.C. 6295(i)(6)(A)(ii) and (i)(6)(A)(v)) NEMA and GE interpreted the backstop as enforcing a 45 lm/W limit average across the entire fleet of GSLs sold. (NEMA, Public Meeting Transcript, No. 19 at pp. 30-31; GE, Public Meeting Transcript, No. 19 at pp. 32-33, 35-36) In contrast, NRDC interpreted the backstop as enforcing the 45 lm/W limit on a per-lamp basis. (NRDC, Public Meeting Transcript, No. 19 at p. 34) The EISA 2007 backstop provision states that, if certain requirements are not met, the sale of *any* GSL that does not meet the 45 lm/W minimum efficacy standard shall be prohibited. (*See* 42 U.S.C. 6295(i)(6)(A)(v)) DOE interprets this to mean that the 45 lm/W backstop mandated by EISA 2007 (which would go into effect beginning on January 1, 2020 if a GSL rulemaking does not occur or does not obtain energy savings equal to or larger than the energy savings of the backstop), would apply to every GSL being sold in the market on a per-lamp basis. DOE also clarifies that it is possible for the 45 lm/W backstop to come into effect concurrently with the GSL energy conservation standards from this rulemaking in the event that the energy savings from this rulemaking do not equal or exceed the savings from the backstop.

CA IOUs, ASAP and CEC provided comments on the inclusion of GSILs in the analyses DOE undertakes. CA IOUs and ASAP stated that DOE cannot accurately analyze the impact of LED and CFL GSL standards without considering the interaction of LED and CFL GSLs with GSILs. (CA IOUs, No. 18 at p. 3; ASAP, Public Meeting Transcript, No. 19 at p. 60) CEC agreed, commenting that DOE must analyze the GSIL market in the rulemaking, as GSILs are the least expensive GSLs and they directly substitute CFL and LED GSLs. (CEC, No. 11 at p. 18) As noted previously, the Appropriations Rider, in relevant part, appears to curtail any further activity to implement or enforce standards for GSILs. Additionally, DOE assumes that the EISA 2007 backstop will go into effect concurrently with the compliance date of this rulemaking; therefore, DOE has assumed that there will be no shipments of incandescent lamps for general service applications during the analysis period, which begins with the compliance date of this rulemaking, eliminating any competition between incandescent GSLs and LED or CFL GSLs.

DOE received a number of other comments on the NIA from NEMA, Lutron Electronics, and ASAP.

NEMA recommends DOE use an analysis period of no longer than 10 years due to the rapid market adoption of LED GSLs and the comparatively short lifetime of other GSL technologies. (NEMA, No. 15 at p. 15) DOE notes that the lifetimes of the CFL and LED GSLs under consideration in this rulemaking are comparable to (and in some cases, longer than) the lifetimes of products in other rulemakings that have used the standard 30-year analysis period.

ASAP commented that DOE needs to account for GSL inventories (*i.e.*, stockpiling) in consumers’ homes in its analyses. (ASAP, Public Meeting Transcript, No. 19 at p. 109) On the other hand, Lutron Electronics encouraged DOE not to become overburdened with trying to incorporate GSL stockpiling into the NIA models, with the reasoning that the lifetime of GSILs is relatively short and consumers will not stockpile other lamp types at this point due to the higher cost of more efficient lamps. (Lutron Electronics, Public Meeting Transcript, No. 19 at pp. 171-172)

DOE agrees with Lutron Electronics’ assessment of lamp stockpiling by consumers. Given the comparatively short lifetime of GSILs (those most likely to be stockpiled by consumers due to the increasing efficacy requirements being phased in by EISA) relative to more efficient GSL technologies, as well as the comparatively high price of more efficacious GSLs, DOE assumed that GSL stockpiling will not have a significant impact on the NIA results.

CEC suggested DOE include the impacts of GSL standards adopted in California when modeling the years 2018 up to the compliance date of the proposed rule, because the California standards are equivalent to the EISA backstop and will have effects on the national GSL market. (CEC, No. 11 at p. 19) In its analyses, DOE has assumed that a potential GSL final rule would have a compliance date that would be concurrent with the compliance date for the EISA 2007 backstop. The years prior to the compliance date of a potential GSL rule are outside of the analysis period for this rulemaking. However, in calibrating the shipments model for the residential sector, DOE assumed a consistent shift in shipments of 15 percent per year from incandescent GSLs to CFL or LED GSLs during the years leading up to the compliance date, which would account for the impacts of GSL standards adopted in California in addition to general market shifts. For the commercial sector, DOE assumed that the current market share of incandescent GSLs is negligible. DOE requests comment on these assumptions.

2.12.1 National Energy Savings

The inputs for determining the national energy savings for each product class are: (1) lamp shipments; (2) annual energy consumption per unit; (3) stocks of lamps in each year; (4) national energy consumption; and (5) site-to-primary energy and fuel-full-cycle conversion factors. The lamp stocks were calculated by the shipments model for each year of the analysis period from the prior year's stock, minus retirements, plus new shipments, accounting for lamp lifetimes. DOE calculated the national electricity consumption in each year by multiplying the number of units of each product class and CSL in the stock by the corresponding power consumption and operating hours. The electricity savings are estimated from the difference in national electricity consumption between the base case (without new standards) and the candidate standards cases for the lifetime of lamps shipped during the 2020-2049 period. To avoid penalizing longer lived lamps for not being retired from service as quickly as shorter-lived lamps, and therefore continuing to consume energy, DOE modified this approach in the years after 2049. The energy savings per lamp was determined for the final year of analysis period, and this multiplier was applied to the remaining stock in each year after the analysis period until the last lamp shipped during the analysis period was retired. For more details, see chapter 10 of this TSD.

DOE has historically presented NES in terms of primary energy savings. In response to the recommendations of a committee on "Point-of-Use and Full-Fuel-Cycle Measurement Approaches to Energy Efficiency Standards" appointed by the National Academy of Science, DOE announced its intention to use full-fuel-cycle (FFC) measures of energy use and greenhouse gas and other emissions in the national impact analyses and emissions analyses included in future energy conservation standards rulemakings. 76 FR 51281 (August 18, 2011). After evaluating the approaches discussed in the August 18, 2011 notice, DOE published a statement of amended policy in the Federal Register in which DOE explained its determination that NEMS is the most appropriate tool for its FFC analysis and its intention to use NEMS for that purpose. 77 FR 49701 (August 17, 2012). For this preliminary analysis, DOE calculated both site and primary energy savings as well as FFC energy savings for the considered ELs.

2.12.2 Net Present Value

The inputs for determining NPV are: (1) total annual installed cost; (2) total annual savings in operating costs; and (3) a discount factor to calculate the present value of costs and savings. DOE calculated net savings each year as the difference between the base case and each standards case in terms of total savings in operating costs versus total increases in installed costs. DOE calculated savings over the lifetime of products shipped in the 30-year analysis period.

For the NPV analysis, DOE calculates increases in total installed costs as the difference in total installed cost between the base case and standards case (*i.e.*, once the standards take effect). Because the more efficacious products bought in the standards case usually cost more than products bought in the base case, cost increases appear as negative values in the NPV.

DOE expresses savings in operating costs as decreases associated with the lower energy consumption of products bought in the standards case compared to the base case. Total savings in operating costs are the product of savings per unit and the number of units of each vintage that survive in a given year.

DOE calculated NPV as the difference between the present value of operating-cost savings and the present value of total installed costs. DOE used a discount factor based on real discount rates of 3 and 7 percent to discount future costs and savings to present values.

2.13 CONSUMER SUBGROUP ANALYSIS

The consumer subgroup analysis, which DOE conducts at the NOPR stage of a rulemaking, evaluates economic impacts on selected groups of consumers. A consumer subgroup comprises a subset of the population that may be affected disproportionately by amended energy conservation standards (*e.g.*, low income consumers, seniors). The purpose of a subgroup analysis is to determine the extent of any such disproportionate effect. DOE will work with industry and other interested parties to identify any subgroups for consideration.

In comparing potential effects on the different consumer subgroups, DOE will use appropriate values for the inputs that affect the LCC and PBP, such as annual energy use, lifetime, and electricity prices. For more detail on the approach to the subgroup analysis, see chapter 11 of this TSD.

NEMA agreed with the proposed subgroups, but also commented that all income groups and age groups should be evaluated individually for impacts specific to the group’s situation. (NEMA, No. 15 at p. 19) Additionally, an independent stakeholder pointed out that the elderly and terminally ill constitute a subgroup that is often unable to afford more efficient lighting technologies, that has an expected lifespan significantly shorter than the expected lifetime of the GSLs under consideration, and that may benefit greatly from not having to replace GSLs. (Wills, No. 13 at p. 1) The commenter also noted that temporary-use, use by non-profit organizations in rented spaces, as well as general low-use applications may make it difficult to justify increased costs for more efficacious GSL technologies.

DOE does not envision a need to separately evaluate all income groups and age groups, because DOE believes that the impacts in these subgroups are reflected in the distribution of LCC results. The LCC analysis also captures impacts on low-use applications. DOE plans to evaluate impacts of potential GSL standards on low-income, senior-only, and small business subgroups.

2.14 MANUFACTURER IMPACT ANALYSIS

The purpose of the MIA is to identify the likely impacts of higher energy conservation standards on manufacturers. In conducting this analysis, DOE will seek input from manufacturers and other interested parties and consider financial impacts, as well as a wide range of quantitative and qualitative industry impacts that might occur after adoption of GSL standards. For example, a particular standard level could require changes to manufacturing practices of GSLs. DOE will identify and discuss these impacts in interviews with manufacturers and other interested parties during the NOPR stage of the analysis.

DOE conducts the MIA in three phases, and further tailors the analytical framework based on the comments it receives. In Phase I, DOE creates an industry profile to characterize the industry and identify important issues that require consideration. In Phase II, DOE prepares an industry cash-flow model and considers what information it might gather in manufacturer interviews. In Phase III, DOE interviews manufacturers and assesses the impacts of standards both quantitatively and qualitatively. DOE assesses industry and subgroup cash flows and industry net present value (INPV) using the Government Regulatory Impact Model (GRIM). DOE then assesses impacts on competition, manufacturing capacity, employment, and cumulative regulatory burden based on manufacturer interview feedback and discussions.

DOE evaluates and reports preliminary MIA information in this preliminary analysis phase. DOE gathered the information for this preliminary analysis during manufacturer interviews. See chapter 12 of this TSD for more detailed information on the MIA.

2.14.1 Sources of Information for the Manufacturer Impact Analysis

The MIA uses outputs from other analyses, such as the engineering analysis, the shipment analysis, and the product price determination. It also uses inputs based on publicly available information, such as 10-K filings, and refines these inputs based on feedback during manufacturer interviews. These analyses provide important information for the MIA, including the number of shipments and the manufacturer production costs for each lamp type. DOE supplements this information with company financial data and other information gathered and/or refined during interviews with manufacturers to estimate the industry financial parameters, such as the tax rate, the R&D rate, the capital expenditure rate, the depreciation rate, the industry discount rate, and manufacturer markups.

DOE aggregates information across manufacturers to create a combined industry opinion or estimate. The interview process plays a key role in the MIA. DOE conducts detailed interviews with manufacturers to gain insight into the range of potential impacts of standards. Typically, DOE solicits both quantitative and qualitative information during the interviews on the potential impacts of ELs on sales, direct employment, capital assets, and industry competitiveness.

2.14.2 Industry Cash Flow Analysis

The industry cash flow analysis relies primarily on the GRIM. DOE uses the GRIM to analyze the financial impacts of energy conservation standards on the industry. The GRIM analysis uses several inputs to determine industry annual cash flows with and without standards. These inputs include shipments, manufacturer production costs, product markups, conversion costs for higher efficacy standards, and industry financial parameters. DOE then compares the industry annual cash flows resulting from two scenarios – one where more efficacious standards are mandated and one where base case projections, which involve no standards, are applied. The financial impact of standards is the difference between the two sets of discounted industry annual cash flows. Other performance metrics, such as return on invested capital, are also available from the GRIM.

NEMA noted that some of the recent lighting rulemakings have had negative INPVs for both high and low shipment scenarios, and urged DOE to create a rule that more closely strikes a compromise between desired energy savings and economic burden on industry and consumers. NEMA requested that DOE consider avoiding future rulemakings with negative INPVs, and to work with industry and other stakeholders to promote non-regulatory initiatives to encourage penetration of more efficacious lighting technologies. (NEMA, No. 15 at pp. 20-21) DOE carefully examines the potential burdens placed on manufacturers of covered products and weighs these burdens against other benefits of energy conservation standards before adopting an appropriate final rule for the analyzed products. DOE will weigh the potential burdens, including any potential loss of GSL manufacturers' INPV, against the potential benefits before proposing standards for GSLs in the NOPR. See chapter 12 of this TSD for more information on the industry cash flow analysis.

2.14.3 Direct Employment Impact Analysis

The impact of energy conservation standards on employment is an important consideration in the rulemaking process. Manufacturer interviews play a significant role in assessing how domestic employment patterns might be impacted by standards. DOE explores current employment trends in the GSL industry and solicits feedback from manufacturers on changes in employment patterns that may result from increased efficacy standards. NEMA expressed concern regarding the potential for GSL standards to offshore LED lamp production, which is currently experiencing growth in the United States. In DOE's "Keeping Manufacturing in the United States" white paper,[84] it is noted that there is strong potential for capital investment to be made in domestic SSL manufacturing. NEMA suggested that DOE take this data into account to monetize the impacts on the cost analyses being performed. (NEMA, No. 15 at p. 20) DOE will examine the potential change in domestic employment as a result of GSL standards during the NOPR MIA. These potential benefits or burdens will be taken into account when

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[84] U.S. Department of Energy. *Keeping Manufacturing in the United States.* July 2010. (Last Accessed November 10, 2014.) http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_whitepaper_july2010.pdf

proposing and ultimately selecting standards for GSLs in the NOPR and final rule stages of the analysis.

NEMA also commented that some manufacturers have invested in adding U.S.-based incandescent production since EISA 2007 was enacted, which could be at risk if this rulemaking does not adequately address the potential impacts to incandescent products. The Appropriations Rider restricts the use of appropriated funds in connection with several aspects of DOE's incandescent lamps program. DOE is not including lamps that meet the definition of GSIL in the GSL rulemaking at this time. See chapter 12 of this TSD for more information on the direct employment impact analysis.

2.14.4 Manufacturer Subgroup Analysis

Average industry impacts may not adequately show differential impacts among subgroups of manufacturers that have different cost structures or operate within different regulatory frameworks. For example, small and niche manufacturers, or manufacturers whose cost structure differs significantly from the industry average, could experience a more negative impact. Ideally, DOE would consider the impact on every firm individually; however, because this usually is not possible, DOE typically uses the results of the industry characterization to group manufacturers exhibiting similar characteristics. One common subgroup identified is small business manufacturers. DOE will analyze impacts on small business manufacturers consistent with the Regulatory Flexibility Act. (5 U.S.C. 601 *et seq*.) NEMA agreed with DOE's proposed subgroups of the GSL manufacturers that it should consider in a manufacturer subgroup analysis. (NEMA, No. 15 at p. 19)

During the interview process, DOE discusses in more detail the potential subgroups and subgroup members it has identified for the analysis. DOE will continue to encourage manufacturers to recommend subgroups or characteristics that are appropriate for the subgroup analysis. In addressing the impacts of potential GSL standards, NEMA suggested that DOE examine manufacturers of different technologies separately because of differing market dynamics for each technology. (NEMA, No. 15 at p. 19) DOE will consider manufacturers of different technologies separately in the MIA if these manufacturers have a significantly different cost structure. See chapter 12 of this TSD for more detail on the manufacturer subgroup analysis.

2.14.5 Competitive Impacts Assessment

EPCA directs DOE to consider any lessening of competition likely to result from the imposition of standards. (42 U.S.C. 6295(o)(2)(B)(i)(V)) It further directs the Attorney General to determine, in writing, the impacts, if any, of any lessening of competition. (42 U.S.C. 6295(o)(2)(B)(ii))

The manufacturer interviews focus on gathering information that would help in assessing impacts on competition, such as asymmetrical cost increases to some manufacturers, increased proportion of fixed costs potentially escalating business risks, and potential barriers to market entry (*e.g.*, proprietary technologies, limited access to resources). DOE will provide the Attorney General with a copy of any NOPR for consideration in evaluating the impact of standards on the lessening of competition. DOE will publish the Attorney General’s letter and address any related comments in any final rule.

2.14.6 Cumulative Regulatory Burden

Other regulations may apply to the GSLs covered under this rulemaking, and to other products produced by GSL manufacturers. DOE recognizes that multiple regulations could result in a significant cumulative regulatory burden on manufacturers. DOE’s initial analysis of regulations affecting GSLs is located in the market and technology assessment (chapter 3 of this TSD). During the NOPR, DOE plans to investigate the regulations manufacturers mentioned in interviews and the public meetings, and will further analyze and consider the impact of multiple, product-specific regulatory actions on GSL manufacturers.

NEMA commented that lighting products are already heavily regulated as there are several DOE, individual State, Environment Protection Agency (EPA), and Federal Trade Commission (FTC) regulations that impose a substantial cumulative regulatory burden on lighting manufacturers. There are currently energy conservation standards for exit signs, set by EPAct 2005; fluorescent lamp ballasts, general service fluorescent lamps and incandescent reflector lamps, metal halide lamp fixtures, all set by DOE. Further DOE’s ongoing standards rulemaking include ceiling fans and ceiling fan light kits, high impact discharge lamps, incandescent elliptical reflector and bulge reflector lamps (on hold but authorized), luminaires (on hold but authorized). Additionally, there are several other non-energy conservation standard regulations that lighting manufacturers must comply with, including the lighting facts label, set by the FTC; ENERGY STAR lamps program, set by EPA; ENERGY STAR luminaires program, specification revision are being discussed by EPA; California building and appliance efficiency regulations rulemakings, there are significant revisions in progress for 2014; California Title 20 enforcement rulemaking; individual State mercury and recycling requirements in Maine, Vermont, Massachusetts, and others that are being proposed; numerous Canadian regulations which U.S. manufacturers attempt to align their products with in an effort to minimize differences between the neighboring markets. (NEMA, No. 15 at pp. 16-17) DOE acknowledges that lighting manufacturers must comply with several lighting regulations. As part of the NOPR MIA, DOE will examine the potential additional cumulative regulatory burden placed on lighting manufacturers imposed by this GSL rulemaking.

NEMA also commented that according to DOE’s own analysis, several energy conservation standards enacted by DOE since 2007 are projected to have a negative impact on the manufacturers of those covered products, as reflected by a decrease in INPV due to the rulemakings adopted. NEMA commented that this underscores the recent regulatory burden placed on lighting manufacturers. (NEMA, No. 15 at p. 17) DOE recognizes that there have been at least three energy conservation standard final rules enacted by DOE since 2007 that cover lighting products. These previous standards covered GSFLs and IRLs (74 FR 34080 [July 14, 2009]), fluorescent lamp ballasts (76 FR 70548 [Nov. 14, 2011]), and metal halide lamp fixtures (79 FR 7746 [Feb. 10, 2014]). The INPV impacts to lighting manufacturers for these rulemakings ranged from moderate to significant, depending on the markup scenario analyzed. Lastly, NEMA commented that since there are numerous small businesses entering the LED lamp market, any regulation that is overly burdensome or imposes a high cost of compliance on

LED lamp manufacturers could result in fewer small businesses entering the LED lamp market and bringing with them potential radical and innovative energy-saving solutions. (NEMA, No. 15 at p. 19) The cumulative regulatory burden seeks to mitigate the overlapping effects on manufacturers of new or revised DOE standards and other regulatory actions affecting those same manufacturers. DOE will consider the cumulative regulatory burden on lighting manufacturers as one of the burdens of complying with GSL standards as part of the NOPR analysis.

2.14.7 Preliminary Results for the Manufacturer Impact Analysis

One important aspect of the preliminary MIA is the opportunity it creates for DOE to identify key manufacturer issues early in the evaluation of energy conservation standards. During preliminary interviews, manufacturers identified two major areas of concern regarding GSL standards: (1) testing burden and (2) impacts of technology neutral standards.

Testing Burden

Several manufacturers expressed concern over the testing burden associated with GSL energy conservation standards. Manufacturers expressed concern regarding new testing requirements for LED lamps and expanded scope of CFLs to comply with GSL standards. Manufacturers stated that they would now need to spend capital that is already limited on testing and certifying already efficacious lamps to demonstrate compliance with GSL standards instead of on research and development that could result in increase of energy savings from these lamps. Additionally, manufacturers claimed that standards covering LED lamps could present a barrier to entry for small LED lamp manufacturers due to the increase in testing and certification requirements caused by GSL standards. Manufacturers claim this could result in a potential decrease of product innovation and energy-saving potential for LED lamps.

Impacts of Technology Neutral Standards

Manufacturers are concerned that technology neutral standards for GSLs could have a disproportionate effect on the range of technologies covered by standards. If GSL standards are set at the highest levels of efficacy, manufacturers are concerned that they may experience a loss of product differentiation among their lighting offerings. Manufacturers claim that as premium products become the baseline offering to consumers, previously offered advantages in lighting utility could be eliminated in an attempt to meet these higher standards.

Several manufacturers also stated they are concerned that GSL standards could be set at unattainable efficacy levels for CFLs. If CFLs are regulated out of the market it could force CFL manufacturers to either make significant investments in converting their production lines to other lighting technologies and cause them to incur a significant loss on the stranded assets associated with their existing CFL production or exit the GSL lighting market altogether. Lastly, manufacturers claim that setting GSL standards at efficacy levels that cannot be attained by CFLs would remove product utility from the market as consumers still value CFLs for certain applications and derive utility from these products.

2.15 EMISSIONS ANALYSIS

In the emissions analysis, DOE will estimate the reduction in power sector emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2) and mercury (Hg) from potential amended energy conservation standards for GSLs. In addition, DOE will estimate emissions impacts in production activities (extracting, processing, and transporting fuels) that provide the energy inputs to power plants. These are referred to as “upstream” emissions. Together, these emissions account for the FFC. In accordance with DOE’s FFC Statement of Policy (76 FR 51281 [Aug. 18, 2011]), the FFC analysis also includes impacts of standards on emissions of methane and nitrous oxide, both of which are recognized as greenhouse gases (GHGs).

DOE will conduct the emissions analysis using emissions factors derived from data in the latest version of EIA’s *AEO*, supplemented by data from other sources. EIA prepares the *AEO* using NEMS. Each annual version of NEMS incorporates the projected impacts of existing air quality regulations on emissions. The text below refers to *AEO 2014*, which generally represents current legislation and environmental regulations, including recent government actions, for which implementing regulations were available as of October 31, 2013.

SO_2 emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap-and-trade programs. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for affected EGUs in the 48 contiguous states and the District of Columbia (D.C.). SO_2 emissions from 28 eastern states and D.C. were also limited under the Clean Air Interstate Rule (CAIR), which created an allowance-based trading program that operates along with the Title IV program in those States and D.C. 70 FR 25162 (May 12, 2005). CAIR was remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit), but it remained in effect.[85] On July 6, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution Rule (CSAPR). 76 FR 48208 (August 8, 2011). On August 21, 2012, the D.C. Circuit issued a decision to vacate CSAPR.[86] The court ordered EPA to continue administering CAIR. *AEO 2014* assumes that CAIR remains a binding regulation through 2040.[87]

The attainment of emissions caps is typically flexible among EGUs and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO_2 emissions allowances resulting from the lower electricity demand caused by the

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[85] See *North Carolina v. EPA*, 550 F.3d 1176 (D.C. Cir. 2008); *North Carolina v. EPA*, 531 F.3d 896 (D.C. Cir. 2008).

[86] See *EME Homer City Generation*, LP v. EPA, 696 F.3d 7, 38 (D.C. Cir. 2012).

[87] On April 29, 2014, the U.S. Supreme Court reversed the judgment of the D.C. Circuit and remanded the case for further proceedings consistent with the Supreme Court's opinion. The Supreme Court held in part that EPA's methodology for quantifying emissions that must be eliminated in certain states due to their impacts in other downwind states was based on a permissible, workable, and equitable interpretation of the Clean Air Act provision that provides statutory authority for CSAPR. See *EPA v. EME Homer City Generation*, No 12-1182, slip op. at 32 (U.S. April 29, 2014). Because DOE is using emissions factors based on AEO 2014, the analysis assumes that CAIR, not CSAPR, is the regulation in force. The difference between CAIR and CSAPR is not relevant for the purpose of DOE's analysis of SO2 emissions.

adoption of an efficiency standard could be used to permit offsetting increases in SO_2 emissions by any regulated EGU. In past rulemakings, DOE recognized that there was uncertainty about the effects of efficiency standards on SO_2 emissions covered by the existing cap-and-trade system, but it concluded that negligible reductions in power sector SO_2 emissions would occur as a result of standards.

Beginning in 2016, however, SO_2 emissions will fall as a result of the Mercury and Air Toxics Standards (MATS) for power plants. 77 FR 9304 (Feb. 16, 2012). In the final MATS rule, EPA established a standard for hydrogen chloride as a surrogate for acid gas hazardous air pollutants (HAP), and also established a standard for SO_2 (a non-HAP acid gas) as an alternative equivalent surrogate standard for acid gas HAP. The same controls are used to reduce HAP and non-HAP acid gas; thus, SO_2 emissions will be reduced as a result of the control technologies installed on coal-fired power plants to comply with the MATS requirements for acid gas. *AEO 2014* assumes that, in order to continue operating, coal plants must have either flue gas desulfurization or dry sorbent injection systems installed by 2016. Both technologies, which are used to reduce acid gas emissions, also reduce SO_2 emissions. Under the MATS, emissions will be far below the cap that would be established by CAIR, so it is unlikely that excess SO_2 emissions allowances resulting from the lower electricity demand would be needed or used to permit offsetting increases in SO_2 emissions by any regulated EGU. Therefore, DOE believes that efficiency standards will reduce SO_2 emissions in 2016 and beyond.

CAIR established a cap on NO_X emissions in 28 eastern states and the District of Columbia. Energy conservation standards are expected to have little effect on NO_x emissions in those states covered by CSAPR because excess NO_x emissions allowances resulting from the lower electricity demand could be used to permit offsetting increases in NO_x emissions. However, standards would be expected to reduce NO_x emissions in the States not affected by the caps, so DOE estimates NO_X emissions reductions from potential standards in the States where emissions are not capped.

The MATS limit mercury emissions from power plants, but they do not include emissions caps and, as such, DOE’s energy conservation standards would likely reduce Hg emissions. DOE will estimate mercury emissions reduction using emissions factors based on *AEO 2014*, which incorporates the MATS.

Power plants may emit particulates from the smoke stack, which are known as direct particulate matter (PM) emissions. NEMS does not account for direct PM emissions from power plants. DOE is investigating the possibility of using other methods to estimate reduction in PM emissions due to standards. The great majority of ambient PM associated with power plants is in the form of secondary sulfates and nitrates, which are produced at a significant distance from power plants by complex atmospheric chemical reactions that often involve the gaseous emissions of power plants, mainly SO_2 and NO_x. The monetary benefits that DOE estimates for reductions in SO_2 and NO_x emissions resulting from standards are in fact primarily related to the health benefits of reduced ambient PM.

2.16 MONETIZING CO_2 AND OTHER EMISSIONS

DOE plans to consider the estimated monetary benefits likely to result from the reduced emissions of CO_2 and NO_X that are expected to result from each of the energy conservation standard levels considered.

To estimate the monetary value of benefits resulting from reduced emissions of CO_2, DOE plans to use the most current Social Cost of Carbon (SCC) values developed and/or agreed to by an interagency process. The SCC is intended to be a monetary measure of the incremental damage resulting from GHG emissions, including, but not limited to, net agricultural productivity loss, human health effects, property damage from sea level rise, and changes in ecosystem services. Any effort to quantify and to monetize the harms associated with climate change will raise serious questions of science, economics, and ethics. But with full regard for the limits of both quantification and monetization, the SCC can be used to provide estimates of the social benefits of reductions in GHG emissions.

The Interagency Working Group on Social Cost of Carbon released an update of its previous report in 2013.[88] The most recent estimates of the SCC in 2015, expressed in 2013$, are $12.0, $40.5, $62.4, and $119 per metric ton of CO_2 avoided. For emissions reductions that occur in later years, these values grow in real terms over time. Additionally, the interagency group determined that a range of values from 7 percent to 23 percent should be used to adjust the global SCC to calculate domestic effects, although DOE will give preference to consideration of the global benefits of reducing CO_2 emissions.

DOE multiplies the CO_2 emissions reduction estimated for each year by the SCC value for that year in each of the four cases. To calculate a present value of the stream of monetary values, DOE discounts the values in each of the four cases using the discount rates that had been used to obtain the SCC values in each case.

DOE recognizes that scientific and economic knowledge continues to evolve rapidly as to the contribution of CO_2 and other GHG to changes in the future global climate and the potential resulting damages to the world economy. Thus, these values are subject to change.

DOE also estimates the potential monetary benefit of reduced NO_X emissions resulting from the standard levels it considers. Estimates of monetary value for reducing NO_X from stationary sources range from $476 to $4,893 per ton in 2013$.[89] DOE calculates monetary

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[88] Interagency Working Group on Social Cost of Carbon. *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. May 2013; revised November 2013. (Last Accessed September 15, 2014.) http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf.

[89] U.S. Office of Management and Budget. 2006 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities. 2006. Washington, D.C. (Last Accessed September 15, 2014.) http://www.whitehouse.gov/sites/default/files/omb/assets/omb/inforeg/2006_cb/2006_cb_final_report.pdf.

benefits using a medium value for NO_X emissions of $2,684 per short ton (in 2013$), and real discount rates of 3 percent and 7 percent, in accordance with OMB guidance.[90]

DOE is evaluating an appropriate valuation of avoided SO_2 and Hg emissions. Whether monetization of these emissions will occur in this rulemaking is yet to be determined.

2.17 UTILITY IMPACT ANALYSIS

In the utility impact analysis, DOE analyzes the changes in electric installed capacity and generation that result for each trial standard level. The utility impact analysis is based on output of DOE/EIA's NEMS. NEMS is a public domain, multi-sectored, partial equilibrium model of the U.S. energy sector. Each year, DOE/EIA uses NEMS to produce an energy forecast for the United States, the Annual Energy Outlook (AEO). The EIA publishes a reference case, which incorporates all existing energy-related policies at the time of publication, and a variety of side cases which analyze the impact of different policies, energy price and market trends. As of 2014, DOE is using a new methodology based on results published for the *AEO 2014* Reference case and a set of side cases that implement a variety of efficiency-related policies.

DOE received comments about the importance of power factor. In the public meeting, NEEA inquired as to DOE's intent on considering the effects of GSLs with power factor less than 1. (NEEA, Public Meeting Transcript, No. 19 at p. 176) Philips stated that it is not the power factor but the impact on actual energy usage that should be considered. (Philips, Public Meeting Transcript, No. 19 at p. 177) NEMA indicated that any issues resulting from a decrease in power factor are already adequately addressed in other standards. (NEMA, No. 15 at p. 19) ALA requested information regarding the effect of lower power factor devices on electricity generating plants, indicating that it was unclear if these devices have much of an impact at the generation plant. (ALA, Public Meeting Transcript, No. 19 at p. 178) DOE acknowledges that phase shifts introduced into the grid by loads could theoretically increase power production and transmission system demands. However, it is the net impact of many loads that ultimately determines the impact, which in turn depends on a dynamically changing load mix. DOE is not aware of field data quantifying the impact of power factor on the electric grid. Therefore, DOE did not account for power factor in its analyses.

2.18 EMPLOYMENT IMPACT ANALYSIS

Employment impacts include direct and indirect changes in the domestic workforce resulting from new or amended energy conservation standards. Direct employment impacts are any changes in the number of employees of manufacturers of the product subject to standards. The MIA addresses impacts in the number of employees working for the manufacturers. Indirect employment impacts from standards consist of the net jobs created or eliminated in the national

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[90] U.S. Office of Management and Budget. *Circular No. A-4, Regulatory Analysis*. 2003. Washington, DC. (Last Accessed September 15, 2014.) http://www.whitehouse.gov/sites/default/files/omb/assets/regulatory_matters_pdf/a-4.pdf.

economy, other than in the manufacturing sector being regulated, caused by: (1) reduced spending by end users on energy; (2) reduced spending on new energy supply by the utility industry; (3) increased spending on new products to which the new standards apply; and (4) the effects of those three factors throughout the economy.

In any NOPR stage of a rulemaking, DOE estimates indirect national employment impacts using an input/output model of the U.S. economy called Impact of Sector Energy Technologies version 3.1.1 (ImSET).[91] ImSET is a special-purpose version of the "U.S. Benchmark National Input-Output" (I–O) model, which was designed to estimate the national employment and income effects of energy saving technologies. The ImSET software includes a computer-based I–O model having structural coefficients that characterize economic flows among 187 sectors most relevant to industrial, commercial, and residential building energy use.

DOE notes that ImSET is not a general equilibrium forecasting model and understands the uncertainties involved in projecting employment impacts, especially changes in the later years of the analysis. Because ImSET does not incorporate price changes, the employment effects predicted by ImSET may overestimate actual job impacts over the long run. Therefore, DOE focuses its quantitative analysis on short-term employment impacts.

DOE received comments from CEC on the proposed employment impact analysis. CEC opposed DOE's use of short-term combined direct and indirect employment impacts, pointing out that DOE's analysis would cover the fixed costs of the regulation, but would only cover a very limited scope of benefits. (CEC, No. 11 at pp. 20-21) CEC therefore recommends that DOE extend its employment assessment until job creation/loss becomes static.

DOE acknowledges that short-term employment impacts do not present a full picture of indirect employment impacts of energy efficiency standards that yield reductions in energy expenditures over a lengthy period. However, DOE has concerns about using ImSET to project employment impacts over the long run, as stated above. DOE does present a qualitative assessment of long-run impacts as part of its analysis.

2.19 REGULATORY IMPACT ANALYSIS

In the NOPR stage of this rulemaking, DOE will prepare an RIA that will address the potential for non-regulatory approaches to supplant or augment energy conservation standards to improve the efficacy of GSLs on the market. DOE recognizes that voluntary or other non-regulatory efforts by manufacturers, utilities, and other interested parties can result in substantial efficacy improvements. DOE intends to analyze the likely effects of non-regulatory initiatives and compare such effects with those projected to result from amended energy conservation standards. DOE will attempt to base its assessment on the actual impacts of any such initiatives

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[91] Scott, M.J., J.M. Roop, O.V. Livingston, R.W. Schultz, and P.J. Balducci. *ImSET 3.1: Impact of Sector Energy Technologies Model Description and User's Guide.* 2009. Pacific Northwest National Laboratory, Richland, WA. Report No. PNNL–18412. (Last Accessed September 15, 2014.) http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18412.pdf.

to date, but will also consider information presented regarding the impacts that any existing initiative might have in the future.

2.20 DEPARTMENT OF JUSTICE REVIEW

Section 325(o)(2)(B)(i)(V) of EPCA states that, before the Secretary of Energy may prescribe a new or amended energy conservation standard, the Secretary shall ask the U.S. Attorney General to make a determination of “the impact of any lessening of competition…that is likely to result from the imposition of the standard.” (42 U.S.C. 6295) Pursuant to this requirement, DOE will solicit the views of the U.S. Department of Justice on any lessening of competition that is likely to result from the imposition of a proposed standard and will give any views provided full consideration in assessing economic justification of a proposed standard.

CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 3. MARKET AND TECHNOLOGY ASSESSMENT

3.1 INTRODUCTION

This chapter consists of four sections: scope of coverage, market assessment, the technology assessment, and product classes. The scope of coverage describes the products covered under this rulemaking and discusses certain amendments to the definitions of these products being considered by the U.S. Department of Energy (DOE). The market assessment provides an overall picture of the market for the products concerned, including the nature of the products, industry structure, and manufacturer market shares; regulatory and non-regulatory efficiency improvement programs; market trends; and quantities of products sold. The technology assessment identifies a preliminary list of technologies to consider in the screening analysis. The product classes section discusses the class-setting factors DOE considered for this rulemaking.

The information DOE gathers from the market and technology assessment serves as resource material for use throughout the rulemaking. DOE considers both quantitative and qualitative information from publicly available sources and interested parties.

3.2 SCOPE OF COVERAGE

In this section, DOE clarifies the scope of lamps included in this rulemaking. The term general service lamp (GSL) includes general service incandescent lamps (GSILs), compact fluorescent lamps (CFLs), general service light-emitting diode (LED) lamps, organic light-emitting diode (OLED) lamps, and any other lamps that the Secretary determines are used to satisfy lighting applications traditionally served by general service incandescent lamps; however, this definition does not apply to any lighting application or bulb shape excluded from the "general service incandescent lamp" definition, or any general service fluorescent lamp or incandescent reflector lamp.

DOE's definition notes that as well as certain lamp types, a GSL is identified as any lamp that is used to satisfy lighting applications traditionally served GSILs. Based on this guidance, DOE has taken a broad interpretation for what can be considered a GSL. DOE has determined GSL to mean any lamp intended to serve in a general lighting application that has an ANSI base; has a lumen output of 310 lumens or greater; is not a light fixture; is not designed and labeled for use in non-general applications; and is not or could not be considered in another rulemaking proceeding.

For each lamp type included in the GSL definition, DOE assessed whether standards for such lamps would result in significant energy savings and, further, if such standards are technologically feasible and economically justified based on criteria specified for products per 42 U.S.C. 6295(o).

DOE first examined factors such as market share and product offerings to ascertain the potential for energy savings. DOE surveyed market and inventory reports on lighting and found that the California Retail Lighting Shelf Survey provided the most detailed information on specific lamp types. DOE also assessed the technological feasibility of setting standards for the lamp types that meet the GSL definition. The following sections discuss each of the lamp types included in the definition of general service lamp and the application of the scope criteria in more detail.

3.2.1 General Service Incandescent Lamps

Section 321 of the Energy Policy and Conservation Act (EPCA; 42 U.S.C. 6291 *et seq.*) contains a definition for GSIL. DOE codified the statutory definition for GSIL in the Code of Federal Regulations (CFR). 10 CFR 430.2. This definition is provided below. 10 CFR 430.2 defines a general service incandescent lamp as follows:

> *General service incandescent lamp* means a standard incandescent or halogen type lamp that is intended for general service applications; has a medium screw base; has a lumen range of not less than 310 lumens and not more than 2,600 lumens or, in the case of a modified spectrum lamp, not less than 232 lumens and not more than 1,950 lumens; and is capable of being operated at a voltage range at least partially within 110 and 130 volts; however this definition does not apply to the following incandescent lamps—
> (1) An appliance lamp;
> (2) A black light lamp;
> (3) A bug lamp;
> (4) A colored lamp;
> (5) An infrared lamp;
> (6) A left-hand thread lamp;
> (7) A marine lamp;
> (8) A marine signal service lamp;
> (9) A mine service lamp;
> (10) A plant light lamp;
> (11) A reflector lamp;
> (12) A rough service lamp;
> (13) A shatter-resistant lamp (including a shatter-proof lamp and a shatter-protected lamp);
> (14) A sign service lamp;
> (15) A silver bowl lamp;
> (16) A showcase lamp;
> (17) A 3-way incandescent lamp;
> (18) A traffic signal lamp;
> (19) A vibration service lamp;
> (20) A G shape lamp (as defined in ANSI C78.20) (incorporated by reference; see § 430.3) and ANSI C79.1-2002 (incorporated by reference; see § 430.3) with a diameter of 5 inches or more;
> (21) A T shape lamp (as defined in ANSI C78.20) (incorporated by reference; see § 430.3) and ANSI C79.1-2002 (incorporated by reference; see § 430.3) and that uses not more than 40 watts or has a length of more than 10 inches; and
> (22) A B, BA, CA, F, G16-1/2, G-25, G30, S, or M-14 lamp (as defined in ANSI C79.1-2002) (incorporated by reference; see § 430.3) and ANSI C78.20 (incorporated by reference; see § 430.3) of 40 watts or less.
>
> 10 CFR 430.2

The Consolidated Appropriations Act, 2014 (Public Law 113-76, January 17, 2014; hereafter referred to as the "Appropriations Rider"), in relevant part, restricts the use of appropriated funds in connection with several aspects of DOE's incandescent lamps energy conservation standards program. Specifically, section 322 states that none of the funds made available by the Act may be used to implement or enforce standards for GSILs, intermediate base incandescent lamps, and candelabra base incandescent lamps. Thus, DOE is not considering GSILs, intermediate base incandescent lamps, or candelabra base incandescent lamps in this rulemaking.

Section 42 U.S.C. 6295(i)(6)(A)(i)(II) also directs DOE to determine whether the exemptions for certain incandescent lamps should be maintained or discontinued based, in part, on exempted lamp sales collected from manufacturers. As stated previously, DOE is prohibited by the Appropriations Rider from using appropriated funds to implement or enforce standards for GSILs and thus cannot modify the existing exemptions for GSILs in the rulemaking. If the limitations imposed by the Appropriations Rider are lifted, DOE can evaluate whether the 22 exemptions for incandescent lamps should be maintained based on sales data and other factors.

3.2.2 Compact Fluorescent Lamps

CFLs are also included in the definition of GSL, however the term "compact fluorescent lamp" is not currently defined in the CFR. CFLs can be integrated (*e.g.*, medium base CFLs) or non-integrated (*e.g.*, pin base CFLs). EPAct 2005 amended EPCA by setting energy conservation standards for MBCFLs. DOE's existing energy conservation standards apply only to integrally ballasted (also referred to as self-ballasted) MBCFLs. 10 CFR 430.32(u) The definition of "medium base compact fluorescent lamp" is as follows:

> *Medium base compact fluorescent lamp* means an integrally ballasted fluorescent lamp with a medium screw base, a rated input voltage range of 115 to 130 volts and which is designed as a direct replacement for a general service incandescent lamp; however, the term does not include—
>
> (1) Any lamp that is—
> (i) Specifically designed to be used for special purpose applications; and
> (ii) Unlikely to be used in general purpose applications, such as the applications described in the definition of "General Service Incandescent Lamp" in this section; or
> (2) Any lamp not described in the definition of "General Service Incandescent Lamp" in this section that is excluded by the Secretary, by rule, because the lamp is—
> (i) Designed for special applications; and
> (ii) Unlikely to be used in general purpose applications.
>
> 10 CFR 430.2

As stated previously, the term "compact fluorescent lamp" is not currently defined but has been determined to apply to both integrated and non-integrated CFLs. DOE is considering a definition for "compact fluorescent lamp" in the CFL TP rulemaking. DOE is considering defining the term “compact fluorescent lamp” to include both integrated and non-integrated CFLs. The definition that DOE is considering is as follows:

> *Compact fluorescent lamp* means an integrated or non-integrated single-ended, low pressure mercury electric-discharge source in which a fluorescing coating transforms some of the ultraviolet energy generated by the mercury discharge into light; however, the term does not include circline or U-shaped fluorescent lamps.

DOE is also considering defining the terms “integrated” and “non-integrated” to further support the scope of this rulemaking. DOE developed technology neutral definitions that can be used to describe the various lamp technologies covered by this rulemaking. The definitions that DOE is considering are as follows:

> *Integrated lamp* means a lamp that contains all components necessary for the starting and stable operation of the lamp, does not include any replaceable or interchangeable parts, and is connected directly to a branch circuit through an ANSI base and corresponding ANSI standard lamp-holder (socket).
>
> *Non-integrated lamp* means a lamp that is not an integrated lamp.

Section 3.2.5 discusses additional CFLs for which DOE is considering establishing standards. Because the definition of GSL explicitly states that the term includes CFLs, and is not in any way limited to a particular base type of CFL, the intent of the definition was to consider all CFLs to be GSLs. Thus, DOE concluded that the exemptions for the lamp types listed in the GSIL definition, referred to in the GSL definition, do not automatically apply to the MBCFLs included in the GSL rulemaking. Otherwise, the inclusion of CFLs in the definition of GSL would be a nullity. DOE conducted a separate assessment to determine if there are MBCFLs that are designed for specialty use and therefore cannot provide overall illumination. DOE identified MBCFLs that were designed for specialty applications and are not able to provide overall illumination, including black light lamps, bug lamps, colored lamps, plant light lamps, and silver bowl lamps. DOE is considering providing exemptions for these specialty applications, which are discussed further in section 3.2.5.

3.2.3 General Service LED Lamps

General service LED lamps are included in the definition of GSL. LED means a p-n junction solid state device of which the radiated output, either in the infrared region, the visible region, or the ultraviolet region, is a function of the physical construction, material used, and exciting current of the device. 10 CFR 430.2 Similar to CFLs, LED lamps can be integrated or non-integrated. DOE proposed a definition for “integrated light-emitting diode lamp” in a test procedure SNOPR for LED lamps (hereafter “LED TP SNOPR”). 79 FR 32048 (June 3, 2014). The proposed definition is as follows:

> *Integrated light-emitting diode lamp* means an integrated LED lamp as defined in ANSI/IESNA RP–16 (incorporated by reference; see § 430.3).

As stated in the LED TP SNOPR, the ANSI/IESNA standard defines integrated LED lamps as comprising the LED source (the LED packages [components] or LED arrays [modules]), LED driver, ANSI standard base, and other optical, thermal, mechanical and electrical components such as phosphor layers, insulating materials, fasteners to hold components within the lamp together, and electrical wiring. The LED lamp is intended to connect directly to a branch circuit through a corresponding ANSI standard socket. 77 FR at 32021-22 (June 3, 2014).

Although 10 CFR 430.2 defines the term "light-emitting diode or LED" and DOE has proposed a definition for "integrated light-emitting diode lamp," DOE does not currently have a definition for "general service LED lamp." As stated previously, DOE has tentatively determined that the term general service LED lamp includes both integrated and non-integrated LED lamps. Therefore, DOE has decided to propose a more general definition similar to the definition proposed for "compact fluorescent lamp" to clearly explain this determination. DOE is proposing the following definition for general service LED lamp:

> *General service light-emitting diode (LED) lamp* means an integrated or non-integrated LED lamp designed for use in general lighting applications (as defined in 430.2).

As stated in the definition, general service LED lamps are used in general lighting applications. DOE determined that the term "general service LED lamp" is not limited to integrated LED lamps. DOE therefore concluded that both integrated and non-integrated LED lamps could be considered in the GSL rulemaking. Further, because the definition of GSL explicitly states that the term includes general service LEDs, the intent of the definition was to consider all general service LEDs to be GSLs. Therefore, DOE determined that the exemptions for certain bulb shapes and lighting applications in the GSIL definition, referred to in the GSL definition, do not apply to the other lamp types included in the definition of GSL. Otherwise all LED lamps would be considered exempt, rendering the inclusion of LED lamps in the GSL definition a nullity. DOE assessed whether LED lamps exist that are designed for specialty applications and therefore cannot provide overall illumination. DOE identified LED lamps that were designed for specialty applications and are not able to provide overall illumination, including black light lamps, bug lamps, colored lamps, plant light lamps, and silver bowl lamps. DOE is considering providing exemptions for these specialty applications, which are discussed further in section 3.2.5.

3.2.4 OLED Lamps

OLED lamps are included in the definition of GSL. OLED means a thin-film light-emitting device that typically consists of a series of organic layers between two electrical contacts (electrodes). 10 CFR 430.2 OLEDs are diffuse light sources made of thin layers of carbon-based semiconductor material. The layer-based construction tends to support development of large, flat surfaces rather than traditional lamp shapes. Because OLEDs are an emerging technology, the commercial availability of OLEDs is very limited. Further, products that are available are not used in general lighting applications due to their size and shape. The OLEDs that are available are marketed for accent lighting, interior design, or are sold integrated into fixtures. In addition, due to the emerging nature of the technology and the limited commercial availability of OLEDs, it is unclear whether the efficacy of existing OLED products can be improved. Therefore, DOE is not considering establishing standards for OLED lamps in this preliminary analysis. To clearly define the scope of this rulemaking, DOE is considering defining OLED lamps as follows:

> *Organic light-emitting diode or OLED lamp* means an integrated or non-integrated lamp that uses OLEDs as the primary source as light.

3.2.5 Other Lamps

Pursuant to the definition of GSL, DOE has the authority to consider additional lamps that it determines are used to satisfy lighting applications traditionally served by GSILs. The definition of GSIL specifies lamps that are: (1) typically intended for general service applications; (2) have a medium screw base; (3) emit between 310 and 2,600 lumens; and (4) are capable of being operated at a voltage range at least partially within 110 and 130 V. DOE defines the term "general lighting application" as follows:

> *General lighting application* means lighting that provides an interior or exterior area with overall illumination.
>
> 10 CFR 430.2

In this preliminary analysis, as noted previously, DOE has taken a broad interpretation for what can be considered a GSL. In this interpretation, GSLs are lamps intended to serve in general lighting applications and have the following basic characteristics: 1) an ANSI base with the exclusion of light fixtures; 2) lumen output of 310 lumens or greater; 3) line voltage or low voltage operation; 4) are not the subject of other rulemakings; and 5) are not designed and labeled for use in certain non-general applications (*i.e.*, appliance lamps, black light lamps, bug lamps, colored lamps, infrared lamps, marine signal lamps, mine service lamps, plant light lamps, sign service lamps, silver bowl lamps, showcase lamps, and traffic signal lamps).

DOE believes that several different base types can be used in general lighting applications, and that GSLs utilize an ANSI base to ensure they can be used in sockets commonly found in residential, commercial, and industrial fixtures. Therefore, DOE considers GSLs to have an ANSI base. To ensure that complete light fixtures with ANSI bases (*e.g.*, certain retrofit kits) are not included in the scope of this rulemaking, DOE is considering defining the term light fixture. DOE is considering defining the term based on the definition in the industry standard, ANSI/IESNA RP-16. The definition DOE is considering for light fixture is as follows:

> *Light fixture* means a complete lighting unit consisting of lamp(s) and ballast(s) (when applicable) together with the parts designed to distribute the light, to position and protect the lamps, and to connect the lamp(s) to the power supply.

DOE also believes that lumen output can restrict a lamp's use in general lighting applications. DOE does not believe that lamps with lumen outputs below 310 lumens are intended for use in general lighting applications because their low lumen output is not sufficient for overall illumination. Thus, DOE considers GSLs to have a lumen output of at least 310 lumens. DOE does not believe there is an upper bound on lumen output that can provide overall illumination.

Additionally, DOE believes that lamps with operating voltage outside the range of 110 to 130 V can be used in general lighting applications. Specifically, DOE believes that both lamps operating on line voltage (*i.e.*, connects directly to a branch circuit) and lamps operating on low voltage (*i.e.*, requires the use of a transformer) can provide overall illumination. Therefore, DOE does not consider GSLs to have a specific voltage range.

Further, to limit the probability that one lamp type might be subject to two different standards, DOE did not consider adding lamp types that are or could be addressed in a separate rulemaking proceeding. For example, the general service fluorescent lamp rulemaking considered establishing standards for additional types of fluorescent lamps (such as 2-foot linear fluorescent lamps). While that rulemaking ultimately concluded that additional lamps should not be subject to standards, DOE did not consider the additional lamps evaluated as general service fluorescent lamps (GSFLs) to be candidates for coverage in the GSL rulemaking.

DOE has identified self-ballasted mercury vapor (SBMV) lamps that are marketed as GSIL replacements and determined that some SBMV lamps are intended for general service applications. However, 10 CFR 431.282 defines a mercury vapor lamp as an HID lamp, which means SBMV lamps are covered by a different rulemaking. Because SBMV lamps could be addressed in a separate rulemaking, DOE is not considering including SBMV lamps in the scope of this GSL rulemaking. DOE is considering defining the term mercury vapor lamp in support of the scope of coverage of this rulemaking. DOE is considering using the definition in 42 U.S.C. 6291(47) for mercury vapor lamp which is defined as follows:

> *Mercury vapor lamp* means a high intensity discharge lamp, including clear, phosphor-coated, and self-ballasted screw base lamps, in which the major portion of the light is produced by radiation from mercury typically operating at a partial vapor pressure in excess of 100,000 Pa (approximately 1 atm).

DOE also considered whether lamps designed or labeled for specific applications could provide overall illumination and therefore meet the definition of general service lamp. DOE determined that the exemptions for specialty applications listed in 42 U.S.C. 6291(30)(D)(ii) are only applicable to GSILs. However, DOE is considering in this rulemaking whether any exemptions for specialty applications are needed for other GSLs. DOE assessed whether each specified lamp type provides overall illumination and therefore can be used in general lighting applications. DOE has preliminarily determined that appliance lamps, black lights, bug lamps, colored lamps, infrared lamps, marine signal lamps, mine service lamps, plant lights, sign service lamps, silver bowl lamps, showcase lamps, and traffic signal lamps cannot provide overall illumination and therefore cannot be used in general lighting applications. DOE found the lumen output of these lamps, when provided by manufacturers, was insufficient to provide overall illumination. DOE notes that for many of the lamp types listed, such as colored lamps and bug lamps, the lumen output is not stated in manufacturer catalogs as providing lumen output is not the primary application. Therefore, DOE is considering not establishing standards for these lamp types under the GSL rulemaking because the lamps are intended for use in non-general applications.

DOE also reviewed left-hand thread lamps, marine lamps, reflector lamps, rough service lamps, shatter-resistant lamps, 3-way lamps, vibration service lamps, and lamps of several specific shapes (such as G, T, B, BA, CA, F, G16.5, G25, G30, S, and M14, as defined in ANSI C79.1-2002 and ANSI C78.20). Based on its assessment, DOE has preliminarily determined that these lamp types provide overall illumination and therefore can serve in general lighting applications.

DOE assessed further whether the utility offered by 3-way lamps, vibration service lamps, rough service lamps, and shatter-resistant lamps is available at higher levels of efficacy, which would indicate that there is no technological reason the utility could not be maintained in the future. DOE found that 3-way CFLs and LED lamps are available. Further, DOE found that one of the most efficacious GSLs currently available on the market is a 3-way LED lamp. Vibration service lamps and rough service lamps are defined specifically in the context of incandescent/halogen technology. However, DOE believes the utility of these lamp types, as well as shatter-resistant lamps, is their service in applications where vibrations occur (such as in a ceiling fan) or in applications where broken glass due to shattering would be a safety hazard (such as a food preparation area). DOE believes that LED lamps are inherently durable and resistant to shattering and thus can provide the necessary utility to serve in these applications. DOE also confirmed that shatter-resistant CFLs exist.

DOE is considering defining terms in support of the scope of coverage. To further explain lamp types DOE identified for use in non-general applications, DOE is considering defining the term “colored lamp” as follows:

> *Colored lamp* means a colored fluorescent lamp, a colored incandescent lamp, or a lamp designed and marketed as a colored lamp and not designed or marketed for general lighting applications with either of the following characteristics (if multiple modes of operation are possible [such as variable CCT], either of the below characteristics must be maintained throughout all modes of operation):
>
>> (1) A CRI less than 40, as determined according to the method set forth in CIE Publication 13.3 (incorporated by reference; see §430.3); or
>> (2) A correlated color temperature less than 2,200 K or greater than 7,000 K as determined according to the method set forth in IES LM-66 or IES LM-79 as appropriate (incorporated by reference; see §430.3).

DOE is also considering defining terms related to the lamp types that can serve in general lighting applications. Specifically, DOE is considering defining “reflector lamp” and “non-reflector” lamp as follows:

Reflector lamp means a lamp that has an R, PAR, BPAR, BR, ER, MR, or similar bulb shape as defined in ANSI C78.20 (incorporated by reference; see §430.3) and ANSI C79.1 (incorporated by reference; see §430.3) and is used to direct light.

Non-reflector lamp means a lamp that is not a reflector lamp.

Thus, for the purposes of this rulemaking, DOE considered lamps that have an ANSI base, are not a light fixture, have a lumen output of 310 lumens or greater, operate at line voltage or low voltage, are not the subject of other rulemakings, are not or could not be considered in another rulemaking proceeding, and are not designed and labeled for use in the following non-general applications, as meeting the definition of GSL: appliance lamps, black light lamps, bug lamps, colored lamps, infrared lamps, marine signal lamps, mine service lamps, plant light lamps, sign service lamps, silver bowl lamps, showcase lamps, and traffic signal lamps.

3.2.5.1 High Lumen Lamps (> 2,600 Lumen)

As stated, DOE is considering lamps with a lumen output of at least 310 lumens as meeting the definition of a GSL. Regarding lamps with a lumen output greater than 2,600 lumens, DOE believes that these lamps can be used in overall illumination and therefore meet the definition of GSL. However, as discussed in section 3.2.1, due to the restrictions of the Appropriations Rider, DOE is unable to consider modifying existing exemptions for GSILs and therefore is not currently including GSILs with lumen output greater than 2,600 lumens in the scope of the rulemaking. DOE believes that establishing energy conservation standards for higher lumen lamps, while not also addressing higher lumen incandescent lamps, may ultimately increase national energy consumption. Further, DOE notes that higher lumen output lamps exist in more efficient technologies (*e.g.*, integrated and non-integrated CFLs). More efficient products typically have lower operating costs but higher initial costs relative to the baseline products available on the market. Because the GSILs with lumen outputs greater than 2,600 lumens are exempt from standards, consumers may choose to purchase incandescent lamps rather than more expensive CFL and LED lamps. Therefore, while DOE considers GSLs to have only the lower bound lumen output of 310 lumens or less, DOE is considering not establishing standards for GSLs with lumen outputs greater than 2,600 lumens at this time.

3.2.5.2 General Service Lamps that Operate in Standby Mode

DOE identified lamps that meet the definition of GSL and can operate in standby mode. Feedback from manufacturers during interviews indicated that few GSLs provide standby mode functionality. Manufacturers noted that only a handful of such lamps exist, and it is a niche market at this time. DOE also found, based on manufacturer feedback, that GSLs that operate in standby mode use a variety of methods to achieve the desired functionality (*e.g.*, remotely turn the lamp on or off, changing lamp color, dimming the lamp), which results in differing power consumption and utility provided. DOE believes that while such GSLs currently represent a very small fraction of the GSL market, the market share for GSLs that can operate in standby mode will increase over the analysis period. Thus, due to the increasing market share of these products, DOE is considering establishing standards for GSLs with standby mode power at this time.

3.2.5.3 Integrated Lamps

Integrated lamps (also referred to as self-ballasted lamps) contain all components necessary to start and operate a lamp and directly connect to a branch circuit via an ANSI base. DOE considered integrated lamps that are not or could not be considered in another rulemaking proceeding, have a lumen output equal to or greater than 310 lumens, have an ANSI base, are not a light fixture, and are not designed and labeled for use in the non-general applications described in section 3.2.5, to meet the definition of general service lamp. The following sections discuss these general service integrated lamps by base type and identify lamps for which DOE is considering establishing standards at this time.

Medium Screw Base

Medium screw base integrated lamps are offered in a variety of technologies and are also offered with or without a reflector. Medium screw base lamps are the most common lamps on the market, given the proliferation of the medium screw base socket. While most of these lamps are omnidirectional, many are also offered with reflectors, which are used to direct the light. Reflector lamps are commonly used in track lighting and recessed can light fixtures. Medium screw base integrated lamps provide overall illumination and are commonly found in residential, commercial, and industrial locations.

Non-reflector medium screw base integrated lamps exist primarily in three technologies: incandescent/halogen, compact fluorescent, and LED.[a] DOE is not considering GSILs that have a medium screw base in this rulemaking due to the Appropriations Rider (see section 3.2.1.).

MBCFLs are addressed in section 3.2.2. As standards already exist for these products, this rulemaking considers whether to amend standards for MBCFLs. DOE also identified lamps that can serve in general lighting applications that use a CFL as the primary lighting source and also contain either a halogen capsule or an LED. The hybrid lamps that DOE identified meet the definition of MBCFL, though the term "hybrid CFL" is not currently defined. DOE is considering a definition for "hybrid CFL" in the CFL TP rulemaking. The definition under consideration is as follows:

> *Hybrid compact fluorescent lamp* means a compact fluorescent lamp that incorporates one or more supplemental light sources of different technology.

Because MBCFLs are included in the scope of this rulemaking hybrid lamps are also included in the scope.

Medium screw base integrated LED lamps are rapidly increasing their market share relative to incandescent/halogen and compact fluorescent technology. In the most recent lamp indices data published by the National Electrical Manufacturers Association (NEMA) for the

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[a] In addition, DOE identified non-reflector medium screw base integrated lamps available in mercury vapor technology. These lamps are discussed in more detail in section 3.2.5.

fourth quarter of 2013, the market share of LED A-shape replacement lamps increased 42.3 percent over the previous quarter.[1] Given their nontrivial market share, DOE has tentatively concluded that standards for medium screw base integrated LED lamps would result in significant energy savings. Technology for these lamps is rapidly changing with further improvements in lamp efficacy possible, thus DOE has tentatively concluded that standards for these lamps are technologically feasible.

Reflector medium screw base integrated lamps are also typically offered with incandescent/halogen, compact fluorescent, or LED technology. Incandescent reflector lamps (IRLs) are specifically excluded from the definition of GSL and therefore will not be considered in this rulemaking. Based on data from the 2010 LMC, DOE determined that reflector CFLs compose less than 2 percent of the total inventory of lamps in the United States. The LED lamp data is not given by lamp shape, however LED lamps compose less than 1 percent of the total inventory of lamps in the United States, of which reflector LED lamps would be an even smaller portion. Although DOE believes that LED reflector lamps may compose a growing portion of the reflector lamp market, DOE has tentatively determined that establishing energy conservation standards for these lamps may ultimately increase national energy consumption. More efficient products typically have lower operating costs but higher initial costs relative to the baseline products available on the market. Because IRLs are not considered in this rulemaking and would be subject to separate, less stringent efficacy requirements, consumers may choose to purchase IRLs rather than more expensive CFL and LED reflector lamps. Further, because IRLs are less efficacious, they require more energy to produce the same amount of light as CFLs and LED lamps and thus any shift to these products could increase overall energy consumption. For these reasons, DOE has tentatively decided to not establish energy conservation standards for reflector medium screw base integrated lamps at this time.

Candelabra and Intermediate Base

Candelabra and intermediate base integrated lamps are offered with incandescent/halogen, compact fluorescent, and LED technology. The candelabra base is the more common of the two base types – about 5 percent of product offerings compared to less than 1 percent for the intermediate base. Candelabra and intermediate base integrated lamps provide overall illumination and are found primarily in residential locations.

Non-reflector candelabra and intermediate base integrated lamps exist primarily in three technologies: incandescent/halogen, compact fluorescent, and LED. DOE is not considering incandescent/halogen lamps that have a candelabra or intermediate screw base in this rulemaking due to the Appropriations Rider. A review of compact fluorescent and LED product offerings indicates that few products are offered in these technologies compared to the number offered with incandescent/halogen technology. After reviewing the available product information, DOE does not believe it is appropriate to establish energy conservation standards for these lamps at this time. DOE found that a large number of CFL and LED candelabra and intermediate base lamps do not have standard ANSI shape designations. DOE believes these non-standard form factors could prevent the CFL and LED lamps from serving in the same applications as lamps with incandescent/halogen technology, and thus these lamp types may not be available at higher levels of efficacy. For these reasons, DOE has tentatively decided to not establish energy conservation standards for non-reflector candelabra and intermediate base integrated lamps at this time.

At the time of this analysis, the vast majority of candelabra and intermediate base integrated lamps were omnidirectional. DOE identified one incandescent/halogen reflector candelabra base integrated lamp and a limited number of incandescent/halogen reflector intermediate base integrated lamps. However, as stated previously, DOE is not considering these lamp types due to the Appropriations Rider. DOE was unable to identify reflector candelabra base or intermediate base integrated lamps in CFL or LED technology. For these reasons, DOE does not believe that standards for reflector candelabra and intermediate base integrated lamps would result in significant energy savings. Therefore, DOE has tentatively decided to not establish energy conservation standards for these lamps at this time.

Pin Base

DOE considers pin base integrated lamps to be integrally ballasted lamps (if applicable) with plug-in lamp bases that operate on line voltage (*i.e.*, connect directly to the branch circuit without the use of a transformer). Pin base integrated lamps are offered in a variety of technologies and are also offered with or without a reflector. Common pin base integrated lamps are tubular quartz halogen lamps, GU24 base lamps, and GU10 base lamps with a MR shape. Pin base integrated lamps provide overall illumination and are found predominately in residential and commercial locations. DOE is considering defining terms related to pin base lamps in support of the scope of this rulemaking. The terms DOE is considering are as follows:

> *Pin base lamp* means a lamp that uses a base type designated as a single pin base or multiple pin base system in Table 1 of ANSI C81.61, Specifications for Electrics Bases (incorporated by reference; see §430.3).
>
> *GU24 base* means the GU24 base standardized in ANSI C81.61 (incorporated by reference; see §430.3).

Non-reflector pin base integrated lamps are available with multiple pin bases and exist with incandescent/halogen, CFL, and LED technology. The incandescent/halogen non-reflector pin base integrated lamps (*e.g.*, G8 and G9 base tubular halogen quartz lamps) have few products available on the market. CFL and LED non-reflector pin base integrated lamps commonly use GU24 bases. Of the integrated pin bases considered, lamps with GU24 bases compose the vast majority of the market. The GU24 base was created as a substitute to the medium screw base to prevent the use of incandescent/halogen lamps. While GU24 lamps may not currently be sold in the same volume as medium screw base lamps, DOE expects their sales to increase considerably as a result of regulations and voluntary program specifications. For example, California’s Building Code Standards Title 24 requires high efficiency lighting to be installed, thus prohibiting screw base sockets.[2] Similarly, the *ENERGY STAR® Program Requirements for Luminaires (Light Fixtures) V1.2* specification prohibits the use of screw bases (*e.g.*, E26) in luminaires in order to achieve ENERGY STAR certification.[3] Given their expected market share, DOE has tentatively concluded that standards for non-reflector GU24 base integrated lamps would result in significant energy savings. Furthermore, because these lamps exist in varying levels of efficacy (*i.e.*, CFL and LED technology), DOE has tentatively concluded that standards for these lamps would be technologically feasible.

Reflector pin base integrated lamps are also offered with multiple pin bases, but in contrast to non-reflector lamps, the GU10 base is the most common base for reflector lamps. Although products are offered with incandescent/halogen, CFL, and LED technology, there are very few CFL products and halogen and LED lamp options dominate the market. Although DOE believes these lamps compose a sizeable portion of the reflector lamp market, DOE does not believe it is appropriate to establish energy conservation standards for these lamps at this time. DOE does not believe that LED technology is currently able to provide the same utility as halogen technology in the MR16 lamp shape. MR lamps are used in recessed downlights and track lighting, typically in retail, hospitality, residential, and museum applications.[4] As noted by DOE's CALiPER program, halogen MR16 lamps deliver focused illumination from their small (2 inch) diameter, have desirable color quality, are easy to use with controls, and are available with a range of different options (*e.g.*, beam angle and intensity) and accessories (*e.g.*, spread lenses). Given this combination of features, the conventional halogen MR16 lamp is one of the most difficult lamps for LED technology to successfully replicate.[5] A recent report by DOE's CALiPER program found that every LED MR16 that claimed to be a replacement for a halogen MR16 produced fewer lumens and had lower center beam intensity than would be predicted using the ENERGY STAR center beam intensity tool. While new products continue to enter the market, LED MR16s still do not offer the same lumen packages as available halogen MR16s (particularly above 500 lumens). This difference is likely because LED lamps must incorporate a driver into an already small form factor and struggle to efficiently dissipate heat to achieve optimal performance. Because more efficient replacements that maintain the same utility are not currently available, DOE has tentatively decided to not establish energy conservation standards for reflector pin base integrated lamps at this time.

Other Bases

Additional base types exist for integrated lamps, including other screw bases, however DOE identified very few integrated non-reflector and reflector lamps with these base types. DOE has tentatively concluded that given their low market share, standards for non-reflector and reflector lamps with other bases such as mogul bases and bayonet bases would not result in significant energy savings.

3.2.5.4 Non-Integrated Lamps

Non-integrated lamps (also referred to as externally ballasted lamps) are lamps that do not contain all components necessary for the starting and stable operation of the lamp. Non-integrated lamps require an external component, such as a ballast, driver, or transformer to operate on a branch circuit. DOE considered non-integrated lamps that are not or could not be considered in another rulemaking proceeding, have a lumen output equal to or greater than 310 lumens, have an ANSI base, are not a light fixture, and are not designed and labeled for use in the non-general applications described in section 3.2.5, to meet the definition of general service lamp. The following sections discuss general service non-integrated lamps by base type and identify lamps for which DOE is considering establishing standards at this time.

Screw Base

Non-reflector and reflector screw base non-integrated lamps are very uncommon and are available in a limited range of technologies. DOE identified one non-reflector medium screw base non-integrated lamp that may meet the definition of GSL. The non-reflector screw base non-integrated lamp is a CFL intended to be used in marine applications and operates using a battery. Similarly, DOE identified few reflector screw base non-integrated lamps. The reflector screw base non-integrated lamp type it did identify is used for providing illumination in pool and spa applications. DOE has tentatively concluded that given their extremely low market share, standards for non-reflector and reflector screw base non-integrated lamps would not result in significant energy savings and is therefore not considering establishing standards for these products at this time.

Pin Base

DOE considers pin base non-integrated lamps to be lamps that use a single pin base or multiple pin base system (as defined by ANSI 81.61) and operate using an external ballast, driver, or transformer. Pin base non-integrated lamps are offered in a variety of technologies and are also offered with or without a reflector. Pin base non-integrated lamps provide overall illumination and are found in residential, commercial, and industrial locations. Common lamp types considered pin base non-integrated lamps are pin base CFLs and low voltage incandescent/halogen lamps with or without a reflector.

Although non-reflector pin base non-integrated lamps are available in incandescent/halogen, CFL, and LED technologies, CFLs are by far the most common type. As stated previously, DOE determined that the term compact fluorescent includes both integrated and non-integrated CFLs and therefore DOE is considering including non-integrated, or pin base, CFLs in the scope of this rulemaking. Pin base CFLs are available in a variety of pin bases including 2-pin and 4-pin configurations such as the G24d-3 and G24q-3 bases, respectively.

DOE notes that the market share of pin base CFLs is not insignificant given the vast number of product offerings and common use in commercial applications. Given their nontrivial market share, DOE has tentatively concluded that standards for pin base CFLs could result in significant energy savings. As discussed in chapter 5 of this TSD, DOE identified some variation in levels of efficacy for non-integrated lamps and therefore believes standards are technologically feasible.

Incandescent/halogen non-reflector pin base non-integrated lamps include quartz halogen lamps that operate on low voltage and thus require the use of a transformer. Common base types for these lamps include G4 and GY6.35 bases. Incandescent/halogen non-reflector pin base non-integrated lamps have few products available on the market. A very limited number of LED non-reflector pin base non-integrated lamps with the same base types, and thus intended to replace the incandescent/halogen versions, are available on the market currently. DOE has tentatively concluded that given their low market share, standards for non-reflector pin base non-integrated lamps would not result in significant energy savings. Further, because LED technology is changing rapidly, DOE believes that establishing standards for these products may slow innovation in a market that appears to be developing.

Reflector pin base non-integrated lamps are also offered with multiple pin bases, but in contrast to non-reflector lamps, the GU5.3 base is the most common base and corresponds to the MR16 lamp shape. Although products are offered with incandescent/halogen, CFL, and LED technology, incandescent/halogen and LED lamp options dominate the market and there are very few CFL products. DOE notes that MR16 lamps can be used in general lighting applications. Although DOE believes these lamps provide overall illumination and compose a sizeable portion of the reflector lamp market, DOE does not believe it is appropriate to establish energy conservation standards for these lamps at this time. For the same reasons described for reflector pin base integrated lamps in section 3.2.5.3, DOE does not believe that LED technology is currently able to provide the same utility as halogen technology in the MR16 lamp shape. Additionally, LED reflector pin base non-integrated lamps have the added complexity of needing to be compatible with an existing transformer. Because replacements that are more efficient and yet maintain the same utility are not currently available, DOE has tentatively decided to not establish energy conservation standards for reflector pin base integrated lamps at this time.

Other Bases

DOE did not identify any additional base types for non-integrated lamps that meet the definition of GSL.

3.2.6 Summary of Lamps

In summary, while many different lamp types meet the definition of GSL, DOE is only considering establishing standards in this rulemaking for the following lamps:

- Integrated, non-reflector, medium screw base lamps with a lumen output between 310 and 2,600 lumens;
- GU24 base, non-reflector lamps with a lumen output between 310 and 2,600 lumens; and
- Non-integrated, non-reflector, pin base, CFLs with a lumen output between 310 and 2,600 lumens.

Standards would not apply to the follow lamp types:

- OLED lamps
- Mercury vapor lamps
- IRLs
- GSFLs

- Light fixtures
- Appliance lamps
- Black light lamps
- Bug lamps
- Colored lamps
- Infrared lamps
- Marine signal lamps
- Mine service lamps
- Plant light lamps
- Sign service lamps
- Silver bowl lamps
- Showcase lamps
- Traffic signal lamps
- GSILs that are:
    - A left-hand thread lamp
    - A marine lamp
    - A reflector lamp
    - A rough service lamp
    - A shatter-resistant lamp (including a shatter-proof lamp and a shatter-protected lamp)
    - A 3-way incandescent lamp
    - A vibration service lamp
    - A G shape lamp (as defined in ANSI C78.20) (incorporated by reference; see §430.3) and ANSI C79.1-2002 (incorporated by reference; see §430.3) with a diameter of 5 inches or more
    - A T shape lamp (as defined in ANSI C78.20) (incorporated by reference; see §430.3) and ANSI C79.1-2002 (incorporated by reference; see §430.3) and that uses not more than 40 watts or has a length of more than 10 inches
    - A B, BA, CA, F, G16-1/2, G-25, G30, S, or M-14 lamp (as defined in ANSI C79.1-2002) (incorporated by reference; see §430.3) and ANSI C78.20 (incorporated by reference; see §430.3) of 40 watts or less.

3.3 SCOPE OF METRICS

In this section, DOE discusses the scope of metrics included in this rulemaking. This rulemaking satisfies the requirements under 42 U.S.C 6295(m)(1) to review existing standards for MBCFLs, as CFLs are included in the definition of a GSL. EPAct 2005 amended EPCA by establishing energy conservation standards for MBCFLs. Performance requirements were specified for five metrics: (1) minimum initial efficacy; (2) lumen maintenance at 1,000 hours; (3) lumen maintenance at 40 percent of lifetime; (4) rapid cycle stress; and (5) lamp life. (42 U.S.C. 6295(bb)(1))

In addition to revising the existing requirements for MBCFLs, DOE has the authority to establish requirements for additional metrics including color rendering index (CRI), power factor, operating frequency, and maximum allowable start time based on the requirements prescribed by the August 9, 2001, ENERGY STAR Program Requirements for CFLs Version 2.0, or establish other requirements after considering energy savings, cost effectiveness, and consumer satisfaction. (42 U.S.C. 6295(bb)(2)-(3)) Therefore, as part of this rulemaking, DOE is reviewing whether all five existing metrics for MBCFLs should be amended and if additional performance requirements, including CRI, power factor, frequency, and start time, among others, should be added.

3.3.1 Existing Metrics for MBCFLs

DOE is considering revising existing metrics and incorporating new metrics that improve the quality of MBCFLs. As stated previously, standards currently exist for initial lamp efficacy, lumen maintenance at 1,000 hours, lumen maintenance at 40 percent of lifetime, rapid cycle stress, and lamp lifetime. The current standards are based on August 9, 2001, ENERGY STAR Program Requirements for CFLs Version 2.0. ENERGY STAR has since released several updates to the specification, the latest of which was finalized in August 2014, ENERGY STAR Lamps Specification V1.1. DOE assessed the revisions in the ENERGY STAR specification for the five existing metrics required by DOE and also surveyed the specifications of commercially available MBCFLs to determine current product performance for the five existing metrics.

The current energy conservation standards for efficacy of MBCFLs vary based on wattage and whether the lamp has a cover. The ENERGY STAR Lamps Specification V1.1 revised the wattage and covering divisions and increased the minimum lamp efficacy requirements. Based on an assessment of commercially available products, DOE determined that MBCFLs are performing above DOE's current efficacy standard. DOE is evaluating revised efficacy requirements for GSLs, which includes MBCFLs, as part of this rulemaking. (See chapter 5 of this TSD for further details.)

DOE also has minimum requirements for lumen maintenance. For lumen maintenance at 1,000 hours, DOE requires that the average of at least five lamps be a minimum of 90 percent of initial lumen output at 1,000 hours. The ENERGY STAR Lamps Specification V1.1 maintained this requirement with the added specification that all units must be surviving at 1,000 hours. For lumen maintenance at 40 percent of lifetime, DOE requires that 80 percent of the initial lumens must be achieved at 40 percent of lifetime. The ENERGY STAR Lamps Specification V1.1 also maintained this requirement with the added specification that no more than three units may be less than 75 percent of the initial lumen rating. DOE found that manufacturers do not publish information in catalogs on lumen maintenance at 1,000 hours and 40 percent of lifetime for MBCFLs. DOE assessed data submitted for the compliance certification management system (CCMS) reporting requirements and found that the majority of lamps certified exceeded the minimum lumen maintenance standards. DOE believes that the current requirements for lumen maintenance adequately address potential issues with lumen depreciation that could lead to consumer dissatisfaction and is therefore considering maintaining the existing requirements for lumen maintenance at 1,000 hours and lumen maintenance at 40 percent of lifetime.

Additionally, there is a minimum requirement for rapid cycle stress for MBCFLs. DOE requires that at least five lamps must survive cycling once per every two hours of rated life. The

ENERGY STAR Lamps Specification V1.1 changed the cycling requirement to once per hour of rated lifetime or a maximum of 15,000 cycles. The ENERGY STAR Lamps Specification V1.1 added an exception for instant start CFLs with a start time less than or equal to 100 milliseconds (ms), which are only required to survive cycling once per every two hours of rated life. For MBCFLs other than instant start CFLs, the increased requirement for rapid cycle stress provides consumer satisfaction by ensuring that MBCFLs are able to survive frequent switching and preventing premature failure. DOE found that manufacturers do not publish information on rapid cycle stress or starting method for MBCFLs. Further, manufacturers simply report the number of surviving units for DOE CCMS reporting requirements. However, DOE has received feedback from manufacturers that the market shifts in response to ENERGY STAR specifications and so DOE believes that MBCFLs are likely already achieving this level of product performance for rapid cycle stress. Therefore, DOE is considering increasing the number of cycles required for non-instant start lamps (*i.e.*, lamps with start times greater than 100 ms) to once per every hour of rated life with a maximum of 15,000 cycles to reduce testing burden.

DOE currently requires a minimum lifetime of 6,000 hours for MBCFLs. The ENERGY STAR Lamps Specification V1.1 revised the minimum lifetime requirement to be 10,000 hours. Lifetime impacts consumer satisfaction as a longer life requires less frequent changes. Based on an assessment of commercially available lamps in manufacturer catalogs, DOE found that the majority of MBCFLs on the market have lifetimes of at least 10,000 hours. Further, of the MBCFLs for which data was submitted to DOE for CCMS reporting, 73 percent have a lifetime of at least 10,000 hours. The ENERGY STAR Certified Light Bulbs Database also supports an increased lifetime with 79 percent of certified products having a lifetime of at least 10,000 hours.[b] Because DOE found that commercially available MBCFLs are already achieving this higher level of performance, DOE is considering revising the lifetime standard for MBCFLs to be a minimum of 10,000 hours.

3.3.2 Additional Metrics for MBCFLs

With respect to requiring additional metrics for MBCFLs, DOE considered power factor, THD, CRI, correlated color temperature (CCT), operating frequency, and start time. DOE's evaluation of these potential metrics for MBCFLs is detailed below.

DOE has explicit authority to consider power factor for MBCFLs. (42 U.S.C. 6295(bb)(2)) Power factor is the ratio of active input power to apparent input power. A low power factor product is inefficient and requires an increase in electric utility's generation and transmission capacity.[6] Because a minimum power factor requirement could decrease energy use, DOE is considering power factor in this rulemaking. Total harmonic distortion is defined as the ratio of the root mean square (rms) values of the harmonic content to that of the fundamental current, expressed as a percentage. Because THD is directly related to power factor, setting a minimum power factor requirement will effectively set a standard for THD and therefore DOE is not considering a setting a separate requirement for THD.

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[b] *ENERGY STAR Program Requirements Product Specification for Lamps (Light Bulbs) Eligibility Criteria Version 1.0* becomes effective September 30, 2014, at which time the updated lifetime of 10,000 hours will be required.

DOE reviewed industry specifications for MBCFLs and found that the ENERGY STAR Lamps Specification V1.1 requires that CFLs have a power factor of 0.5 or greater. ENERGY STAR does not have a separate requirement for THD. The industry standard ANSI C82.77 Harmonic Emission Limits – Related Power Quality Requirements for Lighting Equipment suggests a power factor of 0.5 for integrally ballasted medium screw base compact light sources with input power less than or equal to 35 watts. Based on an assessment of commercially available lamps in manufacturer catalogs, DOE determined that the majority of MBCFLs have a power factor in the range of 0.5 to 0.6 and a limited number of MBCFLs have a power factor greater than 0.6. The ENERGY STAR Certified Light Bulbs Database supported this distribution with about 77 percent of MBCFLs with a power factor in the range of 0.5 to 0.6 and only about two percent of MBCFLs had a power factor greater than 0.8. Thus, DOE believes that requiring a minimum power factor of 0.5 is achievable for MBCFLs while supporting improved overall efficacy. It is also consistent with ENERGY STAR requirements and recommendations in industry standards. DOE is considering adding the requirement for MBCFLs to have a power factor of 0.5 or greater and no separate requirement for THD.

DOE does not currently have a standard for CRI, however, DOE has explicit authority to consider CRI for MBCFLs. (42 U.S.C. 6295(bb)(2)) CRI is a measure of the color rendering properties of a light source, or the ability of a light source to show the “true” color of an object as compared to a reference source.[7] A standard for CRI ensures consumer satisfaction because high CRI light sources render colors well. The ENERGY STAR Lamps Specification V1.1 requires that CFLs have a CRI of at least 80. It also requires that no more than 3 units included in the average have a CRI less than 77 and no units have a CRI less than 75. Based on an assessment of commercially available lamps in manufacturer catalogs, DOE found that over 99 percent of MBCFLs on the market have a CRI of at least 80. DOE identified only a few MBCFLs with a CRI of less than 80. Because a minimum CRI requirement would increase consumer satisfaction and DOE found that nearly all commercially available MBCFLs are already achieving a CRI of at least 80, DOE is considering requiring MBCFLs to have a CRI of 80 or greater.

DOE does not have a standard for correlated color temperature (CCT). CCT is a measure of the perceived color of the white light emitted from a lamp.[8] Lower CCT values correspond to warmer light, with more red content in the spectrum, and higher CCTs correspond to cooler light, with more blue content. The ENERGY STAR Lamps Specification V1.1 requires CCT to correspond to one of six nominal CCTs and fall within a prescribed chromaticity space. DOE believes that different CCTs are desirable depending on the application and therefore is not considering setting a requirement for CCT for MBCFLs.

Currently, DOE does not have a standard for operating frequency. Operating frequency is the frequency of the current measured in hertz supplied by the ballast to the lamp during operation. The ENERGY STAR Lamps Specification V1.1 requires that CFLs have a frequency within 20 to 33 kHz or at least 40 kHz. Requiring an operating frequency within a specified range ensures that lamps do not interfere with other electrical products, such as television remotes. Because operating frequency does not directly impact consumer satisfaction, DOE is not considering setting standards for operating frequency at this time.

DOE does not currently have a standard for start time. The ENERGY STAR Lamps Specification V1.1 requires that the time needed for a lamp to become fully illuminated must be within one second of application of electrical power. DOE believes that start time impacts consumer satisfaction because a delay in starting is undesirable and can affect acceptance of a more efficient lamp technology. DOE reviewed manufacturer catalogs and the ENERGY STAR Certified Light Bulbs Database and found that neither start time nor starting method is typically reported. DOE is considering requiring a start time of within one second of the application of electrical power because the market likely finds one second an acceptable start time since it has been the ENERGY STAR specification for several years.

3.3.3 Summary

Table 3.3.1 summarizes the metrics and corresponding requirements that DOE is considering for MBCFLs.

Table 3.3.1 Performance Metrics for Medium Base Compact Fluorescent Lamps

Metric	Minimum Standard Considered
Efficacy	See chapter 5 of this TSD for more information on candidate standard levels under consideration.
Lumen Maintenance at 1,000 hours	90 percent of initial lumen output at 1,000 hours
Lumen Maintenance at 40 percent of Lifetime	80 percent of initial lumen output at 40 percent of lifetime
Rapid Cycle Stress	MBCFL with start time > 100 ms: survive one cycle per hour of rated lifetime or a maximum of 15,000 cycles MBCFLs with a start time of ≤ 100 ms: survive one cycle per every two hours of rated lifetime
Lifetime	10,000 hours
Power Factor	0.5
CRI	80
Start Time	The time needed for a MBCFL to become fully illuminated must be within one second of application of electrical power

3.4 MARKET ASSESSMENT

For GSLs, the following market assessment identifies the relevant manufacturer trade association and domestic manufacturers; discusses manufacturer market share, regulatory programs, and non-regulatory initiatives; provides historical shipment data and market trends; and defines product classes.

3.4.1 Trade Association

The National Electrical Manufacturers Association (NEMA) is the trade association for GSLs. NEMA's Lighting Systems Division is one of ten product divisions, and is further divided into six product sections. Feedback from manufacturer interviews indicated that the Lamp Section's 27 member companies comprise a significant portion of the U.S. halogen lamp market, but a much lesser portion of the U.S. CFL and LED lamp markets. In addition to GSLs, NEMA's Lighting Systems Division also oversees products such as emergency lighting, lighting controls, and emerging lighting technologies. NEMA provides an organization through which manufacturers of lighting equipment can work together on projects that affect their industry and businesses. NEMA's activities relating to energy efficiency include:[9]

- “Advising the Department of Energy (DOE) and executive agencies on lighting research and market transformation needs
- Participating in the climate change discussions with the Administration and Congress
- Monitoring energy-efficiency rulemakings and standards affecting lighting products by DOE and states
- Promoting the national voluntary luminaire rating and information program under the National Lighting Collaborative
- Supporting adoption of new ASHRAE/IESNA 90.1 lighting provisions
- Advising the DOE Federal Energy Management Program on energy efficient lighting recommendations
- Coordinating with DOE and the Environmental Protection Agency on ENERGY STAR Buildings and ENERGY STAR voluntary product labeling programs.
- Advocating market-based approaches to enhance the use and penetration of energy-efficient technologies”

3.4.2 Manufacturers and Market Share

The following list contains the names of some manufacturers that produce GSLs:

- Bulbrite Industries, Inc.
- Cree, Inc.
- EiKO Global, LLC
- Feit Electric Company, Inc.
- General Electric Company
- GREEN CREATIVE, LLC.
- Halco Lighting Technologies
- Lighting Science Group Corp.
- Litetronics International, Inc.
- MaxLite, Inc.
- OSRAM SYLVANIA, Inc.
- Philips Lighting Company
- Premium Quality Lighting, Inc.
- Satco Products, Inc.
- Technical Consumer Products, Inc.
- Toshiba International Corp.
- Ushio America, Inc.
- Westinghouse Lighting Corp.
- Zenaro Lighting, Inc.

3.4.2.1 Small Businesses

Small businesses may be particularly affected by the promulgation of minimum energy conservation standards for GSLs. The Small Business Administration (SBA) lists small business size standards that are matched to industries as they are described in the North American

Industry Classification System (NAICS). A size standard is the largest that a for-profit concern can be and still qualify as a small business for Federal Government programs. These size standards are generally the average annual receipts or the average employment of a firm. For lamps, the size standard is matched to NAICS code 335110, *Electric Lamp Bulb and Part Manufacturing*, which has a size standard of 1,000 employees or fewer.[10]

DOE studies the potential impacts on these small businesses in detail as part of the manufacturer impact analysis.

3.4.3 Regulatory Programs

Several federal and international regulatory programs affect the markets for GSLs. The following section summarizes U.S., Canadian, and European regulatory initiatives relevant to the lamps covered by this rulemaking. While the following discussion is not exhaustive in describing all regulatory action related to GSLs, it provides detail on some notable initiatives that characterize recent developments in the lighting market.

3.4.3.1 GSL Federal Energy Conservation Standards

EPCA established an energy conservation program for major household appliances. Additional amendments to EPCA gave DOE the authority to regulate the energy efficiency of several products, including GSL types. Specifically, the Energy Policy Act of 2005 established standards for MBCFLs. The standards mandate that lamps manufactured on or after the specified effective dates must meet the minimum lumen maintenance, rapid cycle stress test, average rated lamp life, and average lamp efficacy requirements. 10 CFR Section 430.32(u) DOE published a technical amendment in October 2005 that codified the EPAct 2005 standards into the CFR with an effective date of January 1, 2006. Table 3.4.1 presents these Federal standards.

Table 3.4.1 EPAct 2005 Federal Regulations for Medium Base Compact Fluorescent Lamps

Factor	Requirements
Lamp Power (Watts) & Configuration[1]	Minimum Efficacy: lumens/watt (Based upon initial lumen data).[2]
Bare Lamp:	
Lamp Power < 15	45.0.
15 ≤ Lamp Power	60.0.
Covered Lamp (no reflector):	
Lamp Power < 15	40.0.
15 ≤ Lamp Power < 19	48.0.
19 ≤ Lamp Power < 25	50
25 ≤ Lamp Power	55.0.
1,000-hour Lumen Maintenance	The average of at least 5 lamps must be a minimum 90.0% of initial (100-hour) lumen output @ 1,000 hours of rated life.
Lumen Maintenance	80.0% of initial (100-hour) rating at 40 percent of rated life (per ANSI C78.5 Clause 4.10).

Rapid Cycle Stress Test	Per ANSI C78.5 and IESNA LM-65 (clauses 2,3,5, and 6). *Exception:* Cycle times must be 5 minutes on, 5 minutes off. Lamp will be cycled once for every two hours of rated life. At least 5 lamps *must meet or exceed* the minimum number of cycles.
Average Rated Lamp Life	≥6,000 hours as declared by the manufacturer on packaging. At 80% of rated life, statistical methods may be used to confirm lifetime claims based on sampling performance.

[1] Take performance and electrical requirements at the end of the 100-hour aging period according to ANSI Standard C78.5. The lamp efficacy shall be the average of the lesser of the lumens per watt measured in the base up and/or other specified positions. Use wattages placed on packaging to select proper specification efficacy in this table, not measured wattage. Labeled wattages are for reference only.

[2] Efficacies are based on measured values for lumens and wattages from pertinent test data. Wattages and lumens placed on packages may not be used in calculation and are not governed by this specification. For multi-level or dimmable systems, measurements shall be at the highest setting. Acceptable measurement error is ±3%.

EISA also prescribed new standards for GSILs which DOE codified into the CFR on March 23, 2009. The standards mandate that lamps manufactured on or after the specified effective dates must meet minimum lifetime and lumen output requirements for a given wattage. (42 U.S.C. 6295(i)(1)); 10 CFR Section 430.32(x)(1)). Further, the standards require GSILs to have a CRI greater than or equal to 80, and the modified spectrum GSILs have a CRI greater than or equal to 75. 10 CFR Section 430.32(x)(1) Table 3.4.2 and Table 3.4.3 show the standards which had effective dates ranging from January 1, 2012 to January 1, 2014.

Table 3.4.2 EISA 2007 Federal Regulations for General Service Incandescent Lamps

Rated Lumen Ranges	Maximum Rated Wattage	Minimum Rated Lifetime	Effective Date
1,490-2,600	72	1,000 hrs	1/1/2012
1,050-1,489	53	1,000 hrs	1/1/2013
750-1,049	43	1,000 hrs	1/1/2014
310-749	29	1,000 hrs	1/1/2014

Table 3.4.3 EISA 2007 Federal Regulations for Modified Spectrum General Service Incandescent Lamps

Rated Lumen Ranges	Maximum Rated Wattage	Minimum Rated Lifetime	Effective Date
1,118-1,950	72	1,000 hrs	1/1/2012
788-1,117	53	1,000 hrs	1/1/2013
563-787	43	1,000 hrs	1/1/2014
232-562	29	1,000 hrs	1/1/2014

Currently no energy conservation standards exist for LED lamps, OLED lamps, or the additional GSLs identified under the scope of coverage.

Title III of EPCA sets forth a variety of provisions designed to improve energy efficiency. Part B of Title III (42 U.S.C. 6291-6309) established the "Energy Conservation Program for Consumer Products Other Than Automobiles," which includes major household appliances.[c] Subsequent amendments expanded Title III of EPCA to include additional consumer products, including GSLs—the products that are the focus of this preliminary analysis. In particular, amendments to EPCA in the Energy Independence and Security Act of 2007 (EISA) directed DOE to conduct two rulemaking cycles to evaluate energy conservation standards for GSLs. (42 U.S.C. 6295(i)(6)(A)-(B))

For the first rulemaking cycle, EPCA, as amended by EISA, directs DOE to initiate a rulemaking no later than January 1, 2014, to evaluate standards for GSLs and determine whether exemptions for certain incandescent lamps should be maintained or discontinued. (42 U.S.C. 6295(i)(6)(A)(i)) The scope of the rulemaking is not limited to incandescent lamp technologies. (42 U.S.C. 6295(i)(6)(A)(ii)) Further, for this first cycle of rulemaking, the EISA amendments provide that DOE must consider a minimum standard of 45 lumens per watt (lm/W). (42 U.S.C. 6295(i)(6)(A)(ii)) If DOE fails to meet the requirements of 42 U.S.C. 6295(i)(6)(A)(i)-(iv) or the final rule from the first rulemaking cycle does not produce savings greater than or equal to the savings from a minimum efficacy standard of 45 lm/W, sales of GSLs that do not meet the minimum 45 lm/W standard beginning on January 1, 2020, will be prohibited. (42 U.S.C. 6295(i)(6)(A)(v))

The EISA-prescribed amendments direct DOE to initiate a second rulemaking cycle by January 1, 2020, to determine whether standards in effect for general service incandescent lamps (GSILs) should be amended with more stringent requirements and if the exemptions for certain incandescent lamps should be maintained or discontinued. (42 U.S.C. 6295(i)(6)(B)(i)) For this second review of energy conservation standards, the scope is not limited to incandescent lamp technologies. (42 U.S.C. 6295(i)(6)(B)(ii))

This preliminary analysis is part of DOE's first cycle of review to evaluate standards for GSLs and whether the standards should apply to additional GSL types. (42 U.S.C. 6295(i)(A) Additionally, this rulemaking satisfies the requirements under 42 U.S.C 6295(m)(1) for DOE to review the existing standards for MBCFLs, as CFLs are included in the definition of GSL. It also addresses 42 U.S.C. 6295(gg)(3) in which DOE is directed to incorporate standby mode and off mode energy use in any amended (or new) standard adopted after July 1, 2010, pursuant to 42 U.S.C. 6295(o).

3.4.3.2 California Energy Commission

California's Office of Administrative Law (OAL) enacts statewide regulatory programs published in the California Code of Regulations (CCR). CCR Title 20, Division 2, Chapter 4, Article 4, Section 1605.3 contains state standards for GSLs in accordance with the Warren-Alquist State Energy Resources Conservation and Development Act, last revised in August 2013. This law requires that lighting standards be set to achieve a 50 percent reduction in energy consumption from 2007 levels for indoor residential lighting and a 25 percent reduction from 2007 levels for indoor commercial and outdoor lighting by 2018. Current CCR standards for

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[c] Part B was re-designated Part A on codification in the U.S. Code for editorial reasons.

GSLs use a modified version of the federal GSIL standard with effective dates a year prior to the federal standard. The standards are provided in Table 3.4.4 and Table 3.4.5 below.[11]

Table 3.4.4 California Standards for State-Regulated General Service Incandescent Lamps Tier I

Rated Lumen Ranges	Maximum Rated Wattage	Minimum Rated Lifetime	Proposed California Effective Date
1,490-2,600	72	1,000 hrs	1/1/2011
1,050-1,489	53	1,000 hrs	1/1/2012
750-1,049	43	1,000 hrs	1/1/2013
310-749	29	1,000 hrs	1/1/2013

Table 3.4.5 California Standards for State-Regulated Modified Spectrum General Service Incandescent Lamps Tier I

Rated Lumen Ranges	Maximum Rated Wattage	Minimum Rated Lifetime	Proposed California Effective Date
1,118-1,950	72	1,000 hrs	1/1/2011
788-1,117	53	1,000 hrs	1/1/2012
563-787	43	1,000 hrs	1/1/2013
232-562	29	1,000 hrs	1/1/2013

Similarly, California also has proposed standards for GSLs which will precede the EISA 2007 backstop requirement of 45 lm/W effective January 1, 2020 if a GSL final rule does not yield sufficient energy savings. Section 1605.3(k)(3)(A) of the CCR states that the standards apply to any lamp intended for a general service or general illumination application, regardless of whether it is an incandescent; that has a medium screw base or any screw base not defined in ANSI C81.61-2006; and that has an operating voltage in the range of 110 to 130 V. The requirements are detailed in Table 3.4.6.[12]

Table 3.4.6 California Standards for State-Regulated General Service Lamps Tier II

Rated Lumen Ranges	Minimum Lamp Efficacy	Minimum Rated Lifetime	Proposed California Effective Date
1,490-2,600	45 lm/W	1,000 hrs	1/1/2018

Additionally, California has preliminarily proposed standards for white light LED replacement lamps and retrofit kits with E12, E17, E26, or GU24 bases. This proposal includes omnidirectional, directional, and decorative lamps. The standards, which take into account CRI and efficacy, are expected to come in a two-phase process, as detailed in Table 3.4.7. The proposal also requires omnidirectional lamps to produce a light distribution pattern that aligns with the requirements in ENERGY STAR Lamps Specification V1.1.[13] Lastly, the proposal adds labeling standards that require manufacturers to demonstrate performance before making claims of dimmability, incandescent equivalence, and meeting the Voluntary California Quality LED Lamp Specification.[14]

Table 3.4.7 California Standards for State-Regulated LED Lamps

	Compliance Equation	Minimum Lamp Efficacy	Minimum CRI	Proposed California Effective Date
Tier I	3*CRI + Efficacy ≥ 335	55 lm/W	82	1/1/2017
Tier II	3*CRI + Efficacy ≥ 350	65 lm/W	84	1/1/2019

CCR Title 24, Part 6 contains the 2013 Building Energy Efficiency Standards, Section 150.0(k) of which mandates requirements for residential lighting. These regulations were approved in May 2012 and go into effect on January 1, 2014, replacing the 2008 Building Energy Efficiency Standards. The 2013 Building Energy Efficiency Standards are 25 percent more efficient than the previous standards for residential construction and 30 percent more efficient for non-residential construction.[15] Title 24 also regulates products that can be used with GSLs, such as automatic time-switch control devices, occupancy sensors, multilevel occupancy sensors, automatic day lighting control devices, interior photosensors, multilevel and outdoor astronomical time-switch controls, manual-on occupancy sensors, and dimmers. The regulations mandate that the products have specific features and capabilities in order to be installed.

Section 150.0(k) of the CCR draws divisions between high and low efficacy light sources. The categories are laid out in Table 3.4.8 and Table 3.4.9. In order to comply with the new standards, homeowners must meet certain criteria of high efficacy lighting in various rooms of their home. The section details standards for lighting in kitchens, cabinets, bathrooms, garages, laundry rooms, utility rooms, and all other rooms. There are also stipulations for residential outdoor lighting, illuminated address signs, residential garages for eight or more vehicles, and interior common areas of low-rise multi-family residential buildings. For each space, these standards prescribe either a minimum percentage of high efficacy luminaires, a minimum quantity of high efficacy luminaires, or a maximum wattage. Some standards also include control requirements depending on the space.[16]

Table 3.4.8 California Classification of High Efficacy and Low Efficacy Light Sources

High Efficacy Light Sources	**Low Efficacy Light Sources**
Luminaires manufactured, designed and rated for use with only lighting technologies in this column shall be classified as high efficacy.	Luminaires manufactured, designed or rated for use with any of the lighting technologies in this column shall be classified as low efficacy.
1. Pin-based linear or compact fluorescent lamps with electronic ballasts. Compact fluorescent lamps ≥ 13 watts shall have 4 pins for compliance with the electronic ballast requirements in Section 150.0(k)1D. 2. Pulse-start metal halide lamps. 3. High pressure sodium lamps. 4. GU-24 sockets rated for LED lamps. 5. GU-24 sockets rated for compact fluorescent lamps. 6. Luminaires using LED light sources which have been certified to the Commission as high efficacy in accordance with Reference Joint Appendix JA8. 7. Luminaire housings rated by the manufacturer for use with only LED light engines. 8. Induction lamps. **Note:** Adaptors which convert an incandescent lamp holder to a high-efficacy luminaire shall not be used to classify a luminaire as high efficacy.	1. Line-voltage lamp holders (sockets) capable of operating incandescent lamps of any type. 2. Low-voltage lamp holders capable of operating incandescent lamps of any type. 3. High efficacy lamps installed in low-efficacy luminaires, including screw base compact fluorescent and screw base LED lamps. 3. Mercury vapor lamps. 4. Track lighting or other flexible lighting system which allows the addition or relocation of luminaires without altering the wiring of the system. 6. Luminaires using LED light sources which have not been certified to the Commission as high efficacy. 7. Lighting systems that have modular components that allow conversion between high-efficacy and low-efficacy lighting without changing the luminaires' housing or wiring. 8. Electrical boxes finished with a blank cover or where no electrical equipment has been installed, and where the electrical box can be used for a luminaire or a surface mounted ceiling fan.

Table 3.4.9 California Minimum Requirements for Other Light Sources to Qualify as High Efficacy

Use this table to determine luminaire efficacy only for lighting systems not listed in Table 3.4.7	
Luminaire Power Rating	**Minimum Luminaire Efficacy to Qualify as High Efficacy**
5 watts or less	30 lumens per watt
over 5 watts to 15 watts	45 lumens per watt
over 15 watts to 40 watts	60 lumens per watt
over 40 watts	90 lumens per watt
Note: Determine minimum luminaire efficacy using the system initial rated lumens divided by the luminaire total rated system input power.	

3.4.3.3 Nevada Governor's Office of Energy

In June of 2007, the state of Nevada adopted Assembly Bill 178 which established efficacy standards for general purpose lights sold in the state of Nevada.[17] The bill set the required efficacy to a minimum of 25 lumens per watt (lm/W) of electricity. That standard will be in effect between January 1, 2012 and December 31, 2015. The Director of the Office of

Energy must adopt regulations to establish a new minimum standard to take effect on January 1, 2016, which must exceed 25 lm/W. As used in the legislation, general purpose light means "lamps, bulbs, tubes or other devices that provide functional illumination for indoor and outdoor use. The term does not include 'specialty lighting' or 'lighting necessary to provide illumination for persons with special needs.'" Nevada Revised Statutes 701.260[18]

3.4.3.4 Canadian Energy Efficiency Standards

The Natural Resources Canada (NRCan) Office of Energy Efficiency regulates the energy efficiency of GSLs in Canada.[d] In 1992, the Canadian Parliament passed the Energy Efficiency Act (S.C. 1992, c. 36), which concerns minimum performance levels for energy-using products, effective February 1995. In December 2008, Canada's *Energy Efficiency Regulations* (SOR/2008-323) were amended to include GSLs.

Canada's approach to the regulation of GSLs differs from U.S. energy conservation standards established by EISA discussed in section 3.4.3.1. There are substantial differences in the products covered under Canada's GSL rule compared to the scope of coverage of this rulemaking. Most notably, the Canadian rule for GSLs does not include all integrally ballasted CFLs nor any lamps using solid state technology,[19] thus closely aligning with the definition of a GSIL at 10 CFR 430.2. NRCan does not currently have minimum energy performance standards (MEPs) for CFLs or LEDs, however a CFL test procedure exists in support of labeling. The first GSL standards were published in the 10th amendment to Canada's *Energy Efficiency Regulations*. In October 2013, NRCan pre-published a proposed amendment 12B, which is the most recent update of those standards. The amendment aligns Canadian standards with the EISA 2007 energy conservation standards for GSILs. The MEPs and effective dates are detailed in Table 3.4.10.[20]

Table 3.4.10 NRCan Proposed Amendment 12B

	Type of Light Bulb		Standards	Effective Date
Traditional Incandescent Light Bulb	**Standard Spectrum (lumen range)**	**Modified Spectrum (lumen range)**	**MEPS (maximum wattage)**	**Date of Manufacture (no change)**
100 W	1,490 – 2,600	1,118 – 1,950	72 W	January 1, 2014
75 W	1,050 – 1,489	788 – 1,117	53 W	January 1, 2014
60 W	750 – 1,049	563 – 787	43 W	December 31, 2014
40 W	310 – 749	232 – 562	29 W	December 31, 2014

3.4.3.5 European Energy Efficiency Standards

Commission Regulation (EC) No 245/2009 (March 18, 2009) implemented Directive 2005/32/EC (July 6, 2005) of the European Parliament and the Council of the European Union and amended Council Directive 92/42/EEC and Directives 96/57/EC and 2000/55/EC (September 18, 2000) to establish a framework for setting energy efficiency requirements for

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[d] News and information on NRCan energy efficiency regulations and standards can be found at http://www.nrcan.gc.ca/energy/regulations-codes-standards/6845.

energy-using equipment, including non-integrated CFLs. The energy efficiency requirements apply to equipment available on the market and do not differentiate requirements by lamp application. Lamps that are not white light sources, are directional, or intended for use in applications other than general lighting are exempted from standards.

The European energy efficiency requirements stipulated in Commission Regulation (EC) No 245/2009 regulate the covered equipment in three stages and for three categories. The stages implement the regulations over time with stage one effective in 2010, stage two in 2013, and stage three in 2018. The categories regulate lamp efficacy, performance, and labeling. Part of the first stage required CFLs without integrated ballasts to comply with the efficacies listed in Table 3.4.11 through Table 3.4.13 when tested at 25 °C. The rule also stipulates:

> "In case the nominal wattages or lamp shapes are different from those listed… lamps must reach the luminous efficacy of the nearest equivalent in terms of wattage and shape. If the nominal wattage is at equal distance from two wattages in the table, it shall conform to the higher efficacy of the two. If the nominal wattage is higher than the highest wattage in the table, it shall conform to the efficacy of that highest wattage."

The second and third stage efficacy requirements do not affect non-integrated CFLs.[21]

Table 3.4.11 EU Minimum Efficacy for Single Capped Fluorescent Lamps Working on Electromagnetic and Electronic Ballast

Small Single Parallel Tube, Lamp Cap G23 (2 pin) or 2G7 (4 pin)		**Double Parallel Tubes, Lamp Cap G24d (2 pin) or G24q (4 pin)**		**Triple Parallel Tubes, Lamp Cap GX24d (2 pin) or GX24q (4 pin)**	
Nominal Wattage (W)	**Rated Luminous Efficacy (lm/W) 100 hr Initial Value**	**Nominal Wattage (W)**	**Rated Luminous Efficacy (lm/W) 100 hr Initial Value**	**Nominal Wattage (W)**	**Rated Luminous Efficacy (lm/W) 100 hr Initial Value**
5	48	10	60	13	62
7	57	13	69	18	67
9	67	18	67	26	66
11	76	26	66		
4 Legs in One Plane, Lamp Cap 2G10 (4 pin)		**Long Single Parallel Tube, Lamp Cap 2G11 (4 pin)**			
Nominal Wattage (W)	**Rated Luminous Efficacy (lm/W) 100 hr Initial Value**	**Nominal Wattage (W)**	**Rated Luminous Efficacy (lm/W) 100 hr Initial Value**		
18	61	18	67		
24	71	24	75		
36	78	34	82		
		36	81		

Source: 2010/347/EU

Table 3.4.12 EU Minimum Efficacy for Single Capped Fluorescent Lamps Working on Only an Electronic Ballast

Triple Parallel Tubes, Lamp Cap GX24q (4 pin)		Four Parallel Tubes, Lamp Cap GX24q (4 pin)		Long Single Parallel Tube, Lamp Cap 2G11 (4 pin)	
Nominal Wattage (W)	**Rated Luminous Efficacy (lm/W) 100 hr Initial Value**	**Nominal Wattage (W)**	**Rated Luminous Efficacy (lm/W) 100 hr Initial Value**	**Nominal Wattage (W)**	**Rated Luminous Efficacy (lm/W) 100 hr Initial Value**
32	75	57	75	40	83
42	74	70	74	55	82
57	75			80	75
70	74				

Source: 2010/347/EU

Table 3.4.13 EU Minimum Efficacy for Single Capped Fluorescent Lamps with Square Shape or (Very) High Output

Single Flat Plane Tube, Lamp Cap GR8 (2 pin), GR10q (4 pin) or GRY10q3 (4 pin)		Four or Three Parallel T5 Tubes, Lamp Cap 2G8 (4 pin)	
Nominal Wattage (W)	**Rated Luminous Efficacy (lm/W) 100 hr Initial Value**	**Nominal Wattage (W)**	**Rated Luminous Efficacy (lm/W) 100 hr Initial Value**
10	65	60	67
16	66	82	75
21	64	85	71
28	73	120	75
38	71		
55	71		

Source: 2009/245/EC

2010/347/EU amended the efficacy deductions given in 2009/245/EC for fluorescent lamps with high color temperature, high color rendering, second lamp envelope, or long life, so that required efficacy is cumulatively reduced as shown in Table 3.4.14.[22]

Table 3.4.14 EU Deduction Percentages for Efficacy Values for Fluorescent Lamps

Lamp Parameter	Deduction from Luminous Efficacy at 25 °C
Tc* ≥ 5,000 K	-10%
95 ≥ Ra** > 90	-20%
Ra > 95	-30%
Second lamp envelope	-10%
Lamp Survival Factor ≥ 0.50 after 40,000 burning hours	-5%

*Tc is correlated color temperature.

**Ra is general color rendering index, also referred to as color rendering index.

Source: 2010/347/EU

In addition to lamp efficacy, the EU standards contain requirements for lamp performance, including lamp lumen maintenance factor (LLMF) and lamp survival factor (LSF). The LLMF describes how bright a lamp remains as a percentage of the original brightness after a given period of time, while the LSF describes how long a lamp lasts before ceasing to function and requiring replacement, and is expressed as a percentage of the number of lamps still working after a specified period of time. 2010/347/EU amended the LLMF and LSF requirements given in 2009/245/EC, and added cumulative LLMF deductions for certain lamps. Under current standards, for the first stage requirements, non-integrated fluorescent lamps must have a minimum CRI of 80. For the second stage requirements, all covered fluorescent lamps without an integrated ballast must have a minimum CRI of 80, an LLMF as shown in Table 3.4.15 and Table 3.4.16, and an LSF as shown in Table 3.4.17. Stage three performance requirements do not affect non-integrated fluorescent lamps.[23]

Table 3.4.15 EU Lamp Lumen Maintenance Factors for Fluorescent Lamps

Lamp Lumen Maintenance Factor	**Burning hours**			
Lamp Types	2,000	4,000	8,000	16,000
Double-Capped Fluorescent lamps operating on non-high frequency ballasts	0.95	0.92	0.90	--
T8 Double-Capped Fluorescent lamps on high frequency ballast with warmstart	0.96	0.92	0.91	0.90
Other Double-Capped Fluorescent lamps on high frequency ballast with warmstart	0.95	0.95	0.90	0.90
Circular Single-Capped Fluorescent lamps operating on non-high frequency ballasts, T8 U-shaped double-capped fluorescent lamps and spiral-shaped double-capped fluorescent lamps of all diameters equal to or larger than 16 mm (T5)	0.80	0.74	--	--
	0.72 at 5,000 burning hours			
Circular Single-Capped Fluorescent lamps operating on high frequency ballasts	0.85	0.83	0.80	--
	0.75 at 12,000 burning hours			
Other Single-Capped Fluorescent lamps operating on non-high frequency ballasts	0.85	0.78	0.75	--
Other Single-Capped Fluorescent lamps operating on high frequency ballast with warmstart	0.90	0.84	0.81	0.78

Source: 2010/347/EU

Table 3.4.16 EU Deduction Percentages for Fluorescent Lamp Lumen Maintenance Requirements

Lamp Parameter	**Deduction from Lamp Lumen Maintenance Requirement**
Lamps with 95 ≥ Ra* > 90	At burning hours ≤ 8,000 h: -5% At burning hours > 8,000 h: -10%
Lamps with Ra* > 95	At burning hours ≤ 4,000 h: -10% At burning hours > 4,000 h: -15%
Lamps with a color temperature ≥ 5,000 K	-10%

Source: 2010/347/EU

* Ra is general color rendering index, also referred to as color rendering index.

Table 3.4.17 EU Lamp Survival Factors for Fluorescent Lamps

Lamp Survival Factor	Burning Hours			
Lamp Types	2,000	4,000	8,000	16,000
Double-Capped Fluorescent lamps operating on non-high frequency ballasts	0.99	0.97	0.90	--
Double-Capped Fluorescent lamps on high frequency ballast with warmstart	0.99	0.97	0.92	0.90
Circular Single-Capped Fluorescent lamps operating on non-high frequency ballasts, T8 U-shaped double-capped fluorescent lamps and spiral-shaped double-capped fluorescent lamps of all diameters equal to or larger than 16 mm (T5)	0.98	0.77	--	--
	0.50 at 5,000 burning hours			
Circular Single-Capped Fluorescent lamps operating on high frequency ballasts	0.99	0.97	0.85	--
	0.50 at 12,000 burning hours			
Other Single-Capped Fluorescent lamps operating on non-high frequency ballasts	0.98	0.90	0.50	--
Other Single-Capped Fluorescent lamps on high frequency ballast with warmstart	0.99	0.98	0.88	--

Source: 2010/347/EU

In addition to non-integrated fluorescent lamps, EU began to regulate non-directional household lamps under Commission Regulation (EC) No 244/2009 (March 18, 2009) implementing Directive 2005/32/EC. The exemptions to this regulation include:

- lamps having the following x and y chromaticity coordinates:
  - $x < 0{,}200$ or $x > 0{,}600$
  - $y < – 2{,}3172\ x2 + 2{,}3653\ x – 0{,}2800$ or
  - $y > – 2{,}3172\ x2 + 2{,}3653\ x – 0{,}1000$;
- directional lamps;
- lamps having a luminous flux below 60 lumens or above 12,000 lumens;
- lamps having:
  - 6% or more of total radiation of the range 250-780 nm in the range of 250-400 nm,
  - the peak of the radiation between 315-400 nm (UVA) or 280-315 nm (UVB);
- fluorescent lamps without integrated ballast;
- high-intensity discharge lamps; and
- incandescent lamps with E14/E27/B22/B15 caps, with a voltage equal to or below 60 volts and without integrated transformer in Stages 1-5.

Similar to other EU efficiency regulations, these standards are implemented in a series of stages with increasing strictness. The first stage became effective as of September 2009 and the sixth and final stage will become effective September 2016. The baseline efficacy requirements are detailed in Table 3.4.18. EU defines a “clear lamp” as “a lamp (excluding compact fluorescent lamps) with a luminance above 25,000 cd/m^2 for lamps having a luminous flux below 2,000 lm and above 100,000 cd/m^2 for lamps having more luminous flux, equipped with only transparent envelopes in which the light producing filament, LED or discharge tube is clearly visible.” Further, EU defines a “non-clear lamp” as a lamp that does not meet the specifications of a “clear lamp,” including compact fluorescent lamps. Low lumen output lamps and lamps with G9 or R7s caps will have slightly lower standards at some stages as described in

Table 3.4.20. EU standards also include correction factors, listed in Table 3.4.21, to reduce the burden for unique products.[24]

Table 3.4.18 EU Non-Directional Household Lamp Efficacy Requirements

Application Date	Maximum Rated Power (P_{max}) for a Given Rated Luminous Flux (Φ) (W)	
	Clear Lamps	Non-clear Lamps
Stages 1 to 5	$0.8*(0.88\sqrt{\Phi}+0.049\Phi)$	$0.24\sqrt{\Phi}+0.0103\Phi$
Stage 6	$0.6*(0.88\sqrt{\Phi}+0.049\Phi)$	$0.24\sqrt{\Phi}+0.0103\Phi$

Source: 2009/244/EC

Table 3.4.19 EU Non-Directional Household Lamp Efficacy Exceptions

Scope of the Exception	Maximum Rated Power (W)
Clear Lamps 60 lm ≤ Φ ≤ 950 lm in Stage 1	$1.1*(0.88\sqrt{\Phi}+0.049\Phi)$
Clear Lamps 60 lm ≤ Φ ≤ 725 lm in Stage 2	$1.1*(0.88\sqrt{\Phi}+0.049\Phi)$
Clear Lamps 60 lm ≤ Φ ≤ 450 lm in Stage 3	$1.1*(0.88\sqrt{\Phi}+0.049\Phi)$
Clear Lamps with G9 or R7s cap in Stage 6	$0.8*(0.88\sqrt{\Phi}+0.049\Phi)$

Source: 2009/244/EC

Table 3.4.20 EU Non-Directional Household Lamp Efficacy Correction Factors

Scope of the Correction	Maximum Rated Power (W)
Filament lamp requiring external power supply	P_{max} / 1.06
Discharge lamp with cap GX53	P_{max} / 0.75
Non-clear lamp with color rendering index ≥ 90 and $P \leq 0.5*(0.88\sqrt{\Phi}+0.049\Phi)$	P_{max} / 0.85
Discharge lamp with color rendering index ≥ 90 and $T_c \leq 5{,}000$ K	P_{max} / 0.76
Non-clear lamp with second envelope and $P \leq 0.5*(0.88\sqrt{\Phi}+0.049\Phi)$	P_{max} / 0.95
LED lamp requiring external power supply	P_{max} / 1.10

Source: 2009/244/EC

The EU also requires certain functional requirements for household lamps. The requirements include: LSF, LLMF, switching cycles before failure, start time, time to reach 60 percent output, premature failure rate, maximum UV radiation, lamp power factor, and CRI. The requirements included under this regulation are listed in Table 3.4.21 and Table 3.4.22. Commission Regulation No 859/2009 amended Regulation No 244/2009 to remove ultraviolet radiation requirements for non-directional household lamps excluding CFLs and LEDs because it was technologically infeasible for tungsten halogen lamps without using a second envelope. That requirement would have effectively banned all halogen lamps as of September, 2009.[25]

Table 3.4.21 EU Non-Directional Household Lamp Functionality Requirements for CFLs

Functionality Parameter	Stage 1	Stage 5
Lamp Survival Factor at 6,000 hr	≥ 0.50	≥ 0.70
Lumen Maintenance	At 2,000 hr: ≥ 85 % (≥ 80 % for lamps with second lamp envelope)	At 2,000 hr: ≥ 88 % (≥ 83 % for lamps with second lamp envelope) At 6,000 hr: ≥ 70 %
Number of Switching Cycles Before Failure	≥ half the lamp lifetime expressed in hours ≥ 10,000 if lamp starting time > 0.3 s	≥ the lamp lifetime expressed in hours ≥ 30,000 if lamp starting time > 0.3 s
Starting Time	< 2.0 s	< 1.5 s if P < 10 W < 1.0 s if P ≥ 10 W
Lamp Warm-Up Time to 60 % Φ	< 60 s or < 120 s for lamps containing mercury in amalgam form	< 40 s or < 100 s for lamps containing mercury in amalgam form
Premature Failure Rate	≤ 2.0 % at 200 hr	≤ 2.0 % at 400 hr
UVA + UVB Radiation	≤ 2.0 mW/klm	≤ 2.0 mW/klm
UVC Radiation	≤ 0.01 mW/klm	≤ 0.01 mW/klm
Lamp Power Factor	≥ 0.50 if P < 25 W ≥ 0.90 if P ≥ 25 W	≥ 0.55 if P < 25 W ≥ 0.90 if P ≥ 25 W
CRI	≥ 80	≥ 80

Source: 2009/244/EC

Table 3.4.22 EU Non-Directional Household Lamp Functionality Requirements for Lamps Excluding CFLs and LEDs

Functionality Parameter	Stage 1	Stage 5
Rated Lamp Lifetime	≥ 1,000 hr	≥ 2,000 hr
Lumen Maintenance	≥ 85 % at 75 % rated average lifetime	≥ 85 % at 75 % rated average lifetime
Number of Switching Cycles Before Failure	≥ four times the rated lamp life expressed in hours	≥ four times the rated lamp life expressed in hours
Starting Time	< 0.2 s	< 0.2 s
Lamp Warm-Up Time to 60 % Φ	≤ 1.0 s	≤ 1.0 s
Premature Failure Rate	≤ 5.0 % at 100 hr	≤ 5.0 % at 200 hr
Lamp Power Factor	≥ 0.95	≥ 0.95

Source: 2009/895/EC

Commission Regulation No 1194/2012 (December 12, 2012) implementing Directive 2009/125/EC prescribed regulations for directional lamps, LED lamps, and related equipment. The relevant portion covering general service LED lamps creates standards only for lamp functionality and not performance. These functionality requirements are detailed in Table 3.4.23.[26]

Table 3.4.23 EU Functionality Requirements for Non-Directional and Directional LED Lamps

Functionality Parameter	**Requirement from Stage 1, Except Where Indicated Otherwise**
Lamp Survival Factor at 6,000 hr	From 1 March 2014: ≥ 0.90
Lumen Maintenance at 6,000 hr	From 1 March 2014: ≥ 0.80
Number of Switching Cycles Before Failure	≥ 15,000 if rated lamp life ≥ 30,000 otherwise: ≥ half the rated lamp life expressed in hours
Starting Time	< 0.5 s
Lamp Warm-Up Time to 95 % Φ	< 2 s
Premature Failure Rate	≤ 5.0 % at 1,000 hr
CRI	≥ 80 ≥ 65 if the lamp is intended for outdoor or industrial applications
Color Consistency	Variation of chromaticity coordinates within a six-step MacAdam ellipse or less
Lamp Power Factor for Lamps with Integrated Control Gear	P ≤ 2 W: no requirement 2 W < P < 5 W: > 0.4 5 W< P < 25 W: > 0.5 P > 25 W: > 0.9

Source: 2012/1194/EU

3.4.4 Non-Regulatory Initiatives

DOE reviewed several national, regional, and local voluntary programs that promote the use of energy efficient lighting in the United States. The following section summarizes these programs for the lamps covered by this rulemaking. While it is not an exhaustive list, the discussion provides detail on some notable initiatives that characterize voluntary energy efficiency efforts in the lighting market.

3.4.4.1 Federal Energy Management Program

The Federal Energy Management Program (FEMP) helps Federal buyers identify and purchase energy efficient products including certain CFLs and LED lamps. Section 161 of EPAct 1992 encourages energy efficient Federal procurement. Executive Order 13423 and Federal Acquisition Regulations section 23.203 requires agencies to purchase ENERGY STAR or FEMP-designated products.[27] For CFLs, FEMP typically provides recommendations of power factor and CRI. FEMP also advises consumers to buy CFLs with rated lumen output equal to or greater than the bulbs they replace in order to maintain an appropriate light levels over the lifetime of the CFL.[28] With regards to LED lamps, FEMP redirects consumers to the ENERGY STAR webpage of “LED Light Bulbs Key Product Criteria”. This page lists many performance characteristics (*e.g.*, CRI, Dimming, CCT) of LEDs and the current associated ENERGY STAR criteria for each characteristic.[29] Further, FEMP offers buyer support tools, such as efficiency guidelines, cost-effectiveness examples, and a cost calculator. FEMP also offers training, on-site audits, demonstrations, and design assistance.[30]

3.4.4.2 Consortium for Energy Efficiency

The Consortium for Energy Efficiency (CEE) aims to maximize the impact of energy efficiency programs by influencing manufacturers, stakeholders, and government agencies. The CEE leads initiatives in the residential, commercial, and industrial sectors. Their Residential Lighting Initiative, revised in 2006, primarily promotes high efficiency fixtures, CFLs, and LED lamps. With regards to CFLs, the initiative aims to ensure positive customer experience with ENERGY STAR CFLs and to increase consumer understanding of CFLs and their benefits over traditional incandescent lamps.[31] In 2011, CEE published a *Summary of Residential Lighting Programs in the United States and Canada* featuring dozens of rebate programs focused on CFLs, fluorescent fixtures, LED lamps, LED fixtures, and other products as well. The programs listed were primarily sponsored by utilities, U.S. states, and energy efficiency programs.[32]

3.4.4.3 Efficiency Vermont – Business Rebate Program & SMARTLIGHT

In Vermont, agricultural operations are eligible for prescriptive and customized incentives on equipment proven to help make farms more efficient. Efficiency Vermont gives prescriptive rebates for a variety of equipment and for lighting. Efficiency Vermont will rebate $8 to $50 for interior LED lighting products and $40 to $120 for exterior LED lighting products. Efficiency Vermont also offers $30 to $75 rebates for lighting control systems. Businesses and regular consumers can also purchase replacement lamps with rebates from local lighting distributors through the SMARTLIGHT program. The program applies to select pin and screw base LED lamps, linear fluorescents, CFLs, and metal halide lamps. The rebates range from $4 to $30 per LED lamp and $2 per CFL. This version of the rebate expires at the end of 2014.[33]

3.4.4.4 Southern California Edison – Multiple Rebate Programs

Southern California Edison (SCE) currently offers a variety of rebates to customers who are residences, multi-family building owners, or businesses. The rebates and incentives promote energy efficiency and integration of renewable energy systems. With regards to GSLs in the residential program, SCE offers both a Lamp Exchange and Light Bulb Discount program. The Lamp Exchange allows individuals meeting the program requirements to bring up to 10 incandescent or halogen luminaires to an SCE event where they can exchange those luminaires for new luminaires with ENERGY STAR labeled CFLs. Through the Light Bulb Discount program, SCE is offering up to $15 off of each LED lamp and CFL bought through participating online retailers.[34] SCE also offers rebates for business buying GSLs through its Energy Efficiency Express Solutions program. The program offers $5 to $15 per A-shape LED lamp, $30 per LED fixture, $20 to $60 per low wattage interior CFL replacement fixture, and $10 per low wattage exterior CFL replacement fixture. The program also offers rebates for different lighting control systems. This latest iteration of SCE's program is in effect for 2013-2014.[35]

3.4.4.5 Commonwealth Edison – Business Instant Lighting Discounts Program

Commonwealth Edison (ComEd) sponsors a Business Instant Lighting Discounts program that offers rebates for several GSLs. This program is part of ComEd's larger *Smart Ideas for Your Business®* program which offers incentives to businesses for everything from farm equipment to data center efficiency. The relevant portion of their lighting program offers $8 per LED lamp, $13 per LED trim kit, $1 per standard screw-in CFL, $3 per specialty CFL, $3 per high wattage CFL, and $3 per cold cathode CFL. The lamps must meet ComEd's program requirements of efficacy and performance to qualify. A-shape LED lamps must exceed 55 lm/W and LED trim kits must exceed 42 lm/W. All screw-in CFLs must be ENERGY STAR certified. This program ends May 31, 2015.[36]

3.4.4.6 Consolidated Edison – Multi-Family Energy Efficiency Program

In New York, Consolidated Edison (ConEd) runs a Multi-Family Energy Efficiency Program with rebates for energy efficiency improvements. Owners and managers of multi-family buildings (of 5 to 75 units in size) are eligible for the program. Offers include not only rebates, but also free surveys to evaluate potential energy-saving upgrades as well as free installation inside individual units. The rebate offered for A-shape LED lamps is $15 per lamp. The rebates for common area CFLs include $2 per lamp for CFLs under 32 watts, $3 per lamp for CFLs of 32 watts or more, and $35 per pin-based CFL fixture. The program also offers up to six free CFLs, including installation, per unit. There are no expiration dates for these rebates at this time.[37]

3.4.4.7 Cape Light Compact – Commercial, Industrial and Municipal Buildings Energy Efficiency Rebate Program

Through a multi-member partnership, Cape Light Compact (CLC) and MassSave offer a variety of financial incentives for commercial, industrial, and municipal facilities in Massachusetts. Custom rebate options are available for both new construction and retrofit measures in commercial/industrial buildings, as well as for small businesses and municipal projects. There are prescriptive rebates through the partnership on sensors and GSL lighting equipment and controls for eligible new and existing buildings. Rebates vary depending on whether projects are retrofit or new construction. Through this program, CLC offers $25 to $200 per LED fixture in retrofits, and $15 to $150 per LED fixture in new construction. There are no expiration dates for these rebates at this time.[38]

3.4.4.8 Central Electric Cooperative – Non-Residential Lighting Rebate

In Oregon, the Central Electric Cooperative offers a commercial lighting system improvement incentive for any customer not on a residential utility rate. For existing building projects, the Central Electric Cooperative will give rebates of $40 to $80 per hardwired CFL installed new or as a retrofit, $3 to $12 per screw-in CFL retrofit, and $30 to $50 per LED fixture installed new or as a retrofit. The program also offers rebates for occupancy sensors and other lighting controls. There are no expiration dates for these rebates at this time.[39]

3.4.4.9 Empire District Electric Company – Commercial and Industrial Energy Efficiency Rebate Program

The Empire District Electric Company (Empire) offers a Commercial/Industrial Prescriptive Rebate Program to its non-residential customers in Arkansas who purchase certain high efficiency equipment for eligible facilities. A variety of prescriptive rebates are available to customers served under any non-residential rate schedule in the Empire service territory. The rebates, which can be applied to both new construction and retrofit projects, are offered for certain equipment meeting the program's energy efficiency standards. Empire offers a rebate of $8 to $24 per hardwired or modular CFL fixture (depending on the wattage) and $25 per multi-

CFL industrial fixture. The hardwired or modular fixtures must replace incandescent, halogen, high pressure sodium, or mercury vapor systems and cannot include screw-base CFLs. To qualify, the industrial multi-CFL fixtures must replace T12 or HID systems. There are no expiration dates for these rebates at this time.[40]

3.4.5 GSL Market Trends

Shipment data and market trend information are used to conduct the shipment analysis and develop base-case forecasts in the shipment analysis (see chapter 9 of this TSD). DOE also uses shipment data to identify and analyze representative product classes and lamps to ensure the analysis is representative of the market (see chapter 5 of this TSD). Shipment data also feeds into the national impact analysis (see chapter 10 of this TSD). DOE gathered insights into GSL market trends by reviewing updates to NEMA's lamp indices, which detail progress in the GSL market from 2010-2014 as well as the 2010 U.S. Lighting Market Characterization (LMC) report.

NEMA's lamp indices are composite measures of NEMA member companies' U.S. shipments of a variety of lamp types, including compact fluorescent, halogen, incandescent, and LED lamps. Product shipments data are drawn from NEMA statistical surveys conducted regularly by NEMA and are adjusted for recurring seasonal fluctuations.[41]

An evaluation of NEMA's lamp indices indicates that incandescent lamps rose in market share through 2011, ultimately reaching approximately 82.8 percent of the incandescent-CFL market at the end of 2011. This ratio suggests that CFLs accounted for approximately one out every six incandescent and CFLs sold at that time. The 17.2 percent market penetration of CFLs at year-end 2011 was down from 22.1 percent at year-end 2010. NEMA asserted that the decrease in demand of CFLs was due to the fact that EISA 2007 standards were not yet in effect, and consumers were likely stockpiling incandescent lamps in preparation for the new standards.[42,43]

Starting in 2012, NEMA added halogen A-shape lamps to its incandescent-CFL indices. These lamps began to garner a small market share in 2012 as they continued to develop and be introduced to consumers, eventually climbing to 3.8 percent by the end of 2012. Although incandescent lamps maintained control of the GSL market in 2012, they declined to their lowest market percentage, 74 percent, since 2010. CFLs increased to 22.8 percent in 2012.[44]

The development of LED lamps began to show movement in the market penetration of GSLs in 2013, leading to NEMA's addition of LED A-shape lamps to its lamp indices. By year-end 2013, LED A-shape lamps reached a market penetration of 1.1 percent. Incandescent lamps continued to decline in market share in 2013,[e] dropping to 51.5 percent, and CFLs showed a significant increase in market share, reaching 33.8 percent. Halogen A-shape lamps also increased in market share, rising to 13.6 percent in 2013.[45]

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[e] Starting in 2013 NEMA included only incandescent A-shape lamps in the lamp indices.

Through two quarters thus far in 2014, these trends continued as incandescent A-shape lamps dropped to a 34.7 percent market share; halogen A-shape lamps rose to 26 percent; and LED A-shape lamps increased to 2.9 percent. Most notably, CFLs surpassed the incandescent A-shape lamps to assume the lead position in the market, rising to 36.4 percent.[46]

DOE supplemented its understanding of the NEMA lamp indices with market information from the 2010 LMC and also evaluated data from the 2001 LMC. The LMCs provide estimates of the installed stock, energy use, and lumen production of all lamps operating in the United States. The reports deliver results at a national level and a sector-specific level; the four sectors represented include the residential, commercial, and industrial building sectors as well as an outdoor sector. These estimates have been based primarily on public sources of information, building lighting audits, industry surveys, national lamp shipment data, and interviews with lighting professionals and subject matter experts.

The 2010 LMC estimated that A-shape GSILs represented 25.3 percent and decorative GSILs represented 11.9 percent of the overall lamp market in 2010.[f] The 2001 LMC combined these two categories and estimated general service incandescent lamps to represent 56 percent of the lamp market in 2001. The 2001 and 2010 LMCs estimated general service screw-in CFLs[g] to represent 2 and 14.2 percent of the lamp markets in 2001 and 2010, respectively. Similarly, general service pin-based CFLs[h] represented 1 and 1.7 percent of the lamp markets in 2001 and 2010. Lastly, general service halogen lamps[i] garnered a 0.3 percent market share in the 2010 LMC, while LED lamps[j] reached a 0.8 percent market share in 2010. Both general service halogen lamps and LED lamps had 0 percent reported market share in 2001. For historical shipment data and trends please refer to Chapter 9 of this TSD.

3.5 TECHNOLOGY ASSESSMENT

The purpose of the technology assessment is to develop a preliminary list of technologies that could be used to improve the efficacy of GSLs. GSLs are most commonly used for general lighting applications. Three lamp technologies dominate the GSL market: incandescent, compact fluorescent, and LED. The following assessment provides a description of the basic construction and operation of compact fluorescent lamps and LED lamps, followed by options to improve efficacy within these lamp technologies.

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[f] General service A-type incandescent lamps are defined in the 2010 LMC as standard incandescent lamps greater than 15 W and with an a-type bulb and of all base types. General service decorative incandescent lamps are defined as standard incandescent lamps greater than 15 W with a globe, bullet, candle, tubular, or other decorative-shaped bulb and of all base types.

[g] General service screw-in CFLs are defined in the 2010 LMC as CFLs with an a-type, globe, spiral or other decorative-shaped bulb meant as a direct replacement for general service incandescent lamps having a screw-in base, including all wattages.

[h] General service pin-based CFLs are defined in the 2010 LMC as CFLs with an a-type, globe, spiral, or other decorative-shaped bulb having a non-screw-in base, such as a pin base, including all wattages.

[i] General service halogen lamps are defined in the 2010 LMC as halogen lamps with a tungsten halogen capsule with an a-type, globe, candle or other decorative-shaped bulb meant as a direct replacement for general service incandescent lamps, including all base types and wattages.

[j] LED lamps are defined in the 2010 LMC as LED lamps and luminaires greater than or equal to 2 watts of all shapes, sizes, and bases not including LED screens or decorative walls.

3.5.1 Compact Fluorescent Lamps

CFLs are fluorescent lamps of bent-tube construction. The bent-tube construction of CFLs (*e.g.,* spiral or U-shaped) allows them to fit into smaller spaces. CFLs consist of a glass envelope or tube with a phosphor coating on its interior surface, oxide coated electrodes on each end of the tube, small amounts of mercury or mercury amalgam, and an inert gas (*e.g.,* argon). Voltage is applied to the two electrodes at the ends of the tube, emitting large quantities of electrons that collide with gaseous mercury atoms and excite the electrons within those atoms. As the mercury electrons return to their stable state, they release ultraviolet (UV) radiation. Because UV radiation is not visible to the human eye, phosphors are coated along the inner walls of the tube to absorb the UV radiation and emit visible light. CFLs are also operated with a current-limiting device, either a ballast integrated into the CFL (*i.e.*, self-ballasted) or a ballast separate from the lamp (*i.e.*, externally ballasted).[47]

Like GSFLs, the two electrodes are hermetically sealed to both ends of the bulb, typically constructed from coiled tungsten wires coated with a mixture of alkaline oxides. Once a ballast applies the initial voltage to the electrodes, the tungsten coil and coatings emit large quantities of electrons after the coating has reached the appropriate temperature (800 °C). Although the electrodes are actually in close proximity to each other at the base of the lamp (both tubes connect to the single base of the lamp), the electrons released by the coiled wires travel the full length of the tubes. These electrons collide with gaseous mercury atoms and the inert gas filling the rest of the tube. The inert gas is present to moderate the collisions of mercury ions and minimize evaporation of the electrode coating. The electrons from the electrodes excite those in the mercury atoms to release UV radiation that is absorbed by the phosphors and reemitted as visible light.[48]

A key to the miniaturization of GSFLs into CFLs in the 1980s was the development of new phosphor compositions that are more stable in intense UV radiation. A combination of rare earth phosphors is best suited for the miniaturization and strong radiation, while also providing better color rendering and increased efficacy (lumens per watt).[49] CFLs use the same phosphors as GSFLs, but in different compositions. The five rare earth elements in the phosphors used in these lamps are lanthanum, cerium, europium, terbium, and yttrium. CFLs primarily use a Calcium Tungstate (CAT) phosphor that is higher in cerium, and GSFLs use a Lanthanum Phosphate (LAP) phosphor that is higher in lanthanum.[50]

Fluorescent lamp performance is influenced by the cold spot on a lamp and the ambient temperature of the operating environment. The cold spot is the area where excess mercury condenses, so the temperature of the cold spot defines the level of mercury vapor pressure and thus the luminous flux.[51] CFLs fail when the emissive coating on the electrodes is completely dissipated by evaporation or sputtering. The inert gas is used to prevent this from occurring by protecting the electrodes from the bombardment of mercury ions, but loss of the emissive coating during starting is inevitable, albeit in small amounts.[52]

CFLs must be operated with magnetic or electronic ballasts, which supply the starting and operating voltages required by the lamp and limit the current while the lamp is in use. CFLs can be self-ballasted or externally ballasted (sometimes referred to as pin-based). The majority of CFLs in the marketplace are self-ballasted, and virtually all of these have electronic ballasts.

These self-ballasted CFLs integrate a screw base with a ballast for direct retrofitting of incandescent luminaires. Popular base types for self-ballasted CFLs include E12 (candelabra), E17 (intermediate), E26 (medium), E39 (mogul), or GU24 (twist and lock), with E26 being the most common because it is designed to fit standard luminaires and overhead light fixtures.[48]

External ballasts can be electronic or magnetic, though the market is shifting more toward electronic ballasts due to improved system efficacy and starting time; minimized flickering and operating sounds; and lighter weight. Externally ballasted CFLs can be found with 2-pin or 4-pin socket configurations, with base types including (but not limited to) G23, 2G7, G24d, G24q, 2G11, and GR10q.[53] Base types that are 4-pin are generally paired with electronic ballasts that may be dimmable, while 2-pin bases are typically magnetic and seldom paired with electronic ballasts.[48]

CFL ballast starting modes, for both self-ballasted and externally ballasted CFLs, include preheat, rapid start (RS), instant start (IS), and programmed start (PS). The preheat mode requires an external starter or switch to strike the arc. RS ballasts produce a nearly instant start with almost full lumen output by having a short period of electrode heating, followed by the application of a higher voltage to initiate the arc between the two electrodes. IS ballasts bypass the initial electrode heating and apply high voltage to create an instant start of the arc between the two unheated electrodes. IS ballasts may sustain damage to the electrodes and reduced lamp life when they are started frequently, while PS ballasts are designed to prevent this damage by controlling the frequency of starting.[48,52]

CFL shapes differ depending on whether the lamp is self-ballasted or externally ballasted. Self-ballasted lamps can either be bare tubes (most often spiral-shaped) or tubes with an outer cover. These covered lamps primarily include A-shapes, globes, reflectors, posts, and candles.[54] Externally ballasted CFLs typically consist of an arrangement of bare, bent tubes.[53]

3.5.2 LED Lamps

Generally, LED lamps utilize multiple LEDs inside of a housing that disperses or redirects the light from the point source LEDs to provide general illumination. LEDs work by using semiconductor material intentionally doped with an impurity to make a positive (p-type) and negative (n-type) region. The doping elements contain a similar atomic structure with either slightly fewer valence electrons to create a p-type region or slightly more valence electrons creating a n-type region. This causes the p-type regions to have hole concentrations while the n-type regions have excess electrons. When a voltage is applied, excess electrons from the n-type region combine with holes from the p-type regions and the resulting recombination radiation produces photons. The semiconducting elements most commonly used in LEDs for lighting are group III (boron) and V (nitrogen) combinations such as Gallium Nitride (GaN). The different group III and group V pairings have different size bandgaps, and these different energy levels correspond to distinct parts of the visible spectrum. For instance, GaN LEDs usually emit violet light, however their wavelength can be adjusted by mixing in other elements with different bandgaps. An added benefit of group III-V compositions is that they often have direct rather than indirect bandgaps, leading to more efficient LEDs.[55] An indirect bandgap is less efficient as it requires the electron to pass through an intermediate state and transfer momentum to the crystal lattice before it can recombine with a hole to produce a photon. Figure 3.5.1 displays this phenomenon known as electroluminescence.

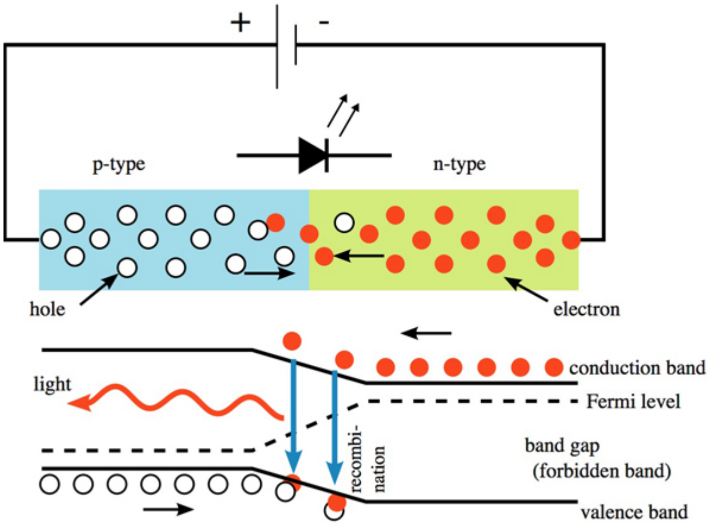

Figure 3.5.1 Photon Production through Electroluminescence
Source: Digi-Key[56]

The photon production happens within the LED chip where the p and n-type regions, known as epitaxial layers, are built on top of a substrate, most commonly made out of sapphire.[57] Often a reflective layer such as silver is used below the active region to help prevent absorption of emitted light into the substrate as seen in Figure 3.5.2. This is just one of many different approaches that are utilized to minimize absorption. The epitaxial layers, substrate, and a covering lens make up the LED module. LED modules or arrays[k] can be integrated into a lamp to provide illumination. If required, a phosphor can be mounted directly onto the LED die, as seen in Figure 3.5.3, or placed remotely to achieve a white light. The LEDs are mounted to the lamp housing which acts as a heat sink for the LEDs. The housing also accommodates the driver which transforms the incoming power supply from AC to DC and controls the flow of power to the LEDs. LED circuitry employs capacitors (typically electrolytic capacitors) to store electric charges on the input AC stage to enable filtering of noise or on the output channel DC stage. Similar to CFLs, LED lamps are offered in a variety of lamp shapes and base types to serve as replacements for GSILs. Figure 3.5.4 shows the breakdown of the components for a typical A-shape LED GSL.

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[k] The IESNA Lighting Handbook defines “LED array or module” as an assembly of LED packages (components), or dies on a printed circuit board or substrate. This assembly could also have optical elements and additional thermal, mechanical, and electrical interfaces that are intended to connect to the load side of a LED driver. However, the power source and ANSI standard base are not incorporated into the device and it cannot be connected directly to the branch circuit.

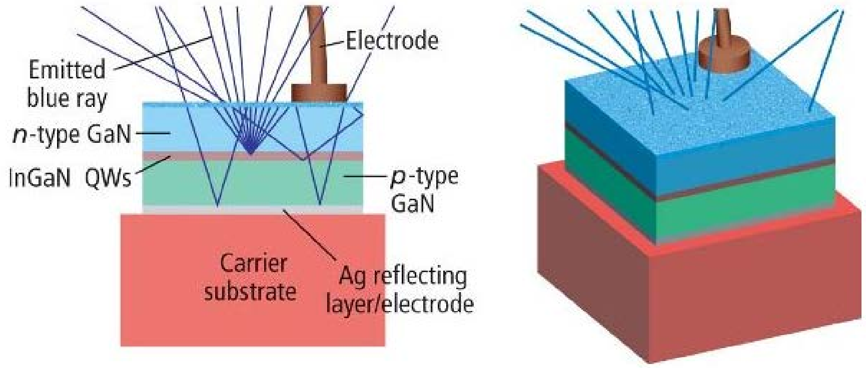

Figure 3.5.2 LED Chip
Source: LED Magazine[58]

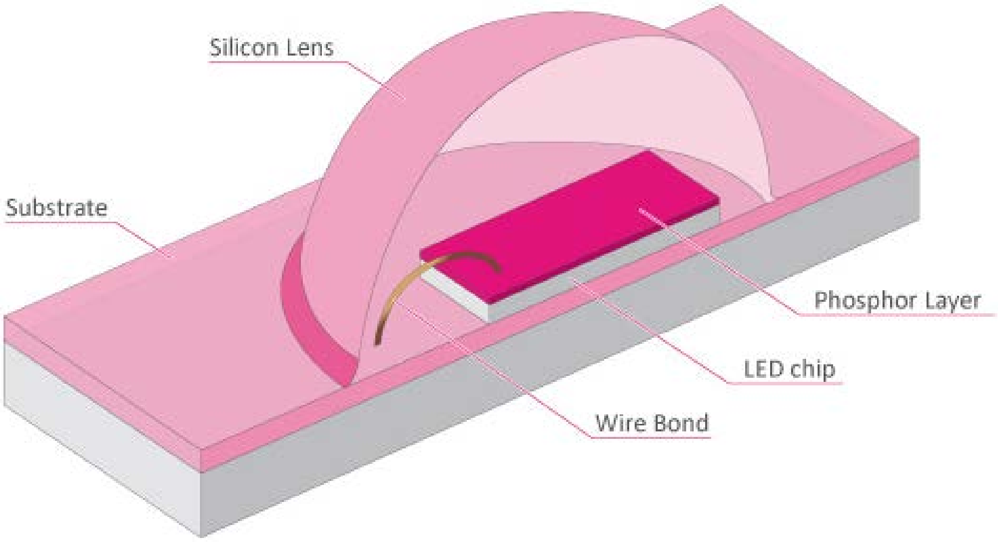

Figure 3.5.3 LED Module
Source: WILA[59]

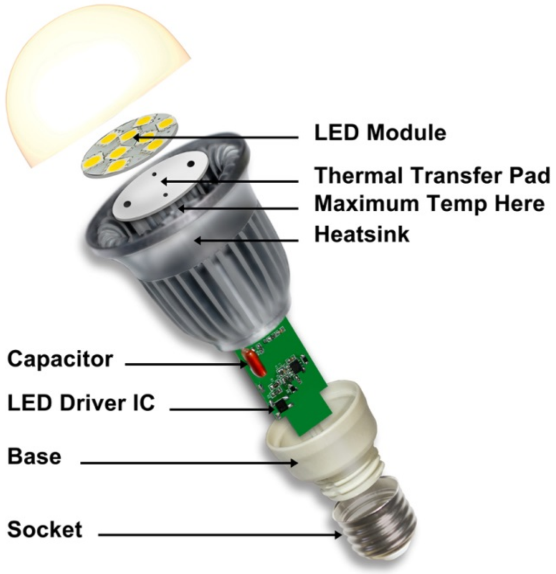

Figure 3.5.4 Exploded View of a LED Lamp
Source: EE Times[60]

White Light. LED lamps typically consist of an InGaN/GaN LED that emits blue light which then meets a yttrium aluminum garnet (YAG) phosphor coating before leaving the luminaire. That phosphor converts a portion of the blue light to longer wavelength (green through red) light to produce a combined white light as shown in Figure 3.5.5. Though phosphor coating a blue LED is the most common mode of producing white light in LED lamps, there are many other LED systems that can achieve white light.

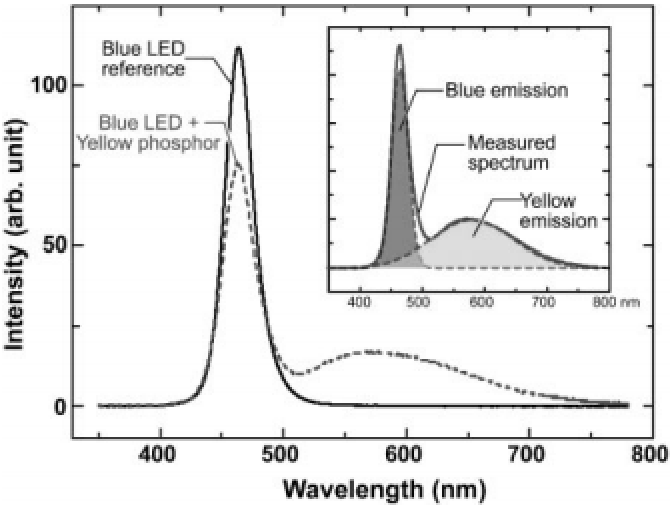

Figure 3.5.5 Light Conversion in a Phosphor-Converted LED Lamp
Source: Japanese Journal of Applied Physics[61]

Combining blue, green, and red LEDs can also produce a balanced white light and is theoretically the most efficient way to produce light since no light is lost during phosphor conversion; however, since green and amber LEDs lag behind blue LEDs in their respective efficiency, this method is uncommon in today's LED lamp market.[62] Hybrid LED architectures contain a mix of LED colors and use phosphor conversion on some of the LEDs. One example of such a product is the Philips L-Prize lamp. The lamp down shifts some blue light to the green spectrum to avoid the least efficient green LEDs and adds in red LEDs to produce white light at a warmer color temperature and a higher CRI. Figure 3.5.6 describes the three primary methods of creating white light with LEDs.

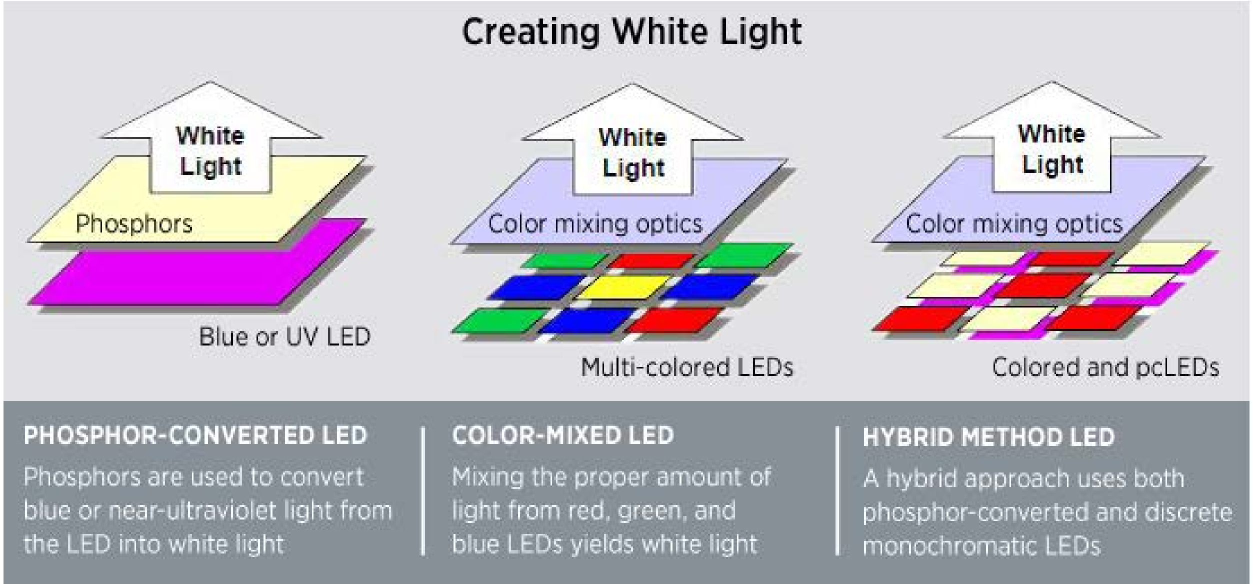

Figure 3.5.6 Creating White Light in LEDs
Source: U.S. Department of Energy[63]

Lifetime. Unlike GSILs and CFLs, LED lamps rarely fail entirely. Rather their light output drops throughout their lifetime. For this reason ENERGY STAR, the lighting industry, and standards organizations have approached lifetime ratings based on the amount of time expected before a 70 percent deterioration in total luminous flux (L_{70}) rather than the expected lifetime of the components, which tend to be much longer.[64] At this stage, two primary causes of premature failure of LED GSLs are overheated capacitors and faulty solder joints. Some electrolytic capacitors used in the lamps are not rated to withstand the high level of heat they endure which will shorten their lifetime. Low quality solder joints, particularly those that are hand soldered, as well as mechanical fatigue from thermal stresses, can also lead to broken contacts and lamp failure.[65]

3.5.3 GSL Technology Options

This section outlines the technology options DOE is considering for improving efficacy of GSLs. DOE reviewed manufacturer catalogs, recent trade publications, technical journals, and patent filings to determine technology options. Table 3.5.1 presents the technology options DOE has preliminarily identified to improve the efficacy of general service lamps. DOE notes in Table 3.5.1 the applicable lamp type for the technology options listed.

Table 3.5.1 GSL Technology Options

Lamp Type	Name of Technology Option	Description
CFL	**Highly Emissive Electrode Coatings**	Improved electrode coatings allow electrons to be more easily removed from electrodes, reducing lamp power and increasing overall efficacy.
	Higher Efficiency Lamp Fill Gas Composition	Fill gas compositions improve cathode thermionic emission or increase mobility of ions and electrons in the lamp plasma.
	Higher Efficiency Phosphors	Techniques to increase the conversion of ultraviolet (UV) light into visible light.
	Glass Coatings	Coatings on inside of bulb enable the phosphors to absorb more UV energy, so that they emit more visible light.
	Multi-Photon Phosphors	Emitting more than one visible photon for each incident UV photon.
	Cold Spot Optimization	Improve cold spot design to maintain optimal temperature and improve light output.
	Improved Ballast Components	Use of higher-grade components to improve efficiency of integrated ballasts.
	Improved Ballast Circuit Design	Better circuit design to improve efficiency of integrated ballasts.
	Change in Technology	Replace CFL with LED technology.
LED	**Efficient Down Converters**	New high-efficiency wavelength conversion materials, including optimized phosphor conversion, quantum-dots and nano-phosphors, have the potential for creating warm-white LEDs with improved spectral efficiency, high color quality, and improved thermal stability.
	Improved Package Architectures	Novel package architectures that can improve package efficacy through use of color mixing with RGB+ or hybrid systems and higher current drivers; resulting in improvement of overall lamp and luminaire efficacy.
	Improved Emitter Materials	The development of efficient red, green, or amber LED emitters, will allow for optimization of spectral efficiency with high color quality over a range of CCT and which also exhibit color and efficiency stability with respect to operating temperature.
	Alternative Substrate Materials	Alternative substrates such as gallium nitride (GaN), silicon (Si), GaN-on-Si, and silicon carbide to enable high-quality epitaxy for improved device quality and efficacy.
	Improved Thermal Interface Materials (TIM)	Develop TIMs that enable high efficiency thermal transfer for long-term reliability and performance optimization of the LED device and overall lamp product.
	Optimized Heat Sink Design	Improve thermal conductivity and heat dissipation from the LED chip thus reducing efficacy loss from rises in junction temperature.
	Active Thermal Management Systems	Devices such as internal fans, vibrating membranes, and circulated liquid cooling systems to improve thermal dissipation from the LED chip.
	Device Level Optics	Enhancements to the primary optic of the LED package that would simplify or remove entirely the secondary optic, and thereby reduce losses due to absorption at interfaces.
	Increased Light Utilization	Reduce optical losses from the lamp housing, diffusion, beam shaping and color-mixing to increase the efficacy of the LED lamp using mechanisms such as highly reflective coatings inside the lamp.

Lamp Type	Name of Technology Option	Description
	Improved Driver Design	Increase driver efficiency through novel and intelligent circuit design.
	AC LEDs	Reduce or eliminate the requirements of a driver and therefore the effect of driver efficiency on lamp efficacy.
	Reduced Current Density	Increase the number of LEDs in a lamp to reduce current density while maintaining lumen output. This reduces the efficiency losses associated with higher current density.

3.5.3.1 Highly Emissive Electrode Coatings

Fluorescent lamp electrodes are generally tungsten filaments coated with a mixture of alkaline earth oxides. The purpose of the electrodes is to emit a sufficient number of electrons to ionize the gas and maintain the lamp discharge. When electrons are more easily emitted from the electrodes, a lower voltage is needed to maintain the arc. Therefore, any improvement in electrode coating that would allow electrons to be more easily removed from the electrodes would reduce the lamp power and increase the overall efficacy of the lamp. Using highly emissive electrode coatings essentially addresses the efficiency of the conversion of electrical input power to visible radiation. In addition to raising efficacy, highly emissive electrode coatings can result in an increased lamp lifetime. Without sufficient electron emission from the electrode, a large voltage gradient is created in front of the electrode during the cathode cycle, which is emitting negatively charged ions and receiving positively charged ions. This high electric field accelerates these ions into the electrode at a high velocity, causing electrode damage. The damage shortens the lifetime of the lamp. Conventional emissive coatings include barium oxide (BaO), calcium oxide (CaO), and strontium oxide (SrO). Additional materials have been mixed with existing conventional oxides to coat fluorescent lamp electrodes. These materials include zirconium oxide (ZrO), which extends lamp lifetime, and silicon carbide (SiC), which more effectively removes electrons from the electrode.

3.5.3.2 Higher Efficiency Lamp Fill Gas Composition

Fluorescent lamps contain mercury vapor, which when ionized produces UV radiation. They also contain a rare gas or combination of gases to facilitate ignition. These “lamp fill gases” affect the mobility of the mercury ions and electrons in the lamp plasma based on their molecular weight. Lower molecular weight gases generally result in higher lamp efficacy. As lighter gases are used, the mobility of mercury ions and electrons increases, allowing them to reach greater velocities. This causes a rise in electron temperature of the plasma, facilitating recombination and ultimately raising the UV radiation to saturation level. However, if the mobility of the ions and electrons exceeds a certain optimal point, they are then able to reach the lamp glass surface, which prevents emission and effectively reduces UV output.

Standard lamps generally use argon gas or a mixture of argon and neon. These gases are usually at low pressures, typically ranging from three to four torr. As the pressure exceeds a certain point, elastic scattering increases, decreasing the mobility of the ions and electrons. This decreased mobility lowers the total UV radiation of the lamp, thereby decreasing lamp efficacy. Because fluorescent lamp ballasts are often current-controlled devices, the use of higher efficiency lamp fill gases results in lower power.

Lamp fill gas composition can also affect lamp lifetime due to collisions between the lamp fill gas and the evaporated electrode coatings. As discussed earlier, one common emissive coating used on electrodes is barium oxide (BaO). During lamp operation the BaO coating slowly evaporates from the surface of the electrode. However, some of these escaped barium atoms then collide with the lamp fill gas, propelling them back toward the electrode and redepositing them. The relative thermionic emission for the cathode, a measure of the number of electrons emitted, is much greater for a larger molecular weight gas than for a lighter gas. This is because a larger mass atom can more effectively collide with and change the trajectory of the barium atoms, providing a lower diffusion rate of the barium atoms away from the electrode. This redeposition of the electrode coating results in a longer lamp lifetime as less of the electron emissive material is lost.

3.5.3.3 Higher Efficiency Phosphors

As described earlier, the main purpose of phosphor in a fluorescent lamp is to absorb the UV radiation and reemit it as visible radiation. Therefore, one method of improving lamp efficacy is to increase phosphor efficiency. As stated, a key to the miniaturization of GSFLs into CFLs in the 1980s was the development of new phosphor compositions that are more stable in intense UV radiation. Specifically, these narrow-band rare earth, or triband, phosphors (containing the rare earth elements terbium, europium, and yttrium), emit light in the short, middle, and long wavelength ranges of the visible spectrum. Compact fluorescent lamps on the market today exclusively use triband phosphors.

Lamp efficacy can be improved by using triband phosphors, which can increase UV absorption and emission of radiation in the visible spectrum relative to other phosphors. Typically, there are efficiency losses in the phosphor’s conversion of UV radiation to visible radiation, or light. Some of these losses are related to the extent to which the phosphors emit light in the visible spectrum (*i.e.*, radiation with wavelengths between 400 and 750 nm) and the extent that they radiate at visually sensitive wavelengths. Triband phosphors allow a lamp to emit light at the wavelengths to which human eyes are most sensitive which increases lamp efficacy. To understand this effect it is important to note the relationship between the efficiency losses in the phosphor’s conversion of light, wavelengths sensitive to the human eye, and measurement of lamp efficacy.

Lumens, used to calculate lamp efficacy, measure the radiometric energy emission from a light source weighted by the response function of the human eye, $V(\lambda)$ (also referred to as the photopic luminous efficiency function). Figure 3.5.7 depicts $V(\lambda)$. The human eye does not have the same level of sensitivity to all wavelengths of light. For example, the eye is highly sensitive to light emission around 550 nm, but less sensitive to emission at 450 nm or 650 nm.

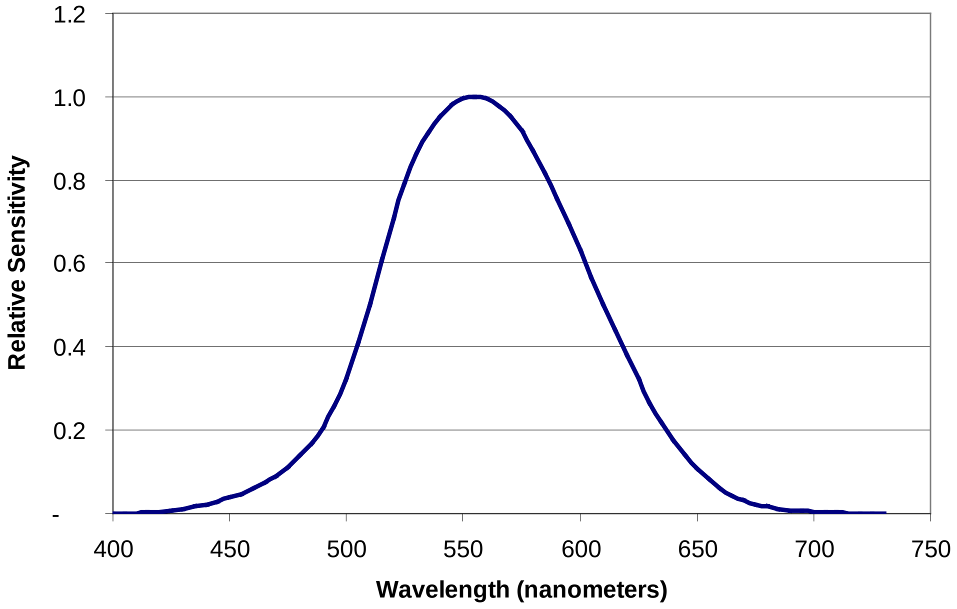

Figure 3.5.7 Human Eye Photopic Spectral Luminous Efficiency Function, V(λ)

Therefore, the specific wavelengths that a lamp emits will affect the lamp's calculated efficacy. In other words, because the human eye is less responsive to certain wavelengths of light, such as those in the blue spectrum, those lamps that contain these less sensitive wavelengths will have lower efficacies. As such, every watt of radiometric energy emitted from a fluorescent lamp is not equal under a lm/W metric. Therefore, by allowing a lamp to emit greater light at wavelengths to which the human eye is more sensitive, triband phosphors are able to increase lamp efficacy.

Lamp efficacy can also be improved by increasing the thickness of the phosphor layer, also called phosphor weight. Generally, as phosphor thickness increases, lamp light output increases until it slightly decreases or stays flat. Figure 3.5.8 illustrates this point, where coating weight is indicative of phosphor thickness.

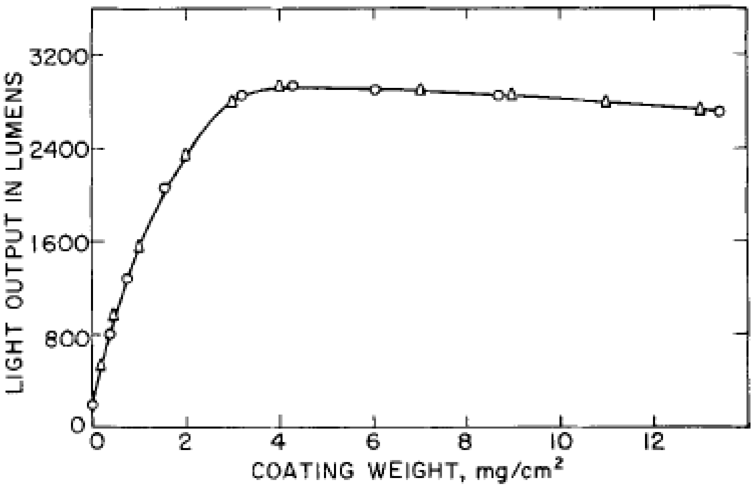

Figure 3.5.8 Light Output versus Phosphor Thickness
Source: Journal of the Electrochemical Society [66]

Different types of phosphor emit light with different spectral power distributions (SPDs), and the choice of phosphor or blend of phosphors greatly affects the color of the lamp. The SPD of light emitted from a lamp characterizes the amount of power radiated at each wavelength in the visible spectrum. SPD determines the CCT and the CRI, both important properties for measuring the color quality of light. CRI, a single value with no units, is a measure of the color rendering properties of a light source, or the ability of a light source to show the "true" color of an object as compared to a reference source.[l] [67] The maximum CRI is 100. Lower CRI values indicate greater variation in an object's apparent color compared to when lit by the reference source. DOE has observed that higher efficiency phosphors on the market typically offer higher CRIs. While CRI is not necessarily positively correlated to efficacy, the majority of phosphors offered in the market currently reflect this relationship. DOE has found that the vast majority of CFLs available on the market have a CRI of 80 or greater.

CCT, a single value with units of degrees Kelvin (K), is a measure of the color appearance of light emitted from a lamp.[m] [n] [68] Lower CCT values correspond to warmer light, with more red content in the spectrum, and higher CCTs correspond to cooler light, with more blue content. As the spectral emission from the lamp is modified to change the CCT, the light emitted often contains more red or blue light. Given the shift in the wavelengths of light emitted from lamps with different CCTs, and the fact that lumens account for the amount of light emitted at particular wavelengths, the efficacy of lamps with different CCTs can vary.

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[l] According to the IESNA Lighting Handbook, the CRI of a light source is "a measure of the degree of color shift objects undergo when illuminated by the light source as compared with those same objects when illuminated by a reference source of comparable color temperature."

[m] According to the IESNA Lighting Handbook, the CCT of a light source is "the absolute temperature of a blackbody whose chromaticity most nearly resembles that of the light source."

[n] While CCT is a single value, light with the same CCT value may have slightly different properties. Therefore, the lighting industry has defined elliptical regions in chromaticity space (called 4 MacAdam color steps) for specific CCT values (*e.g.*, 2,700 K, 3,000 K, 3,500 K, 4,000 K/4,100 K, 5,000 K, and 6,500 K) in ANSI C78.376-2001. These regions act as a tolerance for the color properties of the lamp.

3.5.3.4 Glass Coatings

To increase the UV absorption by the phosphors, the bulb glass can be covered with an antireflective coating. This coating, also referred to as the undercoat or base coat layer, is a refractory oxide, such as aluminum oxide (Al_2O_3), silicon oxide (SiO_2), and titanium oxide (TiO_2). This layer is used to reflect any UV radiation that passes through the phosphor back onto the phosphor, allowing a greater portion of UV to be absorbed. As the phosphors absorb more UV radiation, they will emit more visible light, thereby increasing the overall efficacy of the lamp. When these coatings are used with rare earth phosphors, a good CRI can be achieved while minimizing the phosphor thickness necessary to absorb maximum UV radiation. A recent patent[69] by Philips was issued in 2005 for an improved undercoat that reduces the amount of lamp contaminant resulting from the manufacture process. The improved coating covered under the patent contains an aluminum oxide material and a getter material which reacts with contaminants. This reduction or elimination of contaminants results in improved lamp arc stability.

3.5.3.5 Multi-Photon Phosphors

The use of multi-photon phosphors, or quantum-splitting phosphors, can significantly improve lamp efficacy. Because these phosphors emit more than one visible photon for each incident UV photon, a lamp would be able to emit more light in the visible spectrum for the same amount of power. However, there are technical drawbacks with the technology such as light color output, color stability, and phosphor lifetime.[70]

3.5.3.6 Cold Spot Optimization

The point on a CFL with the lowest temperature is where the vaporized mercury condenses. The temperature of this “cold spot” has an impact on overall lamp efficacy as it influences the vapor pressure of gaseous mercury. With lower cold spot temperatures there is insufficient gaseous mercury which reduces UV output; however, high cold spot temperatures cause UV radiation to become trapped in the tubing. Cold spot temperature is a function of current density, and light output increases with current density until it reaches a certain saturation level. As current density increases, the ionization rate of mercury atoms increases, causing UV radiation to increase, ultimately improving the transfer of UV radiation to visible light. Simultaneously, however, the electron temperature will drop due to a step-wise ionization at the higher current density and the chemical tendency to revert back to a state of equilibrium. As electron temperature decreases and electrons experience de-excitation, the useful UV radiation intensity is unable to increase as quickly as the current density, so it will gradually approach a constant. Therefore, by finding the right cold spot temperature, one can balance these effects and optimize light output. In a study of commercially available T2 and T3 CFLs, Feng and Hu found that light output reaches a maximum at about 48 °C with a fixed current of 140 mA (see Figure 3.5.9). This conclusion is similar to the temperature of 50 °C for T2 tubes found by Han et al. Future CFL designs should ensure that the cold spot reach an optimal temperature in steady state operation to maximize efficacy.[71]

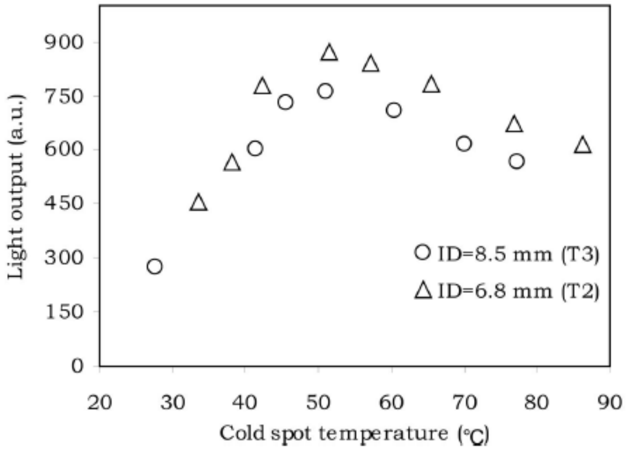

Figure 3.5.9 T2 and T3 Spiral CFL Performance at 140 mA

The lamp's orientation (*i.e.* base up versus base down) also affects the cold spot temperature. A typical spiral CFL's cold spot occurs at the top of the bulb where the two helical spirals meet. Due to rising heat, the cold spot temperature is higher when the lamp is operated base down rather than base up. The higher temperature can result in roughly 10 percent less light output. The use of amalgam in CFLs help alleviates efficacy issues related to lamp orientation but also increases warm up time over liquid Hg CFLs. In 2010, the United States granted GE a patent that involves a CFL with a secondary cold spot to maintain cold spot temperature for base up and base down applications. The secondary cold spot is positioned between the longitudinal end portions of the discharge tube arrangement, contrary to the first cold chamber, which is located in a longitudinal end portion of the tube arrangement. The second is positioned on the wall of the tube and has a cold chamber wall protruding substantially away from the central axis of the discharge tube arrangement. This location optimizes the cooling effect of ambient air to provide efficient cooling of the second cold chamber in base down positions.[72]

3.5.3.7 Improved Ballast Components

Integrated CFLs use electronic ballasts. The use of ballasts with high efficacy factors in integrated CFLs will increase lamp efficacy. Further, proper lamp-ballast combinations can affect lamp life up to 50 percent.[73] New electronic ballast components and novel circuit designs can continue to improve overall lamp efficacy. A common way to increase the efficiency of ballasts is to improve the quality of their components. Magnetics (transformers and inductors), diodes, capacitors, and transistors are the main components that affect efficiency. For example, one way to reduce magnetic component power loss at light loads is to select magnetics with higher quality core materials. Another way to reduce the magnetic component's power loss is to select materials with lower winding losses. The efficiency of the circuit can also be improved by using capacitors with low effective series resistance (ESR). Further, using transistors with drain-to-source resistance (low R_{DS_ON}) can reduce losses.

3.5.3.8 Improved Ballast Circuit Design

Another method of increasing the efficiency of integrated CFLs is to improve the ballast's circuit design. Examples of improved circuit design include cathode cutout technology, integrated circuits, improved starting method, and synchronous rectification.

Cathode cutout technology using an electronic circuit removes the power provided to the filament after the lamp has been started, thereby increasing the efficiency of both PS and RS ballasts. In certain cases, a ballast's efficiency can be improved by substituting integrated circuits for discrete components.[74]Further, RS and PS ballasts are inherently less efficient than IS ballasts even though IS ballasts use extra power to provide filament power to the ballast to increase its lifetime.

3.5.3.9 Change to LEDs

LED lamps can provide a higher level of efficacy than CFLs, and it is likely that LED lamp's efficacy margin over CFLs will grow attributed to ongoing R&D. Therefore, DOE is considering a switch from CFL to LED technology as an option for improving lamp efficacy of GSLs.

3.5.3.10 Efficient Down Converters

The color of light produced by an LED lamp is dependent on the type of semiconductor material used in the lamp, and is not inherently white. Since LEDs themselves emit a single fairly narrow wavelength, some sort of manipulation of light or addition of light is necessary to produce a quality (high CRI) mixed white light source. Currently, manipulation of light in LED lamps is most commonly done through phosphor conversion, converting some light from a UV or blue LED to longer wavelength light (green through red) for a cumulative white light. The conversion of light from shorter wavelength photons to longer wavelength photons is a high to low energy conversion. The difference in energy between the high energy UV or blue photons and the low energy green through red photons is lost in the conversion. The most commonly used phosphor today, with variations, is $Y_3Al_5O_{12}:Ce^{3+}$ (YAG:Ce) with a blue LED. The quantum efficiency (a component of overall phosphor efficiency) of YAG:Ce under excitation of a blue LED can exceed 85 percent.[75] By improving down converter efficiencies more light will be produced for the same input, and lamp efficacy will increase.

Novel compositions of phosphor can further improve down converter efficiencies. The United States recently granted GE a patent for a novel phosphor producing blue-green and green light. The quantum efficiency of the phosphor at 150 °C is 80 percent of quantum efficiency at ambient temperature. Most current phosphors' quantum efficiencies at 150 °C degrade to 60 percent of their efficiency at ambient temperature.[76] This new composition would allow for greater package efficacy at higher system temperatures, which are characteristic of LED lamps.

Although phosphors are the most common type of down converters, other quantum dots can also improve LED efficacy. Colloidal quantum dot phosphors are nanocrystal emitters that can tune their emission wavelength by changing their size and contain no rare earth elements. These could be a potential replacement for traditional phosphors if they can overcome temperature performance issues as well as light flux issues. Researchers at State University of New York (SUNY) at Buffalo have produced quantum dot phosphors emitting green through red wavelengths at efficiencies over 80 percent. Further, the phosphors are able to produce green through red wavelengths with only a five percent loss in efficiency at 150 °C, and have minimal losses at fluxes up to 38,000 W/cm. Researchers have also managed to significantly reduce Auger recombination[o] through these new phosphors.[77] Further, although no longer commercially available, a R30 LED lamp utilizing quantum dot phosphors was introduced by Nexxus Lighting, Inc. and QD Vision in 2010.[78]

3.5.3.11 Improved Package Architectures

LED packages are individual nodes that make up the LED and have their own efficacy which is driven by the method of generating white light, color quality attributes, and drive current. The package efficacy ultimately contributes to the LED lamp efficacy. Improved LED package architectures utilize color mixing with multiple monochromatic LEDs (*e.g.*, red, blue, green) or hybrid systems that incorporate both phosphor-converted (PC) LEDs and multiple monochromatic LEDs. LED color-mixing is one method to generate white light output from LEDs. It entails mixing the appropriate amount of light from multiple monochromatic LEDs (red, green, and blue) to yield white light. Additional LEDs, such as amber, can be added to potentially improve the color characteristics but may also lower efficacy. Because it avoids phosphor conversion losses, LED color mixing is theoretically the most efficient way to produce light from LEDs. However, the efficacy of color mixing package architecture lags behind packages using PC LEDs due to the inability to produce efficient green or amber LEDs which has led to the prevalence of PC LED lamps.

Hybrid package architectures combine the use of multiple monochromatic LEDs as in color mixing along with PC LEDs. Configurations may involve efficient blue LEDs with a phosphor coating to emit green wavelengths and efficient red LEDs to provide combined white light. Such a design could prove to be more efficient than current designs utilizing only PC LEDs by eliminating the loss during blue to red down conversion with phosphor. In 2002, Philips filed a patent for such a device as well as other combinations of LEDs and phosphors to make white light with comparable color rendering and color temperature control to existing LED lamps but with potentially higher efficacies.[79] Further, LED package efficacies tend to be lower at higher CRI as well as at lower CCTs (warm-white). High efficacy warm-white luminaires employing the hybrid approach have been on the market since 2009.[80] In 2013 Philips reported on the development of a warm-white hybrid LED package for general illumination that could potentially achieve 131 lm/W at 85 °C with a CRI 90, a CCT of 2955 K. Philips noted that the hybrid architecture can allow for more efficacious warm-white LEDs and at high CRIs.[81]

Additionally, the driver current also impacts efficacy of the package. A package architecture that increases driver current will increase the lumen output but also results in a proportional decrease in efficacy (an effect called the efficiency droop which is discussed in section 3.5.3.12).

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[o] Auger recombination is a process by which electrons collide and produce heat rather than emit light.

Manufacturer feedback and DOE research indicates that these and various other ways for improving package architecture are being utilized in products and are the subject of further R&D. Cree, for example, produced a traditional PC LED in its lab with an efficacy of 276 lm/W in 2013 owing the improvement in part to advances in LED package architecture.[82] Cree has since improved its lab LED performance to over 300 lm/W as of March 2014.[83] Figure 3.5.10 shows the expected efficacy gains for the color mixing and PC methodologies.

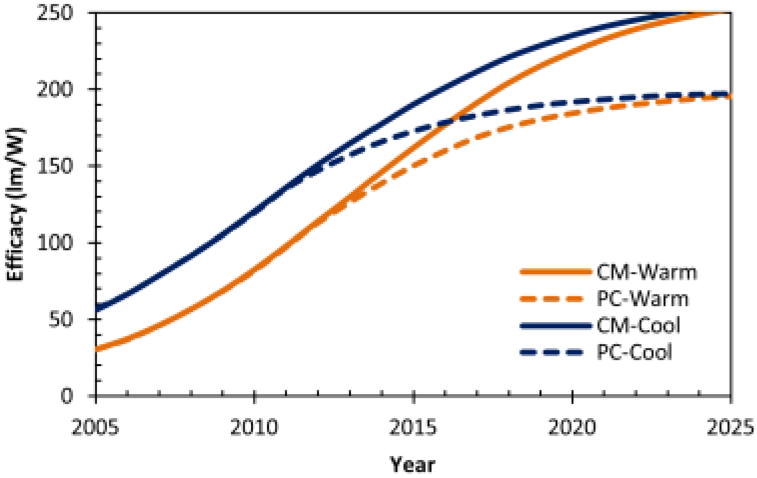

Figure 3.5.10 Projected LED Package Efficacy Trends
Source: DOE's Solid-State Lighting Technology Fact Sheet

3.5.3.12 Improved Emitter Materials

Advanced emitter materials and structures can improve the efficiency of LEDs. The basis of any LED lamp is the LED emitter, which actually produces the light. As mentioned previously, the predominant configuration in the LED GSL market is a PC blue LED which produces white light by mixing the down converted light with some of the blue light which passes through the phosphor unchanged. The color mixing methodology uses individual monochromatic LEDs (*e.g.*, red, green, blue) to produce a mix of colors that generates white light. Because color mixing does not utilize PC LEDs, it avoids down conversion losses associated with the phosphor conversion methodology. While blue LEDs have made good progress towards their theoretical maximum efficiencies, green LEDs remain markedly behind their theoretical maximum of 683 lm/W for a monochromatic light source at 555 nm.[84] Improved emitter materials for green and amber LEDs would allow for development of high efficacy color-mixed LED lamps.

Figure 3.5.11 plots the lumens per watt of various researchers' prototype LEDs versus their wavelength at a given current of 45 Acm^{-2} (note the y axis is logarithmic). The additional lines show the theoretical maximum wall plug efficiency (WPE), a dimensionless efficiency metric of optical radiant flux (in watts) per watt of electricity supplied. Semiconducting materials such as Group III nitrides (such as Gallium Nitride [GaN] and Indium Gallium Nitride [InGaN]) and Group III phosphides (such as Gallium Phosphide [GaP]) are efficient in producing shorter and longer wavelength light, respectively, but have much lower WPEs in the middle of the visible spectrum. This region has been dubbed the “green gap” by researchers because of the difficulty creating highly efficient LEDs in this part of the visible spectrum.

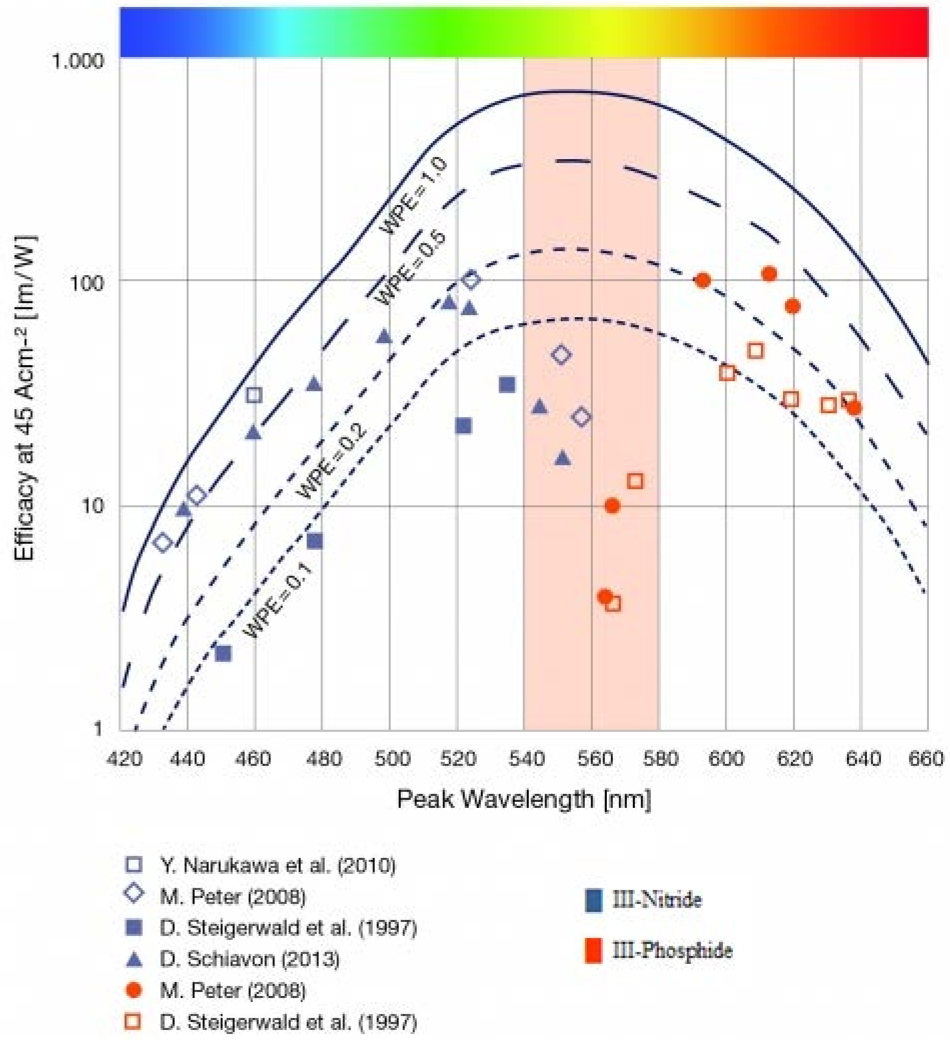

Figure 3.5.11 The “Green Gap”
Source: Compound Semiconductor[85]

In order to emit green light, a high forward voltage must be applied which reduces power conversion efficiency. Also, green LEDs, even more so than other LEDs, fall victim to reduced efficiency with increased current, known as “efficiency droop”. At typical operating currents, the effect is large as seen in Figure 3.5.12.

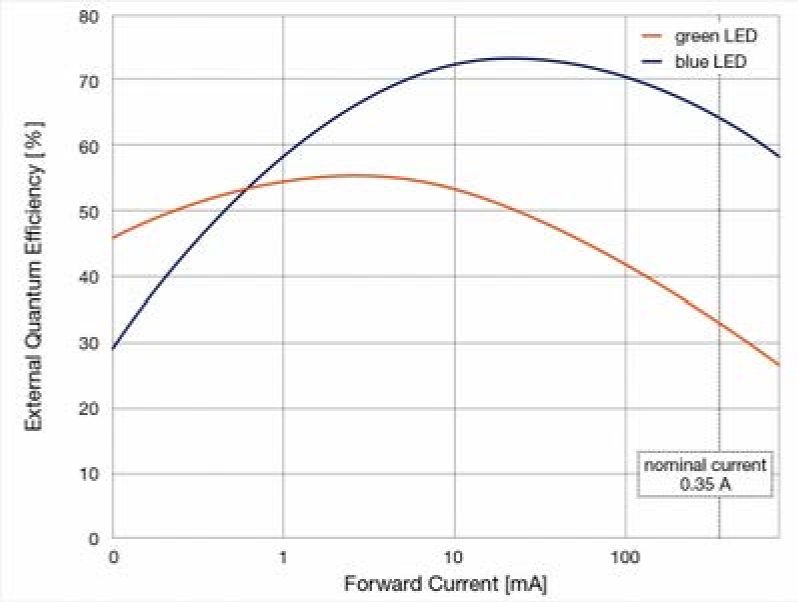

Figure 3.5.12 Efficiency Droop
Source: Compound Semiconductor[86]

While there have been many different theories regarding the efficiency droop, in April 2013, researchers at the University of California, Santa Barbara in collaboration with École Polytechnique in France identified Auger recombination as the primary source of efficiency droop. Auger recombination is a process by which electrons collide and produce heat rather than emit light. The rate at which this process occurs is proportional to third power of carrier density, which leads to low efficacy at high injection rates (*i.e.* high current).[87] The problem is inherent with the technology and not solvable, but can be mitigated through either thicker quantum wells or growth of epitaxial layers along non-polar or semi-polar directions in order to lower carrier density.[88, 89] Accordingly, RPI and other institutions such as NREL are continuing research efforts to reduce the effect through different polarities and even non polar epitaxial structures. In another approach, Dr. Alexander Efros with the U.S. Naval Research Laboratory obtained a patent for a method that utilizes quantum wells with softened confinement electrostatic potential that reduce carrier momentum necessary for the Augur process as a means of reducing efficiency droop.[90,91]

3.5.3.13 Alternative Substrate Materials

One of the major barriers to producing efficient LEDs is the lack of proper substrate materials. The LED substrate is the foundation on which the emitting material is built. The key issues surrounding substrates for LEDs are price and efficiency. The difference between the spacing of the atoms in the crystal lattice of the substrate and epitaxial layer has a large influence on the efficiency of the LED. A mismatch between the substrate and the GaN epitaxial layer creates strain which causes the materials to break away and fracture leading to decreased performance.[92] Better matched substrates will result in less strain in epitaxial layers leading to fewer defects and higher efficiency LEDs, thereby increasing LED lamp efficacy as well.

The oldest and most common LED substrate material is sapphire. Because sapphire has been used for so long, manufacturers have been able to solve a lot of performance issues and bring down price substantially. A few manufacturers are utilizing GaN on silicon carbide substrates which are more costly but also offer higher performance over sapphire (see Table 3.5.2). [93]

Other than silicon-carbide, GaN on GaN LEDs have emerged as a potential alternative substrate option. The major advantage of using GaN on GaN LED material comes from a better crystal lattice match with fewer defects, which enables LEDs to emit more light per unit area of LED material. Further, GaN on GaN LEDs have greater optical transparency and high thermal and electrical conductivity that delivers improved light output and performance.[94] The main issues with GaN substrates are high substrate cost, consistency, and a lack of large diameter wafers.[95] On February 24, 2014 Soraa, a company known for their GaN on GaN LEDs, announced their third generation GaN on GaN LED package achieving a 75 percent WPE at 35 A/cm^2 and 85 °C. It also renders with a CRI of 95 and R_9[p] of 95.[96]

Table 3.5.2 Substrate Comparison

Material	Lattice mismatch (%)	Strength	Weakness
Sapphire	16	Low price, chemical stability	Large lattice mismatch
GaN	0	Homogeneous substrates	Difficulty in high-quality crystal growth, high price. Currently in basic research stage.
SiC	3.5	Small lattice mismatch	Price, difficulty in large substrate growth
Si	18	Low price, large substrate possible	Difficulty in high-brightness manufacturing

Source: Solid State Technology[97]

3.5.3.14 Thermal Interface Materials

Thermal interface materials (TIMs) have the ability to improve cooling of the LED chip. LEDs produce not only light, but also heat during their operation since they are not perfectly efficient light emitters. Increasing heat at the LED junction can decrease LED efficacy.[98, 99] Continuously high junction temperatures are also known to hasten lumen depreciation over time due to LED component degradation, ultimately reducing lamp efficacy and lifetime.[100] There are varying levels of thermal performance offered by commercially available TIMs. For example, Dow Corning offers thermal adhesives, thermal greases, and thermal pads each available in a range of thermal conductivities for use in LED lamps.[101] Additionally, DOE has identified novel approaches to TIMs for use in LEDs and continual R&D advancements in the field. For example

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[p] R_9 is not used in the calculation of CRI. It is part of the special color rendering indices, referred to as R_9 through R_{14}, which are each based on single test colors. R_9, the “strong red” color sample, is especially pertinent because the rendition of saturated red is important for the appearance of skin tones, among other materials. For more information please refer to the LED Color Characteristics Fact Sheet: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-color-characteristics-factsheet.pdf.

chemical vapor deposition (CVD) diamond provides higher thermal conductivity than conventional materials as the diamond acts as an effective heat spreader. Further, a titanium layer can be applied to the diamond allowing for use of platinum or gold enabling attachment via standard methods such as solders or epoxies.[102] There is also research regarding use of carbon nanotubes, which have high thermal conductivity, in TIMs of high-brightness LEDs.[103]

3.5.3.15 Optimized Heat Sink Design

As mentioned in section 3.5.3.14 high LED junction temperatures can lead to a decrease in efficacy. The LED heat sink is the primary means by which LED lamps wick away heat from the LED chips. A well designed heat sink helps reduce LED junction temperature. DOE has found that optimized heat sink designs are being used in commercially available lamps that have traditional A-shape form factors. For example, finned designs made out of materials with high thermal transfer coefficients have been utilized in commercially available A-shape lamps. Further, there are existing patents on optimized heat sinks for LEDs indicating this is an area of ongoing research.[104, 105]

Sapa Extrusions North America recently unveiled a new method in manufacturing high ratio air cooled extruded aluminum heat sinks that are approximately eight percent more thermally efficient than the industry standard. The new technology allows them to achieve heat sink fin ratios, a ratio of the fin height to the spacing between the fins, in excess of 40:1 where they were previously restricted to ratios of 16:1 based on extrusion limitations.[106] This allows an increase in the number of fins on a finite footprint, leading to the boost in convection.

Another novel approach to thermal management in LED lamps is the use of a liquid filler inside the bulb to increase convection from the LED to the surface of the lamp through a liquid with much higher thermal mass than the conventional fluid, which is air. Follett Optoelectronic Co., Ltd. in China has announced liquid cooled LEDs at 6-8 W producing 90-100 lm/W.[107] Cree also recently announced a new LED lamp that removed the need for a heat sink. It is designed with ventilation chambers at the top and bottom of the bulb, and when heat is generated by the LEDs, the heat causes air to circulate, which ultimately cools the components using thermodynamic properties of convection.[108] Further improvements to heat sink manufacturing and materials will increase LED lamp performance and broaden application.

3.5.3.16 Active Thermal Management Systems

As mentioned in section 3.5.3.14 high LED junction temperatures can lead to a decrease in lamp efficacy. Active thermal management systems can provide higher performance alternatives to the conventional passively cooled convection heat sink designs. Active thermal management systems are specifically designed to provide cooling to LED components and theoretically, should provide net gains in overall efficiency even though they consume extra energy. Some active thermal management systems take the form of integral fans or vibrating membranes, increasing convection. The Philips MASTER LEDspot product line with integrated fans for cooling is an example of commercially available lamps that utilize active thermal management systems.[109]

3.5.3.17 Device Level Optics

A primary optic is integrated onto the LED package that optimizes light extraction and/or beam shaping. Secondary optics help further shape light of the LED lamp and are additional components separate and outside of the LEDs itself (*e.g.*, lens or diffuser). Reducing secondary interfaces through integration of a lens onto the LED, or removing the secondary optic altogether, will increase package efficacy of LED lamps. Secondary surfaces lower the efficacy of LED lamps by introducing another layer for light absorption. By removing secondary optics or integrating lens functionality at the package level, LED lamps will suffer fewer absorption losses at the same power input, and therefore have higher efficacy. DOE has found that there are research efforts addressing issues of optimizing extraction efficiency for small package sizes as well as improving beam shaping through only primary optics. An existing patent presents primary optic configurations that achieve more controlled beam shapes while allowing for a more simplified and efficient secondary optic.[110]

3.5.3.18 Increased Light Utilization

Once light is emitted from an LED, there are still a number of losses to the lamp and surrounding housing. Highly reflective coatings inside the lamp can help reduce light absorption losses, thereby increasing overall luminaire efficacy. WhiteOptics, in conjunction with DOE and University of Delaware’s composite materials department, has developed a new reflector composite coating demonstrated in LED luminaires that achieves a 97 percent reflectance as well as 15 percent optical efficiency improvement over benchmark LED luminaires. Further, the diffuse coating allows luminaires it is applied on to produce a uniform light distribution.[111] Other companies, such as SABIC, also offer plastics with reflectivities around 97 percent.[112] Dow Corning won an award at the 2014 LIGHTFAIR® International Innovation Awards for their MS-2002 Moldable White Reflector Silicon for use in LED devices that targets reflectivity up to 98 percent.[113] With fewer reflective interfaces and highly reflective materials, LED lamps will be able to decrease light absorption and increase efficacy.

3.5.3.19 Improved Driver Design

Current LED drivers are typically 85 percent efficient with improvements expected.[114] New designs will allow for smaller, more compact drivers with even higher efficiency, which will boost overall LED lamp efficacy. Philips Light Sources and Electronics is developing drivers with the help of DOE funding. These drivers are expected to have efficiencies over 90 percent and are also smaller and lower in cost. Philips’ new designs for 75 W drivers are 36 percent smaller than existing drivers, enable more precise dimming from 1V to 8V, and have added protection in the case of module overheating.[115] Additionally, manufacturer feedback and DOE’s review of catalogs show a range of efficiencies associated with drivers, indicating the potential for improvement in driver design.

3.5.3.20 AC LEDs

By reducing conventional driver size or removing the driver component, complexity, and efficiency losses, AC-powered LEDs can increase performance of the LED lamp. AC LEDs integrate power conversion into the package, thus requiring few additional components though design specifics vary by manufacturer. In original AC LED setups, half of the LEDs would light up for the first half of the AC power sine wave cycle and only the other half would light up for the second half of the cycle.[q] Under this setup, LEDs were linked together in a series forming strings and provided low efficacy solutions for niche applications such as accent lighting. The latest AC LED designs use a high voltage architecture with simple control circuitry to operate on AC current. Seoul Semiconductor has a number of high voltage AC LED modules commercially available for integration into lamps. In July 2014, Seoul Semiconductor announced a new line of AC LED modules with improved AC drivers designed specifically for the omnidirectional lamps.[116] The new AC driver improves compatibility with TRIAC dimmers and is able to effectively mitigate flicker issues that can arise during dimming of AC LEDs. [117, 118] Additionally, improvements in circuit design can increase LED utilization. For example, Texas Instruments (TI)'s TPS92411 MOSFET switch allows for a small capacitor to be placed across each LED segment on a circuit to store energy keeping all LEDs lit even when the AC line voltage is too low, thereby increasing LED utilization.[119] Some challenges for AC LEDs functionality include total harmonic distortion, power-factor correction, and zonal dimming.

3.5.3.21 Reduced Current Density

As discussed previously, efficiency droop negatively impacts the performance of LEDs at common current densities.[120] Most LEDs peak in efficiency when driven at just tens of milliamps whereas 350 mA is much more common. However, decreasing current also reduces lumen output, thus requiring more LEDs. Therefore, current density must be reduced in a way that increases LED efficacy while maintaining practical levels of lumen output per unit area. One method to achieve this benefit would be to design a lamp with several arrays of medium or low power LEDs in lieu of a small number of high power LEDs. Cree has introduced mid-power LEDs at 154 lm/W that uses the ceramic substrate that is typically utilized in high-power LEDs rather than plastic packaging found in most mid-power LEDs. This product could potentially minimize lumen depreciation and offer lifetimes comparable to the high-power LEDs.[121]

3.6 PRODUCT CLASSES

When evaluating and establishing energy conservation standards, DOE divides covered products into classes by (a) the type of energy used; (b) the capacity of the product; or (c) other performance-related features that justify different standard levels, such as features affecting consumer utility. (See 42 U.S.C. 6295(q)) DOE then conducts its analysis and considers separate standard levels for each product class. DOE applied the criteria of 42 U.S.C. 6295(q) to GSLs to develop product classes in this preliminary analysis. This section of the TSD describes the factors DOE examined in considering product classes for GSLs.

This rulemaking cycle is the first for GSLs and therefore there are no precedents for GSL product classes. The standards set by EPAct 2005 and in EISA 2007 for MBCFLs and GSILs respectively, established product classes for these lamp types. EPAct 2005 divided MBCFLs by whether or not they contained a cover and by wattage. EISA’s standards set separate standards for standard versus modified spectrum lamps and further by lumen bins.

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[q] In the US wall socket power supplies operate at 120 V and 60 Hz

For this preliminary analysis DOE examined several possible characteristics or features of GSLs that could warrant separation of covered products into different product classes, including:

- Cover
- Dimmability
- Ballast Location
- Lamp Technology
- Base Type
- Lamp Spectrum
- Correlated Color Temperature
- Lumen Package
- Standby Mode Operation

The following subsections discuss these lamp attributes and how they pertain to product class divisions.

3.6.1.1 Lamp Technology

In evaluating GSLs, DOE determined that different lamp technologies do not offer consumers different utility. DOE believes that for use in a general service application, a CFL and LED lamp offer similar functionality. Therefore, DOE is not considering product class divisions based on lamp technology. In the product class structure under consideration, medium base CFLs fall into the integrated GSL product class. DOE accounts for the existing standards for medium base CFLs in the analysis of this product class to ensure there is no backsliding.

3.6.1.2 Cover

DOE considered the effect that the presence of a cover over the main light source has on lamp efficacy. Some lamps incorporate an added glass or silicone cover over the main light source which can reduce the lumen output of the lamp. In some cases, covered lamps may offer utility to consumers as they more closely resemble traditional lighting technologies and are frequently utilized where a lamp is visible.

DOE researched the applicability of the covered versus bare feature across different lamp technologies. DOE found that while a cover generally decreased efficacy, particularly in CFLs, a cover could also result in increased efficacy, such as when it has a phosphor coating and transforms light emitted from LEDs into visible light. Further many LED lamps that have covers also have high efficacies. As noted previously, DOE is considering technology neutral product classes in this preliminary analysis. Thus, covered products will still be available at the highest levels of efficacy analyzed. For these reasons, DOE is not considering establishing a product class for covered versus bare products in this preliminary analysis.

3.6.1.3 Dimmability

For certain technologies, such as CFLs and LED lamps, not all products are marketed as capable of being dimmed. Thus a lamp that can be dimmed may offer unique performance characteristics and provide a utility to consumers.

DOE analyzed the impacts of dimming on lamp efficacy. Review of catalog data and feedback from stakeholders, indicated that dimmable lamps are available across a range of efficacies and further confirmed that the ability to dim has a negligible impact on efficacy. Therefore, because there is no discernable impact on efficacy in relation to dimmability, DOE is not considering establishing separate product classes for lamps that are dimmable and those that are not in this preliminary analysis.

3.6.1.4 Ballast Location

Ballast location refers to the use of integrated ballasts (*i.e.*, self-ballasted) or non-integrated ballasts (*i.e.*, externally ballasted). DOE notes that self-ballasted lamps may have lower inherent efficacy compared to lamps that utilize external ballasts due to the additional components and circuitry integrated into a self-ballasted lamp. The use of a self-ballasted lamp can be advantageous in that a consumer need only replace one lamp unit rather than two separate components. Self-ballasted lamps are also generally more compact and thus can be used in applications with size constraints. For these reasons, DOE is considering establishing separate product classes based on ballast location in this preliminary analysis.

The impact on efficacy and utility for this product class division is based on the lamp having all its components enclosed within it as opposed to requiring an external, replaceable component. Therefore, to provide a clearer description of the product class that is applicable across all GSL technology types, DOE is considering using the terms ‘integrated’ and ‘non-integrated’ rather than ‘self-ballasted’ and ‘externally-ballasted.’ Integrated GSLs would comprise lamps that contain all components necessary for the starting and stable operation of the lamp, do not include any replaceable or interchangeable parts, and are connected directly to a branch circuit through an ANSI base and corresponding ANSI standard lamp-holder (socket). Non-integrated GSLs would comprise any lamp that is not an integrated lamp.

3.6.1.5 Base Type

DOE considered that smaller base types, such as candelabra, may warrant a separate product class due to space constraints. However, DOE is not considering setting standards for GSLs with candelabra bases in this rulemaking (see section 3.2.5.3). Therefore, DOE is not considering establishing separate product classes based on base type in this preliminary analysis.

3.6.1.6 Lamp Spectrum

DOE considered lamp spectrum as a product class setting factor. Modified spectrum lamps provide a unique spectral power distribution (SPD) that increases the contrast between reds and greens, resulting in a type of light different from a standard spectrum. DOE’s research indicates that there are various ways to manipulate SPDs to achieve a modified spectrum such as neodymium coating, phosphor mixes and LED color mixing or a combination thereof. DOE has found that certain methods do not require a decrease in efficacy. For example the Philips L Prize lamp and Cree’s existing product line of True White ® color mixed LED modules are able to achieve a modified spectrum at high efficacies. Because efficacy is impacted in different ways based on the method used to achieve modified spectrum GSLs, DOE is not considering separate product classes for standard and modified spectrum GSLs in this preliminary analysis.

3.6.1.7 Correlated Color Temperature

DOE considered CCT as a product class setting factor. CCT is a measure of the perceived color of the white light emitted from the lamp. The perception of light affords consumers a different utility for lamps with different CCT values. DOE found that while there is a reduction in efficacy for fluorescent technology at higher CCTs, LED technology experiences an increase. For CFLs at higher CCTs, more light is converted to shorter wavelengths (*i.e.*, blue, violet) to which human eyes are less sensitive, thereby resulting in a decline in efficacy. In LED lamps, the LED emits blue light (*i.e.*, shorter wavelengths) which is partially down converted to longer wavelengths. While this process results in longer wavelengths to which human eyes are more sensitive, there is a decrease in lumen output due to losses from phosphor conversion and a larger Stokes' shift.[r] To achieve lower CCTs in LED lamps, more down conversion and a larger Stokes' shift is required, resulting in lower efficacy. Due to these underlying differences in technology, the efficacy trends associated with CCT differ for CFLs and LED lamps. Therefore, a consistent correlation between efficacy and CCT cannot be established for all GSLs. Hence DOE is not considering such a product class division based on CCT in this preliminary analysis.

3.6.1.8 Lumen Package

DOE considered lumen packages as a product class setting factor for integrated GSLs. DOE determined that higher lumen output products cannot achieve the same levels of efficacy as lower lumen output products. DOE believes that higher lumen packages offer a consumer utility. After evaluating manufacturer catalogs and other sources,[s] DOE determined that a general service high lumen application would have light output in the range of 2,000 – 2,600 lumens. DOE was unable to identify LED lamp replacements for incandescent lamps of wattages higher than 100 W. However, DOE identify lumen ranges of CFLs marketed as being equivalent to a 125 W incandescent lamp, the next common incandescent wattage higher than the 100 W. Additionally, ENERGY STAR Lamps Specification V1.1[t] defines a 125 W incandescent equivalent lamp to have a lumen range of 2,000 – 2,549. The upper lumen limit of the high lumen package product class under consideration is maintained at 2,600 in accordance with the scope of this rulemaking which is considering setting standards for products in the lumen range of 310 – 2,600. Because of the impact on both efficacy and utility, DOE is considering establishing separate product classes for integrated GSLs with lumen outputs between 310 and 1,999 and integrated GSLs with lumen outputs between 2,000 and 2,600. DOE is not establishing a product class division based on lumen package for non-integrated GSLs, as DOE found lumen packages across a range of efficacies for these products.

3.6.1.9 Standby Mode Operation

DOE considered a division based on the ability of a lamp to operate in standby mode. As stated in section 3.2.5.1, DOE identified integrated lamps that meet the definition of GSL and operate in standby mode. DOE believes that standby mode operation offers a consumer utility

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[r] Stokes' shift is the difference, in nanometres, between the peak excitation and the peak emission wavelengths. Stokes' law states that radiation emitted must be of the longer wavelength than that absorbed.

[s] ENERGY STAR Lamps V1.1 Final Specification, available at http://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Lamps%20V1%201_Specification.pdf.

[t] Ibid.

because these lamps have the ability to be remotely turned off, turned on, dimmed, or other functionality. DOE evaluated whether operation in standby mode impacts lamp efficacy. Based on commercially available products, DOE found that standby power consumption can vary based on the technology used to facilitate standby functionality. DOE assumes that the market will shift to the lowest energy consuming method available, such as Bluetooth or smart controls that are external to the lamp, over the course of the analysis period and therefore believes that the energy consumed in standby mode is negligible. Because DOE believes that the energy consumed while operating standby mode will be negligible for GSLs, DOE does not believe there is a difference in efficacy for lamps that can operate in standby mode compared to lamps that cannot operate in standby mode. Therefore, DOE is not considering a product class division based on standby mode operation.

3.6.1.10 Product Class Summary

After considering GSL characteristics above, in this preliminary analysis, DOE is considering establishing the three GSL product classes summarized in Table 3.6.1.

Table 3.6.1 GSL Product Classes

Lamp Type	Lumen Output
Integrated GSLs (*e.g.*, self-ballasted CFL, integrated LED lamp)	310-1,999
	2,000-2,600
Non-Integrated GSLs (*e.g.*, externally ballasted CFL)	310-2,600

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CHAPTER 4. SCREENING ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 4. SCREENING ANALYSIS

4.1 INTRODUCTION

This chapter discusses the U.S. Department of Energy's (DOE) screening analysis of the technology options identified for general service lamps (GSLs). As discussed in chapter 3 of this technical support document (TSD), DOE consults with industry, technical experts, and other interested parties in developing a list of technology options for consideration. The purpose of the screening analysis is to evaluate the list of options and determine which to consider further and which to screen out.

Section 325(o)(2) of the Energy Policy and Conservation Act (EPCA) provides that any new or revised standard must be designed to achieve the maximum improvement in energy efficiency that is determined to be technologically feasible and economically justified. (42 U.S.C. 6295(o)(2)) In view of the EPCA requirements for determining whether a standard is technologically feasible and economically justified, Appendix A to Subpart C of Title 10, Code of Federal Regulations (CFR), Part 430, "Procedures, Interpretations, and Policies for Consideration of New or Revised Energy Conservation Standards for Consumer Products" (the Process Rule) sets forth procedures to guide DOE in its consideration and promulgation of new or revised efficiency standards. These procedures elaborate on the statutory criteria provided in 42 U.S.C. 6295(o) and, in part, eliminate problematic technologies early in the process of prescribing or amending an energy efficiency standard. In particular, sections 4(b)(4) and 5(b) of the Process Rule provide guidance to DOE for determining which technology options are unsuitable for further consideration:

1. **Technological feasibility.** DOE will consider technologies incorporated in commercially available products or in working prototypes to be technologically feasible.

2. **Practicability to manufacture, install, and service.** If mass production of a technology and reliable installation and servicing of the technology could be achieved on the scale necessary to serve the relevant market at the time the standard requires compliance, then DOE will consider that technology practicable to manufacture, install, and service.

3. **Adverse impacts on product utility or product availability.** If DOE determines a technology would have significant adverse impact on the utility of the product to significant subgroups of consumers, or would result in the unavailability of any covered product type with performance characteristics (including reliability), features, sizes, capacities, and volumes that are substantially the same as products generally available in the United States at the time, it will not further consider this technology.

4. **Adverse impacts on health or safety.** If DOE determines that a technology will have significant adverse impacts on health or safety, it will not further consider this technology.

Section 4.2 of this chapter discusses the technology options DOE screened out from further consideration. Section 4.3 summarizes those options. Section 4.4 lists the remaining technology options not screened out and considered as design options in this preliminary analysis. The market and technology assessment (see chapter 3 of this TSD) discusses in detail all technology options analyzed in this preliminary analysis.

4.2 SCREENED OUT TECHNOLOGIES

This section addresses the technologies that DOE screened out, having considered the following four factors: (1) technological feasibility; (2) practicability to manufacture, install, and service; (3) adverse impacts on product utility or product availability; and (4) adverse impacts on health or safety.

4.1.1 Compact Fluorescent Lamps

4.1.1.1 Multi-Photon Phosphors

Theoretically, the use of multi-photon phosphors, or quantum-splitting phosphors, could significantly improve lamp efficacy of compact fluorescent lamps (CFLs). By emitting more than one visible photon for each ultraviolet photon, a lamp would be able to emit more light for the same amount of power. Researchers at Georgia Tech were issued a patent for an oxide-based phosphor doped with praseodymium and atoms of at least one activator that produces two visible light photons from a single ultraviolet light photon.[1] However, development of this technology for use in lighting products remains in the research phase and DOE is unaware of any prototypes or commercialized products that incorporate multi-photon phosphors.[2] Further, researchers have identified technical drawbacks to this technology such as light color output, color stability, and phosphor lifetime.[3] Thus, DOE screened out this technology option based on the first criterion, technological feasibility, and will not consider multi-photon phosphors as a design option for improving the efficacy of GSLs.

4.2.1 Light-Emitting Diode Lamps

4.1.1.2 Colloidal Quantum Dot Phosphors

Improving the efficiency of down converters in light-emitting diodes (LEDs) can result in more light output with the same power input, thus improving lamp efficacy. One method of down conversion that can result in increased lamp efficacy is the use of colloidal quantum dot phosphors. These quantum dot phosphors are nanocrystal emitters formed from indium phosphide-based nanocrystals that have unique compositional structures enabling higher efficiencies at higher temperatures and minimal losses associated with light flux. While researchers at State University of New York (SUNY) have produced quantum dot phosphors emitting green through red wavelengths at efficiencies over 80 percent, they have been unable to incorporate these nanocrystal emitters into white LED products.[4] Because quantum dot and nanophosphor technologies are still in R&D and not currently commercially available in LED lamps, DOE screened out this technology option based on the first criterion, technological feasibility, and will not consider quantum dot and nanophosphor technologies as a design option for improving the efficacy of GSLs.

4.1.1.3 Improved Emitter Materials

The LED emitter is the component of the LED that generates the actual light output. LED lamps are now able to use color mixing of red, green, and amber emitters to produce white light rather than phosphor coated LEDs. Increasing the efficiency of each of these emitters will increase the efficacy of the lamp. In particular green LEDs are unable to achieve their theoretical maximum efficiency. Green LEDs experience an efficiency droop with increased operating currents. This effect is noticeably large at typical operating currents, compared to other LED colors such as blue. Research has shown that the efficiency problem with green LEDs is inherent with the technology but it can be mitigated through thicker quantum wells or growth of epitaxial layers along non-polar or semi-polar directions in order to lower carrier density and thereby increase lamp efficacy. However, because research in these mechanisms to reduce efficiency droop is ongoing, DOE screened out this technology option based on the first criterion, technological feasibility, and will not consider improved emitter materials as a design option for improving the efficacy of GSLs.

4.1.1.4 AC LEDs

By reducing conventional driver size or removing the driver component, complexity, and efficiency losses, AC-powered LEDs can increase performance of the LED lamp. AC LEDs integrate power conversion into the package, thus requiring few additional components. However, commercially available AC LED products are LED modules, rather than LED lamps. LED modules do not directly incorporate a power source or ANSI standard base within the device, thus it cannot be connected directly to the branch circuit. Because AC LEDs are not currently integrated into lamps, DOE screened out this technology option based on the second criterion, practicability to manufacture, install and service, and will not consider AC LEDs as a design option for improving the efficacy of GSLs.

4.3 SUMMARY OF TECHNOLOGY OPTIONS SCREENED OUT

The following tables summarize the technology options DOE is considering screening out and the associated screening criteria.

Table 4.3.1 GSL Technology Options Screened Out of the Analysis

Technology	Design Option Excluded	Screening Criteria
CFL	Multi-Photon Phosphors	Technological feasibility
LED	Colloidal Quantum Dot Phosphors	Technological feasibility
	Improved Emitter Materials	Technological feasibility
	AC LEDs	Practicability to manufacturer, install and service

4.4 REMAINING TECHNOLOGIES

After screening out those technologies in accordance with the policies set forth in 10 CFR Part 430, Subpart C, Appendix A, (4)(a)(4) and 5(b), DOE is considering the design options in the following list as viable means for improving efficacy. These design options are being utilized in commercially available lamps and have demonstrated that they are technologically feasible, practicable to manufacture, install, and service, and do not result in adverse impacts on product utility/availability or health and safety. The market and technology assessment (see chapter 3 of this TSD) provides a detailed description of these design options.

4.4.1 General Service Lamp Design Options

CFL Design Options

- Highly Emissive Electrode Coatings
- Higher Efficiency Lamp Fill Gas Composition
- Higher Efficiency Phosphors
- Glass Coatings
- Cold Spot Optimization
- Improved Ballast Components
- Improved Ballast Circuit Design
- Change in Technology

LED Design Options

- Efficient Down Converters (with the exception of colloidal quantum dots phosphors)
- Improved Package Architectures
- Alternative Substrate Materials
- Optimized Heat Sink Design
- Active Thermal Management Systems
- Device Level Optics
- Increased Light Utilization
- Improved Driver Design
- Reduced Current Density

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CHAPTER 5. ENGINEERING ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

The U.S. Department of Energy (DOE) performed engineering analyses for general service lamps (GSLs). This chapter of the technical support document (TSD) provides the analyses DOE used to study representative lamps, to select candidate standard levels (CSLs), and to develop power rating estimates for the products analyzed. After selecting representative product classes, DOE then selects lamps that represent the baseline efficacy, as well as more efficacious substitutes for those baseline lamps. DOE uses these more efficacious lamps to develop CSLs. While DOE establishes CSLs based on lamp designs for the engineering analysis, for non-integrated GSLs it also develops lamp-and-ballast systems for use in the life-cycle cost (LCC) analysis and national impact analysis (NIA) because non-integrated compact fluorescent lamps and ballasts[a] operate together in practice.

In energy conservation rulemakings for other products, DOE often develops cost-efficiency relationships in the engineering analysis. However, for this rulemaking, DOE derives CSLs in the engineering analysis and end-user prices in the product price determination. By combining the results of the engineering analysis and the product price determination, DOE derives typical inputs for use in the LCC and NIA. See chapter 6 of this TSD for discussion of DOE's methodology for determining product prices.

5.2 METHODOLOGY OVERVIEW

To the extent possible, DOE bases the engineering analysis on commercially available lamps that incorporate the design options identified in the technology assessment and screening analysis (chapters 3 and 4 of this TSD). The engineering analysis for the lamps DOE analyzes in this rulemaking (*i.e.*, GSLs) takes the following four steps:

1. *Select representative product classes:* DOE first reviews covered lamps and the associated product classes. When multiple product classes are needed, DOE selects certain classes as "representative" and concentrates its analytical effort on these classes. DOE selects representative product classes primarily because of their high market volumes.

2. *Select Baseline Lamps:* For each representative product class, DOE selects a baseline lamp as a reference point against which to measure changes resulting from energy conservation standards. Typically, a baseline lamp is the most common, least efficacious lamp sold in a given product class. For this preliminary analysis, DOE used performance data presented in manufacturer catalogs to determine lamp efficacy. DOE also considers other lamp characteristics in choosing the most appropriate baseline for each product class such as lumen output, correlated color temperature (CCT), color rendering index (CRI), shape, and lifetime.

3. *Identify More Efficacious Substitutes:* DOE selects higher efficacy lamps as replacements for each of the baseline lamps. When selecting higher efficacy lamps, DOE considers only

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[a] DOE is not considering setting standards for commercially available GSLs that operate using an external driver at this time.

design options that meet the criteria outlined in the screening analysis (chapter 4 of this TSD). For non-integrated GSLs, DOE pairs each representative unit with an appropriate ballast because non-integrated GSLs are a component of a system, and their performance is related to the ballast on which they operate.

4. *Determine Candidate Standard Levels:* After identifying more efficacious substitutes for each baseline lamp, DOE develops CSLs. DOE bases its analysis on three factors: (1) the design options associated with the specific lamps studied; (2) the ability of lamps across the lumen range to comply with the CSL of a given product class;[b] and (3) the maximum technologically feasible efficacy level. DOE then scales the CSLs of representative product classes to those product classes not directly analyzed.

The sections that follow discuss how DOE applies this methodology to each GSL product class to create the engineering analysis.

5.3 ANALYSIS

5.3.1 Representative Product Classes

As discussed in the market and technology assessment, DOE is considering three product classes for GSLs based on two class-setting factors: ballast/driver location (*i.e.*, integrated or non-integrated) and lumen package. See chapter 3 of this TSD for more details. DOE typically chooses representative product classes based on the highest shipment volume. In this preliminary analysis, DOE is considering directly analyzing all product classes for GSLs. DOE is considering directly analyzing both the integrated and non-integrated product classes because of technological differences that would preclude scaling from the high volume integrated product class. Specifically, DOE observed different efficacy trends and maximum technologically feasible levels between the two classes. Manufacturer feedback also indicated that scaling between the integrated and non-integrated product classes is not appropriate. Further, for the integrated product class, DOE is considering directly analyzing both the low lumen and high lumen product classes. DOE has found that there are technological limitations to producing high lumen (*i.e.*, 2,000 lumens or greater) GSLs using light-emitting diode (LED) technology and therefore CSLs for this product class cannot be scaled from the low lumen integrated product class.

Table 5.3.1 lists the representative product classes that DOE is considering in this preliminary analysis.

Table 5.3.1 Representative Product Classes for General Service Lamps

Lamp Type	Lumen Output
Integrated GSLs	310-1,999
	2,000-2,600
Non-Integrated GSLs	310-2,600

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[b] CSLs span multiple lamps of different lumen outputs and wattages. In selecting CSLs, DOE considered whether these multiple lamps can meet the standard levels.

5.3.2 Integrated Product Class

5.3.2.1 Existing Standards

Energy conservation standards currently exist for medium base compact fluorescent lamps (MBCFLs). Bare and covered MBCFLs are subsets of compact florescent lamps, which are included in the definition of GSL. DOE has the authority to evaluate energy conservations standards for compact fluorescent lamps (CFLs), including MBCFLs, in this GSL rulemaking. (42 U.S.C. 6291(30)(BB)) The Energy Policy and Conservation Act (EPCA) contains an “anti-backsliding” provision which prevents DOE from prescribing any amended standard that either increases the maximum allowable energy use or decreases the minimum required energy efficiency of a covered product. (42 U.S.C. 6295(o)(1)) Therefore, any standard prescribed for GSLs that is applicable to MBCFLs must not backslide from existing standards. The existing standards for MBCFLs are summarized in Table 5.3.2.

Table 5.3.2 Existing Efficacy Standards for Medium Base Compact Fluorescent Lamps

Configuration	**Lamp Power**	**Minimum Efficacy**
	W	*lm/W*
Bare Lamp	< 15	45.0
	≥ 15	60.0
Covered Lamp (No Reflector)	< 15	40.0
	15 ≤ Lamp Power < 19	48.0
	19 ≤ Lamp Power < 25	50.0
	≥ 25	55.0

MBCFLs fall within the integrated low lumen and integrated high lumen product classes. Because DOE determined that lamp configuration (*i.e.*, bare or covered) is not a class setting factor in the product class structure proposed in this analysis, the baseline efficacy requirements are determined by lamp wattage. Therefore, for products with wattages less than 15 watts (W), which fall into the integrated low lumen product class, DOE set the baseline efficacy at 45 lm/W (the highest of the existing standards for that wattage range) to prevent backsliding. For products with wattages greater than or equal to 15 W, which fall into the integrated high lumen product class, DOE set the baseline efficacy at 60 lm/W to prevent backsliding. The baseline efficacy requirements for the integrated product classes are shown in Table 5.3.3.

Table 5.3.3 Integrated Product Classes Current Standard Efficacy Requirements

Product Class	**Lamp Power**	**Minimum Efficacy**
	W	*lm/W*
Integrated Low Lumen (310-1,999 Lumens)	< 15	45.0
Integrated High Lumen (2,000-2,600 Lumens)	≥ 15	60.0

5.3.2.2 Baseline Lamps

For each representative product class, DOE selects baseline lamps that are typically the most common, least efficacious lamps that meet existing standards (when applicable). To identify baseline lamps, DOE reviews product offerings in catalogs, shipment information, and manufacturer feedback obtained during interviews. DOE determines the most common product characteristics such as lumen output range, shape, lifetime, CCT, and CRI. Among lamps with those characteristics, DOE selects the least efficacious product as the baseline.

Integrated Low Lumen Product Class. DOE first identified the common characteristics of the integrated low lumen product class. DOE utilized a database of commercially available GSLs when determining common lamp characteristics. For the integrated low lumen product class, DOE found that the most common lamps are 60 W equivalent lamps which produce lumen output in the range of 700-900 lumens. Manufacturer feedback confirmed that 60 W equivalent general service incandescent lamp (GSIL) replacements are the GSLs shipped in the highest volume. DOE also found that CFLs are the most common lamp technology, and spiral and "A-shape" are the most common shapes. DOE analyzed the commercially available CFLs in the integrated low lumen product class and determined that a rated lifetime of 10,000 hours was most common. Further, DOE found that the vast majority of CFLs in the integrated low lumen product class have a CCT of 2,700 Kelvin (K) and CRI of 80 to 82.

Of lamps with the common characteristics identified, DOE then selected the least efficacious lamp to represent the baseline. While 13 W spiral CFLs are the most common lamps for the associated lumen range, DOE found that these lamps are not the least efficacious and typically perform well above the applicable existing standard for MBCFLs. Covered CFLs, such as A-shape CFLs, replicate the traditional shape of GSILs and tend to have lower efficacies compared to spiral CFLs. Therefore, DOE has preliminarily selected an A-shape 14 W CFL with lumen output of 750 lumens (53.6 lm/W) as the baseline. The baseline lamp has a medium screw (E26) base, a rated lifetime of 10,000 hours, a CCT of 2,700 kelvin (K) and a CRI of 80.

Integrated High Lumen Product Class. For the high lumen integrated product class, DOE found that the most common lamps are 125 W equivalent lamps which produce lumen output in the range of 2,000-2,600 lumens. DOE found at this time that CFLs are the only lamp technology commercially available in the high lumen integrated product class. Further, DOE found that the vast majority of products in the integrated high lumen product class were spiral shape CFLs. Similar to the low lumen product class, DOE analyzed the commercially available CFLs in the integrated high lumen product class and determined that a rated lifetime of 10,000 hours was most common. Further, DOE found that CFLs in the integrated high lumen product class most commonly have a CCT of 2,700 K and CRI of 80 or above.

Of lamps with the common characteristics identified, DOE then selected the least efficacious lamp to represent the baseline. DOE has preliminarily selected a spiral 32 W CFL with lumen output of 2,000 lumens (62.5 lm/W) as the baseline. The baseline lamp has a medium screw (E26) base, a rated lifetime of 10,000 hours, a CCT of 2,700 K, and a CRI of 80, all of which are common characteristics of the integrated high lumen product class.

Table 5.3.4 lists the specifications for the baseline lamps DOE is considering for the integrated product classes.

Table 5.3.4 Integrated Product Classes' Baseline Lamps

Product Class	Lamp Shape	Base Type	Lamp Type	Nominal Wattage	Initial Lumens	Rated Efficacy	Lifetime	CCT	CRI
				W	*lm*	*lm/W*	*hr*	*K*	
Integrated Low Lumen (310-1,999 Lumens)	A-Shape	E26	CFL	14	750	53.6	10,000	2,700	80
Integrated High Lumen (2,000-2,600 Lumens)	Spiral	E26	CFL	32	2,000	62.5	10,000	2,700	80

5.3.2.3 More Efficacious Substitutes

After choosing a baseline lamp for each representative product class, DOE identifies more efficacious substitutes. When identifying higher efficacy replacement lamps, DOE used lamp efficacy values determined using catalog lumens and catalog wattage. DOE utilized a database of commercially available lamps and selected more efficacious replacement lamps that both save energy[c] and maintain comparable light output to the baseline lamp when possible. Specifically, DOE ensured that potential substitutions maintained light output within ten percent of the baseline lamp lumen output. Further, DOE considered only technologies that met all four criteria in the screening analysis.

DOE also sought to keep characteristics of substitute lamps as similar as possible to the baseline lamps. DOE selected more efficacious substitutes with same base type as the baseline lamp because replacing an integrated lamp with a lamp of a different base type would potentially require a fixture or socket change and is thus considered an unlikely replacement. In addition to maintaining a consistent base type, DOE maintained a CCT of 2,700 K for all replacements. Manufacturer feedback indicated that differences between the common, nominal CCTs (*e.g.*, 2,700 K to 3,000 K) would be noticeable by the consumer, and therefore DOE did not consider a change in CCT to be viable for higher efficacy replacements. DOE maintained a CRI in the range of 80 to 82. DOE also selected replacement lamp units with lifetimes greater than or equal to the lifetime of the baseline lamp. For LED lamps, DOE utilized the L70 lifetime values, which is consistent with DOE's proposal in the LED test procedure (TP) supplementary notice of proposed rulemaking (SNOPR).[d]

DOE also ensured that the LED lamps considered as more efficacious substitutes were marketed as omnidirectional, thus maintaining the uniform light distribution of the baseline lamp. Based on manufacturer feedback, DOE found that the majority of manufacturers consider lamps to be omnidirectional if they meet the performance requirements of the ENERGY STAR®

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[c] DOE considers substitutions that both save energy and do not save energy in the NIA.

[d] DOE's LED TP SNOPR can be found here: http://www.regulations.gov/#!documentDetail;D=EERE-2011-BT-TP-0071-0022

definition[e] for omnidirectional lamps. Omnidirectional lamps evenly distribute light in all directions, whereas the light distribution of semi-omnidirectional lamps is more directed. Some manufacturers noted that semi-omnidirectional lamps are cheaper products that are not desired by the consumer. Further, some manufacturers stated that semi-omnidirectional lamps cannot be used in the same application as omnidirectional lamps. DOE found several lamps marketed as semi-omnidirectional. However, to ensure that the more efficacious substitutes could be used in the same applications as the baseline lamps, DOE only considered lamps that were marketed as omnidirectional in the analysis.

5.3.2.4 Candidate Standard Levels

After identifying more efficacious substitutes for each of the baseline lamps, DOE develops CSLs based on the consideration of several factors, including: (1) the design options associated with the specific lamps being studied (*e.g.*, grades of phosphor for CFLs, improved package architecture for LEDs); (2) the ability of lamps across the applicable lumen range to comply with the standard level of a given product class; and (3) the maximum technologically feasible ("max tech") level. DOE used commercially available lamps and their associated catalog efficacies to determine the design options required to meet each CSL. DOE used catalog data as the basis of its engineering analysis because it is the largest and most comprehensive dataset. To establish final minimum efficacy requirements for each CSL, DOE evaluated whether any adjustments were necessary to the initial CSLs to ensure lamps were available across the entire lumen range represented by the product class.

DOE adopted an equation-based approach to establish CSLs for GSLs, reflecting the relationship between efficacy and lumen output. Because the lamps covered by the scope of this rulemaking span different lighting technologies, GSLs designed to satisfy the same applications are available in a variety of wattages. Further, DOE believes that the primary utility provided by a lamp is lumen output which can be achieved through a wide range of wattages depending on the lamp technology. For these reasons, DOE believes that lamps providing equivalent lumen output, and thus intended for the same applications, should be subject to the same minimum efficacy requirements. DOE developed a smooth, continuous equation that specifies a minimum efficacy requirement across lumen output and represents the potential efficacy a lamp achieves using a particular design option. Because the equations account for changes in efficacy due to lumen output, they can also account for market shifts to new lumen packages.

DOE utilized a database of commercially available lamps to evaluate efficacy trends of integrated GSLs at different lumen outputs. DOE acknowledges that lower lumen output GSLs tend to be less efficacious than higher lumen output GSLs and is considering CSLs with a curved shape rather than a horizontal line for that reason. Specifically, DOE believes that fixed losses in GSLs, such as power consumed by the integrated ballast/driver, become proportionally smaller at higher lumen outputs thereby increasing efficacy. Using the database of commercially available integrated GSLs, DOE conducted regression analyses on a number of different equation forms to find the form that best fit the efficacy trend. DOE included lamps that met the definition of GSL but were outside the lumen range of 310 – 2,600 lumens because DOE believes this dataset

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[e] The ENERGY STAR Program Requirements for Lamps (Light Bulbs) V1.1 specifies luminous intensity distribution requirements for omnidirectional light sources and is available here: http://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Lamps%20V1%201_Specification.pdf.

results in a curve that better represents the relationship between efficacy and lumen output for the technologies analyzed. DOE confirmed the curve fit matched product performance particularly in the low and high ends of the GSL lumen range. DOE also ran regression analyses for the equation forms under consideration on subsets of integrated GSLs by technology (*i.e.* only CFLs or only LEDs) and by manufacturer in order to verify the efficacy trends. The equation form DOE selected for this preliminary analysis, a decaying exponential, was chosen based on its consistent ability to fit the data well (measured by R^2 value[f]) across the subsets of data. DOE is considering establishing CSLs based on an equation for efficacy using lumens as the input in the following form:

$$Efficacy = A - 29.42 * 0.9983^{Lumens}$$

Eq. 5.1

Where:
Efficacy = minimum efficacy requirement,
Lumens = measured lumen output, and
A = an adjustment variable (the “A-value”).

After identifying more efficacious substitutes, DOE calculated the A-value of the equation using catalog lumen output and catalog efficacy for each representative lamp unit. The A-value is an adjustment variable that shifts the equation in a vertical direction and is calculated to represent certain levels of efficacy. DOE evaluated the equation against lamps with the same design options as the representative lamp unit for each CSL and made slight adjustments to capture the efficacy of lamps with those design options across the entire lumen output range thus allowing for continuous CSLs across the integrated product classes.

In general terms, for the integrated low lumen product class, DOE based its CSLs on design options described below.

CSL 1: This level represents an improved CFL with more efficient phosphors and improved ballast components.

CSL 2: This level represents a basic LED lamp with an efficacy near the lowest performing LED lamps currently available on the market.

CSL 3: This level represents an improved LED lamp with improved package architecture, high efficiency driver, and improved optics.

CSL 4: This level represents an advanced LED lamp with further improved package architecture, high efficiency driver, and improved optics.

CSL 5: This level is the maximum technologically feasible level and represents an LED lamp with the most efficacious combination of package architecture, driver, and optics available on the market today.

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[f] R^2 is calculated based on the difference between all observed values (in this case catalog efficacy) versus the modelled values. As the fitted equation becomes closer to modelling the observed values, the R^2 value will increase.

For the integrated high lumen product class, DOE based its CSLs on the design options described below.

CSL 1: This level represents an improved CFL with more efficient phosphors and improved ballast components.

CSL 2: This level is the maximum technologically feasible level and represents the most efficacious combination of phosphors and ballast components.

Table 5.3.5 provides detailed information on the representative lamps in the integrated product classes used in the engineering analysis and subsequent analyses.

Table 5.3.5 Integrated Product Classes' Representative Units

Product Class	**CSL**	**A-value**	**Lamp Shape**	**Base Type**	**Lamp Type**	**Nominal Wattage**	**Initial Lumens**	**Rated Efficacy**	**Lifetime**	**CCT**	**CRI**
						W	*lm*	*lm/W*	*hr*	*K*	
Integrated Low Lumen (310-1,999 Lumens)	Baseline	61.7	A-Shape	E26	CFL	14	750	53.6	10,000	2,700	80
	CSL 1	69.0	Spiral	E26	CFL	13	800	61.5	12,000	2,700	82
	CSL 2	74.2	A-Shape	E26	LED	12	800	66.7	25,000	2,700	82
	CSL 3	80.2	A-Shape	E26	LED	11	800	72.7	25,000	2,700	81
	CSL 4	87.5	A-Shape	E26	LED	10	800	80.0	25,000	2,700	82
	CSL 5	91.7	A-Shape	E26	LED	9.5	800	84.2	25,000	2,700	80
Integrated High Lumen (2,000-2,600 Lumens)	Baseline	63.4	Spiral	E26	CFL	32	2,000	62.5	10,000	2,700	80
	CSL 1	67.6	Spiral	E26	CFL	30	2,000	66.7	10,000	2,700	82
	CSL 2	76.5	Spiral	E26	CFL	29	2,200	75.9	12,000	2,700	82

As stated, DOE found it was necessary to make slight adjustments to the minimum efficacy requirements of the CSLs to develop levels that were continuous across the integrated product classes and representative of lamps across the entire lumen range. At CSL 1, DOE found that the calculated A-value of the representative unit in the integrated low lumen product class was slightly higher than the A-value of the representative unit in the integrated high lumen product class (*i.e.*, 69.0 versus 66.7). Conversely, at CSL 2, DOE found that the calculated A-value of the representative unit in the integrated high lumen product class was slightly higher than the representative unit in the integrated low lumen product class (*i.e.*, 76.5 versus 74.2). To avoid discontinuities in efficacy between the two product classes, DOE made adjustments downward to allow for continuous CSLs across the integrated product classes. Therefore, DOE utilized the minimum A-value of the representative units at each CSL to set the minimum efficacy requirements of CSL 1 and CSL 2 (*i.e.*, 66.7 and 74.2, respectively).

In addition, DOE made adjustments to ensure that lamps were available across the entire lumen range. Specifically, DOE adjusted CSL 5, the max-tech level, in the low lumen product class downward from an A-value of 91.7 to 90.8. DOE made this adjustment to account for the performance of commercially available products at the 100 W GSIL equivalency. Thus, DOE ensured that lumen packages throughout the low lumen product class would be maintained, even at the highest CSL. DOE did not find it was necessary to make any adjustment for 40 W GSIL equivalents as commercially available products with the common characteristics are able to meet the max tech level. Though DOE did not find a commercially available 75 W equivalent GSIL with the common characteristics meeting max tech, DOE believes the level is technologically feasible as both 60 W equivalent and 100 W equivalent lamps can meet the max-tech level under consideration.

DOE also used publicly available certification data and verification testing data from the California Energy Commission's (CEC's) Appliance Efficiency Certified Light Bulbs Database,[g] DOE's LED Lighting Facts Product List,[h] the U.S. Environmental Protection Agency's (EPA's) ENERGY STAR Certified Light Bulbs database,[i] and DOE's Compliance Certification Management System (CCMS) database[j] when possible to verify the CSLs were achievable. The GSL types found in each database are outlined in Table 5.3.6. DOE matched the certification and verification testing data with catalog values for GSLs and found that both the mean and median efficacy of all matched products were higher in the compliance and verification databases than the mean and median catalog values for all matched products for each of the certification and verification databases analyzed.

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[g] Certification data is publicly available on CEC's Appliance Efficiency Database available here: http://www.appliances.energy.ca.gov/Default.aspx.

[h] DOE's LED Lighting Facts Product List is publicly available here: http://www.lightingfacts.com/products.

[i] EPA's ENERGY STAR Certified Light Bulbs database is publicly available here: http://www.energystar.gov/productfinder/product/certified-light-bulbs/results.

[j] DOE's Compliance Certification Database is publicly available here: www.regulations.doe.gov/certification-data/.

Table 5.3.6 Certification and Verification Testing Databases

Database	**GSL Types Included in Database***
CEC Appliance Efficiency Database	Medium base CFLs, medium base LED lamps, GU24 base CFLs, GU24 base LED lamps
LED Lighting Facts Product List	Medium base LED lamps, GU24 base LED lamps
Energy Star Certified Light Bulbs	Medium base CFLs, medium base LED lamps, GU24 base CFLs, GU24 base LED lamps
DOE Compliance Certification Management System	Medium base CFLs
* This table does not include all lamp types reported in the databases. The GSL types listed in this table are only those that DOE is considering setting standards for and thus used in the engineering analysis.	

DOE also used the supplementary data to assess the individual performance of the representative units and equivalent lamps. DOE found that the representative units' catalog efficacies were supported by the certification and verification testing databases. Additionally, DOE found that the efficacy of certified and verified products with similar specifications[k] to those selected as representative units were, in the vast majority of cases, equally or more efficacious than stated by catalog value. Therefore, DOE determined that no further downward adjustments to CSLs were necessary based on additional compliance and testing data.

Lastly, DOE examined the performance of different types of bulbs that are subject to standards including 3-way lamps and dimmable lamps. DOE found dimmable lamps performing at max tech, including those selected as substitutes, and found no reason to make adjustments on that basis. DOE also found 3-way lamps performing at max tech and therefore made no further adjustments to the max-tech level.

DOE notes that data outliers were identified in its review of efficacy values from the compliance and verification testing databases. DOE identified outliers both on the high and low end, and in cases where DOE was unable to verify the value using third party data or manufacturer confirmation, did not consider the lamp in the engineering analysis.

Figure 5.3.1 illustrates the five CSLs for the integrated low lumen product class and the two CSLs for the integrated high lumen product class on a plot with the representative lamp units. The line at 45.0 lm/W for wattages less than or equal to 15 W and 60.0 lm/W for wattages greater than 15 W denotes the existing energy conservation standard. The red triangles identify the baseline lamps. The plot also shows more efficacious substitutes that DOE considered as replacements, which are denoted by square boxes. These replacements were selected such that they have increased efficacy compared to the previous level while maintaining light output within ten percent of the baseline lamp.

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[k] Products were deemed similar if they matched the representative units same technology, lamp shape, base type, wattage, and CCT while having a minimum CRI of 80 and a lumen output between 700-900 lumens.

Figure 5.3.1 CSLs for GSL Integrated Representative Product Classes

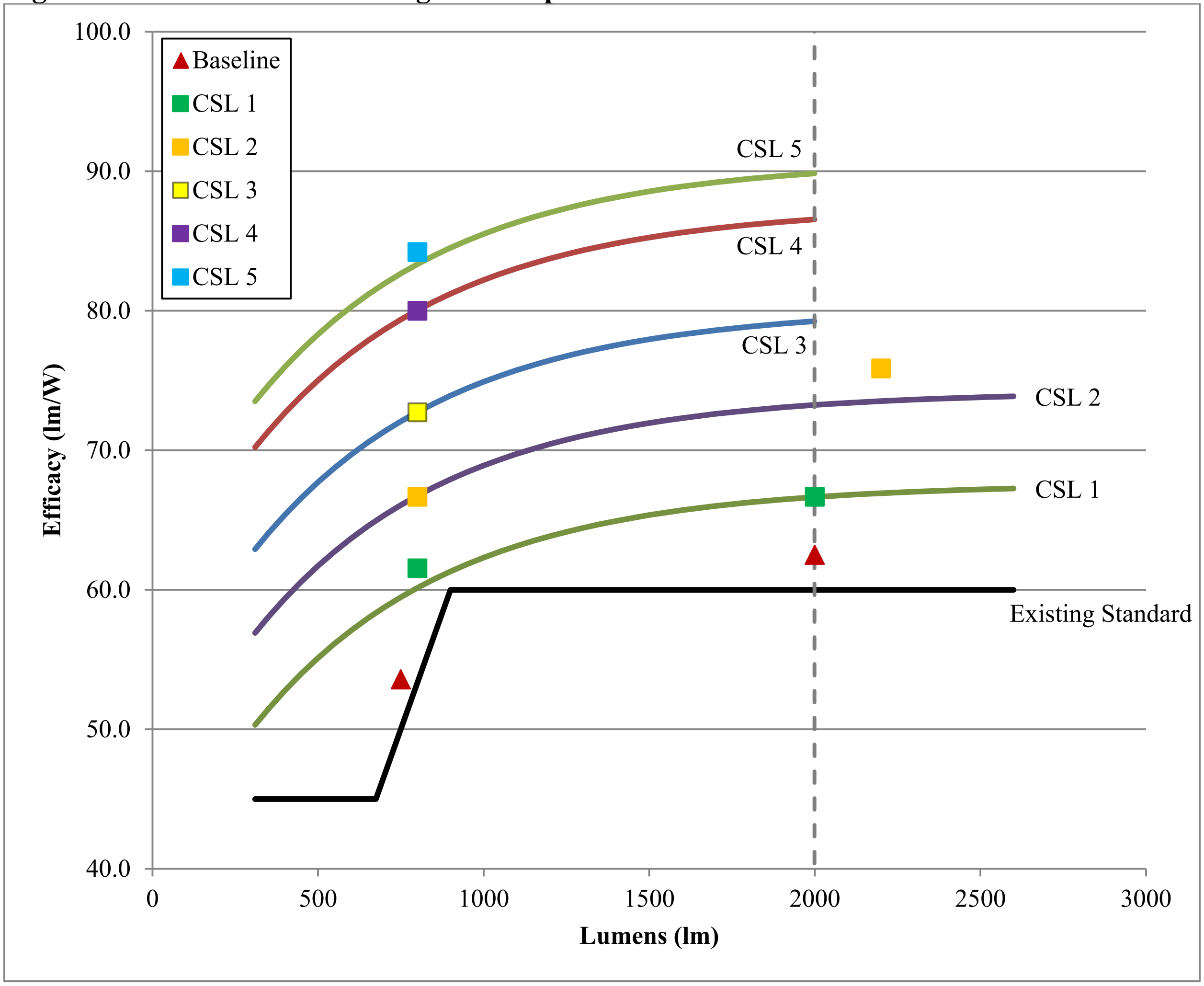

Table 5.3.7 summarizes the resulting efficacy requirements at each CSL after accounting for any adjustments made and rounding A-values to the nearest tenth.

Table 5.3.7 Summary of CSLs for GSL Integrated Representative Product Classes

Representative Product Class	Candidate Standard Level	Efficacy
		lm/W
Integrated Low Lumen (310 – 1,999 Lumens)	CSL 1	67.6-29.42*0.9983^Lumens
	CSL 2	74.2-29.42*0.9983^Lumens
	CSL 3	80.2-29.42*0.9983^Lumens
	CSL 4	87.5-29.42*0.9983^Lumens
	CSL 5	90.8-29.42*0.9983^Lumens
Integrated High Lumen (2,000 – 2,600 Lumens)	CSL 1	67.6-29.42*0.9983^Lumens
	CSL 2	74.2-29.42*0.9983^Lumens

5.3.3 Non-Integrated Product Class

5.3.3.1 Existing Standards

The non-integrated product class does not have any existing applicable energy conservation standards.

5.3.3.2 Baseline Lamps

For each representative product class, DOE selects baseline lamps that are typically the most common, least efficacious lamps that meet existing standards (when applicable). Because the non-integrated product class does not have applicable existing standards, the lowest efficacy lamps on the market were considered. To identify baseline lamps, DOE reviews product offerings in catalogs, shipment information, and manufacturer feedback obtained during interviews. DOE determines the most common product characteristics such as lumen output range, shape, lifetime, CCT, and CRI. Among lamps with those characteristics, DOE selects the least efficacious product as the baseline. For the non-integrated product class, DOE used rated efficacy[l] to evaluate representative lamps for this analysis.

Similar to the integrated product class, DOE first identified the common characteristics of the non-integrated product class. DOE utilized a database of commercially available GSLs when determining common lamp characteristics. In this preliminary analysis, DOE is only considering setting standards for non-integrated CFLs. (See chapter 2 of this TSD for more information on scope.) DOE found that the base types of non-integrated CFLs typically correspond to certain wattages and lumen outputs, and thus DOE concentrated on a common wattage and its associated base type. The most common non-integrated GSL wattages that DOE identified based on its database of commercially available GSLs are 13 W, 18 W, and 26 W which typically correspond to lumen outputs in the range of 700-900, 1,000-1,300, and 1,500-1,800 lumens, respectively. Using manufacturer feedback, DOE confirmed that 26 W CFLs are the highest volume non-integrated GSLs. DOE identified three shapes that comprised the vast majority of non-integrated GSLs: single tube, double tube[m], and triple tube. While non-integrated CFLs of the same wattage are sometimes offered in different lamp shapes, DOE found the double tube shape to be the most common shape associated with 26 W CFLs. DOE found the most common base type associated with 26 W double tube CFLs to be the G24q-3 base. DOE analyzed the commercially available lamps in the non-integrated product class and determined that a 10,000 hour lifetime was most common. Further, DOE identified a CCT of 4,100 K to be the most prevalent across the non-integrated product class. DOE also found that the vast majority of products in the non-integrated product class have a CRI of 80 to 82.

Of lamps with the common characteristics identified, DOE then selected the least efficacious lamp. As stated previously, the non-integrated product class does not have applicable existing standards and therefore the lowest efficacy lamps on the market were considered. DOE has preliminarily selected a 26 W double tube CFL with G24q-3 base and lumen output of 1,710

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[l] For the non-integrated GSLs analyzed, the rated efficacy is the initial lumen output published in manufacturer catalogs divided by the American National Standards Institute (ANSI) rated wattage. For lamp types that do not have a defined ANSI rated wattage, DOE utilized the lamp's nominal wattage to calculate rated efficacy.

[m] The double tube shape for CFLs, that is, a CFL with two U-shaped glass tubes, is also sometimes referred to as quad tube in industry.

lumens (65.8 lm/W) as the baseline. The baseline lamp has a lifetime of 10,000 hours, a CCT of 4,100 K, and a CRI of 82, all of which are common characteristics of the non-integrated product class.

Table 5.3.8 lists the specifications for the baseline lamp DOE is considering for the non-integrated product class.

Table 5.3.8 Non-Integrated Product Class's Baseline Lamp

Lamp Shape	Base Type	Lamp Type	Nominal Wattage	Rated Wattage	Initial Lumens	Mean Lumens	Rated Efficacy	Lifetime	CCT	CRI
			W	*W*	*lm*	*lm*	*lm/W*	*hr*	K	
Double Tube	G24q-3	CFL	26	26	1,710	1,450	65.8	10,000	4,100	82

5.3.3.3 More Efficacious Substitutes

After choosing a baseline lamp for the representative product class, DOE identifies more efficacious substitutes. Similar to the selection of baseline lamps, DOE used the rated efficacy to evaluate more efficacious replacement lamps in its analysis. DOE utilized a database of commercially available lamps and selected more efficacious replacement lamps that did not increase energy consumption relative to the baseline and had light output within ten percent of the baseline lamp-and-ballast system when possible. (See section 5.3.3.4 for more information on lamp-and-ballast systems.) For the non-integrated product class, DOE identified substitute lamps that were the same wattage as the baseline but produced more light and were therefore more efficacious, or lamps that were lower wattage than the baseline but produced similar light and were therefore more efficacious. Further, DOE considered only technologies that met all four criteria in the screening analysis.

DOE also sought to keep characteristics of substitute lamps as similar as possible to the baseline lamp. Due to potential physical and electrical constraints associated with switching base types, DOE selected substitute lamps that had the same base type as the baseline lamp. In addition to maintaining a consistent base type, DOE maintained a CCT of 4,100 K for all replacements. As discussed in section 5.3.2.3, manufacturer feedback indicated that differences between the common, nominal CCTs would be noticeable by the consumer; therefore, DOE did not consider a change in CCT to be viable for higher efficacy replacements. DOE maintained a CRI in the range of 80 to 82. DOE also selected replacement lamp units with lifetimes greater than or equal to the lifetime of the baseline.

5.3.3.4 Non-Integrated GSL Systems

Because non-integrated GSLs operate with an external power converter (*i.e.*, ballast, driver, or other transformer) in practice, DOE analyzed lamp-and-ballast systems in the engineering analysis. DOE is not considering setting standards for any non-integrated incandescent or LED lamps at this time and therefore only considered non-integrated CFL and ballast systems in this preliminary analysis. (See chapter 2 of this TSD for more information on scope.) DOE believes that pairing these lamps with a ballast more accurately captures real-world energy use and light output.

DOE is aware that lumen package is an important consideration for consumers. If consumers do not have the option to purchase substitute lamp systems with similar lumen packages, a modification in the lighting design of their space (*e.g.*, change in fixture spacing) may be required to maintain a similar light output. In assessing light output of the representative systems, DOE made a distinction between mean and initial lumen output. Consistent with industry consensus on efficacy measurements, DOE used catalog initial lumen output to calculate efficacy when determining CSLs. However, the light output of a lamp decreases over time. To account for this real-world depreciation in lumens, DOE analyzed more efficacious systems that maintain mean lumen output within ten percent of the baseline system, when possible. Mean lumen output is a measure of light output midway through the rated life of a lamp, and a ten percent change is a common parameter used by lighting designers to specify acceptable substitute products on the basis of light output.

In the LCC analysis, DOE considers lamp purchase events, or events that cause a consumer to purchase a new lamp. For GSLs, DOE determined that consumers may purchase a new lamp to operate on an existing ballast. For this lamp replacement scenario, DOE selects more efficacious full wattage and reduced wattage replacement lamps that can operate on the installed ballast. DOE only selected replacement lamps that do not have higher energy consumption than the baseline.

For the lamp replacement scenario, DOE determined energy consumption by calculating the system input power of the lamp-and-ballast system. The system input power represents the energy consumption rate of both the lamp and ballast, and therefore is greater than the rated power of the lamp alone. In addition to the rated lamp power, the system power is also affected by the number of lamps operated per ballast, type of ballast used (*i.e.*, electronic or magnetic), starting method, and the ballast factor (BF)[n] of that ballast.

The following sections discuss in more detail how DOE selected a ballast for the representative lamp-and-ballast pairings and its methodology for calculating system input power.

Ballast Selection. Although DOE identifies more efficacious substitutes based on lamp characteristics alone, DOE pairs non-integrated GSLs with representative ballasts because the non-integrated GSLs analyzed in this preliminary analysis (*i.e.*, non-integrated CFLs) operate on a ballast in practice. To develop representative lamp-and-ballast system pairings, DOE determined the most common non-integrated CFL ballasts based on manufacturer feedback and a survey of the market. DOE identified the most common number of lamps operated per ballast, starting method by ballast type, and mode of operation (*i.e.*, electronic or magnetic). Based on this assessment, DOE chose to analyze one-lamp programmed start (PS) electronic ballasts as representative of the lamp-and-ballast combinations present in the market. Manufacturer feedback confirmed that these are among the most common characteristics of non-integrated CFL ballasts.

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[n] BF is defined as the output of a ballast delivered to a reference lamp in terms of power or light divided by the output of the relevant reference ballast delivered to the same lamp (ANSI C82.13-2002). Because BF affects the light output of the system, manufacturers design ballasts with a range of ballast factors to allow consumers to vary the light output, and thus power consumed, of a fluorescent system. See the 2011 Ballast Rule final rule TSD Chapter 3.

After determining the representative lamp-and-ballast system pairing, DOE selected a specific ballast model to use in the systems analyzed. DOE utilized a database of commercially available CFL ballast models to determine the ballast that represents the product that is most likely to be installed in 2020. DOE identified a ballast model with typical light output (*i.e.*, BF) and efficiency (*i.e.*, ballast luminous efficiency [BLE]). DOE found that the majority of the commercially available CFL ballasts had normal BFs (close to 1.0). Because CFL ballasts are not covered by standards, DOE believes that the ballast models of average efficiency would be most representative of the market. DOE determined that the BLE[o] of one-lamp PS normal BF CFL ballasts that are compatible with the non-integrated representative units ranged from 81.1 to 96.2. CFL ballasts operate specific base types, thus DOE selected a ballast model that was compatible with the base type of the baseline lamp and more efficacious substitutes. Therefore for this preliminary analysis, DOE paired the non-integrated representative units with a one-lamp, PS electronic ballast with a BF of 1.04 and an average BLE of 90.2.

System Input Power Calculation. After selecting a ballast to pair with the representative units, DOE then calculated the system input power. The system input power depends on both the total lamp arc power operated by the ballast and the ballast's efficiency, or BLE. DOE first calculated the total lamp arc power of the system by multiplying the catalog BF, number of lamps operated by the ballast, and the high frequency reference lamp arc power. Because DOE selected an electronic ballast for this preliminary analysis, all lamp-and-ballast systems were high frequency. If a high frequency reference arc power was not available for a specific lamp type, DOE used the nominal wattage.

For ballasts paired with full wattage lamps, DOE next determined BLE using catalog ballast efficacy factor[p] (BEF) for the selected ballast model. DOE calculated the BLE by multiplying the catalog BEF, high frequency reference arc power, and number of lamps operated by the ballast. Using the calculated total lamp arc power and converted BLE value of the ballast model, DOE then calculated the system input power, or ballast input power, using Eq. 5.1. This process was repeated for each full wattage lamp-and-ballast system pairing.

$$BLE = \frac{Total\ Lamp\ Arc\ Power}{Ballast\ Input\ Power} * 100 * \beta$$

Eq. 5.1

Where:
β = 1.0 for high frequency ballasts

Because the ballast specifications when operating reduced wattage lamps were not published, DOE had to determine the expected reduced wattage BLE using the known power-efficiency relationship of ballasts. In the 2011 Ballast Rule, DOE developed a power law equation to model the trend between total lamp arc power and average BLE. The power law equation followed the form:

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[o] Ballast luminous efficiency is the ratio of the total lamp arc power to ballast input power multiplied by the appropriate frequency adjustment factor.

[p] Ballast efficacy factor is equal to relative light output divided by input power.

$$BLE = \frac{A}{1 + B * power^{-C}}$$

Eq. 5.2

Where:
power = total lamp arc power

Similar to the full wattage system, DOE first calculated the total lamp arc power of the reduced wattage lamp-and-ballast system. DOE assumed that BF does not change when operating reduced wattage lamps and therefore used the catalog BF of the ballast when operating full wattage lamps to calculate the total lamp arc power for both full wattage and reduced wattage systems.

In general, as lamp arc power increases or decreases, BLE increases or decreases as well. In the 2011 Ballast Rule, DOE defined this relationship using Eq. 5.2. In this rulemaking, DOE assumed that this relationship holds true for individual ballasts. Therefore, DOE assumed that an individual ballast operating full wattage lamps would have the same coefficient *B* when operating reduced wattage lamps. Using this assumption, DOE calculated the selected ballast model's coefficient *B* when operating full wattage lamps using the converted full wattage BLE value, the calculated total lamp arc power at full wattage, and the appropriate exponent *C*, which is dependent on the ballast starting method, and was found to be 0.37 for programmed start ballasts.[q] The coefficient *A* was assumed to be one.[r] DOE was then able to calculate the new BLE when operating reduced wattage lamps by using the total lamp arc power when operating reduced wattage lamps and keeping the coefficient *B*, the exponent *C*, and the coefficient *A* the same. Given this expected BLE and total lamp arc power calculated in the previous steps, DOE determined the system input power of the reduced wattage lamp-and-ballast system using Eq. 5.1.

5.3.3.5 Candidate Standard Levels

After identifying more efficacious substitutes for the baseline lamp, DOE develops CSLs based on the consideration of several factors, including: (1) the design options associated with the specific lamps being studied (*e.g.*, grades of phosphor for CFLs); (2) the ability of lamps across the applicable lumen range to comply with the standard level of a given product class; and (3) the max-tech level. DOE used commercially available lamps and their associated rated efficacies to determine the design options required to meet each CSL. For the non-integrated product class, DOE used the catalog initial lumen output and the ANSI rated wattage of the lamp, or nominal wattage if the ANSI rated wattage was not available, to calculate efficacy. DOE used catalog data as the basis of its engineering analysis because it is the largest and most comprehensive dataset. Although non-integrated GSLs are a component of a system that often

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[q] The exponent *C* was found to be 0.37 for PS ballasts in the 2011 Ballast Rule. See chapter 5 of the 2011 Ballast Rule TSD, available on regulations.gov, docket number EERE-2007-BT-STD-0016 at www.regulations.gov/#!docketDetail;D=EERE-2007-BT-STD-0016.

[r] The coefficient *A* was used as an adjustment factor for testing variation when developing efficiency levels in the 2011 Ballast Rule. In this rulemaking, *A* was assumed to be one as no adjustments were made to the ballast test data used in the calculation.

includes ballasts and fixtures, DOE based its CSLs only on lamp performance because GSLs are the subject of this rulemaking. DOE acknowledges, however, that the energy consumption of non-integrated GSLs is related to the ballast on which they operate. Therefore, DOE paired each lamp with an appropriate ballast to better approximate real-world conditions as discussed in section 5.3.3.4.

As stated previously, DOE adopted an equation-based approach to establish CSLs for GSLs, reflecting the relationship between efficacy and lumen output. Similar to the integrated product classes, DOE developed a smooth, continuous equation that specifies a minimum efficacy requirement across lumen output and represents the potential efficacy a lamp achieves using a particular design option. DOE utilized a similar methodology as the integrated product classes to develop the CSL equation. Using a database of commercially available non-integrated GSLs, DOE conducted regression analyses on several different equation forms to find the form that best fit the efficacy trend. DOE again analyzed products outside of the GSL lumen range (310 – 2,600 lumens) in order to create the best curve fit possible for the technology included in the product class, and confirmed the curve fit matched product performance particularly in the low and high ends of the GSL lumen range. DOE also ran regression analyses for the different equation forms on subsets of non-integrated GSLs to verify the efficacy trends. DOE is considering a decaying exponential equation form based on its consistent ability to fit the data well (measured by R^2 value) across the subsets of data. DOE is considering establishing CSLs based on an equation for efficacy using lumens as the input in the following form:

$$Efficacy = A - 25.00 * 0.9989^{Lumens}$$

Eq. 5.2

Where:
Efficacy = minimum efficacy requirement,
Lumens = measured lumen output, and
A = an adjustment variable (the “A-value”).

After identifying more efficacious substitutes, DOE calculated the A-value of the equation using catalog lumen output and catalog efficacy for each representative lamp unit. The A-value is an adjustment variable that vertically shifts the equation and is calculated to represent certain levels of efficacy. For the preliminary analysis, DOE considered two representative units at CSL 1, consisting of a more efficient full wattage CFL and a reduced wattage CFL. The full wattage representative lamp unit is used to set the minimum efficacy requirements of CSL 1 because it represents the maximum technologically feasible level that applies across all lumen packages within this product class. DOE added a second representative unit, the reduced wattage CFL, which gives consumers the option to replace their current full wattage lamp with one that saves energy. DOE then evaluated the equation against lamps with the same design options as the representative lamp unit to determine if any adjustments were necessary to capture the efficacy of lamps with those design options across the entire lumen output range. In particular, DOE ensured that lamps of different base types were represented at the CSL.

In general terms, for the non-integrated product class, DOE based CSL 1 on the design options described below.

CSL 1: This level represents an improved full wattage (26 W) CFL with more efficient phosphors and a reduced wattage (21 W) CFL that produces similar lumen output as the baseline unit.

Table 5.3.9 provides detailed information on the representative lamps in the non-integrated product class used in the engineering analysis and subsequent analyses.

Table 5.3.9 Non-Integrated Product Class Design Representative Units

CSL	A-value	Lamp Shape	Base Type	Lamp Type	Nominal Wattage	Rated Wattage	Initial Lumens	Mean Lumens	Rated Efficacy	Lifetime	CCT	CRI
					W	*W*	*lm*	*lm*	*lm/W*	*hr*	*K*	
Baseline	69.5	Double Tube	G24q-3	CFL	26	26	1,710	1,450	65.8	10,000	4,100	82
CSL 1	72.6	Double Tube	G24q-3	CFL	26	26	1,800	1,530	69.2	17,000	4,100	82
CSL 1	77.2	Double Tube	G24q-3	CFL	21	21	1,525	1,310	72.6	20,000	4,100	82

As stated, DOE evaluated the impacts of CSL 1 on the individual base types and across the lumen output range in the non-integrated product class to determine if any adjustments were necessary. DOE confirmed that the vast majority of base types were still available at CSL 1, and therefore concluded consumers will not be forced to switch between lamps with differing base types. DOE identified three base types – GX10q-4, GX32d-2, and GX32d-3 – out of an original 26 base types that do not currently have commercially available products at CSL 1. However, based on consultation with manufacturers and electrical distributors, DOE believes these base types are discontinued or are used in applications (*e.g.*, desk lamps) that have already transitioned to higher efficiency technologies. Therefore, DOE did not adjust CSL 1 to account for the availability of base types.

DOE also ensured that the impacts of CSL 1 are consistent across the lumen output range of the entire product class. In particular, DOE considered the impacts of CSL 1 for the high volume non-integrated GSLs not analyzed as representative units. As stated previously, in addition to the 26 W CFL, 13 W and 18 W CFLs are the highest volume products in the non-integrated product class. These wattages typically correspond to lumen output ranges of 700 – 900 and 1,000 – 1,300 lumens, respectively. DOE found that in the 700 – 900 lumen range, CSL 1 resulted in a similar technology impact as the 26 W representative units. DOE determined that improved full wattage 13 W CFLs meet CSL 1. However, for the 700-900 lumen range, DOE did not identify any commercially available reduced wattage CFLs (*i.e.*, higher efficacy lamp with lower wattage) within the lumen range. DOE found that in the 1,000 – 1,300 lumen range, CSL 1 also resulted in similar technology impacts as the 26 W representative units. DOE identified improved full wattage 18 W CFLs that meet CSL 1 and reduced wattage 15 W and 14 W CFLs that meet CSL 1. Because DOE ensured lumen packages across the product class's range of lumen output are available at CSL 1, consumer utility with regard to lumen output is maintained throughout the entire non-integrated product class. Therefore, DOE did not find it necessary to adjust CSL 1 to account for the availability of lumen packages.

For this preliminary analysis, DOE also considered whether replacing the baseline lamp with more efficacious substitutes at the higher CSL would require a fixture change. DOE conducted a survey of the market (*e.g.* lamp manufacturer literature and interviews with fixture manufacturers and distributors) to identify the fixture types most commonly used with non-integrated GSLs and found recessed cans (horizontal and vertical lamp orientation) to be most common. Based on an assessment of the commonly available fixtures, DOE found that the fixtures frequently used with the non-integrated GSLs analyzed were available in configurations for several different lamp types thus indicating flexibility to use lamps of different lengths and shapes within the same fixture. Further, because DOE ensured that the vast majority of base types were available at CSL 1, DOE does not believe that consumers would be forced to change fixtures and therefore considered fixture replacement to be an unlikely replacement scenario. Consequently, DOE assumed that fixture compatibility would not be an issue for the vast majority of consumers and did not evaluate a fixture replacement scenario for this preliminary analysis.

Figure 5.3.2 depicts the CSL for the non-integrated product class on a plot with the representative units. The triangle denotes the baseline representative unit, and the square boxes denote the more efficacious substitutes that DOE is considering as replacement representative units.

Figure 5.3.2 Graph of CSLs for GSL Non-Integrated Representative Product Class

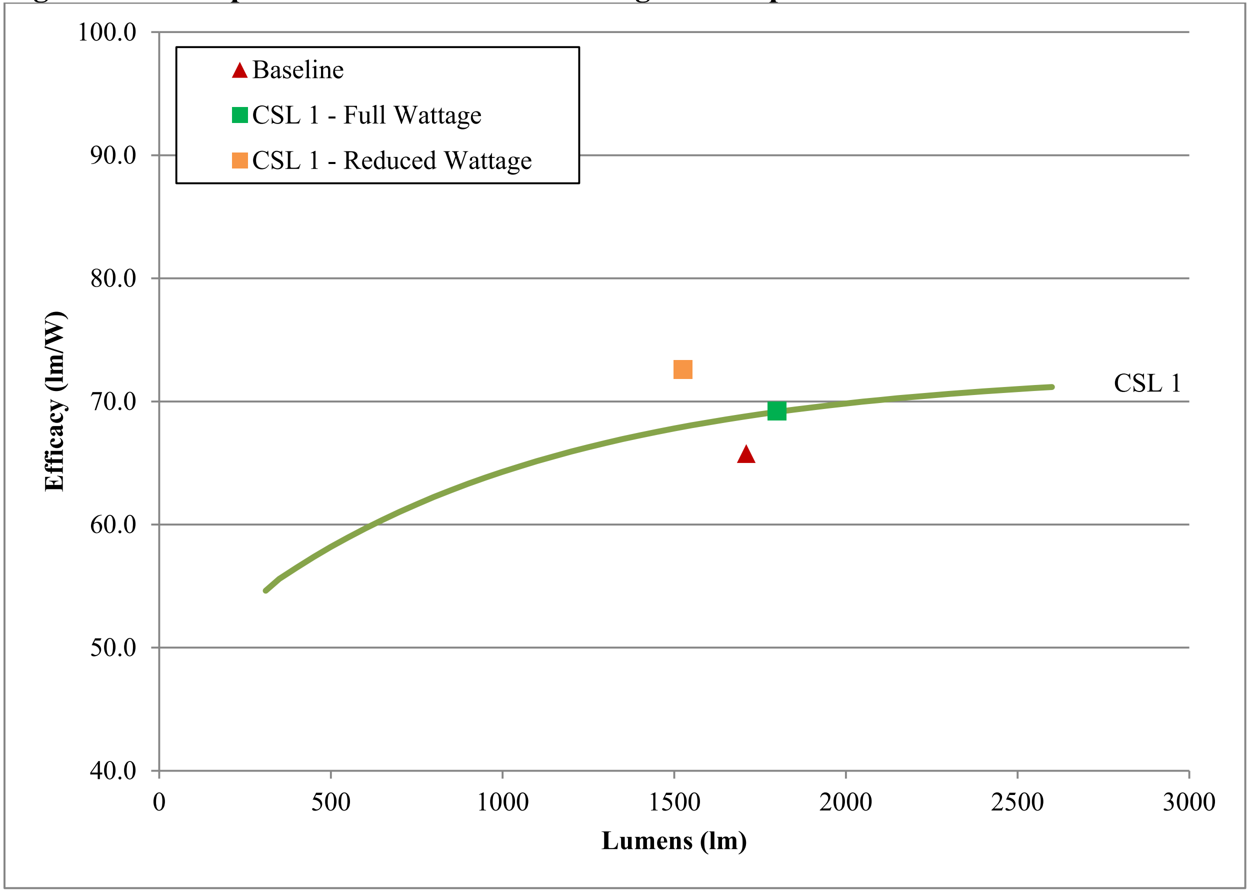


Table 5.3.10 shows the engineering results for the non-integrated GSL representative lamp-and-ballast systems.

Table 5.3.10 Lamp Replacement Engineering Analysis for a One-Lamp Programmed Start 26 W Double Tube, 4,100 K System

CSL	Lamp Shape	Base Type	Lamp Type	Nominal Wattage	Rated Wattage	Initial Lumens	Mean Lumens	Rated Efficacy	Lifetime	CCT	CRI	Number of Lamps	Starting Method	Ballast Factor	System Input Power	BLE	System Initial Light Output	System Mean Light Output
				W	*W*	*lm*	*lm*	*lm/W*	*hr*	*K*					*W*		*lm*	*lm*
Baseline	Double Tube	G24q-3	CFL	26	26	1,710	1,450	65.8	10,000	4,100	82	1	Programmed Start	1.04	30.0	90.2	1,778	1,508
CSL 1	Double Tube	G24q-3	CFL	26	26	1,800	1,530	69.2	17,000	4,100	82	1	Programmed Start	1.04	30.0	90.2	1,872	1,591
CSL 1	Double Tube	G24q-3	CFL	21	21	1,525	1,310	72.6	20,000	4,100	82	1	Programmed Start	1.04	24.4	89.5	1,586	1,362

Table 5.3.11 summarizes the efficacy requirement of CSL 1 for the non-integrated GSLs after rounding A-values to the nearest tenth.

Table 5.3.11 Summary of CSLs for GSL Non-Integrated Representative Product Class

Representative Product Class	Candidate Standard Level	Efficacy
		lm/W
Non-Integrated (310 – 2,600 Lumens)	CSL 1	72.6-25.00*0.9989^Lumens

5.4 SCALING TO PRODUCT CLASSES NOT ANALYZED

DOE identified and selected certain product classes as representative and analyzed these product classes directly. DOE determined certain product classes to be representative due to high market volumes and/or distinct characteristics. In general, CSLs for product classes that are not directly analyzed ("non-representative product classes") are then determined by scaling from the CSLs of the representative product classes. However, DOE chose to directly analyze all product classes as representative in this preliminary analysis. Thus, no scaling was required.

5.5 SUMMARY OF ALL EFFICACY LEVELS FOR COVERED GSLS

Table 5.5.1 shows a summary of CSLs for all GSLs covered by this rulemaking.

Table 5.5.1 Summary of All Efficacy Levels for Covered GSLs

Representative Product Class	**Candidate Standard Level**	**Efficacy**
		lm/W
Integrated Low Lumen (310 – 1,999 Lumens)	CSL 1	67.6-29.42*0.9983^Lumens
	CSL 2	74.2-29.42*0.9983^Lumens
	CSL 3	80.2-29.42*0.9983^Lumens
	CSL 4	87.5-29.42*0.9983^Lumens
	CSL 5	90.8-29.42*0.9983^Lumens
Integrated High Lumen (2,000 – 2,600 Lumens)	CSL 1	67.6-29.42*0.9983^Lumens
	CSL 2	74.2-29.42*0.9983^Lumens
Non-Integrated (310 – 2,600 Lumens)	CSL 1	72.6-25.00*0.9989^Lumens

CHAPTER 6. PRODUCT PRICE DETERMINATION

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 6. PRODUCT PRICE DETERMINATION

6.1 INTRODUCTION

This chapter describes the methodology the U.S. Department of Energy (DOE) followed in developing end-user prices for the general service lamps (GSLs) being analyzed in this rulemaking (see section 6.2). It also provides the results for the lamp end-user prices in section 6.4.

In energy conservation standards rulemakings, DOE often develops cost-efficiency relationships in the engineering analysis (chapter 5 of this technical support document [TSD]). Then, DOE applies markups to derive end-user prices. For this rulemaking, DOE derived candidate standard levels (CSLs) in the engineering analysis and developed the prices in this chapter of this TSD. DOE develops end-user prices directly in the product price determination assessment because reverse-engineering a lamp is impractical, as the lamps are not easily disassembled. By combining the results of the engineering analysis and the product price determination, DOE derived typical inputs for use in the life-cycle cost (LCC; chapter 8 of this TSD) analysis and the national impact analysis (NIA; chapter 10 of this TSD). Section 6.2 of this chapter describes the methodology used to develop end-user prices for lamps that are presented in the engineering analysis. The results for lamp end-user prices are in section 6.4.

Because the non-integrated GSLs analyzed operate with a ballast in practice, DOE also developed prices for ballasts. Section 6.3 of this chapter describes the methodology used to derive the end-user prices for the ballasts that are presented in the engineering analysis. The results for the ballast end-user prices are in section 6.4.

6.2 LAMP METHODOLOGY

End-user price refers to the product price a consumer pays before tax and installation. Typically, DOE develops manufacturing selling prices (MSPs) for covered products and applies markups to create end-user prices to use as inputs to the LCC analysis and NIA. Because GSLs are difficult to reverse-engineer (*i.e.*, not easily disassembled), DOE directly derives end-user prices for the lamps covered in this rulemaking. DOE considered using manufacturers' published end-user price schedules for lamps (hereafter called the manufacturer's "blue book" or "lamp price schedules"). However, DOE found that blue book prices for all GSLs within the scope of this rulemaking were not available. Instead, DOE reviewed and used publicly available retail prices in the pricing analysis.

In its review of publicly available prices for GSLs, DOE observed a range of end-user prices paid for a lamp, depending on the distribution channel through which the lamp is purchased. DOE developed end-user prices for the representative units sold in each of the main distribution channels for GSLs. DOE then calculated an average weighted end-user price using the estimated shipment percentage of each distribution channel. DOE also assessed and accounted for general price trends in relation to efficacy for all GSLs. For example, DOE noted that available data indicated that light-emitting diode (LED) lamp prices decreased with increased lamp efficacy and confirmed that calculated end-user prices reflected this trend.

6.2.1 Distribution Channels

Because of the range of end-user prices paid for a lamp, DOE decided to collect GSL prices from many different vendors representing a variety of distribution channels. Through feedback from manufacturer interviews and market research, DOE determined that the most common channels through which GSLs are sold are State procurement contracts, electrical distributors (*e.g.*, Grainger), home centers (*e.g.*, Home Depot), hardware stores (*e.g.*, Ace Hardware), Internet retailers (*e.g.*, Amazon), mass merchants (*e.g.*, Walmart), grocery stores (*e.g.*, Safeway), and drug stores (*e.g.*, CVS).

Based on manufacturer feedback and an assessment of lamp price data and trends for each of these channels, DOE determined that certain GSL distribution channels should be grouped together. DOE determined that Internet retailers, grocery stores, and drug stores could be grouped into one distribution channel because they all similarly offer consumers a more convenient purchasing option at a typically increased cost. DOE also found that home centers, hardware stores, and mass merchants could be appropriately grouped into one distribution channel based on their similarity in price and target market. In summary, DOE identified the following four main distribution channels for GSLs in this preliminary analysis:

- Small Consumer-Based Distributors: Internet Retailers, Grocery Stores, and Drug Stores;
- Large Consumer-Based Distributors: Home Centers, Hardware Stores, and Mass Merchants;
- Electrical Distributors; and
- State Procurement.

6.2.2 Price Determinations

DOE collected pricing data for GSLs in the scope of this rulemaking from each of the four distribution channels discussed in section 6.2.1.

For the small consumer-based distributor channel, DOE used both online prices and in-store prices. DOE collected Internet prices from several Internet retailers, including Amazon.com, eLightBulbs.com, and GoodMart.com. DOE also collected in-store prices from grocery stores and drug stores, including Giant, Safeway, CVS, and Rite Aid. DOE again ensured that in-store prices collected from grocery and drug stores did not reflect a rebate.

For the large consumer-based distributor channel, DOE collected prices for stores including Target, Walmart, Home Depot, Lowes, and Ace Hardware. DOE ensured that rebated prices were not included in the analysis because rebates are typically available for a limited period of time and are specific to the region of the country. Thus, DOE does not believe that rebated prices are representative of the typical end-user price during the analysis period.

For the electrical distributor distribution channel, DOE surveyed GSL prices from the large electrical distributors identified based on market research and manufacturer feedback to determine appropriate end-user prices for the electrical distributor channel. DOE gathered prices from electrical distributors including Grainger, Graybar, and WESCO.

Lastly, for the State procurement distribution channel, DOE gathered State procurement contracts from all states that had publicly available information and offered discounted prices for GSLs.

The prices gathered for each of the four distribution channels were then used to develop prices for the representative lamp units identified for each CSL analyzed in the engineering analysis (see chapter 5 of this TSD). For each distribution channel, DOE calculated an aggregate price for the representative unit at each CSL using the average lamp model prices for the representative units and their similar lamp models. Because the lamps with similar characteristics as the representative units (*e.g.*, wattage, correlated color temperature [CCT], bulb shape, base type, color rendering index [CRI]) were equivalent in terms of performance and utility, DOE considered the pricing of these lamps to also be representative of the technology of the CSL. When sufficient data was not available at a specific distribution channel, DOE extrapolated pricing from similar lamps with available pricing data. This was done by using the pricing data of similar lamps and developing price trends based on wattage and/or efficacy, as appropriate.

Once DOE determined end-user prices at the four distribution channels for each of the representative units analyzed in the engineering analysis, DOE then developed an end-user price that was weighted by distribution channel. Based on manufacturer feedback in interviews, DOE determined an aggregated percentage of shipments that go through each distribution channel for GSLs. DOE used different shipment percentages for integrated lamps and non-integrated lamps because integrated lamps are more commonly residential products while non-integrated lamps are more commonly commercial products. Because the end-user shipment percentages for distribution channels will vary based on whether the product is residential or commercial, DOE determined that it was appropriate to use different weightings for the two lamp types. The weightings used to calculate the end-user price are shown in Table 6.2.1.

Table 6.2.1 Shipment Weightings Used per Distribution Channel

	Small Consumer-Based Distributors	Large Consumer-Based Distributors	Electrical Distributors	State Procurement
Integrated GSLs	10%	75%	10%	5%
Non-Integrated GSLs	5%	10%	75%	10%

As stated, DOE assessed and accounted for general price trends in relation to efficacy for all GSLs in its determination of end-user prices. Specifically, DOE noted that available data indicated that LED lamp prices decreased with increased lamp efficacy and confirmed that calculated end-user prices reflected this trend. DOE also confirmed that for compact fluorescent lamps (CFLs), a mature technology, an increase in efficacy typically results in an increased price. However, consistent with manufacturer feedback, DOE found that covered CFLs were more expensive than spiral CFLs of similar efficacy. For the non-integrated product class, DOE also found that CFL prices increased with increased lamp efficacy, whether achieved through increasing lumen output or reducing wattage.

6.3 BALLAST METHODOLOGY

Because CFL ballasts are not subject to energy conservation standards, DOE did not analyze these ballasts in the rulemaking for fluorescent lamp ballasts finalized in 2011 (hereafter the “2011 Ballast Rule”). 76 FR 70548 (Nov. 14, 2011). Therefore, DOE developed prices for the ballasts analyzed with the non-integrated GSLs in this rulemaking.

To determine prices for CFL ballasts, DOE compared the blue book prices of CFL ballasts to comparable fluorescent lamp ballasts and developed a scaling factor to apply to the end-user prices of the fluorescent lamp ballasts developed in the 2011 Ballast Rule. DOE considered ballasts with similar specifications, including starting method, maximum number of lamps operated, ballast factor, and input power, to be comparable. DOE calculated the percent difference in blue book prices for the comparable pairs of fluorescent lamp ballasts and CFL ballasts. The average percent decrease from prices of fluorescent ballasts to CFL ballasts was 29 percent. Because DOE determined that 2-lamp programmed start (PS) fluorescent ballasts were the most similar to the CFL ballasts selected for this analysis, DOE reduced the end-user ballast price developed for the 2-lamp PS 4-foot medium bi-pin system by 29 percent to determine the CFL ballast price for this rulemaking.

6.4 RESULTS

Sections 6.4.1, 6.4.2, and 6.4.3 below summarize the prices for each distribution channel, and weighted end-user prices for each GSL product class: low lumen integrated lamps, high lumen integrated lamps, and non-integrated lamps. Section 6.4.3 also summarizes the ballast prices developed for the ballasts paired with non-integrated lamps. (See chapter 3 of this TSD for further details on GSL product classes.)

6.4.1 End-User Prices for Low Lumen Integrated Lamps

The following tables present the end-user prices for low lumen integrated lamps. The prices presented do not include sales tax.

Table 6.4.1 End-User Prices for Low Lumen Integrated Lamps

CSL	Lamp Type	Nominal Wattage *W*	Lamp Efficacy *lm/W*	Initial Lumen Output *lm*	CRI	CCT *K*	Rated Life *hrs*	Lamp End-User Price *2014$*				
								Large Consumer-Based Distributors	**Small Consumer-Based Distributors**	**Electrical Distributors**	**State Procurement**	**Weighted Price**
Baseline	CFL	14	53.6	750	80	2,700	10,000	$4.84	$7.65	$7.63	$9.32	$5.62
CSL1	CFL	13	61.5	800	82	2,700	12,000	$3.10	$6.24	$6.69	$7.13	$3.97
CSL2	LED	12	66.7	800	82	2,700	25,000	$27.47	$25.50	$43.92	$13.29	$28.21
CSL3	LED	11	72.7	800	81	2,700	25,000	$14.25	$25.27	$41.70	$12.61	$18.02
CSL4	LED	10	80.0	800	82	2,700	25,000	$10.00	$23.39	$39.48	$11.92	$14.38
CSL5	LED	9.5	84.2	800	80	2,700	25,000	$9.47	$21.51	$38.37	$11.58	$13.67

6.4.2 End-User Prices for High Lumen Integrated Lamps

The following table presents the end-user prices for high lumen integrated lamps. The prices presented do not include sales tax.

Table 6.4.2 End-User Prices for High Lumen Integrated Lamps

CSL	Lamp Type	Nominal Wattage *W*	Lamp Efficacy *lm/W*	Initial Lumen Output *lm*	CRI	CCT *K*	Rated Life *hrs*	Lamp End-User Price *2014$*				
								Large Consumer-Based Distributors	**Small Consumer-Based Distributors**	**Electrical Distributors**	**State Procurement**	**Weighted Price**
Baseline	CFL	32	62.5	2,000	80	2,700	10,000	$8.62	$9.99	$20.46	$11.80	$10.10
CSL1	CFL	30	66.7	2,000	82	2,700	10,000	$8.75	$11.99	$20.96	$11.86	$10.45
CSL2	CFL	29	75.9	2,200	82	2,700	12,000	$8.82	$18.49	$21.46	$11.89	$11.20

6.4.3 End-User Prices for Non-Integrated Lamps

The following table presents the end-user prices for non-integrated lamps and ballasts. The prices presented do not include sales tax.

Table 6.4.3 End-User Prices for Non-Integrated Lamps

CSL	**Lamp Type**	**Nominal Wattage** ***W***	**Lamp Efficacy** ***lm/W***	**Initial Lumen Output** ***lm***	**CRI**	**CCT** ***K***	**Rated Life** ***hrs***	**Lamp End-User Price** ***2014$***					**Ballast End-User Price** ***2014$***
								Large Consumer-Based Distributors	**Small Consumer-Based Distributors**	**Electrical Distributors**	**State Procurement**	**Weighted Price**	
Baseline	CFL	26	65.8	1,710	82	4,100	10,000	$6.73	$5.70	$16.50	$3.63	$13.70	$13.26
CSL1	CFL	26	69.2	1,800	82	4,100	17,000	$7.23	$7.21	$17.47	$5.57	$14.74	$13.26
CSL1	CFL	21	72.6	1,525	82	4,100	20,000	$8.68	$14.34	$18.42	$9.47	$16.35	$13.26

CHAPTER 7. ENERGY USE CHARACTERIZATION

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 7. ENERGY USE CHARACTERIZATION

7.1 INTRODUCTION

This chapter describes the methodology the U.S. Department of Energy (DOE) followed to estimate the annual energy use of general service lamps (GSLs) as used by consumers in homes and businesses. The results of this analysis are key inputs to the life-cycle cost and payback period analysis, described in chapter 8 of this technical support document (TSD), and the national impact analysis, described in chapter 10. DOE requires information on annual energy use to determine the potential energy and operating cost savings consumers would realize from the use of more efficient products.

DOE determined the annual energy use of GSLs using information on their input power consumption and the way consumers use them (their operating hours per year). DOE derives the annual unit energy consumption (UEC) of GSLs by multiplying the input power by the number of hours of operation per year:

$$UEC = Operating\ Hours \times Input\ Power$$

Eq. 7.1

The energy use analysis is developed for GSLs using the representative lamps described in the engineering analysis (chapter 5 of this TSD). Therefore, the input power used in the energy use analysis is the input power presented in the engineering analysis (chapter 5 of this TSD) for the representative lamp (or lamp and ballast) at each candidate standard level (CSL) for each of the three product classes considered in this rulemaking: Integrated Low-Lumen, Integrated High-Lumen, and Non-Integrated GSLs. The following sections describe the inputs and calculations DOE used to develop annual operating hours, and annual energy use for the GSLs considered in this analysis.

7.2 OPERATING HOURS

This section discusses how DOE calculated operating hours for GSLs used in the residential and commercial sectors.

7.2.1 Residential Sector

The goal of the energy use analysis is to generate energy use values that reflect actual use by consumers in the U.S. Accordingly, DOE used data from various field metering studies to estimate operating hours for GSLs in the residential sector on a regional basis. DOE utilized hours of use (HOU) metered data for regions where such data were available; for regions without HOU metered data, DOE used data from adjacent regions, as described below. This section describes in detail the approach DOE followed to estimate HOU.

DOE did not differentiate HOU by light source technology, but instead assumed that HOU would be the same across all light source technologies during the analysis period (2020-2049). As discussed in chapter 2 of this TSD, some studies currently report higher HOU for CFL

GSLs compared to all GSLs. Specifically, DOE identified the *Residential Lighting End-Use Consumption Study* (RLEUCS)[1] and the *Northeast Residential Lighting Hours-of-Use Study*,[2] which both report higher HOU for CFLs compared to all GSLs. DOE assumed that CFLs are currently disproportionately installed in sockets with higher HOU and that CFLs would have the same HOU as all GSLs during the analysis period, when they will fill more sockets. For LED GSLs, very limited HOU data exist, therefore DOE has assumed the same HOU for LED GSLs as CFLs.

DOE used hours of use data from metering studies in California,[1] Georgia,[3] North Carolina,[4] South Carolina,[5] Maryland,[6] Ohio,[7] Illinois,[8] the Northwest,[9] and the Northeast.[2] For studies that only reported operating hours for CFLs, DOE used a correction factor to estimate operating hours for all GSLs. This correction factor was calculated based on the population-weighted-average fractional difference in operating hours between all GSLs and CFL GSLs. Table 7.2.1 shows the daily all-GSL HOU compared to the CFL-GSL HOU for 5 U.S. states, and the (population-weighted average) CFL-to-all GSL correction factor.

Table 7.2.1 CFL-to-All GSL HOU Correction Factor

State	All GSL HOU	CFL HOU	Population Weight (2013)	HOU Ratio All GSLs/CFLs
CT[2]	2.8	3.1	5%	0.90
RI[2]	2.6	3.0	2%	0.87
MA[2]	2.7	3.0	10%	0.90
NY[2]	3.3	4.0	28%	0.83
CA[1]	1.6	1.9	55%	0.83
CFL-to All GSL Correction Factor (Population-Weighted Average)				**0.84**

For studies that report HOU for CFL GSLs only, DOE applied the CFL-to-all GSL correction factor, as shown in Table 7.2.2.

Table 7.2.2 CFL HOU Converted to All GSL HOU

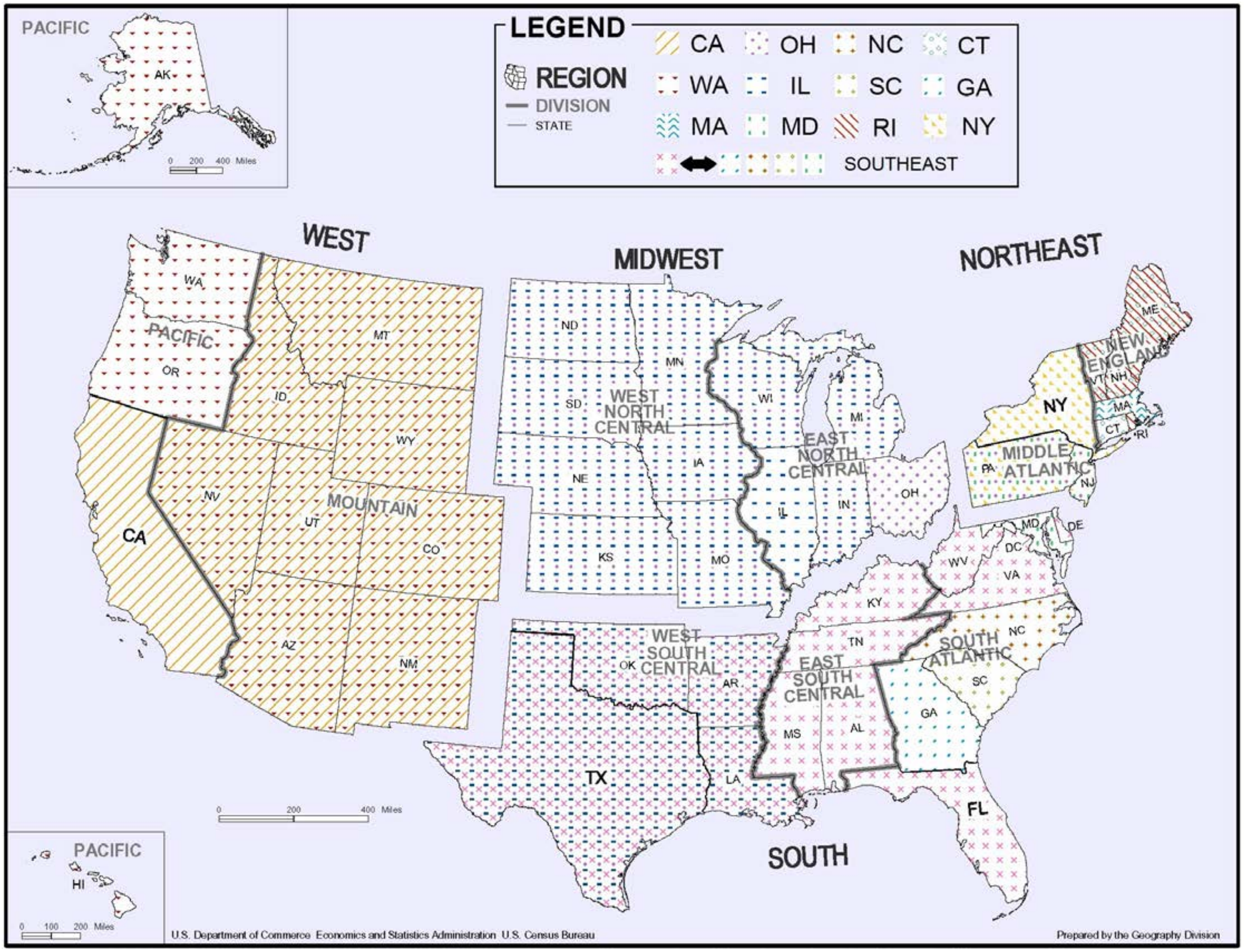
State	CFL GSL HOU	All GSLs HOU
IL[8]	2.7	2.3
OH[7]	2.8	2.4
MD[6]	3.0	2.5
GA[3]	2.8	2.4
NC[4]	2.9	2.5
SC[5]	2.7	2.3

Next, DOE estimated the representative operating hours for each *Residential Energy Consumption Survey* (RECS) reportable domain. (*i.e.*, State, or group of States). To do this, DOE first grouped U.S. states by Census Division and large state. Within each of these groupings, DOE examined whether HOU metering data were available.

If metering data were available in a given Census Division or Large State, DOE divided the region to RECS reportable domains and examined whether HOU metering data were included within each RECS domain. For any RECS reportable domain with metering data, DOE used the HOU data within that reportable domain. When a reportable domain included HOU data from one metering study, the HOU for the reportable domain were those of that one metering study; when multiple metering studies were available within a reportable domain, the HOU were the population-weighted average HOU of all the metering studies in the reportable domain. For RECS reportable domains without metering data, DOE used the population-weighted average HOU within the larger Census Division or Large State.

If metering data were not available in a particular Census Division or Large State, DOE used data from surrounding regions based on proximity, where possible, or having a similar latitude to the region in question (DOE assumed that regions of similar latitude would tend to have similar HOU).

Figure 7.2.1 shows a map of U.S. Census Divisions and Large States, and illustrates how HOU metering data were mapped to each region. For example, the operating hours for both the South Atlantic and East South Central Census Divisions were derived from the population-weighted average of metering studies within the South Atlantic Census Division, specifically metering studies from Georgia, South Carolina, North Carolina, and Maryland. (For clarity, regions where the population-weighted average of these studies was used are designated by a single symbol and the states are collectively referred to as the Southeast, as shown in the legend.) As another example, the HOU in the Mountain Census Division are the population-weighted average HOU from metering studies conducted in California and in the Pacific Northwest Census Division. The HOU in Texas, a state whose immediate neighbors did not have metering studies available, were estimated based on metering studies conducted in the Southeast, Indiana and Ohio.



Note: The map shows how the available HOU metering data were mapped to Census Divisions and large states. DOE used this map to determine HOU for each RECS reportable domain.

Figure 7.2.1 Mapping of Operating Hours to U.S. Regions

The HOU for each RECS reportable domain, as well as the metering data used to estimate those HOU, are shown in Table 7.2.3. DOE estimated that the national weighted average operating hours for the residential sector is 2.3 hours per day, or 839.5 hours per year.

Table 7.2.3 Average Hours of Use of GSLs in each Reportable Domain

RECS[10] Reportable Domain	Source of Data (States)	Average HOU (hrs/day)	Population Weight (2013)
01. CT, ME, NH, RI, VT	CT, RI	2.7	3%
02. MA	MA	2.7	2%
03. NY	NY	3.3	6%
04. NJ	OH, MD, NY	2.9	3%
05. PA	OH, MD, NY	2.9	4%
06. IL	IL	2.3	4%
07. IN, OH	OH	2.4	6%
08. MI	IL, OH	2.3	3%
09. WI	IL, OH	2.3	2%
10. IA, MN, ND, SD	IL, OH	2.3	3%
11. KS, NE	IL, OH	2.3	2%
12. MO	IL, OH	2.3	2%
13. VA	GA, MD, NC, SC	2.4	3%
14. DE, DC, MD, WV	MD	2.5	3%
15. GA	GA	2.4	3%
16. NC, SC	NC, SC	2.4	5%
17. FL	GA, MD, NC, SC	2.4	6%
18. AL, KY, MS	GA, MD, NC, SC	2.4	4%
19. TN	GA, MD, NC, SC	2.4	2%
20. AR, LA, OK	GA, MD, NC, SC, IL, OH	2.4	4%
21. TX	GA, MD, NC, SC, IL, OH	2.4	8%
22. CO	CA, WA	1.6	2%
23. ID, MT, UT, WY	CA, WA	1.6	2%
24. AZ	CA, WA	1.6	2%
25. NV, NM	CA, WA	1.6	2%
26. CA	CA	1.6	12%
27. AK, HI, OR, WA	WA	1.8	4%
National		**2.3**	100%

7.2.2 Commercial Sector

For the commercial sector, DOE used average daily HOU data for 15 building types from the 2010 U.S. Lighting Market Characterization (LMC).[11] DOE notes that the installed stock of

GSLs in the industrial sector is less than 1 percent of the installed stock in the commercial sector, according to the LMC; furthermore, DOE assumes that the hours of operation for GSLs in the industrial sector (*e.g.*, in offices) are approximately equal to the hours of operation for GSLs in the commercial sector. Therefore, DOE analyzed these two sectors together (using data specific to the commercial sector), and refers to the combined sector as the commercial sector.

DOE took the following steps to estimate the national average HOU of GSLs in the commercial sector:

For each commercial building type presented in the LMC, DOE determined the fraction of installed lamps utilizing each of the light source technologies typically used in GSLs (incandescent, halogen, and CFL)[a], which are reported in LMC Table 4-18. Using data on the commercial HOU for each of these light source technologies, (LMC/Table 4-20) and weighting those data by the percentage of lamps that are of each lamp type in each building type (LMC, Table 4-18), DOE estimated the weighted average HOU of CFLK lamps in each building type. The results are shown in Table 7.2.4.

Table 7.2.4 Daily GSL HOU by Building Type in the Commercial Sector

Building Type	GSLs in Each Building Type (%)	GSL Weighted Average HOU (hrs/day)
Education	12	10.6
Food Service	29	10.3
Food Store	5	10.7
Health Care–Inpatient	15	10.5
Health Care–Outpatient	11	10.4
Lodging	45	10.4
Offices (Non-medical)	16	10.5
Public Assembly	30	10.4
Public Order and Safety	8	10.7
Religious Worship	13	10.4
Retail–Mall & Non-Mall	18	11.2
Services	6	10.8
Warehouse and Storage	8	10.8
Other	15	10.9

To estimate the national average HOU for the commercial sector, DOE mapped the HOU of the building types in the LMC to the building types in the 2003 *Commercial Building Energy Consumption Survey* (CBECS).[12] DOE weighted each CBECS building by the *final full sample building weight*[b] type, the area (ft^2) of each CBECS building, the number of lamps per 1000ft^2 according to the LMC (Table 4.21), and the percentage of lamps that are GSLs in each building

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[a] Operating hours specifically for LEDs are not reported in the LMC.

[b] In CBECS, the *final full sample building weight*, denoted by the CBECS variable *ADJWT8*, denotes the number of buildings each building type in the CBECS sample represents.

type, and calculated that, nationwide, GSLs are used an average of 10.7 hours per day or 3891 hours per year in the commercial sector.

Table 7.2.5 CBECS Building Type Average HOU

CBECS Building Type	LMC Building	HOU/day	Building Weight*
Office	Offices (Non-medical)	10.5	22%
Laboratory	Other	10.9	1%
Nonrefrigerated warehouse	Warehouse and Storage	10.8	4%
Food sales	Food Store	10.7	1%
Public order and safety	Public Order and Safety	10.7	1%
Outpatient health care	Health Care – Outpatient	10.4	2%
Refrigerated warehouse	Warehouse and Storage	10.8	0%
Religious worship	Religious Worship	10.4	5%
Public assembly	Public Assembly	10.4	10%
Education	Education	10.6	7%
Food service	Food Service	10.3	5%
Inpatient health care	Health Care – Inpatient	10.5	3%
Nursing	Lodging	10.4	3%
Lodging	Lodging	10.4	11%
Strip shopping mall	Retail - Mall & Non-Mall	11.2	10%
Enclosed mall	Retail - Mall & Non-Mall	11.2	4%
Retail other than mall	Retail - Mall & Non-Mall	11.2	9%
Service	Services	10.8	2%
Other	Other	10.9	1%
	National Average	10.7	100% (total)

*The Building Weight is derived from the product of each CBECS building's area (CBECS variable SQFT8), the final full sample building weight in CBECS (CBECS variable ADJWT8), the number of lamps per 1000 ft^2 by building type and the percentage of lamps that are GSLs in each building type.

7.3 LIGHTING CONTROLS

DOE accounted for the impact of lighting controls on GSL energy use by reducing the energy use by 30 percent for GSLs that operate on lighting controls, for both the residential and commercial sectors. This estimate was based on a meta-analysis of field measurements of energy savings from commercial lighting controls by Williams, et al.[13] Field measurements of energy savings from controls in the residential sector are very limited; DOE assumed that controls would have the same impact as in the commercial sector.

The UEC of GSLs installed on any type of lighting control system, can be computed using the following formula:

$$\boldsymbol{UEC_c = UEC_{nc} \times \left(1 - f_{control} \times f_{effect}\right)}$$

Eq. 7.2

Where:

UEC_c= weighted average annual energy consumption (kWh) of GSLs considering use of lighting controls,

UEC_{nc}= annual unit energy consumption (kWh) of GSLs, operating under full power, computed according to Eq. 7.1,

$f_{control}$= the fraction of lamps estimated to be operating under lighting controls, and

f_{effect} = a parameter describing the effect of lighting controls on energy consumption, *i.e.,* the reduction on energy use due to lighting controls, taken to be 0.3.

7.3.1 Residential Sector

To estimate the fraction of GSLs used with lighting controls for each CSL in the residential sector, DOE first separately considered the fraction of CFL and LED GSLs used with controls in this sector. For CFLs, this fraction is limited technologically by the fraction of dimmable lamps. For LEDs, this fraction is limited by the fraction of dimmable sockets, and by the fraction of lamps with integrated wireless receivers that allow them to be controlled remotely, so called *smart lamps,* which can be installed in standard sockets.

For CFLs, DOE assumed that 5% of CFL GSLs can be used with dimmers, based on feedback from manufacturer interviews. DOE combined this percentage with the percentage of CFL GSLs used with lighting controls other than dimmers from the LMC, to estimate that the overall percentage of CFL GSLs used with lighting controls is about 7.3%. DOE assumes that this fraction remains constant throughout the analysis period for the residential sector.

For LED GSLs, DOE looked at the overall fraction of sockets that are installed with lighting controls in the residential sector (mostly dimmers, with a small fraction on switching controls). This fraction was 14% in 2010, according to the LMC, and DOE assumed that this fraction was constant throughout the analysis period. DOE also assumed that in addition to controlled sockets, there will be an increase in the market share of smart lamps. DOE assumed that the incursion of smart lamps followed a Bass adoption curve, as described in chapter 10 of this TSD.

Based on the incursion of smart lamps, and the fraction of controlled sockets, DOE estimates that at the assumed compliance year (2020), about 42% of GSL LEDs will be associated with some type of lighting control. Note that this relatively high fraction is due, in part, to the preferential use of LEDs in sockets with controls, compared to CFLs. For details on this estimate, see chapter 10 of this TSD.

7.3.2 Commercial Sector

For the commercial sector, DOE used the method developed for amended energy conservation standards for general service fluorescent lamps (GSFL) and incandescent reflector lamps (IRLs). DOE assumed that lighting controls are installed on an increasing fraction of lamps in the commercial sector as a result of updated building codes, as described in appendix

10D of this TSD. DOE estimates that by 2020, about 49% of GSLs will be using controls in the commercial sector.

To estimate the fraction of GSLs using controls in each of the commercial building types analyzed, DOE scaled the fraction of controls reported in the LMC for each building type by the ratio of the overall controls penetration in 2020 (49%) to the overall controls penetration reported in the LMC (30%).

7.4 RESULTS

The following tables present results of the energy use analysis for GSLs in units of kilowatt-hours per year (kWh/yr). Table 7.4.1, Table 7.4.2, and Table 7.4.3 present UEC and annual energy savings with respect to the baseline (CSL 0) at each CSL for each product class in the reference scenario, as well as the “no controls” scenario. The “no controls” scenario is not intended to be realistic, but to illustrate the impact that controls have on energy use and savings.

Table 7.4.1 Average Annual Energy Use and Savings per Unit for Integrated Low Lumen (< 2,000 lm) GSLs for Reference and No Controls Scenarios

	Residential				Commercial			
	Reference		No Controls		Reference		No Controls	
CSL	Energy Use (kWh/yr)	Savings (kWh/yr)	Energy Use (kWh/yr)	Savings (kWh/yr)	Energy Use (kWh/yr)	Savings (kWh/yr)	Energy Use (kWh/yr)	Savings (kWh/yr)
0	11.6	0.0	11.9	0.0	46.3	0.0	54.5	0.0
1	10.8	0.8	11.0	0.8	43.0	3.3	50.6	3.9
2	8.9	2.7	10.2	1.7	39.7	6.6	46.7	7.8
3	8.2	3.4	9.3	2.5	36.4	9.9	42.8	11.7
4	7.4	4.2	8.5	3.4	33.1	13.2	38.9	15.6
5	7.1	4.6	8.1	3.8	31.4	14.9	36.9	17.5

Table 7.4.2 Average Annual Energy Use and Savings per Unit for Integrated High Lumen (≥ 2,000 lm) GSLs for Reference and No Controls Scenarios

	Residential				Commercial			
	Reference		No Controls		Reference		No Controls	
CSL	Energy Use (kWh/yr)	Savings (kWh/yr)	Energy Use (kWh/yr)	Savings (kWh/yr)	Energy Use (kWh/yr)	Savings (kWh/yr)	Energy Use (kWh/yr)	Savings (kWh/yr)
0	26.6	0.0	27.2	0.0	106.0	0.0	124.0	0.0
1	24.9	1.7	25.5	1.7	99.2	6.6	117.0	7.8
2	24.1	2.5	24.6	2.6	95.9	9.9	113.0	11.7

Table 7.4.3 Average Annual Energy Use and Savings per Unit for Non-Integrated GSLs for Reference and No Controls Scenarios

	Residential				Commercial			
CSL	Reference		No Controls		Reference		No Controls	
	Energy Use (kWh/yr)	Savings (kWh/yr)	Energy Use (kWh/yr)	Savings (kWh/yr)	Energy Use (kWh/yr)	Savings (kWh/yr)	Energy Use (kWh/yr)	Savings (kWh/yr)
0	24.9	0.0	25.5	0.0	99.2	0.0	117.0	0.0
1	24.9	0.0	25.5	0.0	99.2	0.0	117.0	0.0
	20.3	4.6	20.7	4.7	80.7	18.4	94.9	21.7

Table 7.4.4 and Table 7.4.5 present UEC for Integrated Low-Lumen GSLs in the residential sector by reportable domain and in the commercial sector by building type.

Table 7.4.4 Annual Energy Use for Integrated Low Lumen (< 2,000 lm) GSLs in the Residential Sector

RECS Reportable Domain	CSL 0 (kWh/yr)	CSL 1 (kWh/yr)	CSL 2 (kWh/yr)	CSL 3 (kWh/yr)	CSL 4 (kWh/yr)	CSL 5 (kWh/yr)
01. CT, ME, NH, RI, VT	13.7	12.7	10.5	9.6	8.7	8.3
02. MA	13.5	12.5	10.3	9.5	8.6	8.2
03. NY	16.5	15.3	12.6	11.6	10.5	10.0
04. NJ	14.5	13.4	11.1	10.1	9.2	8.8
05. PA	14.5	13.4	11.1	10.1	9.2	8.8
06. IL	11.5	10.7	8.8	8.1	7.3	7.0
07. IN, OH	11.9	11.0	9.1	8.3	7.6	7.2
08. MI	11.7	10.9	9.0	8.2	7.5	7.1
09. WI	11.7	10.9	9.0	8.2	7.5	7.1
10. IA, MN, ND, SD	11.7	10.9	9.0	8.2	7.5	7.1
11. KS, NE	11.7	10.9	9.0	8.2	7.5	7.1
12. MO	11.7	10.9	9.0	8.2	7.5	7.1
13. VA	12.0	11.2	9.2	8.4	7.7	7.3
14. DE, DC, MD, WV	12.3	11.5	9.4	8.7	7.9	7.5
15. GA	11.8	10.9	9.0	8.3	7.5	7.1
16. NC, SC	12.0	11.1	9.2	8.4	7.6	7.3
17. FL	12.0	11.2	9.2	8.4	7.7	7.3
18. AL, KY, MS	12.0	11.2	9.2	8.4	7.7	7.3
19. TN	12.0	11.2	9.2	8.4	7.7	7.3
20. AR, LA, OK	11.9	11.0	9.1	8.3	7.6	7.2
21. TX	11.9	11.0	9.1	8.3	7.6	7.2
22. CO	8.2	7.6	6.3	5.8	5.2	5.0
23. ID, MT, UT, WY	8.2	7.6	6.3	5.8	5.2	5.0
24. AZ	8.2	7.6	6.3	5.8	5.2	5.0
25. NV, NM	8.2	7.6	6.3	5.8	5.2	5.0
26. CA	7.9	7.4	6.1	5.6	5.1	4.8
27. AK, HI, OR, WA	9.0	8.4	6.9	6.3	5.7	5.5
U.S. Average	11.6	10.8	8.9	8.2	7.4	7.1

Table 7.4.5 Annual Energy Use for Integrated Low Lumen (< 2,000 lm) GSLs in the Commercial Sector

Building Type	**CSL 0 (kWh/yr)**	**CSL 1 (kWh/yr)**	**CSL 2 (kWh/yr)**	**CSL 3 (kWh/yr)**	**CSL 4 (kWh/yr)**	**CSL 5 (kWh/yr)**
Office	40.4	37.5	34.6	31.7	28.8	27.4
Laboratory	52.4	48.7	44.9	41.2	37.4	35.6
Nonrefrigerated warehouse	51.5	47.8	44.1	40.4	36.8	34.9
Food sales	43.8	40.6	37.5	34.4	31.3	29.7
Public order and safety	53.6	49.8	45.9	42.1	38.3	36.4
Outpatient health care	47.3	43.9	40.5	37.1	33.8	32.1
Refrigerated warehouse	51.5	47.8	44.1	40.4	36.8	34.9
Religious worship	51.9	48.2	44.5	40.8	37.1	35.2
Public assembly	47.1	43.7	40.4	37	33.6	32
Education	49.6	46.1	42.5	39	35.5	33.7
Food service	51.4	47.7	44	40.4	36.7	34.9
Inpatient health care	51.3	47.6	43.9	40.3	36.6	34.8
Nursing	51.8	48.1	44.4	40.7	37	35.1
Lodging	51.8	48.1	44.4	40.7	37	35.1
Strip shopping mall	42.6	39.5	36.5	33.5	30.4	28.9
Enclosed mall	42.6	39.5	36.5	33.5	30.4	28.9
Retail other than mall	42.6	39.5	36.5	33.5	30.4	28.9
Service	49.8	46.3	42.7	39.1	35.6	33.8
Other	52.4	48.7	44.9	41.2	37.4	35.6
U.S. Average	46.3	43	39.7	36.4	33.1	31.4

Table 7.4.6 and Table 7.4.7 present UEC for Integrated High-Lumen GSLs in the residential sector by reportable domain and in the commercial sector by building type.

Table 7.4.6 Annual Energy Use for Integrated High Lumen (≥ 2,000 lm) GSLs in the Residential Sector

RECS Reportable Domain	CSL 0 (kWh/yr)	CSL 1 (kWh/yr)	CSL 2 (kWh/yr)
01. CT, ME, NH, RI, VT	31.3	29.4	28.4
02. MA	30.8	28.9	28.0
03. NY	37.7	35.3	34.2
04. NJ	33.0	31.0	29.9
05. PA	33.0	31.0	29.9
06. IL	26.3	24.7	23.9
07. IN, OH	27.2	25.5	24.6
08. MI	26.8	25.1	24.3
09. WI	26.8	25.1	24.3
10. IA, MN, ND, SD	26.8	25.1	24.3
11. KS, NE	26.8	25.1	24.3
12. MO	26.8	25.1	24.3
13. VA	27.5	25.7	24.9
14. DE, DC, MD, WV	28.2	26.4	25.6
15. GA	26.9	25.2	24.4
16. NC, SC	27.4	25.7	24.8
17. FL	27.5	25.7	24.9
18. AL, KY, MS	27.5	25.7	24.9
19. TN	27.5	25.7	24.9
20. AR, LA, OK	27.1	25.4	24.6
21. TX	27.1	25.4	24.6
22. CO	18.7	17.6	17.0
23. ID, MT, UT, WY	18.7	17.6	17.0
24. AZ	18.7	17.6	17.0
25. NV, NM	18.7	17.6	17.0
26. CA	18.1	17.0	16.4
27. AK, HI, OR, WA	20.6	19.3	18.6
U.S. Average	26.6	24.9	24.1

Table 7.4.7 Annual Energy Use for Integrated High Lumen (≥ 2,000 lm) GSLs in the Commercial Sector

Building Type	**CSL 0 (kWh/yr)**	**CSL 1 (kWh/yr)**	**CSL 2 (kWh/yr)**
Office	92.3	86.5	83.6
Laboratory	120	112	109
Nonrefrigerated warehouse	118	110	107
Food sales	100	93.8	90.6
Public order and safety	123	115	111
Outpatient health care	108	101	97.9
Refrigerated warehouse	118	110	107
Religious worship	119	111	108
Public assembly	108	101	97.6
Education	113	106	103
Food service	117	110	106
Inpatient health care	117	110	106
Nursing	118	111	107
Lodging	118	111	107
Strip shopping mall	97.3	91.2	88.2
Enclosed mall	97.3	91.2	88.2
Retail other than mall	97.3	91.2	88.2
Service	114	107	103
Other	120	112	109
U.S. Average	106	99.2	95.9

Table 7.4.8 and Table 7.4.9 present UEC for Non-Integrated GSLs in the residential sector by reportable domain and in the commercial sector by building type.

Table 7.4.8 Annual Energy Use (kWh/year) for Non-Integrated GSLs in the Residential Sector

RECS Reportable Domain	**CSL 0 (kWh/yr)**	**CSL 1A (kWh/yr)**	**CSL 1B (kWh/yr)**
01. CT, ME, NH, RI, VT	29.3	29.3	23.9
02. MA	28.9	28.9	23.5
03. NY	35.3	35.3	28.7
04. NJ	30.9	30.9	25.2
05. PA	30.9	30.9	25.2
06. IL	24.7	24.7	20.1
07. IN, OH	25.5	25.5	20.7
08. MI	25.1	25.1	20.5
09. WI	25.1	25.1	20.5
10. IA, MN, ND, SD	25.1	25.1	20.5
11. KS, NE	25.1	25.1	20.5
12. MO	25.1	25.1	20.5
13. VA	25.7	25.7	20.9
14. DE, DC, MD, WV	26.4	26.4	21.5
15. GA	25.2	25.2	20.5
16. NC, SC	25.6	25.6	20.9
17. FL	25.7	25.7	20.9
18. AL, KY, MS	25.7	25.7	20.9
19. TN	25.7	25.7	20.9
20. AR, LA, OK	25.4	25.4	20.7
21. TX	25.4	25.4	20.7
22. CO	17.6	17.6	14.3
23. ID, MT, UT, WY	17.6	17.6	14.3
24. AZ	17.6	17.6	14.3
25. NV, NM	17.6	17.6	14.3
26. CA	17.0	17.0	13.8
27. AK, HI, OR, WA	19.3	19.3	15.7
U.S. Average	24.9	24.9	20.3

Table 7.4.9 Annual Energy Use (kWh/year) for Non-Integrated GSLs in the Commercial Sector

Building Type	CSL 0 (kWh/yr)	CSL 1A (kWh/yr)	CSL 1B (kWh/yr)
Office	86.4	86.4	70.4
Laboratory	112	112	91.3
Nonrefrigerated warehouse	110	110	89.7
Food sales	93.7	93.7	76.3
Public order and safety	115	115	93.4
Outpatient health care	101	101	82.4
Refrigerated warehouse	110	110	89.7
Religious worship	111	111	90.5
Public assembly	101	101	82.1
Education	106	106	86.5
Food service	110	110	89.5
Inpatient health care	110	110	89.4
Nursing	111	111	90.2
Lodging	111	111	90.2
Strip shopping mall	91.2	91.2	74.2
Enclosed mall	91.2	91.2	74.2
Retail other than mall	91.2	91.2	74.2
Service	107	107	86.8
Other	112	112	91.3
U.S. Average	**99.2**	**99.2**	**80.7**

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CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 8. LIFE-CYCLE COST AND PAYBACK PERIOD ANALYSIS

8.1 INTRODUCTION

The effect of efficiency standards on individual consumers typically includes a reduction in operating expense and an increase in purchase cost. This chapter describes the methodology and metrics the U.S. Department of Energy (DOE) used to analyze the economic impacts of energy conservation standards for general service lamps (GSLs) on consumers.[a] DOE used the following metrics for its analyses:

- Life-cycle cost (LCC) is the total consumer expense over the life of a product, including purchase, installation costs and operating costs (which are comprised of maintenance, repair, and energy costs). After discounting the future operating costs to the time of purchase, DOE sums the present value of all costs incurred over the lifetime of the product.
- Payback period (PBP) is the amount of time it takes consumers to recover the assumed higher purchase price of more energy-efficient products through lower operating costs.

Inputs to the LCC and PBP calculations are discussed in sections 8.2 and 8.3 of this chapter, respectively. Calculations and results for the LCC and PBP analysis, for each different candidate standard level (CSL), are presented in section 8.4. The calculations discussed here are illustrated with a Microsoft Excel® spreadsheet, which is accessible on DOE's rulemaking website for GSLs: (http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx?ruleid=83). Details on the spreadsheet, and instructions for using it, are included in appendix 8A.

8.1.1 General Approach for Life-Cycle Cost and Payback Period Analysis

Because consumers use GSLs differently, several inputs to the determination of consumer LCC and PBP are either variable or uncertain. DOE analyzes the variability and uncertainty in the LCC and PBP inputs by performing calculations for a representative sample of individual consumers that purchase GSLs. DOE uses Monte Carlo simulation[b] and probability distributions for a sample of 10,000 consumers in the LCC and PBP analysis.

In addition to characterizing several of the inputs to the analysis with probability distributions, DOE developed a sample of individual buildings in the residential and commercial sectors that include GSLs.[c] By developing building samples, DOE was able to account for the variability in energy consumption, energy price, or both, associated with GSL purchases made in each sampled building.

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[a] For the purposes of the PBP and LCC analysis, a consumer is someone who purchases and uses a GSL.

[b] For details on the Monte Carlo simulation, see appendix 8B

[c] According to the 2010 Lighting Market Characterization (LMC), the industrial sector represents less than 1% of the overall GSL market.[1] Therefore, DOE excluded the industrial sector from this analysis.

DOE displays the LCC results as distributions of impacts relative to the absence of an energy conservation standard (hereafter referred to as the “base case”). Results are presented at the end of this chapter and are based on 10,000 samples per Monte Carlo simulation run.

8.1.2 Overview of Life-Cycle Cost and Payback Period Inputs

DOE categorizes inputs to the LCC and PBP analysis for each CSL as follows: (1) inputs for establishing the total installed cost (*i.e.,* purchase price plus installed cost), and (2) inputs for calculating the operating cost.

The primary inputs for establishing the total installed cost are:

- *End-User Product Price*: The weighted-average end-user GSL prices from the engineering analysis. See chapter 6 of this technical support document (TSD) for details on the product price methodology.
- *Sales tax*: The State and local retail sales tax.

Note that DOE did not take into account installation cost as one of the total installed cost inputs. As discussed in the framework document, DOE assumes that the installation cost, which represents all costs required to install the GSL, is not affected by changes in product efficiency and is therefore the same for all CSLs within a given product class and sector. DOE seeks comment on this approach.

The primary inputs for calculating the operating cost are:

- *Power rating*: The site electricity usage rate associated with operating the GSL. Chapter 5 of this TSD details how DOE determined the power ratings for representative GSLs. For the integrated low-lumen product class, DOE considered representative lamps across four lumen ranges. See section 8.2.2 for more details. In the reference scenario, DOE did not account for any standby power that GSLs may have.
- *Annual Operating Hours*: The estimated number of hours a GSL is used over a period of one year. Chapter 7 of this TSD discusses how DOE estimated the GSL operating hours for various geographical regions, rooms (in the residential sector), and building types (in the commercial sector). In the LCC and PBP analysis, DOE developed hours-of-use (HOU) distributions. See section 8.2.7.1 for details.
- *Energy prices*: The prices paid by consumers for electricity.
- *Energy price trends*: Forecasted electricity prices, as reported in the Energy Information Administration’s *Annual Energy Outlook 2014* (*AEO2014*).[2]
- *Repair and maintenance costs*: Repair costs are those associated with repairing or replacing GSLs that have failed. DOE did not take into account repair costs because consumers typically dispose of GSLs when they fail. Also, DOE did not take into account maintenance costs, if any, because those are considered to be independent of efficiency improvements and, therefore, do not vary across CSLs.

- *Disposal Cost*: After GSLs reach the end of their life, some consumers pay to recycle or discard those lamps. The GSL disposal cost represents the cost of disposing these lamps.

- *Lamp Residual Value*: The remaining value of the surviving lamp(s) at the end of the LCC analysis period.[d]

- *Lifetime*: The age at which the GSL is retired from service.

- *Discount rate*: The rate at which DOE discounts future expenditures to establish their present value.

The data inputs to the PBP for each CSL are the total installed cost to the consumer of a GSL (relative to the installed cost of a baseline lamp) and the operating expenses in the first year of ownership. In this preliminary analysis, DOE used a "simple" PBP calculation, which does not take into account changes in operating cost over time. Thus, the input to the total installed cost is the end-user product price (including sales tax) and the inputs to the first year's operating expenses are the annual operating hours, the GSL power rating, and the electricity price in the compliance year of this rulemaking (2020).

Figure 8.1.1 and Figure 8.1.2 depict the relationships among inputs for installed cost and operating costs that DOE used to calculate the LCC and PBP, respectively. The yellow boxes indicate inputs, the green boxes indicate intermediate outputs, and the blue boxes indicate final outputs (the LCC and PBP).

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[d] The LCC analysis period is based on the lifetime of the shortest-lived lamp in each product class and sector (residential or commercial). See section 8.2.7.6 for details on the residual value.

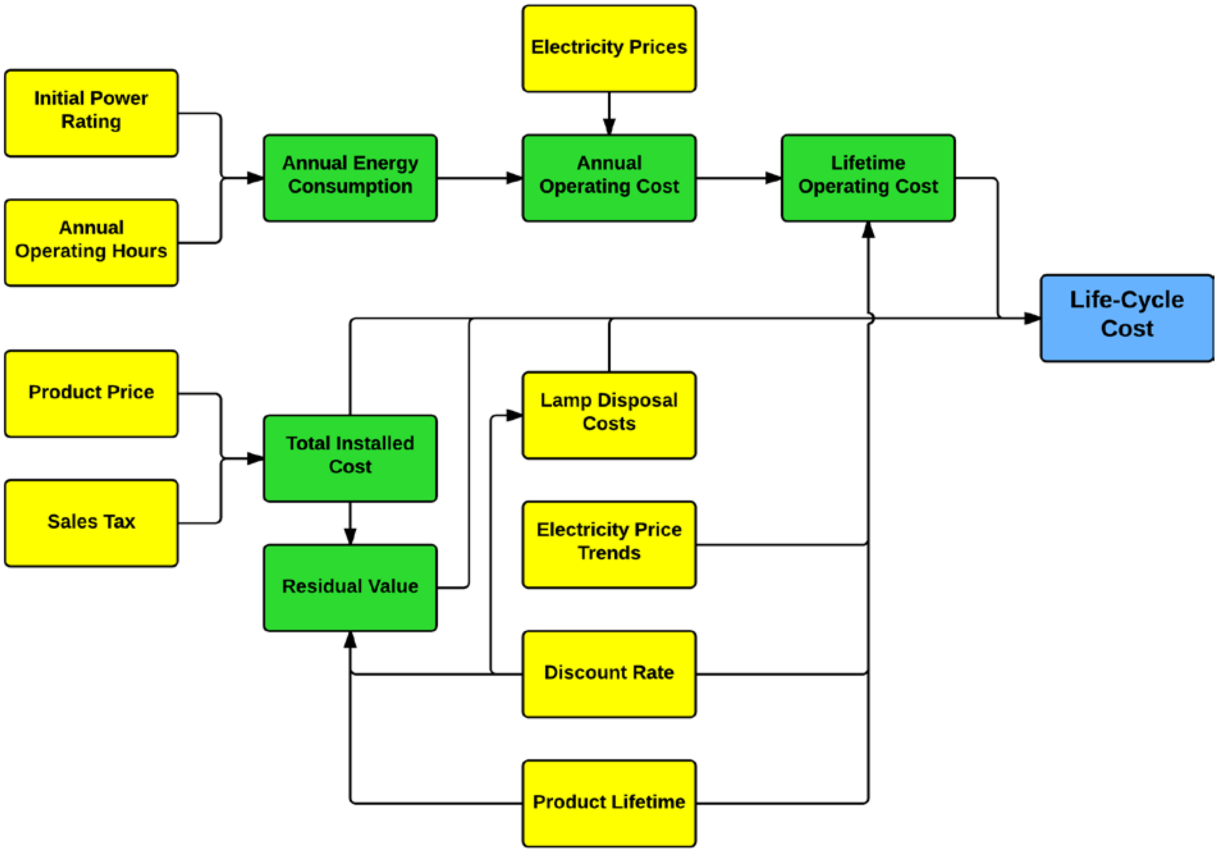

Figure 8.1.1 Life-Cycle Cost Flow Diagram

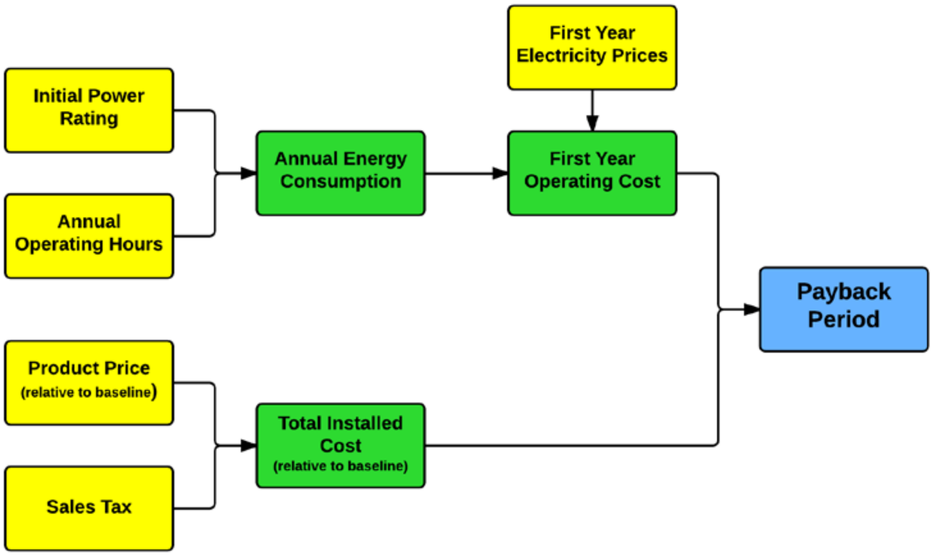

Figure 8.1.2 Payback Period Flow Diagram

Table 8.1.1 Summary of Inputs to Life-Cycle Cost and Payback Period

Inputs	Average or Typical Value	Characterization
Total Installed Cost Inputs		
Product Price	Varies by efficiency level and product class	Single-point value
Sales Tax	7.1%	Varies by region
Operating Cost Inputs		
Power Rating	Varies by CSL and product class	Single-point value
Operating Hours	Residential sector: 2.3 hrs/day Commercial sector: 10.7 hrs/day	Residential: Distribution - varies by room type and region Commercial: Distribution - varies by building type
Electricity Prices	Residential sector: \$0.13 /kWh Commercial sector: \$0.11 /kWh	Vary by region and sector
Electricity Price Trends	*AEO2014* reference case	Vary by AEO growth scenario
Lamp Disposal Costs	Residential sector: None Commercial sector: 1\$ for 10% of CFLs	Vary by sector
Product Lifetime	Median* Residential CFL: 6.8 yrs Residential LED: 19.2 yrs Commercial CFL: 2.7 yrs Commercial LED: 6.8 yrs	Weibull distribution (see appendix 8E)
Discount Rate	Residential: Mean real discount rates range from 0% to 11%. Commercial: Mean real discount rates range from 5.1% to 6.1%.	Distribution (see appendix 8C)
Date Standards Become Effective	2020 (3 years after expected publication of a potential final rule)	Single-point value

*Median lifetimes listed here correspond to CFLs for which the rated lifetime is 10,000 hours and LEDs for which the rated lifetime is 25,000 hours.

8.2 LIFE-CYCLE COST INPUTS

8.2.1 Overview

The LCC analysis calculates the average LCC of GSLs for consumers at each CSL based on the LCCs of purchases of representative products. LCC is the total consumer expense over the life of a product, including initial and operating costs. DOE discounts future operating costs to the time of purchase and sums all costs over the lifetime of the product.

For an individual GSL purchase, DOE defines the LCC by the following equation:

$$LCC = IC + \sum_{y=1}^{N} \frac{OC_y}{(1+r)^y} + \mathrm{DC}\frac{1}{(1+r)^N} - \mathrm{RV}$$

Eq. 8.1

Where:

LCC = life-cycle cost, in dollars,
IC = total installed cost, in dollars,
N = LCC analysis period, in years,
OC = annual operating cost, in dollars,
DC= disposal cost, in dollars,
RV = residual value, in dollars, for GSLs with lifetimes greater than the analysis period,[e]
r = discount rate, and
y = year for which the operating cost is being determined.

DOE expresses costs in 2014$. Total installed cost, operating cost, lifetime, and discount rate are discussed in the following sections. DOE used 2020 as the product purchase year for the LCC calculation, as 2020 is the assumed compliance date of this rulemaking.

To determine the impact of standards on the average LCC for all U.S. consumers, DOE must address how the numerous LCC inputs vary across U.S. residential and commercial consumers, and how the standard itself affects the LCC through the standard's indirect effect on equipment and operating costs. The following sections develop the inputs necessary to address those factors.

8.2.2 Lamp Sampling

8.2.2.1 Overview

Because of the high variability in LED lamp price by light output, DOE analyzed the LCC and PBP across four lumen ranges (310-749 lm, 750-1049 lm, 1050-1489 lm, and 1490-1999 lm) [f] for the integrated low-lumen product class, which is the only product class that includes LED lamps.

The engineering analysis and product price determination (chapters 5 and 6 of this TSD, respectively) yielded representative integrated low-lumen lamp options at each CSL for the 750-1049 lumen range. From these representative lamp options, DOE developed representative lamp options for all other lumen ranges. The following sections discuss in detail how DOE developed these lamp options as well as the market share of each lumen range in the base case.

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[e] The residual value is the present value benefit a consumer receives for not having to buy another GSL at the end of the analysis period, because the GSL is operational after the end of the LCC analysis period. Therefore, the residual value is subtracted from the LCC calculation, as it is applied as a credit to the consumer. For details on the residual value, see section 8.2.7.6.

[f] These lumen ranges were based on the rated lumen ranges for general service incandescent lamps, which were established by the Energy Independence and Security Act of 2007 (EISA).[3] Because the 4 lumen ranges apply only to the integrated low-lumen product class, the 4th lumen range covers 1490-1999 lumens, as opposed to 1490-2600 in EISA.

8.2.2.2 Lamp Option Characteristics

First, DOE identified a characteristic lumen output for each of the lumen ranges (310-749 lm, 750-1049 lm, 1050-1489 lm, and 1490-1999 lm): 500, 800, 1200, and 1600 lumens, respectively.[g] Then, DOE multiplied the lumen output for each representative lamp option from the engineering analysis by the ratio of characteristic lumen output for each range to the lumen output for the 750-1049 lm range. For example, the lumen output of lamps at each CSL in the 310-749 lm range was assumed to be a factor of 500/800 as large as the lumen output of the corresponding representative lamp option in the 750-1049 lumen range. This yielded lumen output values for six lamp options, one for each CSL, in each of the four lumen ranges.

Using the resulting lumen-output value for each lamp option, DOE determined an efficacy, and hence a wattage, for each lamp option using to the formula used to define the minimum efficacy for each CSL in the engineering analysis:

$$LPW_i = \frac{RefLPW_{CSL,i} - 29.42 \times 0.9983^{Lum_i}}{RefLPW_{CSL,i} - 29.42 \times 0.9983^{Lum_{CSL,Rep}}} \times LPW_{CSL,Rep}$$

Eq. 8.2

Where:

LPW_i = the efficacy of lamp option i in lumens per watt,
$RefLPW_{CSL,i}$ = the reference efficacy used to define the CSL corresponding to lamp option i, summarized in Table 8.2.1,
Lum_i = the lumen output of lamp option i,
$Lum_{CSL,Rep}$ = the lumen output of the representative lamp, in the 750-1049 lumen range, which corresponds to the same CSL as lamp option i, and
$LPW_{CSL,Rep}$= the efficacy, in lumens per watt, of the representative lamp that corresponds to the same CSL as lamp option i.

The reference efficacy values $RefLPW_{CSL,i}$ are presented in Table 8.2.1. Since there is no reference value for CSL 0, DOE used the reference values for CSL 1 in Eq. 8.2 when developing efficacy values for lamp options at CSL 0.

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[g] DOE used these lumen values based on typical lumen output data in CFLs and LEDs in each of the lumen ranges based on review of product offerings available in-store and online.

Table 8.2.1 Reference Efficacy Values at Each CSL Used in Eq. 8.2.

CSL	Reference efficacy
0	N/A
1	67.6
2	74.2
3	80.2
4	87.5
5	90.8

To develop prices for the lamp options in the three lumen ranges for which price data were not available from the product price determination (chapter 6 of this TSD), DOE collected online retail data[h] for CFLs and LEDs across all four lumen ranges. To determine the characteristic lamp prices by lumen range and lamp technology, DOE calculated a weighted average[i] of the 10th percentile in price for GSL models available from four retailers, disaggregated by lumen range and lamp technology. The 10th percentile in price was selected because, according to a Lawrence Berkeley National Laboratory report,[5] for LED GSLs this percentile corresponds approximately to the median purchase price. To obtain a final price for the lamp options in each lumen range, DOE multiplied the price of each representative lamp in the engineering analysis by the ratio of the technology-specific weighted-average retail lamp price in each lumen range to the corresponding weighted-average retail price in the 750-1049 lm range.

Finally, DOE assumed that the lifetime for the representative lamps across all lumen ranges was the same as the lifetime of the representative lamp option in the 750-1049 lumen range from the engineering analysis at each CSL. Table 8.2.2 presents characteristics for all representative lamps across all CSLs and lumen ranges.

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[h] The online retail data consisted of 1,031 medium screw base (E26) CFLs, and 289 E26 LED lamps, between 310 and 2600 lumens, collected in July 2014. The data were collected from the following retailers: www.homedepot.com, www.bulbs.com, www.elightbulbs.com, and www.1000bulbs.com.

[i] Detailed share data across the 4 retailers was not available in this analysis. However, DOE is aware that that home improvement stores have a much larger market share than online retailers.[4] To account approximately for these relative market shares, DOE weighted the prices of each retailer as follows: 50% for Home Depot, and 16.67% for each online retailer.

Table 8.2.2 Representative GSL Characteristics for all Lumen Ranges

Lumen Range (lm)	CSL	Lamp Technology	Initial Lamp Lumens	Nominal Wattage	Efficacy (lm/W)	Price in 2020* (2014$)
310-749	0	CFL	469	9.5	49.1	5.20
	1	CFL	500	8.9	56.4	3.30
	2	LED	500	8.1	61.6	25.72
	3	LED	500	7.4	67.7	16.38
	4	LED	500	6.7	75.0	6.94
	5	LED	500	6.3	79.1	6.59
750-1049	0	CFL	750	14.0	53.6	5.62
	1	CFL	800	13.0	61.5	3.57
	2	LED	800	12.0	66.7	28.12
	3	LED	800	11.0	72.7	17.91
	4	LED	800	10.0	80.0	6.98
	5	LED	800	9.5	84.2	6.63
1050-1489	0	CFL	1125	19.8	56.9	7.08
	1	CFL	1200	18.4	65.4	4.50
	2	LED	1200	17.0	70.4	46.83
	3	LED	1200	15.7	76.5	29.83
	4	LED	1200	14.3	83.7	7.25
	5	LED	1200	13.6	88.0	6.89
1490-1999	0	CFL	1500	25.6	58.6	7.96
	1	CFL	1600	23.8	67.3	5.06
	2	LED	1600	22.1	72.3	68.14
	3	LED	1600	20.4	78.3	43.40
	4	LED	1600	18.7	85.6	7.57
	5	LED	1600	17.8	89.9	7.18

*Note that the price of some lamp options may be lower than their price in 2014, due to price learning.

8.2.2.3 Lumen Range Market Shares by Sector

Residential Sector

To find the lumen distribution in the residential sector for the integrated low-lumen product class, DOE used the *Residential Lighting End-Use Consumption Study* (RLEUCS),[6] and data from Cadeo Group.[7]

RLEUCS includes characteristic GSL data for the U.S. residential sector by housing type, lamp type, lamp technology, room type, and U.S. geographic region. DOE assumed that RLEUCS includes GSLs within the 310-2,600 lumen range. DOE first used GSL wattage data from RLEUCS for which the lamp technology type was specified, and converted the wattage data to lumens using a wattage-to-efficacy relationship[j] for each lamp technology in the RLEUCS dataset.[k] After converting the RLEUCS wattages to approximate lumens, DOE computed the weighted national average lamp lumens from the RLEUCS dataset, which was 831 lumens. The weighted average lumen value was used in order to calculate the market share of all lumen ranges, and was calculated by applying a weighting factor to the RLEUCS dataset, as shown in Eq. 8.3:

$$Lm_{avg} = \sum_{i=0}^{n} Lm_i \times \frac{L_i \times N_i}{\sum_{i=0}^{n} L_i \times N_i}$$

Eq. 8.3

Where:

Lm_{avg}= weighted average lumens in the RLEUCS dataset,
i= representative lighting characteristic in the RLEUCS dataset,
L_i= number of lamps per household in the RLEUCS dataset,
N_i= number of U.S. households in the RLEUCS dataset, and
$\sum_{i=0}^{n} L_i \times N_i$ = total of number of GSLs in the RLEUCS dataset.

Next, DOE used data from Cadeo Group to estimate the market share of each lumen range. These data, which were based on sales data from a mass market retailer focused on the residential market, included market shares for the 1050-1489 lm and 1490-2600 lm ranges. Those market shares were 8.7% and 11.4%, respectively. DOE assumed that the representative lumens for these lumen ranges were 1200 lumens for the 1050-1489 lm range and 1600 lumens for the 1490-2600 lm range.

Based on these assumptions and the weighted average lumens from the RLEUCS dataset (831 lumens), DOE was able to estimate the market shares of the 310-749 lm and 750-1049 lumen ranges using Eq. 8.4 and Eq. 8.5.

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[j] For incandescent GSLs, DOE used the wattage-to-efficacy relationship specified in the 2009 energy conservation standards for General Service Incandescent Lamps.[8] For CFL GSLs, DOE used the wattage-to-efficacy relationship from an ENERGY STAR lighting fact sheet.[9] DOE did not use a wattage-efficacy relationship for LEDs because RLEUCS did not include wattage data on LEDs.

[k] For the purposes of this analysis, the RLEUCS dataset was a subset of all lighting characteristics available in RLEUCS. This dataset consisted of incandescent or CFL 'space lamps' for all RECS reportable domains. The dataset was derived from the (complementary to RLEUCS report) Residential Lighting Usage Estimate Tool, available at http://www1.eere.energy.gov/buildings/ssl/residential-lighting-study.html.

$$Lm_{avg} = f_1 \times 500 + f_2 \times 800 + f_3 \times 1200 + f_4 \times 1600$$

Eq. 8.4

$$f_1 + f_2 + f_3 + f_4 = 1$$

Eq. 8.5

Where:

Lm_{avg} = weighted average lumens in the RLEUCS dataset (831 lumens),
f_3 = the market share of the 1050-1489 lm range (8.7%), and
f_4 = the market share of the 1490-2600 lm range (11.4%)

In order to calculate the relative market shares of the four lumen ranges in the integrated low-lumen product class, which has an upper lumen bound of 1999 lumens, DOE first estimated the market share of the 1490-1999 lumen range in comparison to the market share of the 1490-2600 lumen range. DOE used model counts of GSLs available online and found that the 1490-1999 portion of the lumen range represented 76% of the market share of the 1490-2600 lumen range.[l] Based on this estimate, DOE renormalized the market shares for the four lumen ranges of the integrated low-lumen product class. The market shares for the 310-749 lm, 750-1049 lm, 1050-1489 lm, and 1490-1999 lm range were calculated to be 32.5%, 49.7%, 9.0%, and 8.9%[m], respectively, as shown in Figure 8.2.1. DOE assumed that the characteristic lumen output for the 1490-1999 lumen range was 1600 lumens, as with the 1490-2600 lumen range. Using the updated lumen range market shares and Eq. 8.4, DOE also calculated the average lumen output for this product class to be 810 lumens. This lumen value was later used in the analysis to estimate the average lumens of each room type in the RLEUCS database, as discussed in section 8.2.7.1

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[l] To derive this estimate, DOE used online retail data for GSLs between 1490-2600 lumens from the 4 retailers discussed previously (www.homedepot.com, www.bulbs.com, www.elightbulbs.com, and www.1000bulbs.com) and found that 367 from a total of 484 GSLs in that dataset, or 76%, were in the 1490-1999 lm range.
[m] The sum of these market shares does not sum to 100% due to rounding

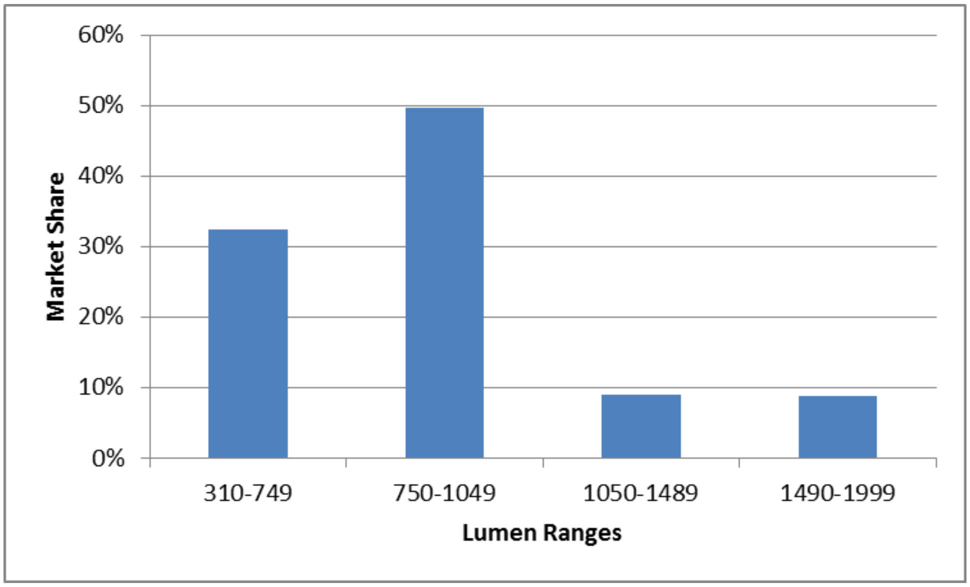

Figure 8.2.1 Residential Sector Lumen Range Distribution for the Integrated Low-Lumen Product Class

Commercial Sector

To determine the lumen distribution for the integrated low-lumen product class in the commercial sector, DOE used California shelf survey data[n] for GSLs from DNV KEMA.[10] The KEMA shelf survey data include breakdowns by lamp technology, lumen range, and base type. Due to a lack of commercial-sector lumen distribution data for integrated low-lumen GSLs, and because pin-based CFLs are predominantly used in the commercial sector,[1] DOE assumed that the market shares across lumen ranges for the integrated low-lumen product class in the commercial sector would be equal to the market shares across lumen ranges for pin-based CFLs. These market shares for the 310-749 lm, 750-1049 lm, 1050-1489 lm, and 1490-1999 lm range were calculated to be 9.0%, 44.1%, 18.8%, and 28.1, and are shown in Figure 8.2.2.

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[n] The shelf survey data were collected in summer of 2013 in 201 retail stores throughout utility service territories in California.

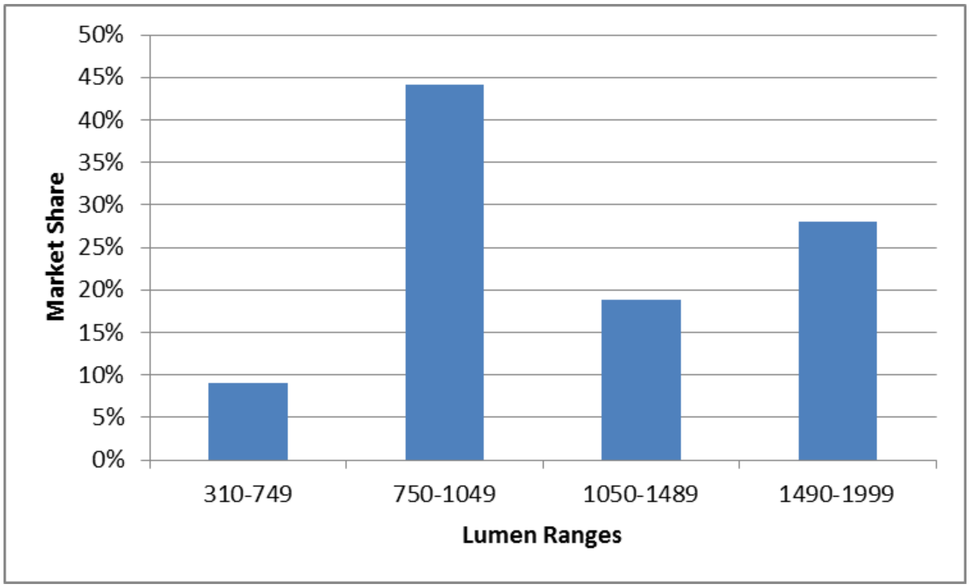

Figure 8.2.2 Commercial Sector Lumen Distribution for the Integrated Low-Lumen Product Class

8.2.3 Consumer Samples

As described previously, the LCC of an individual consumer depends on operating cost, which in turn depends on electricity use and price. Calculating the average LCC of U.S. consumers therefore requires data on the variation in energy use and price across the nation. These data were obtained from energy consumption surveys for residences and commercial buildings administered by the Energy Information Administration (EIA).

DOE used the EIA's 2009 Residential Energy Consumption Survey (RECS)[11] and the 2003 Commercial Buildings Energy Consumption Survey (CBECS)[12] to develop building samples for GSLs in the residential and commercial sector, respectively. RECS and CBECS were constructed by the EIA to be a national representation of the residential and commercial sector in the United States. RECS is a national sample survey of housing units that collects statistical information on the consumption of, and expenditures for, energy in housing units, along with data on energy-related characteristics of the housing units and occupants. RECS 2009 included data from 12,083 housing units to represent almost 113.6 million households. DOE weighted each of the housing units in RECS according to the number of U.S. households it represented. CBECS collects energy-related data for commercial buildings in the United States. CBECS 2003 included data from 5,215 buildings to represent 4.9 million buildings. CBECS categorizes building types by their principal building activity. DOE excluded vacant buildings from its sample and weighted each remaining building according to the building weight[o] defined in chapter 7 of this TSD.

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[o] The building weight is derived from the product of each CBECS building's area, the number of buildings each CBECS building represents, the number of lamps per 1000 ft^2 by building type, and the percentage of lamps that are GSLs in each building type.

8.2.4 Market Distribution of General Service Lamps by Candidate Standard Level

To estimate the average LCC savings of a CSL, DOE first considers the market distribution by CSL, for each product class and sector, in the base case at the assumed compliance year (2020). DOE then considers the market distribution by CSL, for each product class and sector, if a standard were in place, at the assumed compliance year (the candidate standards case efficiency distributions).

The methodology to determine the base case and candidate standards case distributions in 2020 is discussed in detail in chapter 9 of this TSD. Table 8.2.3 presents the base case distribution by CSL, for all product classes, and for both the residential and commercial sectors. Note that for the integrated low-lumen product class, the distribution for all lumen ranges is included.

Table 8.2.3 GSL Market Distribution in the Base Case in 2020

Sector	CSL	Market Share (%)						
		Integrated Low-Lumen				**Integrated High-Lumen**	**Non-Integrated**	
		310-749 lm	**750-1049 lm**	**1050-1489 lm**	**1500-1999 lm**			
Residential	0	1.1	1.1	1.1	1.1	21.4	65.4	
	1	49.0	48.7	47.4	46.9	31.8	30.5	4.1
	2	0.6	0.5	0.2	0.1	46.8		
	3	2.2	1.8	0.7	0.3			
	4	20.5	20.9	22.2	22.6			
	5	26.6	26.9	28.5	29.0			
Total		100	100	100	100	100	100	
Commercial	0	0.1	0.1	0.1	0.1	19.0	65.4	
	1	56.7	55.7	52.1	50.9	43.3	30.5	4.1
	2	0.0	0.0	0.0	0.0	37.7		
	3	0.3	0.2	0.0	0.0			
	4	16.2	16.7	18.3	18.8			
	5	26.6	27.2	29.5	30.3			
Total		100	100	100	100	100	100	

Note: For the LCC and PBP analysis, DOE assumed that the market distributions of non-integrated high lumen GSLs are the same in the residential and commercial sector.

8.2.5 Price Learning

As described in section 8.1.2, lamp prices in the compliance year are an input to the LCC analysis. DOE uses a price learning analysis to account for changes in lamp prices that are expected to occur between the time for which DOE has data for lamp prices (2014) and the assumed compliance date of the rulemaking (2020). Price learning is also incorporated into the residual value of GSLs. Chapter 9 of this TSD discusses in detail the methodology DOE followed on price learning.

8.2.6 Total Installed Cost Inputs

DOE developed end-user product prices in chapter 6 of this TSD. In addition, as discussed previously, for the integrated low-lumen product class, DOE also developed end-user product prices for all lumen ranges in that product class. DOE added sales tax to these prices to derive final product prices, or total installed costs.

DOE calculated the total installed cost based on the following equation:

$$IC = \mathrm{FC} \times (1 + TAX)$$

Eq. 8.6

Where:

FC= end-user weighted-average GSL price, in dollars, and
TAX= sales tax markup.

The sales tax is a multiplicative factor that represents state and local sales taxes applied to the consumer price. DOE derived state and local taxes from data provided by the Sales Tax Clearinghouse.[13] DOE derived population-weighted average[14] tax values for each RECS reportable domain, and at national level, as shown in Table 8.2.4[p]:

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[p] The table presents sales tax for each RECS reportable domain. In the commercial sector, DOE used population-weighted average sales tax data to each Census Division and Large State.

Table 8.2.4 Average Sales Tax Rates by RECS Reportable Domain

RECS Reportable Domain	Population (2013)	Tax Rate (2014)
01. CT, ME, NH, RI, VT	7,925,982	5.1%
02. MA	6,692,824	6.3%
03. NY	19,651,127	8.5%
04. NJ	8,899,339	7.0%
05. PA	12,773,801	6.4%
06. IL	12,882,135	8.0%
07. IN, OH	18,141,710	7.1%
08. MI	9,895,622	6.0%
09. WI	5,742,713	5.5%
10. IA, MN, ND, SD	10,079,066	6.9%
11. KS, NE	4,762,473	7.2%
12. MO	6,044,171	7.4%
13. VA	8,260,405	4.0%
14. DE, DC, MD, WV	9,355,316	5.4%
15. GA	9,992,167	7.1%
16. NC, SC	14,622,899	7.0%
17. FL	19,552,860	6.7%
18. AL, KY, MS	12,220,224	7.3%
19. TN	6,495,978	9.5%
20. AR, LA, OK	11,435,411	8.7%
21. TX	26,448,193	8.0%
22. CO	5,268,367	6.1%
23. ID, MT, UT, WY	6,110,831	5.3%
24. AZ	6,626,624	7.2%
25. NV, NM	4,875,423	7.4%
26. CA	38,332,521	8.4%
27. AK, HI, OR, WA	13,040,657	5.3%
National	316,128,839	7.1%

8.2.7 Operating Cost Inputs

DOE defines the operating cost (OC) for GSLs in year *t* by the following equation:

$$OC_t = \text{UEC} \times EP_t$$

Eq. 8.7

Where:

UEC = annual unit energy consumption (defined in chapter 7 of this TSD), in kWh per year, and
EP_t = electricity price in year t, in dollars.

The annual energy consumption, as discussed in chapter 7 of this TSD, is equal to the annual operating hours of the GSL multiplied by the GSL input power. DOE used electricity price trends to forecast electricity prices into the future and, along with the product lifetime and discount rate, to establish the present value of lifetime energy costs. The following sections discuss in detail the operating cost inputs.

8.2.7.1 Operating Hours

DOE determined the weighted-average GSL operating hours in chapter 7 of this TSD using data from field metering studies for the residential sector and data from the LMC[1] for the commercial sector. DOE estimated GSL HOU for each RECS reportable domain in the residential sector and for each building type in the commercial sector. In the LCC and PBP analysis, DOE used a more detailed approach to sample operating HOU for each consumer, as discussed in the following sections.

Residential Sector

For integrated low-lumen GSLs, the LCC model first sampled a representative lamp from the four lumen ranges (310-749 lm, 750-1049 lm, 1050-1489 lm, and 1490-1999 lm), as discussed in section 8.2.2. Probability distributions were developed for each room type presented RLEUCS, which indicated the probability that a lamp in a particular lumen range would be found in a particular room type. For each sampled lamp, DOE sampled a room type. DOE then sampled from HOU distributions developed for each room type using data from the Northwest Energy Efficiency Alliance’s Residential Building Stock Assessment Metering Study (RBSAM).[15]

For integrated high-lumen GSLs and non-integrated GSLs, DOE assumed that the distribution of lamps across room types would be same as the distribution for the highest lumen range of integrated low-lumen GSLs.

The following sections describe in more detail DOE’s approach to develop HOU distributions.

To develop HOU distributions for each room type and room distributions by lumen range, DOE first calculated the average lumens of each room type across the U.S. in the RLEUCS dataset, using the equivalent of Eq. 8.3 for each room type:

$$Lm_{avg,r} = \sum_{i=0}^{n} Lm_{i,r} \times \frac{L_{i,r} \times N_{i,r}}{\sum_{i=0}^{n} L_{i,r} \times N_{i,r}}$$

Eq. 8.8

Where:

$Lm_{avg,r}$= weighted average lumens in the RLEUCS dataset for room type r in RLEUCS[q],
i, r= representative lighting characteristic in the RLEUCS dataset for room type r,
$L_{i,r}$= number of lamps per household in the RLEUCS dataset for room type r,
$N_{i,r}$= number of U.S. households in the RLEUCS dataset for room type r, and
$\sum_{i=0}^{n} L_{i,r} \times N_{i,r}$ = total of number of GSLs in the RLEUCS dataset for room type r.

DOE multiplied the average room lumens, $Lm_{avg,r}$, by a factor equal to 810/831 to adjust to the analyzed lumen ranges (310-749 lm, 750-1049 lm, 1050-1489 lm, and 1490-1999 lm). DOE then estimated the fraction of lamps ($f_{i,r}$) in a particular lumen range (i) for each room type (r), under the following conditions, where each lumen range was represented by its characteristic lumens (500, 800, 1200, 1600[r]):

$$Lm_{avg,r} = f_{1,r} \times 500 + f_{2,r} \times 800 + f_{3,r} \times 1200 + f_{4,r} \times 1600$$

Eq. 8.9

$$f_{1,r} + f_{2,r} + f_{3,r} + f_{4,r} = 1$$

Eq. 8.10

$$f_{3,r} = \frac{f_3}{f_2} \times f_{2,r}$$

Eq. 8.11

$$f_{4,r} = \frac{f_4}{f_2} \times f_{2,r}$$

Eq. 8.12

DOE assumed that the relative market shares of lamps in the 750-1049, 1050-1489 and 1490-1999 lumen ranges are fixed with the respect to one another, and with the same relative market share in each room type as the overall relative market share of lamps in these lumen ranges in all room types.

Using Eq. 8.9 through Eq. 8.12, DOE determined the lumen distribution for each room type. A weighting factor, based on the total lamps in each room type in the RLEUCS dataset,

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[q] The room types in RLEUCS are the following: bathroom, bedroom, dining room, exterior, garage, hallway, kitchen, living room, office, and other room.

[r] As discussed earlier, DOE assumed that the characteristic lumen output for the 1490-1999 lumen range was 1600 lumens, as with the 1490-2600 lumen range.

was also used to determine the probability that a lamp in a given lumen range would be installed in particular room type.

For each room type, DOE used RBSAM[15] HOU distribution data, along with the average operating hours by RECS reportable domain from chapter 7 of this TSD, to sample hours of use. RBSAM is a metering study of 101 single-family houses across the Northwest (located in Idaho, Montana, Oregon, and Washington), which includes HOU data by room type for each household. DOE mapped the RBSA room types to the RLEUCS room types, and assigned a distribution of HOU data to each room type in the RLEUCS dataset.[s]

DOE assumed that the shape of the HOU distribution for a particular room type would be the same across the U.S., even if the average HOU for that room type varied by geographical location. To adjust the HOU distributions for each RECS reportable domain, DOE used the following approach: First, the model sampled an HOU from RBSAM for a specific room, r, and RECS reportable domain, d. Then, the sampled HOU value was multiplied by two factors: The first factor is the ratio of the average HOU for RECS reportable domain d as calculated in chapter 7 of this TSD, to the average HOU for RECS reportable domain d as reported in RLEUCS. The second adjustment factor is the ratio of the weighted average HOU in room r for RECS reportable domain d from RLEUCS, to the average HOU in room r from RBSAM. Note that in cases where the resulting HOU exceeded 24hr/day, DOE capped the HOU to 24hr/day.

Commercial Sector

For the commercial sector, DOE estimated that on a national level, GSLs are used 10.7 hours per day, as discussed in chapter 7 of this TSD. Each building's weighted-average HOU were estimated to range between 10.3 HOU per day for food service buildings and 11.2 HOU per day for retail buildings.

To capture the variability in GSL HOU for individual consumers in the commercial sector, DOE applied an additional variation to each building's weighted-average HOU when it conducted its LCC and PBP analysis. DOE applied a triangular distribution to each sampled GSL purchase with a minimum of 80% and a maximum of 120% of the HOU value for each building type, with the mean of each distribution corresponding to the respective building type's average daily hours of use.

8.2.7.2 Energy Prices

DOE used average annual electricity prices for all RECS reportable domains, as shown in Table 8.2.5. Using these data, DOE assigned an appropriate electricity price to each purchase made in the residential and commercial sector in the sample, depending on the purchase location.

DOE derived average energy prices from data that are published on EIA Form 861.[16] Those data include, for every utility that serves final consumers, annual electricity sales in kilowatt-hours, revenues from electricity sales, and number of customers in the residential and

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[s] In cases where the RBSAM included HOU data for multiple lamps in the same room, DOE used a simple average of those HOU for that specific room type. DOE also applied a weighting factor based on the number of lamps identified in each room for each of the metered houses.

commercial sectors. For each utility, DOE estimated the average electricity price for each sector by dividing the sector's revenues by the sector's sales volume. DOE then calculated annual electricity prices by weighting each utility's average price by the number of electricity consumers in each utility's service area within each reportable domain. DOE converted the electricity prices to 2014$ using the gross domestic product (GDP) price deflator published by the Bureau of Economic Analysis.[17]

Table 8.2.5 Average Electricity Prices by RECS Reportable Domain

RECS Reportable Domain	Residential Electricity Prices (2014$/kWh)	Commercial Electricity Prices (2014$/kWh)
01. CT, ME, NH, RI, VT	$0.167	$0.142
02. MA	$0.155	$0.147
03. NY	$0.193	$0.161
04. NJ	$0.164	$0.137
05. PA	$0.133	$0.110
06. IL	$0.118	$0.092
07. IN, OH	$0.116	$0.101
08. MI	$0.146	$0.117
09. WI	$0.136	$0.108
10. IA, MN, ND, SD	$0.113	$0.090
11. KS, NE	$0.111	$0.099
12. MO	$0.105	$0.088
13. VA	$0.114	$0.088
14. DE, DC, MD, WV	$0.126	$0.105
15. GA	$0.116	$0.103
16. NC, SC	$0.116	$0.095
17. FL	$0.118	$0.102
18. AL, KY, MS	$0.108	$0.103
19. TN	$0.104	$0.109
20. AR, LA, OK	$0.093	$0.083
21. TX	$0.114	$0.100
22. CO	$0.118	$0.098
23. ID, MT, UT, WY	$0.100	$0.084
24. AZ	$0.116	$0.103
25. NV, NM	$0.121	$0.097
26. CA	$0.159	$0.145
27. AK, HI, OR, WA	$0.124	$0.117
National	$0.130	$0.112

Source: EIA Form 861, Release Date for 2012: Oct. 29, 2013.

8.2.7.3 Energy Price Trends

To calculate operating costs over the lifetime of the product, DOE requires a forecast of energy prices over the lifetime of the product. To arrive at prices in future years, DOE multiplied the average 2012 electricity prices by the forecast of annual average price changes for each census division from EIA's 2014 Annual Energy Outlook (*AEO2014*).[2] For each purchase sampled, DOE applied the projection for the Census division in which the purchase was located.

DOE used the *AEO* Reference Case scenarios for the 9 Census divisions. The reference case is a business-as-usual estimate, given known market, demographic, and technological trends. DOE also included *AEO* High Growth and *AEO* Low Growth scenarios in the analysis. The high- and low-growth cases show the projected effects of alternative growth assumptions on energy markets. To estimate the trends after 2040, DOE followed past guidelines provided to the Federal Energy Management Program (FEMP) by EIA and used the average rate of change during 2025–2040.

Figure 8.2.3 and Figure 8.2.4 show residential and commercial electricity price trends based on the three *AEO2014* projections. For the LCC results presented in section 8.4, DOE used the energy price forecasts from the *AEO* reference case only. Appendix 8B of this TSD presents LCC results for the high- and low-economic growth scenarios.

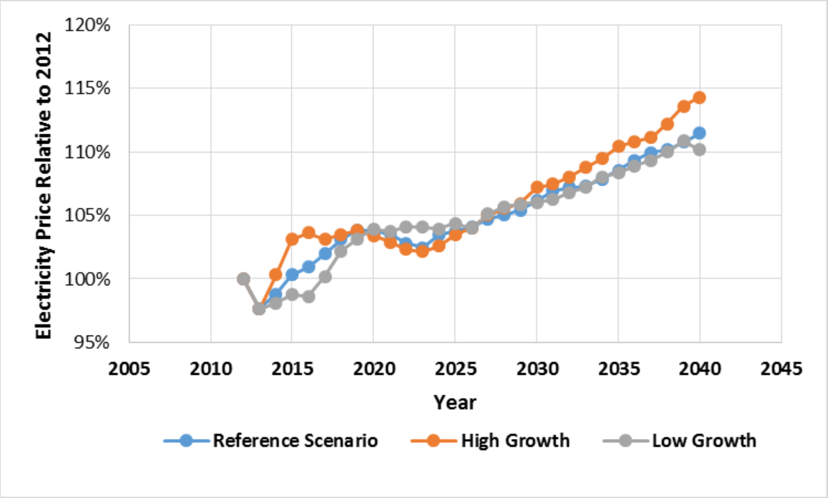

Figure 8.2.3 Trends in Residential Electricity Prices

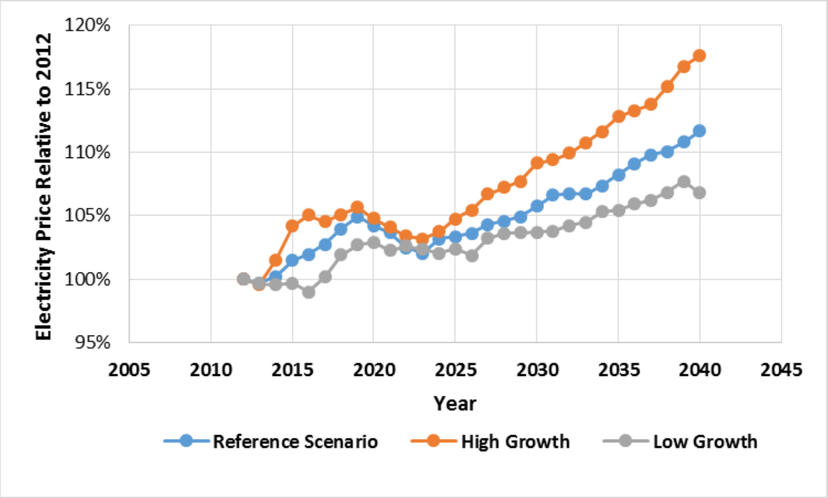

Figure 8.2.4 Trends in Commercial Electricity Prices

8.2.7.4 Lifetime

DOE used Weibull survival models to calculate the probability of survival as a function of lamp age for the residential and commercial sectors and for CFL and LED GSLs. In the analysis, DOE considered the lamp's rated lifetime (taken from the engineering analysis), sector-specific HOU distributions, and effects of on-time cycle length[t], which DOE assumed only applied to residential CFL GSLs. DOE assumed that on-time cycle length does not affect LED GSLs due to lack of data to suggest otherwise. Also, DOE assumed that short on-time cycle lengths in the commercial sector were uncommon based on the increased HOU in this sector (compared to the residential sector), indicating that the lifetime of CFL GSLs in the commercial sector is likely unaffected by on-off cycling. Finally, DOE assumed that GSL lifetimes are not affected by being installed on dimmers.

To generate the residential HOU distributions, DOE used data from RBSAM[15] and the RLEUCS.[6] For the commercial sector, DOE generated HOU distributions using data in the 2010 U.S. Lighting Market Characterization (LMC) and the 2003 CBECS[12] (see chapter 7 of this TSD and section 8.2.7.1 for details on the HOU methodology for the commercial sector). DOE also estimated the effect of on-time cycle length on the life of residential CFL GSLs using metering data from an American Council for an Energy-Efficient Economy (ACEEE) report[18] and a report presented to the California Public Utilities Commission (CPUC)[19] containing the measured lifetime of CFL GSLs as a function of on-time cycle length. DOE used all of this information to analyze the probability of survival as a function of GSL age for three scenarios: (1) "Rated Lifetime," (2) "Renovation-Driven Lifetime" (the reference scenario), and (3) "Early-Replacement Lifetime." In the "rated lifetime" scenario, consumers use GSLs for their full lifetime. The "renovation-driven lifetime" scenario takes into account lamp turnover during renovations or retrofits, while the "early-replacement lifetime" scenario assumes that the lifetime of LED GSLs is similar to that of consumer electronics (about 5 years).

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[t] On-time cycle length is the amount of time a GSL is switched on over one on-off cycle.

DOE modeled each of the three lifetime scenarios using Weibull survival functions, which take the form:

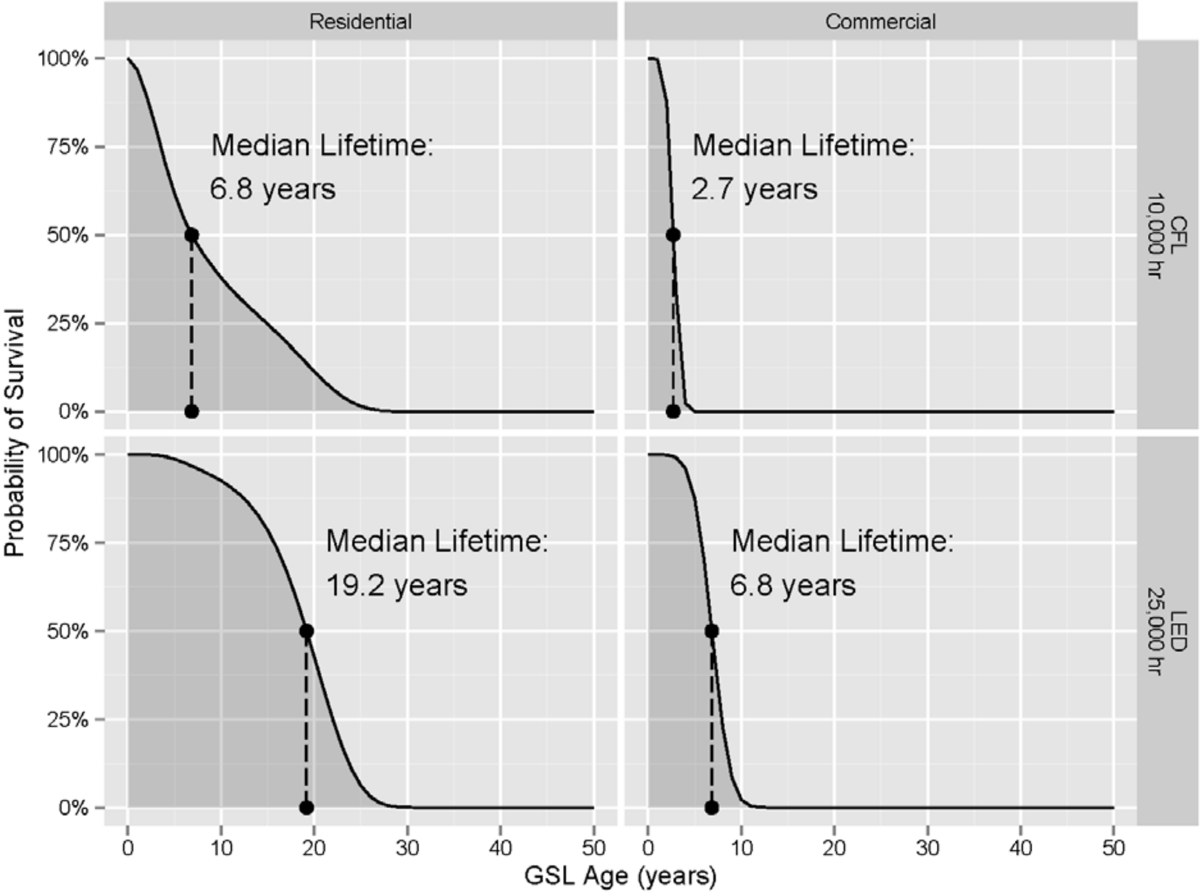
$$w_s(A) = \begin{cases} e^{-\left(\frac{A-d}{\lambda}\right)^k} & \text{for } A > d \\ 1 & \text{for } A \leq d \end{cases}$$

Eq. 8.13

Where:

$w_s(A)$ = the probability that the GSL survives to age A after its initial installation,
A = GSL age,
d = delay parameter, which allows for a delay before any failures occur,
λ = scale parameter, which would be the decay length in an exponential distribution, and
k = shape parameter, which determines the way in which the failure rate changes through time.

In the reference scenario, DOE truncated the resulting survival model from the "Rated Lifetime" scenario using a Weibull survival function with the parameters (λ, k, d) = (21.5, 6.0, 0.0). This Weibull function has a median of 20 years, which is intended to be a representative time scale for renovations or retrofits; furthermore, using scale and shape parameters of 21.5 and 6.0, respectively, results in a probability of survival of approximately 100 percent for the first 10 years, decreasing probability of survival from 10 to 30 years, and 0 percent probability of survival after 30 years for this model. Because this model is used to truncate the model from the "Rated Lifetime" scenario, the probability of survival in the reference scenario essentially equals the probability of survival from the "Rated Lifetime" scenario for the first 10 years, but then results in a decreased probability of survival as compared to the "Rated Lifetime" scenario for lamp ages greater than 10 years. The survival probability of CFL and LED GSLs rated at 10,000 hours and 25,000 hours, respectively, for the reference ("Renovation-Driven Lifetime") scenario as a function of lamp age for the residential and commercial sectors is shown in Figure 8.2.5.



Note: The dashed vertical lines represent the median lifetime for each sector and lamp technology. The survival probability for CFLs and LEDs correspond to a rated lifetime of 10,000 and 25,000 hours, respectively.

Figure 8.2.5 Probability of Survival as a Function of GSL Age (Reference Scenario)

Appendix 8E of this TSD presents the detailed methodology and results of DOE's GSL lifetime modeling for each scenario. DOE invites comment on the assumptions and methodology used to develop GSL lifetime distributions for each scenario.

8.2.7.5 Disposal Cost

When GSLs fail, some consumers choose to recycle the lamps, incurring a disposal cost. According to the Association of Lighting and Mercury Recyclers, 23% of fluorescent lamps (including linear fluorescent lamps) are recycled nationwide.[u] DOE performed market research on the recycling costs of compact fluorescents (CFLs[v]) and found that, on average, disposing of a CFL costs about $1 per lamp. DOE did not find any data for LED bulb disposal costs, and assumed that their disposal costs would be zero. DOE assumed that commercial sector consumers pay recycling costs for 10% of CFL failures. Because few residential sector consumers recycle lamps, and because residential consumers generally do not pay to recycle

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[u] http://www.almr.org/almr_project_web.html (last accessed March 11, 2014).

[v] Based on available vendors on the EPA website: http://www2.epa.gov/cfl/recycling-and-disposal-after-cfl-burns-out (last accessed, March 11, 2014).

lamps, DOE did not apply disposal costs to this sector. DOE requests comment and relevant data on the disposal cost assumptions for CFLs and LEDs.

8.2.7.6 Residual Value

The residual value represents the present value of surviving GSLs at the end of the LCC analysis period. As discussed earlier, the LCC analysis period is the lifetime of the shortest-lived GSL in each product class. To compute the residual value, DOE first considered the annualized first cost (AFC) of a GSL, which includes purchase price with sales tax. The AFC is the size of a single payment in a series of fixed annual payments over the L-year life of the GSL, where the series of payments has a present value equal to the first cost of the GSL. For example, if a GSL has a first cost of \$8, and a lifetime of 20 years, its AFC is \$0.64, which means, that an expense of \$8 in the present has the same present value as an annual expense of \$0.64 over the next 20 years. The AFC can be expressed as follows:

$$AFC_L = \frac{FC}{\sum_{y=1}^{L}\frac{1}{(1+r)^y}}$$

Eq. 8.14

Where:

AFC_L= annualized first cost in dollars of a GSL with a lifetime of L years,
FC = first cost in dollars of the GSL, and
r = discount rate.

To compute the residual value of a GSL with a lifetime longer than the LCC analysis period, DOE considered the first cost of purchasing a replacement GSL at the end of the analysis period, $FC(y_{end})$, which can be annualized to yield $AFC(y_{end})$ according to Eq. 8.14. The present value of postponing this purchase until the end of the GSL's lifetime is equal to the present value of a series of fixed payments of $AFC(y_{end})$ over the remaining life of the GSL. In this preliminary analysis, DOE took the residual value of a surviving GSL to be equal to the value of this postponed cost. Note that the price of a GSL purchased at the end of the LCC analysis period may be lower than the price of a GSL purchased at the assumed compliance year, due to price learning.

The residual value can then be expressed by the following equation:

$$RV = AFC_L(y_{end}) \times \sum_{y=y_{end}+1}^{L} \frac{1}{(1+r)^y}$$

Eq. 8.15

Where:

$AFC_L(y_{end})$ = the annualized first cost of the longer lived GSL purchased in year y_{end},
y_{end} = the last year of the LCC analysis period, and
L = the lifetime of the longer-lived GSL.

8.2.7.7 Discount Rates

The discount rate is the rate at which future expenditures and savings are discounted to establish their present value. DOE estimates discount rates separately for residential and commercial consumers. For residential consumers, DOE calculates discount rates as the weighted average real interest rate across consumer debt and equity holdings. For commercial consumers, DOE calculates commercial discount rates as the weighted average cost of capital (WACC), using the Capital Asset Pricing Model (CAPM).

Discount Rates for Residential Consumers.

The discount rate is the rate at which future savings and expenditures are discounted to establish their present value. DOE uses publicly available data (the Federal Reserve Board's *Survey of Consumer Finances* (SCF)) to estimate a consumer's opportunity cost of funds related to appliance energy cost savings and maintenance costs. The discount rate value is applied in the LCC to future year energy cost savings and non-energy operations and maintenance costs in order to present the estimated net LCC and LCC savings. DOE notes that the discount rate used in the LCC analysis is distinct from an implicit discount rate, as it is not used to model consumer purchase decisions. The opportunity cost of funds in this case may include interest payments on debt and interest returns on assets.

DOE estimates separate discount rate distributions for six income groups, divided based on income percentile as reported in the Federal Reserve Board's SCF.[20] This disaggregation reflects the fact that low and high income consumers tend to have substantially different shares of debt and asset types and tend to face different rates on debts and assets. Summaries of shares and rates presented in this chapter are averages across the entire population.

Table 8.2.6 Definitions of Income Groups

Income Group	Percentile of Income
1	1st to 20th
2	21st to 40th
3	41st to 60th
4	61st to 80th
5	81st to 90th
6	91th to 99th

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, and 2010.

Shares of Debt and Asset Classes

DOE's approach involved identifying all relevant household debt or asset classes in order to approximate a consumer's opportunity cost of funds related to appliance energy cost savings and maintenance costs. The approach assumes that, in the long term, consumers are likely to draw from or add to their collection of debt and asset holdings approximately in proportion to their current holdings when future expenditures are required or future savings accumulate. DOE has included several previously excluded debt types (*i.e.,* vehicle and education loans, mortgages, all forms of home equity loan) in order to better account for all of the options available to consumers.

The average share of total debt plus equity and the associated rate of each asset and debt type are used to calculate a weighted average discount rate for each SCF household (Table 8.2.7). The household-level discount rates are then aggregated to form discount rate distributions for each of the six income groups. Note that previously DOE performed aggregation of asset and debt types over households by summing the dollar value across all households and then calculating shares. Weighting by dollar value gave disproportionate influence to the asset and debt shares and rates of higher income consumers. DOE has shifted to a household-level weighting to more accurately reflect the average consumer in each income group.

DOE estimated the average percentage shares of the various types of debt and equity using data from the Federal Reserve Board's SCF for 1995, 1998, 2001, 2004, 2007, and 2010.[w] DOE derived the household-weighted mean percentages of each source of financing throughout the 5 years surveyed. DOE posits that these long-term averages are most appropriate to use in its analysis.

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[w] Note that two older versions of the SCF are also available (1989 and 1992); these surveys are not used in this analysis, because they do not provide all of the necessary types of data (*e.g.*, credit card interest rates, etc). DOE feels that the 15-year span covered by the six surveys included is sufficiently representative of recent debt and equity shares and interest rates.

Table 8.2.7 Types of Household Debt and Equity by Percentage Shares (%)

Type of Debt or Equity	Income Group					
	1	2	3	4	5	6
Debt:						
Mortgage	18.9%	24.1%	33.1%	38.1%	39.3%	25.0%
Home equity loan	3.1%	3.3%	2.6%	3.6%	4.5%	7.2%
Credit card	15.3%	13.0%	11.8%	8.7%	6.0%	2.7%
Other installment loan	25.1%	20.6%	17.3%	13.2%	9.6%	4.7%
Other residential loan	0.7%	0.6%	0.6%	0.7%	1.0%	1.2%
Other line of credit	1.6%	1.5%	1.3%	1.5%	2.1%	1.8%
Equity:						
Savings account	18.5%	16.0%	12.7%	10.6%	10.4%	7.9%
Money market account	3.6%	4.5%	4.0%	4.5%	5.0%	8.6%
Certificate of deposit	7.0%	7.8%	5.5%	5.0%	4.4%	4.2%
Savings bond	1.8%	1.7%	1.9%	2.2%	1.7%	1.1%
Bonds	0.2%	0.4%	0.5%	0.7%	0.8%	3.8%
Stocks	2.3%	3.1%	4.4%	5.7%	7.6%	15.8%
Mutual funds	2.1%	3.5%	4.3%	5.7%	7.6%	15.9%
Total	100.0	100.0	100.0	100.0	100.0	100.0

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, and 2010.

Rates for Types of Debt

DOE estimated interest rates associated with each type of debt. The source for interest rates for mortgages, loans, credit cards, and lines of credit was the Federal Reserve Board's SCF for 1995, 1998, 2001, 2004, 2007, and 2010, which associates an interest rate with each type of debt for each household in the survey.

In calculating effective interest rates for home equity loans and mortgages, DOE accounted for the fact that interest on both such loans is tax deductible (Table 8.2.8). This rate corresponds to the interest rate after deduction of mortgage interest for income tax purposes and after adjusting for inflation (using the Fisher formula).[x] For example, a 6-percent nominal mortgage rate has an effective nominal rate of 4.5 percent for a household at the 25-percent marginal tax rate. When adjusted for an inflation rate of 2 percent, the effective real rate becomes 2.45 percent.

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[x] Fisher formula is given by: Real Interest Rate = [(1 + Nominal Interest Rate) / (1 + Inflation Rate)] – 1.

Table 8.2.8 Data Used to Calculate Real Effective Mortgage Rates

Year	Mortgage Interest Rates in Selected Years (*%)*			
	Average Nominal Interest Rate	Inflation Rate[21]	Applicable Marginal Tax Rate[22]	Average Real Effective Interest Rate
1995	8.2	2.83	24.2	3.3
1998	7.9	1.56	25.0	4.3
2001	7.6	2.85	24.2	2.8
2004	6.2	2.66	20.9	2.2
2007	6.3	2.85	20.6	2.1
2010	5.7	1.64	20.0	2.9

Table 8.2.9 shows the household-weighted average effective real rates for different types of household debt. Because the interest rates for each type of household debt reflect economic conditions throughout numerous years and various phases of economic growth and recession, they are expected to be representative of rates in effect in 2020.

Table 8.2.9 Average Real Effective Interest Rates for Household Debt

Type of Debt	Income Group					
	1	2	3	4	5	6
Mortgage	6.6%	6.2%	6.1%	5.2%	5.0%	4.0%
Home equity loan	7.0%	6.9%	6.7%	5.9%	5.7%	4.3%
Credit card	15.2%	15.0%	14.5%	14.2%	14.0%	14.5%
Other installment loan	10.8%	10.3%	9.9%	9.4%	8.7%	8.6%
Other residential loan	9.8%	10.2%	8.9%	8.2%	7.7%	7.4%
Other line of credit	9.1%	10.9%	9.6%	8.8%	7.4%	6.1%

Sources: Federal Reserve Board. *Survey of Consumer Finances (SCF)* for 1995, 1998, 2001, 2004, 2007, and 2010.

Rates for Types of Assets

No similar rate data are available from the SCF for classes of assets, so DOE derived asset interest rates from various sources of national historical data (1983-2013). The interest rates associated with certificates of deposit,[23] savings bonds,[24] and bonds (AAA corporate bonds)[25] were collected from Federal Reserve Board time-series data. Rates on money market accounts came from Cost of Savings Index data.[26] Rates on savings accounts were estimated as one half of the rate for money market accounts, based on recent differentials between the return to each of these assets. The rates for stocks are the annual returns on the Standard and Poor's.[27] Rates for mutual funds are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year. DOE assumed rates on checking accounts to be zero.

DOE adjusted the nominal rates to real rates using the annual inflation rate for each year. Average nominal and real interest rates for the classes of household assets are listed in Table 8.2.10. Because the interest and return rates for each type of asset reflect economic conditions throughout numerous years, they are expected to be representative of rates that may be in effect in 2019. For each type, DOE developed a distribution of rates, as shown in appendix 8C.

Table 8.2.10 Average Nominal and Real Interest Rates for Household Equity

Type of Equity	Average Real Rate %
Savings accounts	1.0
Money market accounts	1.9
Certificates of deposit	1.9
Savings bonds	3.4
Bonds	4.2
Stocks	9.4
Mutual funds	7.4

Discount Rate Calculation and Summary

Using the asset and debt data discussed previously, DOE calculated discount rate distributions for each income group as follows. First, DOE calculated the discount rate for each consumer in each of the six versions of the SCF, using the following formula:

$$DR_i = \sum_j Share_{i,j} \times Rate_{i,j}$$

Eq. 8.16

Where:

DR_i = discount rate for consumer *i*,
$Share_{i,j}$ = share of asset or debt type *j* for consumer *i*, and
$Rate_{i,j}$ = real interest rate or rate of return of asset or debt type *j* for consumer *i*.

The rate for each debt type is drawn from the SCF data for each household. The rate for each asset type is drawn from the distributions described previously.

Once the real discount rate was estimated for each consumer, DOE compiled the distribution of discount rates in each survey by income group by calculating the proportion of consumers with discount rates in bins of 1 percent increments, ranging from 0-1 percent to greater than 30 percent. Giving equal weight to each survey, DOE compiled the six-survey distribution of discount rates.

Table 8.2.11 presents the average real effective discount rate and its standard deviation for each of the six income groups. To account for variation among households, DOE sampled a rate for each RECS household from the distributions for the appropriate income group. (RECS provides household income data.) Appendix 8C presents the full probability distributions for each income group that DOE used in the LCC and PBP analysis.

Table 8.2.11 Average Real Effective Discount

Income Group	Discount Rate (%)
1	4.85
2	5.12
3	4.75
4	4.04
5	3.80
6	3.57
Overall Average	4.49

Discount Rates for Commercial Sector Consumers.

The commercial discount rate is the rate at which future operating costs are discounted to establish their present value in the LCC analysis. The discount rate value is applied in the LCC to future year energy costs and non-energy operations and maintenance costs to calculate the estimated net life-cycle cost of products of various efficiency levels and life-cycle cost savings as compared to the baseline for a representative sample of commercial end users.

DOE's method views the purchase of a higher efficiency appliance as an investment that yields a stream of energy cost savings. DOE derived the discount rates for the LCC analysis by estimating the cost of capital for companies that purchase GSLs. The weighted average cost of capital (WACC) is commonly used to estimate the present value of cash flows to be derived from a typical company project or investment. Most companies use both debt and equity capital to fund investments, so their cost of capital is the weighted average of the cost to the firm of equity and debt financing, as estimated from financial data for publicly traded firms in the sectors that purchase GSLs.[28]

Damodaran Online, a widely used source of information about company debt and equity financing, was used as the primary source of data for this analysis.[29] Companies included in the Damondaran Online database were assigned to the aggregate categories listed below:

- Office
- Retail
- Lodging
- Education
- Food Services
- Other

DOE estimated the cost of equity using the CAPM.[30] The CAPM assumes that the cost of equity (k_e) for a particular company is proportional to the systematic risk faced by that company, where high risk is associated with a high cost of equity and low risk is associated with a low cost of equity. The systematic risk facing a firm is determined by several variables: the risk coefficient of the firm (β), the expected return on risk-free assets (R_f), and the equity risk premium (ERP). The risk coefficient of the firm indicates the risk associated with that firm relative to the price variability in the stock market. The expected return on risk-free assets is defined by the yield on long-term government bonds. The ERP represents the difference between the expected stock market return and the risk-free rate. The cost of equity financing is estimated using the following equation, where the variables are defined as above:

$$k_e = R_f + \left(\beta \times ERP\right)$$

Eq. 8.17

Where:

k_e = cost of equity,
R_f = expected return on risk-free assets,
β = risk coefficient of the firm, and
ERP = equity risk premium.

Several parameters of the cost of capital equations can vary substantially over time; therefore, the estimates can vary with the time period over which data is selected and the technical details of the data averaging method. For guidance on the time period for selecting and averaging data for key parameters and the averaging method, DOE used Federal Reserve methodologies for calculating these parameters. In its use of the CAPM, the Federal Reserve uses a forty-year period for calculating discount rate averages, utilizes the gross domestic product price deflator for estimating inflation, and considers the best method for determining the risk-free rate as one where "the time horizon of the investor is matched with the term of the risk-free security."[31]

By taking a forty-year geometric average of Federal Reserve data on annual nominal returns for 10-year Treasury bills, DOE found for this analysis the following risk-free rates for 2011-2013 (Table 8.2.12).[32] DOE also estimated the ERP by calculating the difference between risk-free rates and stock market return for the same time period.[33]

Table 8.2.12 Risk-Free Rate and Equity Risk Premium, 2010-2012

Year	Risk-free rate (%)	ERP (%)
2011	6.61%	2.94%
2012	6.41%	3.99%
2013	6.24%	5.30%

The cost of debt financing (k_d) is the interest rate paid on money borrowed by a company. The cost of debt is estimated by adding a risk adjustment factor (R_a) to the risk-free rate. This risk adjustment factor depends on the variability of stock returns represented by standard deviations in stock prices. So for firm *i*, the cost of debt financing is:

$$k_{di} = R_f + R_{ai}$$

Eq. 8.18

Where:

k_d = cost of debt financing for firm, *i*,
R_f = expected return on risk-free assets, and
R_{ai} = risk adjustment factor to risk-free rate for firm, *i*.

DOE estimates the WACC using the following equation:

$$WACC = k_e \times w_e + k_d \times w_d$$

Eq. 8.19

Where:

$WACC$ = weighted average cost of capital,
w_e = proportion of equity financing, and
w_d = proportion of debt financing.

By adjusting for the influence of inflation, DOE estimates the real WACC, or discount rate, for each company. DOE then aggregates the company real WACC to estimate the discount rate for each of the ownership types in the GSLs analysis. These values are presented in Table 8.2.13. While WACC values for any category may trend higher or lower over substantial periods of time, these values represent a private sector cost of capital that is averaged over major business cycles.

Table 8.2.13 Weighted Average Cost of Capital for Analyzed Sectors

Sector	Standard Deviation	Market Share	Mean Discount Rate
Office	1.3%	36%	5.1%
Retail	1.1%	24%	5.0%
Lodging	1.7%	14%	6.0%
Education	2.2%	7%	2.5%
Food Service	0.9%	5%	4.9%
Other	1.1%	9%	5.0%
		Average Discount Rate:	**5.0%**

Source: Damodaran Online *Data Page: Costs of Capital by Industry Sector,* 2011, 2012, 2013.

8.3 PAYBACK PERIOD INPUTS

The payback period is the amount of time it takes the consumer to recover the estimated higher purchase expense of more energy-efficient products as a result of lower operating costs. As is typical in DOE rulemaking analyses, DOE has used *simple payback period* as the metric.

Simple PBP does not take into account changes in operating expense over time or the time value of money; the calculation is done at an effective discount rate of zero percent.

The equation for PBP is:

$$PBP = \frac{\Delta IC}{\Delta OC}$$

Eq. 8.20

Where:

ΔIC = difference in the total installed cost between the more energy-efficient design and the baseline design, and
ΔOC = difference in annual operating expenses between the more energy-efficient design and the baseline design.

Payback periods are expressed in years. Payback periods greater than the life of the product indicate that the increased total installed cost is not recovered with the reduced operating expenses.

8.4 LIFE-CYCLE COST AND PAYBACK PERIOD RESULTS

This section presents the results of the LCC and PBP analysis for GSLs. As discussed in section 8.1.1, DOE's approach to the LCC analysis relied on developing samples of GSL consumers. DOE also used probability distributions to characterize the uncertainty in many of the inputs to the analysis. DOE used Monte Carlo simulation to perform the LCC calculations for the consumers in the sample.

For each set of sample consumers in each product class, DOE calculated the average installed cost, first year operating cost, lifetime operating cost, and LCC for each CSL. The averages are calculated for each CSL assuming that all of the sample consumers purchase a product at that CSL. This allows the installation costs, operating costs, and LCCs for each CSL to be compared under the same conditions, across a variety of sample consumers. DOE used these average values for installed cost and first year operating cost to calculate the PBP for each CSL, relative to the baseline product.

DOE also calculated the LCC savings of a standard set at each CSL. For the reference scenario, DOE used a "market-transformation" approach to calculate the LCC savings: this is the LCC savings that result when a standard is set at a given CSL and the efficiency distribution of products in the base case is transformed into a different efficiency distribution in the standards case. In both the base case and the standards case, the efficiency distributions have been calculated in the shipments analysis. DOE took a market transformation approach when calculating LCC savings in order to more accurately reflect the impact of a potential standard on consumers. This approach is intended to account for those consumers who, under a particular standard, would select more efficient (and sometimes less expensive) lamp options than the lamps corresponding to that standard level, as estimated by the consumer-choice model in chapter 9 of this TSD.

DOE first assigned products to consumers using the distribution of energy efficiencies in the base case. Then, for each standards case analyzed, DOE re-assigned products to consumers using the distribution of energy efficiencies for the standards case. When re-assigning products to consumers, DOE assumed that consumers would purchase a GSL at least as efficient as the GSL they would have purchased in the base-case. DOE assigned an LCC savings value of zero to all consumers who in both the base-case and standards-case would purchase a GSL of equivalent efficiency.

As an alternative scenario, DOE also used a "roll-up" approach to calculate the LCC savings relative to the LCC that each sample consumer would experience in the base case. Like the market-transformation approach, DOE assigned products to consumers by using the distribution of energy efficiencies for the base case calculated by the shipments analysis. However, in the "roll-up" approach, DOE assumed that all consumers who, in the base case, would purchase a GSL that was less efficient than the standard level being analyzed, would purchase a GSL at the minimum efficiency level allowed in the standards case. DOE also assumed that all consumers who would purchase a GSL that was as efficient as, or more efficient than, the standard level being analyzed in the base case, would purchase the same GSL in the standards case (*i.e.,* at the same CSL as in the base case). Therefore, DOE assigned an LCC savings value of zero to all consumers, who in the base case, would purchase a GSL that was as efficient as, or more efficient than, the CSL being analyzed.

Both the "market transformation" and "roll-up" approach to calculating LCC savings take into account the base case efficiency distribution, For this reason, in both cases, the average LCC savings are not equal to the difference between the LCC of a specific CSL and the LCC of the least efficient product available on the market.

In both approaches, DOE calculated the share of consumers receiving a net LCC cost for each CSL. DOE considered a consumer to receive a net LCC cost if the customer had negative LCC savings at the CSL being analyzed.

LCC and PBP calculations were performed 10,000 times on the sample of consumers established for each product class. Each LCC and PBP calculation was performed on a single consumer selected from the sample in each sector. A consumer was selected based on how representative that particular consumer was of other consumers in the distribution (i.e., selection weight), as discussed in section 8.2.3. Each LCC and PBP calculation also sampled from the probability distributions that DOE developed to characterize many of the inputs to the analysis.

The following sections present the key LCC and PBP findings, as well as figures that illustrate the range of LCC and PBP effects among sample consumers for both the market-transformation approach (section 8.4.1) and roll-up approach (section 8.4.2). Because the lighting market is in the process of undergoing significant transformation, DOE also presents LCC and PBP results for 2025, five years after the assumed compliance year, in section 8.4.3 using the market-transformation approach.

8.4.1 "Market-Transformation" Approach Results

8.4.1.1 Integrated Low-Lumen GSL Results

Table 8.4.1 and Table 8.4.2 show the LCC and PBP results for all efficiency levels considered for Integrated Low-Lumen GSLs.

Table 8.4.1 Average LCC and PBP Results by Candidate Standard Level for Integrated Low-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	6.2	1.6	5.6	11.8	---	8.8
1	4.0	1.5	5.2	8.8	0	9.8
2	34.9	1.3	4.6	23.1	99.6	17.9
3	22.2	1.2	4.2	16.0	40.5	17.9
4	7.5	1.1	3.8	8.5	2.6	17.9
5	7.2	1.0	3.6	8.1	1.7	17.9
Commercial Sector						
0	7.0	6.9	17.7	24.8	---	2.2
1	4.4	6.4	16.5	20.2	0	2.8
2	45.7	6.0	15.3	37.9	40.0	6.3
3	29.1	5.5	14.0	28.4	15.3	6.3
4	7.7	5.0	12.8	17.2	0.4	6.3
5	7.3	4.8	12.2	16.4	0.2	6.3

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

DOE notes that, in the residential sector, the ratio of the lifetime operating costs to the first year's operating costs presented in Table 8.4.1 (and all subsequent results tables presenting first year and lifetime operating costs) is roughly 3.5, which is much smaller than the average lifetime values presented in the table. There are several reasons for this non-intuitive result.

First, as discussed earlier, DOE computed the LCC (and thus the lifetime operating cost) for each product class over the shortest-lived lamp, which, for the reference scenario, is the baseline lamp.[y] Therefore, the lifetimes of non-baseline lamps are not relevant to the lifetime

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[y] In the "early replacement lifetime" scenario, where LEDs are replaced every 5 years, the shortest-lived lamps in the residential sector are LEDs (CSL 2 through 5). See Appendix 8E for details on the "early replacement lifetime" scenario and appendix 8B for LCC and PBP results for this scenario.

operating cost values in Table 8.4.1. Nevertheless, the ratio of lifetime to first-year operating costs is still significantly lower than the average lifetime presented for the baseline lamp in the residential sector. This is partly to be expected, because the lifetime operating costs are discounted, and some residential consumers have very high discount rates (see appendix 8C of this TSD). Discounting alone is not sufficient, however, to explain the difference of more than a factor of two between the average lifetime and the lifetime-to-first-year operating cost ratio. The most important reason for this difference is that lamps' lifetimes are correlated with their first-year operating costs, via the HOU, and the asymmetrical nature of the HOU distribution can lead to unexpected results when looking at average values. As discussed in section 8.2.7.4 (lifetime), a GSL with high HOU will have a short lifetime, while a GSL with low HOU, will have a long lifetime. Conversely, a GSL with high operating hours will have a high first-year operating cost, while a GSL with low HOU will have a low first-year operating cost. The HOU distribution used in this analysis is highly asymmetrical (see appendix 8E of this preliminary TSD); therefore, averages of values that depend on the HOU will not necessarily correspond to typical values. For example, about 24% of baseline GSLs in this analysis have a lifetime of 3 years or less, despite the average lifetime of 8.8 years. Because the first-year operating cost is directly proportional to HOU, while the lifetime is inversely proportional to HOU, the asymmetry of the HOU distribution will tend to skew the average values of those quantities in opposite directions.

Table 8.4.2 Average LCC Savings for Integrated Low-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	0%	0.0
2	27%	-0.1
3	27%	0.0
4	25%	0.3
5	22%	0.5
Commercial Sector		
0	0.0%	0.0
1	0.0%	0.0
2	1.1%	1.7
3	1.1%	1.7
4	0.8%	1.7
5	0.3%	2.1

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

Figure 8.4.1and Figure 8.4.2 show the range of LCC savings for all CSLs in the residential and commercial sector for Integrated Low-Lumen GSLs. The top and the bottom of the box indicate the 75th and 25th percentiles, respectively. The solid bar indicates the median; 50 percent of the households have LCC savings above this value. The horizontal lines above and below each box indicate the 95th and 5th percentiles, respectively.[z] The red dot shows the average LCC savings at the CSL. A negative average LCC savings means that the average LCC with the standard is greater than what it is without the standard.

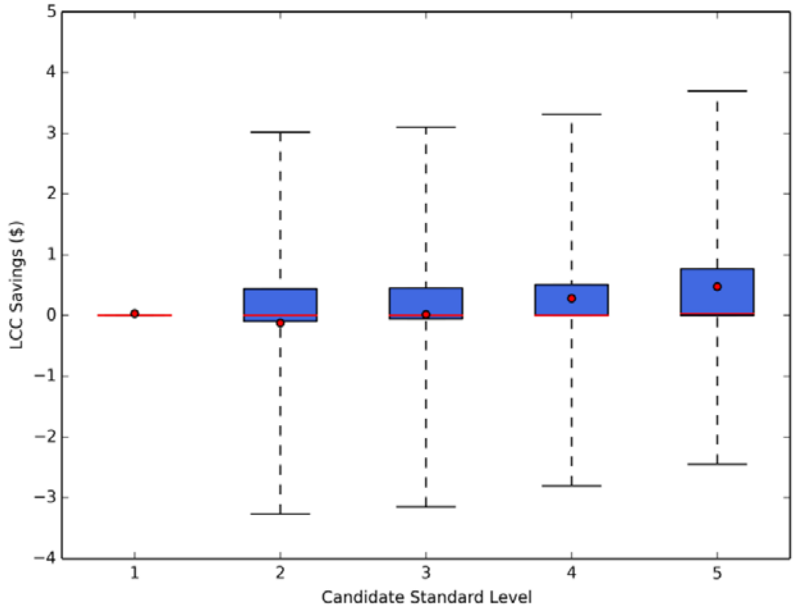

Figure 8.4.1 Range of LCC Savings in Residential Sector for Integrated Low-Lumen GSLs

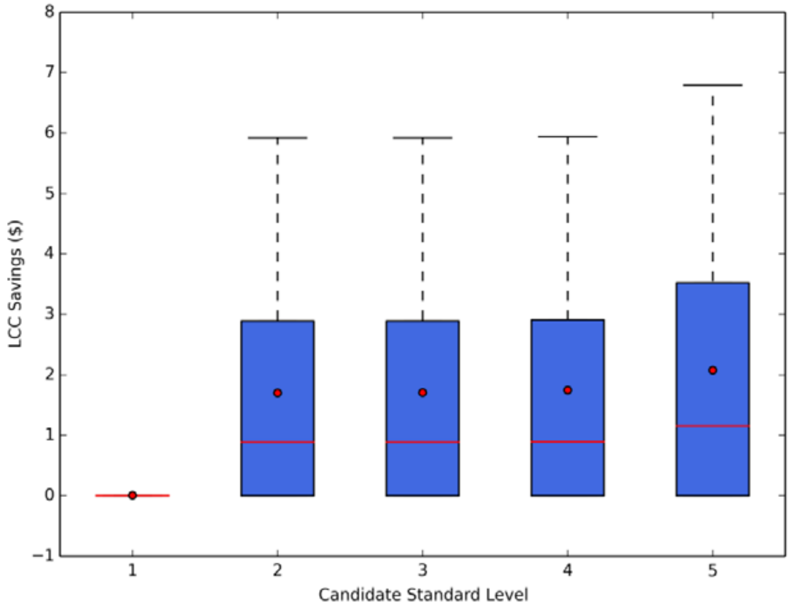

Figure 8.4.2 Range of LCC Savings in Commercial Sector for Integrated Low-Lumen GSLs

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[z] Note that in Figure 8.4.2 (and other subsequent box plot figures) the horizontal line indicating the 5th percentile is overwritten by the lowest part of the box.

Figure 8.4.3 and Figure 8.4.4 show the distribution of LCC impacts for CSL 5 in the residential sector and commercial sector, respectively, for Integrated Low-Lumen GSLs. The figures are presented as frequency charts that show the distribution of LCC impacts with their corresponding probability of occurrence. DOE generated the figures for the distributions from a Monte Carlo simulation run based on 10,000 samples. DOE presents the distribution of impacts specifically at this CSL because this is the case with the highest LCC savings.

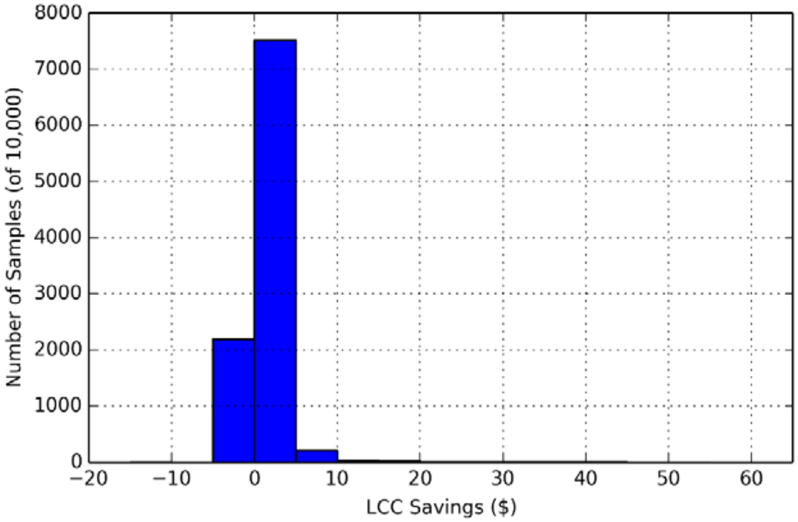

Figure 8.4.3 LCC Savings Distribution in Residential Sector for Integrated Low-Lumen GSLs at CSL 5

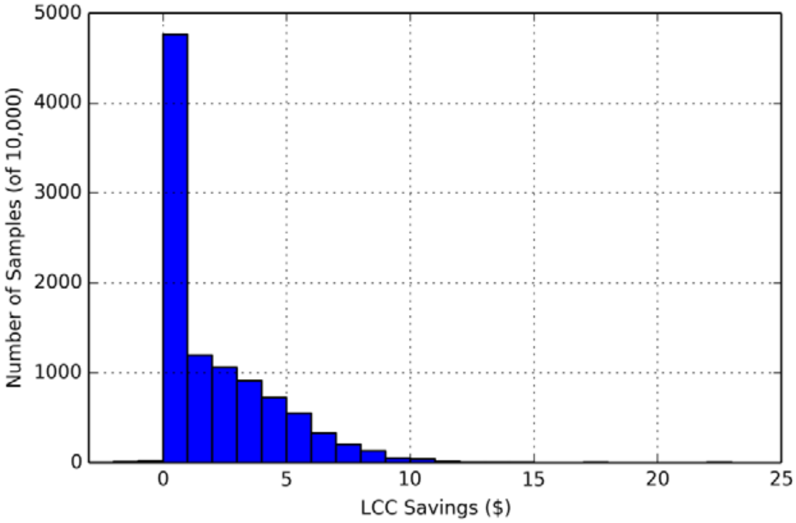

Figure 8.4.4 LCC Savings Distribution in Commercial Sector for Integrated Low-Lumen GSLs at CSL 5

8.4.1.2 Integrated High-Lumen GSL Results

Table 8.4.3 and Table 8.4.4 present the key findings for Integrated High-Lumen GSLs in both the commercial and residential sectors. Figure 8.4.5 and Figure 8.4.6 show the range of

LCC savings for all CSLs in the residential and commercial sector for Integrated High-Lumen GSLs.

Table 8.4.3 Average LCC and PBP Results by Candidate Standard Level for Integrated High-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	9.7	3.6	12.8	22.5	---	8.8
1	10.1	3.4	12.0	22.1	1.5	8.8
2	10.8	3.3	11.6	21.3	3.1	9.8
Commercial Sector						
0	9.7	12.4	31.6	41.5	---	2.2
1	10.1	11.6	29.7	39.8	0.4	2.2
2	10.8	11.2	28.7	37.6	0.9	2.8

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8.4.4 Average LCC Savings for Integrated High-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	6%	0.2
2	13%	0.5
Commercial Sector		
0	0.0%	0.0
1	0.2%	0.5
2	1.2%	1.7

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

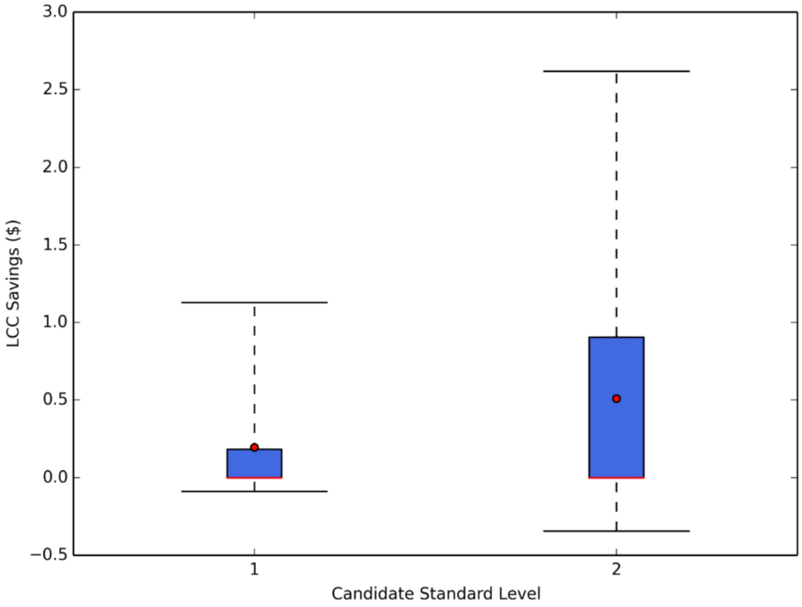

Figure 8.4.5 Range of LCC Savings in Residential Sector for Integrated High-Lumen GSLs

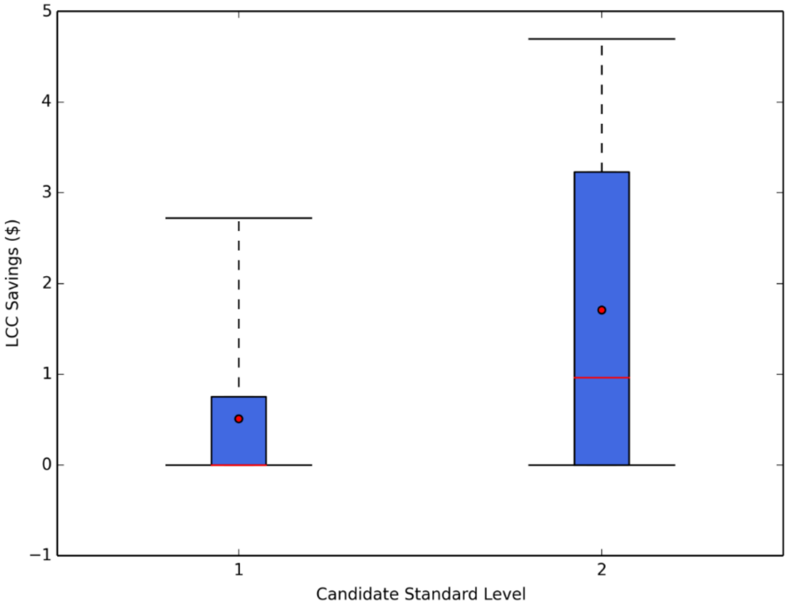

Figure 8.4.6 Range of LCC Savings in Residential Sector for Integrated High-Lumen GSLs

Figure 8.4.7 and Figure 8.4.8 show the distribution of LCC impacts for CSL 2 in the residential sector and commercial sector, respectively, for Integrated High-Lumen GSLs. DOE presents the distribution of impacts specifically at this CSL because this is the case with the highest LCC savings.

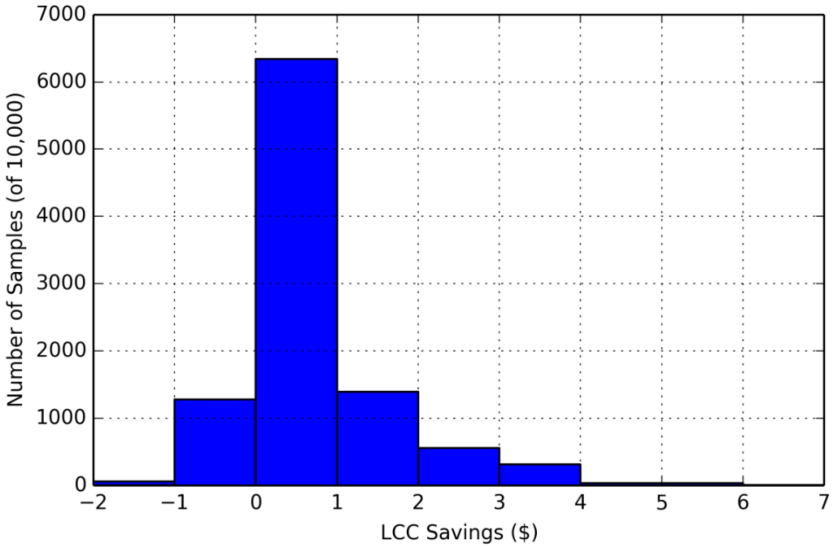

Figure 8.4.7 **LCC Savings Distribution in Residential Sector for Integrated Low-Lumen GSLs at CSL 2**

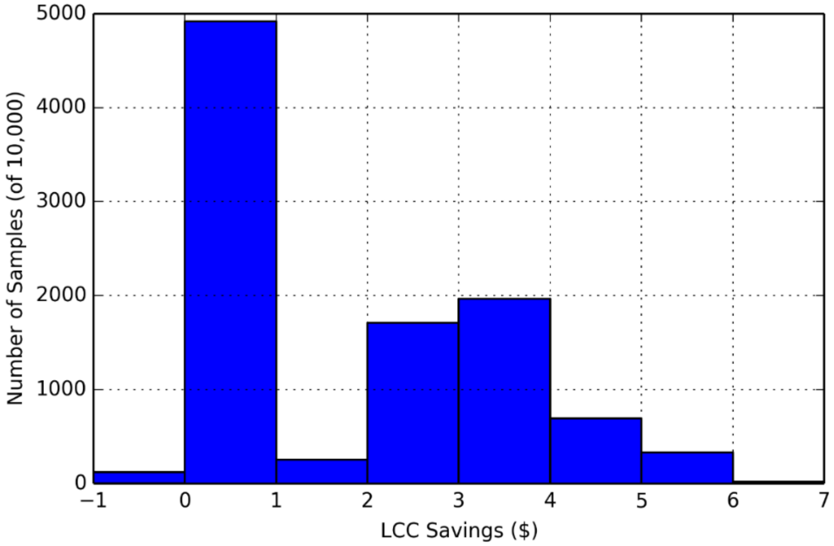

Figure 8.4.8 **LCC Savings Distribution in Commercial Sector for Integrated Low-Lumen GSLs at CSL 2**

8.4.1.3 Non-Integrated GSL Results

Table 8.4.5 and Table 8.4.6 show the LCC and PBP results for all efficiency levels considered for Non-Integrated GSLs. Figure 8.4.9 shows the range of LCC savings for all CSLs in the residential and commercial sector for Non-Integrated GSLs.

Table 8.4.5 Average LCC and PBP Results by Candidate Standard Level for Non-Integrated GSLs

CSL	Average Costs 2014$				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	13.2	3.4	11.9	25.2	---	8.8
1	14.2	3.4	11.9	22.8	N/A	11.6
	15.7	2.8	9.7	21.1	4.0	12.5
Commercial Sector						
0	13.2	11.6	29.6	42.9	---	2.2
1	14.2	11.6	29.6	39.0	N/A	4.1
	15.7	9.4	24.1	33.3	1.2	5.0

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8.4.6 Average LCC Savings for Non-Integrated GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	12%	1.6
Commercial Sector		
0	0.0%	0.0
1	5.4%	2.6

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

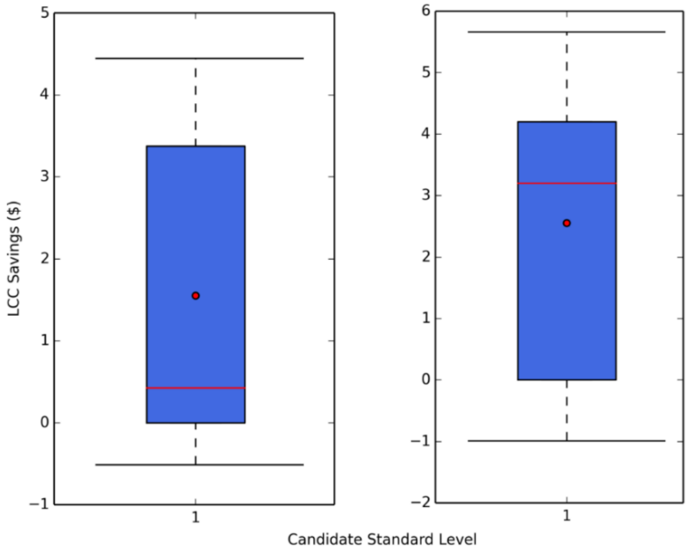

Figure 8.4.9 Range of LCC Savings in Residential Sector (left) and Commercial Sector (right) at CSL 1 for Non-Integrated GSLs

8.4.2 “Roll-up” Approach Results

8.4.2.1 Integrated Low-Lumen GSL Results

Table 8.4.7 and Table 8.4.8 show the LCC and PBP results for all efficiency levels considered for Integrated Low-Lumen GSLs.

Table 8.4.7 Average LCC and PBP Results by Candidate Standard Level for Integrated Low-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	6.2	1.6	5.6	11.8	---	8.8
1	4.0	1.5	5.2	8.8	0	9.8
2	34.9	1.3	4.6	23.1	99.6	17.9
3	22.2	1.2	4.2	16.0	40.5	17.9
4	7.5	1.1	3.8	8.5	2.6	17.9
5	7.2	1.0	3.6	8.1	1.7	17.9
Commercial Sector						
0	7.0	6.9	17.7	24.8	---	2.2
1	4.4	6.4	16.5	20.2	0	2.8
2	45.7	6.0	15.3	37.9	40.0	6.3
3	29.1	5.5	14.0	28.4	15.3	6.3
4	7.7	5.0	12.8	17.2	0.4	6.3
5	7.3	4.8	12.2	16.4	0.2	6.3

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8.4.8 Average LCC Savings for Integrated Low-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	**Average Savings (2014$)**
Residential Sector		
0	0%	0.0
1	0%	0.0
2	49%	-7.1
3	46%	-3.6
4	22%	0.3
5	19%	0.6
Commercial Sector		
0	0.0%	0.0
1	0.0%	0.0
2	53.9%	-9.6
3	53.9%	-4.4
4	0.5%	1.6
5	0.2%	2.2

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8.4.2.2 Integrated High-Lumen GSL Results

Table 8.4.10 and Table 8.4.11 present the key findings for Integrated High-Lumen GSLs in both the commercial and residential sectors.

Table 8.4.9 Average LCC and PBP Results by Candidate Standard Level for Integrated High-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	9.7	3.6	12.8	22.5	---	8.8
1	10.1	3.4	12.0	22.1	1.5	8.8
2	10.8	3.3	11.6	21.3	3.1	9.8
Commercial Sector						
0	9.7	12.4	31.6	41.5	---	2.2
1	10.1	11.6	29.7	39.8	0.4	2.2
2	10.8	11.2	28.7	37.6	0.9	2.8

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8.4.10 Average LCC Savings for Integrated High-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	3%	0.1
2	14%	0.5
Commercial Sector		
0	0.0%	0.0
1	0.0%	0.3
2	1.2%	1.7

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8.4.2.3 Non-Integrated GSL Results

Table 8.4.11 and Table 8.4.12 show the LCC and PBP results for all efficiency levels considered for Non-Integrated GSLs.

Table 8.4.11 Average LCC and PBP Results by Candidate Standard Level for Non-Integrated GSLs

CSL	Average Costs 2014$				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	13.2	3.4	11.9	25.2	---	8.8
1	14.2	3.4	11.9	22.8	N/A	11.6
	15.7	2.8	9.7	21.1	4.0	12.5
Commercial Sector						
0	13.2	11.6	29.6	42.9	---	2.2
1	14.2	11.6	29.6	39.0	N/A	4.1
	15.7	9.4	24.1	33.3	1.2	5.0

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8.4.12 Average LCC Savings for Non-Integrated GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	12%	1.6
Commercial Sector		
0	0.0%	0.0
1	5.2%	2.7

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8.4.3 Results in 2025

8.4.3.1 Integrated Low-Lumen GSL Results

Table 8.4.13 and Table 8.4.14 show the LCC and PBP results for all efficiency levels considered for Integrated Low-Lumen GSLs.

Table 8.4.13 Average LCC and PBP Results by Candidate Standard Level for Integrated Low-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	6.2	1.6	5.7	11.9	---	8.8
1	3.8	1.5	5.3	8.7	0	9.8
2	34.9	1.3	4.5	23.0	86.8	17.9
3	22.2	1.1	4.1	15.9	36.8	17.9
4	6.0	1.0	3.7	7.2	0	17.9
5	5.7	1.0	3.5	6.9	0	17.9
Commercial Sector						
0	7.0	6.7	17.2	24.3	---	2.2
1	4.3	6.2	16.0	19.6	0	2.8
2	45.7	5.7	14.8	37.4	41.7	6.3
3	29.1	5.3	13.6	28.0	15.9	6.3
4	6.1	4.8	12.4	15.6	0	6.3
5	5.7	4.6	11.8	14.9	0	6.3

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8.4.14 Average LCC Savings for Integrated Low-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	**Average Savings (2014$)**
Residential Sector		
0	0%	0.0
1	0%	0.0
2	7%	0.5
3	7%	0.6
4	6%	0.7
5	4%	0.9
Commercial Sector		
0	0.0%	0.0
1	0.1%	0.0
2	0.1%	1.3
3	0.1%	1.3
4	0.0%	1.3
5	0.0%	1.7

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8.4.3.2 Integrated High-Lumen GSL Results

Table 8.4.15 and Table 8.4.16 present the key findings for Integrated High-Lumen GSLs in both the commercial and residential sectors.

Table 8.4.15 Average LCC and PBP Results by Candidate Standard Level for Integrated High-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	9.4	3.7	12.9	22.3	---	8.8
1	9.7	3.4	12.1	21.9	1.4	8.8
2	10.4	3.3	11.7	21.1	3.0	9.8
Commercial Sector						
0	9.4	11.9	30.7	40.2	---	2.2
1	9.7	11.1	28.8	38.6	0.4	2.2
2	10.4	10.8	27.8	36.4	0.9	2.8

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8.4.16 Average LCC Savings for Integrated High-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	7%	0.2
2	17%	0.4
Commercial Sector		
0	0.0%	0.0
1	0.3%	0.5
2	5.0%	1.5

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8.4.3.3 Non-Integrated GSL Results

Table 8.4.17 and Table 8.4.18 show the LCC and PBP results for all efficiency levels considered for Non-Integrated GSLs.

Table 8.4.17 Average LCC and PBP Results by Candidate Standard Level for Non-Integrated GSLs

CSL	Average Costs 2014$				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	12.7	3.4	12.1	24.8	---	8.8
1	13.6	3.4	12.1	22.5	N/A	11.6
	15.1	2.8	9.9	20.7	3.9	12.5
Commercial Sector						
0	12.7	11.1	28.8	41.6	---	2.2
1	13.6	11.1	28.8	37.7	N/A	4.1
	15.1	9.1	23.4	32.1	1.2	5.0

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8.4.18 Average LCC Savings for Non-Integrated GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	12%	1.5
Commercial Sector		
0	0.0%	0.0
1	5.4%	2.6

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8.4.4 Rebuttable Presumption Payback Period

DOE also uses the results of the payback period analysis as a preliminary test of the economic justification of standards. By statute, there is a rebuttable presumption that a standard level is economically justified if the additional costs to the consumer of purchasing a product complying with the standard are less than three times the value of the first year's energy cost savings. (42 U.S.C. §6295 (o)(2)(B)(iii)) However, the statute also specifies that: "A determination by the Secretary that such criterion is not met shall not be taken into consideration in the Secretary's determination of whether a standard is economically justified."

The criterion of the rebuttable presumption is equivalent to a given CSL having a simple payback period of less than three years. For the reference scenario, using the simple payback periods presented in Table 8.4.1, Table 8.4.3, and Table 8.4.5, the rebuttable presumption criterion is met for all product classes for certain CSLs, except for non-integrated GSLs in the residential sector, as shown in Table 8.4.5.

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CHAPTER 9. SHIPMENTS ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 9. SHIPMENTS ANALYSIS

9.1 INTRODUCTION

This chapter describes the methods the U.S. Department of Energy (DOE) used to project the future shipments of general service lamps (GSLs). Projections were developed for several cases: the shipments expected to occur without GSL energy conservation standards (the *base case*) and the projected shipments assuming standards are set at various efficiency levels for each of the GSL product classes (the *candidate standards cases*, or CSCs). Shipments projections are a necessary input to calculations of the national energy savings (NES) and net present value (NPV) in the national impacts analysis (NIA), as well as to the manufacturer impact analysis (MIA).

DOE developed a consumer-choice-based model to estimate shipments of GSLs. The model projects consumer purchases (and hence shipments) based on sector-specific consumer sensitivities to first cost, energy savings, lamp lifetime, and lamp mercury content. To account for non-economic consumer behaviors, a technology diffusion model and a technology acceptance factor are superimposed on the shipments model.

Because of the complexity of the consumer-choice-based shipments analysis, the shipments model was executed as a separate computer model written in the Python language. The inputs and outputs of the shipments model were embedded in the NIA model, which is implemented in a Microsoft Excel® spreadsheet, available on regulations.gov, docket number docket number EERE–2013–BT–STD–0051 at http://www.regulations.gov/#!docketDetail;D=EERE-2013-BT-STD-0051.

For the non-integrated and integrated high-lumen product classes, and for each of four lumen ranges considered in the integrated low-lumen product class, DOE projected the change in shipments that would occur in the case of a standard set at different candidate standard levels (CSLs). In the engineering analysis, DOE developed five different CSLs for integrated low-lumen lamps, 2 CSLs for integrated high-lumen lamps and a single CSL for non-integrated lamps (see chapter 5 of this preliminary TSD). Because lamps at the higher CSLs can have significantly different lifetimes than lamps at the lower CSLs, a standard can have a significant impact on lamp shipments, since, when lamp lifetimes are longer, fewer replacements for failed lamps are required each year to meet a given demand for lighting capacity (i.e., maximum desired lumen output per square foot of floor space). DOE assumes in this analysis that the national average lighting capacity demand is constant over time, so increased lamp lifetimes lead to proportional reductions in the demand for replacement lamps.

To evaluate the impact of a standard set at a particular CSL in each product class (which defines a particular CSC) on shipments of GSLs, DOE calculated the difference between the shipments of lamps in each CSC and those in the corresponding base case for each product class. The CSL for each product class at each CSC is shown in Table 9.1.1.All assumptions in a given CSC are identical to those in the corresponding base case, except that lamp options that do not meet the standard are excluded from the set of consumer purchase options in the standards case. The cumulative impact of each CSC on shipments is determined by summing the annual impacts over a 30-year (2020 through 2049) analysis period. For each CSC, DOE calculated its best estimate of the impact on shipments, broken down by product class.

Table 9.1.1 Standard Levels for Each Product Class at Each CSC

CSC	Integrated Low-Lumen	Integrated High-Lumen	Non-Integrated
Base Case	CSL 0	CSL 0	CSL 0
1	CSL 1	CSL 1	CSL 1
2	CSL 2	CSL 2	CSL 1
3	CSL 3	CSL 2	CSL 1
4	CSL 4	CSL 2	CSL 1
5	CSL 5	CSL 2	CSL 1

In addition to the best estimate, which is referred to as the Reference scenario in this document and uses the reference values for all inputs in the NIA spreadsheet, DOE ran various alternative scenarios, which are described in section 9.4.

This chapter reports the effects on shipments of all the CSCs in a reference scenario and in various alternative scenarios. (Chapter 10 of the TSD, which describes the NIA, documents the resulting effects on NES and NPV.) Section 9.2 presents the model methodology. Section 9.3 describes model calibration and inputs. Section 9.4 describes the alternative analyses. Section 9.5 presents the results of the shipments projections for the GSL base case, CSCs, and alternative analyses.

9.1.1 Analyzed Product Classes, Market Sectors, and Market Segments

DOE projected GSL shipments in each of the three product classes analyzed in the engineering analysis (chapter 5 of this TSD). As discussed in chapter 2 of this TSD, these product classes include only medium screw-base, GU24, and pin-base lamps utilizing compact fluorescent (CFL) or light emitting diode (LED) technologies. General service incandescent lamps (GSILs), including halogen lamps, are not analyzed. The Energy Independence and Security Act of 2007 (EISA 2007)[1] includes a backstop provision specifying a minimum GSL efficacy of 45 lm/W if the current rulemaking is not completed by January 1, 2017, or if it does not yield energy savings that equal or exceed the energy savings that would result from the backstop. The backstop provision does not preclude the promulgation of a more stringent standard for GSLs in addition to the lm/W backstop, however, if energy savings from this rulemaking do not equal or exceed the savings from the backstop.

DOE believes it is extremely unlikely that an energy conservation standard for GSLs would yield energy savings exceeding the savings from the EISA 2007 backstop if the rulemaking excludes GSILs. Therefore, DOE assumed in the shipments analysis that the EISA 2007 backstop minimum efficacy requirement of 45 lm/W will take effect simultaneously with the candidate standards analyzed here, on January 1, 2020.

The largest analyzed product class, integrated low-lumen GSLs, is made up of lamps with a broad range of lumen outputs that are typically used in different applications. Because of this, DOE subdivided this product class into four subcategories based on the lumen ranges established for GSILs by EISA 2007, with modifications to account for the product class definitions used in this preliminary analysis. In the following analysis, subcategories within each product class will be referred to as *lamp categories*. The integrated low-lumen product class consists of four lamp categories, and the other product classes consist of one lamp category each. The shipments analysis projects shipments of lamps and apportions them among the various CSLs within each lamp category separately.

DOE also projected shipments separately for the residential and commercial sectors. DOE analyzed industrial GSL usage as part of the commercial sector, because of both the similar applications for GSLs in these sectors and the relatively small contribution of the industrial sector to overall GSL usage. Residential usage of non-integrated GSLs was considered to be a negligible fraction of all usage for this product class, so the non-integrated product class was not analyzed in the residential sector. The product classes, lamp categories, and sectors analyzed in the shipments analysis are summarized in Table 9.1.2.

Table 9.1.2 Product Classes, Lamp Categories, and Sectors Analyzed in the Shipments Model

Product Class	Lamp Category	Sector	
		Residential	**Commercial**
Integrated low-lumen	310-749 lm	X	X
	750-1049 lm	X	X
	1050-1489 lm	X	X
	1490-1999 lm	X	X
Integrated high-lumen	2000-2600 lm	X	X
Non-integrated	All non-integrated (310-2600 lm)		X

9.1.2 Analyzed Time Periods

The shipments model projects shipments for thirty years following the compliance date of a potential GSL standard, assumed to be January 1, 2020, in this preliminary analysis. This thirty-year period, from 2020 through 2049, is referred to as the *analysis period* in this preliminary TSD. The shipments model is initialized based on historical shipments data or estimates covering a sufficiently long period (the *historical period*), as discussed in section 9.3.1. In this analysis, the historical period runs from 1980 through 2013. DOE then projects shipments for the full *shipments projection period*, which runs from the year after the last year of the historical period, 2014, through the end of the analysis period in 2049. Finally, to enable accounting in the NIA of the energy consumed by products shipped at the end of the analysis period over their full lifetimes, DOE calculates the surviving installed stock of GSLs shipped during the analysis period during the years following the analysis period, until essentially all such lamps have been retired. This is referred to in this chapter as the *stock attrition period*. Because of the potentially very long lifetimes of certain GSLs (see appendix 8E of this preliminary TSD), the stock attrition period for this analysis is also long, running from 2050 through 2099. The various time periods considered in the shipments analysis are summarized in Table 9.1.3.

Table 9.1.3 Time Periods Considered in the Shipments Analysis

Period	Years Covered
Historical period	1980-2013
Shipments projection period	2014-2049
Analysis period	2020-2049
Stock attrition period	2050-2099

9.2 SHIPMENTS MODEL METHODOLOGY

This section describes the conceptual framework of the shipments model, the mathematical implementation, and the modeling assumptions. Model calibration and inputs are addressed in section 9.3.

9.2.1 Conceptual Framework of the Shipments Model

The shipments model estimates the changing market distributions across lamp categories and CSLs for input to the NIA. Shipments are projected for a base case, in which no new standard is assumed to take effect in 2020, and for several different CSCs considered in this preliminary analysis.

The shipments model has three main interacting elements: (1) a demand module, which estimates the demand for new GSL shipments in each lamp category for each year of the shipments projection period; (2) a consumer choice module, which assigns shipments to lamps at different efficacy levels based on consumer sensitivities to lamp price, energy consumption, lifetime, and mercury content; and (3) a price projection module, which projects future lamp prices based on historic price trends and projected future shipments. To apportion shipments among the CSLs, the consumer choice model consults substitution matrices, which specify the lamp options that are available to consumers making a given purchase decision, within the CSC for which shipments are being projected. Based on the features and projected prices of the available lamps, the consumer choice model allocates the national lamp demand among the available CSLs for each year of the shipments projection period. A schematic representation of the shipments model is shown in Figure 9.2.1.

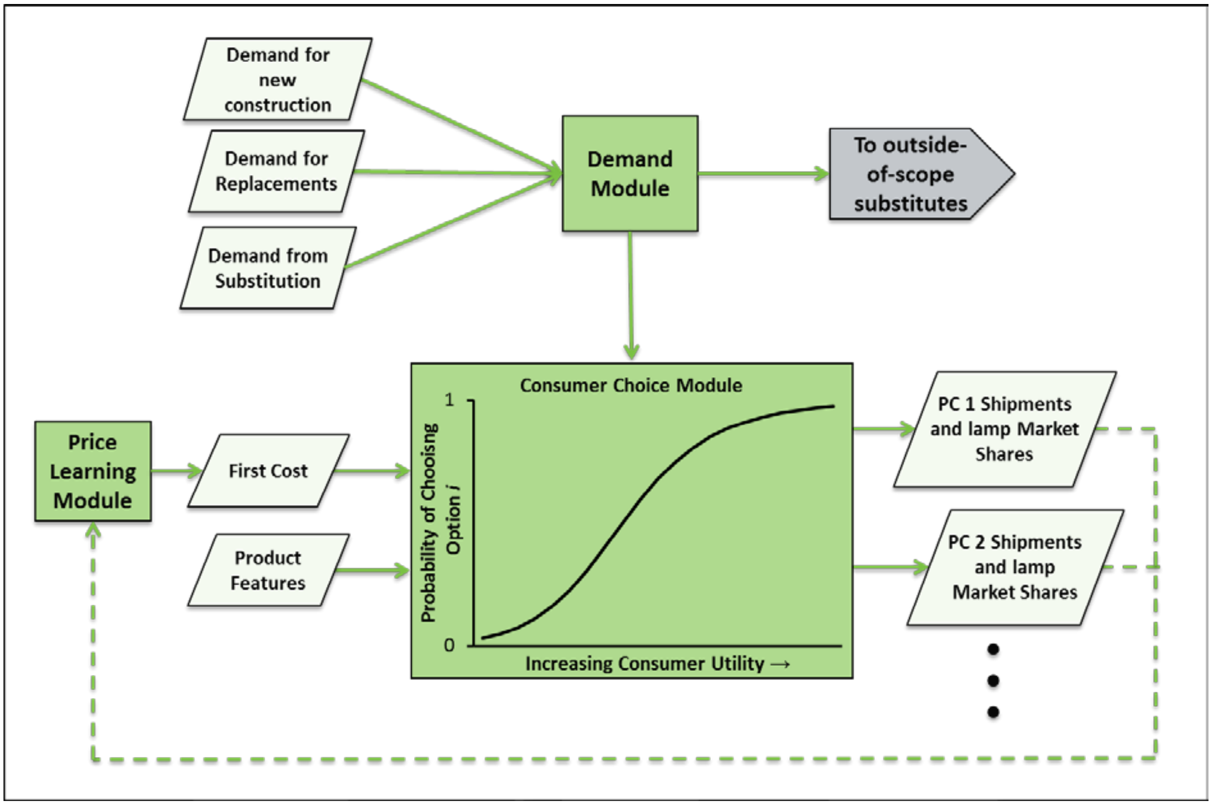

Figure 9.2.1 Schematic Representation of the Shipments Model

9.2.1.1 Lamp options considered in the shipments analysis

In the shipments modeling, DOE represented each CSL by one or more representative lamps in each of the lamp categories covered by that CSL. These representative lamps, referred to hereafter as *lamp options*, are identical to the lamp options analyzed in the LCC analysis (chapter 8 of this TSD), which were themselves derived from the representative lamps analyzed in the engineering analysis (chapter 5 of this TSD). Table 9.2.1, Table 9.2.2, and Table 9.2.3 summarize the properties of the lamp options analyzed in the shipments analysis for each product class. A more complete description of the characteristics of the lamp options is presented in section 9.3.4.

Table 9.2.1 GSL Options Used in the Shipments Analysis for the Integrated Low-lumen Product Class

Lamp Category	CSL	Lamp Technology	Initial Lamp Lumens	Nominal Wattage	Efficacy (lm/W)
310-749 lm	0	CFL	469	9.5	49.1
	1	CFL	500	8.9	56.4
	2	LED	500	8.1	61.6
	3	LED	500	7.4	67.7
	4	LED	500	6.7	75.0
	5	LED	500	6.3	79.1
750-1049 lm	0	CFL	750	14.0	53.6
	1	CFL	800	13.0	61.5
	2	LED	800	12.0	66.7
	3	LED	800	11.0	72.7
	4	LED	800	10.0	80.0
	5	LED	800	9.5	84.2
1050-1489 lm	0	CFL	1125	19.8	56.9
	1	CFL	1200	18.4	65.4
	2	LED	1200	17.0	70.4
	3	LED	1200	15.7	76.5
	4	LED	1200	14.3	83.7
	5	LED	1200	13.6	88.0
1490-1999 lm	0	CFL	1500	25.6	58.6
	1	CFL	1600	23.8	67.3
	2	LED	1600	22.1	72.3
	3	LED	1600	20.4	78.3
	4	LED	1600	18.7	85.6
	5	LED	1600	17.8	89.9

Table 9.2.2 GSL Options Used in the Shipments Analysis for the Integrated High-lumen Product Class

CSL	Lamp Technology	Initial Lamp Lumens	Nominal Wattage	Efficacy (lm/W)
0	CFL	2000	32.0	62.5
1	CFL	2000	30.0	66.7
2	CFL	2200	29.0	75.9

Table 9.2.3 GSL Options Used in the Shipments Analysis for the Non-integrated Product Class

CSL	Lamp Technology	Initial Lamp Lumens	Nominal Wattage	Efficacy (lm/W)
0	CFL	1710	26.0	65.8
1*	CFL	1800	26.0	69.2
	CFL	1525	21.0	72.6

*Two lamp options were analyzed at CSL 1 in the non-integrated product class.

9.2.1.2 Demand Module

The lamp demand module of the shipments model projects the demand for shipments of GSLs, both for installation in new construction and as replacements for failed or retired lamps, in each year of the shipments projection period. The module estimates the demand for replacement GSLs by computing the number of lamps retired in each year based on a lamp failure and retirement model described in section 9.2.2.

To project the demand for GSLs in new construction, the lamp demand module makes the assumption that the amount of light desired to fully light a space (measured in lumens per square foot), is constant over time. That is, sector-specific lumen demand per square foot stays constant, while total national lumen demand grows proportionally with total floor area. Therefore, the lamp demand module increases the total lumen demand in each year of the shipments projection period based on the sector-specific floor-space growth rates extracted from *Annual Energy Outlook 2014 (AEO 2014)*.[2] The increment in lumen demand in each year represents the lumen demand for new construction.

To compute the total GSL demand in each year, DOE combined the lumen demand for GSL replacements with the lumen demand for GSL applications in new construction. In this preliminary analysis, DOE assumed that an increasing fraction of this total lumen demand will be fulfilled by integrated LED luminaires, which are outside the scope of the present analysis. This attenuates the overall demand for GSL shipments in each year. DOE further assumed that, in the early part of the shipments projection period, demand for CFL and LED GSLs increases relative to other GSL technologies, as consumers switch away from the other GSLs. Details of the assumed substitution patterns are given in section 9.2.2.3. The retirement, floor-space growth, and substitution considerations yield the total lumen demand to be fulfilled by CFL and LED GSLs in each year of the shipments projection period.

To apportion the demand among the different lamp categories, DOE assumed that the GSLs used to meet the demand have a fixed distribution of lumen outputs throughout the shipments projection period. DOE also assumed in this preliminary analysis that the fraction of all installed GSLs that are non-integrated GSLs remained constant throughout the shipments projection period. These assumptions yield a final projection of the demand for new shipments in each of the analyzed product classes and lamp categories.

9.2.1.3 Consumer Choice Module

The consumer choice module constitutes the analytical heart of the shipments model. The basic framework of the consumer choice module, also used to model consumer behavior in other contexts,[3,4] allocates market shares as an aggregate of many individual purchasing decisions. A simplifying assumption of the model is that lamp efficacies exist only at the discrete levels defined by the lamp options listed in section 9.2.1.1. In each year of the shipments projection period the consumer choice model assigns a share of new purchases (shipments) to each of the lamp options that are available to the consumer, based on consumer sensitivities to first cost and to other product features, as well as on diffusion rates of new technologies into the market.

Specifically, the consumer choice module couples an econometric logit model for consumer choice with a Bass model[5] for technology diffusion, which limits the technology adoption rate based on historical observations. The logit model captures consumer sensitivity to product price and features for familiar technologies. The Bass diffusion model captures barriers to market entry, like lack of consumer information, that diminish over time with consumer exposure to new technologies. As those barriers diminish, the technology achieves a market share that is more perfectly described by the economic factors captured by the logit model. While the Bass diffusion model captures increases in product adoption over time, there are also non-economic reasons for consumer preferences that persist over time and are not captured in this model. The consumer choice module uses acceptance factors, which place a cap on the potential market share of certain options, to capture these additional deviations from economic factors. The remainder of this section describes the logit and diffusion model in mathematical terms.

The Logit Model. The logit model calculates the probability P_i that a consumer will purchase option *i* from a set of *n* choice options, based on a logistic curve probability function. The category of econometric logit models contains several subtypes that are appropriate for different choice situations. The current analysis considers lamp options utilizing different lighting technologies (fluorescent and LED) in the integrated low-lumen product class. When faced with a choice among options that can be subdivided into groups of products having features that provide similar consumer utility, an appropriate logit model is the nested logit model.[6] In such a model, the choice options $\mathrm{i} \in \{1, \dots, \mathrm{n}\}$ are subdivided into *K* total subgroups, or “nests,” $\mathrm{N_k} \in \{1, \dots, K\}$. The choice probability then takes the form

$$\boldsymbol{P_{i,k}(z_i) = \frac{e^{z_i/\lambda_k}\left(\sum_{j\in N_k} e^{z_j/\lambda_k}\right)^{\lambda_k-1}}{\sum_{\ell=1}^{K}\left(\sum_{j\in N_\ell} e^{z_j/\lambda_\ell}\right)^{\lambda_\ell}}}$$

Eq. 9.1

Where:

$P_{i,k}(z)$ = the probability a consumer will purchase product i in nest N_k among all possible options,
K = the total number of nests,
N_ℓ = the ℓth nest out of the K total nests,
λ_ℓ = a parameter associated with nest ℓ that controls the relative probability of choosing options within that nest relative to other nests, and
z_j = the logit, which is a function that combines economic and other variables that describe option j with parameters that describe consumer sensitivity to the variables.

The logit is typically written as a linear function in the variables:

$$\boldsymbol{z_i = \sum_{j=1}^{m} \beta_j v_{j,i}}$$

Eq. 9.2

Where:

$v_{j,i}$ = the jth variable describing product i,
m = the total number of variables used in the model, and
β_j = a parameter describing consumer sensitivity to the jth variable.

In this analysis, the variables used to construct the logit, and the values of the coefficients (beta values) were developed from a report investigating consumer GSL preferences for a major utility company.[7]

As mentioned previously, DOE also applies acceptance factors in some cases, to cap the market share for certain options whose market share may be limited by factors not captured by the model. The acceptance factor for a given option takes values between zero and one, representing the fraction of consumers who will consider that option in their choice. If only one option has a non-unit acceptance factor, the consumer choice model is run twice, with the option in question being excluded from the choice matrix in the second run. The results of these two runs are combined in a weighted sum, with the first run given a weight equal to the acceptance factor and the second run receiving complementary weight to yield the final fraction of consumers who choose each option. If multiple options have acceptance factors applied, the consumer choice is run repeatedly, with the acceptance factors treated hierarchically: the option having lowest acceptance is excluded in the second run, and options with higher acceptance are excluded in later runs, until the only remaining options all have unit acceptance. If no option has unit acceptance, then, prior to any model runs, all acceptance factors are scaled up by a constant factor such that the largest acceptance factor is equal to unity. The acceptance factors applied to the lamp options may vary depending on which lamp option is being replaced. The logit model with acceptance factors applied thus yields the probability P_{ji} that lamp i is selected, given that lamp j is being replaced.

Full details of the development and calibration of the consumer choice model are presented in section 9.3.2.

The Bass Technology Diffusion Curve. One of the factors that may restrict the potential market share of certain lamp options is limited consumer adoption of new and unfamiliar technologies (e.g., LED lighting products). In the shipments analysis, DOE parameterized this adoption rate using a Bass technology diffusion curve.

The Bass diffusion curve sets the market penetration (i.e., the fraction of the market share at full product maturity) for an individual lamp type at any given point in time following its introduction to the market, based on the historical technology diffusion rate for lighting products. The diffusion curve is treated as a variable cap on the market share for each option; in each year, this cap is implemented by multiplying the Bass market penetration for each option by the existing acceptance factor for each option. The resulting product is treated as the new acceptance factor for the year in question and is applied as discussed previously.

A Bass adoption curve is a 2-parameter diffusion curve widely used to describe how new products enter into markets.[5] The two parameters, p and q, represent external and internal influences, respectively, on markets. If the fraction of the market is zero at time t_0, the Bass diffusion curve is expressed as follows:

$$\boldsymbol{MP(t) = \frac{1 - e^{-(p+q)(t-t_0)}}{1 + \left(\frac{q}{p}\right) e^{-(p+q)(t-t_0)}}}$$

Eq. 9.3

Where:

$MS(t)$ = market penetration at time *t*,
t = the time variable,
t_0 = the time at which the product was introduced to the market,
p = the coefficient of external influence, and
q = the coefficient of internal influence.

9.2.1.4 Price Projection Module

The consumer choice module uses product prices as one of the descriptive variables in the logit model. Consistent with current practice in DOE rulemaking analyses, DOE has adopted a price learning model to project product prices over the shipments projection period.[8,9] As originally defined, price learning reflects systematic decreases in manufacturing costs resulting from cumulative production experience. When price learning analyses are considered on an industry-wide basis, rather than at the manufacturer level, and when they include learning effects downstream of production (for example, increased efficiencies in product distribution), the price learning curve is typically referred to as an experience curve, but it takes the same mathematical form. A broad range of cost and price metrics have been used to quantify learning rates for appliances and equipment (see, for example, Weiss et al., 2010, Table A1).[10]

DOE used historical data to estimate the impact of price learning by fitting the data to an experience curve of the following form:

$$\boldsymbol{p(X) = p_{init} \times X^{-b}}$$

Eq. 9.4

Where:

$p(X)$ = the price of a particular product as a function of cumulative production,
p_{init} = the initial price of the product at the time of market introduction,
X = cumulative production (total shipments) of the product from the time of its market introduction (number of units), and
b = a positive constant parameter that describes the rate of price decline with production.

As described in section 9.3.3, DOE used historical price and shipments data from the U.S. Census to determine the cumulative historical production and prices of lamps sold into the U.S. market and, thus, to calibrate the learning rate parameter, *b*.

Eq. 9.4 can be used to obtain a projection for price in each year, $p(y)$, if the cumulative production is written explicitly as a function of time:

$$\boldsymbol{X(y) = \sum_{v=y_{init}}^{y-1} s(v)}$$

Eq. 9.5

Where:

$X(y)$ = the cumulative production (total shipments) of a product between the year of its introduction and year y (number of units),
y = the current year[a],
v = the vintage, or year in which a product was shipped to market,
y_{init} = the year of the product's market introduction, and
$s(v)$ = the shipments in vintage year v (number of units).

Eq. 9.4 and Eq. 9.5 can then be combined to compute a price learning factor to correct the price in a particular reference year to the price in an arbitrary year:

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[a] The time variable y in this analysis is a discrete variable representing the year being analyzed. Throughout the remainder of this analysis, quantities that depend on y will be written in the form *D(y)*, which is more typically used for functions of a continuous variable, rather than the usual subscript form that is conventionally used for discrete variables D_y. This is done for the sake of avoiding confusion with other subscripts used in the notation.

$$\boldsymbol{PLF(y) = \left(\frac{X(y)}{X(y_0)}\right)^{-b}}$$

Eq. 9.6

Where:

$PLF(y)$ = the price learning factor in year y,
y_0 = the reference year, and
all other variables are defined in Eq. 9.4 and Eq. 9.5.

For any component of total lamp price that is subject to learning, the price learning factor can then be used to calculate the price in any year, given the price in the reference year, using the following equation:

$$\boldsymbol{p_L(y) = PLF(y) \times p_L(y_0)}$$

Eq. 9.7

Where:

$p(y)$ = the learning-impacted price component in year *y*, and
all other variables are as defined in Eq. 9.6.

In this analysis, not all components of lamp price were treated as subject to learning. For compact fluorescent lamps (CFLs), DOE decomposed the price into a component arising from rare earth oxide (REO) costs and a component arising from other manufacturing inputs. Only the latter component is subject to learning; the REO costs are assumed to be constant in real dollars during the shipments projection period (although they may be assumed to be boosted relative to the present-day REO price in some scenarios). The details of the REO price assumptions are presented in appendix 8D; these assumptions yield a price evolution model for CFLs given by the following equation:

$$\boldsymbol{p_{CFL}(y) = p_{REO}(y) + PLF(y) \times (p_{CFL}(y_0) - p_{REO}(y_0))}$$

Eq. 9.8

Where:

$p_{CFL}(y)$ = the price of a CFL in year y,
$p_{REO}(y)$ = the component of CFL price arising from REO costs in year y, and
all other variables are as defined previously in this section.

A more detailed version of this equation is presented in appendix 8D.

To project prices for LED GSLs, DOE made use of a study[11] from Lawrence Berkeley National Laboratory (hereafter the LBNL GSL price report) that tracked recent price and shipments data to construct a learning curve for lamps in the lowest lumen lamp category considered for the integrated low-lumen product class in this analysis (see Table 9.2.1). That study also measured exponential time trends in incremental price for the brighter lumen ranges relative to the lowest lumen range. For this analysis, DOE combined these results to construct a model for LED GSL prices that consists of a base price for an LED GSL in the lowest lumen range, which is subject to price learning, and an incremental price of increased lumen output, which declines exponentially with time:

$$\boldsymbol{p_{LED}(y) = (PLF(y) \times\ p_{base}(y_0)) + \left(p_{\ell}(y_0) \times e^{-\alpha_{\ell}(y-y_0)}\right)}$$

Eq. 9.9

Where:

$p_{LED}(y)$ = the price of an LED GSL in year y,
$p_{base}(y_0)$ = the price, in the reference year, of an LED GSL in the lowest-lumen lamp category considered in this analysis,
$p_{\ell}(y_0)$ = the incremental price above p_{base}, in the reference year, for an LED GSL in lamp category ℓ,
α_{ℓ} = a constant positive parameter controlling the rate of decline in the incremental price for lamps in lamp category ℓ, and
all other variables are as defined previously in this section.

As discussed in more detail in section 9.3.3.1, the price trends presented in Eq. 9.8 and Eq. 9.9 were not applied to a subset of the available CFL and LED lamp options, which DOE assumed to represent obsolete technologies that are exiting the present market.

9.2.1.5 The Coupled Model

The shipments model uses the price learning equations presented in the previous section to calculate the price of each product in each year of the analysis, according to the additions to the cumulative production estimate produced by the shipments model up to that point. The model then proceeds step-wise in each year to calculate product shipments based on the projected prices and other variables of the logit model via the demand and consumer choice modules. It then calculates the following year's product prices after adding that year's shipments to the previous estimate of cumulative production.

9.2.2 Detailed Modeling and Assumptions

DOE projected the annual shipments of GSLs within the commercial and residential sectors separately. All quantities referenced in the equations or discussion in this section (e.g., the total lamp demand or shipments) are intended to be specific to a particular sector. The modeling was performed once for the residential sector and once for the commercial sector, with different inputs for each sector.

To project the shipments of GSLs, DOE first computed the demand in each year and lamp category for GSLs or GSL substitutes to be used for

- new construction,
- replacement of retired lamps within the lamp category

- replacement of retired lamps from other lamp categories, or from lighting technologies not explicitly analyzed in this preliminary analysis, by consumers who are substituting between lamp categories or technologies (if any), and
- integrated LED luminaires to be used as substitute replacements for lamps within the lamp category

DOE then combined these sources of demand to obtain the total demand for new shipments of each lamp option, using the following equation:

$$\boldsymbol{D_i(y) = D_{NC,i}(y) + D_{R,i}(y) + D_{in,i}(y) - D_{out,i}(y)}$$

Eq. 9.10

Where:

y = the year of the shipments projection period,
$D_i(y)$ = the total demand for shipments of lamp option i in year y (number of units),
$D_{NC,i}(y)$ = the demand for shipments of lamp option i in new construction (number of units),
$\mathrm{D}_{\mathrm{R,i}}(y)$= the demand for replacement of retired units of lamp option i (number of units),
$D_{in,i}(y)$ = the incoming demand for lamp option i as a substitute for lamps from other lamp categories or technologies (if any) (number of units), and
$D_{out,i}(y)$ = the outgoing demand for units of lamp option i being replaced by integrated LED luminaires (number of units).

Eq. 9.10 represents the disaggregated demand for GSLs within a given lamp option. It can be used to derive the total demand for GSLs within a lamp category, product class, or sector by summing over the relevant lamp options.

After computing the disaggregated demand, DOE reapportioned this demand among the various lamp options within each lamp category via the consumer choice module to determine the shipments of each lamp option in each year. The lamp options DOE considered in the shipments analysis are discussed in section 9.2.1.1.

Given values for the retirements and new shipments in year *y*, as well as the total stock in year *y-1*, the stock of GSLs in year *y* for a particular lamp option can be calculated as:

$$\boldsymbol{\mathbb{S}_i(y) = \mathbb{S}_i(y-1) - R_i(y) + s_i(y)}$$

Eq. 9.11

Where:

$\mathbb{S}_i(y)$ = the national stock of lamps corresponding to lamp option i in year y (number of units),
$\mathrm{R_i(y)}$ = units of lamp option i that are retired (because of failure or for any other reason) in year y (number of units), and
$\mathrm{s_i(y)}$ = the total shipments of new units of lamp option i in year y (number of units).

The total stock of GSLs in each lamp category or sector is then given by summing over the stock of all relevant lamp options.

Eq. 9.11 requires the stock to be initialized at the beginning of the shipments projection period. This is accomplished by combining the lamp survival probability as a function of lamp age with the historical shipments data discussed in section 9.3.1:

$$\mathbb{S}_{\boldsymbol{i}}(\boldsymbol{y_0}) = \sum_{y=y_{first}}^{y_0-1} \boldsymbol{P_{surv,i}}(\boldsymbol{y_0} - \boldsymbol{y}) \times \boldsymbol{s_{hist,i}}(\boldsymbol{y})$$

Eq. 9.12

Where:

$P_{surv,i}(y_0 - y)$ = the survival probability in year y_0 of a GSL of lamp option i shipped in year y, as derived in appendix 8E of this TSD for various lifetime scenarios,
y_0 = the first year of the shipments projection period, 2014,
y_{first} = the first year of the historical period, and
$s_{hist,i}(y)$ = the historical shipments of GSLs of lamp option i in year y (number of units).

The different lamp options can have different survival probability functions, since they may have different lifetimes (see section 9.3.4).

Eq. 9.10 and Eq. 9.11 are the fundamental equations underlying the shipments and stock modeling of the lamp categories in this analysis. The remainder of this section will be devoted to deriving the various components of these equations for GSLs, as a preliminary step to computing the GSL shipments and stock, starting with lamp demand.

9.2.2.1 Modeling GSL Demand for New Construction

To project the lamp demand for new construction, DOE assumed that the demand for lumen capacity per square foot of new floor space (lm/ft^2 at maximum lamp output), as well as the overall GSL lumen distribution in the installed stock, is constant over time, so that overall lumen demand in each lamp category grows at the same sector-specific annual growth rate as floor space. Thus, the annual demand for GSLs in new construction is given by:

$$\boldsymbol{D_{NC,i}}(\boldsymbol{y}) = \mathbb{S}_{\boldsymbol{i}}(\boldsymbol{y_0})[(\boldsymbol{1} + \boldsymbol{\gamma})^{\boldsymbol{y}-\boldsymbol{y_0}} - (\boldsymbol{1} + \boldsymbol{\gamma})^{\boldsymbol{y}-\boldsymbol{y_0}-\boldsymbol{1}}]$$

Eq. 9.13

Where:

$\mathrm{D_{NC,i}}(y)$ = the total demand from new construction for GSLs of lamp option i in year y (number of lamps),
$\mathbb{S}_{\boldsymbol{i}}(y_0)$ = the installed national stock of GSLs in lamp option i in year y_0 (number of lamps), as defined in Eq. 9.12,
y_o = the initial year of the shipments projection period, and
γ = the sector-specific, 30-year (2010-2040) average annual floor space growth rate projected by *AEO 2014*.

The total GSL demand for new construction, $D_{NC}(y)$, is then given by the summation over all lamp options within each sector.

9.2.2.2 Modeling demand for replacement of retiring GSLs

DOE determined the demand for replacement shipments in a given year by computing the number of shipments from previous years that would be expected to retire in that year. The probability that a given lamp will retire A years after installation is:

$$\boldsymbol{P_{ret,i}(A) = P_{surv,i}(A-1) - P_{surv,i}(A)}$$

Eq. 9.14

Where:

A = the lamp's age (years since installation),
$P_{ret,i}(A)$ = the probability that a GSL of lamp option i is retired when it is A years old, and
$P_{surv,i}(A)$ = the probability that the lamp survives (i.e., is not retired) for A years after installation, derived in appendix 8E of this TSD for different lifetime scenarios.

The retirement probability function is used to compute the expected lamp failures in year y, given a time series of historical shipments spanning the maximum expected age reached by any lamp, A_{max}:

$$\boldsymbol{R_i(y) = \sum_{v=y-A_{\max}}^{y-1} P_{ret,i}(y-v)\, s_i(v)}$$

Eq. 9.15

Where:

$R_i(y)$ = retirements of GSLs of lamp option i in year y (number of units),
y = current year,
v = lamp vintage (i.e., year of shipment),
A_{max} = maximum expected lamp lifetime (yr),
$P_{ret,i}(y-v)$ = probability of lamp retirement in year $y-v$ of a lamp's lifetime (Eq. 9.14), and
$s_i(v)$ = total shipments of lamp option i that occurred in a particular vintage (number of units).

Since LED GSLs can have very long lifetimes, DOE assumed a maximum lamp lifetime of $A_{max} = 50$ years throughout this analysis. The demand for replacements for retired GSLs of lamp option i is then simply given by the retirements in each year:

$$\boldsymbol{D_{R,i}(y) = R_i(y)}$$

Eq. 9.16

Where:

$D_{R,i}(y)$ = the demand for replacement of retired units of lamp option i (number of units), and
$R_i(y)$ is defined in Eq. 9.15.

The total annual retirements $R(y)$ and demand for replacement shipments $D_R(y)$ can be computed for each lamp category and sector by summing over the relevant lamp options.

9.2.2.3 Incoming and outgoing demand

The demand formula in Eq. 9.10 includes terms for demand entering and leaving the demand pool for the analyzed lamp options from and to other lighting technologies. In the case of outgoing demand, DOE assumed that, in each year of the shipments model, some fraction of the lighting demand historically fulfilled by the modeled product classes would instead be fulfilled by installation of integrated LED luminaires. To compute the incoming demand, in the years prior to 2020, DOE assumed that some consumers who historically utilized GSL technologies that are not analyzed here (i.e., incandescent and halogen GSLs) will switch to CFLs or LED GSLs in either of the integrated product categories. Zero incoming demand was assumed for non-integrated GSLs. After 2020, DOE assumed that all remaining demand for those technologies would be fulfilled by CFLs or LED GSLs, in accordance with the EISA 2007 backstop provision (see section 9.1.1).

To model the fraction of demand transferred to integrated LED luminaires in each year, DOE utilized the Bass adoption curve given in Eq. 9.3 with the parameterization presented in section 9.3.2.2. Specifically, DOE assumed that integrated LED luminaires would eventually displace a certain fraction of GSL luminaires at full market penetration and that this displacement would grow from zero percent in 2007 according to the Bass diffusion curve. The displacement of GSL sockets in each year corresponds to a reduction in demand for new shipments that is persistent in all future years. Thus, the outgoing demand in each year of the shipments model is given by the following formula:

$$\boldsymbol{D_{out,i}(y) = \left[D_{NC,i}(y) + D_{R,i}(y)\right] \times f_{integ} \times MP(y)}$$

Eq. 9.17

Where:

$D_{out,i}(y)$ = the outgoing demand leaving the demand pool for GSL lamp option i in year y (number of units),
$D_{NC,i}(y)$ = the demand for GSLs in lamp option i for new construction (Eq. 9.13) (number of units),
$D_{R,i}(y)$ = the demand for replacement of retired units of lamp option i (Eq. 9.16) (number of units),
f_{integ} = the fraction of all GSL sockets displaced by integrated LED luminaires at maximum market penetration, and
$MP(y)$ = the market-penetration given by the Bass adoption curve (Eq. 9.3).

Note that this equation implicitly assumes that adoption of integrated LED luminaires will reduce demand by the same fraction across all lamp categories and lamp options. The total outgoing demand can be computed by summing across all relevant lamp options.

The total incoming demand from incandescent and halogen GSLs was assumed to constitute a fixed fraction of the previous year's demand for such lamps, in years before 2020:

$$\boldsymbol{D_{in}(y < 2020) = f_{sub} \times D_{other}(y - 1)}$$

Eq. 9.18

Where:

$D_{in}(y < 2020)$ = the incoming demand for analyzed GSLs from technologies other than CFL and LED in year y (for years before 2020) (number of units),
f_{sub} = the fraction of the previous year's demand for other technologies that is transferred to analyzed GSLs through substitution, and
$D_{other}(y - 1)$ = the previous year's demand for GSLs utilizing other technologies (number of units).

DOE disaggregated this demand among the lamp options by assuming it was proportional to the fraction of the previous year's shipments represented by each lamp option:

$$\boldsymbol{D_{in,i}(y) = \frac{s_i(y-1)}{s_{ILL}(y-1) + s_{IHL}(y-1)} D_{in}(y)}$$

Eq. 9.19

Where:

$D_{other,i}(y)$ = the incoming demand from other technologies for GSLs in integrated lamp option i (number of units),
$s_i(y-1)$ = the shipments of lamp option i in year $y-1$ (number of units), and
$s_{ILL}(y-1), s_{IHL}(y-1)$ = the total shipments in the integrated low-lumen and integrated high-lumen product classes, respectively, in year $y-1$ (number of units).

The previous year's demand, $D_{other}(y-1)$, in Eq. 9.18 is given by reducing the 2013 shipments of other technologies by a fixed fraction in each year:

$$\boldsymbol{D_{other}(y) = s_{other}(2013) \times (1 - f_{sub})^{y-2013}}$$

Eq. 9.20

Where:

$s_{other}(2013)$ = the shipments of non-CFL and non-LED GSLs in 2013, and
all other variables are as defined in Eq. 9.18.

The selection of the input parameter values used for the equations in this section is described in section 9.3.2.3.

In 2020, DOE assumed that 100% of the demand that would have gone to other technologies is instead fulfilled by CFLs or LED GSLs, owing to the EISA 2007 backstop provision. For the years after 2020, DOE assumed that a shrinking number of non-CFL and non-LED GSLs will require replacement, since other GSL technologies have relatively short lifetimes, often a year or less. Specifically, DOE assumed that demand for such replacements in 2021 would be 10% of the 2020 demand and zero thereafter. Hence, DOE used the following formulas for the incoming demand in 2020 and beyond:

$$\boldsymbol{D_{in}(y = 2020) = D_{other}(y = 2020)}$$

$$\boldsymbol{D_{in}(y = 2021) = 0.1 * D_{in}(y = 2020)}$$

$$\boldsymbol{D_{in}(y > 2021) = 0}$$

Eq. 9.21

Where:

all variables are as defined earlier in this section.

9.2.2.4 Turnover and Shipments

Because the different lamp options considered in each lamp category may have significantly different lifetimes (e.g., LED versus CFL options), it was necessary to explicitly model the shipments for each lamp option separately. Additionally, because of the different usage patterns in each sector, DOE modeled lamps separately in the residential and commercial sectors. DOE computed the total yearly demand D_i for each lamp option separately within each sector according to the disaggregated form of Eq. 9.10. DOE then reallocated this demand among all lamp options in the same lamp category using the consumer choice module, yielding a projection for the shipments of each lamp option in each year:

$$\boldsymbol{s_i(y) = \sum_j D_j(y)\sigma_{ji}(y)}$$

Eq. 9.22

Where:

$s_i(y)$ = projected shipments to a particular sector for GSL option *i* in year *y* (number of units),
$D_j(y)$ = the total in-sector demand in year y for lamp option j, defined in Eq. 9.10 (number of units), and
σ_{ji} (y) = the substitution matrix in year *y*.

The substitution matrix, σ_{ji}, specifies the fraction of consumers who switch between the lamp options, according to the consumer choice model:

$$\boldsymbol{\sigma_{ji}(y) = P_{ji}(y) \times A_{ji}(y)}$$

Eq. 9.23

Where:

$P_{ji}(y)$ = probability of purchasing lamp option *i* in year y from among the available lamp options, given that option j is being replaced, according to the consumer choice module described in section 9.2.1.3,
y = the year of the shipments model, and
$A_{ji}(y)$ = the availability matrix in year y.

The availability matrix $A_{ji}(y)$ specifies the products that are available to a consumer who is retiring a unit from lamp option j and replacing it. This matrix is zero when lamp option *i* is not a direct substitute for *k,* or when lamp option *i* has been eliminated by a candidate standard in the standards case; it is equal to unity otherwise.

DOE used the model above to project the shipments of each GSL option in each year of the analysis, for the base case and for the CSCs listed in Table 9.1.1. The input parameters, and their calibration, are discussed in section 9.3.2. Given the projections of failures, renovations, and new shipments in each year, and a calculation of the total operating stock in the initial year of the shipments projection period, Eq. 9.11 then yields the total operating stock of GSLs in the

United States in each subsequent year as an input for computing the NES in the NIA (chapter 10 of this preliminary TSD).

9.2.2.5 Stock Attrition

As mentioned in section 9.1.2, in addition to projecting shipments through the end of the analysis period, DOE also projects the surviving installed stock of GSLs shipped during the analysis period through 2099. During the time after the analysis period, this quantity shrinks steadily as lamps fail and are replaced by shipments that fall outside of the analysis period. The surviving stock during the stock attrition period is given by the following formula:

$$\mathbb{S}_i(y) = \sum_{y'=y-A_{max}}^{y_{end}} P_{surv,i}(y - y') \times s_i(y')$$

Where:

$\mathbb{S}_i(y)$ = the stock of GSLs of lamp option i in year y following the end of the analysis period, which were shipped during the analysis period (number of units),
A_{max} = the assumed maximum lifetime of a GSL (taken to be 50 years in this analysis),
y_{end} = the final year of the analysis period (2049 in this analysis),
$P_{surv,i}(y - y')$ = the survival probability in year y of a GSL of lamp option i shipped in year y' of the analysis period, as derived in appendix 8E of this TSD for various lifetime scenarios, and
$s_i(y')$ = the shipments of GSLs of lamp option i in year y' of the analysis period (number of units).

9.3 MODEL INPUTS AND CALIBRATION

9.3.1 Historical Shipments Data

Because the lamp shipments modeled in any given year depend on sums of shipments of GSLs in prior years, DOE needed historical data to initialize the shipments model. To accurately compute the initial shipments and stock projections from historical data, it is necessary to have data spanning a sufficiently long time period such that products shipped at the beginning of the historical period have a negligible surviving fraction in today's stock. DOE estimates that, for GSLs, 30 years is a sufficiently long historical period to meet this criterion. The remainder of this section describes the sources of the historical shipments data; their disaggregation into different sectors, product classes, and technology options; and their use in initializing the shipments and stock model.

9.3.1.1 Sources of Historical Shipments Data

In support of the shipments analysis, DOE received estimates of historical GSL shipments to the U.S. market, developed by Cadeo Group,[12] for medium screw-base integrated CFL and LED lamps (aggregated across both integrated product categories) and for non-integrated CFLs. The estimates covered the years 2010 through 2013; they are presented in Table 9.3.1.

Table 9.3.1 Estimated Shipments of GSLs to the U.S. Market, by Technology Type[12]

Year	CFL A-line, medium screw base (thousands of lamps)	LED A-line , medium screw base (thousands of lamps)	Non-integrated CFL (thousands of lamps)
2010	262,241	1,540	48,314
2011	250,178	2,002	46,864
2012	249,428	5,544	45,458
2013	243,441	14,630	44,095

As mentioned previously in this section, a historical shipments time series spanning 30 years is required for an accurate initialization of the GSL shipments model. For the period from 2001 to 2009, DOE estimated this time series for integrated and non-integrated CFLs by utilizing the lamp shipments indices published periodically by NEMA,[13] as compiled in the LBNL GSL price report. The compiled indices provide relative shipments levels, on a quarterly basis, referenced to the average quarterly shipments in 2011. DOE aggregated these quarterly indices to produce annual indices and scaled the shipments estimates shown in Table 9.3.1 by the resulting indices to produce a historical time series of estimated shipments from 2001 to 2013. To estimate CFL shipments in years prior to 2001, DOE assumed that CFLs were introduced to the U.S. market in 1981 and that shipments increased linearly until 2001. Since nearly all lamps shipped during this period have retired by 2014, this approximation is sufficiently accurate for this analysis.

In the case of LED GSLs, the NEMA lamp indices do not give sufficient coverage of the years prior to 2010. DOE therefore assumed that LED GSLs in each of the four integrated low-lumen lamp categories (see Table 9.1.2) were introduced to the market in 2004, 2008, 2012, and 2013, in order of increasing lumen output. For the two lowest-lumen lamp categories, DOE assumed linear growth in the historical shipments through 2009 and 2010, respectively, after which shipments for each of these lamp categories were determined by the disaggregation of historical shipments data described in the following section.

9.3.1.2 Subdivision of Historical Shipments by Sector, Lamp Category, and CSL

The data and historical projections described in the previous section were aggregated across sectors, lumen outputs and lamp efficacies for integrated LEDs, integrated CFLs, and non-integrated CFLs. This section describes the inputs and assumptions that DOE used to disaggregate these historical shipments—first by sector, then by lamp category, and finally by CSL—in order to properly initialize the shipments model.

When subdividing the historical shipments of non-integrated GSLs by sector, DOE assumed that all shipments of non-integrated GSLs occur in the commercial sector, with negligible shipments in the residential sector. Thus, no further disaggregation of the historical shipments by sector is required for the non-integrated product class.

For the two integrated product classes, DOE estimated the residential fraction of each product's shipments using a simple stock turnover model utilizing sector-specific mean lamp lifetimes and estimates of medium screw-base GSL stocks in the 2010 LMC. The resulting estimate of the residential fraction of integrated GSL shipments is given by

$$\boldsymbol{f_{Res}} = \frac{\frac{\boldsymbol{S_{Res}}}{\boldsymbol{L_{Res}}}}{\frac{\boldsymbol{S_{Res}}}{\boldsymbol{L_{Res}}} + \frac{\boldsymbol{S_C}}{\boldsymbol{L_C}}}$$

Eq. 9.24

Where:

f_{Res} = the fraction of lamp shipments in the residential sector,
S_{Res} = the stock of lamps in the residential sector, as reported in Table 4.1 of the LMC (number of units),
S_C = the stock of lamps in the commercial sector, from the same table (number of units),
L_{Res} = the median lamp lifetime in the residential sector (yr), *i.e.,* the average failure age derived from the 50% failure point in the lamp retirement distribution derived in appendix 8E of this TSD, using the appropriate hours-of-use distribution and lamp switching rates for the residential sector, and
L_C = the median lamp lifetime in the commercial sector (yr), computed as above, except with the use of the appropriate hours-of-use distribution and switching rates for the commercial sector.

Based on this equation, DOE assumed that 79.2% of historical GSL shipments went to the residential sector.

The two integrated product classes comprise five lamp categories with different lumen ranges. DOE subdivided historical shipments of integrated CFLs into these five lamp categories in each sector according to the lamp lumen distributions developed in chapter 8 of this TSD. These fractions were assumed to be constant over time. For LED GSLs, DOE assumed no historical shipments to the integrated high-lumen product class; thus the CFLs assigned to that product class represent its full time series of historical shipments.

In the integrated low-lumen product class, DOE notes that LED products were only introduced to market in 2013 for the highest lumen range. Therefore, DOE assumed that, in both the residential and commercial sector, only 1% of LED GSL shipments fell into that lamp category in 2013, and that no LED GSL shipments existed in that lamp category in earlier years. For the 750-1049 lumen and 1050-1489 lumen lamp categories, DOE assumed that the fraction of all LED GSL shipments in those categories was the same as the fraction of all integrated CFL shipments in those categories starting in 2011 and 2012, respectively. Prior to this, DOE assumed a linear historical increase in shipments starting in the introduction year for GSL LEDs in each category, as described in the previous section. After apportioning LED shipments among the other lamp categories, DOE assumed that the lowest-lumen lamp category made up the remainder of the historical shipments presented in Table 9.3.1.

Having subdivided the historical shipments of integrated lamps among the various lamp categories, DOE then apportioned these shipments to the various lamp options in each category. This task is simplified somewhat by the fact that the lamp options available to a consumer in the consumer choice model are independent of the lamp option that is being replaced (see section9.3.2.1). Therefore, the historical shipments breakdown needs only be accurate enough to correctly initialize the lamp demand in the first year of the shipments model. As discussed in section 9.2.2, the only lamp property on which the lamp demand depends is the lamp survival function (see Eq. 9.14). Lamp options within each lamp category are assumed to have identical usage patterns, so lamp options of like technology having identical lifetimes will have identical survival functions. Thus, it is only necessary to apportion historical shipments among the lamp options that have substantially different technologies or lifetimes in each category; there is no need to further subdivide them between the lamp options that have identical technologies and similar lifetimes. In both of the integrated product classes, the different CFL lamp options have nearly equal lifetimes, as do the various LED lamp options. Therefore, since the particular CSL level at which historical shipments of CFLs or LEDs occurred would have negligible impact on the shipments projections, DOE assigned all historical CFL and LED shipments to the lowest available CSL for each technology. In contrast, for the non-integrated lamp category, the different CFL lamp options have significantly different lifetimes. Based on the output of the calibrated consumer choice module (see section 9.3.2), DOE assumed that the baseline lamp option made up 66%, and that the full and reduced-wattage lamp options at CSL 1 made up 30% and 4%, respectively, of all historical shipments of non-integrated GSLs.

9.3.2 Consumer Choice Module Development and Calibration

This section describes the methods DOE used to determine the various functional forms and parameters that control the behavior of the consumer choice module used in this shipments analysis. These include the form and parameters of the logit model, the parameters of the Bass adoption model, and parameters of the stock turnover model.

9.3.2.1 Development and Calibration of the Logit Model

As introduced in section 9.2.1.3, DOE used a nested logit model, described by Eq. 9.1 and Eq. 9.2, as the main driver of the consumer choice model used to predict product market share. The logit z_i depends on certain variables that describe lamp option i, as well as a set of coefficients associated with each of the variables. This section describes the selection of the descriptive variables for GSLs and the determination of appropriate coefficients, first discussing the selection of the nests, then the determination of the variables and coefficients used to construct the logit formula from Eq. 9.2, and finally the determination of the nest parameters λ_k used in Eq. 9.1.

Selection of the nests. The nested logit model conceptually divides the utility that a consumer derives from a particular product selection into two components: an observed component, consisting of the variables utilized in constructing the logit equation, and an unobserved component, made up of elements of the utility that are not explicitly modeled because they are not or cannot be observed (e.g., variation in consumer tastes).[6] The standard logit model assumes that the unobserved component is independently and identically distributed for each of the products. The nested logit model used in this analysis accounts for the situation in which certain subsets of the available options have unobserved components of utility that are correlated with one another, rather than being independent.

In the current analysis, the lamp options in the integrated low-lumen product class include lamps utilizing CFL and LED technologies. These two technologies can be broadly distinguished by certain features relating to lamp utility that are similar for lamps using each of the two technologies. For example, lamp appearance, start time, warm-up time, and dimming performance are generally different when comparing a CFL to an LED GSL, while these features will be more similar when comparing lamps within each of the technologies. For this reason, in the consumer choice module, DOE subdivided the integrated low-lumen lamp options into two nests: one for CFLs and one for LED GSLs. For the other two product classes, there was only a single nest, so the model reduces to a conditional logit model.

Development and calibration of the logit. To determine the logit variables and coefficients used in Eq. 9.2, DOE made use of a report issued by Pacific Gas & Electric utility (PG&E) that used extensive consumer surveys to probe consumer preferences for GSLs as a function of several descriptive variables.[7] The report authors used a conjoint model to produce a preference index for each variable, ranging from 0 to 100, and indicating relative levels of consumer preference. The preference index for each variable can be interpreted as representing the difference in the fraction of consumers who would choose a test product option over a reference option, where the two options differ only in the variable of interest, with all other features identical:

$$\boldsymbol{I = 100 \times (P_{test} - P_{ref})}$$

Eq. 9.25

subject to the constraint

$$\boldsymbol{P_{test} + P_{ref} = 1}$$

Eq. 9.26

Where:

I = the preference index,
P_{test}= the probability of choosing the test option, and
P_{ref} = the probability of choosing the reference option.

If the test and reference options are identical, the index has a value of zero, reflecting the equal probabilities that consumers would choose either option. An index value of 100 indicates that 100% of consumers would choose the test option over the reference option, an index value of 50 indicates that 75% of consumers would choose the test option and 25% would choose the reference option, and so on.

Considering the logit probability function in Eq. 9.1, one notes that the two products in this test case can be assumed to be in the same nest, since they have identical features aside from the variable being considered. With that assumption, combining Eq. 9.25 with the logit probability function yields an equation for the probability index in terms of the relevant logit variable and coefficient:

$$\boldsymbol{I_i = 100 \times \left(1 - \frac{e^{\beta_i v_{i,test}} - e^{\beta_i v_{i,ref}}}{e^{\beta_i v_{i,test}} + e^{\beta_i v_{i,ref}}}\right)}$$

Eq. 9.27

Where:

I_i = the preference index for variable v_i,
β_i = the logit coefficient for variable v_i, and
$v_{i,test}, v_{i,ref}$ = the value of variable v_i for the test and reference product options, respectively.

To develop the logit model DOE fitted this equation to the preference indices extracted from the PG&E report to yield beta coefficients for four lamp features: price, fractional energy savings (relative to the reference lamp), lifetime, and the presence of mercury. These lamp features were chosen since they can be used to categorically distinguish between the lamp options corresponding to different CSLs. Other lamp features considered in the PG&E report, such as energy-efficiency labeling or dimmability, could vary within a given CSL, and so they are not helpful variables for a consumer-choice model that considers a choice among the CSLs considered in this analysis.[b] In the derivation of the logit model, features such as these are handled as unobserved random variables that drop out of the final logit formula.

The presence-of-mercury variable is a binary (dummy) variable equal to unity for CFLs and zero for LED GSLs. In this case, Eq. 9.27 can be solved analytically to provide a value for the coefficient. For the other three lamp features considered, DOE fitted Eq. 9.27 to the data via least-squares minimization, using two different functional forms: first, DOE assumed that the variable v_i was simply equal to the lamp feature being considered (price, lifetime, or energy savings), and second, DOE assumed that v_i was equal to the natural logarithm of the lamp feature. The linear model represents a consumer choice based on absolute differences between features, whereas the logarithmic model is more appropriate if consumers choose based on fractional differences between features. In developing the logit model to be used in the consumer choice module, DOE chose either the linear or the logarithmic scaling for each variable, depending on which one gave a better description of the data.

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[b] The PG&E report also presents a preference index for the amount of money that could be saved by using a particular lamp option, which could be used to distinguish between the CSLs. This variable is partially redundant with both the fractional energy savings and the lifetime, however, and it depends strongly on consumer usage patterns, so DOE did not use it in the logit model for this shipments analysis.

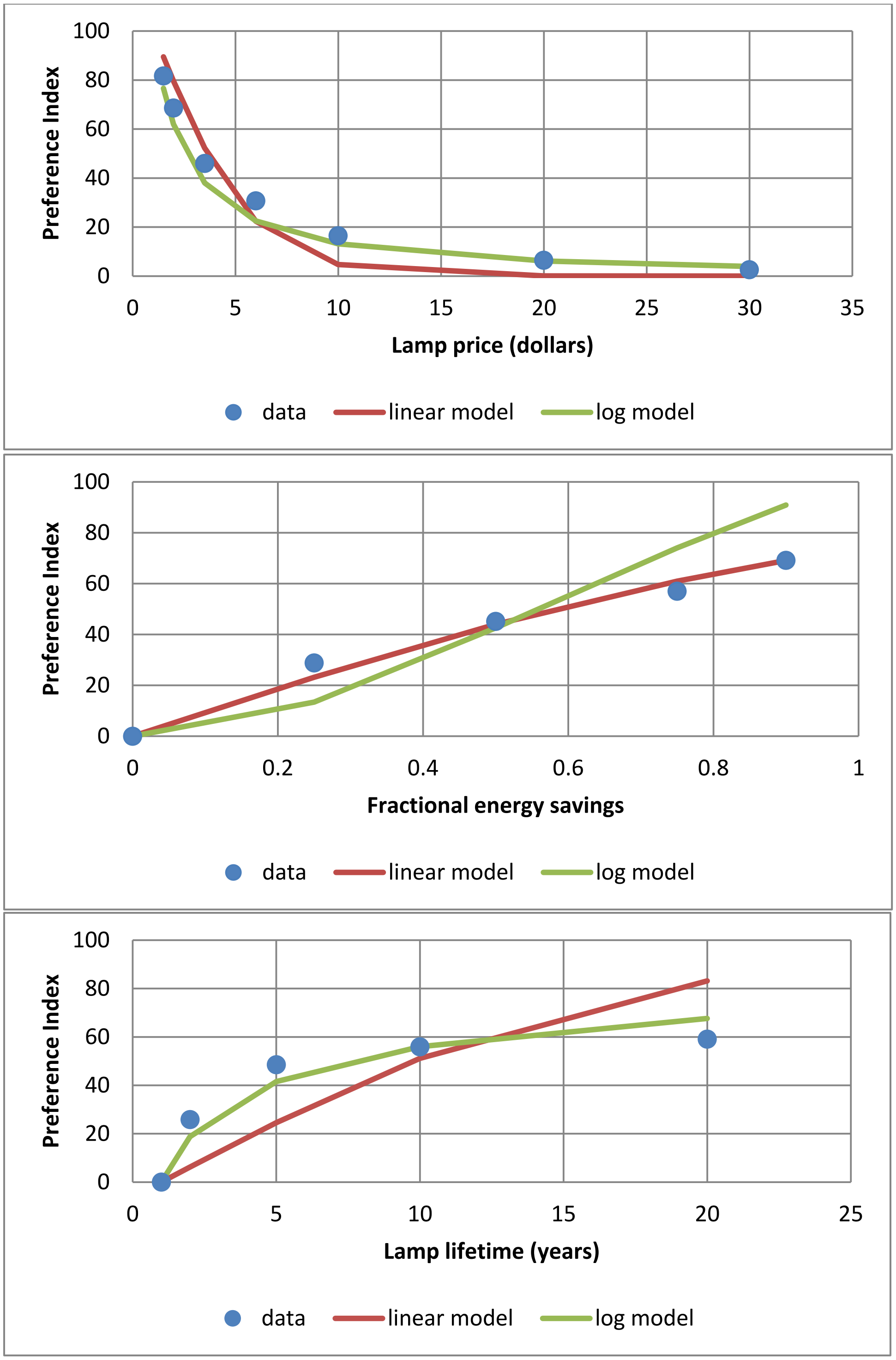

Figure 9.3.1 Preference Index Data from a Report[7] for PG&E on Consumer Lamp Preferences, Fitted to Models Given by Eq. 9.27, with Variables that are either Linear or Logarithmic in the Quantity Plotted on Each Plot's Horizontal Axis.

The fits of Eq. 9.27 to the PG&E data are shown in Figure 9.3.1, for both the linear and the logarithmic models. As shown, the logarithmic model gives a more accurate description of the preference indices for price and lifetime, whereas the linear model gives a more accurate description of the index for fractional energy savings. (It is interesting to note that this suggests the preference for absolute energy savings is also logarithmic.) Therefore, DOE assumed that the logit model depends logarithmically on price and lifetime and linearly on fractional energy savings and the presence of mercury. Thus, the logit function in Eq. 9.2 becomes

$$\boldsymbol{z_i = \beta_P \ln(P_i) + \beta_L \ln(L_i) + \beta_W \left(1 - \frac{W_i}{W_0}\right) + \beta_M M_i}$$

Eq. 9.28

Where:

z_i = the logit for lamp option i,
P_i = the price of lamp option i (dollars),
L_i = the median lifetime of lamp option i (years),
W_i = the system wattage of lamp option i,
W_0 = the system wattage of the baseline lamp option,
M_i = a binary (dummy) variable indicating the presence or absence of mercury lamp option i, and
β_X = the logit coefficient for variable X.

The median lifetime was used as a representative lifetime variable in the shipments model, since the lifetime in years of any individual lamp depends strongly on its usage. The median lifetime was computed by taking the time to 50% survival from the survival probability function P_{surv} as derived in appendix 8E of this preliminary TSD. The values of the lamp variables used as inputs to this equation are presented in section 9.3.4. The residential-sector beta coefficients are given by the fits described in this section; they are presented in Table 9.3.2.

DOE was unable to obtain appropriate data to directly calibrate the logit coefficients for consumers in the commercial sector. To estimate these, DOE made use of the sector-specific logit scaling factors developed for the shipments analysis in the TSD for the 2014 Notice of Proposed Rulemaking for General Service Fluorescent Lamps and Incandescent Reflector Lamps (chapter 11 of that TSD).[14] Based on the sector-specific scaling performed for the logit coefficients in that analysis, DOE assumed for the present analysis that the absolute value of the price coefficient in the residential sector was 45% lower than in the commercial sector, while the absolute values of the lifetime and fractional energy savings coefficients were 50% lower in the residential sector than the commercial sector. The consumer sensitivity to mercury content was assumed to be identical in the two sectors. The resulting logit coefficients for the commercial sector are presented in Table 9.3.2.

Table 9.3.2 Sector-Specific Parameters of the Logit Formula Given in Eq. 9.28.

Variable	Residential coefficient	Commercial coefficient
Log Price	-2.64	-4.8
Fractional Energy Savings	1.89	3.78
Log Lifetime	1.27	2.54
Presence of Mercury	-1.18	-1.18

Calibration of the nest parameters. It was also necessary to calibrate the nest parameters, λ_k, from Eq. 9.1. There are two such parameters for the nested logit model used in this analysis: one for CFLs and one for LED GSLs. To calibrate these parameters, DOE started by assuming that both parameters were equal to unity (and that all other parameters were as determined in this section). When the model was run with this parameterization, the relative market shares of CFLs and LED GSLs were significantly different from the market shares observed in the historical shipments data. Therefore, DOE varied the two parameters λ_{CFL} and λ_{LED}until the market shares predicted by the model were consistent with the market shares revealed in the historical data. The same nest parameters were applied in both the residential and commercial sectors. The calibrated parameters resulting from this procedure are presented in Table 9.3.3.

Table 9.3.3 Nest Parameters Used in the Consumer Choice Module

$\boldsymbol{\lambda_{CFL}}$	0.2
$\boldsymbol{\lambda_{LED}}$	0.5

9.3.2.2 Bass Adoption Model

As discussed in section 9.2.1.3 DOE used a Bass diffusion curve (Eq. 9.3) to restrict adoption of new technologies in the shipments model. The diffusion model was used to place an increasing ceiling on the market share of LED GSLs in each year of the shipments projection period as outlined in section 9.2.1.3. It was also used to determine the demand for integrated LED luminaires as substitutes for GSLs, as presented in Eq. 9.17.

The adoption parameters used for this analysis were chosen to match the adoption model used to forecast LED adoption in a recent report[15] from DOE's SSL program, which used a similar consumer-choice based approach to the one utilized in this analysis. The adoption curve coefficients of external and internal influence used in Eq. 9.3, p and q, are presented in Table 9.3.4, and the Bass adoption curve is plotted in Figure 9.3.2. For all LED technologies considered, DOE computed the market penetration assuming that the year of product introduction was 2008.

Table 9.3.4 Bass Adoption Model Parameters

p	0.012
q	0.29

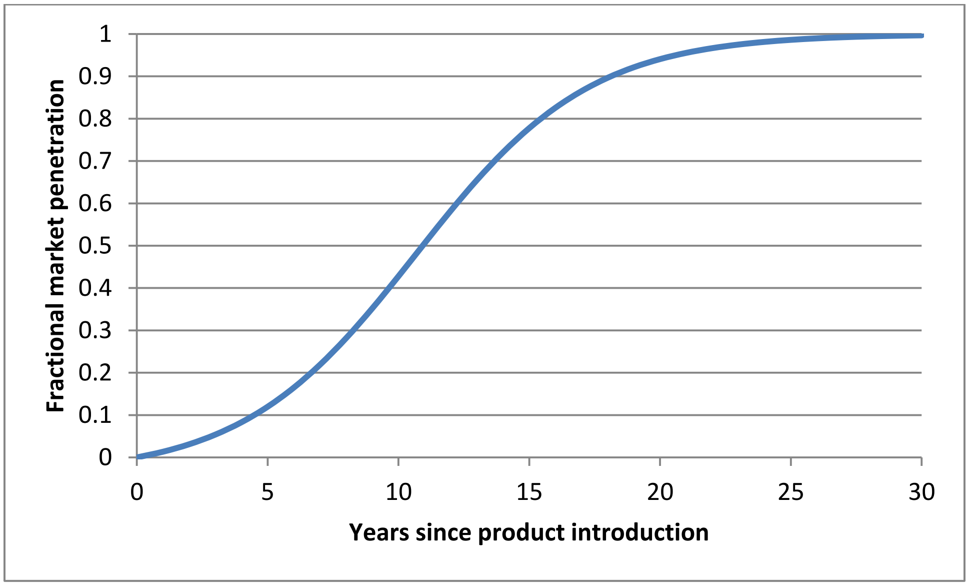

Figure 9.3.2 Bass Diffusion Curve for LED Technologies Using the Parameters Presented in Table 9.3.4

9.3.2.3 Incoming and outgoing demand

As discussed in section 9.2.2.3, DOE assumed that some demand for the GSL lamp options modeled here will be displaced in each year by consumers' switching to integrated LED fixtures. DOE also assumed, in the early years of the projection period, that the demand for CFL and LED GSLs will be supplemented by consumers' switching away from incandescent and halogen GSLs, either independently or as a result of the EISA 2007 backstop.

The outgoing demand model (see Eq. 9.17) depends on a free parameter f_{integ} that defines the maximum fraction of GSL luminaires that will be displaced by integrated LED luminaires when the latter reach their maximum market penetration. Based on input from manufacturers and lighting experts, DOE adopted a value of $f_{integ} = 0.15$ in its reference analysis. DOE views this fraction as highly uncertain, however. To assess the impact of this assumption on the results of the shipments and later analyses, DOE performed alternative scenario analyses with different assumed values for f_{integ}; these are discussed in section 9.4.

The incoming demand model (see Eq. 9.18) is based on an assumed fraction f_{sub} of consumers' substituting CFLs or LED GSLs for other GSL technologies in each year prior to 2020. The model depends on the shipments of other GSL technologies in 2013, the year before the projection begins and on the assumed fraction of consumers who switch in each year. Based on the historical shipments estimates provided by Cadeo Group,[12] DOE assumed that 748 million GSLs using non-CFL and non-LED technologies were shipped to the US market in 2013.

DOE then determined a sector-specific value for f_{sub} in both the commercial and residential sectors by using this quantity as a calibration parameter. Starting with an assumed value of $f_{sub} = 0$, if the projected combined shipments of CFLs and LED GSLs in 2014 were substantially below the 2013 historical shipments in a given sector, then that sector's f_{sub} value was increased until the shipments projection yielded a smooth transition from the historical shipments. This procedure yielded values of $f_{sub} = 0$ and $f_{sub} = 0.15$ for the commercial and residential sectors, respectively. These values amount to an assumption that the commercial sector has largely switched away from incandescent and halogen GSLs almost completely, while significant transition is still underway in the residential sector.

9.3.2.4 Availability Matrix

The availability matrix A_{ji} (see Eq. 9.23) specifies whether or not lamp option i is available for selection if lamp option j is being replaced. This section defines the availability matrix that DOE used for this shipments analysis.

Within each lamp category in the integrated product classes, all lamp options in the model are directly interchangeable, while lamp options in different lamp categories are not interchangeable. Thus, for all integrated lamp options, $A_{ji} = 1$ whenever lamp options j and i are in the same lamp category and option i is not eliminated by the standard under consideration. Otherwise, $A_{ji} = 0$.

For the non-integrated product category, there is one baseline lamp option and two lamp options at CSL1. One of the CSL1 lamp options has the same wattage as the baseline lamp, but higher lumen output, while the other lamp option has reduced wattage. Input to DOE from lighting manufacturers suggests that the reduced-wattage lamp option has extremely low market share on the order of 5% of less. Moreover, in its assessment of the market, DOE found that reduced-wattage options do not exist for the majority of non-integrated GSL base types. For these reasons, DOE assumed in the shipments analysis that the reduced-wattage lamp option is a niche product, so that consumers currently using it will continue to use it, but consumers currently using full-wattage lamps will not switch to the reduced-wattage option.

Thus, the availability matrix for non-integrated GSLs was equal to one for consumers replacing a full-wattage lamp with either of the two full-wattage lamp options, and it was equal to one for consumers replacing a reduced-wattage with a reduced-wattage lamp, but it was zero for substitutions between full and reduced-wattage lamps. The historical shipments calibration discussed in section 9.3.1.2 assumed that the reduced wattage lamp option made up approximately 5% of the non-integrated GSL market; the availability matrix then ensured that the reduced wattage lamp retained a market share at approximately the same level throughout the shipments projection period.

9.3.2.5 Acceptance Factors

As discussed in section 9.2.1.3, the consumer choice module can utilize acceptance factors to restrict the market share of certain options and account for market factors not explicitly modeled. Given the market-share restrictions arising from the Bass adoption model for LED technology (section 9.3.2.2), as well as the nest parameters which set the relative desirability of

CFL and LED GSLs (section 9.3.2.1), the market shares for CFLs and LED GSLs at the start of the shipments projection period were consistent with the market share trends at the end of the historical period. Moreover, the availability matrix discussed in section 9.3.2.4 ensures that the market shares of different non-integrated lamp options are consistent with historical values. Therefore, no further restriction of the market shares for any of the lamp options was required for this analysis, so all acceptance factors were assumed equal to unity prior to the application of the Bass adoption curve in each year.

9.3.3 Price Trend Projection

As discussed in section 9.2.1.4, DOE uses a learning-curve model, with certain modifications, to project future prices in its shipments analysis. Accordingly, the initial lamp prices determined in the pricing analysis (chapter 6 of this TSD) are subsequently adjusted over the shipments projection period to account for projected price trends. The price model consists of a learning-curve component applied to all technologies, with a separate treatment of the price component arising from REOs for CFLs, and a separate treatment of the incremental price of more luminous lamps for LED GSLs. To construct the price model, DOE made use of the LBNL GSL price report and the REO price analysis conducted in appendix 8D of this TSD.

9.3.3.1 Lamp Options Excluded from the Price Trend Projection

The mix of GSL products on the US market has been evolving rapidly in recent years, with once cutting-edge products being rapidly supplanted by new, less expensive, more efficacious, and more aesthetically pleasing lamps, on time scales of a year or less. This situation can temporarily create an unusual price structure in which the most efficacious products on the market are also the least expensive, since the older, less efficacious products were introduced to the market at a higher price point, and have since become effectively obsolete. This price structure is reflected in the results of the product price determination (chapter 6 of this TSD), where the CFL and LED GSL lamp options in the integrated low-lumen product class decline monotonically in price as their efficacy increases.

In the shipments analysis and NIA, for the integrated low-lumen product class, DOE assumed that the two most efficacious LED lamp options, at CSLs 4 and 5, represent recent introductions to the market, whereas the two least efficacious LED options, CSLs 2 and 3, represent older products that are being supplanted by the newer entrants to the market. Similarly, for the integrated low-lumen product class, DOE assumed that the baseline CFL lamp option represents an older product that is being supplanted by the newer entrant at CSL1. Since further research and development is unlikely to occur on the now-obsolescent products, there is little driving force to bring their prices down.

Therefore, in the integrated low-lumen product class, DOE applied the LED GSL price trend model only to the lamp options at CSLs 4 and 5, and DOE applied the CFL price trend model only to the lamp option at CSL 1. DOE assumed that all other lamp options in the product class will have fixed real prices over the shipments projection period. This assumption will effectively eliminate the older products from the market by early in the analysis period. In the integrated high-lumen and non-integrated product classes, by contrast DOE applied the CFL price trend model to all lamp options, since prices in those product classes increase monotonically as a function of luminous efficacy.

9.3.3.2 Learning Rate Parameters

The LBNL GSL price report measures the learning rate parameter, b, defined in Eq. 9.6 for both CFLs and LED GSLs and compares these to the rates for other lighting technologies. It concludes that the learning rate parameter for CFLs is similar to the one observed for other lighting technologies, whereas the learning rate parameter for LEDs is substantially higher. DOE believes that that the higher LED learning rate may be a transitory phenomenon arising from strong market competition and the supportive current policy environment for LED research and development. In that case, the learning rate for LED GSLs may be expected to fall to a value nearer the rate observed for other lighting technologies. Thus, in its reference analysis, DOE assumed that both CFLs and LED GSLs have the same learning rate parameter of $b = 0.22$ during the shipments projection period. As discussed in section 9.4, DOE also analyzed an alternative scenario in which LED GSLs have the higher learning rate observed in the LBNL GSL price report, as well as an alternative scenario in which prices are fixed in real dollars for all lamp options.

9.3.3.3 Incremental Price Trends for LED GSLs

For LED GSLs, in addition to applying a learning curve to the base price of the technology, DOE modeled an exponential price trend on the incremental price of increased lumen output, as detailed in section 9.2.1.4, specifically Eq. 9.9. The rates of exponential decline used in applying that equation were taken from the LBNL GSL price report; they are presented in Table 9.3.5.

Table 9.3.5 Exponential Decline Parameters for the Incremental Price of Increased Lumen Output for LED GSLs

Lamp Category	**Incremental price decline parameter α_ℓ* (yr^{-1})**
310-749 lm	0.00
750-1049 lm	0.56
1050-1489 lm	0.59
1490-1999 lm	0.59

*As defined in Eq. 9.9

9.3.3.4 Rare Earth Costs

As described in section 9.2.1.4, DOE considered the impact of possible changes in REO prices in its GSL shipments modeling. REOs are used in fluorescent lamp phosphors at higher concentrations in more efficient models. REOs saw large price increases in the third quarter of 2010 and into 2011, which have now largely corrected themselves, as shown by the fluorescent tri-band phosphor price index shown in Figure 9.3.3 and described in appendix 8D This volatility has resulted in significant uncertainty about the potential long-term impact on prices for fluorescent lamps, including CFLs.

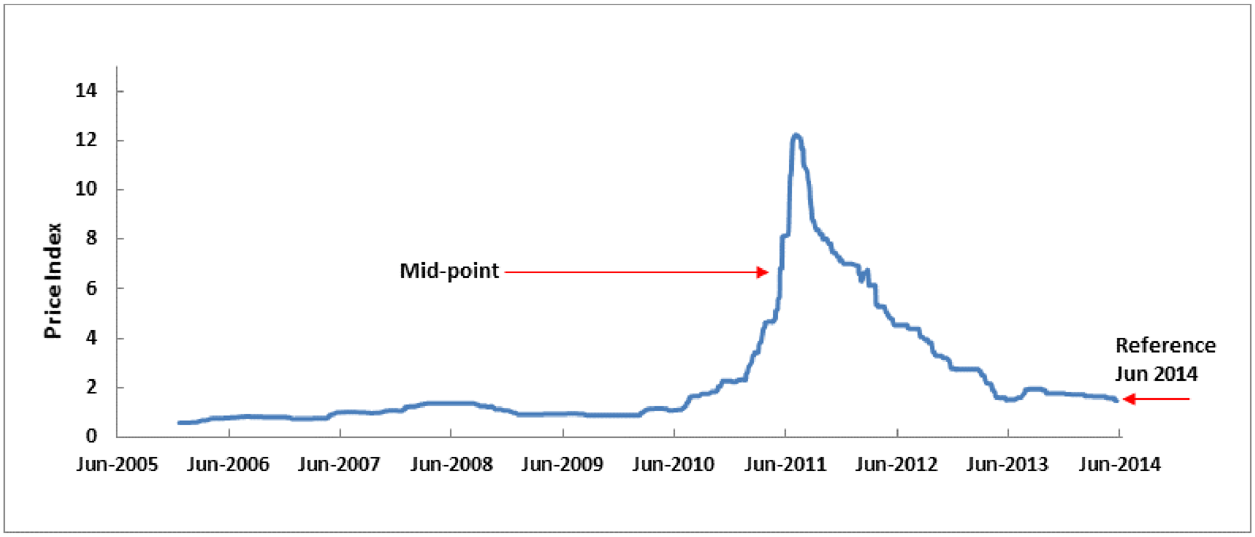

Figure 9.3.3 Inflation-Adjusted, Tri-band Phosphor REO Price Index

Given the large uncertainty caused by such price volatility, DOE modeled CFL prices assuming two different REO price scenarios detailed in appendix 8D a reference (best estimate) scenario, which reflects the REO prices with recent price data (June 2014), and a high REO price scenario (corresponding to the identified mid-point in Figure 9.3.3), which reflects the mid-point REO price between the 2011 peak price and the 2006 – 2009 baseline average price. Given the lack of any clear, consistent price trend, in both scenarios the REO price was assumed to remain constant in real dollars over the shipments projection period.

9.3.4 General Service Lamp Characteristics

Table 9.3.6,
Table 9.3.7, and Table 9.3.8 show the characteristics of the GSL lamp options used as inputs to the shipments model in DOE's reference scenario analysis.

Table 9.3.6 Lamp Characteristics Used as Inputs to the Shipments Model for the Integrated Low-Lumen Product Class in the Reference Scenario

Lamp Category	CSL	Lamp Technology	Initial Lamp Lumens	Nominal Wattage	Efficacy (lm/W)	Lamp Price (incl. Sales tax, 2014$)	Rare Earth Cost (2014$)	Life Hours	Median Lifetime, Residential (Years)	Median Lifetime, Commercial (Years)	System Wattage* (W)	Energy Savings Relative to Baseline	Contains Mercury
310-749 lm	0	CFL	469	9.5	49.1	$5.57	$0.02	10000	6.8	2.6	9.5	0.00	Yes
	1	CFL	500	8.9	56.4	$3.93	$0.02	12000	8.2	3.1	8.9	0.07	Yes
	2	LED	500	8.1	61.6	$27.55	-	25000	19.2	6.5	8.1	0.15	No
	3	LED	500	7.4	67.7	$17.54	-	25000	19.2	6.5	7.4	0.23	No
	4	LED	500	6.7	75.0	$13.98	-	25000	19.2	6.5	6.7	0.30	No
	5	LED	500	6.3	79.1	$13.27	-	25000	19.2	6.5	6.3	0.34	No
750-1049 lm	0	CFL	750	14.0	53.6	$6.02	$0.03	10000	6.8	2.6	14.0	0.00	Yes
	1	CFL	800	13.0	61.5	$4.25	$0.03	12000	8.2	3.1	13.0	0.07	Yes
	2	LED	800	12.0	66.7	$30.12	-	25000	19.2	6.5	12.0	0.14	No
	3	LED	800	11.0	72.7	$19.18	-	25000	19.2	6.5	11.0	0.21	No
	4	LED	800	10.0	80.0	$15.28	-	25000	19.2	6.5	10.0	0.29	No
	5	LED	800	9.5	84.2	$14.51	-	25000	19.2	6.5	9.5	0.32	No
1050-1489 lm	0	CFL	1125	19.8	56.9	$7.58	$0.05	10000	6.8	2.6	19.8	0.00	Yes
	1	CFL	1200	18.4	65.4	$5.36	$0.05	12000	8.2	3.1	18.4	0.07	Yes
	2	LED	1200	17.0	70.4	$50.16	-	25000	19.2	6.5	17.0	0.14	No
	3	LED	1200	15.7	76.5	$31.95	-	25000	19.2	6.5	15.7	0.21	No
	4	LED	1200	14.3	83.7	$25.46	-	25000	19.2	6.5	14.3	0.28	No
	5	LED	1200	13.6	88.0	$24.17	-	25000	19.2	6.5	13.6	0.31	No

Lamp Category	CSL	Lamp Technology	Initial Lamp Lumens	Nominal Wattage	Efficacy (lm/W)	Lamp Price (incl. Sales tax, 2014$)	Rare Earth Cost (2014$)	Life Hours	Median Lifetime, Residential (Years)	Median Lifetime, Commercial (Years)	System Wattage[*] (W)	Energy Savings Relative to Baseline	Contains Mercury
1490-1999 lm	0	CFL	1500	25.6	58.6	$8.52	$0.06	10000	6.8	2.6	25.6	0.00	Yes
	1	CFL	1600	23.8	67.3	$6.02	$0.06	12000	8.2	3.1	23.8	0.07	Yes
	2	LED	1600	22.1	72.3	$72.98	-	25000	19.2	6.5	22.1	0.14	No
	3	LED	1600	20.4	78.3	$46.48	-	25000	19.2	6.5	20.4	0.20	No
	4	LED	1600	18.7	85.6	$37.04	-	25000	19.2	6.5	18.7	0.27	No
	5	LED	1600	17.8	89.9	$35.17	-	25000	19.2	6.5	17.8	0.30	No

[*] For integrated GSLs, the system wattage is equal to the nominal wattage. For non-integrated GSLs, the system wattage depends on the lamp-and-ballast combination; for details see chapter 5 of this TSD.

Table 9.3.7 Lamp Characteristics Used as Inputs to the Shipments Model for the Integrated High-Lumen Product Class in the Reference Scenario

CSL	Lamp Technology	Initial Lamp Lumens	Nominal Wattage	Efficacy (lm/W)	Lamp Price (incl. Sales tax, 2014$)	Rare Earth Cost (2014$)	Life Hours	Median Lifetime, Residential (Years)	Median Lifetime, Commercial (Years)	System Wattage[*] (W)	Energy Savings Relative to Baseline	Contains Mercury
0	CFL	2000	32.0	62.5	$10.82	$0.07	10000	6.8	2.6	32.0	0.00	Yes
1	CFL	2000	30.0	66.7	$11.19	$0.07	10000	6.8	2.6	30.0	0.06	Yes
2	CFL	2200	29.0	75.9	$12.01	$0.07	12000	8.2	3.1	29.0	0.09	Yes

[*] For integrated GSLs, the system wattage is equal to the nominal wattage. For non-integrated GSLs, the system wattage depends on the lamp-and-ballast combination; for details see chapter 5 of this TSD.

Table 9.3.8 Lamp Characteristics Used as Inputs to the Shipments Model for the Non-Integrated Product Class in the Reference Scenario

CSL	Lamp Technology	Initial Lamp Lumens	Nominal Wattage	Efficacy (lm/W)	Lamp Price (incl. Sales tax, 2014$)	Rare Earth Cost (2014$)	Life Hours	Median Lifetime, Residential (Years)	Median Lifetime, Commercial (Years)	System Wattage* (W)	Energy Savings Relative to Baseline	Contains Mercury
0	CFL	1710	26.0	65.8	$14.67	$0.06	10000	N/A	2.6	30.0	0.00	Yes
1**	CFL	1800	26.0	69.2	$15.79	$0.06	17000	N/A	4.4	30.0	0.00	Yes
	CFL	1525	21.0	72.6	$17.51	$0.06	20000	N/A	5.2	24.4	0.19	Yes

[*] For integrated GSLs, the system wattage is equal to the nominal wattage. For non-integrated GSLs, the system wattage depends on the lamp-and-ballast combination; for details see chapter 5 of this TSD.

[**] Two lamp options were analyzed at CSL 1 in the non-integrated product class.

9.4 ALTERNATIVE SCENARIOS

9.4.1 Overview

In addition to determining the best estimates of the impacts of the CSCs described in the introduction to this chapter (section 9.1), DOE conducted alternative analyses to gauge the importance of various assumptions for the results of the shipments analysis and NIA. Alternative analyses that affect the NIA only are described in chapter 10 of this TSD. This section describes the analyses that affect shipments, and, therefore, also the NIA. A complete summary of the alternative scenario analyses is given in appendix 8B.

As summarized in Table 9.4.1, these analyses explore the model sensitivity to uncertainties in the penetration of integrated LED luminaires, in the actual lamp service lifetime, in the price learning rate, and in REO prices. An individual scenario tests the effect of modifying only one scenario variable. The effect is determined by comparing the results of the alternative scenario model runs to the results in the reference scenario, which holds all variables at their reference (best estimate) values. Summary shipments analysis results for the alternative scenarios are presented in section 9.5.

Table 9.4.1 Summary of Alternative Scenarios Analyzed in the Shipments Analysis

Scenario Name	**Scenario Options Analyzed**	**Scenario Description**
Reference	Reference selection indicated in bold below	DOE's best estimate of the national impacts of a GSL standard
Integrated LED incursion	0%	Incursion of LED luminaires into the market for traditional GSL luminaires at the end of the analysis period; see appendix 8B of this TSD
	15%	
	50%	
Lamp Service Lifetime	Rated	Varies assumptions about the primary driver for lamp replacements (lamp failure, renovation, or early replacement with newer technology); see chapter 8 of this TSD.
	Renovation-Driven	
	Early-Replacement	
Learning Rate	None	Learning rates used to develop lamp price trends, as described in section 9.3.3.2
	CFL	
	Technology	
High Rare Earth	**Constant**	Price scenario for rare earth oxides, applies to CFLs only; see appendix 8D of this TSD
	High	

9.5 RESULTS

This section presents summary results of the GSL shipments analysis for DOE's reference scenario and for the alternative scenarios described in section 9.4. Complete results can be viewed using the Microsoft Excel® NIA spreadsheet tool described in appendix 10A of this TSD.

9.5.1 Reference Scenario Results

Figure 9.5.1 presents the base-case shipments for each product class by sector and lamp option. The large spike in shipments in the residential sector that occurs at the beginning of the analysis period is due to increased demand for CFLs and LED GSLs owing to the assumption that the EISA 2007 backstop provision takes effect concurrent to this rulemaking, as described in sections 9.1.1 and 9.2.2.3.

Figure 9.5.2 and Figure 9.5.3 present the base case shipments by technology type for the commercial and residential sectors, respectively. Figure 9.5.4, Figure 9.5.5, and Figure 9.5.6 present the total estimated historical GSL shipments from 2010-2013 and projected shipments in each CSC for the integrated low-lumen product class, integrated high-lumen and non-integrated product classes respectively. The estimated historical data are disaggregated by product class from the historical shipments data presented in Table 9.3.1. Table 9.5.1 presents the base case cumulative shipments in each product class and the percent change in cumulative shipments under each CSC.

The strong, periodic variation in the shipments of non-integrated GSLs in the standards case, visible in Figure 9.5.6, occurs because the full-wattage CSL 1 lamp option has a much longer lifetime than the baseline lamp option. Therefore, there is a large influx of lamps with longer lifetimes in the compliance year, which are all replaced at approximately the same cadence (set by the average lamp lifetime) in future years. This causes the observed “ringing” in the shipments for this product class. Similar considerations cause more muted ringing effects in other product classes for certain CSCs.

Finally, price trends for each lamp option are presented. Figure 9.5.7 shows the base-case price trends for the integrated low-lumen product class by lamp option for each lamp category. Figure 9.5.8 and Figure 9.5.9 show the base-case price trends by lamp option, for the integrated high-lumen and non-integrated product classes respectively.

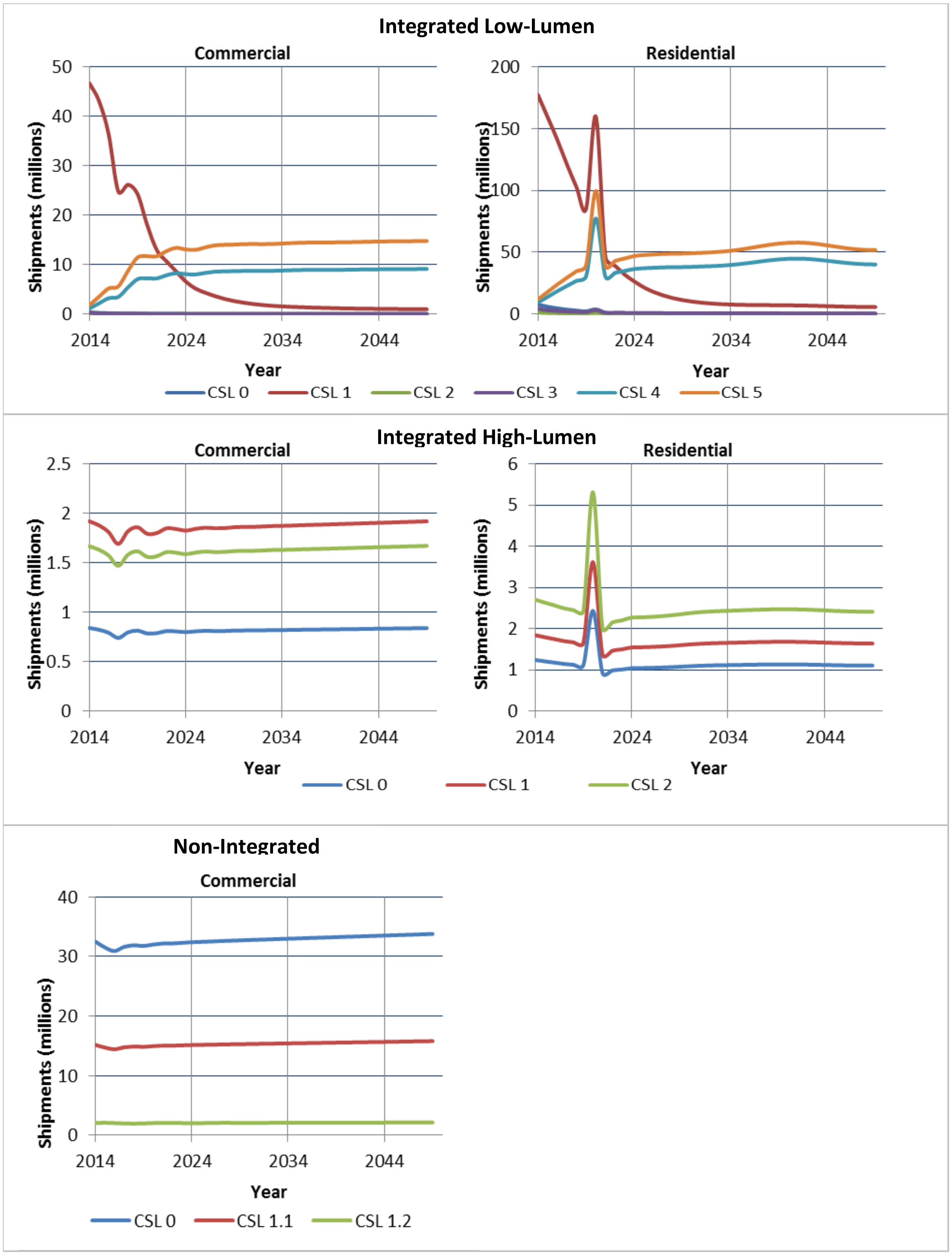

Figure 9.5.1 **Reference Scenario Base Case Shipments by Product Class, CSL, and Lamp Option**

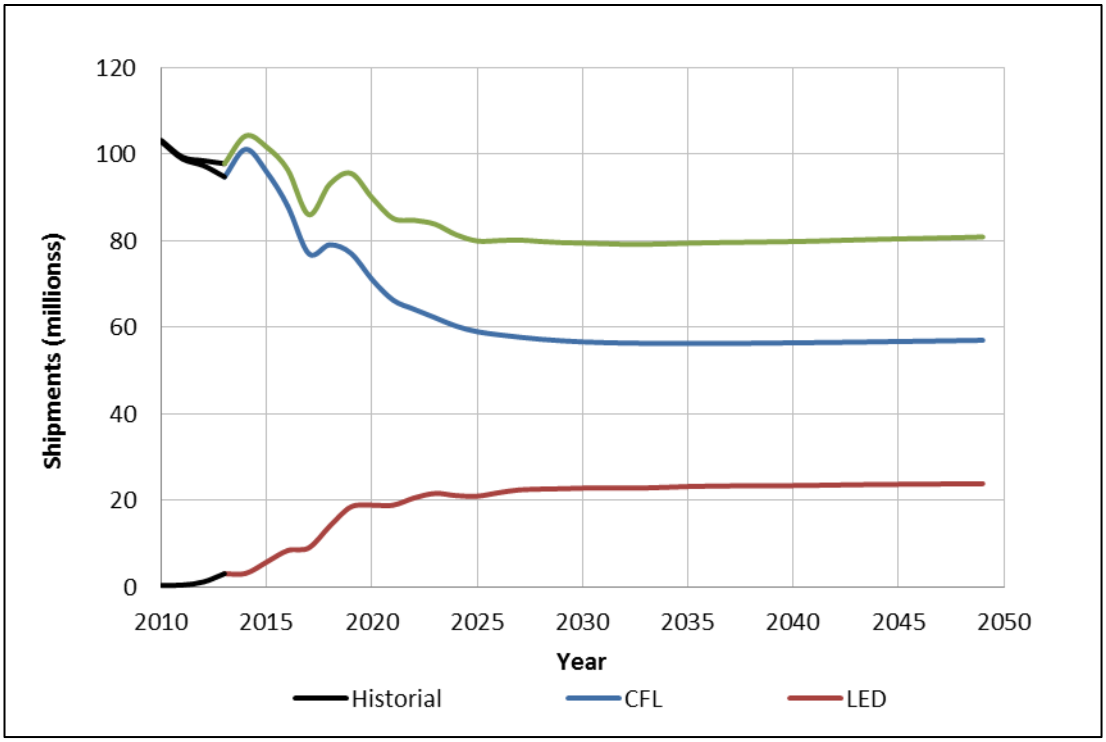

Figure 9.5.2 Reference Scenario Base Case Shipments by Lamp Technology in the Commercial Sector

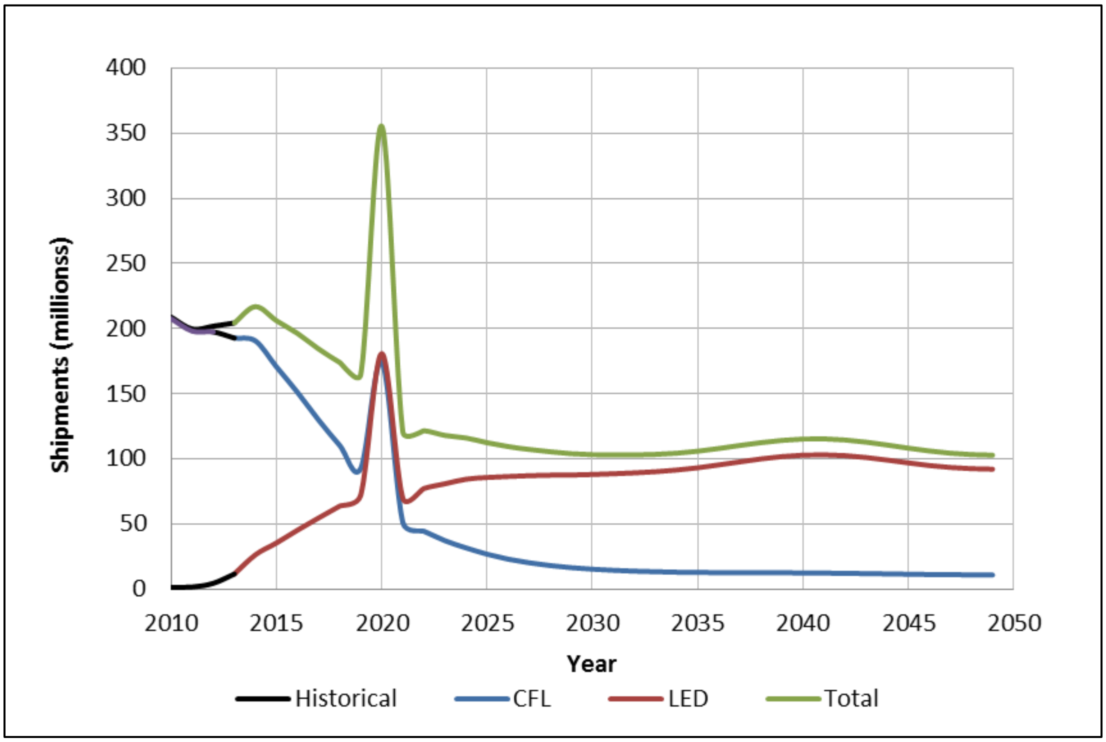

Figure 9.5.3 Reference Scenario Base Case Shipments by Lamp Technology in the Residential Sector

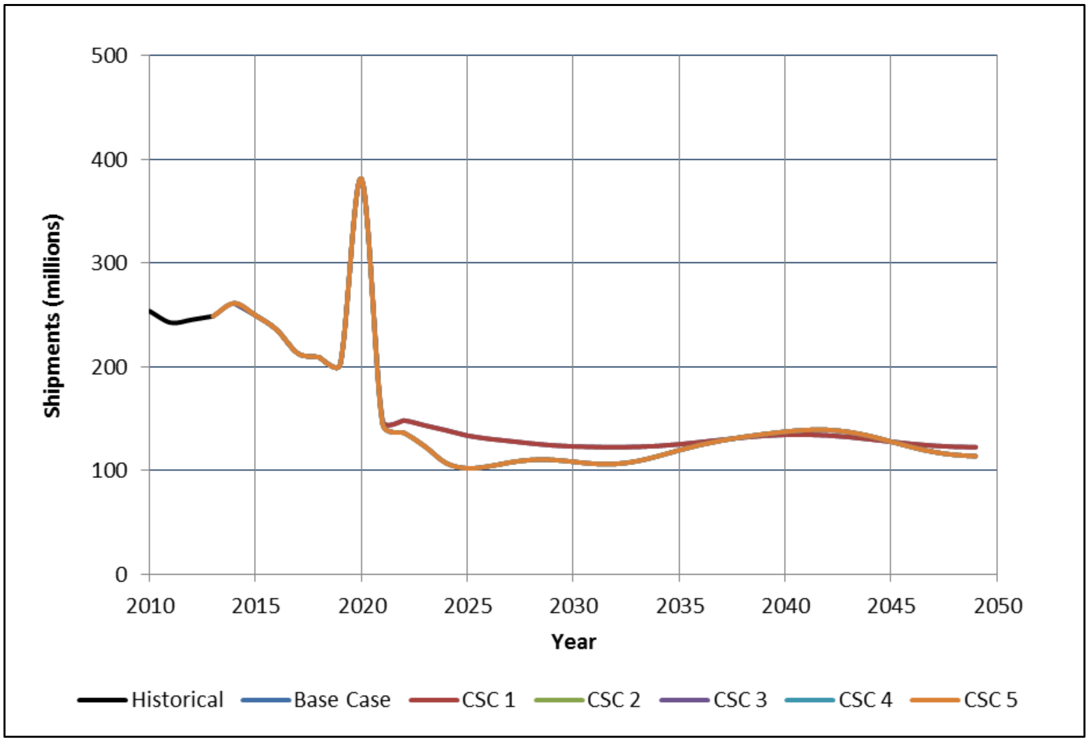

Figure 9.5.4 Total Shipments of Integrated Low-Lumen Lamps in the Reference Scenario for All CSCs

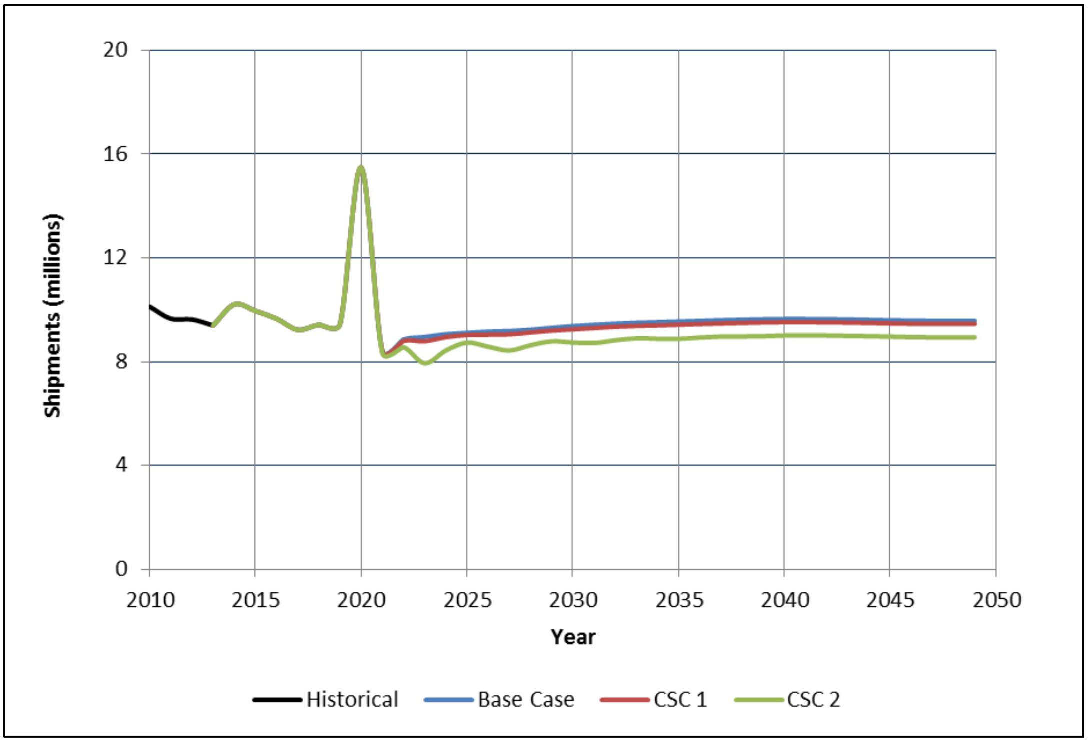

Figure 9.5.5 Total Shipments of Integrated High-Lumen Lamps in the Reference Scenario for All CSCs

Figure 9.5.6 **Total Shipments of Non-Integrated Lamps in the Reference Scenario for All CSCs**

Table 9.5.1 **Impact of Candidate Standards on the Cumulative Shipments of GSLs, 2020-2049**

Product Class	**Cumulative Shipments in the Base Case (billions)**	**Fractional change in cumulative shipments under candidate standards cases**				
		CSC 1	**CSC 2**	**CSC 3**	**CSC 4**	**CSC 5**
Integrated low-lumen	4.24	0%	-8%	-8%	-8%	-8%
Integrated high-lumen	2.88	-1%	-6%	-6%	-6%	-6%
Non-integrated	1.51	-23%	-23%	-23%	-23%	-23%

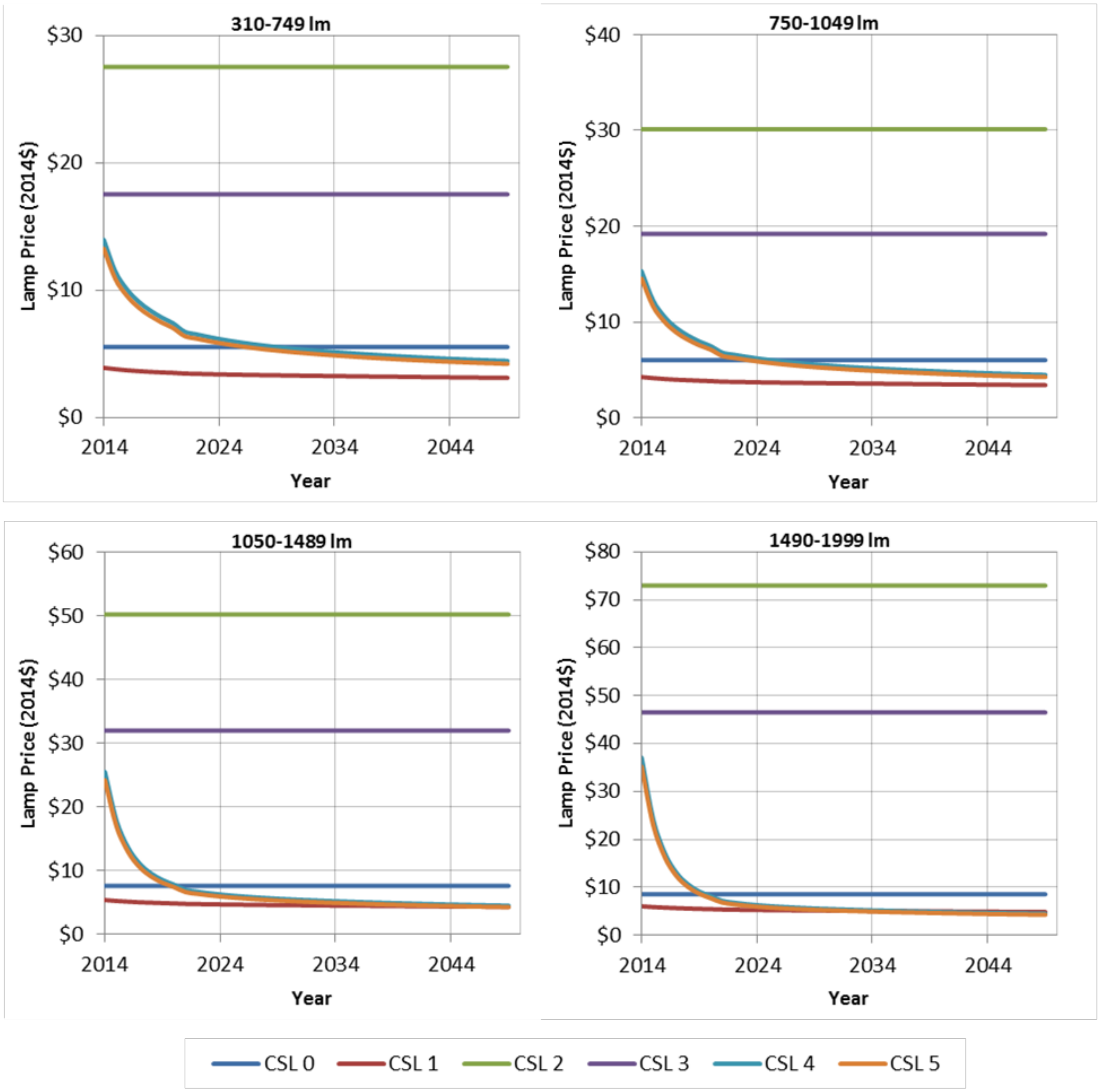

Figure 9.5.7 Base Case Price Trends for Lamp Options in the Integrated Low-Lumen Product Class by Lamp Category

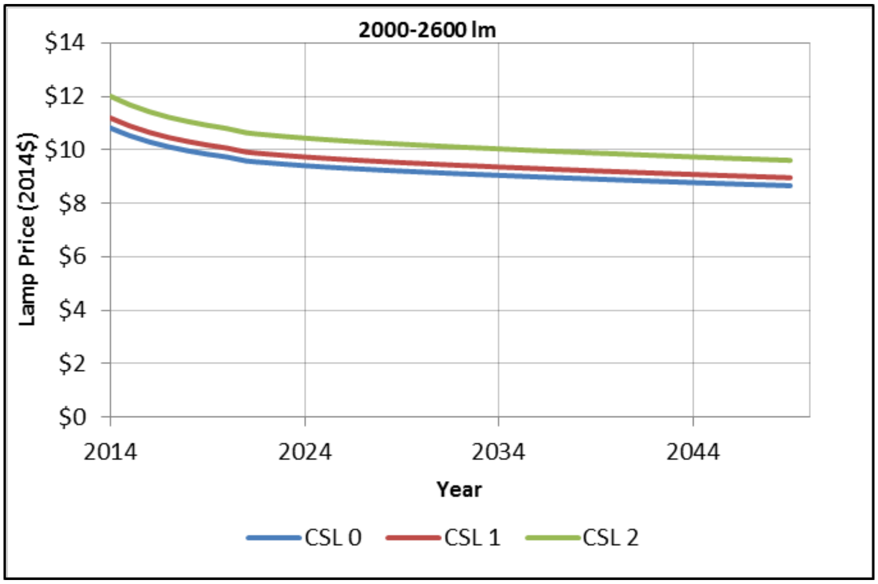

Figure 9.5.8 Base Case Price Trends for Lamp Options in the Integrated High-Lumen Product Class

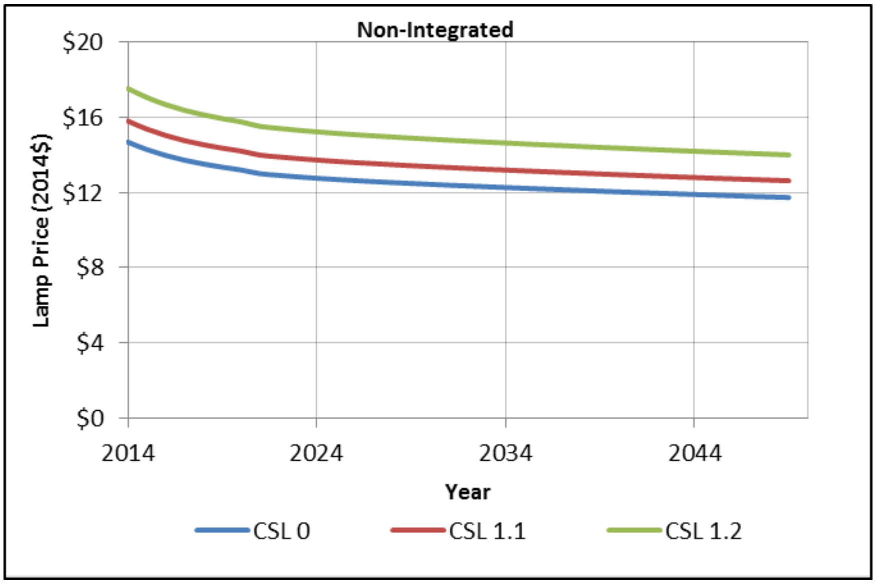

Figure 9.5.9 Base Case Price Trends for Lamp Options in the Non-Integrated Product Class

9.5.2 Results of the Alternative Scenario Analyses

Table 9.5.2 presents the cumulative shipments in the reference base case for each product class and the percent change in the base case cumulative shipments for each of the alternative scenarios that impact the shipments analysis (as summarized in Table 9.4.1).

Table 9.5.2 Impact of Alternative Scenario Assumptions on the Cumulative Shipments of GSLs in the Base Case, 2020-2049

Product Class	**Cumulative Base-case Shipments in the Reference Scenario (billions)**	**Fractional change in cumulative base-case shipments in each alternative scenario**						
		Integrated LED Incursion		**Lamp Service Lifetime**		**Learning Rate**		**Rare Earth Price**
		None	High	Early Replacement	Rated	None	Technology	High
Integrated low-lumen	4.24	12%	-22%	107%	-35%	7%	-2%	0%
Integrated high-lumen	2.88	13%	-23%	-1%	-14%	0%	0%	0%
Non-integrated	1.51	16%	-28%	0%	0%	0%	0%	0%

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CHAPTER 10. NATIONAL IMPACTS ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 10. NATIONAL IMPACTS ANALYSIS

10.1 INTRODUCTION

This chapter describes the method used to estimate the national impacts of energy conservation standards that the U.S. Department of Energy (DOE) is considering establishing for general service lamps (GSLs). In the national impacts analysis (NIA), DOE assessed the cumulative national energy savings (NES) of products shipped during a 30-year analysis period (2020 – 2049) and the net present value (NPV) of the total consumer economic impacts of various candidate standard cases (CSCs). To fully quantify energy savings realized by lamps with long lifetimes, DOE continued to account for use and retirements during a period after 2049 of those lamps shipped during the analysis period; this stock attrition period extends from 2050 through 2099 when the last lamp shipped during the analysis period is assumed to retire if it has not already. Each CSC is composed of lamps in each product class that meet or exceed various candidate standard levels (CSLs), which are defined in terms of lamp luminous efficacy. Table 10.1.1 lists the CSLs for all product classes at each CSC. In addition to NES and NPV, this chapter reports DOE's estimate of the monetary value of cumulative national energy savings and the cumulative change in equipment costs nationwide resulting from each CSC relative to a base case in which no new standards are assumed to take effect. In both the base case and the standards cases the backstop provision of the Energy Independence and Security Act of 2007[1] (EISA) is assumed to take effect requiring all GSLs shipped after January 1, 2020 to have a minimum efficacy of 45 lumens per watt.

Table 10.1.1 CSL for Each Product Class in Each CSC

Standards Case	Integrated Low-Lumen	Integrated High-Lumen	Non-Integrated
Base Case	0	0	0
CSC 1	1	1	1
CSC 2	2	2	1
CSC 3	3	2	1
CSC 4	4	2	1
CSC 5	5	2	1

DOE performs all NIA calculations using a Microsoft Excel® spreadsheet which is available on regulations.gov, docket number EERE–2013–BT–STD–0051 at http://www.regulations.gov/#!docketDetail;D=EERE-2013-BT-STD-0051. Details regarding, and instructions for using, the NIA spreadsheet are provided in appendix 10A.

Table 10.1.2 summarizes the inputs to the NIA spreadsheet model. A brief description of the data is given for each input.

Table 10.1.2 Summary of NES and NPV Inputs

Input	**Data Description**
Shipments	Annual shipments projections from the GSL shipments model (see chapter 9 of this preliminary TSD)
Stock of lamps	Modeled from historical data and shipments projections (see chapter 9 of this preliminary TSD)
Assumed effective date of standard	January 1, 2020
Analysis period	For products shipped from 2020 through 2049
Stock attrition period	2050-2099, to account for the full energy savings of long-lived LED GSLs that are shipped during the analysis period
Maximum lamp lifetime	Assumed to be 50 years to accommodate long-lived LED GSLs in the residential sector. To account for lamps that live this long, the NES calculation must include energy consumption costs for some lamps out to 2099.
Lamp characteristics	Wattage, first cost, and disposal cost (see chapters 5 and 8 of this preliminary TSD)
Lamp Prices	Prices of lamps, adjusted for price trend projections in each year (see chapter 9 of this preliminary TSD)
Projected electricity prices	From the Energy Information Administration's *Annual Energy Outlook 2014*[2] (*AEO 2014*) to 2040 and extrapolated beyond 2040
Site-to-primary electricity conversion	Generated by the National Energy Modeling System (NEMS) version corresponding to the *AEO 2014* to 2040 and extrapolated beyond 2040
Rebound effect	Percent of total energy savings in the commercial and residential sector (see appendix 10D)
Discount rate	Real 3 and 7 percent
Present year	Future costs and savings are discounted to the year 2014

The following sections describe in detail the methodology and inputs for the NIA. Section 10.2 discusses DOE's methods for calculating national energy consumption in the base case and standards cases, and the resulting NES of the standards cases with respect to the base case. Section 10.3 discusses the NPV calculation method. Section 10.4 presents the NES and NPV results for the different CSCs, and under various scenarios.

10.2 NATIONAL ENERGY SAVINGS

This section describes DOE's calculation of the NES for GSLs in the CSCs considered in this analysis.

10.2.1 Primary Energy Savings

The annual NES quantifies the difference in energy use between GSLs in the base case and a standards case in a given year. During the analysis period (2020-2049) this is the annual energy consumption (AEC) of the standards case subtracted from the annual energy consumption of the base case, adjusted for any rebound:

$$\boldsymbol{NES_{analysis}(y) = \left(AEC_{\,base}(y) - AEC_{\,std}(y)\right) \times RF}$$

Eq. 10.1

Where:

$NES_{analysis}(y)$ = national energy savings in year y[a] during the analysis period (2020-2049) (quads),
$AEC_{base}(y)$ = base case annual national energy consumption at the power plant for all lamps in year y (quads),
$AEC_{std}(y)$ = standards case annual national energy consumption at the power plant for all lamps in year y (quads), and
RF = rebound rate factor, given by 1- rebound rate (see appendix 10D).

The shipments analysis characterizes the GSL market by analyzing shipments of various *lamp options* within *lamp categories.* As described in chapter 9 of this preliminary TSD, lamp categories were developed to subdive the broad lumen range contained in the integrated low-lumen product class. The four lamp categories in the integrated low-lumen product class are based on the lumen ranges developed for general service incandescent lamps in EISA 2007,[1] modified for the product class definitions used in this preliminary analysis. The integrated high-lumen and non-intgrated product class each contain one lamp category. The lamp options within each lamp category are based on the representative units described in chapters 5 and 8 of this preliminary TSD.In each CSC, only lamp options that meet or exceed the corresponding CSL are assumed to be shipped during the analysis period. DOE computed the AEC in year y during the analysis period as follows:

$$\boldsymbol{AEC(y) = \left(\sum_{l} STOCK_{l}(y) \times UEC_{l}(y)\right) \times SP(y)}$$

Eq. 10.2

Where:

$STOCK_l(y)$ = the installed stock in year y of lamp option l (number of units),
$UEC_l(y)$ = the annual unit energy consumption of lamp option l in year y, as described in section 10.2.3.2 (kWh), and
$SP(y)$ = time variable site-to-power-plant conversion factor that converts site electricity use (kWh) to primary energy consumed at the power plant (quads/kWh).

---

[a] Note that the time variable y is a discrete variable representing any year between 2020-2099 and is not continuous. For quantities that depend on y, the notation $f(y)$ is used, instead of f_y, to avoid confusion with other subscripts.

During the stock attrition period (2050-2099) DOE used a different method to calculate annual energy savings to account for the longer lifetimes of LED GSLs compared to CFLs. If CFLs comprise a larger fraction of the stock at the end of the analysis period in the base case compared to the standards case, when the shorter-lived CFLs are retired their contribution to the total analyzed energy consumption will be zero thereafter, but the longer-lived LEDs will continue contributing to the total energy consumption energy, thus reducing the apparent amount of energy saved in the standards case. Therefore, for each lamp category, DOE calculated the stock-weighted per-lamp average energy savings in 2049 (Eq. 10.3) and applied it to all lamps within that lamp category remaining in the stock after 2049 in the standards case to calculate the annual NES during the stock attrition period (Eq. 10.4). The average energy savings in each lamp category is given by the following formula:

$$\boldsymbol{\overline{ES}_c(y_{end}) = \frac{\sum_l [STOCK_{l,c,base}(y_{end}) \times UEC_l]}{\sum_l STOCK_{l.c,base}} - \frac{\sum_l [STOCK_{l,c,std}(y_{end}) \times UEC_l]}{\sum_l STOCK_{l,c,std}}}$$

Eq. 10.3

Where:

$\overline{ES}_c(y)$ = the stock weighted average energy savings per lamp in lamp category *c*, in year *y*, (kWh) and

y_{end} = end year of the shipments analysis (2049),

$STOCK_{l,c,base}(y)$ = stock of lamp option *l* in lamp category *c,* in the base case in year *y* (number of units),

$STOCK_{l,c,std}$ = stock of lamp option *l* in lamp category *c,* in the standards case in year *y* number of units), and

UEC_l = unit energy consumption of lamp option *l* accounting for controls, defined in Eq. 10.11 below (kWh/year).

The NES in a given lamp category during the stock attrition period is then computed as follows:

$$\boldsymbol{NES_{c,attrition}(y) = \overline{ES}_c(y_{end}) \times STOCK_{c,std}(y) \times SP(y)}$$

Eq. 10.4

Where:

$NES_{c,attrition}(y)$ = the national energy savings in year y during the stock attrition period (2050-2099) (quads),

$\overline{ES}_c(y_{end})$ = the average energy savings per lamp in lamp category *c*,in the last year of the analysis period, 2049, defined in Eq. 10.3, (kWh/unit),

$STOCK_{c,std}(y)$ = is the stock of lamps in lamp category *c,* in year *y* in the stock attrition period (number of units), and

$SP(y)$ = time variable site-to-power plant conversion factor that converts site electricity use (kWh) to primary energy consumed at the power plant (quad/kWh).

The annual NES during the stock attrition period is the sum over all lamp categories:

$$\boldsymbol{NES_{attrition}(y) = \sum_{c} NES_{c,attrition}(y)}$$

Eq. 10.5

Where:

all variables are as previously defined.

The cumulative national energy savings is given by the sum over the annual NES in the analysis and stock attrition periods:

$$\boldsymbol{NES_{cum} = \sum_{y=2020}^{2049} NES_{analysis}(y) + \sum_{y=2050}^{2099} NES_{attrition}(y)}$$

Eq. 10.6

Positive values of NES correspond to a net energy savings following standards implementation[b].

10.2.2 Full-Fuel-Cycle Energy Savings

DOE has historically presented the NES computed based on the primary energy savings at the power plant, as described in the previous section. Per DOE's 2011 *Statement of Policy for Adopting Full Fuel Cycle Analyses*, DOE now uses full-fuel-cycle (FFC) measures of energy use and emissions in its energy conservation standards analyses.[3] In addition to the primary energy used at the power plant to supply electricity to the site of use and account for transmission and distribution losses, the FFC analysis also accounts for energy consumed up-stream of the power plant in extracting, processing, and transporting or distributing the primary fuels to the power plant, as described in appendix 10B of this preliminary TSD.

As shown in Eq. 10.7, the FFC national energy savings (NES_{FFC}) were obtained by multiplying the primary energy savings (Eq. 10.1during the 30 year analysis period and Eq. 10.5 during the stock attrition period) by the FFC multiplier computed for the same year, $\mu(y)$:

$$\boldsymbol{NES_{FFC}(y) = NES_{primary}(y) \times RF \times \mu(y)}$$

Eq. 10.7

Where:

$\mu(y)$ = the FFC multiplier in year y (for details, see appendix 10B of this preliminary TSD),

$NES_{primary}(y)$ = the energy saving in year y given by Eq. 10.1 during the analysis period (2020-2049) and Eq. 10.53 during the stock attrition period (2050-2099) and

RF = rebound factor.

---

[b] Following the example of the 2011 fluorescent lamp ballast final rule and for reasons given therein, DOE is assuming that the effects of heating, ventilating, and air conditioning (HVAC) interactions on NES are negligible.

The cumulative FFC energy savings are calculated by summing the annual savings from 2020 through 2099:

$$\boldsymbol{NES_{FFC,cum} = \sum_{y} NES_{FFC}(y)}$$

Eq. 10.8

10.2.3 National Energy Savings Inputs

As described in the preceding sections, the following inputs were used for calculating the national energy savings:

- shipments and stock projections,
- average unit energy consumption (*UEC*),
- site-to-power-plant conversion factor (SP),
- primary energy to full fuel cycle multiplier for each year of the analysis (μ), and
- rebound rate factor (RF).

These inputs are discussed further in the following sections.

10.2.3.1 Shipments and Stock

The shipments model, described in chapter 9 of this preliminary TSD, calculated the shipments of GSLs and market share distributions among product classes and lamp options for different candidate standards cases in each year of the 30-year shipments analysis period (2020 through 2049). Based on that analysis, the model developed a projection of the installed stock of GSLs shipped through 2049 that are affected by the rulemaking.

10.2.3.2 Average Unit Energy Consumption

DOE calculated the average annual UEC for each lamp option by multiplying the average lamp power consumption by the sector-dependent average annual hours of use for that lamp, as shown in Eq. 10.9 below.

$$\boldsymbol{UEC_l = \frac{W_l \times \bar{u}}{1000}}$$

Eq. 10.9

Where:

UEC_l = the annual UEC of lamp option *l* (kWh),
W_l = the rated wattage of lamp option *l* (W), and
$\bar{u}$ = the average annual hours of use for the sector being considered (hours), as presented in chapter 7 of this TSD.

Ingrowth of controls

In the NIA DOE considered the effects of lighting controls (including manual dimmers and automated control systems) on GSL energy use. For the commercial sector DOE used the method developed for the proposed amended energy conservation standards for general service fluorescent lamps (GSFL) and incandescent reflector lamps (IRLs),[4] and assumed that lighting controls are installed on an increasing fraction of lamps in the commercial sector as a result of updated building codes as described in appendix 10C of this preliminary TSD. To assess the impact that controls have on energy savings DOE also performed an alternative analysis that assumed the percentage of controls in the commercial sector remains fixed at its 2014 level throughout the analysis period.

To account for controls in the residential sector, DOE assumed a fixed fraction of lamps are installed in sockets with controls. In the residential sector only, DOE also assumed that in addition to controlled sockets, there was an increase in the number of LED GSLs with integrated wireless receivers that allow them to be controlled remotely, and which can be installed in standard sockets: so-called *smart lamps.* DOE assumed that the incursion of smart lamps followed a Bass adoption curve, discussed below.

Bass adoption curves are commonly used to predict the growth in market share for new products over time:[5,6]

$$\boldsymbol{MS(t) = MS_{max}\frac{1 - e^{-(p+q)t}}{1 + \left(\frac{q}{p}\right)e^{-(p+q)t}}}$$

Eq. 10.10

Where:

$MS(t)$ = market share at time t,
MS_{max} = maximum market share,
t = time since the product was introduced to the market (yr),
p = the coefficient of external influence, and
q = the coefficient of internal influence.

The coefficients of internal and external influence were derived from projections of LED incursion into general lighting markets[7] (see chapter 9 of this preliminary TSD). In its reference analysis DOE assumed that at the end of the analysis period smart lamps comprise 50 percent of the LED GSL shipments in the residential sector. DOE also performed alternative analyses in which the fraction of smart lamp shipments in the residential sector is zero or 100 percent of the shipments in the residential sector at the end of the analysis period.

Effects of controls and smart lamps on UEC

In both the commercial and residential sector DOE assumed that all lamps under controls, including smart lamps, reduce their UEC by a fixed fraction of 30 percent based on a meta-analysis performed by Williams et al.[8] In addition to energy savings realized from smart lamps, DOE considered the possibility of standby losses associated with smart lamps. In its reference scenario, DOE assumed zero standby power for smart lamps. DOE additionally performed an alternative scenario assuming 1W of standby power for all smart lamps.

The unit energy consumption of lamps installed on any type of lighting control system, including any standby power draw, was computed using the following formula (where 8760 is the number of hours in a year):

$$\boldsymbol{UEC_l(y) = UEC_l \times \left(1 - f_{control}(y) \times f_{effect}\right) + \frac{W_{standby,l} \times (8760 - \bar{u})}{1000}}$$

Eq. 10.11

Where:

$UEC_l(y)$ = weighted average annual energy consumption (kWh) of lamp option *l,*
UEC_l = annual unit energy consumption (kWh) of lamp option *l,* operating under full power for the average number of hours of use per year, computed using Eq. 10.9,
$f_{control}(y)$ = the fraction of lamps estimated to be operating under lighting controls in year *y*, and
f_{effect} = a parameter describing the effect of lighting controls on energy consumption, taken to be 0.3,
$W_{standby,l}$ = the assumed standby power, if any, of lamp option *l* (W), and
all other variables as previously defined.

10.2.3.3 Site-to-Power Plant Conversion Factor

To estimate the energy used at the power plant to supply the electricity used on-site by GSLs, DOE multiplied the site energy consumption, $UEC_l(y)$, by a lighting specific site-to-power-plant conversion factor,[c] which accounts for average losses associated with the generation, transmission, and distribution of electricity from the fleet of U.S. power plants to the point of use. DOE used annual site-to-power-plant conversion factors based on the version of the National Energy Modeling System (NEMS) that corresponds to the Energy Information Administration's *Annual Energy Outlook 2014* (*AEO2014*).[2] The factor takes into account the time of use distribution for lighting end uses and changes over time in response to projected changes in generation sources (the types of power plants projected to provide electricity to the country). Figure 10.2.1 shows how the site-to-power plant conversion factor is expected to change during the NES and NPV analysis period.

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[c] In previous rulemakings the site-to-power-plant conversion factor has been referred to as the *site-to-source conversion factor.* The terminology is modified here to clarify that the analysis only accounts for the energy used at the power plants, but not energy used upstream of the power plants to provide that service. The latter is incorporated in the full-fuel-cycle analysis.

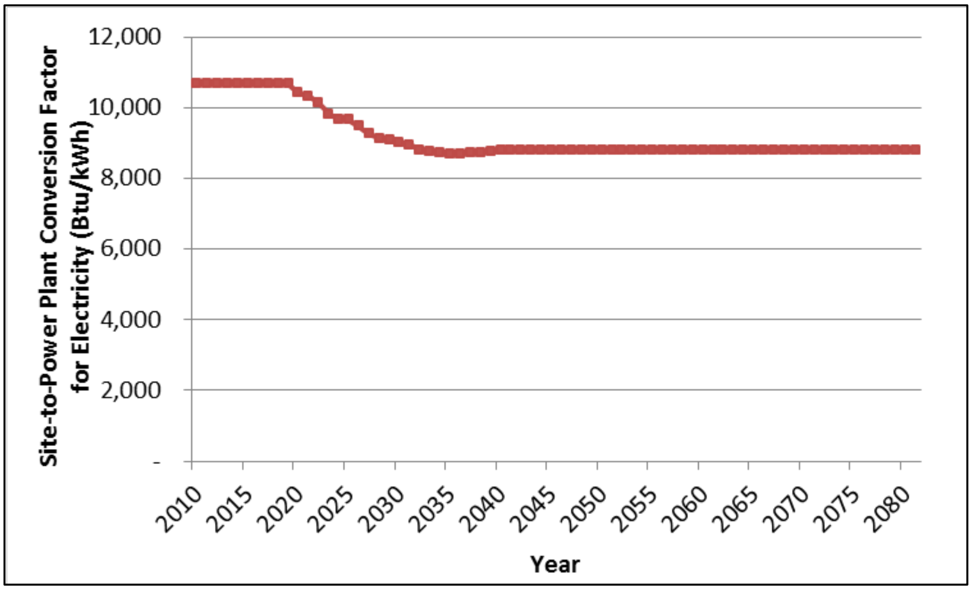

Figure 10.2.1 Site-to-Power Plant Conversion Factor for Electricity

10.2.3.4 Primary Energy to Full-Fuel-Cycle Multipliers

For this analysis, DOE calculated FFC energy savings using a methodology described in appendix 10B. As discussed previously, the FFC energy savings are obtained by multiplying the primary energy savings at the power plant by the FFC multiplier (Eq. 10.7). The estimated FFC multiplier (μ) is nearly constant, ranging between 1.044 and 1.047 from 2020 to 2099.

10.2.3.5 Rebound Rate Factor

DOE generally accounts for the direct rebound effect in its estimates of the NES. For this preliminary analysis DOE used the same rebound assumptions developed for the 2014 GSFL-IRL notice of proposed rulemaking,[4] which are described in appendix 10D of this preliminary TSD. In the reference scenario, the rebound rate is zero for both the commercial and residential sectors, and DOE additionally performed two sensitivity analyses on the rebound rate. The rebound rates for all scenarios are summarized in Table 10.2.1 below.

Table 10.2.1 Rebound Rate Scenarios for GSLs

Rebound Scenario	Commercial Rebound Rate	Residential Rebound Rate
None	0%	0%
Low	1%	8.5%
High	15%	15%

10.3 NATIONAL NET PRESENT VALUE

10.3.1 Definition

The NPV is the difference between the present value of savings (PVS) in operating cost resulting from the use of more efficient appliances under the standard and the present value of changes in total installed costs (PVC) of those appliances. The NPV is described by the following equation:

$$\boldsymbol{NPV = PVS - PVC}$$

Eq. 10.12

Where:

PVS = present value of savings in operating costs (including costs for energy, repair, and maintenance) from all lamps shipped during the analysis period (2014\$); and
PVC = present value of the change in total installed cost (including costs for equipment, installation, and disposal in 2014\$) from of all lamps shipped during the analysis period (2014\$).

Under this definition, reductions in operating costs contribute positively to the NPV, while increases in total installed costs contribute negatively to the NPV. Notably, because LED GSLs have substantially longer lifetimes than the baseline CFL considered in this analysis, it is possible that some CSCs may yield a *reduction* in total installed costs, which would contribute positively to the NPV.

DOE determined the *PVS* and *PVC* according to the following equations:

$$\boldsymbol{PVS} = \sum_{\boldsymbol{y}} \boldsymbol{OCS}(\boldsymbol{y}) \times \boldsymbol{DF}(\boldsymbol{y})$$

Eq. 10.13

$$\boldsymbol{PVC} = \sum_{\boldsymbol{y}} \boldsymbol{ECI}(\boldsymbol{y}) \times \boldsymbol{DF}(\boldsymbol{y})$$

Eq. 10.14

Where:

$OCS(y)$ = total annual operating cost savings realized by the affected stock in year *y,* (2014\$),
$ECI(y)$ = total annual equipment cost increment for shipments in year *y*, relative to the base case (2014\$), and
$DF(y)$ = discount factor in each year (defined in section 10.3.2.3).

DOE calculated PVC and PVS for all lamps projected to be shipped from 2020 to 2049, the duration of the shipments analysis period. To account for all energy savings that accrue over the full lifetime of lamps shipped near the end of the analysis period, it was necessary to consider energy consumption and cash flows through 2099. The contributions to PVC and PVS for each year were discounted to 2014. The following sections describe how DOE derives the variables in Eq. 10.13 and Eq. 10.14.

10.3.2 Net Present Value Inputs

The inputs to DOE’s calculation of the NPV of costs and savings for the nation are:

- the total annual installed cost (TIC) of equipment shipped in each year of the analysis, in the base case and the standards cases,
- the total annual operating cost (TOC) for the affected stock in the base case and the standards cases, and
- the discount factor (DF).

The computation of these inputs from the outputs of upstream analyses is detailed in the following sections.

10.3.2.1 Total Annual Installed Cost Increment

DOE calculated the total annual change in equipment cost of using more efficient lamps in the standards cases relative to the base case as the difference between the TIC in the standards case and the base case:

$$\boldsymbol{ECI(y) = TIC_{std}(y) - TIC_{base}(y)}$$

Eq. 10.15

Where:

$ECI(y)$ = the total annual increment in equipment cost in the standards case, relative to the base case, in year *y* (2014$),
$TIC_{std}(y)$ = the total installed cost of equipment shipped in year *y* in the standards case (2014$), and
$TIC_{base}(y)$ = the total installed cost of equipment shipped in year *y* in the base case (2014$).

As discussed previously, the annual equipment cost increment can be negative in the case of GSLs, owing to the longer lifetimes of LED GSLs relative to the baseline CFL lamp option.

The installed cost of a GSL is the purchase price plus any installation and disposal costs. For this preliminary analysis DOE assumed the installation costs for all lamps is zero and that only CFLs incur a disposal cost. As described in chapter 8 of this preliminary TSD, DOE assumes that only consumers in the commercial sector pay a disposal cost for CFLs. Based on research also described in chapter 8, the per-lamp disposal cost for a CFL in the commercial sector is assumed to be one dollar, and 10-percent of CFL consumers pay the disposal cost. To take into account that disposal costs are paid at the end of the life of a lamp, DOE discounts the disposal costs by the average lifetime of a CFL before adding it to the initial costs. The total installed cost is given by:

$$\boldsymbol{TIC(y) = \sum_{l} s_l \times (p_l(y) + DC \times f_{disp})}$$

Eq. 10.16

Where:

$s_l(y)$ = total shipments of lamp option *l* in year *y* (number of units),
$p_l(y)$ = purchase price of lamp option *l* in year *y*, including any price trend corrections (2014$/unit),
DC = disposal costs, for CFLs in the commercial sector only, discounted by the average lifetime of a CFL (2014$/unit), and
f_{disp} = fraction of lamps that pay a disposal cost.

The total installed costs are calculated for the years 2020 to 2049, with all shipments assumed to be zero after 2049 (the final year of the analysis period).

10.3.2.2 Total Annual Operating Cost Savings

DOE expresses savings in operating costs as cost reductions associated with the lower energy consumption of products shipped in the standards case compared to the base case. Similarly to the NES, DOE calculated the annual operating cost savings (OCS) for GSLs in two parts, for the analysis period (2020-2049) and the stock attrition period (2050-2099). During the analysis period the annual OCS is the difference between the TOC in the standards case and the base case.

$$\boldsymbol{OCS_{ship}(y) = TOC_{base}(y) - TOC_{std}(y)}$$

Eq. 10.17

Where:

$OCS_{ship}(y)$ = the total operating cost saving of the affected stock in year *y* between 2020 and 2049 (2014$),
$TOC_{base}(y)$ = the total operating cost of the stock in year *y* between 2020 and 2049 in the base case (2014$), and
$TOC_{std}(y)$ = the total operating cost of the stock in year *y* between 2020 and 2049 in the standards case (2014$).

The only component of annual operating cost for GSLs is the cost of electricity consumption. DOE calculated the total annual operating costs based on national average electricity prices. DOE used the reference-case, sector-specific electricity price projections from *AEO2014* to establish all electricity prices. As *AEO2014* only projects prices through 2040, electricity prices in later years were extrapolated based on the 2030 through 2040 sector-specific trends, up through 2060, after which prices were assumed to remain constant.

DOE calculated annual TOC during the 30 year analysis period for GSLs by summing over the operating costs of all lamp options in the stock, according to the following expression:

$$\boldsymbol{TOC(y) = p_E(y) \times \sum_{l} [STOCK_l(y) \times UEC_l(y)]}$$

Eq. 10.18

Where:

$p_E(y)$= the price of electricity, in year *y*, as forecasted in the *AEO2014* reference scenario (2014$/kWh),
$STOCK_l(y)$ = the stock of lamp option *l* in year *y* (number of units), and
$UEC_l(y)$ = the average unit energy consumption of lamp option *l* in year *y,* as computed using Eq. 10.11(kWh/unit).

During the stock attrition period the annual OCS is given by:

$$\boldsymbol{OCS_{attrition}(y) = p_E(y) * \sum_{c} \overline{ES}_c\,(y_{end}) * \mathrm{STOCK_c}(y)}$$

Eq. 10.19

Where:

$\overline{ES}_c(y_{end})$ = is the average energy savings per lamp in lamp category *c,* defined in Eq. 10.3,
$STOCK_c$ = the stock of all lamps in lamp category *c,* and
all other variables as previously defined.

The cumulative OCS for a given standard is then calculated as:

$$OCS_{cum} = \sum_{y=2020}^{y=2049} OCS_{ship}(y) + \sum_{y=2050}^{y=2099} OCS_{attrition}(y)$$

Eq. 10.20

Where

all variables are as previously defined.

As stated previously, DOE used the forecast of national-average commercial and residential electricity prices for its analysis in the commercial and residential sectors, respectively. To understand the importance of uncertainty in these projections, DOE performed sensitivity analyses using the high- and low-economic growth scenarios from *AEO2014* to establish electricity prices. Figure 10.3.1 shows annual electricity price projections used as inputs for the high-, reference-, and low-economic growth scenarios, for all sectors. Note that there is not a consistent relationship over time between the economic growth scenario and its impact on electricity prices. For example, in the early years of the analysis period, the low-economic growth scenario in the residential sector results in higher electricity prices than the high growth scenario. The opposite is true in later years.

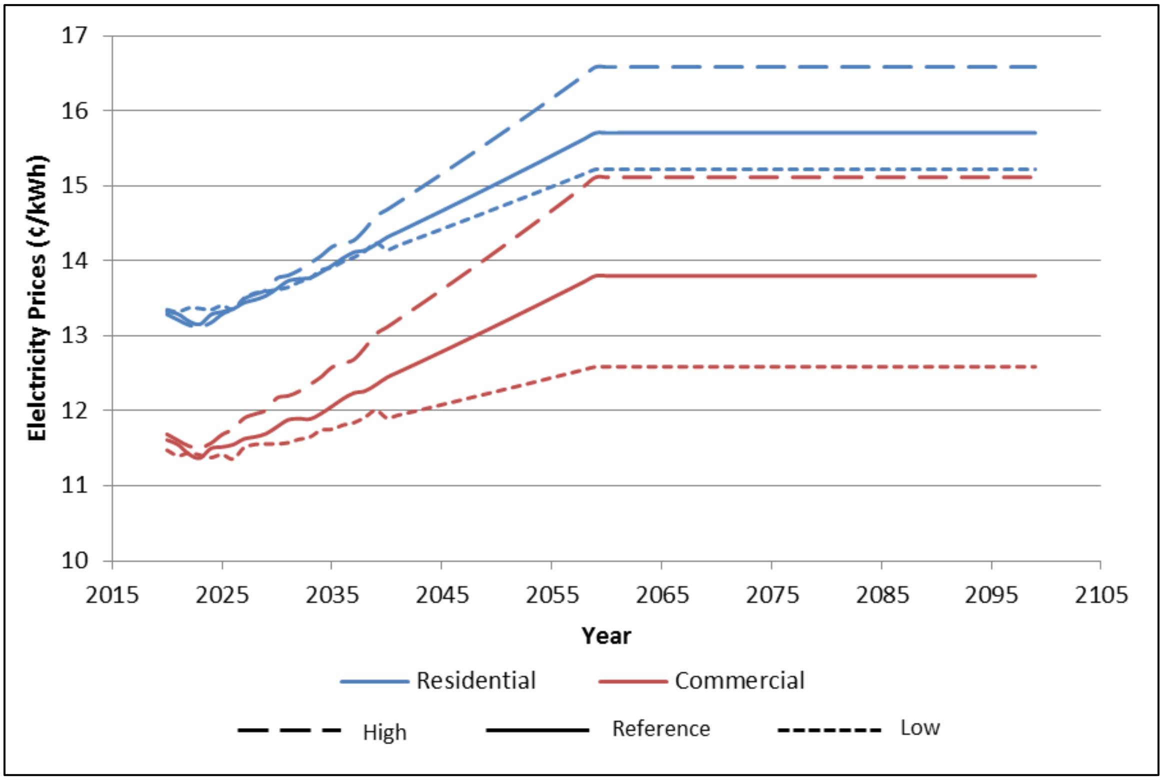

Figure 10.3.1 Annual Electricity Prices by Sector (2014$)

As discussed in section 10.2.3.5, DOE has included in this analysis scenarios that include various assumptions about rebound to adjust its estimates of NES. In principle, the rebound effect also affects the energy costs to consumers in the standards case. However, the take-back in energy consumption associated with the rebound effect provides consumers with increased value (*e.g.,* improved lighting service). As described in the 2014 residential furnace fan final rule TSD,[9] DOE believes that, if it were able to monetize the increased value to consumers of the rebound effect, this value would be similar in value to the foregone energy savings. Therefore, the economic impacts on consumers with or without the rebound effect are the same, so DOE does not adjust operating cost savings in the NIA based on rebound.

10.3.2.3 Discount Factor

DOE multiplies monetary values in future years by a discount factor to determine the present value. The DF is described by the equation:

$$\boldsymbol{DF = \frac{1}{(1+r)^{(y-y_p)}}}$$

Eq. 10.21

Where:

r = discount rate,
y = year of the future monetary value (savings or expenditure), and
y_P = year for which the present value is being determined.

DOE estimates NPV using both a 3-percent and a 7-percent real discount rate, in accordance with the Office of Management and Budget's guidance to Federal agencies on the development of regulatory analysis, particularly section E therein: *Identifying and Measuring Benefits and Costs*. DOE defines the present year for this preliminary analysis as 2014.

10.4 RESULTS

This section summarizes the NES and NPV modeling results for the different candidate standards cases, as well as the results of the alternative scenarios.

10.4.1 National Energy Savings Results

The annual FFC NES is presented in Figure 10.4.1 for all product classes at all CSCs. The cumulative site, power plant and FFC NES are given in Table 10.4.1,Table 10.4.2, and Table 10.4.3, respectively.

The lack of energy savings for the non-integrated product class is a result of the available lamp options in that product class. There is one lamp option at the baseline (CSL 0) and two lamp options at CSL 1, a lamp with the same energy consumption as the baseline lamp but producing more light, and a lamp with reduced energy consumption. As described in chapter 9 of this preliminary TSD, DOE assumed the reduced wattage option is a niche product. Accordingly, DOE assumed that consumers using the reduced wattage lamps will continue to do so under a standard, while consumers using the full wattage lamp will continue to purchase full wattage lamps under a standard. These consumers will not realize any energy savings, but they will have an increase in the lighting service (in terms of lumens per square foot) from the more efficacious lamps. The effects on the NPV are discussed in section 10.4.2 below.

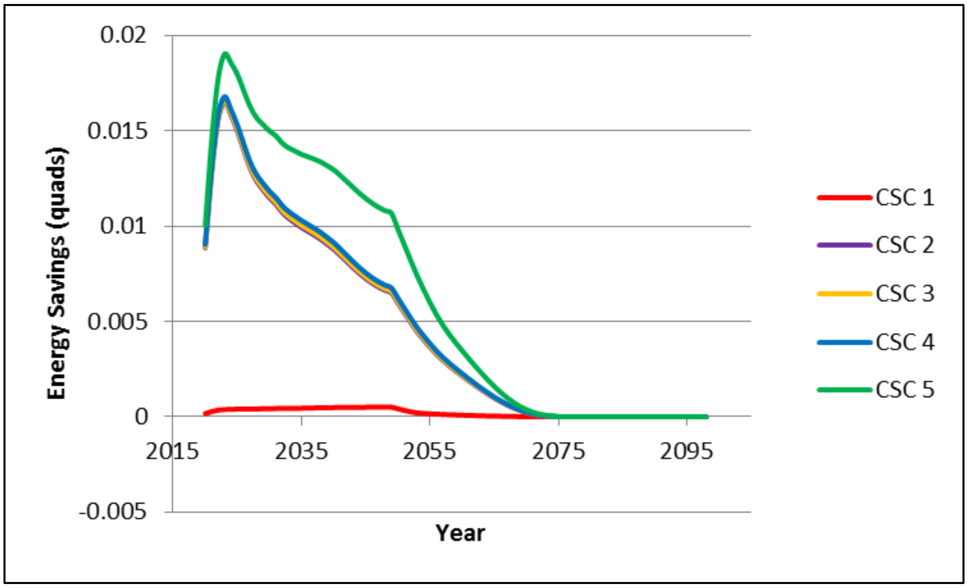

Figure 10.4.1 Annual FFC NES for Product Classes at All CSCs

Table 10.4.1 Cumulative Site National Energy Savings for All Product Classes and CSCs in TWh

CSC	Integrated		Non-Integrated
	Low Lumen (<2000lm)	High Lumen (≥ 2000lm)	
1	0.27	1.35	0.00
2	34.93	2.58	
3	35.33		
4	36.18		
5	49.52		

*See text for discussion of the NES for the non-integrated product class.

Table 10.4.2 Cumulative Power Plant National Energy Savings for All Product Classes and CSCs in Quads

CSC	Integrated		Non-Integrated
	Low Lumen (<2000lm)	High Lumen (≥ 2000lm)	
1	0.00	0.01	0.00
2	0.32	0.02	
3	0.32		
4	0.33		
5	0.45		

Table 10.4.3 Cumulative Full Fuel Cycle National Energy Savings for All Product Classes and CSCs in Quads

CSC	Integrated		Non-Integrated
	Low Lumen (<2000lm)	High Lumen (≥ 2000lm)	
1	0.00	0.01	0.00
2	0.34	0.02	
3	0.34		
4	0.35		
5	0.47		

10.4.2 Net Present Value Results

Annual NPV at 3 and 7-percent discount rates for all product classes and CSCs are presented in Figure 10.4.2 and Figure 10.4.3 respectively. The fluctuations that occur are due to the CSL 1, full wattage lamp option in the non-integrated product class. This lamp has a much longer lifetime than the baseline lamp (17,000 hours compared to 10,000 hours), therefore when the standard takes effect there is a large influx of longer lived lamps that are more likely to be replaced at the same time, causing 'ringing' in the NPV as new lamp purchases are made at regular intervals (the average lamp lifetime). This effect decreases over time.

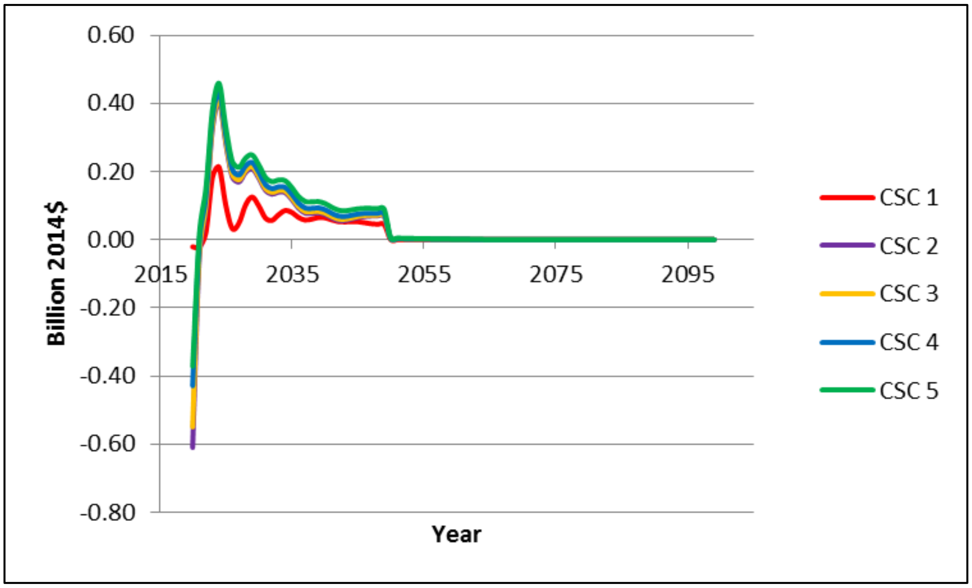

Figure 10.4.2 Annual NPV at 3% for All Product Classes at All CSCs

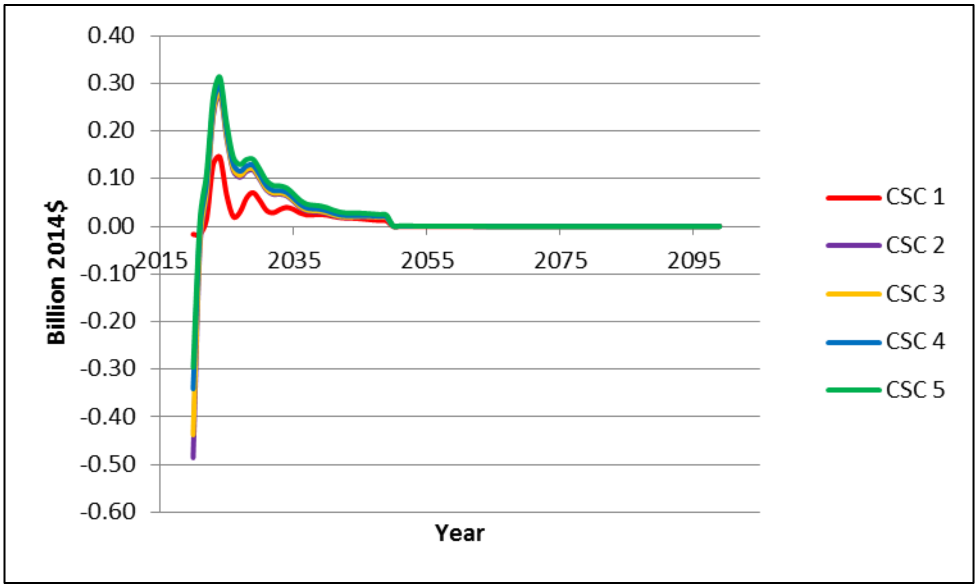

Figure 10.4.3 Annual NPV at 7% for All Product Classes at All CSCs

The net present value for all product classes at all CSCs is given in Table 10.4.4 and Table 10.4.5 for 3 and 7 percent, respectively. The TIC at 3 and 7 percent are given in Table 10.4.6 and Table 10.4.7. It should be noted that for integrated low-lumen lamps and non-integrated lamps the TIC is negative. The decrease in TIC is a result of a longer lamp lifetime for the more efficient lamps in these two product classes. This necessitates fewer lamp replacements, and hence lowers the shipments in that product class. The savings from reduced purchases outweigh the increases in per-lamp cost for the CSCs considered in this preliminary analysis; this makes it possible to have a positive NPV, even, as in the case of the non-integrated product class, with zero NPV. The OCS at 3 and 7 percent are given in Table 10.4.8 and Table 10.4.9 below.

Table 10.4.4 Cumulative Net Present Value at 3% for All Product Classes and CSCs in Billion 2014$

CSC	Integrated		Non-Integrated
	Low Lumen (<2000lm)	High Lumen (≥ 2000lm)	
1	0.02	0.04	1.95
2	1.21	0.09	
3	1.44		
4	1.90		
5	2.52		

Table 10.4.5 Cumulative Net Present Value at 7% for All Product Classes and CSCs in Billion 2014$

CSC	Integrated		Non-Integrated
	Low Lumen (<2000lm)	High Lumen (≥ 2000lm)	
1	0.02	0.02	0.96
2	0.54	0.04	
3	0.67		
4	0.96		
5	1.28		

Table 10.4.6 Cumulative Total Installed Cost Increment at 3% for All Product Classes and CSCs in Billion 2014$

CSC	Integrated		Non-Integrated
	Low Lumen (<2000lm)	High Lumen (≥ 2000lm)	
1	-0.02	0.01	-1.95
2	-0.33	0.02	
3	-0.55		
4	-1.01		
5	-1.28		

Table 10.4.7 Cumulative Total Installed Cost Increment at 7% for All Product Classes and CSCs in Billion 2014$

CSC	Integrated		Non-Integrated
	Low Lumen (<2000lm)	High Lumen (≥ 2000lm)	
1	-0.01	0.01	-0.96
2	-0.03	0.01	
3	-0.17		
4	-0.45		
5	-0.60		

Table 10.4.8 Cumulative Operating Cost Savings at 3% for All Product Classes and CSCs in Billion 2014$

CSC	Integrated		Non-Integrated
	Low Lumen (<2000lm)	High Lumen (≥ 2000lm)	
1	0.01	0.05	0.00
2	0.88	0.11	
3	0.89		
4	0.89		
5	1.24		

Table 10.4.9 Cumulative Operating Cost Savings at 7% for All Product Classes and CSCs in Billion 2014$

CSC	Integrated		Non-Integrated
	Low Lumen (<2000lm)	High Lumen (≥ 2000lm)	
1	0.00	0.03	0.00
2	0.50	0.06	
3	0.51		
4	0.51		
5	0.68		

10.4.3 Alternative Analyses Results

10.4.3.1 Overview

Table 10.4.10 lists the alternative scenarios analyzed in the NIA; scenario options indicated in bold are used in the reference scenario. Complete descriptions of the alternative scenarios not described previously are given in appendix 8B of this TSD.

Table 10.4.10 Alternative Scenarios Analyzed

Scenario Name	Scenario Description	Alternative Scenario Options Analyzed	Analyses Impacted by Scenario
Reference	DOE's best estimate of the national impacts of a GSL standard	Reference option indicated in bold below	**All (Best Estimate)**
AEO growth	AEO economic growth scenario for electricity prices	Low	**NIA only**
		Reference	
		High	
Controls	Commercial sector controls growth rate, described in appendix 10C,	**Reference**	
		Fixed	
Rebound	Rebound rate associated with energy savings from lighting end uses (see appendix 10D of this TSD for more details).	**No**	
		Low	
		High	
Smart lamp incursion	The maximum market share of smart lamp shipments at the end of the analysis period (applies to the residential sector only).	0%	
		50%	
		100%	
Smart lamps standby power	Standby power associated with all smart lamps (applies to residential sector only).	**0W**	
		1W	
Integrated LED incursion	Incursion of LED luminaires into the market for traditional GSL luminaires at the end of the analysis period (see chapter 9 of this TSD)	0%	**Shipments and NIA**
		15%	
		50%	
Lamp Service Lifetime	Parameter assumed to be the driver for lamp replacements, see appendix 8E of this TSD.	Rated	
		Renovation-Driven	
		Early-Replacement	
Learning Rate	Learning rates used to develop lamp price trends, as described in chapter 9 of this TSD.	None	
		CFL	
		Technology	
Rare Earth Cost	Price scenario for rare earth minerals, applies to CFLs only (see appendix 8D of this TSD).	**Constant**	
		High	

10.4.3.2 Alternative Analyses: National Energy Savings Results

Table 10.4.11, Table 10.4.12 and Table 10.4.13 present the cumulative full fuel cycle NES for the alternative analyses in the integrated low-lumen, integrated high-lumen and non-integrated product classes respectively. For each candidate standards case, the scenario result for the alternative analyses should be compared to the reference scenario to determine the impact.

Table 10.4.11 Integrated Low-Lumen Alternative Analyses Full Fuel Cycle National Energy Savings in Quads

Scenario Name	Alternatives	CSC 1	CSC 2	CSC 3	CSC 4	CSC 5
Reference	-	0.00	0.34	0.34	0.35	0.47
AEO growth	Low	0.00	0.34	0.34	0.35	0.47
	High	0.00	0.34	0.34	0.35	0.47
Controls	Fixed	0.00	0.34	0.35	0.36	0.49
Rebound	Low	0.00	0.31	0.32	0.32	0.44
	High	0.00	0.29	0.29	0.30	0.40
Smart lamp incursion	0%	0.00	0.27	0.28	0.29	0.43
	100%	0.00	0.40	0.40	0.41	0.52
Smart lamp standby	1W	0.00	0.14	0.14	0.15	0.28
Integrated LED incursion	0%	0.00	0.36	0.37	0.38	0.52
	50%	0.00	0.27	0.27	0.28	0.37
Lamp Service Lifetime	Rated	0.00	0.37	0.37	0.38	0.54
	Innovation	0.01	0.70	0.71	0.71	0.82
Learning Rate	None	0.01	0.61	0.64	0.71	0.83
	Technology	0.00	0.25	0.25	0.26	0.38
High Rare Earth	High	0.00	0.33	0.34	0.34	0.47

Table 10.4.12 Integrated High-Lumen Alternative Analyses Full Fuel Cycle National Energy Savings in Quads

Scenario Name	Alternatives	CSC 1	CSC 2
Reference	-	0.01	0.02
AEO growth	Low	0.01	0.02
	High	0.01	0.02
Controls	Fixed	0.01	0.03
Rebound	Low	0.01	0.02
	High	0.01	0.02
Smart lamp incursion	0%	0.01	0.02
	100%	0.01	0.02
Smart lamp standby	1W	0.01	0.02
Integrated LED incursion	0%	0.01	0.03
	50%	0.01	0.02
Lamp Service Lifetime	Rated	0.01	0.03
	Innovation	0.01	0.02
Learning Rate	None	0.01	0.02
	Technology	0.01	0.02
High Rare Earth	High	0.01	0.02

Table 10.4.13 Non-Integrated Alternative Analyses Full Fuel Cycle National Energy Savings in Quads

Scenario Name	Alternatives	CSC 1
Reference	-	0.00
AEO growth	Low	0.00
	High	0.00
Controls	Fixed	0.00
Rebound	Low	0.00
	High	0.00
Smart lamp incursion	0%	0.00
	100%	0.00
Smart lamp standby	1W	0.00
Integrated LED incursion	0%	0.00
	50%	0.00
Lamp Service Lifetime	Rated	0.00
	Innovation	0.00
Learning Rate	None	0.00
	Technology	0.00
High Rare Earth	High	0.00

10.4.3.3 Alternative Analyses: Net Present Value Results

This section presents the cumulative NPV for the alternative scenarios at 3 and 7-percent. Table 10.4.14 and Table 10.4.15 present results for the Integrated Low-Lumen product class, Table 10.4.16 and Table 10.4.17 present results for the Integrated High-Lumen product class, and Table 10.4.18 and Table 10.4.19 present results for the Non-Integrated product class.

Table 10.4.14 Integrated Low-Lumen Alternative Analyses Net Present Value at 3% in 2014$

Scenario Name	Alternatives	CSC 1	CSC 2	CSC 3	CSC 4	CSC 5
Reference	-	0.02	1.21	1.44	1.90	2.52
AEO growth	Low	0.02	1.20	1.42	1.89	2.50
	High	0.02	1.23	1.46	1.92	2.55
Controls	Fixed	0.02	1.21	1.44	1.90	2.52
Rebound	Low	0.02	1.21	1.44	1.90	2.52
	High	0.02	1.21	1.44	1.90	2.52
Smart lamp incursion	0%	0.02	1.17	1.39	1.86	2.49
	100%	0.02	1.26	1.48	1.94	2.56
Smart lamp standby	1W	0.02	1.07	1.29	1.76	2.38
Integrated LED incursion	0%	0.03	1.35	1.58	2.08	2.77
	50%	0.02	0.91	1.10	1.51	1.98
Lamp Service Lifetime	Rated	0.02	1.26	1.42	1.75	2.29
	Innovation	0.03	-2.03	-1.61	-0.70	0.21
Learning Rate	None	0.06	-2.15	-1.11	0.44	1.48
	Technology	0.02	1.40	1.50	1.71	2.24
High Rare Earth	High	0.03	1.22	1.44	1.91	2.53

Table 10.4.15 Integrated Low-Lumen Alternative Analyses Net Present Value at 7% in 2014$

Scenario Name	Alternatives	CSC 1	CSC 2	CSC 3	CSC 4	CSC 5
Reference	-	0.02	0.54	0.67	0.96	1.28
AEO growth	Low	0.02	0.53	0.67	0.95	1.27
	High	0.02	0.55	0.68	0.96	1.29
Controls	Fixed	0.02	0.54	0.67	0.96	1.28
Rebound	Low	0.02	0.54	0.67	0.96	1.28
	High	0.02	0.54	0.67	0.96	1.28
Smart lamp incursion	0%	0.02	0.52	0.65	0.94	1.26
	100%	0.02	0.56	0.69	0.97	1.29
Smart lamp standby	1W	0.02	0.48	0.61	0.89	1.22
Integrated LED incursion	0%	0.02	0.60	0.74	1.04	1.39
	50%	0.01	0.39	0.51	0.76	1.02
Lamp Service Lifetime	Rated	0.01	0.56	0.67	0.88	1.17
	Innovation	0.02	-1.23	-0.99	-0.48	-0.01
Learning Rate	None	0.04	-1.71	-1.14	-0.30	0.25
	Technology	0.01	0.78	0.84	0.98	1.25
High Rare Earth	High	0.02	0.55	0.68	0.96	1.28

Table 10.4.16 Integrated High-Lumen Alternative Analyses Net Present Value at 3% in 2014$

Scenario Name	Alternatives	CSC 1	CSC 2
Reference	-	0.04	0.09
AEO growth	Low	0.04	0.09
	High	0.04	0.09
Controls	Fixed	0.04	0.09
Rebound	Low	0.04	0.09
	High	0.04	0.09
Smart lamp incursion	0%	0.04	0.09
	100%	0.04	0.09
Smart lamp standby	1W	0.04	0.09
Integrated LED incursion	0%	0.05	0.10
	50%	0.03	0.07
Lamp Service Lifetime	Rated	0.04	0.11
	Innovation	0.04	0.06
Learning Rate	None	0.05	0.14
	Technology	0.04	0.09
High Rare Earth	High	0.04	0.09

Table 10.4.17 Integrated High-Lumen Alternative Analyses Net Present Value at 7% in 2014$

Scenario Name	Alternatives	CSC 1	CSC 2
Reference	-	0.02	0.04
AEO growth	Low	0.02	0.04
	High	0.02	0.04
Controls	Fixed	0.02	0.04
Rebound	Low	0.02	0.04
	High	0.02	0.04
Smart lamp incursion	0%	0.02	0.04
	100%	0.02	0.05
Smart lamp standby	1W	0.02	0.04
Integrated LED incursion	0%	0.02	0.05
	50%	0.02	0.04
Lamp Service Lifetime	Rated	0.01	0.03
	Innovation	0.02	0.03
Learning Rate	None	0.02	0.07
	Technology	0.01	0.02
High Rare Earth	High	0.02	0.04

Table 10.4.18 Non-Integrated Alternative Analyses Net Present Value at 3% in 2014$

Scenario Name	Alternatives	CSC 1
Reference	-	1.95
AEO growth	Low	1.95
	High	1.95
Controls	Fixed	1.95
Rebound	Low	1.95
	High	1.95
Smart lamp incursion	0%	1.95
	100%	1.95
Smart lamp standby	1W	1.95
Integrated LED incursion	0%	2.18
	50%	1.51
Lamp Service Lifetime	Rated	1.96
	Innovation	1.91
Learning Rate	None	2.38
	Technology	1.96
High Rare Earth	High	1.96

Table 10.4.19 Non-Integrated Alternative Analyses Net Present Value at 7% in 2014$

Scenario Name	Alternatives	CSC 1
Reference	-	0.96
AEO growth	Low	0.96
	High	0.96
Controls	Fixed	0.96
Rebound	Low	0.96
	High	0.96
Smart lamp incursion	0%	0.96
	100%	0.96
Smart lamp standby	1W	0.96
Integrated LED incursion	0%	1.06
	50%	0.78
Lamp Service Lifetime	Rated	0.97
	Innovation	0.95
Learning Rate	None	1.16
	Technology	0.97
High Rare Earth	High	0.97

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CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

TABLE OF CONTENTS

CHAPTER 11. CONSUMER SUBGROUP ANALYSIS

11.1 METHODOLOGY

The consumer subgroup analysis evaluates impacts on any identifiable groups or consumers who may be disproportionately affected by a national energy conservation standard. DOE will conduct this analysis as one of the analyses for the notice of proposed rulemaking (NOPR). DOE will accomplish this, in part, by analyzing the life-cycle costs (LCCs) and payback periods (PBPs) for those customers that fall into any identifiable groups. DOE plans to evaluate variations in regional energy prices, variations in energy use, and variations in installation costs that might affect the net present value of a standard to customer subpopulations. To the extent possible, DOE will obtain estimates of each input parameter's variability and will consider this variability in its calculation of consumer impacts.

DOE will determine the impact on consumer subgroups using the LCC Spreadsheet Model, which allows for different data inputs. The standard LCC analysis (described in chapter 8) focuses on the customers that use general service lamps. DOE can use the LCC Spreadsheet Model to analyze the LCC for any subgroup by sampling only that subgroup. (Chapter 8 explains in detail the inputs to the model used in determining LCC and PBPs.) In the case of general service lamps, one subgroup DOE plans to consider is low-income households.

DOE will be especially sensitive to increases in the purchase price of the product due to amended standards, to avoid negative impacts on identifiable population groups that may not be able to afford significant increases in product price.

CHAPTER 12. PRELIMINARY MANUFACTURER IMPACT ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 12. PRELIMINARY MANUFACTURER IMPACT ANALYSIS

12.1 INTRODUCTION

The purpose of the manufacturer impact analysis (MIA) is to identify and quantify the likely impacts of energy conservation standards on manufacturers. The Process Rule[a] provides guidance for conducting this analysis with input from manufacturers and other interested parties. The U.S. Department of Energy (DOE) will apply this methodology to its evaluation of energy conservation standards for general service lamps (GSLs). DOE will consider financial impacts and a wide range of quantitative and qualitative industry impacts. For example, a particular standard level could require changes to manufacturing practices for GSLs. DOE will identify and analyze these impacts through interviews with manufacturers and other interested parties during the notice of proposed rulemaking (NOPR) stage of the analysis.

DOE announced changes to the MIA format through a report issued to Congress in January 2006 (as required by section 141 of the Energy Policy Act of 2005 [EPAct 2005]), entitled “Energy Conservation Standards Activities.”[b] Previously, DOE did not report any MIA results before the NOPR phase; however, under this new format, DOE collects, evaluates, and reports preliminary information and data in the preliminary analysis. Such information includes market data, key issues, product mixes, conversion costs, foreign competition, market shares, industry consolidation, and cumulative regulatory burden information. DOE solicits this information during the preliminary manufacturer interviews and reports the results in this chapter of the preliminary technical support document (TSD). Appendix 12A includes a copy of the interview guide that DOE distributed to manufacturers.

12.2 METHODOLOGY

DOE conducts the MIA in three phases. In Phase I, DOE creates an industry profile to characterize the industry and conducts preliminary manufacturer interviews to identify important issues that require consideration. Section 12.3 of this chapter presents initial findings of the Phase I analysis. In Phase II, DOE prepares an industry cash flow model and an interview questionnaire to guide subsequent discussions with manufacturers. In Phase III, DOE interviews manufacturers and assesses the impacts of energy conservation standards both quantitatively and qualitatively. DOE assesses industry and subgroup cash flow impacts and the industry net present value (INPV) using the Government Regulatory Impact Model (GRIM). DOE then assesses impacts on competition, manufacturing capacity, employment, and regulatory burden, based on manufacturer interviews and discussions. The NOPR will present the results of the Phase II and III analyses.

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[a] On July 15, 1996, the Department of Energy published a Process Improvement Rule establishing procedures, interpretations, and policies to guide the Department in the consideration of new or revised appliance efficiency standards (Procedures for Consideration of New or Revised Energy Conservation Standards for Consumer Products). 61 FR 36974.

[b] This report is available on the DOE website at: www1.eere.energy.gov/buildings/appliance_standards/pdfs/congressional_report_013106.pdf.

12.2.1 Phase I: Industry Profile

In Phase I of the MIA, DOE collects pertinent qualitative and quantitative financial and market information. This includes research and development (R&D) expenses; selling, general, and administrative (SG&A) expenses; capital expenditures; property, plant, and equipment expenses; tax rate; and depreciation rate for GSL manufacturers, as well as wages, employment, and industry costs for GSLs. Sources of information include reports published by industry groups, trade journals, the U.S. Census Bureau, and Securities Exchange Commission (SEC) 10-K filings. In addition, DOE relies on information from its market and technology assessment, engineering analysis, life-cycle cost analysis, and consumer price analysis, as well as feedback from preliminary manufacturer interviews, to characterize the GSL manufacturing industries.

12.2.2 Phase II: Industry Cash Flow Analysis and Interview Guide

Phase II activities occur after publication of the preliminary analysis. In Phase II, DOE performs a preliminary industry cash-flow analysis and prepares a questionnaire, or interview guide, for interviewing manufacturers.

12.2.2.1 Industry Cash Flow Analysis

DOE uses the GRIM to analyze the financial impacts of energy conservation standards. The implementation of these standards may require additional investment, raise production costs, and/or affect revenue through higher prices and lower shipments. The GRIM uses several factors to determine a series of annual cash flows for the years leading up to the effective date of energy conservation standards and for several years after implementation. These factors include annual expected revenues, costs of sales, SG&A costs, taxes, and capital expenditures. Inputs to the GRIM include financial information, manufacturing costs, shipment forecasts, and price forecasts developed in other analyses. Financial information is developed based on publicly available data and confidentially submitted manufacturer information. DOE compares the GRIM results for the standards case at each trial standard level (TSL) against the results for the base case, in which no energy conservation standards are in place. The financial impact of energy conservation standards is the difference between the two sets of discounted annual cash flows.

12.2.2.2 Interview Guide

DOE conducts interviews with manufacturers to gather information on the effects of energy conservation standards could have on revenues and finances, direct employment, capital assets, and industry competitiveness. These interviews take place during Phase III of the MIA. Before the interviews, DOE distributes an interview guide that will help identify the impacts of energy conservation standards on individual manufacturers or subgroups of manufacturers within the GSL industry. The interview guide covers production costs; shipment projections; market share; product mix; conversion costs; markups and profitability; assessment of the impact on competition; manufacturing capacity; and other relevant topics.

12.2.3 Phase III: Subgroup Analysis

Phase III activities occur after publication of the preliminary analysis. These activities include manufacturer interviews; revision of the industry cash flow analysis; a manufacturer subgroup analysis; an assessment of the impacts on industry competition, manufacturing capacity, direct employment, and the cumulative regulatory burden; and other qualitative impacts.

12.2.3.1 Manufacturer Interviews

DOE supplements the information gathered in Phase I and the cash-flow analysis performed in Phase II with information gathered through interviews with manufacturers during Phase III. The interview process plays a key role in the MIA because it provides an opportunity for interested parties to express their views privately on important issues.

DOE conducts detailed interviews with manufacturers to gain insight into the potential impacts of energy conservation standards on sales, direct employment, capital assets, and industry competitiveness. Interviews are scheduled well in advance to provide every opportunity for key individuals to be available for comment. Although a written response to the questionnaire is acceptable, DOE prefers interactive interviews, which help clarify responses and provide the opportunity to identify additional issues.

A non-disclosure agreement allows DOE to consider confidential or sensitive information in the decision-making process. Confidential information, however, is not made available in the public record. At most, sensitive or confidential information may be aggregated and presented in industry-wide representations.

12.2.3.2 Revised Industry Cash Flow Analysis

During the interviews, DOE requests information about profitability impacts, necessary plant changes, and other manufacturing impacts. Following the interviews, DOE revises the preliminary GRIM prepared in Phase II based on the feedback it receives during interviews.

12.2.3.3 Manufacturer Subgroup Analysis

The use of average cost assumptions to develop an industry cash flow estimate does not adequately assess differential impacts of energy conservation standards among manufacturer subgroups. Smaller manufacturers, niche players, and manufacturers exhibiting a cost structure that differs largely from the industry average could be more negatively affected. Ideally, DOE would consider the impact on every firm individually; however, it typically uses the results of the industry characterization to group manufacturers with similar characteristics. During the interviews, DOE discusses the potential subgroups that have been identified for the analysis. DOE asks manufacturers and other interested parties to suggest what subgroups or characteristics are most appropriate for the analysis.

One common subgroup identified is small business manufacturers. Should DOE determine this rulemaking impacts any small business manufacturers, DOE will conduct a regulatory flexibility analysis pursuant to the Regulatory Flexibility Act. (5 U.S.C. 601 *et seq*.)

12.2.3.4 Competitive Impact Assessment

Section 342 (6)(B)(i)(V) of the Energy Policy Act of 1992 (EPAct 1992) directs DOE to consider any lessening of competition likely to result from the imposition of standards. EPAct 1992 further directs the U.S. Attorney General to determine any likely impacts resulting from a decrease in competition. DOE gathers firm-specific financial information and attempts to determine the impact of standards on industry competition. The results of this effort are reported in the competitive impact assessment. The competitive impact assessment is based on manufacturer cost data and information collected from the manufacturer interviews. The interviews focus on assessing asymmetrical cost increases to some manufacturers, the potential increase in business risks from an increased proportion of fixed costs, and potential barriers to market entry (*e.g.*, proprietary technologies). The competitive impact analysis also focuses on assessing any differential impacts to smaller manufacturers.

12.2.3.5 Manufacturing Capacity Impact

One of the significant outcomes of energy conservation standards can be the obsolescence of existing manufacturing assets, including tooling and other investments. The manufacturer interview guide has a series of questions to help identify impacts on manufacturing capacity, specifically capacity utilization and plant location decisions in North America with and without energy conservation standards; the ability of manufacturers to upgrade or remodel existing facilities to accommodate the new requirements; the nature and value of any stranded assets; and estimates for any one-time restructuring or other charges, where applicable.

12.2.3.6 Employment Impact

The impact of energy conservation standards on employment is an important consideration in the rulemaking process. Manufacturer interviews play a significant role in assessing how domestic employment patterns might be impacted by energy conservation standards. The interview guide contains a series of questions that are designed to explore current employment trends in the GSL industry and to solicit manufacturers' views on changes in employment patterns that may result from increased standard levels. These questions focus on current employment levels at production facilities, expected future employment levels with and without energy conservation standards, differences in workforce skills, and employee retraining.

12.2.3.7 Cumulative Regulatory Burden

DOE seeks to mitigate the overlapping effects on manufacturers of energy conservation standards and other regulatory actions affecting the same products or companies. DOE analyzes and considers the impact of multiple, product-specific regulatory actions on manufacturers.

12.3 INDUSTRY OVERVIEW

The following section summarizes publicly available industry data.

12.3.1 Industry Cost Structure

DOE developed the GSL industry cost structure from the U.S. Census Bureau *Annual Survey of Manufacturers*: *Statistics for Industry Groups and Industries* with data from 2003 to 2011. GSL manufacturing is classified under the North American Industry Classification System (NAICS) code 335110 (*Electric Lamp Bulb and Part Manufacturing*).

DOE is unaware of any publicly available industry-wide cost data specific to only manufacturers of GSLs. DOE presents the data below as a broader industry proxy for the GSL industry.

Table 12.3.1 presents the electric lamp bulb and part employment levels and payroll from 2003 to 2011. The statistics show a 34.0 percent decrease in the number of production workers from 2003 to 2011, with a corresponding 7.0 percent decrease in the overall industry payroll from 2003 to 2011.

Table 12.3.1 Electric Lamp Bulb and Part Industry Employment and Earnings

Year	**Production Workers**	**All Employees**	**Payroll for All Employees** *thousand current year U.S. dollars*
2003	8,972.00	10,790.00	481,524.00
2004	8,022.00	9,867.00	512,514.00
2005	7,604.00	9,289.00	495,057.00
2006	6,669.00	8,192.00	449,809.00
2007	7,477.00	9,358.00	447,983.00
2008	7,884.00	10,152.00	462,196.00
2009	6,419.00	7,612.00	415,900.00
2010	6,100.00	7,698.00	464,118.00
2011	5,919.00	7,605.00	447,752.00

U.S. Census Bureau. *Annual Survey of Manufacturers: 2005 and Earlier Years*; *Annual Survey of Manufacturers: 2006 and 2005*; *Annual Survey of Manufacturers: 2008 and 2007*; *Annual Survey of Manufacturers: 2009 and 2008*; *Annual Survey of Manufacturers: 2010 and 2009; and Annual Survey of Manufacturers: 2011 and 2010*

Table 12.3.2 presents the costs of electric lamp bulb and part materials and industry payroll as a percentage of shipment value from 2003 to 2011. The cost of materials has significantly increased by 45.1 percent as a percentage of shipment value from 2003 to 2011. While the cost of payroll for production workers has significantly decreased by 25.3 percent, the cost of payroll for all employees has moderately increased by 10.8 percent as a percentage of shipment value from 2003 to 2011.

Table 12.3.2 Electric Lamp Bulb and Part Industry Material and Payroll Costs

Year	**Cost of Materials** *percent of shipment value*	**Cost of Payroll for Production Workers** *percent of shipment value*	**Cost of Payroll for All Employees** *percent of shipment value*
2003	36.0	14.8	18.5
2004	35.8	15.4	20.4
2005	42.6	15.6	20.8
2006	44.6	15.7	20.9
2007	44.7	14.7	20.3
2008	47.2	13.3	21.4
2009	49.0	16.3	21.4
2010	53.4	14.7	21.9
2011	52.2	13.2	20.5

U.S. Census Bureau. *Annual Survey of Manufacturers: 2005 and Earlier Years*; *Annual Survey of Manufacturers: 2006 and 2005*; *Annual Survey of Manufacturers: 2008 and 2007*; *Annual Survey of Manufacturers: 2009 and 2008*; *Annual Survey of Manufacturers: 2010 and 2009; and Annual Survey of Manufacturers: 2011 and 2010*

12.3.2 Inventory Levels

Table 12.3.3 shows the year-end inventory for the electric lamp bulb and part industry obtained from the U.S. Census Bureau *Annual Survey of Manufacturer*: *Statistics for Industry Groups and Industries* with data from 2003 to 2011. The industry's end-of-year inventory from 2003 to 2011 increased 20.7 percent when expressed in U.S. dollars, and grew significantly by 43.8 percent when expressed as a percentage of shipment value.

Table 12.3.3 Electric Lamp Bulb and Part Industry End-of-Year Inventory

Year	**End-of-Year Inventory** *thousand current year U.S. dollars*	**End-of-Year Inventory** *percent of shipment value*
2003	212,207	8.2%
2004	226,482	9.0%
2005	235,934	9.9%
2006	227,013	10.5%
2007	254,351	11.5%
2008	258,409	12.0%
2009	178,773	9.2%
2010	203,758	9.6%
2011	256,221	11.7%

U.S. Census Bureau. *Annual Survey of Manufacturers: 2005 and Earlier Years*; *Annual Survey of Manufacturers: 2006 and 2005*; *Annual Survey of Manufacturers: 2008 and 2007*; *Annual Survey of Manufacturers: 2009 and 2008*; and *Annual Survey of Manufacturers: 2010 and 2009;* and *Annual Survey of Manufacturers: 2010 and 2011.*

12.4 INTERVIEW TOPICS AND PRELIMINARY FINDINGS

The following section summarizes information gathered during interviews held in the second and third quarters of 2014 for the preliminary MIA.

12.4.1 Market Shares and Industry Consolidation

Energy conservation standards can alter the competitive dynamics of the marketplace, prompting companies to enter the market, exit the market, or merge with other companies. The preliminary MIA interview questions asked manufacturers to share their perspectives on industry consolidation both in the absence of energy conservation standards and assuming standards at various efficacy levels. The interview questions focused on gathering information that assessed:

- disproportionate cost increases to some manufacturers;
- increased proportion of fixed costs potentially increasing business risks; and
- potential barriers to market entry (*e.g.*, proprietary technologies).

The need to assess anti-competitive effects of energy conservation standards comes from the need to protect consumer interests. During the interviews, DOE solicited information to determine whether energy conservation standards could result in disproportionate economic or performance penalties for particular consumer or user subgroups. Manufacturers were also asked if energy conservation standards could result in products that will be more or less desirable to consumers due to changes in product functionality, utility, or other features.

Market Shares: DOE inquired about the current market share of manufacturers in the GSL industry and how those market shares might change due to the imposition of energy conservation standards. Manufacturers agreed in interviews that potential market share impacts would vary by product. Manufacturers expect that for less efficacious technologies, market shares will be unchanged. While shipments of less efficacious technologies and market size may decrease as a result of standards, manufacturers maintain that market shares will be unaffected as manufacturers do not hold significant design advantages over their competitors. For more efficacious technologies such as light-emitting diode (LED), manufacturers suggested that the market shares of industry leaders will increase as they can readily meet more stringent standards whereas other manufacturers may have difficulty doing so.

Industry Consolidation: The GSL industry is mainly composed of a few large manufacturers, but there are a handful of smaller manufacturers. As described in chapter 3 of this TSD, four manufacturers hold the majority of the domestic market share of GSLs. The lighting divisions of most of these companies also manufacture other products, such as general service fluorescent lamps, high intensity discharge lamps and metal halide lamp fixtures.

All of the manufacturers interviewed agreed that there would be significant consolidation in the GSL industry in the absence of standards. As new and innovative GSL technology brings new entrants into the market, manufacturers agree that eventually these more specialized newcomers could either merge together to increase product offerings and capabilities or be acquired by larger manufacturers. They also agreed that standards most likely would not lead to additional consolidation.

12.4.2 Production and Product Mix

DOE requested manufacturers' feedback on what they perceived to be the possible impact of energy conservation standards on cash flow and profitability. For instance, the capital and product conversion outlays needed to upgrade or redesign products before they have reached the end of their useful life may result in reduced cash flow and stranded investments. Higher energy conservation standards could also result in higher per-unit costs that could cause consumers to shift to less expensive products.

12.4.2.1 Impact on Product Mix

Manufacturers believe that energy conservation standards could affect the product mix of GSLs depending on the efficacy levels selected for the standards. Some manufacturers stated they may exit less efficacious sectors of the GSL industry if standards require significant investment to be compliant.

12.4.2.2 Product Utility

A few manufacturers expressed concern that energy conservation standards might require changes in product functionality, utility, and other features that would make products less desirable to consumers. Manufacturers stated if efficacy standards were significantly more stringent, manufacturers might have to shorten the life of the lamps to meet higher efficacy levels. Manufacturers also expressed concern that stringent standards could lead to unplanned fixture renovations as some fixtures and ballasts may not be compatible with LEDs.

12.4.3 Conversion Costs

In some instances, manufacturers may be able to meet proposed standard levels by modifying existing products. In other cases, the necessary changes may entail a complete product-line redesign. In either case, more stringent energy conservation standards would cause manufacturers to incur one-time capital and product conversion costs. Capital conversion costs are one-time investments in property, plant, and equipment. Product conversion costs include one-time investments in research, product development, testing, and marketing.

All manufacturers stated that the conversion costs associated with standards would depend on the efficacy level established by those standards. However, several manufacturers stated that testing, accreditation, and laboratory expenditures due to energy conservation standards for GSLs would account for a large portion of product conversion costs. Manufactures stated that they are unlikely to make investments in lower efficacious technologies such as compact fluorescent lamps (CFLs), and would most likely exit that sector of the GSL market if standards require significant investment. Manufacturers also noted that they could be forced to make investments in increasing their LED production capacity to meet heightened demand if manufacturers reduce their product offerings as a result of standards or if lower efficacy products are regulated out of the market.

12.4.4 Cumulative Regulatory Burden

While any one regulation may not impose a significant burden on manufacturers, the combined effects of several impending regulations may have serious consequences for individual manufacturers, groups of manufacturers, or entire industries. Assessing the impact of a single regulation may overlook this cumulative regulatory burden.

Expenditures associated with meeting other regulations are an important aspect of DOE's consideration of the cumulative regulatory burden the industry faces. The manufacturer interviews helped DOE identify the level and timing of investments manufacturers are expecting to incur because of these regulations. Manufacturers were also asked under what circumstances they might be able to make expenditures related to regulations and energy conservation standards.

Several Federal, international, and state regulatory programs may affect the markets for GSLs. The market and technology assessment discusses some of the notable initiatives that characterize recent developments in the lighting market. See chapter 3 of this TSD for a list and description of the regulatory requirements DOE identified.

Several of the large GSL manufacturers also manufacture other lighting products that are regulated by other DOE efficiency standards, such as the fluorescent lamp ballast standards (76 FR 70548 [Nov. 14, 2011]) and the metal halide lamp fixture standards (79 FR 7746 [February 10, 2014]) and the upcoming general service fluorescent lamps and incandescent reflector lamps update standard. Additionally, there are existing GSL standards implemented by the general service incandescent lamps standards (74 FR 12058 [March 23, 2009]).

12.5 OVERALL KEY ISSUES

One important aspect of the preliminary MIA is the opportunity it creates for DOE to identify key manufacturer issues early in the evaluation of energy conservation standards. During preliminary interviews, manufacturers identified two major areas of concern regarding GSL standards: (1) testing burden and (2) impacts of technology neutral standards.

12.5.1 Testing Burden

Several manufacturers expressed concern over the testing burden associated with GSL energy conservation standards. Manufacturers expressed concern regarding new testing requirements for LED lamps and expanded scope of CFLs to comply with GSL standards. Manufacturers stated that they would now need to spend capital that is already limited on testing and certifying already efficacious lamps to demonstrate compliance with GSL standards instead of on research and development that could result in increase of energy savings from these lamps. Additionally, manufacturers claimed that standards covering LED lamps could present a barrier to entry for small LED lamp manufacturers due to the increase in testing and certification requirements caused by GSL standards. Manufacturers claim this could result in a potential decrease of product innovation and energy-saving potential for LED lamps.

12.5.2 Impacts of Technology Neutral Standards

Manufacturers are concerned that technology neutral standards for GSLs could have a disproportionate effect on the range of technologies covered by standards. If GSL standards are set at the highest levels of efficacy, manufacturers are concerned that they may experience a loss of product differentiation among their lighting offerings. Manufacturers claim that as premium products become the baseline offering to consumers, previously offered advantages in lighting utility could be eliminated in an attempt to meet these higher standards.

Several manufacturers also stated they are concerned that GSL standards could be set at unattainable efficacy levels for CFLs. If CFLs are regulated out of the market it could force CFL manufacturers to either make significant investments in converting their production lines to other lighting technologies and cause them to incur a significant loss on the stranded assets associated with their existing CFL production or exit the GSL lighting market altogether. Lastly, manufacturers claim that setting GSL standards at efficacy levels that cannot be attained by CFLs would remove product utility from the market as consumers still value CFLs for certain applications and derive utility from these products.

CHAPTER 13. EMISSIONS ANALYSIS

TABLE OF CONTENTS

CHAPTER 13. EMISSIONS ANALYSIS

13.1 INTRODUCTION

The U.S. Department of Energy (DOE) conducts an emissions analysis for the notice of proposed rulemaking (NOPR) stage. In the emissions analysis, DOE estimates the reduction in power sector and site combustion emissions of carbon dioxide (CO_2), nitrogen oxides (NO_X), sulfur dioxide (SO_2), mercury (Hg), methane (CH_4) and nitrous oxide (N_2O) from potential energy conservation standards for general service lamps. In addition, DOE estimates emissions impacts in production activities (extracting, processing, and transporting fuels) that provide the energy inputs to power plants and for site combustion. These are referred to as "upstream" emissions. Together, these emissions account for the full-fuel-cycle (FFC). In accordance with DOE's FFC Statement of Policy (76 FR 51282 (August 18, 2011)), the FFC analysis includes impacts on emissions of methane and nitrous oxide, both of which are recognized as greenhouse gases.

13.2 APPROACH

DOE conducts the emissions analysis using emissions factors that are primarily derived from data in the latest version of the Energy Information Administration's (EIA's) *Annual Energy Outlook* (*AEO*), supplemented by data from other sources. EIA prepares the *AEO* using the National Energy Modeling System (NEMS).[a] Site emissions of CO_2 and NO_X are estimated using emissions intensity factors from a publication of the Environmental Protection Agency (EPA).[1] Combustion emissions of CH_4 and N_2O are estimated using emissions intensity factors published by the EPA GHG Emissions Factors Hub.[b] The FFC upstream emissions are estimated based on the methodology developed by Coughlin (2013).[2] The upstream emissions include both emissions from fuel combustion during extraction, processing and transportation of fuel, and "fugitive" emissions (direct leakage to the atmosphere) of CH_4 and CO_2.

13.3 AIR QUALITY REGULATIONS AND EMISSIONS IMPACTS

Each annual version of NEMS incorporates the projected impacts of existing air quality regulations on emissions. The text below refers to *AEO 2014,* which generally represents current legislation and environmental regulations, including recent government actions, for which implementing regulations were available as of October 31, 2013. The NOPR will use emissions factors derived from the most current available *AEO* data.

SO_2 emissions from affected electric generating units (EGUs) are subject to nationwide and regional emissions cap and trading programs. Title IV of the Clean Air Act sets an annual emissions cap on SO_2 for affected EGUs in the 48 contiguous states and the District of Columbia

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[a] For more information about NEMS, please refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is National Energy Modeling System: An Overview 2009, DOE/EIA-0581 (October 2009), available at: http://www.eia.gov/oiaf/aeo/overview/.

[b] http://www.epa.gov/climateleadership/inventory/ghg-emissions.html.

(D.C.). SO_2 emissions from 28 eastern states and D.C. were also limited under the Clean Air Interstate Rule (CAIR), which created an allowance-based trading program that operates along with the Title IV program in those States and D.C. 70 FR 25162 (May 12, 2005). CAIR was remanded to EPA by the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit), but it remained in effect.[c] On July 6, 2011 EPA issued a replacement for CAIR, the Cross-State Air Pollution Rule (CSAPR). 76 FR 48208 (August 8, 2011). On August 21, 2012, the D.C. Circuit issued a decision to vacate CSAPR.[d] The court ordered EPA to continue administering CAIR. *AEO 2014* assumes that CAIR remains a binding regulation through 2040.[e]

The attainment of emissions caps is typically flexible among EGUs and is enforced through the use of emissions allowances and tradable permits. Under existing EPA regulations, any excess SO_2 emissions allowances resulting from the lower electricity demand caused by the adoption of an efficiency standard could be used to permit offsetting increases in SO_2 emissions by any regulated EGU. In past rulemakings, DOE recognized that there was uncertainty about the effects of efficiency standards on SO_2 emissions covered by the existing cap-and-trade system, but it concluded that no reductions in power sector emissions would occur for SO_2 as a result of standards.

Beginning in 2016, however, SO_2 emissions will fall as a result of the Mercury and Air Toxics Standards (MATS) for power plants. 77 FR 9304 (Feb. 16, 2012) In the final MATS rule, EPA established a standard for HCl as a surrogate for acid gas hazardous air pollutants (HAP), and also established a standard for SO_2 (a non-HAP acid gas) as an alternative equivalent surrogate standard for acid gas HAP. The same controls are used to reduce HAP and non-HAP acid gas; thus, SO_2 emissions will be reduced as a result of the control technologies installed on coal-fired power plants to comply with the MATS requirements for acid gas. *AEO 2014* assumes that, in order to continue operating, coal plants must have either flue gas desulfurization or dry sorbent injection systems installed by 2016. Both technologies, which are used to reduce acid gas emissions, also reduce SO_2 emissions. Under the MATS, emissions will be far below the cap that would be established by CSAPR, so it is unlikely that excess SO_2 emissions allowances resulting from the lower electricity demand would be needed or used to permit offsetting increases in SO_2 emissions by any regulated EGU. Therefore, DOE believes that efficiency standards will reduce SO_2 emissions in 2016 and beyond.

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[c] See *North Carolina v. EPA*, 550 F.3d 1176 (D.C. Cir. 2008); *North Carolina v. EPA*, 531 F.3d 896 (D.C. Cir. 2008).

[d] See *EME Homer City Generation, LP v. EPA*, 696 F.3d 7, 38 (D.C. Cir. 2012).

[e] On April 29, 2014, the U.S. Supreme Court reversed the judgment of the D.C. Circuit and remanded the case for further proceedings consistent with the Supreme Court's opinion. The Supreme Court held in part that EPA's methodology for quantifying emissions that must be eliminated in certain states due to their impacts in other downwind states was based on a permissible, workable, and equitable interpretation of the Clean Air Act provision that provides statutory authority for CSAPR. See *EPA v. EME Homer City Generation*, No 12-1182, slip op. at 32 (U.S. April 29, 2014). Because DOE is using emissions factors based on *AEO 2014*, the analysis assumes that CAIR, not CSAPR, is the regulation in force. The difference between CAIR and CSAPR is not relevant for the purpose of DOE's analysis of SO_2 emissions.

CSAPR established a cap on NO_X emissions in eastern States and the District of Columbia. Energy conservation standards are expected to have little or no physical effect on these emissions in those States covered by CSAPR because excess NO_X emissions allowances resulting from the lower electricity demand could be used to permit offsetting increases in NO_X emissions. However, standards would be expected to reduce NO_X emissions in the States not affected by CSAPR. Therefore, DOE estimates NO_X emissions reductions from potential standards in the States where emissions are not capped.

The MATS limit mercury emissions from power plants, but they do not include emissions caps and, as such, DOE's energy conservation standards would likely reduce Hg emissions. For this rulemaking, DOE plans to estimate mercury emissions reductions using emissions factors based on *AEO 2014*, which incorporates the MATS.

Power plants may emit particulates from the smoke stack, which are known as direct particulate matter (PM) emissions. NEMS does not account for direct PM emissions from power plants. DOE is investigating the possibility of using other methods to estimate reduction in PM emissions due to standards. The great majority of ambient PM associated with power plants is in the form of secondary sulfates and nitrates, which are produced at a significant distance from power plants by complex atmospheric chemical reactions that often involve the gaseous emissions of power plants, mainly SO_2 and NO_X. The monetary benefits that DOE estimates for reductions in SO_2 and NO_X emissions resulting from standards are in fact primarily related to the health benefits of reduced ambient PM.

REFERENCES

1. U.S. Environmental Protection Agency. *AP-42: Compilation of Air Pollutant Emissions Factors*. 1998. Washington, D.C. http://www.epa.gov/ttn/chief/ap42/.

2. Coughlin, K. *Projections of Full-Fuel-Cycle Energy and Emissions Metrics*. 2013. Lawrence Berkeley National Laboratory. Report No. LBNL-6025E. http://ees.lbl.gov/sites/all/files/lbnl6025e_ffc.pdf.

CHAPTER 14. MONETIZATION OF EMISSIONS REDUCTION BENEFITS

TABLE OF CONTENTS

CHAPTER 14. MONETIZATION OF EMISSIONS REDUCTION BENEFITS

14.1 INTRODUCTION

As part of its assessment of energy conservation standards, the U.S. Department of Energy (DOE) considers the estimated monetary benefits likely to result from the reduced emissions of carbon dioxide (CO_2) and nitrogen oxides (NO_X) that are expected to result from the energy efficiency standards levels considered for general service lamps. To make this calculation, similar to the calculation of the net present value (NPV) of consumer benefit, DOE considers the reduced emissions expected to result over the lifetime of the equipment shipped in the projection period for each standard level.

14.2 APPROACH

To estimate the monetary value of benefits resulting from reduced emissions of CO_2, DOE plans to use the most current Social Cost of Carbon (SCC) values developed and/or agreed to by an interagency process. The SCC is intended to be a monetary measure of the incremental damage resulting from greenhouse gas (GHG) emissions, including, but not limited to, net agricultural productivity loss, human health effects, property damage from sea level rise, and changes in ecosystem services. Any effort to quantify and to monetize the harms associated with climate change will raise serious questions of science, economics, and ethics. But with full regard for the limits of both quantification and monetization, the SCC can be used to provide estimates of the social benefits of reductions in GHG emissions.

The Interagency Working Group on Social Cost of Carbon released an update of its previous report in 2013.[1] The most recent estimates of the SCC in 2015, expressed in 2013$, are $12.0, $40.5, $62.4, and $119 per metric ton of CO_2 avoided. For emissions reductions that occur in later years, these values grow in real terms over time. Additionally, the interagency group determined that a range of values from 7-percent to 23-percent should be used to adjust the global SCC to calculate domestic effects, although DOE will give preference to consideration of the global benefits of reducing CO_2 emissions. To calculate a present value of the stream of monetary values, DOE will discount the values in each of the four cases using the discount rates that had been used to obtain the SCC values in each case.

DOE recognizes that scientific and economic knowledge continues to evolve rapidly as to the contribution of CO_2 and other GHG to changes in the future global climate and the potential resulting damages to the world economy. Thus, these values are subject to change.

DOE also estimates the potential monetary benefit of reduced NO_X emissions resulting from the standard levels it considers. Estimates of monetary value for reducing NO_X from stationary sources range from $476 to $4,893 per ton in 2013$.[2] DOE calculates monetary benefits using a medium value for NO_X emissions of $2,684 per short ton (in 2013$), and real discount rates of 3-percent and 7-percent.

REFERENCES

1. Interagency Working Group on Social Cost of Carbon. *Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866*. 2013. http://www.whitehouse.gov/sites/default/files/omb/assets/inforeg/technical-update-social-cost-of-carbon-for-regulator-impact-analysis.pdf.

2. U.S. Office of Management and Budget. *2006 Report to Congress on the Costs and Benefits of Federal Regulations and Unfunded Mandates on State, Local, and Tribal Entities*. 2006. Washington, D.C. http://www.whitehouse.gov/sites/default/files/omb/assets/omb/inforeg/2006_cb/2006_cb_final_report.pdf.

CHAPTER 15. UTILITY IMPACT ANALYSIS

TABLE OF CONTENTS

CHAPTER 15. UTILITY IMPACT ANALYSIS

15.1 INTRODUCTION

In the utility impact analysis, the U.S. Department of Energy (DOE) analyzes the changes in electric installed capacity and power generation that result for each trial standard level (TSL).

The utility impact analysis is based on output of the DOE/Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).[a] NEMS is a public domain, multi-sectored, partial equilibrium model of the U.S. energy sector. Each year, DOE/EIA uses NEMS to produce an energy forecast for the United States, the Annual Energy Outlook (AEO). The EIA publishes a reference case, which incorporates all existing energy-related policies at the time of publication, and a variety of side cases which analyze the impact of different policies, energy price and market trends. As of 2014, DOE is using a new methodology based on results published for the *Annual Energy Outlook 2014 (AEO 2014)* Reference case and a set of side cases that implement a variety of efficiency-related policies.[2]

The new approach retains key aspects of DOE's previous methodology, and provides some improvements:

- The assumptions used in the AEO reference case and side cases are fully documented and receive detailed public scrutiny.
- NEMS is updated each year, with each edition of the AEO, to reflect changes in energy prices, supply trends, regulations, *etc.*
- The comprehensiveness of NEMS permits the modeling of interactions among the various energy supply and demand sectors.
- Using EIA published side cases to estimate the utility impacts enhances the transparency of DOE's analysis.
- The variability in impacts estimates from one edition of AEO to the next will be reduced under the new approach.

On the average, however, over the full analysis period, the results from the new approach are comparable to results from the old approach.

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[a] For more information on NEMS, refer to the U.S. Department of Energy, Energy Information Administration documentation. A useful summary is *National Energy Modeling System: An Overview*.[1]

15.2 METHODOLOGY

DOE estimates the marginal impacts of reduction in energy demand on the energy supply sector. In principle, marginal values should provide a better estimate of the actual impact of energy conservation standards.

NEMS uses predicted growth in demand for each end use to build up a projection of the total electric system load growth. The system load shapes are converted internally to load duration curves, which are then used to estimate the most cost-effective additions to capacity. When electricity demand deviates from the AEO reference case, in general there are three inter-related effects: the annual generation in terawatt hours (TWh) from the stock of electric generating capacity changes, the total generation capacity itself in gigawatts (GW) may change, and the mix of capacity by fuel type may change.[b] Each of these effects can vary for different types of end use. The change in total generating capacity is sensitive to the degree to which the end-use is peak coincident, while the capacity mix is sensitive to the hourly load shape associated with the end use. Changes in generation by fuel type lead in turn to changes in total power sector emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_X), mercury (Hg), and carbon dioxide (CO_2).

DOE's new approach examines a series of AEO side cases to estimate the relationship between demand reductions and the marginal energy, emissions and capacity changes. The assumptions for each side case are documented in Appendix E of the AEO.[c] The side cases, or scenarios, that incorporate significant changes to equipment efficiencies relative to the Reference case are:

- 2013 Technology (leaves all technologies at 2013 efficiencies);
- Best Available Technology (highest efficiency irrespective of cost);
- High Technology (higher penetration rates for efficiency and demand management);
- Extended Policies (includes efficiency standards that are not in the reference).

Scenarios that incorporate policies that directly affect the power sector without changes in energy demand (for example, subsidies for renewables, or high fuel price assumptions) are not appropriate for this analysis. The methodology proceeds in seven steps:

1. Supply-side data on generation, capacity and emissions, and demand-side data on electricity use by sector and end-use, are extracted from each side case. The data are converted to differences relative to the AEO Reference case.

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[b] The terawatt is equal to one trillion (10^{12}) watts. The total power used by humans worldwide (about 16 TW in 2006) is commonly measured in this unit. The gigawatt is equal to one billion (10^9) watts or 1 gigawatt = 1000 megawatts. This unit is often used for large power plants or power grids.

[c] Appendix E of AEO 2014 is available at http://www.eia.gov/forecasts/aeo/section_appendices.cfm and http://www.eia.gov/forecasts/aeo/data_side_cases.cfm

2. The changes in electricity use on the demand-side data are allocated to one of three categories: on-peak, shoulder, and off-peak. These categories are used in the utility sector to correlate end-use consumption with supply types. For each of the end-uses that are modeled explicitly in NEMS, load shape information is used to identify the fraction of annual electricity use assigned to each category. On-peak hours are defined as 12:00 noon to 5:00 p.m., June through September. Off-peak hours are nights and Sundays. All other hours are assigned to the shoulder period.

3. For each year and each side case, the demand-side reductions to on-peak, off-peak and shoulder-period electricity use are matched on the supply-side to reductions in generation by fuel type. The fuel types are petroleum fuels, natural gas, renewables, nuclear and coal. The allocation is based on the following rules:

    3.1. All petroleum-based generation is allocated to peak periods;

    3.2. Natural gas generation is allocated to any remaining peak reduction; this is consistent with the fact that oil and gas steam units are used in NEMS to meet peak demand;

    3.3. Base-load generation (nuclear and coal) is allocated proportionally to all periods;

    3.4. The remaining generation of all types is allocated to the remaining off-peak and shoulder reductions proportionally.

4. The output of Step 3 defines fuel-share weights giving the fraction of energy demand in each load category that is met by each fuel type as a function of time. These are combined with the weights that define the load category shares by end-use to produce coefficients that allocate a marginal reduction in end-use electricity demand to each of the five fuel types.

5. A regression model is used to relate reductions in generation by fuel type to reductions in emissions of power sector pollutants. The model produces coefficients that define the change in total annual emissions of a given pollutant resulting from a unit change in total annual generation for each fuel type, as a function of time. These coefficients are combined with the weights calculated in Step 4 to produce coefficients that relate emissions changes to changes in end-use demand.

6. A regression model is used to relate reductions in generation by fuel type to reductions in installed capacity. The categories used for installed capacity are the same as for generation except for peak: NEMS uses two peak capacity types (combustion turbine/diesel and oil and gas steam) which are combined here into a single "peak" category. The model produces coefficients that define the change in total installed capacity of a given type resulting from a unit change in total annual generation for the corresponding fuel type. These coefficients are combined with the weights calculated in Step 4 to produce coefficients that relate installed capacity changes to changes in end-use demand, as a function of time.

7. The coefficient time-series for fuel share, pollutant emissions and capacity for the appropriate end use are multiplied by the stream of energy savings calculated in the NIA to produce estimates of the utility impacts.

This analysis does not take into account pumped storage, fuel cells, and distributed generation, as these generation types are not affected by the policy changes modeled in the EIA side cases. The methodology is described in more detail in K. Coughlin, "Utility Sector Impacts of Reduced Electricity Demand."[3]

REFERENCES

1. U.S. Department of Energy-Energy Information Administration. *The National Energy Modeling System: An Overview 2009*. 2009. Report No. DOE/EIA-0581. http://www.eia.gov/oiaf/aeo/overview/.

2. Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040*. 2014. Washington, D.C. http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

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CHAPTER 16. EMPLOYMENT IMPACT ANALYSIS

TABLE OF CONTENTS

CHAPTER 16. EMPLOYMENT IMPACT ANALYSIS

16.1 INTRODUCTION

The U.S. Department of Energy's (DOE's) employment impact analysis estimates indirect national job creation or job elimination resulting from possible new energy conservation standards, due to reallocation of the associated expenditures for purchasing and operating certain equipment. DOE conducts this analysis for the notice of proposed rulemaking (NOPR) stage where it estimates national impacts on major sectors of the U.S. economy, using publicly available data.

Energy conservation standards can impact employment both directly and indirectly. Direct employment impacts are changes in the number of employees at the plants that produce the covered equipment, along with the affiliated distribution and service companies, resulting from standards. DOE evaluates direct employment impacts in its manufacturer impact analysis, as described in chapter 12 of this Technical Support Document. The employment impact analysis described in this chapter covers indirect employment impacts which may result from expenditures shifting between goods (the substitution effect) and changes in income and overall expenditure levels (the income effect) that occur due to the implementation of standards.

DOE expects new or amended energy conservation standards to decrease energy consumption and, therefore, reduce expenditures for energy. In turn, savings in energy expenditures may be redirected for new investment and other items. Notwithstanding, energy conservation standards may potentially increase the purchase price of equipment, including the retail price plus sales tax, and may increase installation costs.

Using an input-output model of the U.S. economy, the employment impact analysis seeks to estimate the year-to-year effect of these expenditure impacts on net national employment. DOE intends the employment impact analysis to quantify the indirect employment impacts of these expenditure changes.

16.2 METHODOLOGY

To investigate the and indirect employment impacts, DOE uses the Pacific Northwest National Laboratory's (PNNL's) "Impact of Sector Energy Technologies" (ImSET 3.1.1) model.[1] PNNL developed ImSET, a spreadsheet model of the U.S. economy that focuses on 187 sectors most relevant to industrial, commercial, and residential building energy use, for DOE's Office of Energy Efficiency and Renewable Energy. ImSET is a special-purpose version of the U.S. Benchmark National Input-Output (I-O) model, which has been designed to estimate the national employment and income effects of energy saving technologies that are deployed by DOE's Office of Energy Efficiency and Renewable Energy. In comparison with the previous versions of the model used in earlier rulemakings, this version allows for more complete and automated analysis of the essential features of energy efficiency investments in buildings, industry, transportation, and the electric power sectors.

The ImSET software includes a computer-based I-O model with structural coefficients to characterize economic flows among the 187 sectors. ImSET's national economic I-O structure is based on the 2002 Benchmark U.S. table, specially aggregated to 187 sectors.[2]

DOE intends to use the ImSet model to estimate changes in employment in the overall U.S. economy resulting from changes in expenditures in the various sectors of the economy. DOE has designed the employment impact analysis to estimate the year-to-year net national employment effect of these different expenditure flows.

REFERENCES

1. Roop, J. M., M. J. Scott, and R. W. Schultz. *ImSET: Impact of Sector Energy Technologies*. 2005. Pacific Northwest National Laboratory: Richland, WA. http://www.pnl.gov/main/publications/external/technical_reports/PNNL-15273.pdf.

2. Lawson, A. M., K. S. Bersani, M. Fahim-Nader, and J. Guo. Benchmark Input-Output Accounts of the U. S. Economy, 1997. *Survey of Current Business*. 2002. 82 pp. 19–117.

CHAPTER 17. REGULATORY IMPACT ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 17. REGULATORY IMPACT ANALYSIS

17.1 INTRODUCTION

For "economically significant regulatory actions," Executive Order 12866 requires Federal agencies to provide "an assessment, including the underlying analysis, of costs and benefits of potentially effective and reasonably feasible alternatives to the planned regulation, identified by the agencies or the public (including improving the current regulation and reasonably viable non-regulatory actions), and an explanation why the planned regulatory action is preferable to the identified potential alternatives." 58 FR 51735, 51741 (October 4, 1993). Accordingly, in the notice of proposed rulemaking (NOPR) stage, the U.S. Department of Energy (DOE) plans to analyze feasible alternatives that possibly could provide incentives for the same energy efficiency levels as the proposed standards for the equipment that are subject of the general service lamps rulemaking. In addition, DOE proposes to analyze five feasible policy alternatives to energy conservation standards for the equipment considered in this rulemaking. The policy alternatives are listed below in Table 17.1.1. DOE will evaluate each alternative in terms of its ability to achieve significant energy savings at a reasonable cost, and will compare the effectiveness of each alternative to the effectiveness of each candidate standard.

The technical support document (TSD) is prepared in support of DOE's notice of proposed rulemaking and includes a complete quantitative analysis of each alternative, the methodology for which is briefly addressed below.

Table 17.1.1 Alternatives to Standards

No New Regulatory Action
Consumer Rebates
Consumer Tax Credits
Manufacturer Tax Credits
Voluntary Energy Efficiency Targets
Bulk Government Purchases

17.2 METHODOLOGY

DOE uses the national impact analysis (NIA) spreadsheet model to calculate the national energy savings and the net present value (NPV) corresponding to each alternative to proposed energy conservation standards. The NIA model is discussed in chapter 10 of the TSD. To compare each alternative quantitatively to the proposed energy conservation standards, DOE quantifies the effect of each alternative on the purchase and use of energy efficient equipment, such as general service lamps. DOE then creates an integrated model, built on the NIA model, in order to make the appropriate revisions to the inputs in the NIA models. Key inputs that DOE may revise are the market shares of equipment meeting the target efficiency levels, which correspond to the efficiency levels set for the mandatory standards at each trial standard level.

The following are the key measures of the impact of each alternative:

- National Energy Savings *(NES)*, given in quadrillion Btus (quads), will describe the potential cumulative national primary energy to be saved over the lifetime of equipment purchased during the 30-year analysis period starting in the effective date of the policy.[a]

- Net Present Value (NPV), will represent the value of net monetary savings from equipment purchased during the 30-year analysis period starting in the compliance date of the policy. DOE calculates NPV as the difference between the present values of installed equipment cost and operating expenditures in the base case and the present values of those costs in each policy case. DOE then calculates operating expenses (including energy costs) for the life of equipment.

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[a] The British thermal unit (Btu) is the amount of energy needed to cool or heat one pound of liquid water by one degree Fahrenheit at a constant pressure of one atmosphere.

APPENDIX AA. ACRONYMS AND ABBREVIATIONS

ACEEE	American Counsel for an Energy-Efficient Economy
AEC	Annual Energy Consumption
AEO	Annual Energy Outlook
AFC	Annualized first cost
AHS	American Housing Survey
Al_2O_3	Aluminum oxide
ALA	American Lighting Association
ANSI	American National Standards Institute
ASAP	Appliance Standard Awareness Project
BaO	Barium oxide
BEF	Ballast efficacy factor
BF	Ballast factor
BLE	Ballast luminous efficiency
BLS	Bureau of Labor Statistics
BPAR	Bulged parabolic aluminum reflector
BR	Bulged reflector
CAIR	Clean Air Interstate Rule
CA IOUs	California Investor-Owned Utilities
CaO	Calcium oxide
CAPM	Capital asset pricing model
CAT	Calcium tungstate
CBECS	Commercial Buildings Energy Consumption Survey
CCE	Certification, compliance, and enforcement
CCMS	Compliance certification management system
CCR	California Code of Regulations
CCT	Correlated color temperature
CEE	Consortium for Energy Efficiency
CEC	California Energy Commission
CFL	Compact fluorescent lamp
CFR	Code of Federal Regulations
CLC	Cape Light Compact
CMS	Critical Materials Strategy
CO_2	Carbon dioxide
CPUC	California Public Utilities Commission
ComEd	Commonwealth Edison
ConEd	Consolidated Edison
CPI	Consumer Price Index
CRI	Color rendering index
CSAPR	Cross-State Air Pollution Rule
CSC	Candidate standard case
CSL	Candidate standard level
CVD	Chemical vapor deposition
DF	Discount Factor

DOE	U.S. Department of Energy
ECI	Equipment Cost Increment
ECS	Energy conservation standards
EEI	Edison Electric Institute
EGU	Electric utility generating unit
EIA	U.S. Energy Information Administration
EISA	Energy Independence and Security Act
EL	Efficacy level
EMI	Electromagnetic interference
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act
EPCA	Energy Policy and Conservation Act
ER	Elliptical reflector
ERP	Equity risk premium
ESR	Effective series resistance
EU	European Union
FEMP	Federal Energy Management Program
FFC	Full-fuel-cycle
FTC	Federal Trade Commission
GaN	Gallium nitride
GaP	Gallium phosphide
GDP	Gross domestic product
GE	General Electric
GHG	Greenhouse gas
GRIM	Government Regulatory Impact Model
GSFL	General service fluorescent lamp
GSIL	General service incandescent lamp
GSL	General service lamp
HAP	Hazardous air pollutant
Hg	Mercury
HID	High-intensity discharge
HIR	Halogen infrared reflector
HOU	Hours of use
IEC	International Electrotechnical Commission
IESNA	Illuminating Engineering Society of North America
ImSET	Impact of Sector Energy Technologies model
InGaN	Indium gallium nitride
INPV	Industry net present value
I-O	Input-Output
IR	Infrared
IRL	Incandescent reflector lamp
IS	Instant start
K	Kelvin
kWh	Kilowatt-hour
LAP	Lanthanum phosphate
LBNL	Lawrence Berkeley National Laboratory

LCC	Life-cycle cost
LED	Light-emitting diode
LLMF	Lamp lumen maintenance factor
LMC	U.S. Lighting Market Characterization
Lm/W	Lumens per watt
LSF	Lamp survival factor
MATS	Mercury and Air Toxics Standards
MBCFL	Medium base compact fluorescent lamp
MECS	Manufacturing Energy Consumption Survey
MEPs	Minimum energy performance standards
MIA	Manufacturer impact analysis
MOSFETs	Metal-oxide-semiconductor field-effect transistors
MR	Multifaceted reflector
ms	Milliseconds
MSB	Medium screw base
MSP	Manufacturer selling price
NAICS	North American Industry Classification System
NEEA	Northwest Energy Efficiency Alliance
NEEP	Northeast Energy Efficiency Partnerships
NEMA	National Electrical Manufacturers Association
NEMS	National Energy Modeling System
NES	National energy savings
NIA	National impact analysis
NODA	Notice of data availability
NOPM	Notice of public meeting
NOPR	Notice of proposed rulemaking
NO_X	Nitrogen oxides
NPV	Net present value
NRCan	Natural Resources Canada
NRDC	Natural Resources Defense Council
OAL	Office of Administrative Law
OCS	Operating Cost Savings
OLED	Organic light-emitting diode
OMB	Office of Management and Budget
OSI	OSRAM SYLVANIA
PAR	Parabolic aluminized reflector
PBP	Payback period
PC	Phosphor converted
PFC	Power factor correction
PG&E	Pacific Gas and Electric
PM	Particulate matter
PPI	Producer Price Index
P.R. China	People's Republic of China
PS	Programmed start
PVC	Present Value of Costs
PVS	Present Value of Savings

R	Reflector
R&D	Research and development
RBSAM	Residential Building Stock Assessment Metering
RECS	Residential Energy Consumption Survey
REO	Rare earth oxideRIA Regulatory impact analysis
RIN	Regulatory information number
RLEUCS	Residential Lighting End-Use Consumption Study: Estimation Framework and Initial Estimates
RLS	Residential Lighting Strategy
rms	Root mean square
ROI	Returns on investment
RS	Rapid start
SBA	Small Business Administration
SBMV	Self-ballasted mercury vapor
SCC	Social cost of carbon
SCE	Southern California Edison
SCF	Survey of Consumer Finances
SEC	Securities Exchange Commission
SG&A	Selling, general, and administrative
SNOPR	Supplementary notice of proposed rulemaking
Si	Silicon
SiC	Silicon carbide
SiO_2	Silicon oxide
SO_2	Sulfur dioxide
SPD	Spectral power distribution
SrO	Strontium oxide
SSL	Solid-state lighting
SUNY	State University of New York
THD	Total harmonic distortion
TI	Texas Instruments
TIC	Total Installed Cost
TIM	Thermal interface material
TiO_2	Titanium oxide
TOC	Total Operating Cost
TP	Test procedure
TSD	Technical support document
TSL	Trial standard level
UEC	Unit Energy Consumption
U.S.C.	United States Code
UL	Underwriters Laboratories
UV	Ultraviolet
W	Watt
WACC	Weighted average cost of capital
WPE	Wall plug efficiency
YAG	Yttrium aluminum garnet

APPENDIX 8A. USER INSTRUCTIONS FOR LCC AND PBP SPREADSHEET

TABLE OF CONTENTS

APPENDIX 8A. USER INSTRUCTIONS FOR LIFE-CYCLE COST ANALYSIS SPREADSHEET

8A.1 INTRODUCTION

The detailed results of the life-cycle cost (LCC) and payback period (PBP) analysis are illustrated with a Microsoft Excel® spreadsheet, which is accessible on the U.S. Department of Energy's (DOE) rulemaking website for GSLs.[a] The spreadsheet posted on the DOE website has been tested with Microsoft Excel 2010.

8A.2 DESCRIPTION OF LIFE-CYCLE COST SPREADSHEET

For all of the product classes, DOE created a single LCC workbook file containing a collection of worksheets. The LCC workbook contains the following worksheets that present results and sample calculations:

Summary	This worksheet contains summary LCC and PBP results and box plots for all product classes, and for all alternative scenarios, at each candidate standard level (CSL). Users can select between the reference scenario or alternative scenarios to generate results.
Res Example, Com Example	Each of these worksheets contains detailed results and sample calculations for a single consumer (*i.e.,* a purchaser of a GSL) in all product classes for the residential sector (Res Example) and the commercial sector (Com Example), respectively. Users can choose consumer characteristics with a series of drop-down menus and fillable cells. Users can also choose the base case CSL (*i.e.*, the selected GSL's CSL in the base case), the candidate standards case (*i.e.*, the standard level for the selected GSL in the standards case), and the candidate standards case CSL (*i.e.*, the selected GSL's CSL in the standards case). The right side of each sheet shows LCC and LCC savings results for the selected parameters.

The LCC workbook contains the following worksheets that present inputs used in the LCC and PBP analysis:

Res Sample, Com Sample	The Res Sample and Com Sample worksheets contain the samples of 10,000 consumers for the residential and commercial sector, respectively. During a simulation, DOE uses these samples to derive results for the analysis.

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[a] http://www.regulations.gov/#!docketDetail;D=EERE-2013-BT-STD-0051 (accessed November 19, 2014).

GSL Prices	This worksheet contains inputs for GSL purchase prices for all lamp options at the base case and the candidate standards cases. Note that GSL prices are different across standards cases due to price learning.
E_Price&Trends	This worksheet shows the prices and price trends used to estimate electricity price for each purchaser.
Discount Rates	This worksheet contains the distributions of discount rates.
Lifetime	This worksheet contains the cumulative distributions of daily operating hours for the residential and commercial sectors, and the probability of survival as a function of lamp age by rated life (hours) and sector
Market Distribution	This worksheet contains the market distribution for all product classes for the selected scenario
Energy Use	This worksheet contains inputs used to calculate annual GSL energy use by CSL: GSL power input values, operating hours, market data on controls and smart lamps, room distribution by lumen ranges, and the lumen range distribution.
Other Parameters	This worksheet contains other input parameters used in the analysis, including tax rates and disposal costs.

APPENDIX 8B. UNCERTAINTY AND VARIABILITY

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX 8B. UNCERTAINTY AND VARIABILITY

8B.1 INTRODUCTION

This appendix discusses uncertainty and variability and describes how the U.S. Department of Energy (DOE) incorporated these into the life-cycle cost (LCC) and payback period (PBP) analysis and other downstream analyses reported in this preliminary analysis technical support document (TSD) for the general service lamp (GSL) energy conservation standards (ECS) rulemaking. The two key approaches are (1) to use distributions to capture uncertainties and variations in input variables when such distributions are reasonably well defined, and (2) to use scenarios that capture the bounds of uncertainty when the bounds are less well defined.

8B.2 INTRODUCTION TO UNCERTAINTY AND VARIABILITY

DOE develops mathematical models to analyze the impacts of proposed energy conservation standards. The models generate outputs (e.g., the LCC impact of proposed standards) based on inputs that are often uncertain, variable, or both.

Variability means that the quantity of interest takes on different values at different times or under different conditions. Variability may be caused by many factors. For example, the hours of use of a lamp depend on environmental factors (e.g., diurnal variations in light) and behavioral factors (e.g., the schedules and preferences of the inhabitants of a house). Manufacturing irregularities can also cause variability. For example, 10 lamps of the same model may each have slightly different power consumptions. DOE attempts to account for major sources of variability in its analyses.

Uncertainty has many sources. Variability may lead to uncertainty in model inputs, because analysts frequently must estimate the values of interest based on samples of a variable quantity (for example, the hours of use of lighting in a home). Measurement uncertainty is another source of uncertainty, which may result from instrumental uncertainties (resulting, for example, from drift, bias, and precision of resolution) and human factors (e.g., variations in experimental setup, errors in instrument readings or recordings). Uncertainty can also arise when there is limited data available to estimate a particular parameter. DOE attempts to address the major sources of uncertainties in its analyses.

8B.2.1 Approaches to Address Uncertainty and Variability

This section describes two approaches to address uncertainty and variability in numerical modeling that in practice are often used in tandem, as they are in this rulemaking: (1) probability analysis and (2) scenario analysis.

Probability analysis considers the probability that a variable has a given value over its range of possible values. For quantities with variability (e.g., electricity rates in different households), data from surveys or other forms of measurement can be used to generate a frequency distribution of numerical values to estimate the probability that the variable takes a given value. By sampling values from the resulting distribution, it is possible to quantify the impact of known variability in a particular variable on the outcome of the analysis. In this rulemaking, DOE used probability distributions to estimate GSL service lifetime, annual lamp energy use, consumer electricity prices, and other variables.

Unlike probability analysis, which considers the impact of known variability, scenario analysis estimates the sensitivity of an analysis to sources of uncertainty and variability whose probability distribution is not well known. Certain model inputs are modified to take a number of different values, and models are re-analyzed, in a set of different model scenarios. Because only selected inputs are changed in each scenario, the variability in the results for each scenario helps to quantify the impact of uncertainty in the input parameters. In this rulemaking, for example, the reference LCC analysis was performed assuming GSLs having a standby mode (i.e., "smart lamps") had zero standby power consumption. An alternative scenario analysis assumed that such lamps consume 1 watt of power when in standby mode (with all other input variables unchanged from the reference scenario). Whereas it is relatively simple to perform scenario analyses for a range of scenarios, scenario analyses provide no information regarding the likelihood of any given scenario's actually occurring.

Scenario and probability analysis provide some indication of the robustness of the policy given the uncertainties and variability. A policy is robust when the impacts are acceptable over a wide range of possible conditions.

8B.3 PROBABILITY ANALYSIS AND THE USE OF MONTE CARLO SIMULATION IN THE LCC AND PBP ANALYSIS

To quantify the uncertainty and variability that exist in inputs to the LCC and PBP analysis, DOE used Monte Carlo simulation and probability distributions to conduct probability analyses.

Simulation refers to any analytical method meant to imitate a real-life system, especially when other analyses are too mathematically complex or too difficult to reproduce. Without the aid of simulation, a model will only reveal a single outcome, generally the most likely or average scenario. Probabilistic risk analysis uses both a spreadsheet model and simulation to automatically analyze the effect of varying inputs on the outputs of a modeled system. One type of simulation is Monte Carlo simulation, which repeatedly generates random values for uncertain variables, drawn from a probability distribution, to simulate a model.

For each uncertain variable, the range of possible values is controlled by a probability distribution. The type of distribution selected is based on the conditions surrounding that variable. Probability distribution types include normal, triangular, uniform, and Weibull distributions, as well as custom distributions where needed. Example plots of these distributions are shown in Figure 8B.3.1.

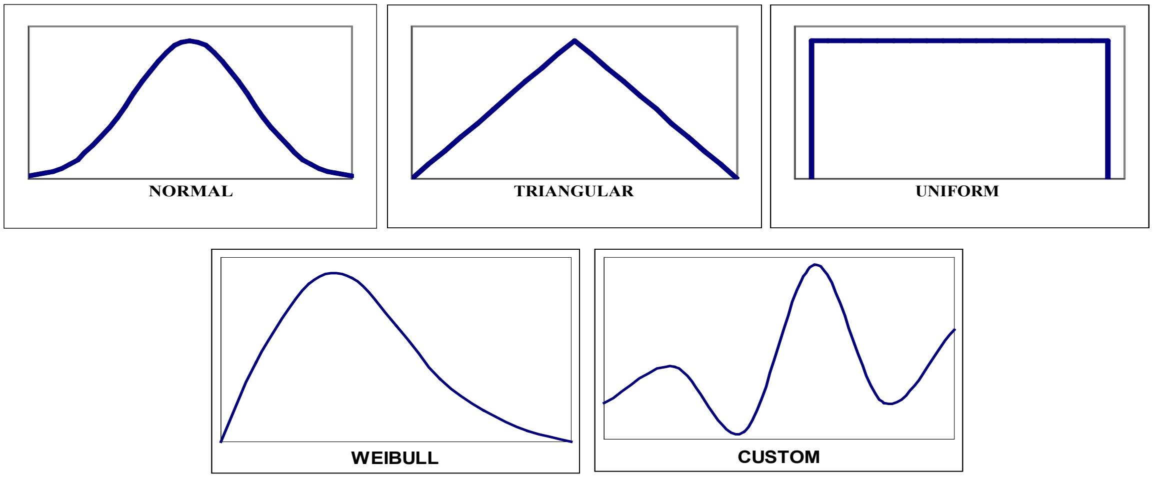

Figure 8B.3.1 Normal, Triangular, Uniform, Weibull, and Custom Probability Distributions

During a simulation, multiple scenarios of a model are calculated by repeatedly sampling values from the probability distributions for the uncertain variables and using those values for that input. Monte Carlo simulations can consist of as many trials as desired, with larger numbers of trials yielding more accurate average results. During a single trial, the simulation randomly selects a value from the defined possibilities (the range and shape of the probability distribution) for each uncertain variable and then recalculates the result for that trial.

8B.4 ALTERNATIVE SCENARIOS CONSIDERED IN THIS RULEMAKING

DOE considered a number of alternative scenarios in this rulemaking to account for uncertainty and variability in key analysis inputs whose probability distribution was not well known. Many, but not all, of the alternative scenarios DOE considered in this rulemaking directly impact the LCC and PBP analysis. Many scenarios also affect the Shipments and National Impacts analyses (chapters 9 and 10 of this preliminary TSD). The alternative scenarios DOE considered are:

- **Lamp service lifetime:** DOE believes the service lifetime of a GSL can be modeled using a Weibull survival function (i.e., probability of survival as a function of GSL age) of the GSL's rated lifetime, truncated by another Weibull survival function to ensure GSLs are not in service long after the assumed renovation/retrofit cycle length (20 years). However, given the uncertainty in this assumption, DOE analyzed two alternative scenarios. See appendix 8E of this TSD for more details.
- **Rare earth cost:** The reference scenario assumes that prices of rare earth elements are constant at their June 2014 level. DOE also considered an alternative scenario in which the prices of rare earth elements are midway between their 2011 peak and the 2006 – 2009 baseline average price. See appendix 8D of this TSD for details.
- **Controls:** DOE believes that lighting controls in the commercial sector are installed on an increasing fraction of lamps as a result of updated building codes, but there is uncertainty in this assumption. Therefore, DOE considered an alternative scenario where

the fraction of commercial GSLs on controls remains constant over the analysis period at 2014 levels. See appendix 10C of this TSD for more information.

- **Smart lamp incursion:** DOE believes that the residential sector will experience an increase in the number of LED GSLs with a standby mode and with integrated wireless receivers that allow them to be controlled remotely (referred to as *smart lamps*). DOE believes that these features may have a significant impact on energy consumption for these lamps. DOE also believes these lamps will be a growing share of the market over the period covered by the NIA, but there is uncertainty as to the fraction of LED GSL shipments that are smart lamps at the end of the projection period. DOE therefore tested the impact of varying its assumptions about the final smart-lamp market share. See chapter 10 of this TSD for more details.
- **Smart lamps standby power:** In the reference scenario, DOE assumed no standby power consumption for smart-lamp GSLs that have a standby mode. DOE analyzed another scenario in which the standby power consumption was assumed to be 1 watt.
- **AEO Growth:** The reference scenario uses future electricity prices based on reference electricity price trends projected by the Energy Information Administration in its *Annual Energy Outlook 2014* (AEO 2014).[1] Because of the uncertainty present when attempting to estimate future electricity prices, DOE analyzed two alternative economic growth scenarios: a low economic growth, and a high economic growth scenario from AEO 2014.
- **Rebound:** In the reference scenario, DOE estimated no rebound effect in either the residential or commercial sectors. DOE explored other rebound rates for the commercial and residential sectors to illustrate the impact of DOE's estimation on the analysis. See appendix 10D for more details.
- **Integrated LED incursion:** DOE believes that a growing fraction of GSL shipments may be displaced over the course of the shipments projection period by integrated LED fixtures, which do not require the use of replaceable lamps. DOE believes these fixtures will displace a growing fraction of shipments over time, but there is uncertainty as to the fraction of shipments that will be displaced by the end of the analysis period. DOE therefore tested the impact of varying its assumptions about the final integrated-luminaire market share. See chapter 9 of this TSD for more details.
- **Learning rate:** While price learning is known to occur for GSLs, DOE considers the future learning rate for LED GSLs to be uncertain, because LEDs are in an early phase of their market adoption. DOE estimates that the current LED learning rate is substantially higher than the learning rate for CFLs, but DOE believes that this trend may not continue over the duration of the analysis period. Therefore, in the reference scenario DOE assumed LED GSLs have a price learning rate equal to the historic learning rate for CFLs. In two alternative scenarios, DOE analyzed the possibility of a sustained LED learning rate at the current LED learning rate over the analysis period as well as the possibility of no price learning for any GSLs. See chapter 9 of this TSD for more details.

Table 8B.4.1 and Table 8B.4.2 provide summary descriptions of the reference and alternative scenarios DOE considered in this rulemaking. Table 8B.4.1 contains the alternative analyses that directly affect the LCC and PBP analysis, whereas Table 8B.4.2 contains the alternative analyses that do not directly affect the LCC and PBP analysis, but that do have implications for other analyses in this rulemaking (e.g., the shipments analysis and NIA).

Table 8B.4.1 Scenarios Considered in this Rulemaking that Directly Affect the LCC and PBP Analysis

Scenario Name	Scenario Options Analyzed	Description of Alternative Scenarios
Reference	Reference option indicated in bold below	DOE's best estimate for each variable considered in its analyses
Lamp Service Lifetime	Rated Lifetime	Full rated lifetime (taking into account effects of on-cycle length on CFL lifetimes)
	Renovation-Driven Lifetime	The Rated Lifetime distribution truncated by a Weibull distribution with a 20-year median
	Early-Replacement Lifetime	For LEDs, the Rated Lifetime distribution truncated by a Weibull distribution with a 5-year median; for CFLs, lifetime as in the reference scenario
Rare Earth Cost	**Constant**	Remain constant at current level over analysis period
	High	Remain constant at increased level over analysis period
Controls (commercial sector only)	**Reference**	The fraction of commercial floor space utilizing various types of controls grows from 30% today to a projected value of 80% in 2049
	Fixed	The current fraction of commercial GSLs with controls remains constant over the analysis period
Smart Lamp Incursion (residential sector only)	0%	0% market share of smart lamp shipments at the end of the analysis period
	50%	50% market share of smart lamp shipments at the end of the analysis period
	100%	100% market share of smart lamp shipments at the end of the analysis period
Smart Lamps Standby Power (residential sector only)	**0 W**	No power consumption for smart lamps in standby mode
	1 W	1 watt power consumption for smart lamps in standby mode
AEO Growth	Low	Low economic growth scenario from AEO 2014 for electricity prices
	Reference	Reference economic growth case from AEO 2014 for electricity prices
	High	High economic growth scenario from AEO 2014 for electricity prices

Table 8B.4.2 Scenarios Considered in this Rulemaking that Do Not Directly Affect the LCC and PBP Analysis

Scenario Name	Scenario Options Analyzed	Description of Alternative Scenarios
Rebound	**No**	No rebound
	Low	8.5% for residential sector; 1% for commercial sector
	High	15% for residential and commercial sectors
Integrated LED Incursion	0%	0% incursion of integrated LED luminaires into the market for traditional GSL luminaires at the end of the analysis period
	15%	15% incursion of integrated LED luminaires into the market for traditional GSL luminaires at the end of the analysis period
	50%	50% incursion of integrated LED luminaires into the market for traditional GSL luminaires at the end of the analysis period
Learning Rate	None	No price learning (constant real prices)
	CFL	Historic CFL price learning rate for both LEDs and CFLs
	Technology	Historic technology-specific price learning rates for LEDs and CFLs

8B.5 LCC AND PBP ALTERNATIVE SCENARIO RESULTS

DOE addressed input uncertainties in its LCC and PBP analysis for this rulemaking in both its reference case analyses and in its alternative scenario analyses. DOE used the Monte Carlo approach with 10,000 runs per alternative scenario to determine how the results of the LCC and PBP analysis change under the different assumptions for the inputs shown in Table 8B.4.1.

This section presents the results of the LCC and PBP for those alternative scenario analyses. Note that DOE examined each scenario independently, while keeping all other parameters according to the reference scenario.

8B.5.1 Lamp Service Lifetime

This section presents results for the ‘rated lifetime’ and ‘early-replacement lifetime’ scenarios.

8B.5.1.1 Rated Lifetime

Table 8B.5.1 through Table 8B.5.6 show results for the ‘rated lifetime’ scenario.

Table 8B.5.1 Average LCC and PBP Results by Candidate Standard Level for Integrated Low-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	6.2	1.6	5.8	12.1	---	12.9
1	4.0	1.5	5.4	8.9	0	14.7
2	34.9	1.3	4.7	20.5	99.6	37.1
3	22.2	1.2	4.4	14.4	40.5	37.1
4	7.5	1.1	4.0	8.1	2.5	37.1
5	7.1	1.0	3.8	7.7	1.7	37.1
Commercial Sector						
0	7.0	6.9	17.7	24.8	---	2.2
1	4.4	6.4	16.5	20.2	0	2.8
2	45.7	6.0	15.3	37.9	40.0	6.3
3	29.1	5.5	14.0	28.4	15.3	6.3
4	7.6	5.0	12.8	17.2	0.3	6.3
5	7.3	4.8	12.2	16.4	0.1	6.3

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.2 Average LCC Savings for Integrated Low-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	0%	0.0
2	20%	0.2
3	20%	0.3
4	18%	0.5
5	16%	0.7
Commercial Sector		
0	0.0%	0.0
1	0.0%	0.0
2	1.0%	1.7
3	1.0%	1.8
4	0.8%	1.8
5	0.2%	2.1

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

Table 8B.5.3 Average LCC and PBP Results by Candidate Standard Level for Integrated High-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	9.8	3.6	13.3	23.0	---	12.9
1	10.1	3.4	12.4	22.6	1.5	12.9
2	10.8	3.3	12.0	21.7	3.1	14.7
Commercial Sector						
0	9.8	12.4	31.6	41.5	---	2.2
1	10.1	11.6	29.7	39.8	0.4	2.2
2	10.8	11.2	28.7	37.6	0.9	2.8

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.4 Average LCC Savings for Integrated High-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	5%	0.2
2	10%	0.6
Commercial Sector		
0	0.0%	0.0
1	0.3%	0.5
2	1.2%	1.7

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

Table 8B.5.5 Average LCC and PBP Results by Candidate Standard Level for Non-Integrated GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	13.2	3.4	12.4	25.7	---	12.9
1A	14.2	3.4	12.4	22.9	N/A	18.4
1B	15.8	2.8	10.1	20.9	4.0	20.4
Commercial Sector						
0	13.2	11.6	29.6	43.0	---	2.2
1A	14.2	11.6	29.6	39.0	N/A	4.1
1B	15.8	9.4	24.1	33.3	1.2	5.0

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.6 Average LCC Savings for Non-Integrated GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	**Average Savings (2014$)**
Residential Sector		
0	0%	0.0
1	10%	1.8
Commercial Sector		
0	0.0%	0.0
1	5.4%	2.6

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8B.5.1.2 Early-Replacement Lifetime

Because this scenario only affects LED GSLs, this section presents results only for the low-lumen integrated product class, which is the only product class that includes LEDs.

Table 8B.5.7 Average LCC and PBP Results by Candidate Standard Level for Integrated Low-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback years	Average Lifetime years
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	6.2	1.6	4.6	9.3	---	8.8
1	3.9	1.5	4.2	6.9	0	9.8
2	34.9	1.3	3.7	36.2	99.6	4.5
3	22.2	1.2	3.4	24.1	40.5	4.5
4	7.7	1.1	3.1	10.4	3.0	4.5
5	7.3	1.0	2.9	9.8	2.0	4.5
Commercial Sector						
0	7.0	6.9	17.7	24.8	---	2.2
1	4.4	6.4	16.5	20.2	0	2.8
2	45.7	6.0	15.3	46.6	40.0	4.2
3	29.1	5.5	14.0	34.0	15.3	4.2
4	7.9	5.0	12.8	18.7	0.5	4.2
5	7.5	4.8	12.2	17.7	0.2	4.2

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.8 Average LCC Savings for Integrated Low-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	0%	0.0
2	54%	-2.3
3	54%	-2.0
4	53%	-1.5
5	52%	-1.3
Commercial Sector		
0	0.0%	0.0
1	0.0%	0.0
2	12.9%	1.0
3	12.9%	1.0
4	12.6%	1.0
5	8.1%	1.4

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8B.5.2 Rare Earth Cost

Table 8B.5.9 through Table 8B.5.14 present results for the alternative rare earth price scenario. Note that DOE assumes that rare earth content in LED GSLs is negligible; therefore, this scenario does not affect LED GSLs.

Table 8B.5.9 Average LCC and PBP Results by Candidate Standard Level for Integrated Low-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	6.2	1.6	5.6	11.8	---	8.8
1	4.0	1.5	5.2	8.8	0	9.8
2	34.9	1.3	4.6	23.1	99.6	17.9
3	22.2	1.2	4.2	16.0	40.5	17.9
4	7.5	1.1	3.8	8.5	2.6	17.9
5	7.2	1.0	3.6	8.1	1.7	17.9
Commercial Sector						
0	7.0	6.9	17.7	24.8	---	2.2
1	4.5	6.4	16.5	20.2	0	2.8
2	45.7	6.0	15.3	37.9	40.0	6.3
3	29.1	5.5	14.0	28.4	15.3	6.3
4	7.7	5.0	12.8	17.2	0.4	6.3
5	7.3	4.8	12.2	16.4	0.2	6.3

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.10 Average LCC Savings for Integrated Low-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	0%	0.0
2	27%	-0.1
3	27%	0.0
4	25%	0.3
5	22%	0.5
Commercial Sector		
0	0.0%	0.0
1	0.0%	0.0
2	1.1%	1.7
3	1.1%	1.7
4	0.8%	1.8
5	0.3%	2.1

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

Table 8B.5.11 Average LCC and PBP Results by Candidate Standard Level for Integrated High-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	9.8	3.6	12.8	22.6	---	8.8
1	10.1	3.4	12.0	22.1	1.5	8.8
2	10.9	3.3	11.6	21.4	3.1	9.8
Commercial Sector						
0	9.8	12.4	31.6	41.5	---	2.2
1	10.1	11.6	29.7	39.9	0.4	2.2
2	10.9	11.2	28.7	37.7	0.9	2.8

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.12 Average LCC Savings for Integrated High-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	6%	0.2
2	13%	0.5
Commercial Sector		
0	0.0%	0.0
1	0.2%	0.5
2	1.3%	1.7

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

Table 8B.5.13 Average LCC and PBP Results by Candidate Standard Level for Non-Integrated GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	13.2	3.4	11.9	25.2	---	8.8
1A	14.2	3.4	11.9	22.8	N/A	11.6
1B	15.8	2.8	9.7	21.1	4.0	12.5
Commercial Sector						
0	13.2	11.6	29.6	43.0	---	2.2
1A	14.2	11.6	29.6	39.0	N/A	4.1
1B	15.8	9.4	24.1	33.3	1.2	5.0

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.14 Average LCC Savings for Non-Integrated GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	12%	1.6
Commercial Sector		
0	0.0%	0.0
1	5.4%	2.6

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8B.5.3 Controls

Results for the alternative scenario are presented in Table 8B.5.15 through Table 8B.5.20. Note that this scenario affects only the commercial sector; therefore, the tables below do not present results for the residential sector.

Table 8B.5.15 Average LCC and PBP Results by Candidate Standard Level for Integrated Low-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Commercial Sector						
0	7.0	7.3	18.6	25.7	---	2.2
1	4.4	6.8	17.3	21.0	0	2.8
2	45.7	6.3	16.0	38.6	38.1	6.3
3	29.1	5.8	14.8	29.1	14.5	6.3
4	7.7	5.3	13.5	17.9	0.4	6.3
5	7.3	5.0	12.8	17.0	0.1	6.3

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.16 Average LCC Savings for Integrated Low-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Commercial Sector		
0	0.0%	0.0
1	0.0%	0.0
2	1.0%	1.8
3	1.0%	1.8
4	0.7%	1.9
5	0.2%	2.2

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

Table 8B.5.17 Average LCC and PBP Results by Candidate Standard Level for Integrated High-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Commercial Sector						
0	9.7	13.0	33.3	43.1	---	2.2
1	10.1	12.2	31.2	41.3	0.4	2.2
2	10.8	11.8	30.1	39.1	0.9	2.8

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.18 Average LCC Savings for Integrated High-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Commercial Sector		
0	0.0%	0.0
1	0.2%	0.5
2	0.9%	1.8

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

Table 8B.5.19 Average LCC and PBP Results by Candidate Standard Level for Non-Integrated GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Commercial Sector						
0	13.2	12.2	31.1	44.4	---	2.2
1A	14.2	12.2	31.1	40.5	N/A	4.1
1B	15.7	9.9	25.4	34.5	1.1	5.0

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.20 Average LCC Savings for Non-Integrated GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Commercial Sector		
0	0.0%	0.0
1	5.4%	2.6

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8B.5.4 Smart Lamp Incursion

The following sections (8B.5.4.1 and 8B.5.4.2) present results for the alternative scenarios only for the residential sector, which is the only sector where DOE assumes that smart lamps are used.

8B.5.4.1 Zero Percent Smart Lamps

Table 8B.5.21 through Table 8B.5.22 present results for the zero percent smart lamps scenario.

Table 8B.5.21 Average LCC and PBP Results by Candidate Standard Level for Integrated Low-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	6.2	1.6	5.6	11.8	---	8.8
1	4.0	1.5	5.2	8.8	0	9.8
2	34.9	1.3	4.7	23.2	111.8	17.9
3	22.2	1.2	4.3	16.1	43.6	17.9
4	7.5	1.1	3.9	8.6	2.7	17.9
5	7.2	1.0	3.7	8.2	1.7	17.9

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.22 Average LCC Savings for Integrated Low-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	0%	0.0
2	28%	-0.2
3	27%	0.0
4	25%	0.2
5	23%	0.4

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8B.5.4.2 100 Percent Smart Lamps

Table 8B.5.23 through Table 8B.5.24 present results for the 100 percent smart lamps scenario.

Table 8B.5.23 Average LCC and PBP Results by Candidate Standard Level for Integrated Low-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	6.2	1.6	5.6	11.8	---	8.8
1	4.0	1.5	5.2	8.8	0	9.8
2	34.9	1.3	4.5	23.0	89.9	17.9
3	22.2	1.2	4.1	15.9	37.7	17.9
4	7.5	1.1	3.7	8.4	2.5	17.9
5	7.2	1.0	3.5	8.0	1.6	17.9

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.24 Average LCC Savings for Integrated Low-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	0%	0.0
2	27%	-0.1
3	26%	0.1
4	25%	0.3
5	22%	0.5

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8B.5.5 Smart Lamps Standby Power

This section presents results for the alternative scenario only for the residential sector, which is the only sector where DOE assumes that smart lamps are used.

Table 8B.5.25 Average LCC and PBP Results by Candidate Standard Level for Integrated Low-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	6.2	1.6	5.6	11.8	--	8.8
1	4.0	1.5	5.2	8.8	0.0	9.8
2	34.9	1.4	5.1	23.7	133	17.9
3	22.2	1.3	4.7	16.6	49.5	17.9
4	7.5	1.1	4.4	9.1	3.0	17.9
5	7.2	1.1	4.2	8.7	1.9	17.9

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.26 Average LCC Savings for Integrated Low-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	0%	0.0
2	29%	-0.4
3	28%	-0.3
4	26%	0.0
5	24%	0.2

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8B.5.6 AEO Growth

This section presents results for the alternative AEO 2014 growth electricity price scenarios.

8B.5.6.1 High

Table 8B.5.27 through Table 8B.5.32 present results for the high economic growth electricity price trends from AEO 2014.

Table 8B.5.27 Average LCC and PBP Results by Candidate Standard Level for Integrated Low-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	6.2	1.6	5.6	11.8	---	8.8
1	4.0	1.5	5.2	8.8	0	9.8
2	34.9	1.3	4.6	23.1	99.6	17.9
3	22.2	1.2	4.2	16.0	40.4	17.9
4	7.5	1.1	3.8	8.5	2.6	17.9
5	7.2	1.0	3.6	8.1	1.7	17.9
Commercial Sector						
0	7.0	7.0	17.9	24.9	---	2.2
1	4.4	6.5	16.6	20.3	0	2.8
2	45.7	6.0	15.4	38.0	39.8	6.3
3	29.1	5.5	14.2	28.5	15.2	6.3
4	7.7	5.0	12.9	17.3	0.4	6.3
5	7.3	4.8	12.3	16.5	0.2	6.3

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.28 Average LCC Savings for Integrated Low-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	0%	0.0
2	27%	-0.1
3	27%	0.0
4	25%	0.3
5	22%	0.5
Commercial Sector		
0	0.0%	0.0
1	0.0%	0.0
2	1.0%	1.7
3	1.0%	1.7
4	0.8%	1.8
5	0.3%	2.1

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

Table 8B.5.29 Average LCC and PBP Results by Candidate Standard Level for Integrated High-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	9.7	3.6	12.8	22.5	---	8.8
1	10.1	3.4	12.0	22.1	1.5	8.8
2	10.8	3.3	11.6	21.3	3.1	9.8
Commercial Sector						
0	9.7	12.5	31.9	41.7	---	2.2
1	10.1	11.7	29.9	40.1	0.4	2.2
2	10.8	11.3	28.9	37.8	0.9	2.8

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.30 Average LCC Savings for Integrated High-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	6%	0.2
2	13%	0.5
Commercial Sector		
0	0.0%	0.0
1	0.2%	0.5
2	1.2%	1.7

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

Table 8B.5.31 Average LCC and PBP Results by Candidate Standard Level for Non-Integrated GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	13.2	3.4	12.0	25.2	---	8.8
1A	14.2	3.4	12.0	22.8	N/A	11.6
1B	15.7	2.8	9.7	21.1	4.0	12.5
Commercial Sector						
0	13.2	11.7	29.9	43.1	---	2.2
1A	14.2	11.7	29.9	39.2	N/A	4.1
1B	15.7	9.5	24.3	33.4	1.2	5.0

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.32 Average LCC Savings for Non-Integrated GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	12%	1.6
Commercial Sector		
0	0.0%	0.0
1	5.4%	2.6

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

8B.5.6.2 Low

Table 8B.5.33 through Table 8B.5.38 present results for the low economic growth electricity price trends from AEO 2014.

Table 8B.5.33 Average LCC and PBP Results by Candidate Standard Level for Integrated Low-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	6.2	1.6	5.6	11.8	---	8.8
1	4.0	1.5	5.2	8.8	0	9.8
2	34.9	1.3	4.6	23.1	100.0	17.9
3	22.2	1.2	4.2	16.0	40.6	17.9
4	7.5	1.1	3.8	8.5	2.6	17.9
5	7.2	1.0	3.6	8.1	1.7	17.9
Commercial Sector						
0	7.0	6.8	17.6	24.6	---	2.2
1	4.4	6.4	16.3	20.0	0	2.8
2	45.7	5.9	15.1	37.7	40.6	6.3
3	29.1	5.4	13.9	28.3	15.5	6.3
4	7.7	4.9	12.7	17.1	0.4	6.3
5	7.3	4.7	12.1	16.3	0.2	6.3

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.34 Average LCC Savings for Integrated Low-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	0%	0.0
2	27%	-0.1
3	27%	0.0
4	25%	0.3
5	22%	0.5
Commercial Sector		
0	0.0%	0.0
1	0.0%	0.0
2	1.1%	1.7
3	1.1%	1.7
4	0.8%	1.7
5	0.3%	2.1

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

Table 8B.5.35 Average LCC and PBP Results by Candidate Standard Level for Integrated High-Lumen GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	9.7	3.6	12.8	22.5	---	8.8
1	10.1	3.4	12.0	22.1	1.5	8.8
2	10.8	3.3	11.6	21.3	3.1	9.8
Commercial Sector						
0	9.7	12.2	31.3	41.1	---	2.2
1	10.1	11.4	29.3	39.5	0.4	2.2
2	10.8	11.1	28.4	37.3	0.9	2.8

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.36 Average LCC Savings for Integrated High-Lumen GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	6%	0.2
2	13%	0.5
Commercial Sector		
0	0.0%	0.0
1	0.3%	0.5
2	1.2%	1.7

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

Table 8B.5.37 Average LCC and PBP Results by Candidate Standard Level for Non-Integrated GSLs

CSL	Average Costs (2014$)				Simple Payback (years)	Average Lifetime (years)
	Installed Cost	First Year's Operating Cost	Lifetime Operating Cost	LCC		
Residential Sector						
0	13.2	3.4	12.0	25.2	---	8.8
1A	14.2	3.4	12.0	22.8	N/A	11.6
1B	15.7	2.8	9.7	21.1	4.0	12.5
Commercial Sector						
0	13.2	11.4	29.3	42.6	---	2.2
1A	14.2	11.4	29.3	38.7	N/A	4.1
1B	15.7	9.3	23.9	33.0	1.2	5.0

Note: The results for each CSL are calculated assuming that all consumers use products with that efficiency level. The LCC may not equal the sum of installed cost and lifetime operating cost because it may also include residual value and disposal cost. The PBP is measured relative to the least efficient product currently available on the market.

Table 8B.5.38 Average LCC Savings for Non-Integrated GSLs

CSL	Life-Cycle Cost Savings	
	% of Consumers that Experience Net Cost	Average Savings (2014$)
Residential Sector		
0	0%	0.0
1	12%	1.6
Commercial Sector		
0	0.0%	0.0
1	5.4%	2.6

Note: The results for each CSL represent the impact a standard set at that CSL, based on base case and standards case efficiency distributions calculated in Chapter 9 of this TSD.

REFERENCES

1. Energy Information Administration. *Annual Energy Outlook 2014 with Projections to 2040*. 2014. Washington, D.C. http://www.eia.gov/forecasts/aeo/pdf/0383(2014).pdf.

APPENDIX 8C. DISCOUNT RATE DISTRIBUTIONS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX 8C. DISCOUNT RATE DISTRIBUTIONS

8C.1 INTRODUCTION

The U.S. Department of Energy (DOE) derived discount rates for the life-cycle cost (LCC) analysis using data on interest or return rates for various types of debt and equity to calculate a real effective discount rate for each household in the Federal Reserve Board's *Survey of Consumer Finances (SCF)* in 1995, 1998, 2001, 2004, 2007, and 2010.[1] To account for variation among households in rates for each of the types, DOE sampled a rate for each household in its building sample from a distribution of discount rates for each of six income groups. This appendix describes the distributions used.

8C.2 DISTRIBUTION OF RATES FOR DEBT CLASSES

Figure 8C.2.1 through Figure 8C.2.6 show the distribution of real interest rates for different types of household debt. The data source for the interest rates for mortgages, home equity loans, credit cards, installment loans, other residence loans, and other lines of credit is the Federal Reserve Board's *SCF* in 1995, 1998, 2001, 2004, 2007, and 2010.[1] DOE adjusted the nominal rates to real rates using the annual inflation rate in each year.

Using the appropriate *SCF* data for each year, DOE adjusted the nominal mortgage interest rate and the nominal home equity loan interest rate for each relevant household in the *SCF* for mortgage tax deduction and inflation. In cases where the effective interest rate is equal to or below the inflation rate (resulting in a negative real interest rate), DOE set the real effective interest rate to zero.

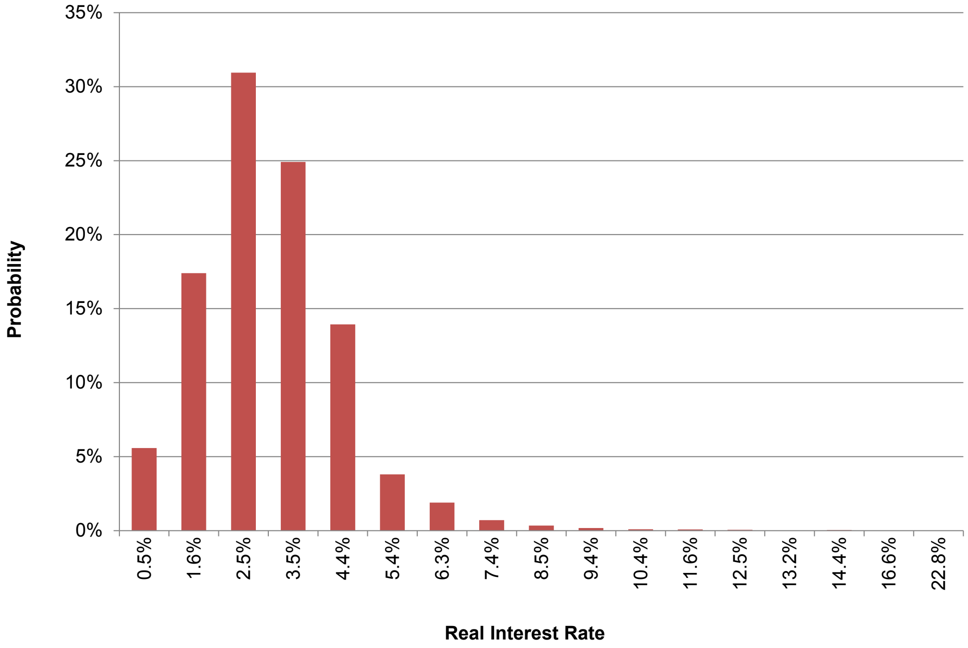

Figure 8C.2.1 Distribution of Mortgage Interest Rates

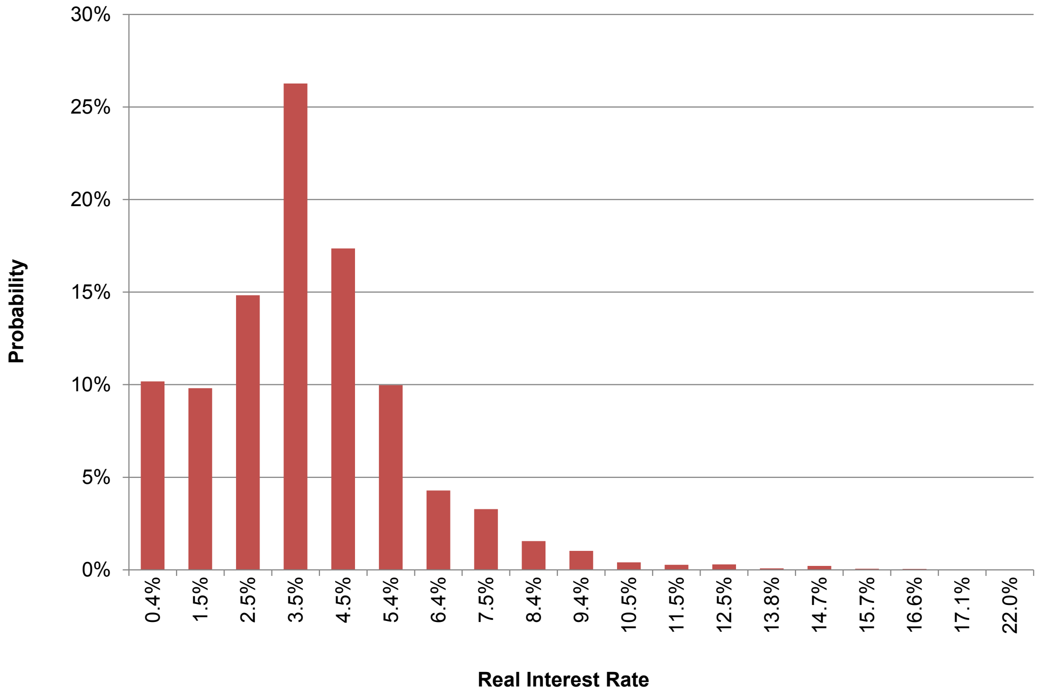

Figure 8C.2.2 Distribution of Home Equity Loan Interest Rates

Figure 8C.2.3 Distribution of Credit Card Interest Rates

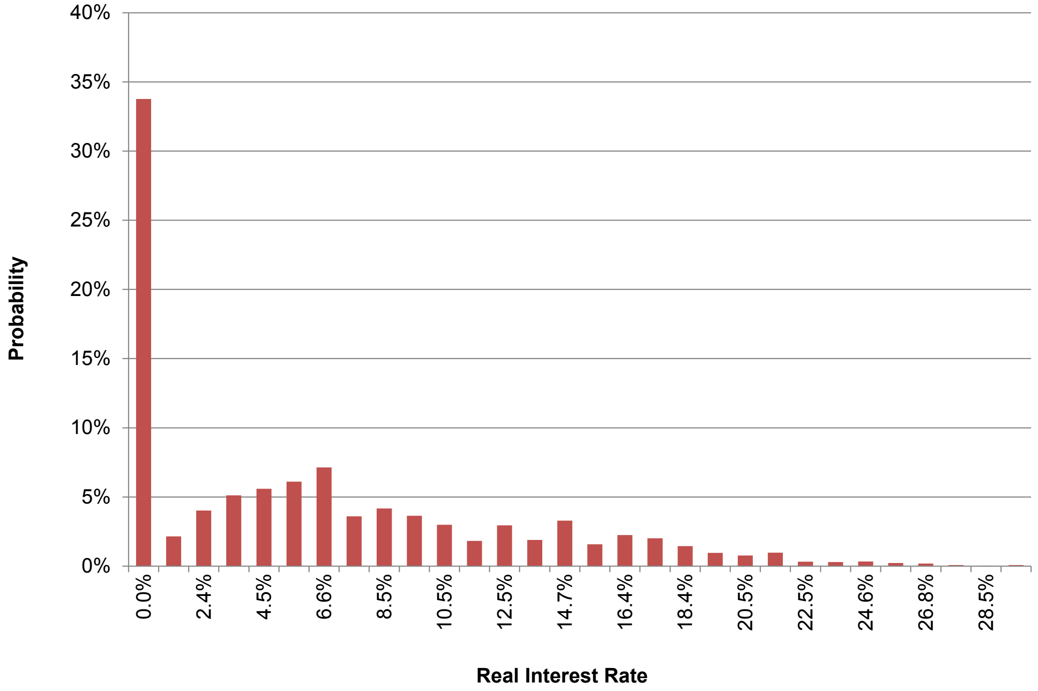

Figure 8C.2.4 Distribution of Installment Loan Interest Rates

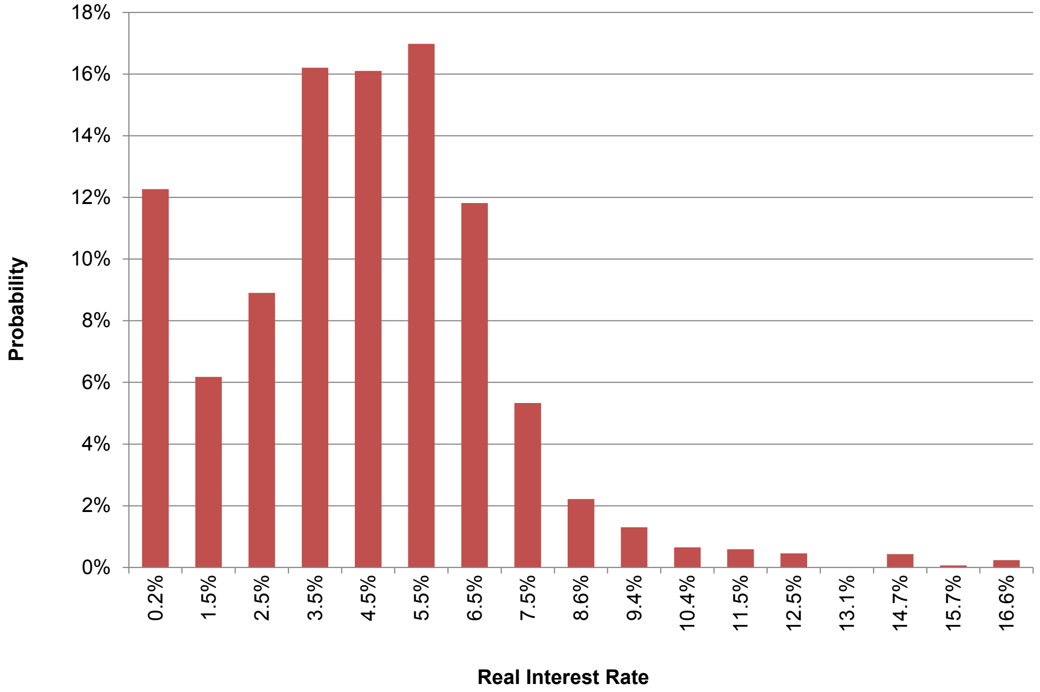

Figure 8C.2.5 Distribution of Other Residence Loan Interest Rates

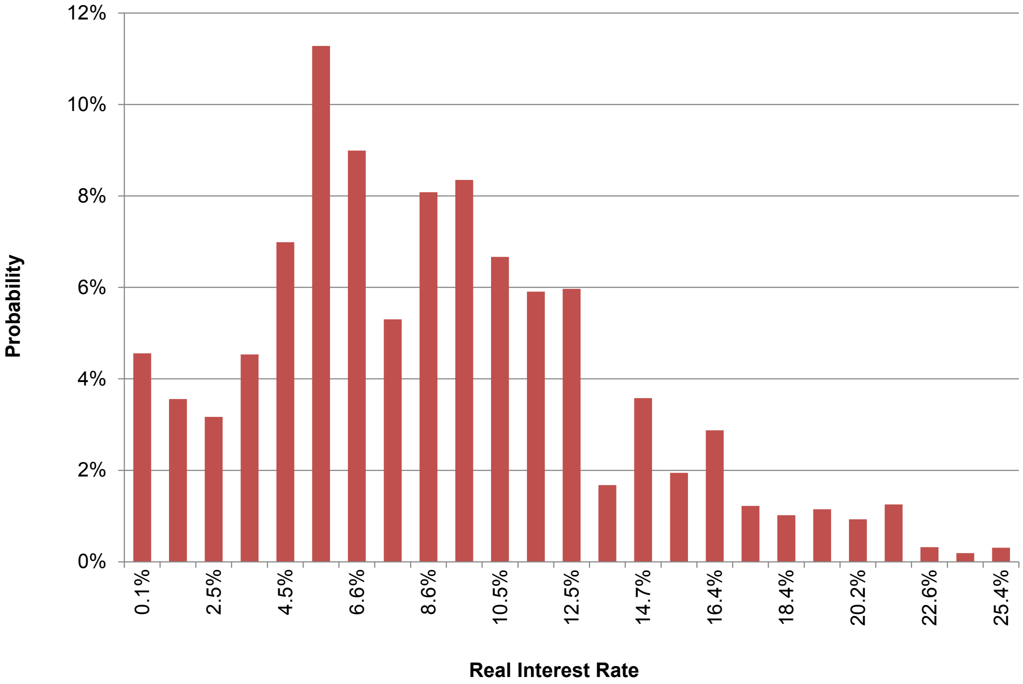

Figure 8C.2.6 Distribution of Other Lines of Credit Loan Interest Rates

8C.3 DISTRIBUTION OF RATES FOR EQUITY CLASSES

Figure 8C.3.1 through Figure 8C.3.7 show the distribution of real interest rates for different types of equity. Data for equity classes are not available from the Federal Reserve Board's *SCF*, so DOE derived data for these classes from national-level historical data (1984-2013). The interest rates associated with certificates of deposit (CDs),[2] savings bonds,[3] and AAA corporate bonds[4] are from Federal Reserve Board time-series data. DOE assumed rates on checking accounts to be zero. Rates on savings and money market accounts are from Cost of Savings Index data.[5] The rates for stocks are the annual returns on the Standard and Poor's (S&P) 500.[6] The mutual fund rates are a weighted average of the stock rates (two-thirds weight) and the bond rates (one-third weight) in each year. DOE adjusted the nominal rates to real rates using the annual inflation rate in each year.

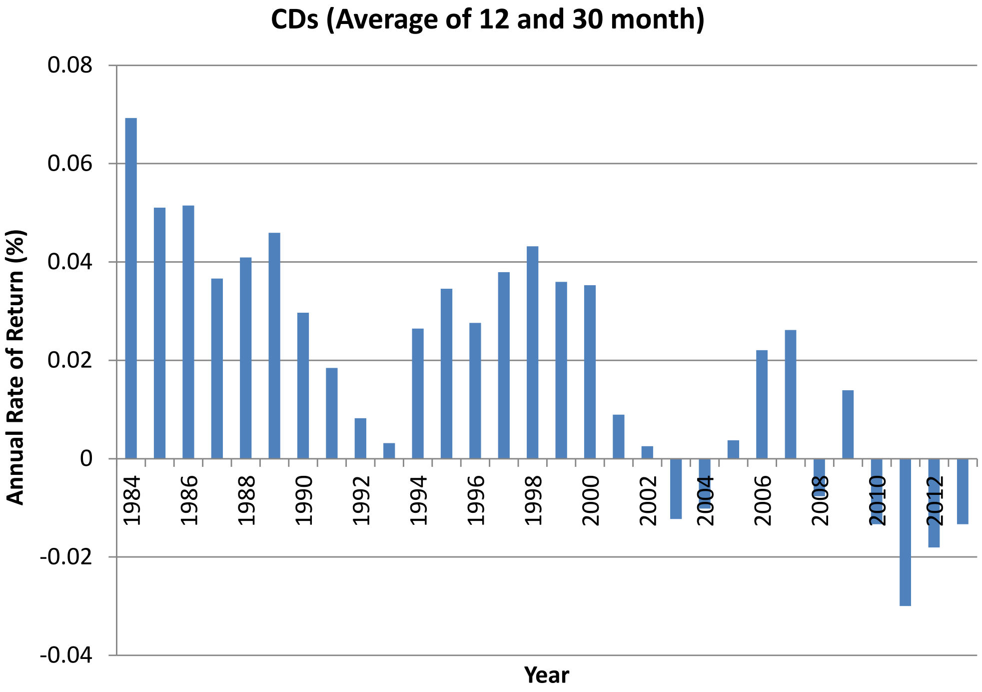

Figure 8C.3.1 Distribution of Annual Rate of Return on CDs

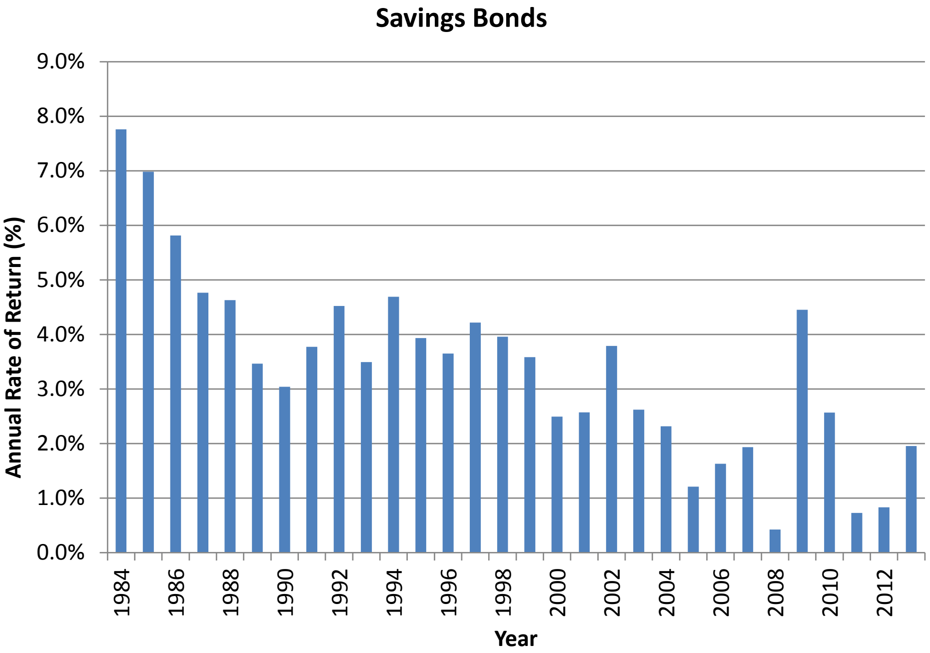

Figure 8C.3.2 Distribution of Annual Rate of Return on Savings Bonds

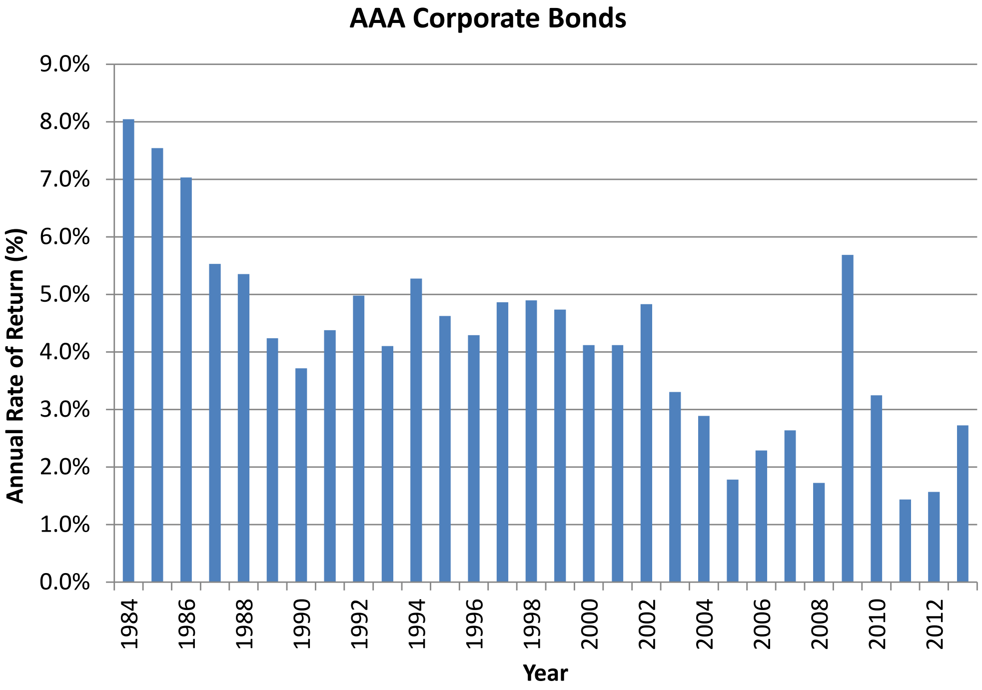

Figure 8C.3.3 Distribution of Annual Rate of Return on Corporate AAA Bonds

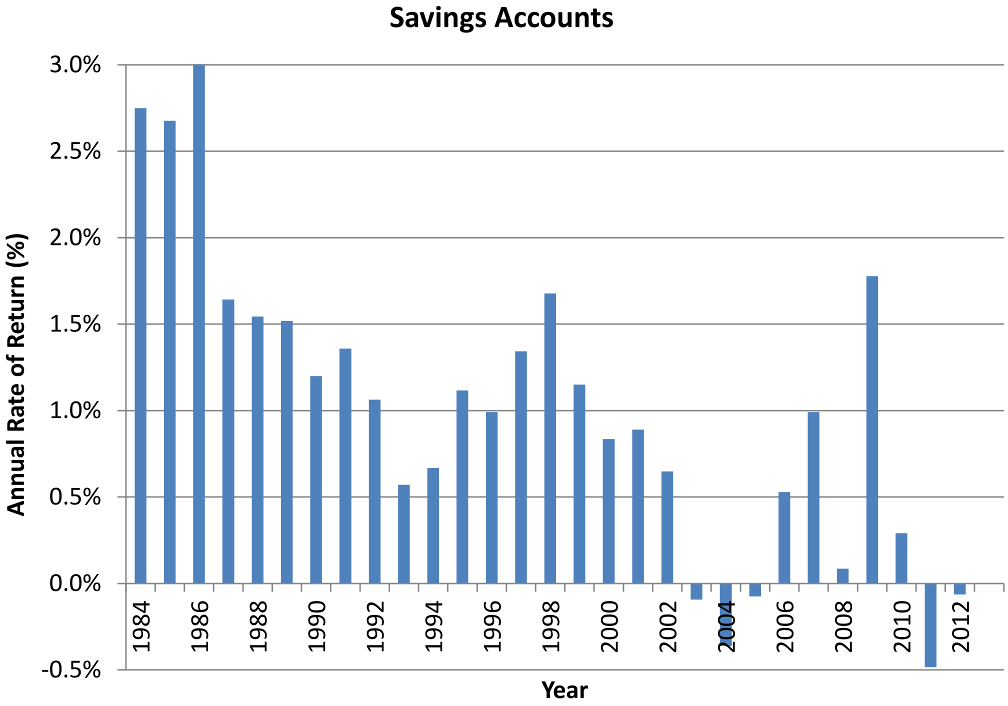

Figure 8C.3.4 Distribution of Annual Rate of Savings Accounts

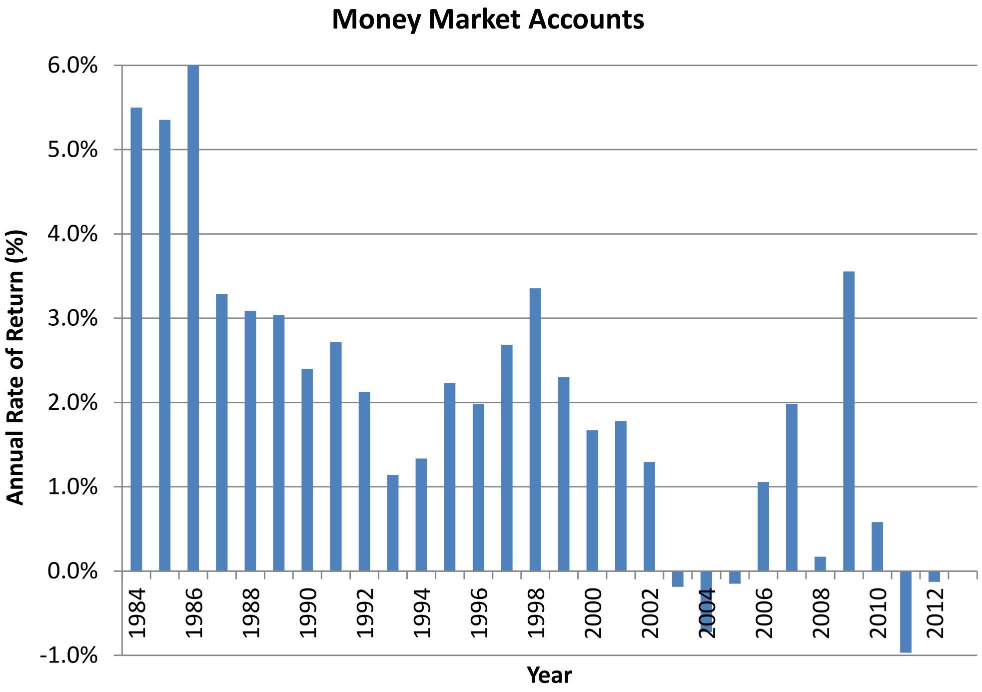

Figure 8C.3.5 Distribution of Annual Rate of Money Market Accounts

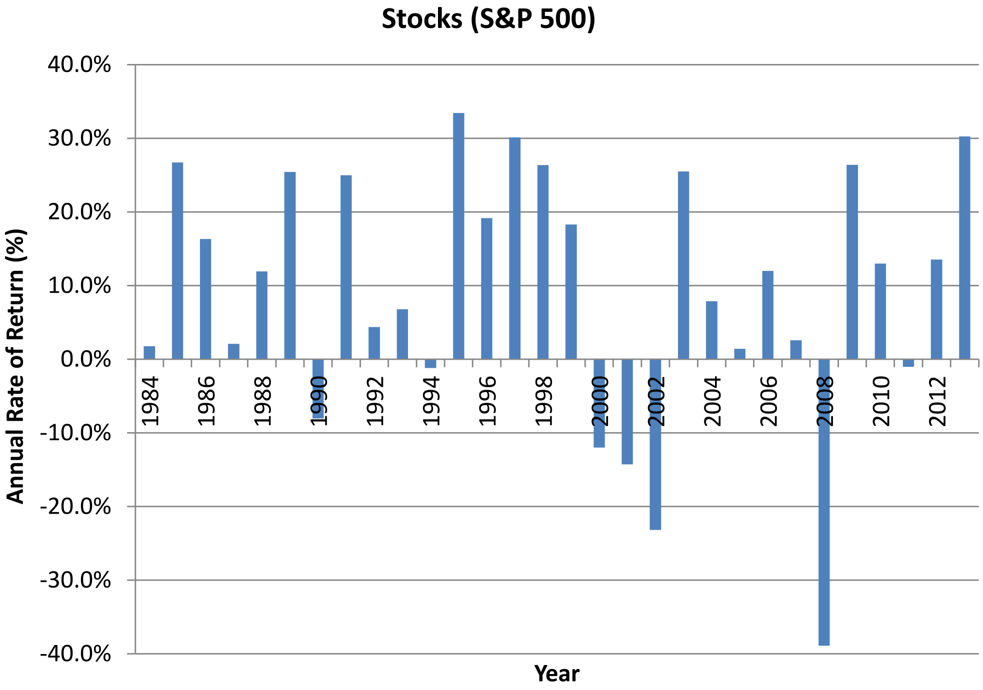

Figure 8C.3.6 Distribution of Annual Rate of Return on S&P 500

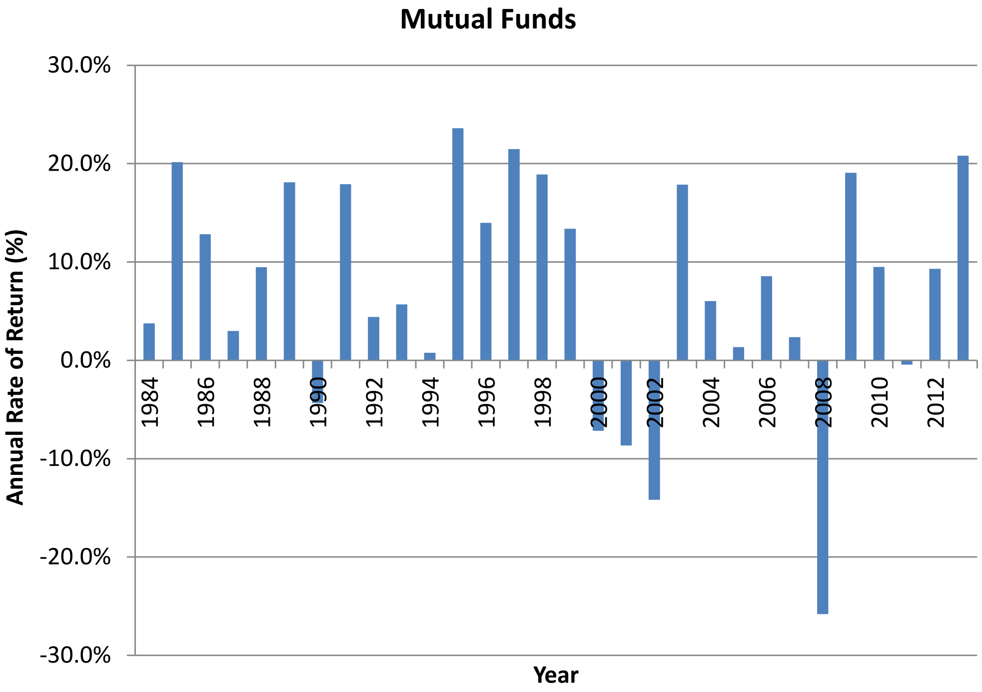

Figure 8C.3.7 Distribution of Annual Rate of Return on Mutual Funds

8C.4 DISTRIBUTION OF REAL EFFECTIVE DISCOUNT RATES BY INCOME GROUP

Figure 8C.4.1 and Table 8C.4.1 present the distributions of real discount rates for each income group.

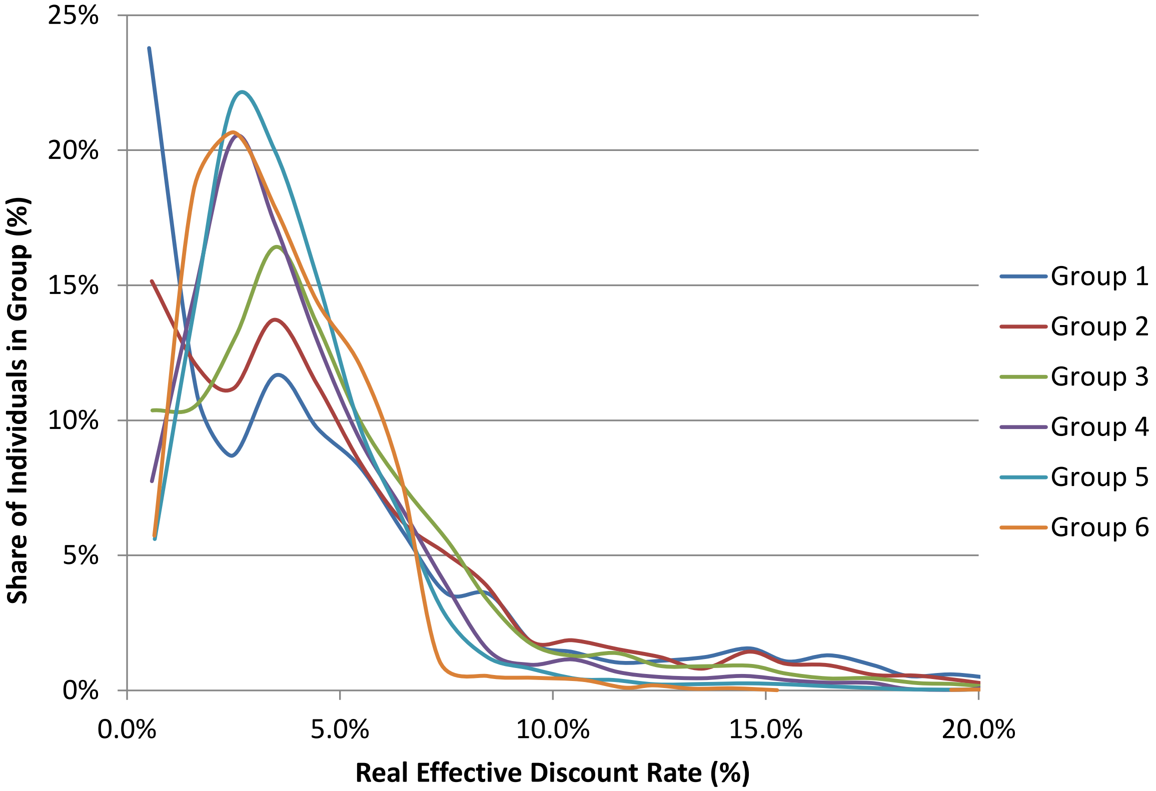

Figure 8C.4.1 Distribution of Real Discount Rates by Income Group

Table 8C.4.1 Distribution of Real Discount Rates by Income Group

DR Bin	Income Group 1 (1-20 percentile)		Income Group 2 (21-40 percentile)		Income Group 3 (41-60 percentile)		Income Group 4 (61-80 percentile)		Income Group 5 (81-90 percentile)		Income Group 6 (90-99 percentile)	
	rate	weight	rate	weight	rate	weight	rate	weight	rate	weight	rate	weight
0-1	0.5%	0.238	%	0.152	0.6%	0.104	0.6%	0.077	0.6%	0.056	0.6%	0.057
1-2	1.6%	0.110	1.6%	0.120	1.6%	0.105	1.6%	0.146	1.6%	0.142	1.6%	0.185
2-3	2.5%	0.087	2.5%	0.112	2.6%	0.131	2.5%	0.205	2.5%	0.219	2.5%	0.207
3-4	3.5%	0.117	3.5%	0.137	3.5%	0.164	3.5%	0.173	3.5%	0.200	3.5%	0.178
4-5	4.5%	0.097	4.5%	0.113	4.5%	0.136	4.5%	0.129	4.5%	0.153	4.5%	0.144
5-6	5.5%	0.083	5.5%	0.084	5.5%	0.100	5.5%	0.093	5.5%	0.098	5.5%	0.120
6-7	6.5%	0.058	6.5%	0.062	6.5%	0.075	6.5%	0.067	6.5%	0.063	6.4%	0.079
7-8	7.5%	0.036	7.5%	0.051	7.6%	0.054	7.4%	0.041	7.4%	0.029	7.3%	0.011
8-9	8.5%	0.036	8.4%	0.039	8.4%	0.034	8.5%	0.015	8.4%	0.012	8.5%	0.005
9-10	9.5%	0.017	9.5%	0.018	9.5%	0.017	9.5%	0.010	9.5%	0.008	9.6%	0.005
10-11	10.5%	0.014	10.5%	0.019	10.5%	0.013	10.5%	0.011	10.6%	0.004	10.7%	0.004
11-12	11.5%	0.010	11.5%	0.015	11.5%	0.014	11.5%	0.007	11.4%	0.004	11.7%	0.001
12-13	12.5%	0.011	12.5%	0.012	12.5%	0.009	12.4%	0.005	12.4%	0.002	12.4%	0.002
13-14	13.6%	0.012	13.5%	0.008	13.5%	0.009	13.5%	0.004	13.5%	0.002	13.3%	0.001
14-15	14.6%	0.016	14.6%	0.014	14.6%	0.009	14.5%	0.005	14.6%	0.003	14.2%	0.001
15-16	15.5%	0.011	15.5%	0.010	15.5%	0.006	15.6%	0.004	15.6%	0.002	15.3%	0.000
16-17	16.5%	0.013	16.5%	0.009	16.5%	0.004	16.5%	0.003	16.5%	0.001	0.0%	0.000
17-18	17.5%	0.009	17.6%	0.006	17.5%	0.005	17.5%	0.003	17.6%	0.001	17.7%	0.001
18-19	18.4%	0.005	18.5%	0.005	18.6%	0.003	18.4%	0.001	18.2%	0.000	0.0%	0.000
19-20	19.4%	0.006	19.4%	0.004	19.4%	0.002	19.7%	0.000	19.7%	0.000	19.4%	0.000
20-21	20.6%	0.004	20.4%	0.002	20.5%	0.001	20.3%	0.001	20.5%	0.000	20.3%	0.000
21-22	21.4%	0.003	21.4%	0.002	21.4%	0.001	21.5%	0.001	0.0%	0.000	21.4%	0.000
22-23	22.5%	0.002	22.4%	0.001	22.6%	0.001	22.9%	0.000	22.8%	0.000	22.3%	0.000
23-24	23.6%	0.001	23.4%	0.001	23.6%	0.001	0.0%	0.000	0.0%	0.000	24.0%	0.000
24-25	24.6%	0.001	24.5%	0.000	24.6%	0.000	24.1%	0.000	24.3%	0.000	0.0%	0.000
25-26	25.4%	0.001	25.4%	0.001	25.5%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
26-27	26.5%	0.001	26.5%	0.000	26.4%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
27-28	27.8%	0.000	27.6%	0.000	27.8%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
28-29	28.2%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
29-23	29.9%	0.000	29.3%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000	0.0%	0.000
>30	59.1%	0.001	142.7%	0.002	0.0%	0.000	53.3%	0.000	0.0%	0.000	0.0%	0.000

8C.5 DISTRIBUTIONS USED FOR COMMERCIAL DISCOUNT RATES

Table 8C.4.1 shows the probability distribution used for commercial discount rates by different commercial sector groups:

Table 8C.5.1 Real Interest Rate Distribution for Commercial Buildings

Retail		Medical		Lodging		Food Service		Office		Education		Other	
Rate (%)	Weight (%)	Rate (%)	Weight (%)	Rate (%)	Weight (%)	Rate (%)	Weight (%)	Rate (%)	Weight (%)	Rate (%)	Weight (%)	Rate (%)	Weight (%)
2.9	6.0	2.9	6.2	2.9	4.5	2.9	4.7	2.9	6.7	-1.3	17.1	2.9	6.4
3.8	11.8	3.6	4.3	3.9	7.1	3.7	14.5	3.7	12.6	0.7	7.3	3.8	5.3
4.5	32.1	4.6	41.9	4.6	15.8	4.6	37.1	4.5	31.2	1.5	14.6	4.6	41.0
5.5	31.9	5.5	38.3	5.6	30.7	5.6	35.7	5.5	27.8	2.7	7.3	5.4	31.3
6.5	15.9	6.3	7.3	6.4	20.8	6.5	7.7	6.4	15.4	3.6	31.7	6.4	11.9
7.3	1.8	7.5	1.7	7.4	9.2	7.3	0.3	7.5	3.5	4.2	9.8	7.3	2.6
8.2	0.4	8.6	0.3	8.4	5.1	8.3	0.0	8.4	1.5	5.4	9.8	8.3	1.0
9.3	0.0	9.6	0.1	9.3	3.7			9.2	1.2	6.1	2.4	9.5	0.4
10.0	0.0	10.6	0.0	10.6	3.2			10.3	0.0			10.4	0.1
								11.4	0.0			11.6	0.0
												12.3	0.0
												13.0	0.0

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APPENDIX 8D. MODELING OF RARE EARTH PRICE IMPACTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX 8D. MODELING OF RARE EARTH PRICE IMPACTS

8D.1 BACKGROUND

Lamp manufacturers use triband phosphors to increase the efficacy of fluorescent lamps and improve their color quality and lumen maintenance. According to DOE's 2011 Critical Materials Strategy (CMS),[1] all CFLs use triband phosphors. Triband phosphors contain certain rare earth elements - lanthanum (La), cerium (Ce), europium (Eu), terbium (Tb), and yttrium (Y) - which, according to manufacturer interviews provided to the U.S. Department of Energy (DOE), are generally purchased by lamp manufacturers in their oxide form. Between the second quarter of 2010 and the fourth quarter of 2011, the price of rare earth oxides (REOs) increased sharply, causing concerns about the resulting price impacts on fluorescent lamps. However, as shown in Figure 8D.1.1, REO prices[2] have recently fallen considerably.

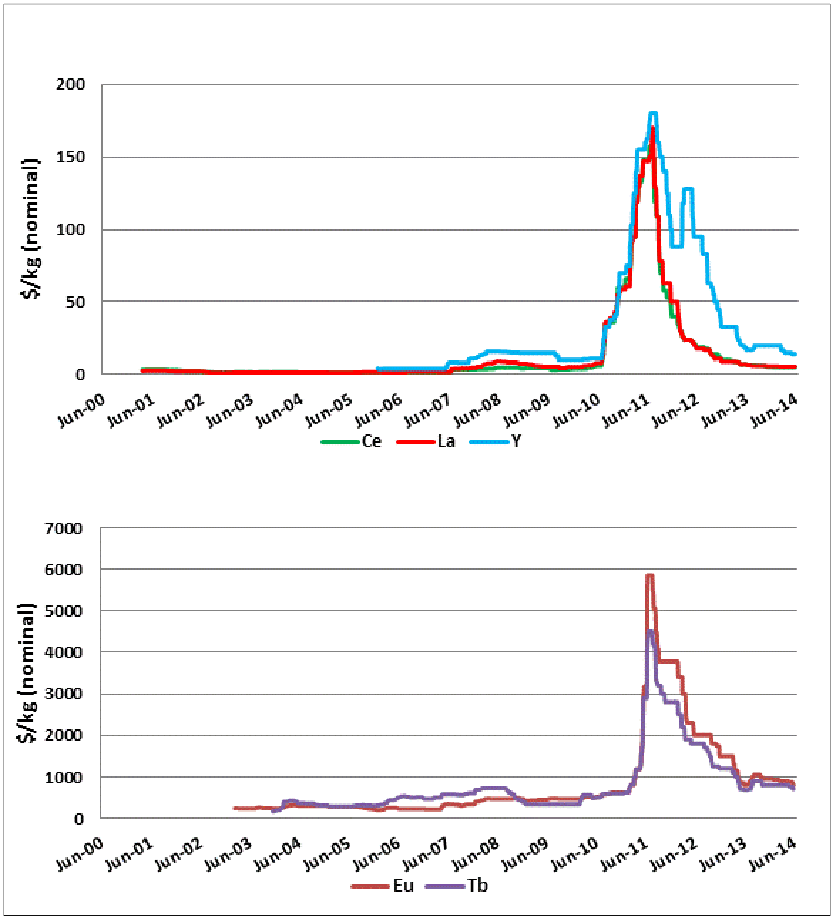

Figure 8D.1.1 Rare Earth Oxide Historic Prices[a]

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[a] The reported oxide prices correspond to 99% purity minimum Free-on-Board (FOB) China for Ce, La, and Tb, 99.9% purity minimum FOB China for Eu, and 99.999% purity minimum FOB China for Y.

DOE has examined the REO market and considers future rare earth prices significantly uncertain. DOE incorporates the potential impact of higher rare earth prices and price volatility in a scenario of the life-cycle cost (LCC) and payback period (PBP) analyses (chapter 8 of this TSD), as well as of the shipments and national impact assessment analyses (chapters 9 and 10 of this TSD). This appendix describes the approach DOE took to projecting the potential impacts of volatile rare earth prices on future prices of CFLs, for use in analyzing the LCC and PBP, lamp shipments, energy savings, and net present value of candidate standard levels (CSLs) considered in this preliminary analysis. Note that in this analysis, DOE assumes that the REO content in LED GSLs is negligible.

8D.2 ANALYSIS

DOE analyzed the impact of REO prices on CFL costs based on historical prices of REOs (Figure 8D.1.1) and on estimates of the average rare earth element content in phosphors of CFLs.

According to the 2011 CMS, CFLs are assumed to use a maximum of about to 1.5 g/bulb of tri-band phosphor, with 60% of that content representing rare earth mass content.[b] Other sources of information confirm the 2011 CMS estimate of 1.5 g/bulb in phosphor.[3]

As discussed in chapter 8 of this TSD, DOE analyzed GSLs in 4 different lumen ranges for the integrated low-lumen product class (310-749, 750-1049, 1050-1489, and 1490-1999 lumens). In addition, the integrated high-lumen product class covers the 2000-2600 lumen range.

Because the amount of phosphor included in fluorescent lamps is approximately proportional to their surface area,[1] using primarily manufacturer catalogs, DOE reviewed the sizes and shapes of CFLs across lumen ranges to estimate their surface area. The CFL surface area was estimated based on typically observed number of spiral windings in each CFL, the spiral diameter, and the CFL spiral tube length, for each lumen range, as shown in Table 8D.2.1.

Table 8D.2.1 Estimated CFL Surface Area across Lumen Ranges

Lumen Range	Number of CFL Spiral Windings	CFL Outside Diameter (Inches)	Spiral Tube Length (Inches)	CFL Surface Area (square inches)
310-749	2.5	1.75	11.8	9.3
750-1049	3.5	2	19.2	15.1
1050-1489	4.5	2.25	28.3	22.2
1490-1999	5.5	2.5	38.9	30.5
2000-2600	5.5	2.75	43.2	33.9

Note: CFLs spiral tubes typically have a diameter equal to ¼ of an inch (T2)

According to the 2011 CMS, the rare earth mass content per unit area for linear fluorescent lamps ranges between 3 and 4 milligrams per square centimeter of lamp surface area (mg/cm^2). For this analysis, DOE assumed that CFLs contain 4mg/cm^2. Using this estimate, and

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[b] These estimates were based on manufacturer interviews.

the surface area of CFLs from Table 8D.2.1, DOE calculated the REO mass content of CFLs for each lumen range, as shown in

Table 8D.2.2.[c]

Table 8D.2.2 Mass Density, Surface Area and REO Mass Content in CFLs

Lumen Range	Mass Content per surface area (mg/cm^2)	Spiral Tube Surface Area (cm^2)	REO Mass Content (g/bulb)
310-749	4	59.7	0.24
750-1049		97.5	0.39
1050-1489		143.3	0.57
1490-1999		197.0	0.79
2000-2600		218.9	0.88

Table 8D.2.3 shows the average percentage contribution of the five rare earth elements used in CFL triband phosphors according to the 2011 CMS.

Table 8D.2.3 Average Rare Earth Element Mass Percentages used in CFL Triband Phosphors

Element	Content
Lanthanum	8.5%
Cerium	20.0%
Europium	4.5%
Terbium	5.0%
Yttrium	62.0%
TOTAL	100%

For this rulemaking, using the data shown in Figure 8D.1.1, DOE calculated a triband phosphor price index for CFLs that reflects the rare earth element mass percentages reported in Table 8D.2.3, and the corresponding rare earth oxide prices reported on metalpages.com.[d] The index, shown in Figure 8D.2.1, is inflation adjusted and normalized with respect to the average triband phosphor cost between 2006 and 2009, the longest period prior to the peak for which data for all relevant REOs were available. As shown in the figure, the index rose rapidly in 2010 from a relatively stable period to a peak in 2011, after which it dropped almost monotonically, to a point near its pre-peak level.

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[c] Based on the assumption that the rare earth element mass content is 60% of the triband phosphor content, the calculated maximum REO content which is 0.88 g per bulb for the 2000-2600 lumen range, is consistent with the estimated maximum triband phosphor content in CFLs (1.5g). (60% of 1.5g is 0.9g).

[d] This analysis assumes that mass fractions of REOs needed for manufacturing are the same as the elemental mass fractions in Table 8D.2.3.

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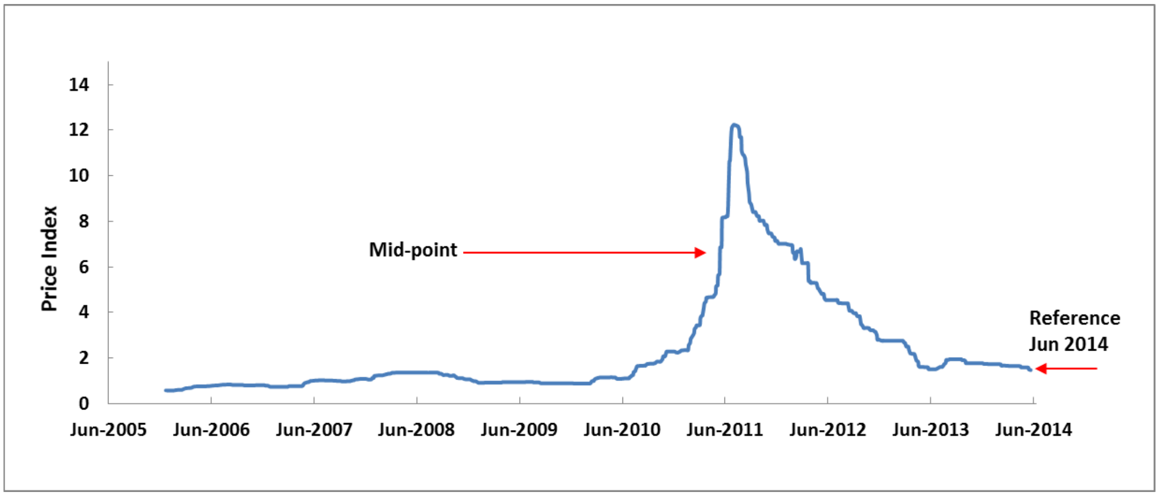

Figure 8D.2.1 Inflation-Adjusted, Triband Phosphor REO Price Index for CFLs

The future trajectory of REO prices is highly uncertain. Therefore, DOE developed an alternative scenario for future REO prices for the LCC, PBP, shipments, and national impact analyses. The reference assumption is that REO prices remain constant at their June 2014 level. These data were used in this preliminary analysis because they represented the most recent price data available at the time the analysis was performed. The high REO price scenario uses the REO price midway between the 2011 peak and the 2006 – 2009 baseline average price, referred to here as the *mid-point REO price*.

DOE used the REO mass content and REO mass percentages in CFLs from Table 8D.2.2 and Table 8D.2.3, respectively, to determine the inflation adjusted (2014$) reference scenario REO cost, based on June 2014 REO prices, for all representative CFLs considered in this analysis. Table 8D.2.4 shows the reference scenario REO costs for the representative lamps developed in the engineering analysis. These REO costs serve as reference from which to account for the potential impacts of potential future higher REO prices. (Table 8D.2.4 also shows LEDs for completeness).

Table 8D.2.4 Reference Scenario REO Costs

Product Class	CSL	Technology	Lumen Range	REO content (gr/bulb)	Reference REO Cost ($2014), no tax
Integrated Low Lumen (<2000)	Baseline	CFL	750-1049	0.39	$ 0.03
	CSL 1	CFL	750-1049	0.39	$ 0.03
	CSL 2	LED*	750-1049	0	$ -
	CSL 3	LED*	750-1049	0	$ -
	CSL 4	LED*	750-1049	0	$ -
	CSL 5	LED*	750-1049	0	$ -
Integrated High Lumen (>=2000)	Baseline	CFL	2000-2600	0.88	$ 0.07
	CSL 1	CFL	2000-2600	0.88	$ 0.07
	CSL 2	CFL	2000-2600	0.88	$ 0.07
Non-Integrated	Baseline	CFL	1490-1999	0.79	$ 0.06
	CSL 1	CFL	1490-1999	0.79	$ 0.06
		CFL	1490-1999	0.79	$ 0.06

*Note: DOE assumes in this analysis that the REO content in LED GSLs is negligible

Recognizing that REO costs are only one element of CFL prices, which may have an independent trajectory, DOE accounts for REO costs and the balance of lamps' costs independently. The price of each CFL, as a function of the REO cost, is expressed as follows:

$$\boldsymbol{p(y)_{CFL} = m_r \times \left(c_{REO,scen} + c(y)_{else}\right)}$$

Eq. 8D.1

Where:

$p(y)_{CFL}$ = lamp price at year y,
m_r = markup of manufacturer cost to retail price: estimated as 2.31,[e]
$c_{REO,scen}$ = REO cost for price scenario (reference, or mid-point), and
$c(y)_{else}$ = cost to manufacture lamp at year y, excluding $C_{REO,scen}$.

DOE addresses price learning in its shipments and national impact analysis (NIA) calculations. However, because price learning is not applicable to raw materials inputs to manufacturing and, therefore, is not applicable to the REO part of lamps costs, Eq. 8D.1 was rewritten in the following way for use in the shipments and NIA models:

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[e] This estimate is based on the markup of manufacturer cost to retail price used in the 2014 general service fluorescent lamp and incandescent reflector lamp (GSFL-IRL) notice of proposed rulemaking energy conservation standard.[4]

$$\boldsymbol{p(y)_{CFL} = m_r \times \left(SM \times c_{REO,Ref} + PLF(y) \times \left(\frac{P_{CFL,0}}{m_r} - c_{REO,Ref} \right) \right)}$$

Eq. 8D.2

Where:

SM = scenario multiplier for REO cost scenarios (described below),
$c_{REO,Ref}$ = reference scenario REO cost per CFL (itemized in Table 8D.2.4),
$PLF(y)$ = price learning correction factor at year y (described below) and,
$p_{CFL,0}$ = 2014 'weighted average' CFL price.

The scenario multiplier (SM) is based on the triband phosphor price index, normalized to its reference scenario value. The reference and the mid-point scenario correspond to the price index of the mid-point REO price, and the index of the most recent REO price (June 2014), respectively:

- Reference scenario, $SM = 1$
- Mid-point scenario, $SM = 4.5$

The price learning correction factor (PLF) is defined as follows (see chapter 9 of this TSD for more details):

$$\boldsymbol{PLF(y) = \left(\frac{X(y)}{X(y_0)}\right)^{-b}}$$

Eq. 8D.3

Where:

$X(y)$ = the cumulative production (total shipments) of CFLs between the year of introduction to the market and year y,
$X(y_0)$ = the cumulative production (total shipments) of CFLs between the year of introduction the market and the initial year of the forecasting period, y_0, and
b = the learning rate parameter, as defined in chapter 9 of this TSD.

The 'weighted average' 2014 CFL price ($p_{CFL,0}$) is derived from chapter 6 of this preliminary analysis, Product Price Determination.

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APPENDIX 8E. LIFETIME MODELING

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

8E.1 INTRODUCTION

This appendix describes the methodology the U.S. Department of Energy (DOE) used to model the distribution of general service lamp (GSL) lifetimes. The lifetime distribution of a GSL is used as an input to the life-cycle cost and payback period analysis (chapter 8 of this TSD) and the shipments analysis (chapter 9 of this TSD). DOE modeled GSL lifetime distributions separately for the residential and commercial sectors and for compact-fluorescent lamp (CFL) and light-emitting diode (LED) GSLs. DOE used Weibull survival probability functions in combination with the lamp's rated lifetime (in hours), sector-specific hours-of-use (HOU) distributions, and effects of on-time cycle length[a] (in the case of residential CFL GSLs) to model the probability of survival for a given GSL as a function of lamp age.

8E.2 LIFETIME MODELING ASSUMPTIONS

The method DOE used to model product lifetime distributions incorporates several key assumptions:

- A Weibull distribution appropriately models GSL lifetime.
- The GSL survival function does not change form through time.
- The GSL lifetime models have a Weibull shape parameter (β) of at least 2.
- A log-normal distribution appropriately models the variation of on-cycle time by residential room types.
- Switching effects do not negatively impact the service life of LED GSLs or commercial CFL GSLs.
- Dimming has no effect on CFL or LED GSL lifetime.
- A triangular distribution with a mean corresponding to the building types' mean daily HOU captures the variation in commercial daily hours or use.

Many of these assumptions reflect analytical choices made by DOE. First, DOE assumed that a Weibull distribution is the appropriate distribution to use for observed rates of lamp retirement, which may include other factors outside of failure rate (e.g., retirement due to reasons other than product failure). This distribution is the standard one used in lifetime analyses, but the possibility exists that the model may not reflect actual real-world experience. Next, DOE constrained the Weibull models' shape parameter (k) to values larger than two in order to avoid potential nonsensical behavior, such as sharp changes in purchaser behavior or appliance survival immediately following the delay period (d). DOE also assumed log-normal and triangular distributions adequately capture the variation of on-cycle time by residential room types and daily HOU by commercial building types, respectively. DOE took this approach in this preliminary analysis as a first-order way to account for inherent variability in the face of insufficient data. DOE further assumed on-time cycle length does not affect the service life of LED GSLs (based on insufficient data to suggest otherwise) or the service life of commercial CFL GSLs, because DOE expects commercial GSLs to have long enough on-time cycle lengths so as to not negatively impact the service life of CFL GSLs. Last, DOE assumed that dimming does not affect CFL or LED GSL lifetime.

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[a] On-time cycle length is the amount of time a GSL is switched on over one on-off cycle.

8E.3 RESIDENTIAL GSL HOURS OF USE

For the residential sector, DOE mapped daily HOU metering data from the Northwest Energy Efficiency Alliance's Residential Building Stock Assessment[1] to the room types used in the 2012 Residential Lighting End-Use Consumption Study (RLEUCS).[2] DOE then used Eq. 8E.1 to combine these HOU distributions by room type into a single HOU distribution. Each room type was assigned a weight, which DOE calculated as the product of the average number of GSLs for that room type (reported in RLEUCS) and the number of households represented with that room type in each of the 2009 Residential Energy Consumption Survey's (RECS)[3] reportable domains[b].

$$F_{res}(HOU) = \sum_{i=1}^{n} f_i(HOU) \times w_i$$

Eq. 8E.1

Where:

$F_{res}(HOU)$ = the weighted residential HOU frequency distribution across all RLEUCS room types, in hours,
i = the room type,
n = the total number of RLEUCS room types,
$f_i(HOU)$ = the daily HOU frequency distribution for room type i, in hours, and
w_i = the weight for room type i.

Figure 8E.3.1 shows the final, weighted HOU distribution for residential GSLs with the median (1.45 h/day) and mean (2.37 h/day) of the distribution indicated. DOE notes the slight difference in the mean daily residential HOU for these distributions, compared to the national average of 2.33 h/day calculated in the energy use analysis (chapter 7 of this TSD). This difference is the result of using different methodologies and data sources to estimate the daily residential HOU for GSLs in the two cases. Because DOE needed HOU distributions for GSL lifetime modeling, it was able only to use the subset of the data sources that provided such values. In the energy use analysis, by contrast, DOE only needed an average daily HOU point value, so all available data sources were used, yielding a slightly different average value.

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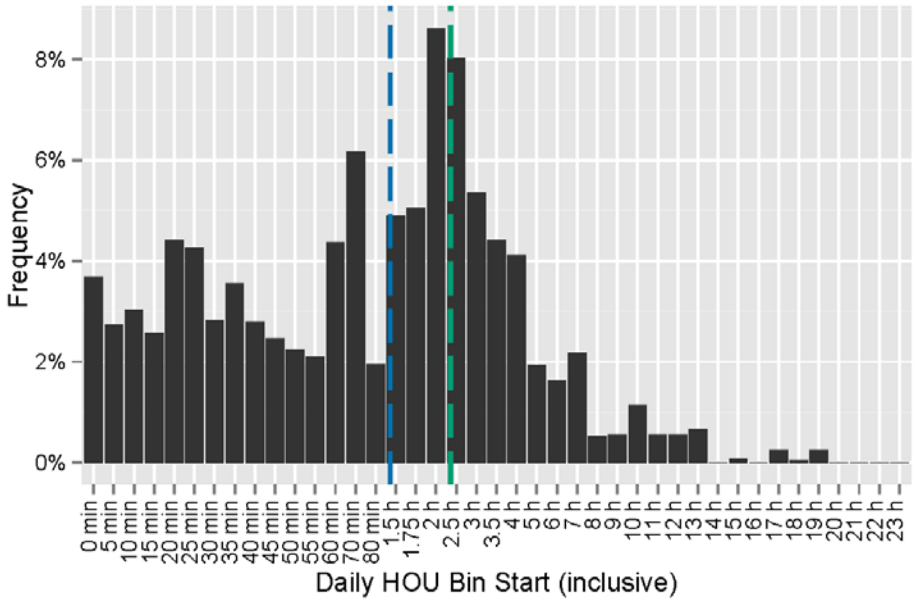
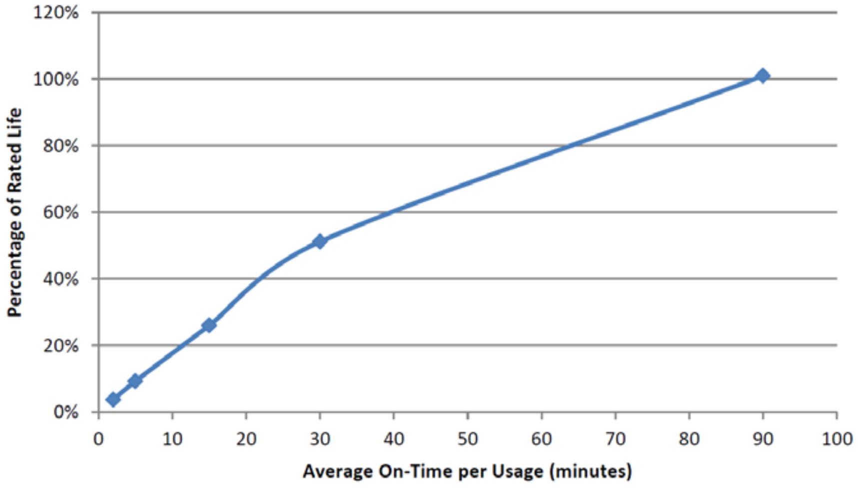
[b] The 2009 RECS separated the 50 states (plus the District of Columbia) into 27 reportable domains, which allowed the survey data to be analyzed across smaller geographic regions, when compared to using the U.S. Census Bureau's census regions and divisions.



Note: The mean and median daily HOU are represented by the green and blue dashed lines, respectively.

Figure 8E.3.1 Weighted Daily HOU Distribution for Residential GSLs

DOE accounted for the effect of on-time cycle length for residential CFL GSLs by using average on-time cycle length residential metering data from an American Council for an Energy-Efficient Economy (ACEEE) report[4] (hereafter referred to as "the ACEEE report") and a report presented to the California Public Utilities Commission (CPUC)[5] containing the measured lifetime of CFL GSLs as a function of on-time cycle length (hereafter referred to as "the CPUC report"). Figure 8E.3.2 is a plot summarizing the measured lifetime results reported in the CPUC report.



Note: Adapted from the CPUC report.[5]

Figure 8E.3.2 Estimated Percentage of a CFL GSL's Rated Life Obtained as a Function of Average On-Time Cycle Length

To account for variation in on-time cycle length by room type, DOE developed log-normal probability distribution functions based on the average on-time cycle length by room type and the provided histogram of on-time cycle lengths across all room types from the ACEEE report. The log-normal probability density function takes the form:

$$P(x) = \frac{1}{x\sqrt{2\pi\sigma}} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}}$$

Eq. 8E.2

Where:

$P(x)$ = the log-normal probability density at x,
μ = the mean of the natural logarithm of x, and
σ = the standard deviation of the natural logarithm of x.

For each room type, DOE set μ to the natural log of the mean on-time cycle length for that room type. Then, DOE re-binned the raw on-time cycle length histogram data from the ACEEE report into eight bins,[c] which resulted in a new histogram of the raw data that more closely resembles a log-normal distribution. For each room type, DOE set $P(0\text{ min} \leq x < 2\text{ min})$ equal to the percentage of loggers across all room types with on-time cycle lengths up to 2 minutes (i.e., the percentage of loggers in the first bin). Given μ and a point at which $P(x)$ is known, DOE was then able to back-calculate σ to optimally fit the log-normal distribution for each room type. With the log-normal distribution generated for each room type, DOE then discretized the distribution functions by assigning the cumulative probability across the eight bins of on-time cycle lengths. With the binned probabilities calculated, DOE determined the reduced life of residential CFL GSLs for each room type using the following equation:

$$l_{red}(l_{rated}) = l_{rated} \times \sum_{x=1}^{8} P(x) \times l_{frac}(x)$$

Eq. 8E.3

Where:

$l_{red}(l_{rated})$ = the reduced life of a residential CFL GSL as a function of the rated lifetime, in hours,
l_{rated} = the rated life of a residential CFL GSL (from the engineering analysis), in hours,
x = the on-time cycle length bin,
$P(x)$ = the log-normal distribution probability in bin x, and
$l_{frac}(x)$ = the expected fraction of a residential CFL GSL's rated life available with on-time cycle length of bin x, obtained from Figure 8E.3.2.

DOE assumed—based on insufficient data to suggest otherwise—that on-time cycle length does not affect the lifetime of LED GSLs (regardless of sector).

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[c] The minimum on-time cycle length for each of the eight bins DOE used are: 0 min, 2 min, 5 min, 15 min, 30 min, 1.5 h, 4 h, and 23 h.

8E.4 COMMERCIAL GSL HOURS OF USE

For the commercial sector, DOE used the average daily HOU provided in the energy use analysis (chapter 7 of this TSD) for each of the building types analyzed in the 2003 Commercial Building Energy Consumption Survey (CBECS).[6] DOE then accounted for variability in daily HOU by developing triangular HOU distributions for each CBECS building type. The triangular distribution is a continuous probability distribution taking the form:

$$P(x) = \begin{cases} 0 & \text{for} \quad x < a \\ \dfrac{2(x-a)}{(b-a)(c-a)} & \text{for} \quad a \leq x < c \\ \dfrac{2}{b-a} & \text{for} \quad x = c \\ \dfrac{2(b-x)}{(b-a)(b-c)} & \text{for} \quad c < x \leq b \\ 0 & \text{for} \quad b < x \end{cases}$$

Eq. 8E.4

Where:

$P(x)$ = the triangular probability density at x,
a = the lower limit of the triangular distribution, in hours,
b = the upper limit of the triangular distribution, in hours, and
c = the mode of the triangular distribution, in hours.

DOE set the mode of each distribution to the respective building type’s average daily HOU. The lower and upper limits of the building types’ distributions were set to the distribution mode less 20% and the distribution mode plus 20%, respectively (e.g., with a mode of 10 HOU per day, the base of the triangular distribution would start at 8 hours and end at 12 hours). DOE then combined the triangular HOU distributions using the building weights provided in the energy use analysis (chapter 7 of this TSD). The following equation was used to calculate the weighted commercial GSLs HOU distribution:

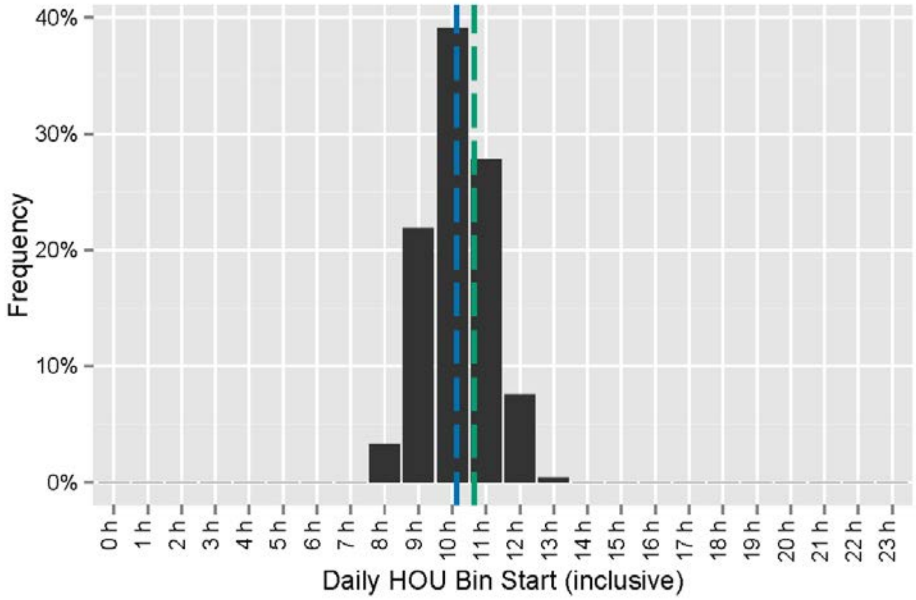
$$F_{comm}(HOU) = \sum_{i=1}^{n} f_i(HOU) \times w_i$$

Eq. 8E.5

Where:

$F_{comm}(HOU)$ = the weighted commercial HOU frequency distribution across all CBECS building types, in hours,
i = the building type,
n = the total number of CBECS building types,
$f_i(HOU)$ = the daily HOU frequency distribution for building type i, in hours, and
w_i = the weight for building type i.

Figure 8E.4.1 shows the final, weighted HOU distribution for commercial GSLs with the median (10.1 h) and mean (10.7 h) of the distribution indicated.



Note: The mean and median daily HOU are represented by the green and blue dashed lines, respectively.

Figure 8E.4.1 Weighted Daily HOU Distribution for Commercial GSLs

DOE assumed that on-time cycle length does not affect commercial CFL GSLs, because DOE expects commercial GSLs to have long enough on-time cycle lengths so as to not negatively impact the service life of CFL GSLs. DOE also notes that—in contrast to the residential sector—the daily energy use analysis for the commercial sector (see chapter 7 of this TSD) uses the same data that DOE used in this analysis, resulting in equal mean daily HOU estimates. The only difference is that in this case DOE assumed a distribution of daily HOU for commercial buildings, which was unnecessary for the energy use analysis.

8E.5 PERCENTAGE OF EXPECTED LIFE CONSUMED AS A FUNCTION OF TIME

As a final step before modeling GSL lifetime distributions, DOE calculated the percent of a GSL's expected life consumed as a function of the GSL age. DOE used the following set of equations to calculate the percent expected life in each HOU bin (the same bins used to calculate residential and commercial GSL HOU distributions) for a GSL that has aged one year:

$$L_{cons}(A, hb) = \begin{cases} A \times \sum_{i=1}^{n} \left[\left(\frac{hb \times 365}{l_{red,i}} \right) \times w_i \right] & \text{for residential CFL GSLs} \\ A \times \left(\frac{hb \times 365}{l_{rated}} \right) & \text{for all other GSLs} \end{cases}$$

Eq. 8E.6

Where:

$L_{cons}(A, hb)$ = the percent of a GSL's expected life consumed as a function of GSL age and HOU bin,
A = GSL age, in years,
hb = the daily HOU bin for the residential or commercial sector, in hours,
i = the room type,
n = the total number of RLEUCS room types,
$l_{red,i}$ = the reduced life of a residential CFL GSL located in room type i, in hours,
w_i = the weight for room type i, and
l_{rated} = the rated life of a GSL (from the engineering analysis), in hours.

8E.6 CALCULATING SURVIVAL PROBABILITY AS A FUNCTION OF GSL AGE

To calculate the probability of survival as a function of GSL age, DOE applied survival functions, which were assumed to have the form of cumulative Weibull distributions. The Weibull distribution is a probability distribution commonly used to measure failure rates. Its form is similar to an exponential distribution, which models a fixed failure rate, except that a Weibull distribution allows for a failure rate that changes over time in a particular fashion. The cumulative Weibull distribution takes the general form:

$$w_s(A) = \begin{cases} e^{-\left(\frac{A-d}{\lambda}\right)^k} & \text{for } A > d \\ 1 & \text{for } A \leq d \end{cases}$$

Eq. 8E.7

Where:

$w_s(A)$ = the probability that the appliance survives to age A after its initial installation,
A = appliance age,
d = delay parameter, which allows for a delay before any failures occur,
λ = scale parameter, which would be the decay length in an exponential distribution, and
k = shape parameter, which determines the way in which the failure rate changes through time.

When k=1, the failure rate remains constant over time, giving the distribution the form of a cumulative exponential distribution. In the case of appliances, k commonly exceeds 1, reflecting an increasing failure rate as appliances age.

DOE first computed the survival probability distribution assuming the GSL is used for its full lifetime, until failure occurs.[d] For this model, DOE applied a survival function having parameters representing the GSL's probability of survival as a function of the percentage of the GSL's expected service life consumed at a given GSL age. The parameters (λ, k, d) = (108.8, 5.5, 0.0) characterize the function, which has mean and median percentages of the GSL's expected service life of 100% and 102%, respectively.[e] The function is modeled by Eq. 8E.8 (assuming d equals 0):

$$P_{surv}(A) = \sum_{i=1}^{n} \left(e^{-\left(\frac{L_{cons}(A)_i \times 100}{108.8}\right)^{5.5}} \times w_i \right)$$

Eq. 8E.8

Where:

$P_{surv}(A)$ = the probability of survival at age A assuming the GSL is used for its full lifetime, until failure,
i = the HOU bin,
n = the total number of HOU bins (differs between residential and commercial sectors),
$L_{cons}(A)_i$ = the percent of a GSL's expected life consumed as a function of GSL age and HOU bin, and
w_i = the residential or commercial HOU weighting in HOU bin i.

DOE then considered three GSL lifetime scenarios: one scenario in which all consumers use GSLs for the full lifetime of the GSL, which is characterized by Eq. 8E.8, and two other scenarios in which lamps may be retired prior to failure. To model the possibility of GSLs being retired before they fail, DOE multiplied the first scenario—called the "Rated Lifetime" scenario—by a Weibull distribution defined as a function of GSL age. The second scenario, and DOE's reference scenario—called the "Renovation-Driven Lifetime" scenario— truncates the "Rated Lifetime" scenario distribution to account for lamp turnover when a renovation or retrofit occurs. The third scenario—called the "Early-Retirement Lifetime" scenario—further truncates the "Rated Lifetime" scenario distribution to account for the possibility of the service lifetime of LED GSLs being similar to the service lifetimes of consumer electronic devices (approximately five years). Table 8E.6.1 provides the Weibull model parameters, along with the mean and median GSL lifetime of each model, for the "Renovation-Driven Lifetime" and "Early-Retirement Lifetime" scenarios.

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[d] In the case of LED GSLs, failure is commonly defined as the point at which the GSL's light output has decreased to 70% of its initial light output. This is often referred to as "L70."

[e] DOE derived this Weibull survival function from a plot of fluorescent lamp mortality as a function of the percent of average life from the 9th edition of the Illuminating Engineering Society of North America's Lighting Handbook.[7]

Table 8E.6.1 Weibull Survival Model Parameters for the "Renovation-Driven Lifetime" and "Early-Replacement Lifetime" Scenarios

GSL Lifetime Scenario	Weibull Survival Function Parameters			GSL Lifetime	
	Scale ($\boldsymbol{\lambda}$)	Shape ($\boldsymbol{k}$)	Delay ($\boldsymbol{d}$)	Mean (years)	Median (years)
Renovation-Driven Lifetime	21.5	6.0	0	20	20
Early-Replacement Lifetime	5.55	3.5	0	5	5

Eq. 8E.9 is the general form of the equation DOE used to model the "Renovation-Driven Lifetime" and "Early-Replacement Lifetime" scenarios. For the each scenario, the corresponding shape and scale parameters provided in Table 8E.6.1 were used (the delay parameter equaled zero for both scenarios).

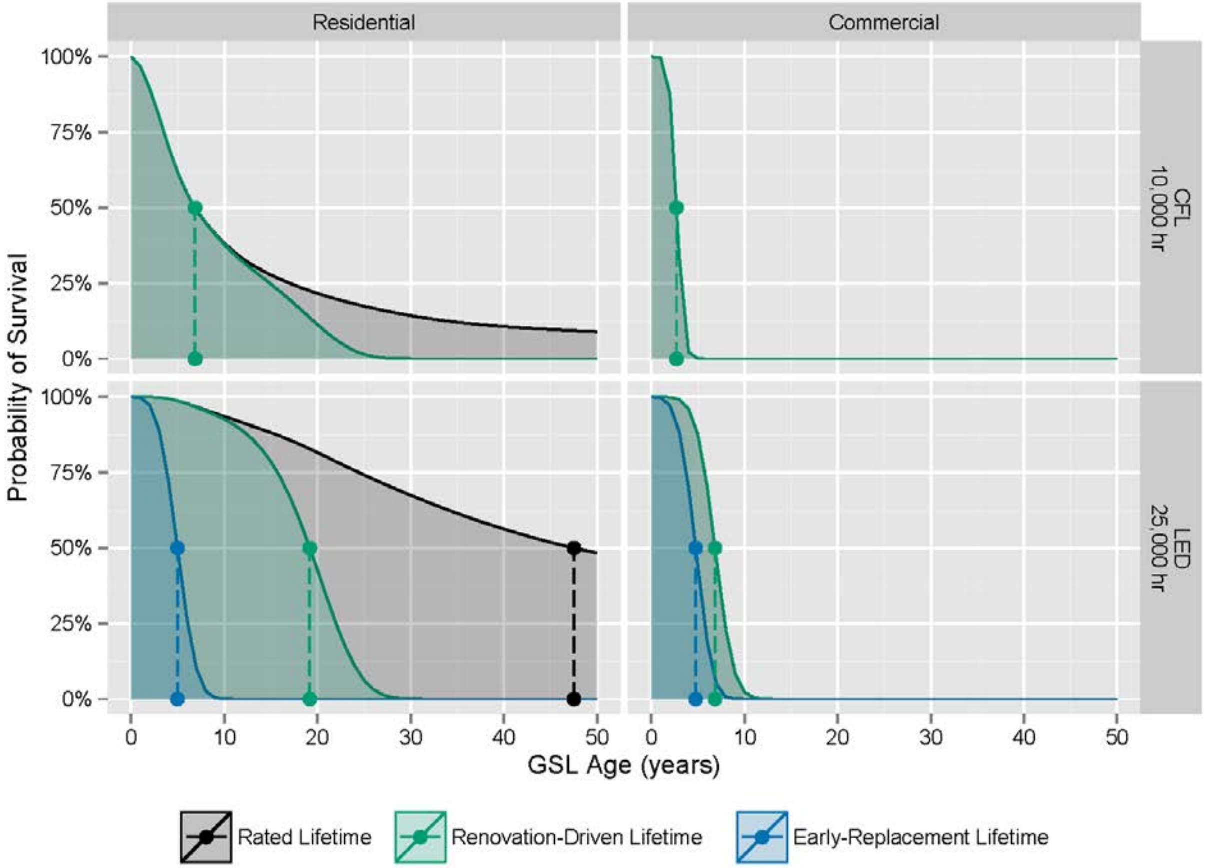
$$P_{surv,scenario}(A) = P_{surv}(A) \times \left[1 - e^{-\left(\frac{A}{\lambda_{scenario}}\right)^{k_{scenario}}}\right]$$

Eq. 8E.9

Where:

$P_{surv,scenario}(A)$ = the probability of survival at age A for the "Renovation-Driven Lifetime" or "Early-Replacement Lifetime" scenario,
$P_{surv}(A)$ = the probability of survival at age A assuming the GSL is used for its full lifetime, until failure (i.e., the probability of survival in the "Rated Lifetime" scenario),
A = the GSL age, in years,
$\lambda_{scenario}$ = the scale parameter for the "Renovation-Driven Lifetime" or "Early-Replacement Lifetime" scenario, and
$k_{scenario}$ = the shape parameter for the "Renovation-Driven Lifetime" or "Early-Replacement Lifetime" scenario.

Figure 8E.6.1 is an example summary plot of the survival probability models for the scenarios considered as a function of GSL age. CFL GSLs rated at 10,000 hours, 12,000 hours, 17,000 hours, and 20,000 hours, and LED GSLs rated at 25,000 hours were provided in the engineering analysis (see chapter 5 of this TSD), and DOE computed lifetime distributions for each of these cases in each lifetime scenario. To provide an example of the lifetime distributions, Figure 8E.6.1 displays the lifetime distributions for CFLs rated at 10,000 hours and LEDs rated at 25,000 hours. The top and bottom rows contain the models for CFL and LED GSLs, respectively, and the left and right columns contain the models for the residential and commercial sectors, respectively. Furthermore, the dashed vertical lines on the plots indicate the models' median GSL lifetime (i.e., the GSL age at which the probability of survival equals 50%).



Note: The CFL and LED GSLs represented here have rated lifetimes of 10,000 hours and 25,000 hours, respectively. The solid black, green, and blue lines represent the resultant “Rated Lifetime,” “Renovation-Driven Lifetime,” and “Early-Replacement Lifetime” scenario models, respectively (the CFL subplots do not show a distribution for the “Early-Replacement Lifetime” scenario, as this scenario was only considered for LED GSLs). The vertical dashed lines in each plot represent the median GSL lifetime for each model.

Figure 8E.6.1 Survival Probability as a Function of GSL Age for Residential and Commercial, and CFL and LED GSLs

As a result of DOE applying the “Renovation-Driven Lifetime” and “Early-Replacement Lifetime” scenario models to the models from the “Rated Lifetime” scenario, the medians of the “Renovation-Driven Lifetime” and “Early-Replacement Lifetime” scenario Weibull distributions (see Table 8E.6.1), when taken alone, always exceed the final median GSL lifetimes for the “Renovation-Driven Lifetime” and “Early-Replacement Lifetime” scenarios shown in Figure 8E.6.1. The final, median GSL ages from the lifetime distributions as a function of scenario, sector, and GSL type are provided in Table 8E.6.2.

Table 8E.6.2 Resulting Median GSL Lifetimes by Scenario, Sector, and GSL Type

Scenario	Sector	GSL Type	Median GSL Lifetime (yrs)
Rated Lifetime	Residential	CFL: 10,000 hours	6.9
		CFL: 12,000 hours	8.2
		CFL: 20,000 hours	13.7
		LED: 25,000 hours	47.5
	Commercial	CFL: 10,000 hours	2.7
		CFL: 12,000 hours	3.3
		CFL: 17,000 hours	4.6
		CFL: 20,000 hours	5.5
		LED: 25,000 hours	6.8
Renovation-Driven Lifetime	Residential	CFL: 10,000 hours	6.8
		CFL: 12,000 hours	8.2
		CFL: 20,000 hours	12.8
		LED: 25,000 hours	19.2
	Commercial	CFL: 10,000 hours	2.7
		CFL: 12,000 hours	3.3
		CFL: 17,000 hours	4.6
		CFL: 20,000 hours	5.5
		LED: 25,000 hours	6.8
Early-Replacement Lifetime	Residential	LED: 25,000 hours	5.0
	Commercial		4.8

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APPENDIX 10A. USER INSTRUCTIONS FOR NATIONAL IMPACT ANALYSIS SPREADSHEET MODEL

TABLE OF CONTENTS

10A.1 ACCESSING THE SPREADSHEET MODEL

DOE performs all NIA calculations using a Microsoft Excel® spreadsheet which is available on regulations.gov, docket number EERE–2013–BT–STD–0051 at http://www.regulations.gov/#!docketDetail;D=EERE-2013-BT-STD-0051.

10A.2 STARTUP

The NIA spreadsheet enables the user to perform a National Impact Analysis (NIA) for the candidate standard cases (CSCs) for general service lamps (GSL). To execute the spreadsheet, DOE assumes that the user has access to a PC with Microsoft Excel® 2007 or later installed under the Windows operating system.

10A.3 DESCRIPTION OF NATIONAL IMPACT ANALYSIS WORKSHEETS

The NIA spreadsheets perform calculations to forecast the change in national energy use and net present value of financial impacts due to an amended energy efficiency standard. The energy use and associated costs for a given standard are determined by first calculating the shipments and then calculating the energy use and costs for all lamps shipped under that standard. The differences between the standards and base case can then be compared and the overall energy savings and net present values determined. The NIA spreadsheets consist of the following worksheets listed in Table 10A.3.1 below.

Table 10A.3.1 Brief Description of the Contents of All Worksheets in the NIA Workbook

Introduction	Includes an introduction to the spreadsheet calculations, and information on the User Options & Summary worksheet
User Options & Summary	Includes user-selected scenarios and a summary table of the cumulative shipments, NES, and NPV under each CSC for the user selected scenario. (More information on the User Options & Summary worksheet can be found in Section 10A.4)
Charts	Includes charts of shipments, stock, NES and NPV, and price trends for each standards case for the user selected scenario and CSC
Shipments, Stock and Prices	Includes the shipments, stock and prices for the residential and commercial sectors for the user selected scenario
Energy Savings – Res	Includes the calculation of the annual energy saving for each standard case for the residential sector, for the user selected scenario
Energy Savings -Com	Includes the calculation of the annual energy savings for each standards case for the commercial sector, for the user selected scenario
Electricity Cost Savings	Includes the change in operating costs for the residential and commercial sectors for the user selected scenario
Change in Equipment Cost	Includes the change of equipment cost for the residential and commercial sectors for the user selected scenario
Parameters	Includes the parameters and assumption inputs for the shipments analysis and NIA
Substitution	Includes the change in equipment cost for the residential and commercial sectors for the user selected scenario
Retirement	Includes survival and failure probabilities for lamps in the residential and commercial sectors
Electricity Price Trends	Includes electricity price trends and site to power plant conversion factors for the residential and commercial sectors, and full fuel cycle multipliers for each year in the analysis
Controls & Smart Lamp Incursion	Includes the trends in controls in the commercial sector for the user selected controls scenario and the fraction of LED GSL shipments that are smart lamps for the user selected smart lamp scenario

10A.4 BASIC INSTRUCTIONS FOR OPERATING THE NATIONAL IMPACT ANALYSIS SPREADSHEETS

Basic instructions for operating the NIA spreadsheets are as follows: Once the NIA spreadsheet file has been downloaded from the Internet, open the file using Excel®. Use Excel's® View/Zoom commands at the top menu bar to change the size of the display to make it fit your monitor.

Calculations are performed under a range of different sets of assumptions (scenarios), which can be selected by the user on the *User Options & Summary* worksheet. A description of the available options is given below. For each of the scenario options, the user should select one option in the associated yellow drop down menu; users must click on the yellow cell for the drop down menu to appear. Results throughout the spreadsheet will update automatically.

There are two types of scenarios that can be investigated, NIA scenarios and Shipments scenarios. NIA Scenarios do not change shipment quantities, while Shipments Scenarios change shipment quantities based on the selected options.

NIA Scenarios

Users can vary these scenarios independently of the shipments scenarios. Values used in the DOE's best estimate reference scenario are italicized.

AEO 2014 Economic Growth Scenarios

- *Reference Case*
- High economic growth
- Low economic growth

Commercial Controls

- *Reference – Assumes increasing growth of controls in the commercial sector, driven by building codes*
- Fixed – Assumes the fraction of commercial floorspace utilizing controls remains fixed at 2014 levels

Smart Lamp Max Shipments

- 0% - Assumes no smart lamps in the residential sector
- *50% - Assumes 50% of the shipments of lamps in the residential sector, at the end of the analysis period are smart lamps*
- 100% - Assumes 100% of the shipments of lamps in the residential sector, at the end of the analysis period are smart lamps

Smart Lamp Standby Power (W)

- *0 – Assumes smart lamps use no power in standby mode*
- 1 – Assumes all smart lamps use 1 W of power in standby mode

Rebound Scenarios

- *No - Assumes 0% rebound in the commercial sector and 0% in the residential sector.*
- Low - Assumes 1% rebound in the commercial sector and 8.5% in the residential sector
- High - Assumes a rebound rate of 15% in both sectors.

Shipment Scenarios

There are eight Alternative Scenarios users can view in the shipments scenarios listed below.

- Reference – DOE's best-estimate scenario
- Early-Replacement Lifetime – Assumes turnover for LED GSLs is driven by consumer preference for newer products rather than product lifetime (reference scenario assumes renovation-driven turnover)

- Rated Lifetime – Assumes turnover for all GSLs is driven by the full rated product lifetime (reference scenario assumes renovation-driven turnover)
- No Int-LED – Assumes that integrated LED fixtures do not displace GSLs
- 50% Int-LED – Assumes that integrated LED fixtures comprise 50% of the lumen demand at the end of the analysis period (reference scenario assumes 15%)
- Tech learning – Assumes a technology dependent price learning rate for lamps (reference scenario assumes a single learning rate for all technologies)
- Fixed Real Prices – All prices are held constant at their 2014 (in 2014$) level throughout the analysis period, i.e., no price learning.
- High REO Price – Assumes REO prices increase to 4.5 times their 2014 levels and remain there throughout the analysis period (reference scenario assumes real REO prices are constant at 2014 levels).

APPENDIX 10B. FULL-FUEL-CYCLE MULTIPLIERS

TABLE OF CONTENTS

LIST OF TABLES

APPENDIX 10B. FULL-FUEL-CYCLE MULTIPLIERS

10B.1 INTRODUCTION

This appendix summarizes the methods used to calculate full-fuel-cycle (FFC) energy savings expected to result from potential standards. The FFC measure includes point-of-use (site) energy, the energy losses associated with generation, transmission, and distribution of electricity, and the energy consumed in extracting, processing, and transporting or distributing primary fuels. DOE's traditional approach encompassed only site energy and the energy losses associated with generation, transmission, and distribution of electricity. Per DOE's 2011 *Statement of Policy for Adopting Full Fuel Cycle Analyses*, DOE now uses FFC measures of energy use and emissions in its energy conservation standards analyses.[1] This appendix summarizes the methods used to incorporate the full-fuel-cycle impacts into the analysis.

This analysis uses several different terms to reference energy use. The physical sources of energy are the primary fuels such as coal, natural gas, liquid fuels, *etc*. Primary energy is equal to the heat content (Btu) of the primary fuels used to provide an end-use service. Site energy use is defined as the energy consumed at the point-of-use in a building or industrial process. Where natural gas and petroleum fuels are consumed at the site (for example in a furnace), site energy is identical to primary energy, with both equal to the heat content of the primary fuel consumed. For electricity, site energy is measured in kWh. In this case the primary energy is equal to the quads of primary energy required to generate and deliver the site electricity. This primary energy is calculated by multiplying the site kWh times the site-to-power-plant conversion factor, given in chapter 10 of this preliminary TSD. For the FFC analysis, the upstream energy use is defined as the energy consumed in extracting, processing, and transporting or distributing primary fuels. FFC energy use is the sum of primary plus upstream energy use.

Both primary fuels and electricity are used in upstream activities. The treatment of electricity in fuel cycle analysis must distinguish between electricity generated by fossil fuels and uranium, and electricity generated from renewable fluxes (wind, solar and hydro). For the former, the upstream fuel cycle impacts are derived from the amount of fuel consumed at the power plant. For the latter, no fuel *per se* is used, so there is no upstream component.

10B.2 METHODOLOGY

The mathematical approach is discussed in the paper *A Mathematical Analysis of Full Fuel Cycle Energy Use,*[2] and details on the fuel production chain analysis are presented in the paper *Projections of Full-Fuel-Cycle Energy and Emissions Metrics.*[3] The text below provides a brief summary of the methods used to calculate FFC energy.

When all energy quantities are normalized to the same units, the FFC energy use can be represented as the product of the primary energy use and an *FFC multiplier*. The FFC multiplier is defined mathematically as a function of a set of parameters representing the energy intensity and material losses at each production stage. These parameters depend only on physical data, so the calculations do not require any assumptions about prices or other economic data. While in general these parameter values may vary by geographic region, for this analysis national averages are used.

In the notation below, the indices x and y are used to indicate fuel type, with x=c for coal, x=g for natural gas, x=p for petroleum fuels, x=u for uranium and x=r for renewable fluxes. The fuel cycle parameters are:

- a_x is the quantity of fuel x burned per unit of electricity output, on average, for grid electricity. The calculation of a_x includes a factor to account for transmission and distribution system losses.
- b_y is the amount of grid electricity used in production of fuel y, in MWh per physical unit of fuel y.
- c_{xy} is the amount of fuel x consumed in producing one unit of fuel y.
- q_x is the heat content of fuel x (MBtu/physical unit)[a]
- $z_x(s)$ is the emissions intensity for fuel x (mass of pollutant s per physical unit of x)

The parameters are calculated as a function of time with an annual time step; hence, a time series of annual values is used to estimate the FFC energy and emissions savings in each year of the analysis period. Fossil fuel quantities are converted to energy units using the heat content factors q_x. To convert electricity in kWh to primary energy units, on-site electricity consumption is multiplied by the site-to-power-plant conversion factor indicated in chapter 12 of this final rule TSD. The site-to-power-plant conversion factor is defined as the ratio of the total primary energy consumption by the electric power sector (in quadrillion Btu) divided by the total electricity generation in each year.

The FFC multiplier is denoted μ (mu). A separate multiplier is calculated for each fuel used on site. A multiplier is also calculated for electricity reflecting the fuel mix used in its generation. The multipliers are dimensionless numbers that are applied to primary energy savings to obtain the FFC energy savings. The upstream component of the energy savings is proportional to (μ-1). The fuel type is denoted by a subscript on the multiplier μ.

For DOE's appliance standards energy savings estimates, the fuel cycle analysis methodology is designed to make use of data and projections published in the *Annual Energy Outlook* (*AEO*). Table 10B.2.1 provides a summary of the *AEO* data used as inputs to the different parameter calculations. The *AEO* does not provide all the information needed to estimate total energy use in the fuel production chain. Reference 3 describes the additional data sources used to complete the analysis. However, the time dependence in the FFC multipliers arises exclusively from variables taken from the *AEO*. The FFC analysis for this preliminary analysis used data from *AEO 2014*.[4]

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[a] Where MBtu = 1000 Btu.

Table 10B.2.1 Dependence of FFC Parameters on AEO Inputs

Parameter	Fuel	AEO Table	Variables
q_x	all	Conversion Factors	MBtu per physical unit
a_x	all	Electricity Supply, Disposition, Prices, and Emissions	Generation by fuel type
		Energy Consumption by Sector and Source	Electric power sector energy consumption
b_c, c_{nc}, c_{pc}	coal	Coal Production by Region and Type	Production by coal type and sulfur content
b_p, c_{np}, c_{pp}	petroleum	Refining Industry Energy Consumption	Refining only energy use
		Liquid Fuels Supply and Disposition	Crude supply by source
		International Liquids Supply and Disposition	Crude oil imports
		Oil and Gas Supply	Crude oil domestic production
c_{nn}	natural gas	Oil and Gas Supply	US dry gas production
		Natural Gas Supply, Disposition and Prices	Pipeline, lease and plant fuel
z_x	all	Electricity Supply, Disposition, Prices and Emissions	Power sector emissions

10B.3 FULL-FUEL-CYCLE ENERGY MULTIPLIERS

FFC energy multipliers are presented in Table 10B.3.1 for selected years. To extend the analysis period beyond 2040, the last year in the *AEO 2014* projection, the 2040 value was held constant. The multiplier for electricity reflects the shares of various primary fuels in total electricity generation over the forecast period.

Table 10B.3.1 Full Fuel Cycle Energy Multipliers (Based on AEO 2014)

	2015	2020	2025	2030	2035	2040
Electricity	1.041	1.041	1.040	1.040	1.041	1.040
Natural Gas	1.101	1.101	1.100	1.098	1.099	1.100
Petroleum Fuels	1.139	1.140	1.148	1.158	1.166	1.168

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APPENDIX 10C. LIGHTING CONTROLS MARKET PENETRATION PROJECTION

TABLE OF CONTENTS

LIST OF FIGURES

APPENDIX 10C. LIGHTING CONTROLS MARKET PENETRATION PROJECTION

10C.1 BACKGROUND

Lighting controls include a range of technologies to turn lights off or down when they are not needed or wanted. Of interest to this rulemaking are control technologies that go beyond manual on-off switching, which is almost universally included in lighting. These include manual dimmers, automatic timers, and sensor-based controls. Timers can be used to automatically adjust lighting based on occupancy schedules and daylight hours. More advanced sensor-based controls adjust light output based on signals received from the sensors. Occupancy sensors—often referred to as motion sensors for outdoor applications and vacancy sensors for indoor applications—include infrared, ultrasonic, and, to a far lesser extent, microwave sensors. Photosensors are used to adjust light output to account for background light levels, typically from daylight.

The purpose of this appendix is to describe the assumptions and analysis the U.S. Department of Energy (DOE) used to project changes in the penetration of lighting controls in the commercial sector over the analysis period of this rulemaking. DOE incorporates lighting controls in the analysis, because they affect lamp energy use and, therefore, the national impact analysis (NIA) (chapter 10). There are large, inherent uncertainties in the extent to which the penetration of specific controls technologies will change over time. The next section describes the approach DOE took to estimate the penetration of lighting controls technologies in the building stock for the NIA analysis for this rulemaking.

10C.2 APPROACH

DOE considered the impact of state building codes and other factors in estimating the adoption of lighting controls over the analysis period, as described in the following sections.

10C.2.1 The Impact of State Building Codes on Controls Penetration

Federal model energy codes drive the adoption and revision of state building codes. DOE adopts different model codes for commercial and residential buildings. ASHRAE Standard 90.1 is the model energy code for commercial and multi-family high-rise residential buildings. The International Energy Conservation Code (IECC) is the model energy code for low-rise residential buildings. Both include provisions on lighting and are updated periodically. The Energy Conservation and Production Act (ECPA), as amended, requires that DOE, within one year of revision of either document, issue a determination as to whether the revised edition will improve energy efficiency compared to previous editions.[1] If DOE finds that the newest version of ASHRAE 90.1 is more energy efficient than the previous version, states are required by the Energy Policy Act of 1992 (EPACT 1992) to certify that their building energy codes or standards meet or exceed the requirements of the new standard within two years. If the analysis shows that the revised IECC is more energy efficient than the previous edition, EPACT 1992 requires states to certify that they have reviewed their residential building energy codes regarding energy efficiency and made a decision as to whether it is appropriate for that state to revise its residential building code to meet or exceed the revised code.[2]

Therefore, state compliance with the model codes is compulsory for commercial buildings, but not for residential buildings. DOE therefore treated the two sectors differently in this analysis. For the residential sector, DOE assumed that the use of lighting controls remains constant at today's level.

To project the future penetration of commercial lighting controls, DOE assumed that state building code requirements remain as they are today, with controls being installed as required for new construction and renovation. The current model energy code for commercial buildings, ASHRAE 90.1-2007, section 9.4.1.1, mandates that almost all interior lighting be controlled either by a timer, an occupancy sensor, or a signal from a separate system. Exceptions are made for buildings that are less than 5,000 square feet in floor area and for health and safety; hospital operating rooms and spaces that specifically require 24-hour lighting. In the current building stock, the square footage covered by these exceptions totals 9% of commercial floor space. Most of that is exempted because the floor area is less than 5,000 square feet. However, DOE has determined that ASHRAE 90.1-2010 will yield significant additional savings, so it will become the new model code. The 2010 code eliminates the exception for commercial buildings less than 5,000 square feet, with the result that an estimated 98% of total commercial floor space would be required to include lighting controls—essentially all viable floor area. DOE does not model the adoption of the 2010 code in this rulemaking because it is uncertain if and when states will adopt the code.

In addition to the mandatory general lighting provisions of section 9.4.1.1 described previously, ASHRAE 90.1-2007 includes additional requirements for lighting controls in some smaller spaces, such as individual offices, which may be superimposed on controls required under the general provisions. DOE did not attempt to account for the effect of multiple layers of controls or improvements in control technologies that may take place over time. This appendix calculates only the lighting capacity (in teralumens) covered by controls. Given the lack of data on whether multiple levels of controls would be adopted and which controls will be adopted in which areas, the energy use calculations in chapter 12 of this final rule TSD assume that controls yield a fixed 30% energy savings if controls are required for the floor area.[3]

Compliance rates are the largest source of uncertainty in the analysis. Given that all of the most populous states are currently compliant with the federal requirement to adopt the model code or better, future changes in the level of state compliance should do little to change the results of the energy analysis. The level of builders' compliance with state codes is less clear. This analysis assumes a 75 percent overall compliance rate.

Using the assumptions described above, DOE estimated the national commercial lighting capacity (in teralumens) covered by lighting controls for each year of the analysis, based on the floor space projected to be operating under lighting controls, using a computational model developed by Sturges (2012).[4] The model estimates the commercial floor area incorporating controls, accounting for the current variation in standards adopted by the states, the relevant floor area in each state, the breakdown of floor area by application, and the code requirements for each floor area application. Because the analysis period in Sturges' study extended only until 2030, for this rulemaking DOE extrapolated Sturges' projection to the end of the analysis period (2049). The results of the analysis are described in section 10C.3.

10C.2.2 The Impact of Other Factors on Controls Penetration

In addition to lighting controls installed as a result of state building codes, some fraction of building owners install controls for other reasons. For the commercial sector, DOE computed the current lighting capacity installed for other reasons from the difference between the current total lighting capacity under controls and the lighting capacity under controls as a result of building codes, based on Sturges' model. DOE's 2010 Lighting Market Characterization (LMC) estimates that 30% of commercial lighting was governed by lighting controls in 2010.[5] The building codes analysis estimated that state codes would have resulted in only 12% of floorspace having implemented lighting controls at the beginning of the analysis period. Assuming that floorspace fractions equate approximately to lighting fractions, an estimated 18% of commercial lighting is assumed to be using lighting controls for other reasons. DOE held that fraction fixed throughout the analysis period.

10C.3 RESULTS AND CONCLUSIONS

Figure 10C.3.1 shows DOE's projection of the teralumen hours of capacity expected to be operating under controls as a result of building codes, and for other reasons. Total lumen capacity is also included in the plot for comparison. As shown, by the end of the analysis period approximately 75% of commercial floor space is expected to be operating under lighting controls, assuming that today's building codes remain frozen in place and a 75 percent compliance rate. If ASHRAE 90.1-2010 is adopted by the states, there will be some increase in lumen capacity covered by controls, because the lighting controls exception for small buildings will be eliminated. The magnitude of that increase will depend on which states adopt the standard and when. However, a larger uncertainty appears to be the rate at which builders comply with state code requirements. Currently, DOE is assuming a 75% compliance rate.

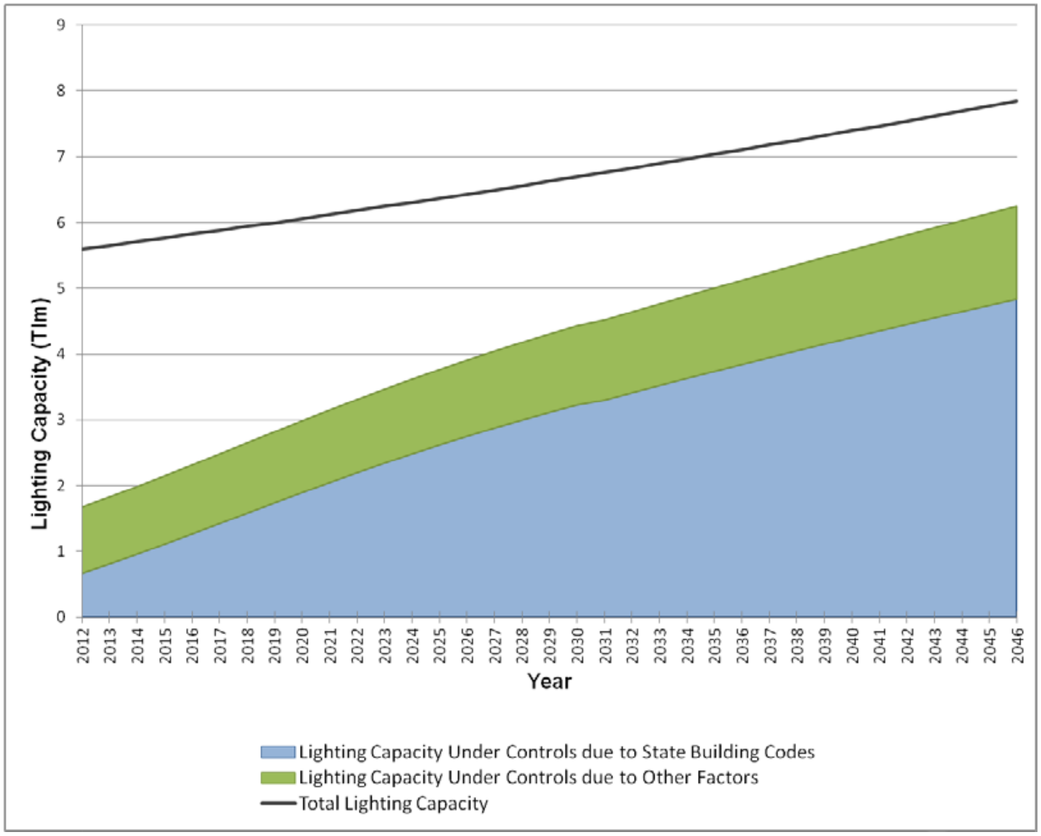

Figure 10C.3.1 U.S. Total Annual Commercial Lighting Capacity and the Capacity Projected to be Operating under Lighting Controls

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APPENDIX 10D. REBOUND EFFECT

TABLE OF CONTENTS

LIST OF TABLES

APPENDIX 10D. REBOUND EFFECT

10D.1 BACKGROUND

The U.S. Department of Energy (DOE) accounts for the direct rebound effect in its estimates of national energy savings.[a] Direct rebound is the concept that an increase in the energy efficiency of equipment may indirectly induce greater usage by the end-user, thereby undercutting expected energy savings. Economic theory suggests that if efficiency improvements decrease the cost of obtaining a desired service—lighting, in this case—then demand for that service will increase, assuming demand is not saturated.

In the case of lighting, the increased usage should be normalized to floor area. Therefore, if a rebound is occurring there must be a change in lighting density (lumens per square foot). Any combination of the following potential consumer responses to increased lighting efficiency could increase lighting density and, therefore, indicate a positive rebound effect:

- an increase in the average operating hours of lamps,
- a tendency to replace less efficient lamps with more luminous efficient lamps, and
- an increase in the number of fixtures or sockets per unit floor area (ft^2).

While it is the change in service demand (lighting density in lm/ft^2), concomitant with an improvement in lighting efficiency, that is the final determinant of rebound, lacking such data, rebound researchers have relied on the individual factors listed previously as proxies for lighting rebound. (See, for example, the papers by Nadel (1993)[1] and Greening et al. (2000)[2]) In keeping with the literature on rebound, causation is not addressed in this analysis.

Lighting rebound can be quantified by the following formula:

$$\boldsymbol{Observed\ Savings = Expected\ Savings\ \times (1 - rr)}$$

Eq. 12B.1

Where:

Observed Savings = observed reduction in power consumption per square foot (W/ft^2) during a period,

Expected Savings = expected reduction in power consumption per square foot (W/ft^2), given the efficiency improvements that occurred during that period, if lighting density (lm/ft^2) had remained constant, and

rr = rebound rate.

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[a] DOE does not include rebound effects in its NPV calculation, however, for the following reasons: The take-back in energy consumption associated with the rebound effect provides consumers with increased value (e.g., increased lighting services). DOE believes that, if it were able to monetize the increased value to consumers of the rebound effect, this value would be similar in value to the foregone energy savings. Therefore, the economic impacts on consumers with or without the rebound effect are the same, so DOE does not adjust operating cost savings in the NIA.

Therefore, a direct rebound rate of 10 percent means that 10 percent of the energy savings expected to materialize from efficiency improvements alone would not materialize because of increased lighting density.

In repose to comments received during the general service fluorescent lamps (GSFLs) and incandescent reflector lamps (IRLs) framework public meeting that the rebound rates proposed in that rulemaking were too high,[3] DOE further researched lighting rebound rates. The rates of 8.5-percent for the residential sector and 1-percent for the commercial sector were based on studies cited by Greening *et al.*[2] The lighting rebound estimates quoted in the Greening paper were taken from Nadel[1] (1993). Nadel, in turn, cited earlier surveys of lamp operating hours conducted by Pacific Gas & Electric Company (PG&E), Boston Edison (BE), and New England Electric System (NEES). Greening *et al*. used the results of quoted PG&E and BE studies only as the basis of their estimated 5 – 12 percent rebound for residential lighting. The results of the two NEES studies were not used, apparently because they had conflicting results. This may have been the genesis of the conclusion by Greening *et al.* that the data available on lighting rebound were 'inconclusive'.[b]

DOE sought more recent studies on lighting rebounding rates. Many authors have noted that appliance saturation effects can reduce rebound.[4–8] Therefore, rebound rates can change significantly with time.[5] While Greening et al. (2000), and to a lesser extent Nadel (1993), has been repeatedly cited as a source for lighting rebound rates.[6,7,9,10] DOE found no studies that evaluated rebound rates based on more recent data. The National Energy Modeling System (NEMS) also cites Greening *et al*.[2] as the source of its rebound rates, but NEMS uses a combined average rebound rate of 15 percent for all appliances and applies that to lighting, as well as to other technologies. The NEMS assumptions for commercial rebound are described in the Energy Information Administration's Commercial Sector Demand Module documentation for NEMS[11] the rebound rate used in the residential demand module was inferred.

Lacking more recent journal publications on U.S. lighting rebound, DOE sought lighting data from which rebound rates could be estimated. DOE identified two large studies of lamp operating hours in California that are directly comparable to the original studies cited by Nadel (1993) and Greening *et al.* (2000). DOE also used lighting data from its 2001 and 2010 U.S. Lighting Market Characterization (LMC) studies, which are a better source for national rebound rates, given their scope.[12,13] The results are described in sections 10D.2 and 10D.3.

10D.2 OPERATING HOURS OF EFFICIENT AND STANDARD RESIDENTIAL LIGHTING IN CALIFORNIA

A 2005 study by KEMA conducted for three California utilities (PG&E, Southern California Edison Company, and San Diego Gas and Electric Company) compared hours of use of compact fluorescent lamps (CFL)[14] to hours of use of all residential lamp types that were reported in a 1999 California Energy Commission study for the same service territory.[15] These

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[b] See Table 3 footnote in Greening *et al*.

studies were based on large and more recent data sets for service areas that overlapped those reported in Nadel (1993) and Greening *et al.* and used the same metric. The sample sizes used in the two studies and the reported hours of lamp use are reported in Table 10D.2.1. The studies found no discernible difference in lamps hours of use. Given that changes in lamp operating hours are only one possible cause of rebound, and the data are only for California, DOE sought national data to check the result. These are reported in the following section.

Table 10D.2.1 Sample Disposition of Residential Lighting Studies

	KEMA 2005[14]	**CEC 1999**[15]
Residences	369	683
Fixtures	752	16,275
Lamps	1,514	26,203*
	CFLs only	**All lamps**
Reported Hours of Use of Lamps, Average Daily	2.3 hrs/day	2.34 hrs/day

* Total number of lamps calculated from reported average lamp per fixture values.

10D.3 NATIONAL LIGHTING DENSITY AS THE DETERMINANT OF LIGHTING REBOUND

DOE sought evidence of U.S. lighting rebound based on national lighting data reported in DOE's 2001 and 2010 U.S. LMC studies.[12,13] As indicated in section 10D.1, by definition a positive lighting rebound occurs if there is an increase in lighting density (lm/ft^2) concomitant with an increase in lighting efficiency. A decrease in lighting density yields a negative rebound rate, indicating a greater energy savings than expected from efficiency improvements alone.

DOE used data from the two LMC reports to estimate lighting density in 2001 and 2010 using the following equation:

$$\textbf{Lighting Density}\ (lm/ft^2) = \frac{N_{lamps} * W_{lamp} * \varepsilon_{lamp}}{Floorspace}$$

Eq. 10D.1

Where:

N_{lamps} = the number of lamps in the category under consideration in the United States,
W_{lamp} = the average wattage (W) of the lamp category,
ε_{lamp} = the average efficacy (lm/W) of the lamp category, and
Floorspace = the total floor space in the sector (ft^2).

As shown in Table 10D.3.1, while reported lighting efficiency increased from 2001 to 2010, lighting density decreased, implying a negative rebound rate. The table reports the associated percentage decreases in power consumption per lumen: 5 percent in the residential sector and 21 percent in the commercial sector. In the absence of rebound, lighting power density

(W/ft^2) would be expected to decrease by the same amounts. Instead, it drops by considerably larger percentages: 29 and 31 percent in the residential and commercial sectors, respectively. This implies a large reduction in lighting demand: from 30 to 23 lumens per square foot in the residential sector, and from 90 to 75 lumens per square foot in the commercial sector.

Table 10D.3.1 U.S. Residential and Commercial Lighting in 2001 and 2010

	Average Efficacy* E_{lamp} (lm/W)		Change in Watts per Lumen	Lamps* (Millions)		Average Lamp Power* (W)		Floor Space* (Billion ft^2)		Average Lighting Density (lm/ft^2)		Lighting Power Density (W/ft^2)			Change in Lighting Power Density (W/ft^2)
	2001	2010		2001	2010	2001	2010	2001	2010	2001	2010	2001	2010	2010-EXP**	
Residential	18	19	-5%	4611	5812	63	46	174	223	30	23	1.7	1.2	1.6	-29%
Commercial	55	70	-21%	1966	2069	56	42	67	81	90	75	1.6	1.1	1.3	-31%

* Data taken from LMC reports. All other values calculated.
** The expected power density in 2010 in the absence of rebound.

According to the LMC data, only in the residential sector are the reductions in lighting density explained (at least in part) by reductions in operating hours. As shown in Table 10D.3.2, in the residential sector lamp operating hours were estimated to have decreased by 10 percent, explaining only part of the estimated 23 percent reduction in lighting density. In the commercial sector the reported lamp operating hours increased. However, LMC 2010 indicates that the large change in estimated operating hours could be an artifact of changes in the characterization of commercial versus industrial lighting. Therefore, the results should not be considered conclusive.

Table 10D.3.2 Changes in Lamp Operating Hours Compared to Changes in Lighting Density, U.S. Residential and Commercial Sectors

Sector	Average Daily Operating Hours*		Percent Change in Operating Hours	Average Lighting Density (lm/ft^2)		Percent Change in Average Lighting Density
	2001	2010		2001	2010	
Residential (Total)	2	1.8	-10%	30	23	-23%
Commercial (Total)	9.9	11.2	13%	90	75	-17%

* Data taken from LMC reports. All other values calculated.

Using the result from Table 10D.3.2, DOE estimated the rebound rates implied by the LMC data as follows:

$$rr = 1 - \frac{observed\ power\ savings}{expected\ power\ savings}$$

Eq. 10D.2

Where:

observed power savings = the difference between the 2001 and 2010 lighting power density, and

expected power savings = percentage change in watts per lumen multiplied by the 2001 lighting power density.

The results are reported in Table 10D.3.3.

Table 10D.3.3 Estimated Rebound Rates based on LMC Data

	Observed Power Savings	Expected Power Savings	Estimated Rebound Rate
Residential	0.5	0.09	-4.9 (-490%)
Commercial	0.5	0.34	-0.5 (-50%)

10D.4 CONCLUSIONS

DOE concludes that the most recent available data do not support a lighting rebound effect for either the residential or commercial sector. The data may indicate a systematic trend in residential sector rebound, moving from a modest positive rebound in the early 1990s, to zero rebound in 2005, to a very large negative rebound in 2012. An initial reduction in rebound rates from positive to zero is what is expected if demand for a service saturates. Goldstein[5] explains that negative rebounds can occur if consumers use efficiency cost savings to invest in more energy efficiency rather than in more energy consumption. The same may be true of commercial lighting, though there are fewer data to support such a conclusion. However, given the uncertainties inherent in comparing different data sources for different times, DOE took a conservative approach in estimating energy savings and assumed in this analysis no rebound effect for its reference scenario for both sectors. DOE also conducted alternative analyses of rebound rates, the low rebound alternative uses the rates originally proposed in the GSFL and IRL rulemaking (8.5-percent for the residential sector and 1-percent for the commercial sector), and the high rebound alternative uses values from NEMS (15-percent for both the residential and commercial sectors). The results are described in chapter 10 of this preliminary analysis TSD.

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APPENDIX 12A MANUFACTURER IMPACT ANALYSIS INTERVIEW GUIDE

TABLE OF CONTENTS

12A.1 PRELIMINARY MANUFACTURER INTERVIEW GUIDE FOR GENERAL SERVICE LAMPS

May 2014

Purpose:
To gather information on the U.S. general service lamp (GSL) market to assist in the Department of Energy's (DOE) energy conservation standards analysis.

Method:
Navigant Consulting, Inc. (Navigant) is circulating this interview guide to manufacturers of general service fluorescent lamps who operate in the U.S. market. Navigant will combine all the responses from individual manufacturers to protect proprietary information of any one manufacturer. Individual responses to this questionnaire and any other data provided will all be covered under a non-disclosure agreement, which Navigant will enter into with each participating manufacturer. Navigant will handle all individual company data in the strictest confidence.

If you have any questions, please contact:

Aisha Husain
Navigant Consulting, Inc.
aisha.husain@navigant.com
Tel: 202.481.8301
Fax: 202.973.2401

Maureen Kienle
Navigant Consulting, Inc.
maureen.kienle@navigant.com
Tel: 202.481.8342
Fax: 202.973.2401

Amendments to Title III of Energy Policy and Conservation Act of 1975 (EPCA) (42 U.S.C. 6291 *et seq.*) in the Energy Independence and Security Act of 2007 (EISA) directed DOE to conduct two rulemaking cycles to evaluate energy conservation standards for GSLs. (42 U.S.C. 6295(i)(6)(A)-(B)). DOE initiated the first rulemaking cycle through publication of a framework document in December 2013 that describes the procedural and analytical approaches DOE anticipates using to evaluate potential energy conservation standards.[1]

1 SCOPE OF COVERAGE

DOE defines general service lamp as follows:

> General service lamp includes general service incandescent lamps, compact fluorescent lamps, general service light-emitting diode lamps, organic light-emitting diode lamps, and any other lamps that the Secretary determines are used to satisfy lighting applications traditionally served by general service incandescent lamps; however, this definition does not apply to any lighting application or bulb shape excluded from the "general service incandescent lamp" definition, or any general service fluorescent lamp or incandescent reflector lamp.
>
> 10 CFR 430.2
>
> Applications and bulb shapes excluded from the general service lamp definition are provided below:
>
> (1) An appliance lamp;
> (2) A black light lamp;
> (3) A bug lamp;
> (4) A colored lamp;
> (5) An infrared lamp;
> (6) A left-hand thread lamp;
> (7) A marine lamp;
> (8) A marine signal service lamp;
> (9) A mine service lamp;
> (10) A plant light lamp;
> (11) A reflector lamp;
> (12) A rough service lamp;
> (13) A shatter-resistant lamp (including a shatter-proof lamp and a shatter-protected lamp);
> (14) A sign service lamp;
> (15) A silver bowl lamp;
> (16) A showcase lamp;
> (17) A 3-way incandescent lamp;

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[1] The framework document is available through DOE's website at: http://www1.eere.energy.gov/buildings/appliance_standards/rulemaking.aspx?ruleid=83

(18) A traffic signal lamp;
(19) A vibration service lamp;
(20) A G shape lamp (as defined in ANSI C78.20) (incorporated by reference; see § 430.3) and ANSI C79.1-2002 (incorporated by reference; see § 430.3) with a diameter of 5 inches or more;
(21) A T shape lamp (as defined in ANSI C78.20) (incorporated by reference; see § 430.3) and ANSI C79.1-2002 (incorporated by reference; see § 430.3) and that uses not more than 40 watts or has a length of more than 10 inches; and
(22) A B, BA, CA, F, G16-1/2, G-25, G30, S, or M-14 lamp (as defined in ANSI C79.1-2002) (incorporated by reference; see § 430.3) and ANSI C78.20 (incorporated by reference; see § 430.3) of 40 watts or less.

10 CFR 430.2

1.1 DOE is using the following criteria to define the scope of GSLs covered in this rulemaking: lamps that have an output between 279-2,860 lumens, lamps that have an ANSI base, and lamps that do not meet the 22 exemptions specified above. Would you agree with this approach? The GSL scope under consideration would include: 1) hybrid lamps (such as a compact fluorescent lamp (CFL) with a halogen capsule to provide instant illumination), 2) self-ballasted mercury vapor lamps, and 3) low voltage lamps. Are these lamp types used in GSL applications?

1.2 The GSL scope under consideration would include: 1) hybrid lamps (such as a compact fluorescent lamp (CFL) with a halogen capsule to provide instant illumination), 2) self-ballasted mercury vapor lamps, and 3) low voltage lamps. Are these lamp types used in GSL applications?

1.3 Do you manufacture any additional lamp types not discussed that you would consider GSLs? If so, please explain. In general, what is the market share and shipment trends of these lamps for your company?

1.4 What types of CFLs would fall under exemptions 20-22 listed above? Please explain. What types of light-emitting diode (LED) lamps would fall under exemptions 20-22 listed above? Please explain.

1.5 DOE defines colored fluorescent lamp as stated below. How would you modify this definition to apply to a colored CFL? How would you modify this definition to apply to a colored LED lamp? Are these industry accepted definitions?

> *Colored fluorescent lamp* means a fluorescent lamp designated and marketed as a colored lamp and not designed or marketed for general illumination applications with either of the following characteristics:
>
> (1) A CRI less than 40, as determined according to the method set forth in CIE Publication 13.3 (incorporated by reference; *see* §430.3); or

(2) A correlated color temperature less than 2,500K or greater than 7,000K as determined according to the method set forth in IES LM-9 (incorporated by reference; *see* §430.3).

10 CFR 430.2

1.6 DOE defines rough service lamp, shatter-resistant lamp, and vibration service lamp as stated below. Do these terms represent distinct technologies for CFLs and LED lamps?

How would you modify the definitions to apply to a CFL? Does the definition vary for a self-ballasted versus externally ballasted CFL? How would you modify the definitions to apply to an LED lamp? Are these industry accepted definitions?

Rough service lamp means a lamp that—
(1) Has a minimum of 5 supports with filament configurations that are C-7A, C-11, C-17, and C-22 as listed in Figure 6-12 of the IESNA Lighting Handbook (incorporated by reference; *see* §430.3), or similar configurations where lead wires are not counted as supports; and
(2) Is designated and marketed specifically for ‘rough service’ applications, with
(i) The designation appearing on the lamp packaging; and
(ii) Marketing materials that identify the lamp as being for rough service.

Shatter-resistant lamp, *shatter-proof lamp*, or *shatter-protected lamp* means a lamp that—
(1) Has a coating or equivalent technology that is compliant with NSF/ANSI 51 (incorporated by reference; *see* §430.3) and is designed to contain the glass if the glass envelope of the lamp is broken; and
(2) Is designated and marketed for the intended application, with
(i) The designation on the lamp packaging; and
(ii) Marketing materials that identify the lamp as being shatter-resistant, shatter-proof, or shatter-protected.

Vibration service lamp means a lamp that—
(1) Has filament configurations that are C-5, C-7A, or C-9, as listed in Figure 6-12 of the IESNA Lighting Handbook (incorporated by reference; *see* §430.3) or similar configurations;
(2) Has a maximum wattage of 60 watts;
(3) Is sold at retail in packages of 2 lamps or less; and
(4) Is designated and marketed specifically for vibration service or vibration-resistant applications, with—
(i) The designation appearing on the lamp packaging; and
(ii) Marketing materials that identify the lamp as being vibration service only.

10 CFR 430.2

2 MARKET ANALYSIS

2.1 In order to calculate the aggregate national energy savings, DOE needs data on shipment trends. For each of the lamp types covered in this rulemaking (listed below), DOE is interested in obtaining shipment data for the lamp types specified below that have a lumen range of 279-2,860, an ANSI base, and are not included in the 22 exemptions (e.g., reflector lamps). Please specify the type of data and units (i.e., unit sales, percent shipments) provided. Feel free to modify the table structure as appropriate to your data.

Absent new energy conservation standards, do you expect these proportions to change over time? If so, how?

Table 12-1 Shipment Projections for GSL

		Historical (Fill in years as appropriate)				**Current**	**Projections**	
Lamp Structure/Type		**20XX**	**20XX**	**20XX**	**20XX**	**2014**	**2020**	**2025**
Integrated	Self-ballasted CFLs							
	LED lamps with internal driver							
	Self-ballasted hybrid lamps							
	Self-ballasted mercury vapor lamps							
	Other lamps							
Non-Integrated	Externally ballasted CFLs							
	LED lamps with external driver							
	Low voltage CFLs							
	Low voltage LED lamps							
	Low voltage other lamps							
Total GSLs								

2.2 How do consumers select a GSL? What characteristics are they most interested in (e.g., lumen output, color quality, technology type)? Do they weigh input power or light output more heavily?

2.3 For GSLs, what are the most common wattages? Does this vary for each of the lamp types covered (e.g., self-ballasted CFLs, externally ballasted CFLs, integrated LED lamps, and LED lamps with an external driver)? What percent of shipments are represented by each of these wattages? Absent new energy conservation standards, do you expect these proportions to change over time? If so, how?

2.4 For GSLs, what are the most common lumen outputs? Does this vary for each of the lamp types covered (e.g., self-ballasted CFLs, externally ballasted CFLs, integrated LED lamps, and LED lamps with an external driver)?

2.5 What are general trends you see in the market? Do you expect future market shares for the most common GSL types to change in the presence of new energy conservation standards for GSLs?

2.6 Absent new energy conservation standards, do you foresee *other* technologies increasing in market share over the next thirty years? If so, how?

2.7 DOE intends to consider GSLs operating in different sectors. For GSLs under consideration in this rulemaking, can you provide an estimate of the percent of GSLs by lamp type (e.g., self-ballasted CFLs, externally ballasted CFLs, integrated LED lamps, and LED lamps with an external driver) sold into the commercial, industrial, and residential sectors?

2.8 What percent of GSLs by lamp type (e.g., self-ballasted CFLs, externally ballasted CFLs, integrated LED lamps, and LED lamps with an external driver) are sold in the new construction/renovation market and the replacement market?

2.9 Do you expect a substantial drop in GSL shipments owing to the adoption of LED lamps, which have longer lifetimes than conventional lamps? If so, when do you expect lamp shipments to peak?

2.10 What do you project your sales breakdown will be between high (90 and above) and lower CRI lamps?

2.11 What do you anticipate will be your sales breakdown between lamps with and without standby power (e.g., for connection to a home network)? What will be the typical standby load?

2.12 What percentage of your CFL and LED lamps do you project will be dimmable?

2.13 What is your estimate of the percentage of GSL sockets that will be displaced by integral LED fixtures?

3 TECHNOLOGY ASSESSMENT AND SCREENING ANALYSIS

3.1 How is self-ballasted CFL efficacy expected to change over time? For externally ballasted CFLs? How are research and development efforts focused on these products?

3.2 What technology options can be used to improve lamp efficacy of self-ballasted CFLs? Of externally ballasted CFLs? What are the expected gains from these options?

3.3 What is the range of ballast efficiencies of self-ballasted CFLs? Of externally ballasted CFLs? What are the typical efficiencies?

3.4 What differences in design and technology are attributable to the different efficacies between a self-ballasted CFL and externally ballasted CFL with the same wattage?

3.5 What factors determine the lifetime of a self-ballasted CFL? Of an externally ballasted CFL? Is there a relationship between lifetime and efficacy for CFLs?

3.6 How is integrated LED lamp efficacy expected to change over time? For LED lamps with external drivers? How are research and development efforts focused on these products?

3.7 What technology options can be used to improve lamp efficacy of integrated LED lamps? Of LED lamps with external drivers? What are the expected gains from those options?

3.8 What is the range of driver efficiencies of integrated LED lamps? Of LED lamps with external drivers? What are the typical efficiencies?

3.9 What factors determine the lifetime of an integrated LED lamp? Of LED lamps with external drivers? Is there a relationship between lifetime and efficacy for LEDs?

3.10 Is there any patent, technology, or other issue that you are aware of that would prevent your company or competitors form implementing higher efficacy designs for any GSL included in this rulemaking? When do these patents expire?

4 PRODUCT CLASSES

4.1 DOE separates products into categories called product classes based on differences in efficacy and consumer utility (i.e., features valued by consumers). DOE then conducts its analyses and establishes separate standard levels for each product class. DOE is considering separating product classes based on whether all necessary components for operation are enclosed in a lamp (i.e., integrated) versus a lamp that requires external components (i.e., non-integrated), as shown in the table below. Do you agree with the product class divisions presented below? Are there other parameters that should be considered in defining product classes for GSLs?

Table 12-2 GSL Product Classes

Lamp Type
Integrated GSLs (e.g., self-ballasted CFL, integrated LED lamp)
Non-integrated GSLs (e.g., externally ballasted CFL, LED lamps with external drivers)

4.2 DOE selects certain product classes (called representative product classes) to directly analyze in detail. The representative product classes are selected primarily based on shipment volume and/or distinct characteristics. For GSLs, DOE is considering directly analyzing both product classes. Do you agree with the representative product classes under consideration?

4.3 DOE considered a product class division separating “covered” and “uncovered” lamps. In the framework public meeting, stakeholders also suggested “clear” versus “diffuse” as a product class division. How would these divisions be defined and applied to self-ballasted CFLs, externally ballasted CFLs, integrated LED lamps, and LED lamps with external drivers? What are the differences in utility and efficacy?

4.4 Is there a difference in efficacy for low voltage lamps compared to lamps that operate on line voltage? Does this vary by technology type? Do low voltage CFLs and/or low voltage LED lamps offer a utility not offered by their line voltage counterparts? Please explain.

4.5 DOE received comments that DOE should develop a definition for a modified spectrum GSL based on the color point defined in DOE’s definition for incandescent modified spectrum lamps (see below). What definition would you propose for modified spectrum CFLs? For modified spectrum LED lamps?

> *Modified spectrum* means, with respect to an incandescent lamp, an incandescent lamp that—

(1) Is not a colored incandescent lamp; and
(2) When operated at the rated voltage and wattage of the incandescent lamp—
  (A) Has a color point with (x,y) chromaticity coordinates on the C.I.E. 1931 chromaticity diagram, figure 2, page 3 of IESNA LM-16 (incorporated by reference; *see* §430.3) that lies below the black-body locus; and
  (B) Has a color point with (x,y) chromaticity coordinates on the C.I.E. 1931 chromaticity diagram, figure 2, page 3 of IESNA LM-16 (incorporated by reference; *see* §430.3) that lies at least 4 MacAdam steps, as referenced in IESNA LM-16, distant from the color point of a clear lamp with the same filament and bulb shape, operated at the same rated voltage and wattage.

10 CFR 430.2

4.6 What unique utility do modified spectrum CFLs provide? Modified spectrum LED lamps?

4.7 What are the specific technologies/designs used to construct modified spectrum CFLs? Modified spectrum LED lamps? What is the difference in efficacy between standard spectrum versus modified spectrum CFLs? For standard spectrum versus modified spectrum LED lamps?

5 ENGINEERING ANALYSIS

5.1 In the tables below, please review the information on efficacy and typical characteristics of the baseline model and provide information on design pathways for achieving higher efficacies. Please indicate which of your product lines would meet each candidate standard level (CSL). Feel free to add rows to the tables as needed.

Table 12-3 Integrated GSLs

Level	Lamp Type	Efficacy (lumens/watt)	Key Design Characteristics	Technology Options	End-User Price
Baseline	14 W CFL	52.6	A-Shape, 80 CRI, 2700K CCT, 750 initial lumens, 10,000 hour rated lifetime	Basic electrode and glass coatings; basic fill gas; triphosphors; basic ballast components and design	
Candidate Standard Level (CSL)1					
CSL2					
CSL3					
CSL4 Maximum Technologically Feasible					

Table 12-4 Non-Integrated GSLs

Level	Lamp Type	Efficacy (lumens/ANSI rated wattage)	Key Design Characteristics	Technology Options	End-User Price
Baseline	18 W Quad Tube with G24q-2 base CFL	63.9	Full wattage, 82 CRI, 4100K CCT, 1,150 initial lumens, 10,000 hour rated lifetime	Basic electrode and glass coatings; basic fill gas; triphosphors	
CSL1					

CSL2					
CSL3 Maximum Technologically Feasible					

5.2 DOE selects baseline models within a representative product class. The baseline model typically represents the most common, least efficacious lamp available. Do you agree with the baseline models selected in the tables above?

5.3 Should DOE ensure that the same range of CCTs is maintained when selecting more efficacious substitutes?

5.4 What are the most common lifetimes by lamp type (e.g., self-ballasted CFLs, externally ballasted CFLs, integrated LED lamps, and LED lamps with an external driver)? Do you expect these lifetimes to change in future products?

5.5 DOE plans to use catalog values to calculate efficacy and subsequently CSLs for GSLs. Do you agree with this approach?

5.6 For this rulemaking, DOE is considering an equation-based approach that reflects the relationship between efficacy and lumen output. Specifically, DOE is considering the equation forms below. Would you agree with this approach?

Integrated product class:

$$Efficacy = \frac{1.28}{0.019 + 1.48 * Lumens^{-1.08}} + A$$

Non-integrated product class:

$$Efficacy = \frac{0.44}{0.016 * Lumens^{-0.11}} + A$$

5.7 Because externally ballasted CFLs covered under this rulemaking operate on a ballast in practice, DOE is considering analyzing these lamps with the following:

- 1-lamp electronic rapid start ballasts; and
- 1-lamp electronic programmed start ballasts.

Are these pairings the most common lamp-and-ballast systems used with externally ballasted

CFLs?

5.8 What are the typical ballast factors of ballasts paired with externally ballasted CFLs?

5.9 What is the interchangeability between externally ballasted CFLs with different base types? For example, if a G24d-2 base lamp is replaced with a G24q-2 or GX24q-2 base lamp, what needs to be replaced in the existing lamp system (e.g., the socket, lamp holder, ballast, fixture, etc.)?

5.10 What is the interchangeability between externally ballasted CFLs with different shapes? For example, if a quad tube is replaced with a multi tube shaped lamp, what needs to be replaced in the existing lamp system (e.g., the socket, lamp holder, ballast, fixture, etc.)?

5.11 DOE found that many integrated LED lamps, especially those of higher efficacy, are marketed as semi-omnidirectional rather than omnidirectional. How would you define semi-omnidirectional lamps? What application do semi-omnidirectional integrated LED lamps serve? Are omnidirectional integrated LED lamps inherently less efficacious than semi-omnidirectional integrated LED lamps?

5.12 DOE has been unable to identify high lumen output (i.e., greater than or equal to 2,600 lumens) LEDs. Are these products technologically feasible, and what are the current limitations if any?

5.13 DOE understands that there is a relationship between efficacy and rare earth content for CFLs. Please provide the percentage of halophosphor CFLs only; tri-band CFLs only; and those that are a mix.

5.14 How does LED lamp efficacy depend on rare earth content?

5.15 What is the relative content of rare earth elements in comparable CFL and LED lamps (e.g., what are the relative quantities of rare earth elements in lamps with similar lumen outputs and CRI)?

6 PRODUCT PRICE DETERMINATION

6.1 Ideally, DOE would like to estimate end-user price directly by collecting manufacturer suggested price lists (“blue books”) and applying a discount based on the distribution channel through which the lamp is purchased. DOE has had difficulty finding adequate pricing data in blue books for integrated LED lamps and LED lamps with external drivers. Would you know why pricing for these lamps is not in blue books?

6.2 Due to the lack of blue book data, DOE is considering determining end-user prices by gathering prices directly from distribution channels (e.g., Home Depot, Lowes, elightbulbs.com) and developing average prices for each channel at each CSL. DOE is considering then deriving a weighted price based on the shipments that go through each distribution channel. Would you agree with this approach? Would you suggest an alternative approach?

6.3 Can you describe how the distribution chain operates for GSLs and which end-use sector (e.g., commercial, residential) utilizes each distribution chain identified?

6.4 DOE is considering evaluating the following distribution channels for GSLs: home-improvement/hardware stores, grocery/pharmacy stores, internet retailers, and state procurement contracts. Would you agree with this approach for GSLs?

6.5 Do distribution channels vary by technology (e.g., self-ballasted CFLs, externally ballasted CFLs, integrated LED lamps, and LED lamps with external drivers)?

6.6 What proportion of shipments move through the various channels?

6.7 What performance characteristics usually come at a cost premium for GSLs? What about for each technology? How much?

6.8 In the future do you anticipate these additional costs to increase, decrease, or remain the same? As an individual cost? As a percentage of the product cost?

6.9 Do end-user ballast prices change with ballast factor? If so, explain how?

7 LIFETIME AND OPERATING HOURS

7.1 What is your estimate of the fraction of lamps disposed of through recommended channels rather than through the general waste stream? Does this vary by lamp type (e.g., self-ballasted CFLs, externally ballasted CFLs, integrated LED lamps, and LED lamps with external drivers)?

7.2 What is the manufacturer disposal cost per lamp by lamp type (e.g., self-ballasted CFLs, externally ballasted CFLs, integrated LED lamps, and LED lamps with external drivers)?

7.3 Do you anticipate that actual LED service lifetimes will differ from their functional lifetimes (e.g., because consumers replace lamps prior to failure as newer lamps come on the market)?

7.4 Do you anticipate that the frequency of on/off switching could significantly affect the lifetime of LED lamps (as with fluorescent lamps)? If so, how?

8 PRELIMINARY MANUFACTURER IMPACT ANALYSIS

Key Issues

8.1 In general, what are the key issues for your company regarding energy conservation standards and this rulemaking?

8.2 Are there any patent, technology, or other issues that you are aware of that would prevent your company or competitors from implementing higher-efficacy designs?

Shipment Projections

8.3 What is your company's approximate market share for the GSLs DOE is considering including in coverage? Does this vary by technology (i.e., CFL versus LED)?

8.4 Would you expect your market share to change if higher standards are adopted?

8.5 Do you expect shipments to change for the industry as a whole as a function of standards? If so, why?

8.6 Do you expect an increased purchase price for GSLs to result in reduced demand or shipments (price elasticity)? If so, how sensitive do you think shipments will be to price changes? Does it vary with product class?

8.7 What is the proportion of domestically consumed GSLs shipped by the National Electrical Manufacturers Association (NEMA) companies versus non-NEMA companies? Does this vary based on lamp type?

Conversion Costs

8.8 What level of capital expenditure and product conversion costs would you anticipate making at higher standard levels? Please describe what they are and provide your best estimate of their respective magnitudes.

8.9 How would the imposition of new energy conservation standards affect capacity utilization and manufacturing assets at your domestic production facilities? Would a new standard result in stranded capital assets? Would any facilities be closed or downsized? Added or upgraded?

Product Mix and Profitability

8.10 Generally, how would new standards impact your customer mix, distribution channels, and corresponding profit margins?

8.11 Are your profitability and markups consistent across all GSL types? Does it vary by lamp technology?

Market Share and Industry Consolidation

8.12 In the absence of new standards, do you expect any industry consolidation?

8.13 How would new standards affect your ability to compete?

8.14 Could new standards disproportionally advance or harm the competitive positions of some firms?

8.15 Could new standards result in disproportionate economic or performance penalties for particular consumer/user subgroups?

8.16 Beyond pricing and energy efficiency, could new standards result in products that will be more or less desirable to consumers due to changes in product functionality, utility, or other features?

Cumulative Regulatory Burden

8.17 Are there recent or impending regulations on your specific products or other products that impose a cumulative burden on the industry?

8.18 If so, what is the total expected impact of those regulations?