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Executive Summary

The Energy Policy and Conservation Act of 1975, as amended by the Energy Independence and Security Act of 2007 (EISA 2007), requires that the Secretary of Energy "shall prohibit the sale" of any general service lamp (GSL) that does not meet a minimum efficacy of 45 lumens per watt (lm/W) if the U.S. Department of Energy (DOE) fails to complete a rulemaking regarding GSLs in accordance with certain statutory criteria. This is referred to as the EISA 2007 backstop requirement. DOE recently proposed to interpret the EISA 2007 backstop as having been triggered. Based on its statutory authority, DOE also recently proposed to revise the definition of the term GSL to include certain lamps that were either previously excluded or not explicitly mentioned in the EISA 2007 definition. For this proposed definition of GSLs, we estimate the impacts of the EISA 2007 backstop in regard to annualized national economic costs and benefits to consumers.

To estimate these impacts, we project the energy use, purchase price, and operating cost of representative lamps purchased during a 30-year analysis period, 2022-2051, for cases in which the EISA 2007 backstop does and does not take effect in 2022. We first consider the purchase price and energy use of those commercially-available GSLs that would be prohibited under implementation of the EISA 2007 backstop and those more efficacious GSLs that would continue to be available. We then develop a shipments model to project GSL shipments for the cases in which the EISA 2007 backstop does and does not take effect. Shipments are estimated using a stock turnover model and market shares are estimated using a consumer-choice model sensitive to first cost, energy savings, lamp lifetime, the presence of mercury, and ability to dim. The shipments analysis also considers the impact of price learning on product price. Based on the shipments projections, we calculate the national consumer economic impacts of the 45 lm/W backstop, by comparing the total installed product costs and operating costs in the backstop case to the case in which the backstop does not take effect.

We also analyze the reduction in several greenhouse gases and other pollutants that would result from the EISA 2007 backstop using emissions intensity factors representing the marginal impacts of the change in electricity consumption associated with the backstop. We consider the estimated monetary benefits from the reduction in emissions of CO2, N2O, CH4, NOX, and SO2 that are expected to result from a 45 lm/W efficacy requirement. The monetized value of the CO2, N2O, and CH4 reduction is calculated using interim estimates published in 2021 developed by an Interagency Working Group on the Social Cost of Greenhouse Gases (IWG). The monetized value of NOX and SO2 emissions reductions is estimated based on analysis conducted by the US Environmental Protection Agency (EPA). DOE has determined that the estimates from the IWG's 2021 TSD are based upon sound analysis and provide well founded estimates for DOE's analysis of the impacts of the reductions of emissions anticipated from the proposed rule.

The time-series of costs and benefits are converted into annualized values based on the present value in 2021. The present value is calculated using discount rates of 3 and 7 percent for consumer costs and benefits, NOX, and SO2 reduction benefits and case-specific discount rates for the value of the other emissions (CO_2, N_2O, and CH_4) reduction benefits.

High and low benefits scenarios are analyzed using inputs from the High and Low Economic growth variants of DOE's Annual Energy Outlook 2021 Reference case and different price learning rates for lamps with light emitting diodes (LEDs).

Annualized consumer costs and benefits attributable to the implementation of the 45 lm/W backstop are shown in Table ES - 1. Table ES - 2 presents the social value of emissions reductions. We include the range in estimated monetary reduction of GHGs using the low and high social cost values provided by the IWG in our calculation of total and net benefits. Table ES - 3 shows the total annualized costs and benefits. The total benefits in Table ES - 3 include the consumer operating cost savings from Table ES - 1 and the emissions reduction benefits from Table ES - 2.

Table ES - 1. Summary of Annualized Consumer Benefits and Costs

	Primary Estimate	Low-Net-Benefits Estimate	High-Net-Benefits Estimate
	Annualized (million 2020$/year)		
Consumer Operating Cost Savings			
7% discount rate	2,864.5	2,725.3	3,010.0
3% discount rate	2,955.1	2,788.0	3,128.8
Incremental Product Costs			
7% discount rate	177.6	180.3	173.0
3% discount rate	148.9	150.9	145.0
Net Consumer Benefits			
7% discount rate	2,686.9	2,545.0	2,837.0
3% discount rate	2,806.2	2,637.0	2,983.8

Table ES - 2. Summary of Annualized Social Value of Emissions Reductions, 2022-2051

	Primary Estimate	Low-Net-Benefits Estimate	High-Net-Benefits Estimate
	Annualized (million 2020$/year)		
GHG Benefits			
5% discount rate, average	205.2	198.4	210.2
3% discount rate, average	593.2	573.2	608.3
2.5% discount rate, average	835.5	807.2	856.9
3% discount rate, 95th perc	1,767.6	1,707.9	1,812.8
NOx Benefits			
7% discount rate	123.1	119.5	125.8
3% discount rate	128.5	124.3	131.7
SO2 Benefits			
7% discount rate	136.8	132.9	139.7
3% discount rate	151.0	146.2	154.7

Note: GHG benefits are calculated using four different estimates of the social cost of carbon (SC-CO_2), methane (SC-CH_4), and nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate).

Table ES - 3. Summary of Total Costs and Benefits, 2022-2051

	Primary Estimate	Low-Net-Benefits Estimate	High-Net-Benefits Estimate
	Annualized (million 2020$/year)		
Total Benefits			
7% discount rate	3,718	3,551	3,884
3% discount rate	3,828	3,632	4,023
Total Costs			
7% discount rate	178	180	173
3% discount rate	149	151	145
Net Benefits			
7% discount rate	3,540	3,371	3,711
3% discount rate	3,679	3,481	3,879

Note: Total Benefits for both the 3-percent and 7-percent cases are presented using the average GHG social costs with 3-percent discount rate. GHG reduction benefits are calculated using four different estimates of the social cost of carbon (SC-CO_2), methane (SC-CH_4), and nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate) as shown in Table ES - 2. For the presentational purposes of this table, we show the total and net benefits associated with the average SC-GHG at a 3 percent discount rate, but note that DOE did not use a single central SC-GHG point estimate in a past rulemaking. Considering the four SC-GHG estimates, the equivalent annual net benefit would be between $3.1 billion to $4.9 billion for the primary estimate, $3 billion to 4.6 billion for the Low-Net-Benefits Estimate and $3.3 to $5.1 billion for the High-Net-Benefits Estimate. All net benefits are calculated using GHG benefits discounted at 3 percent.

1. Introduction

Beginning with the Energy Policy and Conservation Act of 1975 (EPCA), a series of congressional acts have directed the U.S. Department of Energy (DOE) to establish minimum energy conservation standards for a variety of consumer products and commercial and industrial equipment. These products include certain varieties of compact electric lamps, commonly referred to as light bulbs. In particular, the Energy Independence and Security Act of 2007 (EISA 2007) amended EPCA to expand coverage to include general service lamps (GSLs), defined by statute as including general service incandescent lamps (GSILs), compact fluorescent lamps (CFLs), general service light-emitting diode (LED) or organic LED (OLED) lamps, and "any other lamps that the Secretary [of Energy] determines are used to satisfy lighting applications traditionally served by general service incandescent lamps", with certain exclusions (*Energy Independence and Security Act of 2007*, 2007; *U.S. Code Title 42—The Public Health and Welfare*, 2010). In addition to expanding coverage, EISA 2007 set a series of energy efficiency standards for GSILs that took effect between 2012 and 2014.

In addition to setting standards for GSILs, EISA 2007 directed DOE to undertake an energy conservation standards rulemaking for GSLs, to be completed by January 1, 2017. If the rulemaking was not completed in accordance with certain statutory provisions, or if the rulemaking did not produce savings greater than or equal to the savings from a minimum efficacy standard of 45 lumens per watt (lm/W), a statutory provision (referred to as the backstop requirement) directed the Secretary of Energy to prohibit the sale of any GSL that does not meet a minimum efficacy of 45 lm/W, beginning January 1, 2020.

In two definition final rules published on January 19, 2017, DOE revised the GSL definition to include additional lamp types, under its authority within the EISA 2007 definition to determine other lamp types that are used to satisfy lighting applications traditionally served by GSILs (Title 42, Section 6291(30)(BB)(i)(IV) of the U.S. code), as well as its authority to determine whether the exemptions for certain incandescent lamps should be maintained or discontinued based, in part, on exempted lamp sales collected by the Secretary from manufacturers pursuant to Title 42, Section 6295(i)(6)(A)(i)(II). DOE clarified in the January 2017 definition final rules that the definition of a general service lamp is a lamp that (1) has an American National Standards Institute (ANSI) base, (2) is able to operate at a voltage of 12 volts or 24 volts, at or between 100 to 130 volts, at or between 220 to 240 volts, or at 277 volts, (3) has an initial lumen output greater than or equal to 310 lumens and less than or equal to 3300 lumens, (4) is not a light fixture, (5) is not an LED downlight retrofit kit, and (6) is used in general lighting applications[1] (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2017a, 2017b). DOE clarified that certain exclusions exist, including the exclusion of high intensity discharge lamps and general service fluorescent lamps, the latter of which are covered by a

[1] The GSL definition differs slightly for modified spectrum GSILs and non-integrated lamps (*i.e.*, GSLs that require an external ballast, driver, or voltage transformer). See U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2017a, 2017b for full details.

separate set of standards[2]. DOE also determined that exclusions from the GSL definition specified by EISA 2007 for certain incandescent lamp types should be discontinued, including reflector lamps, rough service lamps, shatter-resistant lamps, three-way incandescent lamps, vibration service lamps, and lamps of certain shapes[3], per its authority under EISA 2007 to determine whether the exemptions for certain incandescent lamps should be maintained or discontinued.

Prior to the effective date, DOE withdrew the revised definition of GSL in a final rule published on September 5, 2019, reinstating the statutory definition of a GSL as the regulatory definition (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2019a). On December 27, 2019, DOE also determined that the statutory backstop had not been imposed (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2019b). However, upon further review and consideration, DOE has recently proposed to interpret the EISA 2007 backstop as having been triggered, because an energy conservation standards rulemaking for GSLs was not completed in accordance with the specified statutory provisions in EISA 2007. If finalized, the projected implementation date for this proposed reinterpretation would be in 2022. DOE also recently proposed to adopt the definition of the term GSL originally set forth in the January 2017 definition final rules (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2021). Based on the estimates of stock[4] from the 2015 Lighting Market Characterization (LMC 2015), the proposed definition increases the number of lamps defined as a GSL by approximately 2 billion, from 3.8 billion lamps to 5.8 billion lamps, compared to the December 2019 definition final rule (Navigant Consulting, Inc., 2017).[5]

The lighting market is currently undergoing a transition to LED technologies as more products become available and the prices of these products continue to drop. During this transition period incandescent products continue to be sold. Since incandescent technologies cannot meet the 45 lm/W minimum efficacy required by the EISA 2007 backstop, the backstop will result in a more rapid and complete transition to LED technology than would have occurred otherwise, yielding energy savings compared to a scenario in which the EISA backstop provision does not take effect.

Previously, before DOE's January 2017 GSL definition final rules were withdrawn, we estimated the national energy savings, net present value, and CO_2 emissions reductions that would result from the application of the EISA 2007 backstop, beginning in 2020, to lamps that met DOE's January 2017 GSL definition but were not explicitly included in the EISA 2007 statutory definition (Kantner et al., 2017). This paper details the methodology and data inputs used to estimate the annualized national economic costs and benefits to consumers associated

[2] A full list of exclusions is included in a footnote in section 2.1.

[3] Throughout this report we refer to lamps by their base type and/or shape. For illustrations of lamp shapes and base types, see http://www.lightopedia.com/bulb-shapes-sizes and http://www.lightopedia.com/bases-filament-types.

[4] The stock is the total quantity of GSLs in the U.S. (in homes, businesses, etc.).

[5] We assumed lamps categorized as "General Purpose-A-Shape", "General Purpose – Pin", "General Purpose Screw" or "General Purpose" in the 2015 LMC represented GSLs as defined in the December 2019 final rule. We assumed the stock of lamps included in the recently proposed definition includes lamps from the December 2019 final rule and any lamps categorized as "Decorative" or "Reflector" as well as linear LED lamps.

with the application of the EISA 2007 backstop in 2022 to all GSLs in DOE's recently proposed definition of GSLs and summarizes the results of that analysis.

2. Methods

Our goal is to estimate the annualized U.S. national economic costs and benefits to consumers associated with improved energy efficiency for GSLs, following implementation of the EISA 2007 backstop in 2022, considering shipments over a 30-year period (2022-2051), which is the standard time horizon used for estimating the national impact of DOE energy conservation standards. Specifically, we estimate annualized values of consumer operating cost savings, incremental product costs, and net benefits, as well as the benefits resulting from greenhouse gas emissions reductions. In what follows, we often refer to these quantities collectively as the *impact of the backstop*. To calculate this impact, we compare the projected total national consumer costs and emissions in two cases: (1) a base case that assumes that the market for lamps under examination will follow recent forecasts, and (2) a backstop case that assumes that any GSL with an efficacy less than 45 lumens per watt is prohibited from being sold in 2022 or thereafter.

To estimate the impact of the backstop, we must model, in each case, the energy use, purchase price, and operating cost of GSLs purchased during the 30-year analysis period. To accomplish this, we first divide the lamps into product categories according to their characteristics and typical applications. We then develop a limited number of representative lamps for each product category, including lamp options that would and would not meet a 45 lm/W efficiency standard. These representative lamps are used as a proxy for the more diverse set of lamps available to consumers on the real-world market; simplifying the market in this way allows a tractable model to be constructed while still yielding a representative estimate of energy consumption and consumer costs. We estimate the annual energy consumption associated with each representative lamp based on operating hours, lamp wattage, and the reduction in energy consumption expected from the use of lighting controls. We also estimate a simple payback period for each of the representative lamps relative to the baseline lamp in each category.

Shipments (representing consumer purchases in each year) and national stock (total installed units) for each representative lamp are estimated for each year in the analysis period. By considering the energy consumption of each lamp in the installed stock, we compute the total annual national energy consumption for each case. Together with projections of electricity prices, this also yields an estimate of annual consumer operating costs in each case. Similarly, the total consumer costs associated with lamp purchases are estimated for each case. Total operating cost savings and incremental product purchase and installation costs in the backstop case relative to the base case are annualized to estimate annualized net consumer benefits resulting from the EISA 2007 backstop. Emissions reductions are estimated by applying emissions factors to any estimated energy savings between cases. We estimate monetary benefits from the projected reduction in emissions expected to result from the backstop.

In the following sections we discuss in more detail each step in the analysis. Section 2.1 describes the scope of lamps analyzed and how the analyzed lamp types are categorized; section 2.2 describes the representative lamps used in the analysis; section 2.3 describes the hours of use, energy use, lifetime, and payback period for each of our representative lamps; section 2.4 describes the initial estimates for shipments and installed stock for each lamp category, and the stock turnover model and projected efficiency distribution used to estimate shipments in each year; section 2.5 describes the calculation of the national energy savings; and section 2.6 describes the calculation of the annualized national consumer costs and benefits; and section 2.7 describes the calculation of emissions reductions and their monetization.

2.1 Lamp Scope and Categorization

The scope of lamps under consideration in this analysis is defined as the lamps that meet the definition of a GSL recently proposed by DOE, which is the same as the definition set forth in the January 2017 definition final rules (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2021). This includes the set of eight types of medium screw-base (MSB) lamps for which DOE recently proposed that the exemptions from the EISA 2007 GSL definition would be discontinued: reflector lamps, rough service lamps, shatter-resistant lamps, three-way lamps, vibration service lamps, T-shape lamps of 40 Watts or less or length of 10 inches or more, and B, BA, CA, F, G16-1/2, G25, G30, S, M-14 lamps of 40 Watts or less. In addition, this includes any lamp that (1) has an ANSI base, (2) is able to operate at a voltage of 12 volts or 24 volts, at or between 100 to 130 volts, at or between 220 to 240 volts, or at 277 volts, (3) has an initial lumen output greater than or equal to 310 lumens and less than or equal to 3300 lumens, (4) is not a light fixture, (5) is not an LED downlight retrofit kit, and (6) is used in general lighting applications was determined to be used to satisfy lighting applications traditionally served by general service incandescent lamps, with certain exceptions (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2021).[6,7] Among the most common lamps that fall into this broad definition are traditional A-type (pear-shaped) lamps, candle-shaped lamps, and reflector lamps.[8]

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[6] General service lamps do not include: Appliance lamps; Black light lamps; Bug lamps; Colored lamps; G shape lamps with a diameter of 5 inches or more; General service fluorescent lamps; High intensity discharge lamps; Infrared lamps; J, JC, JCD, JCS, JCV, JCX, JD, JS, and JT shape lamps that do not have Edison screw bases; Lamps that have a wedge base or prefocus base; Left-hand thread lamps; Marine lamps; Marine signal service lamps; Mine service lamps; MR shape lamps that have a first number symbol equal to 16 (diameter equal to 2 inches), operate at 12 volts, and have a lumen output greater than or equal to 800; Other fluorescent lamps; Plant light lamps; R20 short lamps; Reflector lamps that have a first number symbol less than 16 (diameter less than 2 inches) and that do not have E26/E24, E26d, E26/50x39, E26/53x39, E29/28, E29/53x39, E39, E39d, EP39, or EX39 bases; S shape or G shape lamps that have a first number symbol less than or equal to 12.5 (diameter less than or equal to 1.5625 inches); Sign service lamps; Silver bowl lamps; Showcase lamps; Specialty MR lamps; T shape lamps that have a first number symbol less than or equal to 8 (diameter less than or equal to 1 inch), nominal overall length less than 12 inches, and that are not compact fluorescent lamps; Traffic signal lamps.

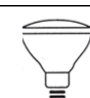
[7] As noted previously, the GSL definition differs slightly for modified spectrum GSILs and non-integrated lamps (*i.e.*, GSLs that require an external ballast, driver, or voltage transformer). See U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2021 for full details.

[8] These lamp types represent a significant majority of GSLs in the national stock, as discussed in Kantner et al., 2017.

For the analyses discussed in this report, GSLs are initially grouped into categories based on whether they require an external ballast, driver, or voltage transformer to operate and whether they produce directional or omnidirectional light, attributes that affect both efficacy and application. This results in three initial categories: integrated omnidirectional lamps, integrated directional lamps, and non-integrated directional lamps. Non-integrated omnidirectional lamps are not considered in this analysis as there are no lamps on the market with efficacy below 45 lm/W in this category, and thus lamps in this category would not be directly impacted by the EISA 2007 backstop. Similarly, within the analyzed categories, lamp types for which there is not a direct substitute on the market with efficacy below 45 lm/W, such as linear LED lamps, are not analyzed as they would not be directly impacted by the EISA 2007 backstop.

The integrated omnidirectional lamp category is further split into two categories for our analysis, A-type lamps and non-A-type lamps, to account for differences in product offerings (such as the availability of traditional incandescent lamp options) as well as typical characteristics and applications. The integrated omnidirectional A-type lamp category is dominated by the most common type of light bulb: medium screw-base A-type lamps found in a wide variety of applications. The integrated omnidirectional non-A-type lamp category includes candle-shape lamps with candelabra screw bases often found in chandeliers, pendants, and sconces, as well as globe shape lamps often found in bathrooms. The integrated directional lamp category includes various reflector lamps that are commonly used in recessed cylindrical ceiling fixtures (commonly known as "cans"). The non-integrated directional lamp category includes pin-based multi-faceted reflector (MR) lamps commonly used in track lighting. See Table 1 for a summary of the analyzed lamp categories, including defining characteristics, typical applications, and example lamps.

Table 1. Lamp Categorization

Lamp Category	Defining Characteristics	Typical Application	Example Lamp	
Integrated Omnidirectional A-type	Pear-shape; operates without an external ballast/driver/transformer; omnidirectional light output.	Various	A19 shape, MSB	
Integrated Omnidirectional non-A-type	Not pear-shaped; operates without external ballast/driver/ transformer; omnidirectional light output. Includes candle- and globe-shaped lamps, as well as other shapes.	Chandelier, sconce, pendant	B11 shape, E12 base	
Integrated Directional	Reflector shape; operates without an external ballast/driver/transformer; directional light output	Recessed ceiling fixture	PAR38 shape, MSB	
Non-integrated Directional	Reflector shape; operates with an external ballast/driver/transformer; directional light output	Track lighting	MR16 shape, GU5.3 base	

2.2 Representative Lamps

As mentioned earlier, for each lamp category, our analysis considers a simplified market made up of a limited set of representative lamp options, which span the range of relevant features (technologies and efficiency levels) that will be impacted by the backstop. Each modeled lamp option is meant to serve as a proxy representing a number of similar lamp options available to consumers. For each category, we chose a set of typical lamp properties and then constructed representative lamp options having these properties for each of the common lighting technologies (traditional incandescent, halogen incandescent, CFL, or LED) in use within each category.

In selecting representative lamp options for the analysis, it was required that each of the options (1) be advertised as dimmable, (2) have a color-rendering index (CRI) of 80 or greater, and (3) have a correlated color temperature (CCT) of approximately 2700 K, as these are typical properties of these lamp types. For integrated omnidirectional A-type lamps, integrated directional lamps, and non-integrated directional lamps, a database of commercially available lamps was consulted to select lamp options meeting these criteria with typical values for lumen output, lifetime, and CRI within each available technology and spanning the range of lamp efficacies on the market, following DOE's methodology in lighting rulemakings for GSLs and GSILs (U.S. Department of Energy, 2016, 2019a). Publicly available retail prices were reviewed and used to estimate prices for the representative lamps. The price for each of the representative lamp options was calculated based on the average price of similar lamp models.

A similar process as described above was performed for identifying the incandescent integrated omnidirectional non-A-type lamp option. LED integrated omnidirectional non-A-type lamps were not available in the dataset used to develop the representative LED integrated omnidirectional A-type lamps. For LED non-A-type lamp options, we performed an analysis of online product offerings and found a similar price-efficacy relationship for A-type and non-A-type LED lamps. Based on this result, we developed a set of non-A-type LED lamps analogous to the A-type LED lamp options. The most common lumen output for non-A-type lamps in our dataset was 450 lumens. For each A-type LED lamp option, we scaled the wattage and efficacy to the expected value for a 450 lumen non-A-type LED lamp, at the same price and rated lifetime as the 800 lumen A-type option. Non-A-type CFL lamps are not included as options for this lamp category based on limited product offerings found on major retail websites, indicating a lack of consumer interest.

Table 2 presents the properties of all the representative lamps used in our analyses. Prices listed for the representative lamp options in Table 2 are for the year 2020 and include sales tax. Future price projections are discussed in section 2.4.4.

Table 2. Representative Lamp Options and Properties

Lamp Option	Technology	Wattage	Initial Lumens	Rated Lifetime (Hours)	Efficacy (lm/W)	Price per Lamp (2020$)
Integrated Omnidirectional A-Type						
1	Halogen	43.0	750	1,000	17.4	1.48
2	CFL	15.0	900	10,000	60.0	3.20
3	CFL	14.0	900	10,000	64.3	3.34
4	CFL	13.0	900	10,000	69.2	3.48
5	LED	10.0	800	15,000	80.0	3.41
6	LED	10.0	800	25,000	80.0	4.65
7	LED	9.0	800	15,000	88.9	4.18
8	LED	9.0	800	25,000	88.9	5.69
9	LED	8.0	800	15,000	100.0	4.95
10	LED	7.0	800	15,000	114.3	5.71
11	LED	6.5	810	15,000	124.6	6.09
Integrated Omnidirectional Non-A-Type						
1	Incandescent	60.0	535	1,500	8.9	1.02
2	LED	7.0	450	15,000	64.0	3.41
3	LED	7.0	450	25,000	64.0	4.65
4	LED	6.1	450	15,000	73.0	4.18
5	LED	6.1	450	25,000	73.0	5.69
6	LED	5.3	450	15,000	84.0	4.95
7	LED	4.6	450	15,000	99.0	5.71
8	LED	4.1	450	15,000	109.0	6.09
Integrated Directional						
1	Halogen	60.0	1,070	1,500	17.8	7.51
2	CFL	23.0	1,100	10,000	47.8	16.93
3	LED	17.0	1,200	25,000	70.6	13.49
4	LED	16.0	1,200	25,000	75.0	12.49
5	LED	15.0	1,200	25,000	80.0	11.52
6	LED	14.0	1,200	25,000	85.7	10.42
7	LED	12.5	1,200	25,000	96.0	8.52
Non-Integrated Directional						
1	Halogen	50.0	500	2,000	10.0	5.09
2	LED	8.0	500	25,000	62.5	10.15
3	LED	7.0	500	25,000	71.4	11.19
4	LED	6.5	500	25,000	76.9	12.10
5	LED	6.0	500	25,000	83.3	12.97

2.3 Hours of Use, Energy Consumption, Lifetime, and Payback Period

Two key inputs for estimating the impact of the backstop are the annual energy consumption and service lifetime of the representative lamps. These depend on properties intrinsic to the lamp design as well as on consumer usage patterns, such as the daily hours of use (HOU) and the frequency and degree to which lamps are dimmed. We estimate sector-specific annual energy consumption because HOU are typically much longer in the commercial sector.

To estimate HOU for integrated omnidirectional A-type lamps in the residential sector, we use the national-average of 2.3 hours/day developed for such lamps as part of DOE's 2016 GSL NOPR analysis, which considered a number of field metering studies conducted across the U.S. (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2016, Chap. 7). For integrated omnidirectional non-A-type lamps, integrated directional lamps, and non-integrated directional lamps, we estimate average HOU by scaling from the national average HOU for integrated omnidirectional A-type lamps. Scaling factors are developed based on the distribution of room types that particular lamp types (*e.g.*, candelabra-base lamps, globe-shaped lamps, integrated reflectors or MRs) are typically installed in and the HOU associated with those room types, relative to the distribution of room types and associated HOU for integrated omnidirectional A-type lamps. We rely on a study in California performed for the public utilities commission (KEMA, Inc., 2010) (henceforth the CPUC study) to estimate the distribution by room type for each lamp type. The hours of use associated with those room types are estimated using data from the Northwest Energy Efficiency Alliance's (NEEA) 2014 Residential Building Stock Assessment Metering Study (Ecotope Inc., 2014).

For the commercial sector, we use data from the 2015 LMC (Navigant Consulting, Inc., 2017) to estimate the weighted-average daily HOU for integrated omnidirectional A-type lamps. We did not have sufficiently representative data to estimate different HOU for the other lamp types in this analysis, so we assume the same average daily HOU for all lamp types in the commercial sector. Table 3 lists the average daily HOU used in this analysis for each product category.

Table 3. Average Daily Hours of Use by Lamp Type and Sector

	Residential	Commercial
Integrated Omnidirectional A-Type	2.3	11.5
Integrated Omnidirectional Non-A-Type	2.6	11.5
Integrated Directional	2.9	11.5
Non-Integrated Directional	2.9	11.5

A lamp's unit energy consumption (UEC) is determined by its operating wattage, hours of use, and the effects of lighting controls, if any. Lighting controls can affect energy use by reducing the operating wattage (*e.g.*, dimmers) or the hours of use (*e.g.*, occupancy sensors). For the residential sector, we assume any reduction in hours of use from lighting controls is already implicitly accounted for in field metering studies of hours of use, but take into account the reduction in energy consumption as a result of dimming. A meta-study of lighting controls in commercial applications found a 30% reduction in energy use for systems that utilize lighting controls, such as dimmers, compared to systems that do not (Williams et al., 2012). Similar data do not appear to exist, at present, for the effects of lighting controls in the residential sector and so we assume the same 30% energy reduction for lamps operating with dimmers in the residential sector.

In the residential sector, we also assume that for each lamp category the fraction of lamps installed on dimmers will remain constant at its 2015 level, which is estimated using the fraction of the corresponding lamp type installed in each room type from the CPUC study and the fraction of dimming controls by room type reported in DOE's 2015 LMC (Navigant Consulting, Inc., 2017). The fraction of Integrated Omnidirectional A-Type, Integrated Omnidirectional Non-A-Type, and Integrated and Non-Integrated Directional lamps in the residential sector is 9%, 14%, and 10%, respectively.

To determine the fraction of lamps operated with lighting controls in the commercial sector in each year of the analysis period, we use the trend from the 2016 GSL NOPR, which assumes an increasing utilization of controls over time, arising from updated building codes that are increasingly specifying lighting controls in commercial construction and renovation (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2016, App. 10C). For any increase in the fraction of lamps operated with controls in the commercial sector, we assume a 30% reduction in energy savings, consistent with the study of commercial lighting controls mentioned previously.

The average annual UEC calculated for each representative lamp in 2022 is listed in Table 4.

The final attribute of the representative lamp options needed as an input to our analysis is the probability of lamp retirement (owing to lamp failure or other reasons) as a function of lamp age. For each lamp option we model the probability of lamp retirement as a function of lamp age following the methodology from DOE's 2016 GSL NOPR for CFL and LED lamps and the methodology from the 2019 GSIL Final Determination for incandescent and halogen lamps (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2019c, App. 8C, 2016, App. 8E). The methodology for all lamp types employs a Weibull distribution based on the lamp's rated lifetime, sector-specific HOU distributions, on-time cycle length (for residential CFLs), and the presence of controls (for incandescent and halogen lamps). Moreover, in keeping with the reference scenarios from the 2016 GSL NOPR and 2019 GSIL Final Determination, we truncated the resulting survival function using another Weibull model with a median lifetime of 20 years to help ensure that LED lamps do not have unrealistically long lifetimes.[9] The median service lifetime, in years, is the lamp year that has a survival probability of 50%. The service lifetime for all lamp options is listed in Table 4.

[9] The 20-year median is intended to be representative of typical renovation or retrofit time scales.

Table 4. Service Lifetime, Unit Energy Consumption in 2022, and Simple Payback Period for All Lamp Options

Lamp Option	Technology	Residential			Commercial		
		Median Service Lifetime (years)	Annual UEC (kWh/yr)	Simple Payback Period** (years)	Median Service Lifetime (years)	Annual UEC* (kWh/yr)	Simple Payback Period** (years)
Integrated Omnidirectional A-Type							
1	Halogen	1.9	35.0	--	0.5	168.8	--
2	CFL	11.0	12.2	0.5	3.2	58.9	0.1
3	CFL	11.0	11.4	0.5	3.2	55.0	0.2
4	CFL	11.0	10.6	0.5	3.2	51.0	0.2
5	LED	18.2	8.1	0.5	4.7	39.3	0.1
6	LED	19.1	8.1	0.8	7.9	39.3	0.2
7	LED	18.2	7.3	0.6	4.7	35.3	0.2
8	LED	19.1	7.3	1.0	7.9	35.3	0.3
9	LED	18.2	6.5	0.8	4.7	31.4	0.2
10	LED	18.2	5.7	1.0	4.7	27.5	0.3
11	LED	18.2	5.3	1.0	4.7	25.5	0.3
Integrated Omnidirectional Non-A-Type							
1	Incandescent	2.1	54.3	--	0.6	233.8	--
2	LED	17.8	6.3	0.3	4.8	27.3	0.1
3	LED	18.9	6.3	0.5	7.9	27.3	0.2
4	LED	17.8	5.5	0.4	4.8	23.8	0.1
5	LED	18.9	5.5	0.6	7.9	23.8	0.2
6	LED	17.8	4.8	0.5	4.8	20.6	0.2
7	LED	17.8	4.2	0.6	4.8	17.9	0.2
8	LED	17.8	3.7	0.7	4.8	16.0	0.2
Integrated Directional							
1	Halogen	3.2	61.2	--	0.6	235.1	--
2	CFL	9.9	23.5	1.7	3.2	90.1	0.6
3	LED	18.7	17.3	0.9	7.9	66.6	0.3
4	LED	18.7	16.3	0.7	7.9	62.7	0.3
5	LED	18.7	15.3	0.6	7.9	58.8	0.2
6	LED	18.7	14.3	0.4	7.9	54.9	0.2
7	LED	18.7	12.7	0.1	7.9	49.0	0.1
Non-Integrated Directional							
1	Halogen	2.2	51.0	--	0.9	195.0	--
2	LED	18.7	8.2	0.8	7.9	31.2	0.3
3	LED	18.7	7.1	0.9	7.9	27.3	0.3
4	LED	18.7	6.6	1.0	7.9	25.4	0.4
5	LED	18.7	6.1	1.2	7.9	23.4	0.4

* Commercial UEC indicates the energy that would be consumed by a lamp over the course of a full year, even if the median service lifetime is less than a year.
** The simple payback period is calculated relative to the baseline lamp in each lamp category. The calculation assumes the lamps are operated for a full year and does not take into account replacements costs for lamps with different lifetimes.

To help put the estimated service lifetime in context, we also include an estimate of the simple payback period in Table 4. The simple payback period is the amount of time it takes consumers to recover any higher purchase price of more energy-efficient lamps through lower operating costs, without accounting for changes in operating costs over time or the time value of money. We use the annual UEC values in Table 4 and the lamp prices in Table 2 to calculate the simple payback period for each representative lamp, relative to the lamp category's baseline lamp. Consistent with the approach in the 2016 GSL NOPR analysis, we use sector-specific electricity prices using 2020 electricity price data from the Edison Electric Institute (EEI) and electricity price trends from Annual Energy Outlook (AEO) 2021 to calculate operating costs (Edison Electric Institute, 2020; U.S. Energy Information Administration, 2021). The simple payback period calculation assumes the lamps are operated for a full year and does not account for the additional cost of any needed replacement lamps when comparing lamps with different lifetimes.

2.4 Stock and Shipments

We developed a shipments model to estimate the consumer purchases of each representative lamp in each year of the analysis period in the base case (*i.e.*, the case in which the backstop is not implemented) and the backstop case over a 30-year period from 2022-2051. The model starts from initial estimates of the historical shipments of lamps in each category, as well as the present-day stock, and it projects these estimates forward using a stock-turnover modeling methodology. In this section we summarize our methods for estimating the historical shipments and stock and for projecting these quantities over the analysis period.

2.4.1 Historical Shipments and Stock Estimates

Historical shipments estimates for each lamp category by technology are estimated based on publicly-available sources including shipments information published in public comments provided by the National Electrical Manufacturer's Association (NEMA) in response to the February 2019 GSL Definitional NOPR (NEMA, 2019) and the 2017 General Service Incandescent Lamp (GSIL) Notice of Data Availability (NEMA, 2017) and NEMA's online shipments indices[10]. From these sources, we are able to develop historical time series for integrated omnidirectional A-type and non-A-type lamps of all technologies, incandescent integrated directional lamps, and incandescent non-integrated directional lamps. Historic shipments for LED integrated directional and LED non-integrated directional lamps are estimated assuming shipments of each lamp type would follow a Bass diffusion curve (Bass, 1969), using parameter estimates from DOE's GSIL Final Determination (U.S. Department of Energy, 2019a), and that the projected stock associated with the shipments would match the 2018 stock value reported in the DOE's Adoption of LEDs in Common Applications report for that lamp category (Guidehouse, Inc., 2020). Historic shipments for CFL integrated directional lamps are estimated using a simple stock turnover method utilizing estimates for installed stock from the DOE's 2015 Lighting Market Characterization report (Navigant Consulting, Inc., 2017) and average lifetimes of typical incandescent and CFL integrated directional lamps (based on the lifetime distributions described in section 2.2). We assume no historic shipments of CFL

[10] Available at https://www.nema.org/analytics/lamp-indices (Last accessed on September 8, 2021)

non-integrated directional or integrated omnidirectional non-A-type lamps based on limited product availability for those lamps.

2.4.2 Stock Turnover Model

To project the stock of lamps into the future we use a stock turnover model similar to that used in DOE's 2016 GSL NOPR analysis to estimate future demand for lamps by lamp category. This model calculates shipments in each year of the analysis based on demand for replacements of retired lamps (*i.e.*, lamps that failed or were replaced in renovation) and for lamps to be installed in new construction. DOE's 2016 GSL NOPR analysis describes the governing equations of the stock turnover model in detail (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2019c, 2016, Chap. 9). Broadly speaking, the shipments model projects future shipments by estimating the demand for new lamps in each year, for use in new construction and in replacement of retired lamps.

The demand for retirement replacements is given by computing the number of shipments in past vintages that are retired in a given year. The demand for lamps in new construction is driven by growth in total floor space, which is taken to be 1.0% in the commercial and residential sectors based on the floor space and housing stock forecasts in DOE's Annual Energy Outlook (U.S. Energy Information Administration, 2021).

The stock turnover model also accounts for the reduction in demand due to the adoption of integral LED luminaires into lighting applications traditionally served by GSLs, both prior to and during the analysis period. In each year, an increasing portion of demand is assumed to be met by integral LED luminaires. We modelled the growth of integral LED luminaires as a Bass diffusion curve with a maximum market share of 15% of shipments demand, following the approach from the 2016 GSL NOPR.[11]

2.4.3 Market-Share Model

We used an econometric consumer-choice model to project the market share for lamp options in each lamp category over time in both the base case and the backstop case. The consumer-choice model allocates market share amongst available lamp options in each lamp category based on each representative unit's characteristics. Similar to the methodology employed by DOE in the GSL and GSIL energy conservation rulemakings, we use a conditional logit model with consumer sensitivities to lamp price, median lamp lifetime, energy savings, presence of mercury, and ability to dim[12,13] (for example, see Chapter 9 of the 2016 GSL NOPR TSD or the 2019 GSIL Final Determination TSD) (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2019c, 2016, Chap. 9). The model is calibrated with historical market

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[11] As noted in Chapter 9 of the 2016 GSL NOPR TSD, the fraction of the market that will eventually shift to integral LED luminaires is uncertain. The 15% estimate is based on input from lighting manufacturers and industry experts.
[12] CFLs have historically displayed poor dimming functionality in comparison to other technologies making CFLs less desirable.
[13] Note that preferences for warm versus cool tones were not accounted for because the representative lamps are selected to have the same color temperature.

share data.[14] A simplifying assumption of the model is that lamp efficacies and wattages exist only at the discrete levels defined by the lamp options listed in section 2.2. In each year of the shipments projection period, the consumer-choice model assigns a share of new purchases.

The market-share module also incorporates a limit on the diffusion of LED technology into the market using the widely accepted Bass adoption model. Specifically, the Bass adoption model includes a parameter, referred to here as MP_{max}, which controls the maximum market penetration that is achievable by a new technology[15]. MP_{max} can take on values between 0 and 1 (inclusive). In this analysis, then, the quantity $(1 - MP_{max})$ represents the fraction of consumers that will continue to purchase traditional incandescent or halogen lamps even as LED options become more cost effective. This 'holdout' fraction limits the maximum proportion of the stock that is achievable for LED lamps in the absence of the EISA 2007 backstop, since it implies that a certain fraction of consumers (representing a certain fraction of the stock) will consider only traditional incandescent or halogen lamps unless those lamp options are not available to them due to the backstop.

NEMA sales data from 2019-2021 for integrated omnidirectional A-type lamps suggest that the market share for LED lamps has plateaued at approximately 80% of A-type shipments. Based on this observation, we adopt $MP_{max} = 0.8$ for integrated omnidirectional A-type lamps. The current penetration of LED technologies in other lamp categories lags behind that of integrated omnidirectional A-type lamps. For all other lamp categories, we assume an MP_{max} that corresponds to a stock holdout fraction of 25%, similar to the assumption made in a previous study (Kantner et al., 2017). Note, that we only apply a non-unity MP_{max} in the residential sector. DOE's 2015 LMC report generally finds a higher penetration of LED technologies in the commercial sector in 2015, relative to the residential sector, indicating that commercial consumers are less likely to be 'holdouts' (Navigant Consulting, Inc., 2017). Thus, for the commercial sector, we set $MP_{max} = 1$ for LED technologies.

To allocate market share among lamps in the backstop case, we assume that after January 1, 2022 only lamp options with an efficacy above 45 lm/W are available for purchase, since they are the only option remaining that meets the minimum efficacy requirement for each lamp category. Thus, all lamps are CFLs or LEDs starting in 2022 in the backstop case.

2.4.4 Lamp Price Learning

Prices for LEDs have been shown to decrease in a manner that is consistent with a learning curve (Gerke et al., 2014). Learning curves reflect systematic decreases in manufacturing costs resulting from cumulative production experience (Wright, 1936; Yelle, 1979). Typically these manifest as a decline in consumer price and are represented as a power-law function

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[14] Data do not exist to support modeling consumer preference specifically related to bulb appearance, but to the degree that there might be differences in appearance based on lamp technology, consumer preference for appearance should be implicitly accounted for since the model is calibrated to historic market share data.

[15] The Bass adoption model also incorporates parameters representing external and internal influence, derived from fitting the LED market share for A-type lamps from the December 2019 GSIL Final Determination (U.S. Department of Energy, 2019b).

dependent on the cumulative shipments to market of a particular technology. As described in the previous section, lamp price is a key input to the consumer-choice model which apportions market share to each lamp option. To estimate future prices of the lamps, we use a standard price-learning model which relates the price of a given technology to its cumulative production, as represented by total cumulative shipments.

For LED lamps, we use a learning parameter which corresponds to an 18% decrease in price for each doubling in cumulative shipments, consistent with the historic price learning rate observed by a study of the evolution of LED lamp prices (Gerke et al., 2015). Because LED lamps are a relatively young technology, their cumulative shipments increase relatively rapidly and hence they undergo a substantial price decline of 27.5% during the analysis period. We assume that incandescent and CFL technologies do not undergo price learning in the analysis period due to the long history of these lamps in the market.

2.5 National Energy Savings

National energy savings (NES) from the implementation of the backstop is a critical input into estimating the annualized operating cost savings and avoided greenhouse gas emissions. NES is the difference in the total national energy consumption in the base case and the backstop case. To calculate the national annual energy consumption (AEC) in each year for each case, we multiply the stock of lamps of each type in that year by the average annual UEC for that lamp type, and sum over all lamp types. The difference in national AEC between the cases yields energy savings at the site of consumption (*i.e.*, the reduction in energy consumption in homes and buildings, as would be reflected in a utility bill).

The lamp options presented in Table 2 are meant to represent typical products in each lamp category, but do not necessarily reflect the entire range or products within the full distribution of lumen outputs of that category. We adjust the energy use of the representative units for the integrated omnidirectional A-type category to account for the full distribution of GSL lumen outputs (*i.e.*, 310 – 3300 lumens) based on data provided by the National Resource Defense Council in comments (NRDC, 2015) in response to DOE's December 2014 GSL Preliminary Analysis (U.S. Department of Energy, 2014).

Site energy savings are then converted to a reduction in primary energy consumption at the source of generation (*i.e.*, reduction in energy consumption at the power plant), measured in quadrillion BTUs (quads), by applying a site-to-power-plant conversion factor in each year of the analysis period, as developed by DOE in the 2016 GSL NOPR TSD (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2016, Chap. 10). We also account for the full-fuel-cycle (FFC) energy use of lamps—which includes the energy required to extract, refine, and deliver primary fuel sources—following the methodology described in appendix 10B of the GSL NOPR TSD (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2016, App. 10B). Our analysis accounts for the energy used over the full lifetime of all lamps shipped during the 30-year analysis period. For long-lived lamps and lamps shipped late in the analysis period, this means tracking energy consumption through 2090, the year in which the last lamp shipped during the analysis period is assumed to be retired. As in

DOE's 2016 GSL NOPR analysis, we also account for the ingrowth of lighting controls in the commercial sector as discussed in section 2.2 (U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2016, Chap. 10).

Federal rulemaking assessments of potential energy savings associated with more efficient appliances typically consider a rebound effect, which reflects the idea that as appliances become more efficient, the reduced operating costs will lead consumers to use their appliance more often. In the context of this analysis, a rebound effect would reduce the estimated national energy savings attributed to the implementation of the backstop due to either increased HOU or increased lumen density (i.e., lamps per square foot) in the backstop case. As in DOE's 2016 GSL NOPR and 2019 GSIL Final Determination, however, we assume no rebound effect (U.S. Department of Energy, 2016; U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2019b). We also note that a series of LMC reports suggest no evidence of an increase in overall operating hours for GSLs accompanying the increase in the overall efficiency of GSLs in the installed stock between 2001 and 2015 (Navigant Consulting, Inc., 2017; Navigant Consulting, Inc., 2012; Navigant Consulting, Inc., 2002).

2.6 Annualized National Costs and Benefits

Annualized national consumer costs and benefits are calculated from the time series of increased consumer first costs and operating cost savings attributed to the implementation of the backstop. Cumulative national costs and benefits are summed over the years of operation for lamps shipped during the 30-year analysis period and discounted to year 2021 using discount rates of 3% and 7%. These discount rates are used because they are consistent with standard DOE practice (U.S. Department of Energy, 2016). Annualized values are derived by calculating the fixed annual value over a 30-year period, starting in 2022, that yields the same present value as the cumulative value.

The total first cost in a given year is the product of the installed price of a lamp option and the shipments of that option, summed over all lamp options. The installed price of a lamp is the purchase price of the lamp in a given year, taking into account price trends, and including nationally-representative average sales tax[16] and installation cost, if any. We assume that lamps installed in the residential sector had zero installation costs and lamps in the commercial sector have a per lamp installation cost of $1.57 based on Bureau of Labor Statistics hourly wage data (U.S. Department of Labor–Bureau of Labor Statistics., 2019), assuming it takes five minutes to replace a failed lamp.

The total operating cost in each year is the product of the sector-specific average annual energy consumption, for all lamp options in the installed stock, and the sector-specific cost of electricity, summed over sectors. Electricity prices and price trends come from EEI and AEO 2021, as discussed in section 2.3.

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[16] Sales tax data came from Sales Tax Clearinghouse: http://thestc.com/STrates.stm

In addition to our reference inputs, we also analyze a high and low benefits scenarios that use inputs from variants of the AEO 2021 Reference case. For the high benefits scenario, we use the AEO 2021 High Economic Growth scenario, which has a higher energy price trend relative to the Reference case. In order to consider a broad range of potential benefits resulting from the implementation of the EISA 2007 backstop we also assume a lower price learning rate in the high benefits scenario. The lower learning rate in this scenario slows down the adoption of more efficacious lamp options in the base case, increasing the available energy savings attributable to the implementation of the backstop. For the low benefits scenario, we use the AEO 2021 Low Economic Growth scenario, which has a lower energy price trend relative to the Reference case, as well as a higher price learning rate. The higher learning rate in this scenario increases the adoption of more efficacious lamp options in the base case, decreasing the available energy savings attributable to the implementation of the backstop. Higher and lower learning rates are taken from the 95% confidence interval on the learning parameter relating cumulative LED A-type shipments and the corresponding price (see section 2.4.4).

2.7 Emissions Reduction and Monetization

We calculate the reduction in greenhouse gases and other pollutants due to the implementation of the backstop in 2022 considering contributions from two components. The first component estimates the effect of the reduction in national energy use due to the backstop on power sector emissions of CO_2, NO_X, HG, and SO_2. The second component estimates the impacts of potential standards on emissions of two additional greenhouse gases, CH_4 and N_2O, as well as the reductions to emissions of other gases due to “upstream” activities in the fuel production chain. These upstream activities comprise extraction, processing, and transporting fuels to the site of combustion. The associated emissions are referred to as upstream emissions and they include “fugitive” emissions (direct leakage to the atmosphere) of CH_4 and CO_2.

The estimated emissions reduction is computed from the energy savings in each year of the analysis by applying a multiplier representing the projected average carbon intensity per unit of electricity delivered. These multipliers were developed by DOE for its energy efficiency rulemakings, and are based on the projected mix of electricity generators on the grid. The methodology is based on results published for the Annual Energy Outlook (AEO) prepared by the Energy Information Administration, including a set of side cases that implement a variety of efficiency-related policies. The methodology is described in the report “Utility Sector Impacts of Reduced Electricity Demand” (Coughlin, 2019, 2014). A description of the methodology and the emission intensity factors used in this analysis can be found in Appendix A.

We calculate the estimated monetary benefits from the reduction in emissions of CO_2, CH_4, N_2O, NO_X, and SO_2 that are expected to result from implementation of the backstop in 2022. We estimate the global social benefits of CO_2, CH_4, and N_2O expected from this proposed rule using the SC-GHG estimates presented in the *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide Interim Estimates under Executive Order 13990* published in February 2021 by the Interagency Working Group on the Social Cost of Greenhouse Gases (IWG) (Interagency Working Group on Social Cost of Greenhouse Gasses, United States Government, 2021) and shown in Table 5. As a member of the IWG involved in the development of the February 2021 SC-GHG TSD, DOE has agreed in DOE rulemakings that the interim SC-GHG estimates represent the most appropriate estimate of the SC-GHG until revised estimates have been developed reflecting the latest, peer-reviewed science.[17] In those rulemakings, DOE has stated that the SC-GHG estimates were developed over many years, using transparent process, peer-reviewed methodologies, the best science available at the time of that process, and with input from the public. The same SC-GHG estimates are used in this report. The monetized value of NO_X and SO_2 emission reductions is estimated based on multiplying the emissions estimated using the methods described in Appendix A by the benefit per ton estimates for PM2.5 precursors, NOx, and SO2 from analysis conducted by EPA for the Clean Power Plan rulemaking (U.S. Environmental Protection Agency – Office of Air and Radiation and Office of Air Quality Planning and Standards, 2015) and shown in Table 6. We note that EPA has very recently updated their benefit-per-ton methodology.[18] As the full set of results has not yet been released, the results here reflect the 2015 estimates that have historically been used in DOE rulemaking analyses. We plan to update our methodology to reflect EPA's updates in a future impact analysis if DOE issues a final rule, but we do not have time to fully vet the new methods for this impact analysis. We have included an illustrative discussion of the monetized health benefits using the newer methodology in Appendix B.

Table 5. Social Cost of Greenhouse Gases, 2020-2050 (in 2020$ per Metric Ton of Greenhouse Gas)

	Discount Rate	2020	2025	2030	2035	2040	2045	2050
CO_2	5%, average	14	17	19	22	25	28	32
	3%, average	51	56	62	67	73	79	85
	2.5%, average	76	83	89	96	103	110	116
	3%, 95th perc	152	169	187	206	225	242	260
CH_4	5%, average	670	800	940	1,100	1,300	1,500	1,700
	3%, average	1,500	1,700	2,000	2,200	2,500	2,800	3,100
	2.5%, average	2,000	2,200	2,500	2,800	3,100	3,500	3,800
	3%, 95th perc	3,900	4,500	5,200	6,000	6,700	7,500	8,200
N_20	5%, average	5,800	6,800	7,800	9,000	10,000	12,000	13,000
	3%, average	18,000	21,000	23,000	25,000	28,000	30,000	33,000
	2.5%, average	27,000	30,000	33,000	36,000	39,000	42,000	45,000
	3%, 95th perc	48,000	54,000	60,000	67,000	74,000	81,000	88,000

[17] See, *e.g.,* U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy, 2021. Energy Conservation Program: Energy Conservation Standards for Manufactured Housing: Supplemental Notice of Proposed Rulemaking, 86 Fed. Reg., 47814-47816.
[18] See EPA's 2021 *Technical Support Document: Estimating the Benefit per Ton of Reducing Directly-Emitted PM2.5, PM2.5 Precursors and Ozone Precursors from 21 Sectors* available at https://www.epa.gov/system/files/documents/2021-10/source-apportionment-tsd-oct-2021_0.pdf.

Table 6. Total dollar value (mortality and morbidity) per ton of directly emitted PM2.5 and PM2.5 precursor reduced by the Electricity Generating Unit sector (2015$)

	Discount Rate	2020	2025	2030
NOx	3%	9,000	9,700	11,000
	7%	8,100	8,800	9,500
SO_2	3%	56,000	61,000	67,000
	7%	51,000	55,000	60,000

Note: Benefits per ton values are presented for select years, but benefits per ton are estimated for each year.

To convert the time-series of benefits from avoided emissions into annualized values, we use the same methodology described in section 2.6. The calculation uses discount rates of 3 and 7 percent for all costs and benefits except for the value of greenhouse gas reductions (CO_2, CH_4, and N_2O). For greenhouse gas emissions, we use the full range of values and discount rates published in the IWG report.

As in our calculation of consumer costs and benefits, we include results for high and low benefits scenarios in our estimates for the benefits in reduced emissions (see section 2.6 for details).

3. Results

In this section we present the estimated annualized national consumer costs and net benefits resulting from the implementation of EISA 2007 backstop in 2022, applied to lamps in the recently proposed GSL definition, based on the impact-assessment model outlined in section 2. In particular, we present the annualized national consumer operating cost savings, incremental product costs, and net benefits, as well as the benefits resulting from emissions reductions arising from all lamps shipped to market over a 30-year analysis period, for an analytical case in which the backstop takes effect as compared to a base case in which the backstop does not take effect.

In the backstop case, all lamp demand for new construction and replacements is assumed to be fulfilled by lamps with an efficacy of at least 45 lm/W, yielding a substantial reduction in energy consumption and an associated savings in energy costs relative to the base case. We estimate national FFC energy savings of 5.7 quads from the implementation of a 45 lm/W backstop. Since the LED lamps have significantly longer lifetime than the incandescent lamps they replace, there is also a significant reduction in overall lamp shipments, which offsets higher prices for more efficacious lamps to a significant extent, resulting in a relatively low increase in incremental product costs. Table 7 summarizes the estimated annualized consumer costs and benefits.

As discussed in section 2.6, we have included sensitivities of the key variables that could impact the costs and benefits as a result of the backstop. Table 7 presents these results in the high and low benefits scenarios which were analyzed using inputs from the High and Low

Economic growth variants of the AEO 2021 Reference case and low and high price learning rates.

Table 7. Summary of Annualized Consumer Benefits and Costs

	Primary Estimate	Low-Net-Benefits Estimate	High-Net-Benefits Estimate
	Annualized (million 2020$/year)		
Consumer Operating Cost Savings			
7% discount rate	2,864.5	2,725.3	3,010.0
3% discount rate	2,955.1	2,788.0	3,128.8
Incremental Product Costs			
7% discount rate	177.6	180.3	173.0
3% discount rate	148.9	150.9	145.0
Net Consumer Benefits			
7% discount rate	2,686.9	2,545.0	2,837.0
3% discount rate	2,806.2	2,637.0	2,983.8

As discussed in section 2.5, we also convert site energy savings to FFC energy savings at the generation source by accounting for energy savings from generation, transmission and distribution, and primary fuel extraction, refinement, and delivery. We compute the associated reductions in emissions that accrue from these energy savings resulting in significant emission reductions as shown in Table 8. Table 9 presents annualized social value for avoided emissions. Table 10 shows the total costs and benefits.

Table 8. Summary of Emissions Reduction

	Power Sector Emissions Reduction	Upstream Emissions Reduction	FFC Emissions Reduction
CO_2 (million metric tons)	207.8	14.1	221.9
SO_2 (thousand tons)	99.6	1.2	100.8
NO_X (thousand tons)	99.2	207.7	299.9
Hg (tons)	0.6	0.0	0.6
CH4 (thousand tons)	17.6	1,368.1	1385.7
N20 (thousand tons)	2.5	0.1	2.6

Table 9. Summary of Annualized Social Value of Emissions Reductions, 2022-2051

	Primary Estimate	Low-Net-Benefits Estimate	High-Net-Benefits Estimate
	Annualized (million 2020$/year)		
GHG Benefits			
5% discount rate, average	205.2	198.4	210.2
3% discount rate, average	593.2	573.2	608.3
2.5% discount rate, average	835.5	807.2	856.9
3% discount rate, 95th perc	1,767.6	1,707.9	1,812.8
NOx Benefits (as PM2.5)			
7% discount rate	123.1	119.5	125.8
3% discount rate	128.5	124.3	131.7
SO2 Benefits (as PM2.5)			
7% discount rate	136.8	132.9	139.7
3% discount rate	151.0	146.2	154.7

Note: GHG benefits are calculated using four different estimates of the social cost of carbon (SC-CO_2), methane (SC-CH_4), and nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). Health benefits in this table are calculated by multiplying emissions by benefit-per-ton estimates for a given discount rate in Table 6. All fine particles are assumed to have equivalent health effects. The benefit-per-ton method does not take into account seasonal variations in energy usage and PM formation. NOx health benefits may be under or over-estimated due to limits on NOx emissions in effect for some states under the Cross-state Air Pollution rule. The monetized co-benefits incorporate the conversion from precursor emissions to ambient fine particles.

Table 10. Summary Total Costs and Benefits, 2022-2051

	Primary Estimate	Low-Net-Benefits Estimate	High-Net-Benefits Estimate
	Annualized (million 2020$/year)		
Total Benefits			
7% discount rate	3,718	3,551	3,884
3% discount rate	3,828	3,632	4,023
Total Costs			
7% discount rate	178	180	173
3% discount rate	149	151	145
Net Benefits			
7% discount rate	3,540	3,371	3,711
3% discount rate	3,679	3,481	3,879

Note: Total Benefits for both the 3-percent and 7-percent cases are presented using the average GHG social costs with 3-percent discount rate. GHG reduction benefits are calculated using four different estimates of the social cost of carbon (SC-CO_2), methane (SC-CH_4), and nitrous oxide (SC-N_2O) (model average at 2.5 percent, 3 percent, and 5 percent discount rates; 95th percentile at 3 percent discount rate). For the presentational purposes of this table, we show the total and net benefits associated with the average SC-GHG at a 3 percent discount rate, but note that DOE did not use a single central SC-GHG point estimate in a past rulemaking. Considering the four SC-GHG estimates, the equivalent annual net benefit would be between $3.1 billion to $4.9 billion for the primary estimate, $3 billion to 4.6 billion for the Low-Net-Benefits Estimate and $3.3 to $5.1 billion for the High-Net-Benefits Estimate. All net benefits are calculated using GHG benefits discounted at 3 percent.

Despite the expected widespread adoption of LEDs in the base case, the EISA backstop provision nevertheless yields large impacts. We estimate a range of annualized net consumer benefits of $2.5 billion per year to $3.0 billion per year, with an estimate of $2.7 billion per year at a 7% discount rate and $2.8 billion per year at a 3% discount rate in our primary estimate. Including the social value of emission reductions, we estimate a range of annualized net benefits from $3.0 billion per year to $5.1 billion per year, with an estimated range of $3.2 billion per year to $4.9 billion per year in our primary estimate.

We find considerable consumer benefits and social value from avoided emissions resulting from the application of the EISA 2007 backstop in 2022 to lamps included in DOE's proposed GSL definition. These results demonstrate the consequential nature of DOE's proposed interpretive rule regarding the EISA 2007 backstop in combination with DOE's proposed GSL definition.

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Appendix A. Emissions Intensity Factors

In this appendix we describe the methodology developed to calculate the emission intensity factors used to estimate emission reductions from the implementation of the backstop. The methodology is the same as the one used by DOE to estimate emissions reductions in energy conservation standards rulemakings using the most recent available version of EIA's AEO.

Power sector marginal emissions factors are calculated by looking at the difference, over the full analysis period, in fuel consumption and emissions across a variety of cases published with the AEO 2021. The analysis produces a set of emissions intensity factors that quantify the reduction in emissions of a given pollutant per unit reduction of fuel used in electricity generation for each of the primary fossil fuel types (coal, natural gas and oil). These factors are combined with estimates of the fraction of generation allocated to each fuel type, also calculated from AEO 2021 data, for the residential and commercial sector. Total power-sector emissions reductions are estimated by multiplying the intensity factors times the energy savings. Table A - 1 shows the time series of emissions intensity factors used in this analysis for the residential and commercial sectors in 5-year increments.

Table A - 1. Power Sector Emissions Factors in Million Short Tons per Quad Site Electricity Use

Sector	Pollutant	2025	2030	2035	2040	2045	2050
Residential	**CO_2**	4.63×10^{2}	4.12×10^{2}	3.78×10^{2}	3.60×10^{2}	3.43×10^{2}	3.29×10^{2}
	NO_X	2.01×10^{-1}	1.73×10^{-1}	1.52×10^{-1}	1.39×10^{-1}	1.29×10^{-1}	1.22×10^{-1}
	SO_2	2.04×10^{-1}	1.77×10^{-1}	1.58×10^{-1}	1.57×10^{-1}	1.50×10^{-1}	1.44×10^{-1}
	Hg	1.19×10^{-6}	1.12×10^{-6}	1.01×10^{-6}	9.61×10^{-7}	9.06×10^{-7}	8.57×10^{-7}
	CH_4	3.65×10^{-2}	3.28×10^{-2}	2.97×10^{-2}	2.72×10^{-2}	2.50×10^{-2}	2.37×10^{-2}
	N_20	5.16×10^{-3}	4.64×10^{-3}	4.20×10^{-3}	3.83×10^{-3}	3.51×10^{-3}	3.32×10^{-3}
Commercial	**CO_2**	4.29×10^{2}	3.80×10^{2}	3.50×10^{2}	3.34×10^{2}	3.20×10^{2}	3.07×10^{2}
	NO_X	1.80×10^{-1}	1.54×10^{-1}	1.36×10^{-1}	1.25×10^{-1}	1.15×10^{-1}	1.09×10^{-1}
	SO_2	1.70×10^{-1}	1.47×10^{-1}	1.30×10^{-1}	1.30×10^{-1}	1.23×10^{-1}	1.18×10^{-1}
	Hg	9.77×10^{-7}	9.15×10^{-7}	8.28×10^{-7}	7.85×10^{-7}	7.38×10^{-7}	6.97×10^{-7}
	CH_4	3.11×10^{-2}	2.78×10^{-2}	2.51×10^{-2}	2.30×10^{-2}	2.12×10^{-2}	2.00×10^{-2}
	N_20	4.36×10^{-3}	3.90×10^{-3}	3.52×10^{-3}	3.21×10^{-3}	2.94×10^{-3}	2.78×10^{-3}

Estimates for upstream emissions intensity factors uses an full-fuel cycle (FFC) accounting approach (Coughlin, 2013) and includes contributions from fuel combustion during extraction, processing and transportation of fuel, and "fugitive" emissions (direct leakage to the atmosphere) of CH_4 and CO_2. When demand for a particular fuel is reduced, there is a corresponding reduction in the upstream activities associated with production of that fuel (mining, refining etc.) These upstream activities also consume energy and therefore produce combustion emissions. The FFC accounting estimates the total consumption of electricity, natural gas and petroleum-based fuels in these upstream activities. The relevant combustion emissions factors are then applied to this fuel use to determine the total upstream emissions intensities from combustion, per unit of fuel delivered to the consumer. Table A - 2 shows the time series of upstream emissions factors used in this analysis in 5-year increments.

Table A - 2. Electricity Upstream Emissions Intensity Factors

Pollutant	Unit	2025	2030	2035	2040	2045	2050
CO_2	kg/MWh	26.1	24.3	23.0	22.8	23.0	22.3
NO_X	g/MWh	344.7	322.4	307.7	305.6	310.7	302.3
SO_2	g/MWh	2.2	2.0	1.7	1.6	1.5	1.4
HG	g/MWh	4.0×10^{-6}	4.3×10^{-6}	3.6×10^{-6}	3.3×10^{-6}	2.9×10^{-6}	2.6×10^{-6}
CH_4	g/MWh	2222.2	2117.6	2021.1	2038.6	2055.2	2024.2
N_20	g/MWh	0.145	0.134	0.123	0.113	0.106	0.100

Appendix B. Updated Benefits Per Ton

In this appendix, we note EPA's updated 2021 benefit-per-ton methodology for estimating the average avoided human health impacts, and monetized benefits related to emissions PM2.5 precursors including NOx and SO2 using the results of source apportionment photochemical modeling, the results of which have been partially released[19]. EPA's 2021 benefit-per-ton estimates from the electric generating unit (EGU) sector for 2025 and 2030 and 3 and 7 percent discount rates are shown in Table B - 1. EPA's 2021 Technical Support Document (TSD) improves upon previously published benefit-per-ton estimates from EPA in the following ways: (1) quantifying and reporting ozone benefit per-ton values (BPT); (2) estimating PM and Ozone-related effects using concentration-response parameters that reflect new evidence reported in the most recently published Integrated Science Assessments (ISA) for PM2.5 and Ozone[20]; and, (3) reporting regional or state-level benefit per-ton values for each sector. In general, the NOx benefit-per-ton estimates have decreased and the SO_2 benefit-per-ton estimates have increased since 2015 when comparing Table B - 1 to Table 6. Once the full benefit per ton estimates are released, it is likely that this would result in decreased health benefits from NOx and increased health benefits from SO_2 as a result of DOE's recent proposals to interpret the EISA 2007 backstop as having been triggered and revise the definition of the term GSL to include certain lamps that were either previously excluded or not explicitly mentioned in the EISA 2007 definition.

The benefit-per-ton approach relies on estimates of human health responses to exposure to PM obtained from the peer-reviewed scientific literature. These estimates are used in conjunction with population data, baseline health information, air quality data and economic valuation information to conduct health impact and economic benefits assessments. These assessments form the key inputs to calculating benefit-per-ton estimates. Thus, to develop estimates of benefits, one transfers both the underlying health and economic information from previous studies and information on air quality responses to emission reductions from other air quality modeling. Benefit-per-ton approaches apply an average benefit-per-ton derived from modeling of benefits of specific air quality scenarios to estimates of emission reductions for scenarios where no air quality modeling is available.

[19] See EPA's Technical Support Document: Estimating the Benefit per Ton of Reducing Directly-Emitted PM2.5, PM2.5 Precursors and Ozone Precursors from 21 Sectors at https://www.epa.gov/system/files/documents/2021-10/source-apportionment-tsd-oct-2021_0.pdf.

[20] More information on how EPA updated the concentration response parameters according to the peer-reviewed literature and most recent ISAs for PM2.5 and Ozone is available in the TSD for the Final Revised Cross-State Air Pollution Rule for the 2008 Ozone NAAQS Update titled Estimating PM2.5- and Ozone-Attributable Health Benefits available at https://www.epa.gov/sites/default/files/2021-03/documents/estimating_pm2.5-_and_ozone-attributable_health_benefits_tsd.pdf.

Table B - 1. Summary of the Total dollar value (mortality and morbidity) per ton of PM2.5 precursor reduced by Electricity Generating Units (EGU) (2016$)[*]

Pollutant	**Discount Rate**	**2025**	**2030**
NOx (as PM2.5)	3%	6,400	7,100
	7%	5,700	6,390
SO_2 (as PM2.5)	3%	73,000	82,000
	7%	65,700	73,800

Note: These values represent a national average $/ton of total emissions for electricity generating units (EGU) as shown in EPA's 2021 *Technical Support Document:* Estimating the Benefit per Ton of Reducing Directly-Emitted PM2.5, PM2.5 Precursors and Ozone Precursors from 21 Sectors *(https://www.epa.gov/system/files/documents/2021-10/source-apportionment-tsd-oct-2021_0.pdf)*. EPA modeled health benefits for the EGU sector at the state level, which are available here https://www.epa.gov/benmap/estimating-benefit-ton-reducing-pm25-precursors-21-sectors.