Codes and Standards Enhancement (CASE) Initiative For PY2008: Title 20 Standards Development

Title:

Analysis of Standards Options for General Service Incandescent Lamps

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1 Executive Summary

The Pacific Gas and Electric Company (PG&E) Codes and Standards Enhancement (CASE) Initiative Project seeks to address energy efficiency opportunities through development of new and updated Title 20 standards. Individual reports document information and data helpful to the California Energy Commission (Commission) and other stakeholders in the development of these new and updated standards. The objective of this project is to develop CASE Reports that provide comprehensive technical, economic, market, and infrastructure information on each of the potential appliance standards. This CASE report covers standards that serve to accelerate the implementation of the federal standards for general service lamps set to take effect in 2012 through 2014. Because the proposed California standards discussed hereunder represent only a one or two year acceleration of adopted federal standards, we have shortened our usual comprehensive CASE Report format to focus on the savings analysis of such an acceleration.

Energy efficient lighting advocates have called for the use of compact fluorescent lamps (CFLs) for years, pointing out their high efficacy (calculated in lumens per watt), decreased size, rapid paybacks, improved color rendition and variety of color temperatures. For most applications of ambient lighting, fluorescent or HID lighting are recommended on a lifecycle cost basis. The pace of that market transformation, though steady, still leaves incandescent lamps as the dominant light source in the residential sector, with approximately 70% of market share.[1]

In October of 2007, Governor Schwarzenegger signed into law AB1109, also known as the Huffman Bill. This bill requires that the Commission take action to reduce indoor residential and state facility lighting energy use by at least 50% by 2018. The bill also requires a 25% reduction in commercial lighting and outdoor lighting energy use by the same date. These requirements make it imperative that the Commission begin to take regulatory action to reduce the energy use of indoor lamps. Given that, as stated above, incandescent lamps still account for approximately 70% of the market share, they are an obvious target for improved efficiency standards. With so many incandescent lamps in service, even a small improvement in efficiency can lead to large energy savings.

The recent passage of the Energy Independence and Security Act of 2007 (EISA 2007) essentially pre-empted California's Title 20 authority to regulate most general service lighting. However, the bill does allow for California to accelerate the implementation of the federal standards by one year. This document reviews potential energy savings and economic analysis of adopting the federal Tier 1 standards a year early and Tier 2 standards two years early–as permitted by EISA 2007. The summary table below shows the total savings that can be expected from accelerated implementation of each Federal Tier.

[1] This data is based on Department of Commerce values for compact fluorescent and incandescent lamp imports, as well as NEMA data on NEMA member sales of both lamp types published in the Wall Street Journal, November 2007.

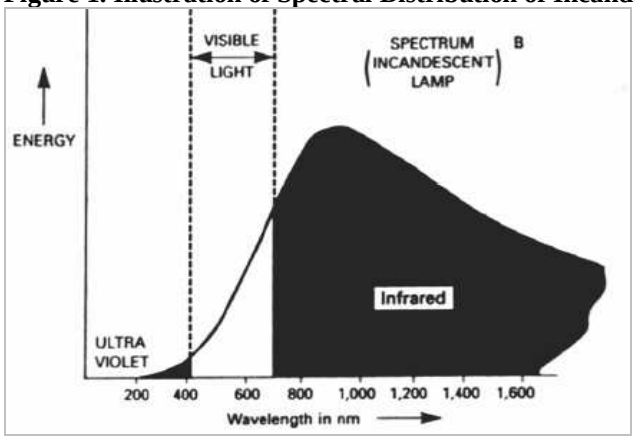
Table 1. Summary of Total Energy Savings

Scenario	Reduction in Peak Demand (MW)	Total Energy Savings (GWh)
Tier 1 Implementation in 2011-2013	64	926
Tier 2 Implementation in 2018	106	11,327
Accelerated Implementation of Both Tier1 and Tier 2	170	12,253

2 Product Description

Incandescent lamp technology has undergone evolutionary and incremental improvement since Thomas Edison first patented his carbon filament version in 1879, but few revolutionary breakthroughs have occurred. Modern incandescent lamps use a tungsten filament and gas fill instead of a carbon filament in a partially evacuated envelope, but the basic technology remains the same: heat a thin wire with an electrical current until it glows. Most of the energy consumed by incandescent lamps produces waste heat (infrared radiation), as shown in Figure 1.

Figure 1. Illustration of Spectral Distribution of Incandescent Lamp Output



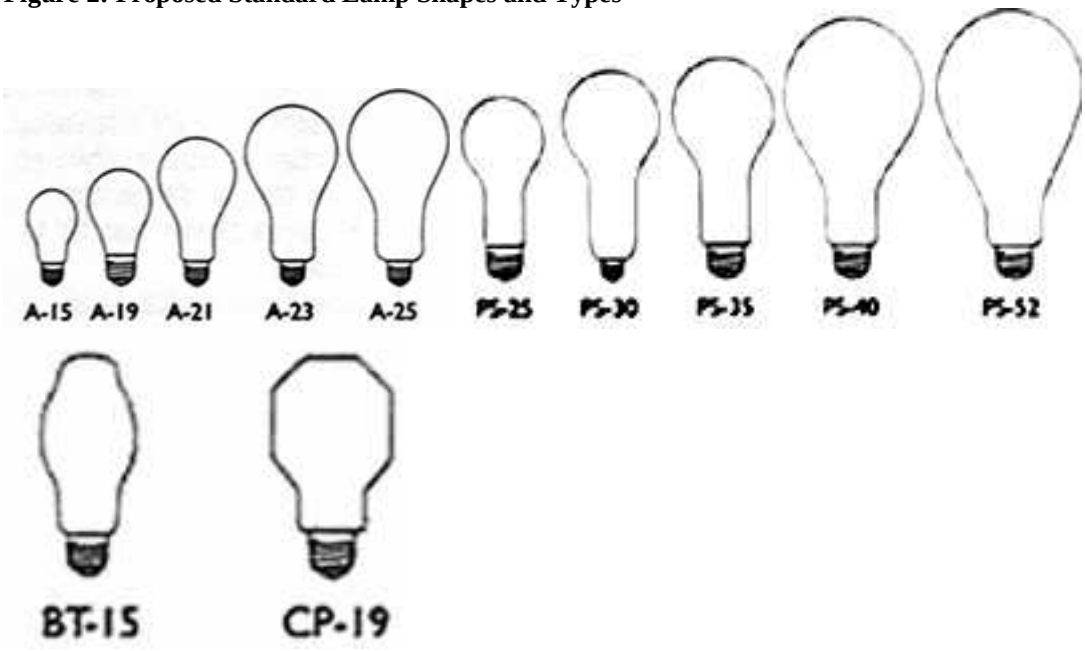
The efficiency of a lamp is measured in lumens per watt (lpw) and is referred to as efficacy. The need for greater efficacy has been an important aspect of incandescent lighting since its earliest production. Edison's original incandescent lamp had an efficacy of about 1 lpw. Modern incandescent lamp types within the proposed scope of this research have an efficacy in the range of 7 to 20 lumens per watt (Kane, Raymond, and Heinz Sell, 2001). The theoretical maximum efficacy of an incandescent source is 53 lpw. Compact fluorescent lamps (CFLs) and solid state lighting (SSL) products already in the market have efficacies ranging from 40 to 110 lpw. As a result, the standards levels

proposed in this document which are the same as those adopted in EISA 2007 for the nation as a whole, seek not to force a dramatic technological breakthrough, but merely to accelerate usage of the efficient technologies—even within the limited context of incandescent technologies—that are already well understood and established.

Many factors affect the efficacy of an incandescent lamp. In general, a lamp's efficacy increases with the operating temperature of its filament, because higher temperature operation shifts the peak of the spectral curve in Figure 1 toward shorter wavelengths (closer to the visible spectrum). Tungsten filaments reach their maximum efficacy immediately before their melting point. However, high temperature operation also shortens lamp life.

The scope of the regulations in ESIA 2007 covers non-reflector incandescent lamps intended for general lighting applications, with power between 25 and 150 Watts. This includes any lamp that is intended for general service applications, has a medium screw base, produces between 310 and 2600 lumens, and is capable of being operated at a voltage between 110 and 130 volts. See Figure 2 below for examples of these lamp shapes and types.

Figure 2: Proposed Standard Lamp Shapes and Types



Source: Philips Lighting Company, Lamp Specification & Application Guide, 2001/2002.

EISA 2007 explicitly excludes the following lamps from this regulation: appliance lamps, black light lamps, bug lamps, colored lamps, infrared lamps, left-hand screw lamps, marine lamps, marine signal service lamps, mine service lamps, plant light lamps, reflector lamps, rough service lamps, shatter-resistant lamps, sign service lamps, silver bowl lamps, showcase lamps, 3-way incandescent lamps, traffic signal lamps, vibration service lamps, and various specialty shaped lamps. PG&E addresses potential efficiency requirements for these excluded lamps in other CASE documents. The Tier 1

recommendations in this CASE document deal specifically with the lamps covered in EISA 2007, section 321 a.

Note that both EISA 2007 Tier 1 and Tier 2 standards do apply to modified spectrum lamps. These lamps are addressed in EISA 2007 using slightly different lumen bins than those used for standard spectrum lamps. For this reason, we have broken out standard and modified spectrum lamps in all the following analyses. Each stage in the savings calculations discussed in this paper includes separate tables for standard and modified spectrum lamps.

3 Energy Usage

3.1 Test Methods

3.1.1 Current Test Methods

California Title 20 currently mandates that all lamp efficiency testing be performed in accordance with the Code of Federal Regulations (CFR), Title 10, Part 430.23, 2005 version. (Also written as10 CFR Section 430.23, 2005.) The Code of Federal Regulations in turn references the Illuminating Engineering Society of North America (IESNA), stating that the efficiency of general service incandescent lamps be measured using IESNA LM-45. For medium base compact fluorescent lamps, the CFR requires efficiency testing to be performed in accordance with sections 1, 2, 3, and 7 of IESNA LM-66.

3.1.2 Proposed Test Methods

The Commission is required to utilize lamp efficiency test methods described in 10 CFR Section 430.23, 2005, in accordance with the requirements of EISA 2007.

3.2 Baseline Energy Use Per Product

This report breaks out standard and modified spectrum lamps into separate analyses. In order to develop a baseline for evaluating Tier 1 savings, we first estimated the 2007 energy use of lamps that do not comply with the proposed Federal Tier 1 standards.[2] Total statewide energy use is calculated by multiplying the average per unit power draw of the lamp, times the lifetime operating hours, times the unit sales per year. The estimates assume little compliance with the current California Title 20 Tier 2 standards for incandescent lamps at this early date, which is consistent with products observed on

[2] In the analyses contained in this report, PG&E has made a number of simplifying assumptions because very current market information needed to facilitate more precise calculations for 2007 were not readily available on a shipment weighted basis. Furthermore, no party can accurately predict the value of all factors in 2011 and especially in 2018. PG&E understands that the real world is far more complicated and nuanced than implied by the calculations in this report. PG&E has attempted to use reasonable estimates and appropriate simplifying assumptions, rather than executing far more complicated analysis with uncertain input values that might yield more precise but not necessarily more accurate estimates.

the shelf. Lifetime operating hours are likewise based on the ratings of products currently available for sale. The values for standard and modified spectrum lamps can be found in Tables 1 and 2 respectively. These values are not used in the analysis of measure impact. Rather, they are included to illustrate some of the data informing our 2011-2013 base case estimates.

Table 2. Energy Use of EISA 2007 Tier 1 Non-Compliant Standard Spectrum Lamps in California, 2007

Lumen Range	Average Power Draw Per Unit (W)	Lifetime Operating Hours	Annual Unit Sales (in millions)	Lifetime Energy Use (GWh/yr)
310 to 749	40	1000	10.4	418
750 to 1049	60	1000	36.9	2212
1050 to 1489	75	750	17.5	982
1490 to 2600	100	750	15.3	1145
Total	n/a	n/a	80.0	4757

Incandescent sales estimates in previous CASE reports were defined from RER Itron cash register data, and omitted sales to commercial customers. The prior numbers also did not explicitly account for modified spectrum, which have been growing steadily in sales. They omitted sales through other channels as well, including
the Internet, wholesalers, and others. The subsequent Navigant study for DOE and the import data from Department of Commerce provide evidence that sales were higher than originally thought.

Table 3. Energy Use of EISA 2007 Tier 1Non-Compliant Modified Spectrum Lamps in California, 2007

Lumen Range	Average Power Draw Per Unit (W)	Lifetime Operating Hours	Annual Unit Sales (in millions)	Lifetime Energy Use (GWh/yr)
232-562	40	1000	1.6	62
563-787	60	1000	5.5	330
788-1117	75	750	2.6	147
1118-1950	100	750	2.3	171
Total	n/a	n/a	12.0	711

After estimating current energy use of EISA 2007 non-compliant lamps, we developed a similar projection for the years 2011 through 2013, as shown in Tables 4 and 5 below. The estimates for 2011-2013 assume 100% compliance with California Title 20 Tier 2 regulations, as well as an increase in lamp lifetime (Johnson, 2004). The projections of unit sales assume that California accounts for 11% of national lamp sales, and that

incandescent lamps will account for 65% of general service lamps sold in 2011-2013. The projection of total unit sales decreases to reflect increased market share of compact florescent and other non-incandescent lamps. This is based on published NEMA manufacturer data, Department of Commerce import data, and Ecos' proprietary models. The unit sales projections also reflect an increase in market share of modified spectrum lamps, which is consistent with current market trends.

Lifetime energy use is calculated by taking the total amount of energy that will be used by all lamps bought in a given year, over their entire functional life. These energy use values were used as the baseline for evaluating the savings potential of accelerating of the EISA 2007 Tier 1 standards.

Table 4. Expected Energy Use of EISA 2007 Tier 1 Non-Compliant Standard Spectrum Lamps in California, 2011-2013

Lumen Range	Average Power Draw Per Unit (W)	Lifetime Operating Hours	Annual Unit Sales (in millions)	Lifetime Energy Use (GWh/yr)
310 to 749	38	1000	5.4	205
750 to 1049	57	1000	19.0	1083
1050 to 1489	71	1000	9.0	641
1490 to 2600	95	1000	7.9	748
Total	n/a	n/a	41.3	2676

Table 5. Expected Energy Use of EISA 2007 Tier 1 Non-Compliant Modified Spectrum Lamps in California, 2011-2013

Lumen Range	Average Power Draw Per Unit (W)	Lifetime Operating Hours	Annual Unit Sales (in millions)	Lifetime Energy Use (GWh/yr)
232-562	40	1000	1.8	72
563-787	60	1000	6.3	380
788-1117	75	1000	3.0	225
1118-1950	100	1000	2.6	262
Total	n/a	n/a	13.8	939

3.3 Efficiency Measures

Numerous materials and design strategies to increase the efficiency relative to standard incandescent lamps are in use and under development. For incandescent lamps, in the near term the most promising and prominent of these strategies currently include halogen gas fill and infrared reflective coatings. Brief summaries of these measures are included below.

Halogen
Use of a halogen gas fill within an interior quartz or hard-glass encasement prevents the slowly evaporating tungsten from depositing on the inner surface of the bulb and instead deposits the tungsten back on the filament. This tungsten cycle allows the filament to be operated at a higher temperature without depleting the filament, thereby increasing efficacy without sacrificing life. Most halogen lamps are optimized for life with little change in efficacy. Because the bulb does not blacken as much with use, halogen lamps suffer less lumen depreciation than standard incandescent lamps.

Halogen infrared reflecting
A dichroic (i.e. spectrally reflective) coating can be applied to the inner wall of the halogen capsule, which reflects long wave radiation (heat) back to the filament while allowing radiation in the visible spectrum (light) to pass through. The reflected heat is directed back to the filament to increase its temperature for a given amount of power input.

Low Voltage
Manufacturers are beginning to explore the benefits of low voltage lamps, currently available for sale in Europe. These lamps use a chip to step down the incoming voltage and increase the current through the filament, which results in better efficacy. While some energy is lost in the voltage conversion, it is more than made up by the increase in filament efficiency.

Patterned Filament
Patent searches and discussions with industry experts indicate growing interest in filament patterning. This technique apparently applies a pattern to the surface of the filament which may preserve filament heat and thus improves efficiency.

3.4 Energy Savings

3.4.1 Tier 1 Standards: 2011-2013
The projected baseline energy use of non-compliant lamps in 2011-2013 was shown above in Section 3.2. In order to calculate energy savings from this measure, we then estimated what the energy use of those non-compliant lamps would be if they were required to meet Federal Tier 1 standards. For the sake of simplicity, we assume that the average power use for each lumen bin will just meet the federal standards, with no extra efficiency increase. This is a conservative assumption given the probability that the standard will increase market share for CFLs and other high efficacy products due to the presumed higher price of EISA 2007 compliant incandescent lamps relative to base case incandescent lamps. Lifetime operating hours are assumed to increase somewhat as a result of various efficiency technologies, as well as apparent manufacturer preference for reducing light output to facilitate regulatory compliance.

The projections of unit sales for this calculation are the same as those used for the 2011-2013 baseline case. Note that this assumption ignores the possibility of a market shift

toward compact fluorescents as incandescent lamps increase in price. This estimate also does not account for the possibility of "bin jumping", wherein manufacturers produce lamps at the lowest end of the lumen range for each bin (because it is easier to comply at that point), and customers therefore buy lamps from the next highest bin in order to achieve adequate light output. This behavior is likely to occur, although it is difficult to predict how prevalent it will be. For the purposes of simplicity, this model ignores bin jumping.

Table 6. Energy Use of EISA 2007 Tier 1 Compliant Standard Spectrum Lamps, 2011-2013

Lumen Range	Average Power Draw Per Unit (W)	Lifetime Operating Hours	Annual Unit Sales (in millions)	Lifetime Energy Use (GWh/yr)
310 to 749	29	2500	5.4	390
750 to 1049	43	2500	19.0	2042
1050 to 1489	53	2000	9.0	954
1490 to 2600	72	2000	7.9	1133
Total	n/a	n/a	41.3	4520

Table 7. Energy Use of EISA 2007 Tier 1 Compliant Modified Spectrum Lamps, 2011-2013

Lumen Range	Average Power Draw Per Unit (W)	Lifetime Operating Hours	Annual Unit Sales (in millions)	Lifetime Energy Use (GWh/yr)
232-562	29	2500	1.8	130
563-787	43	2500	6.3	681
788-1117	53	2000	3.0	318
1118-1950	72	2000	2.6	378
Total	n/a	n/a	13.8	1507

The calculation of energy savings for Tier 1 is a straightforward difference in power use, multiplied by the number of hours the lamp is used and the number of lamps the standard will affect. The savings from modified spectrum lamps are smaller because we project much lower sales of modified spectrum lamps than standard spectrum lamps for the relevant time period.

Table 8. Savings in Tier 1: Standard Spectrum Lamps in California, 2011-2013

Lumen Range	Average Reduction in Power Draw Per Unit (W)	Attributable Operating Hours	Annual Unit Sales (in millions)	First Year Energy Savings (GWh/yr)	Recognizable Life Cycle Savings (GWh/yr)
310 to 749	9	1000	5.4	48	48
750 to 1049	14	1000	19.0	266	266
1050 to 1489	18	1000	9.0	164	164
1490 to 2600	23	1000	7.9	181	181
Total	n/a	n/a	41.3	660	660

Note: This table accounts for a one-year acceleration of the EISA 2007 Tier 1 standard. Energy savings from this acceleration accrue over 1 lifetime of the base case lamp, which in this case is equal to one year, so that First year Savings and Recognizable Savings are equal.

Table 9. Savings in Tier 1: Modified Spectrum Lamps in California, 2011-2013

Lumen Range	Average Reduction in Power Draw Per Unit (W)	Attributable Operating Hours	Annual Unit Sales (in millions)	First Year Energy Savings (GWh/yr)	Recognizable Life Cycle Savings (GWh/yr)
232-562	11	1000	1.8	20	20
563-787	17	1000	6.3	108	108
788-1117	22	1000	3.0	66	66
1118-1950	28	1000	2.6	73	73
Total	n/a	n/a	13.8	267	267

Note: This table accounts for a one-year acceleration of the EISA 2007 Tier 1 standard. Energy savings from this acceleration accrue over 1 lifetime of the base case lamp, which in this case is equal to one year, so that First year Savings and Recognizable Savings are equal.

The proposed early adoption by California will affect one year's worth of lamp sales, because California can implement the federal standard for each lumen bin only one year early. It is very important to note that although the more efficient lamp may have a much longer operating lifetime, we can only claim savings for the operating hours in the first year. In the base case, once the non-compliant lamp operating hours had been reached, the customer would have been required to buy a new lamp. At that time the Federal Standards would have gone into effect nationally, and the customer would have purchased an efficient lamp, after which there would be no difference in energy use between the base case and proposed case. Therefore energy savings from this proposal occur only during the operating hours of the first year.

3.4.2 Tier 2 Standards: 2018

The second half of the standard recommendation for this CASE paper deals with the Tier 2 standards set in EISA 2007. The Federal bill allows for a new DOE rulemaking on

lamp efficiency, to become effective in 2020.[3] If no rulemaking is held, the default standard will be set at 45 lumens per Watt. This regulation will apply to all the lamps covered under Tier 1, without the exclusion of non-incandescent lamps. At the time of the rulemaking the committee may also choose to include some of the other lamps exempted under Tier 1. The savings calculations for Tier 2 assume that the default value will take effect in California in 2018, two years ahead of the EISA 2007 standard.[4]

The calculation of savings for the early adoption of the Federal Tier 2 standard requires the creation of a new baseline that reflects the impact of the proposed Federal Tier 1 standards. . As with the Tier 1 analysis, a number of simplifying assumptions and reasonable guesses are used. More complex analyses may not add more accuracy given the uncertainties around forecasting product performance and market shares ten years hence. Tables 9 and 10 show the revised baseline power use for standard and modified spectrum lamps that would not comply with Tier 2 regulations in 2018. The values were estimated assuming 100% product compliance with Tier 1 and no major product category exemptions by the Secretary of Energy. As a result, they also assume an operating lifetime equal to that for the Tier 1 compliant cases.

The projections of unit sales now predict a slight increase in market share for incandescent lamps. This projection is based on the assumption that incandescent market share will remain steady through 2016, and then rise again as new high-efficiency incandescent lamps become available and cost-competitive. The sales projections also assume that modified spectrum lamps will lose significant market share when forced to comply with the Tier 2 requirements, as many models will no longer qualify for sale.

Table 10. Energy Use of EISA 2007 Tier 2 Default Value Non-Compliant Standard Spectrum Lamps in California, 2018

Lumen Range	Average Power Draw Per Unit (W)	Lifetime Operating Hours	Annual Unit Sales (in millions)	Lifetime Energy Use (GWh/yr)
310 to 749	29	2000	7.4	429
750 to 1049	43	2000	26.1	2246
1050 to 1489	53	2000	12.4	1311
1490 to 2600	72	2000	10.8	1558
Total	n/a	n/a	56.7	5544

[3] EISA 2007 stipulates that the final rule for this Federal Tier 2 be published by January 1, 2017.
[4] Note that Congress may enact a rulemaking different from the 45 lumens per watt default value, in which case Tier 2 savings calculations would change.

Table 11. Energy Use of EISA 2007 Tier 2 Default Value Non-Compliant Modified Spectrum Lamps in California, 2018

Lumen Range	Average Power Draw Per Unit (W)	Lifetime Operating Hours	Annual Unit Sales (in millions)	Lifetime Energy Use (GWh/yr)
232-562	29	2000	0.8	48
563-787	43	2000	2.9	250
788-1117	53	2000	1.4	146
1118-1950	72	2000	1.2	173
Total	n/a	n/a	6.3	616

The calculations of expected energy use for otherwise non-compliant lamps under the Federal Tier 2 standards assume that the default 45 lumens per watt regulation is applied for both standard and modified spectrum lamps. Currently, this efficiency is only available from compact fluorescent and other non-incandescent lamps. The operating hours for this calculation are based on the operating hours of compact fluorescent lamps that currently meet this efficiency standard. Energy Star currently specifies compact fluorescents of this efficiency to have a 6000 hour operating lifetime, which is the value used in this model.

The annual unit sales are expected to be the same as in the Tier 2 base case scenario. As in the case of Tier 1 projections, the unit sales numbers do not account for a likely market shift toward compact fluorescent lamps as a result of implementing this regulation, nor do they account for the likelihood of bin jumping.

Table 12. Expected Energy Use of EISA 2007 Tier 2 Default Value Compliant Standard Spectrum Lamps, California, 2018

Lumen Range	Average Power Draw Per Unit (W)	Lifetime Operating Hours	Annual Unit Sales (in millions)	Lifetime Energy Use (GWh/yr)
310 to 749	12	6000	7.4	523
750 to 1049	20	6000	26.1	3132
1050 to 1489	28	6000	12.4	2093
1490 to 2600	45	6000	10.8	2950
Total	n/a	n/a	56.7	8698

Table 13. Expected Energy Use of EISA 2007 Tier 2 Default Value Complaint Modified Spectrum Lamps, California 2018

Lumen Range	Average Power Draw Per Unit (W)	Lifetime Operating Hours	Annual Unit Sales (in millions)	Lifetime Energy Use (GWh/yr)
232-562	9	6000	0.8	44
563-787	15	6000	2.9	261
788-1117	21	6000	1.4	174
1118-1950	34	6000	1.2	246
Total	n/a	n/a	6.3	725

The calculation of Tier 2 savings uses the same unit sales as in the Tier 2 base case. As noted in the Tier 1 calculations, the savings are calculated using the lifetime of the base case lamp.[5]

Table 14. Energy Savings in Tier 2: Standard Spectrum Lamps in California, 2018-2019

Lumen Range	Average Reduction in Power Draw Per Unit (W)	Attributable Operating Hours	Annual Unit Sales (in millions)	First Year Energy Savings (GWh/yr)	Recognizable Life Cycle Savings (GWh/yr)
310 to 749	17	2000	7.4	127.6	510
750 to 1049	23	2000	26.1	600.9	2404
1050 to 1489	25	2000	12.4	306.5	1226
1490 to 2600	27	2000	10.8	287.3	1149
Total	n/a	n/a	56.7	1322.3	5289

Note: This table accounts for savings resulting from a two year acceleration of the EISA 2007 Tier 2 default standard. The savings accrue over two lifetimes of a base case lamp, which in this case is 2000 hours (2 years). The Recognizable Savings are therefore four times the First Year Savings.

[5] The Total Recognizable Savings realized from the Tier 2 acceleration will continue to accrue after the 2018 deadline specified in the Huffman bill. Only the First Year Savings from the Tier 2 acceleration can be applied to the Huffman requirements.

Table 15. Energy Savings in Tier 2: Modified Spectrum Lamps in California, 2018-2019

Lumen Range	Average Reduction in Power Draw Per Unit (W)	Attributable Operating Hours	Annual Unit Sales (in millions)	First Year Energy Savings (GWh/yr)	Recognizable Life Cycle Savings (GWh/yr)
232-562	20	2000	0.8	16.6	66
563-787	28	2000	2.9	81.2	325
788-1117	32	2000	1.4	43.7	175
1118-1950	38	2000	1.2	45.6	182
Total	n/a	n/a	6.3	187.1	749

Note: This table accounts for savings resulting from a two year acceleration of the EISA 2007 Tier 2 default standard. The savings accrue over two lifetimes of a base case lamp, which in this case is 2000 hours (2 years). The Recognizable Savings are therefore four times the First Year Savings.

4 Market Saturation and Sales

4.1 Current Market Situation

PG&E, through its sub-contractor, Ecos Consulting, has estimated that California had 437 million general service light sockets in 2007. Standard performance, incandescent, general service lamps represent over 70% of general service lamp sales. Compact fluorescent lamps comprise an additional 24 to 29%, with high performance incandescent lamps (halogen, coiled-coil and other technologies) comprising the remaining fraction.[6]

4.2 Future Market Adoption of High Efficiency Options

Population growth, demographics, and construction and remodeling practices indicate that the demand for general service lamps will continue to increase over time. On the other hand, longer lamp lifetimes mean that lamps will be replaced less frequently, thus lowering yearly lamp sales. Taking both of these factors into account, we predict the total California sales of incandescent general service lamps for 2018 to be 63 million units. For this analysis the percentage of total market share captured by compact fluorescents in 2018 is projected to be 35%, while the incandescent market share is projected to be 60%, with the remaining 5% accounting for emerging technologies such as LEDs. These assumptions reflect the projected impact of the Tier 1 standards on the lighting market.[7]

[6] Based on data from the Department of Commerce and NEMA, See Footnote 1.

[7] Based on internal Ecos models, which attempt to account for population growth, demographic shifts, regulatory impacts, and technological advances. These modeling results are still preliminary, but we are aware of no other more appropriate projections at this time.

5 Savings Potential

5.1 Statewide California Energy Savings

Tables 15 and 16 below show the total savings for early implementation of each Federal Tier, combining both modified and standard spectrum lamps. As these tables show, even a one year acceleration of the EISA standards results in impressive energy savings. These tables do not show values for savings after stock turnover, because savings after the first year would be captured by the Federal standards, regardless. This report focuses only on the additional savings resulting from an accelerated adoption of Federal standards, which would accrue only in the first year of implementation for each bin. In the case of Tier 2, California will realize two years of savings for each of the two years of product sales as a result of implementing the standard two years early. In the case of Tier 2, two years of savings are recognized for each product sold, because the base case lamp is expected to have a 2,000 hour (two year) life. Consequently, "recognized" life cycle savings are twice the first year savings. [8]

Table 16. California Statewide Energy Savings per Year, Tier 1

	Reduction in Peak Demand (MW)	First Year Energy Savings (GWh)	Total Recognizable Energy Savings (GWh)
Standard Spectrum	46	660	660
Modified Spectrum	18	267	267
Total	64	926	926

Note: See Tables 8 and 9

Table 17. California Statewide Energy Savings per Year, Tier 2

	Reduction in Peak Demand (MW)	First Year Energy Savings (GWh)	Total Recognizable Energy Savings (GWh)
Standard Spectrum	93	2,645	10,578
Modified Spectrum	13	187	749
Total	106	2,832	11,327

Note: See tables 14 and 15

5.2 Other Benefits and Penalties

Non-energy benefits are diverse and well-documented elsewhere, including reduced pollution, longer-life lighting technologies, and life cycle cost savings.

[8] All peak demand calculations assume a 0.07 coincidence factor.

6 Economic Analysis

6.1 Incremental Cost

Determining actual incremental cost impacts on a percentage basis for each model is complex for a number of reasons:

- Percentage markups can be very large (200 to 300%) in the incandescent lamp business, in part, because three manufacturers dominate most of the production and two retailers account for about half of all sales. As a result, modest increases in the cost of materials could yield larger retail price increases unless competitive forces reduce markup percentages (Energy Solutions, Ecos Consulting, and Davis Energy Group, 2004).
- The base retail price of current incandescent lamps can range from as little as $0.20 to as much as $2.00, so percentage markups resulting from a fixed incremental cost increase can vary widely (Ibid.).

6.1.1 Tier 1 Costs

The incremental costs for each lumen range were estimated separately. Tables 17 and 18 show the estimated incremental costs for implementation of the Tier 1 standard.

A few specialty incandescent lamps are currently available that meet the proposed Tier 1 efficiency standards. The Halogena lamp, for example, is available in stores for $5.00 per unit. Because this is currently a niche market with very little competition, we expect the price for similar performing products to drop significantly as more options appear. Due to the extremely limited availability of Tier 1 compliant incandescent products on the existing market, we have used price data for compliant compact fluorescent lamps to estimate maximum likely incremental costs. We predict that once Tier 1 regulations take effect, manufacturers of efficient incandescent alternatives will price their products at or below compact fluorescent products in order to preserve sales. Based on this prediction, we have assumed the future incremental cost of efficient incandescent alternatives to be equal to the future incremental cost of compact fluorescent alternatives.

Current market research shows that multi-packs of compact fluorescent lamps can be purchased for $1.5-$2.00 per lamp, even in non-subsidized (i.e., no utility program) markets. We expect that by 2011 that price will have come down so that individual compact fluorescent lamps will be sold for $1.50 a piece. Assuming that the value of the lamp depreciates at a constant rate, we estimate a one year equivalent cost of $0.75 for a compact fluorescent lamp with a two year lifespan. Given an average one year incandescent lamp price of $0.25[9], we estimate incremental costs around $0.50 per lamp. Lamp prices will likely vary somewhat with output, which accounts for the slightly different incremental costs for each lumen bin.

[9] Based on a mix of prices from both large discount retailers and smaller specialty stores.

Table 18. Incremental Costs, Tier 1 Standard Spectrum

Lumen Range	Incremental Cost
310 to 749	$0.90
750 to 1049	$1.00
1050 to 1489	$1.10
1490 to 2600	$1.20
Average	$1.05

Table 19. Incremental Costs, Tier 1 Modified Spectrum

Lumen Range	Incremental Cost
232-562	$0.90
563-787	$1.00
788-1117	$1.10
1118-1950	$1.20
Average	$1.05

Modified spectrum lamps currently experience a markup in the range of $0.30. For simplicity we assume that future efficient modified spectrum products will be marked up by the same amount, leading to identical incremental cost figures for standard and modified spectrum lamps in Tier 1.

6.1.2 Tier 2 Costs

Estimating the incremental costs for Tier 2 requires a 10 year projection of the lighting market. There are currently no incandescent products on the market that comply with the 45 lpw requirement of Tier 2. Given the rapid pace of technological development in the field, it is extremely difficult to assign a price premium to lighting efficiency in the next decade. In order to develop an incremental cost model for Tier 2, we therefore used similar assumptions to the Tier 1 estimates. We assumed that a Tier 2-compliant incandescent lamp could not cost more than an equally efficient compact fluorescent lamp for market reasons. We also assumed that the base case cost of an EISA Tier 2 non-compliant lamp would not significantly change from 2011 to 2018.

In order to estimate the cost of a single Tier 2 compliant compact fluorescent lamp in 2018, we considered both price reduction and performance improvement. We assumed that, rather than dropping in price, compact fluorescent lamps will remain at approximately $1.50 per unit and improve in performance. Performance improvements may include color tuning, dimmability, and increase in form factor options, among other possibilities.

Given that we assume the lifetime-adjusted incremental cost of both our base case and efficient case will remain the same as in Tier 1, the incremental costs for Tier 2 are the same as for Tier 1. Once again, we assume that price premiums for modified spectrum lamps will remain steady between the base case and efficient case, such that they don't affect incremental costs.

Table 20. Incremental Costs, Tier 2 Standard Spectrum

Lumen Range	Incremental Cost
310 to 749	$0.90
750 to 1049	$1.00
1050 to 1489	$1.10
1490 to 2600	$1.20
Average	$1.05

Table 21. Incremental Costs, Tier 2 Modified Spectrum

Lumen Range	Incremental Cost
232-562	$0.90
563-787	$1.00
788-1117	$1.10
1118-1950	$1.20
Average	$1.05

6.2 Design Life

Based on an average of 750 to 1000 hours of life and nearly three hours of operation per day, an incandescent lamp will currently last about one year. Incandescent lamp lifetimes are expected to increase in the coming years, as a result of improved technology.

Lifetime operating hours in 2011-2013 are assumed to increase to 2000 hours for ESIA Tier 1 compliant lamps as a result of various efficiency technologies, as well as apparent manufacturer preference for reducing light output to facilitate regulatory compliance, which extends lamp life.

The operating hours for the Tier 2 calculation are based on the operating hours of compact fluorescent lamps that currently meet the EISA 2007 Tier 2 efficiency standard. Energy Star currently specifies such compact fluorescents to have a 6000 hour operating lifetime, which is the value used in this model.

6.3 Lifecycle Cost / Net Benefit

Based on previously discussed energy savings, design life, and incremental costs, the lifecycle benefits from energy savings for each Tier and spectrum type are shown in Tables 21 through 24 below.[10] Recognizable life cycle benefits per unit are calculated considering only the first year of use in the case of Tier 1 and the first two years of use in the Tier 2 analysis, because the savings stream that counts is limited to the lifetime of the base case lamp (one year for Tier 1 and two years for Tier 2). Thus, recognizable life cycle benefits do not account for the longer life of the more efficient lamps relative to the base case lamps.

[10] Tier 2 Net Present Value dollars are calculated assuming a 2 year measure life and a discount rate of 3%. Current energy costs are assumed to be $0.12 per kilowatt-hour

Table 22. Per Unit Lifecycle Costs And Benefits, Tier 1 Standard Spectrum

Lumen Range	Design Life (hours)	Lifecyle Costs per Unit (Present Value $)	Recognizable Lifecyle Benefits per Unit (Present Value $)
310 to 749	1000	$0.90	$1.06
750 to 1049	1000	$1.00	$1.65
1050 to 1489	1000	$1.10	$2.15
1490 to 2600	1000	$1.20	$2.71
Average	1000	$1.05	$1.90

Note: See footnote 9 for assumptions about discount rate and energy cost.

Table 23. Per Unit Lifecycle Costs And Benefits, Tier 1 Modified Spectrum

Lumen Range	Design Life (hours)	Lifecyle Costs per Unit (Present Value $)	Recognizable Lifecyle Benefits per Unit (Present Value $)
232-562	1000	$0.90	$1.30
563-787	1000	$1.00	$2.01
788-1117	1000	$1.10	$2.60
1118-1950	1000	$1.20	$3.30
Average	1000	$1.10	$2.64

Note: See footnote 9 for assumptions about discount rate and energy cost.

Table 24. Per Unit Lifecycle Costs And Benefits, Tier 2 Standard Spectrum

Lumen Range	Design Life (hours)	Lifecyle Costs per Unit (Present Value $)	Recognizable Lifecyle Benefits per Unit (Present Value $)
310 to 749	2000	$0.90	$4.07
750 to 1049	2000	$1.00	$5.35
1050 to 1489	2000	$1.10	$5.77
1490 to 2600	2000	$1.20	$6.18
Average	2000	$1.05	$5.34

Note: See footnote 9 for assumptions about discount rate and energy cost.

Table 25. Per Unit Lifecycle Costs And Benefits, Tier 2 Modified Spectrum

Lumen Range	Design Life (hours)	Lifecyle Costs per Unit (Present Value $)	Recognizable Lifecyle Benefits per Unit (Present Value $)
232-562	2000	$0.90	$4.69
563-787	2000	$1.00	$6.51
788-1117	2000	$1.10	$7.40
1118-1950	2000	$1.20	$8.82
Average	2000	$1.05	$6.86

Note: See footnote 9 for assumptions about discount rate and energy cost.

The following tables address net lifecycle cost for all lamps affected by the accelerated EISA 2007 standards. These tables rely on the annual sales estimates documented in Section 3.4 above.

Table 26. Net Present Value Lifecycle Benefits, Tier 1 Standard Spectrum

Lumen Range	Present Value Benefit/Cost Ratio	Net Present Value ($)		
		Per Unit ($)	First Year Sales ($M)	All Recognizable Sales ($M)
310 to 749	1.2	$0.16	$1	$1
750 to 1049	1.7	$0.65	$12	$12
1050 to 1489	2.0	$1.05	$9	$9
1490 to 2600	2.3	$1.51	$12	$12
Average	1.8	$0.85	$9	$9
Total	n/a	n/a	$35	$35

Note: See footnote 9 for assumptions about discount rate and energy cost.

Table 27. Net Present Value Lifecycle Benefits, Tier 1 Modified Spectrum

Lumen Range	Present Value Benefit/Cost Ratio	Net Present Value ($)		
		Per Unit ($)	First Year Sales ($M)	All Recognizable Sales ($M)
232-562	1.4	$0.40	$1	$1
563-787	2.0	$1.01	$6	$6
788-1117	2.4	$1.50	$4	$4
1118-1950	2.8	$2.10	$6	$6
Average	2.1	$1.25	$4	$4
Total	n/a	n/a	$17	$17

Note: See footnote 9 for assumptions about discount rate and energy cost.

In the case of Tier 1, the total recognizable net present value of the measure is equal to the net present value for the first year of sales, because the measure only affects one year of sales. In Tier 2 the total recognizable net present value is double the net present value of the first year of sales, because the measure affects two years of sales.

Table 28. Net Present Value Lifecycle Benefits, Tier 2 Standard Spectrum

Lumen Range	Present Value Benefit/Cost Ratio	Net Present Value ($)		
		Per Unit ($)	First Year Sales ($M)	All Recognizable Sales ($M)
310 to 749	4.5	$3.17	$23	$47
750 to 1049	5.4	$4.35	$114	$227
1050 to 1489	5.2	$4.67	$58	$115
1490 to 2600	5.1	$4.98	$54	$108
Average	5.1	$4.29	$62	$124
Total	n/a	n/a	$249	$497

Table 29. Net Present Value Lifecycle Benefits, Tier 2 Modified Spectrum

Lumen Range	Present Value Benefit/Cost Ratio	Net Present Value ($)		
		Per Unit ($)	First Year Sales ($M)	All Recognizable Sales ($M)
232-562	5.2	$3.79	$3	$6
563-787	6.5	$5.51	$16	$32
788-1117	6.7	$6.30	$9	$17
1118-1950	7.3	$7.62	$9	$18
Average	6.5	$5.81	$9	$18
Total	n/a	n/a	$37	$74

7 Acceptance Issues

The Commission has met with the National Electric Manufacturers Association and the American Lighting Association to discuss the EISA 2007 lighting regulations. The industry has registered no written concerns at this time.

8 Recommendations

8.1 Recommended Standards

We recommend that the Commission adopt the Tier 1 efficiency requirements of EISA 2007 regarding 100 watt general service incandescent lamps, to be effective Jan 1, 2011, 75 watt general service lamps in 2012, and 60 and 40 watt general service lamps in 2013, as allowed for California by EISA 2007 The maximum wattage for each given range of lumens under this standard is shown in Tables 25 and 26 below.

Table 30. Recommended Standard, Clear Lamps

Lumen Range	Maximum Rate Wattage	Minimum Rate Lifetime (hrs)	Effective Date
310 to 749	29	1000	1/1/2013
750 to 1049	43	1000	1/1/2013
1050 to 1489	53	1000	1/1/2012
1490 to 2600	72	1000	1/1/2011

Source: EISA 2007

Table 31. Recommended Standard, Modified Spectrum Lamps

Lumen Range	Maximum Rate Wattage	Minimum Rate Lifetime (hrs)	Effective Date
232-562	29	1000	1/1/2013
563-787	43	1000	1/1/2013
788-1117	53	1000	1/1/2012
1118-1950	72	1000	1/1/2011

Source: EISA 2007

Proposed Changes to the Title 20 Code Language
Precise formulation of the proposed language will be developed after further review by the CEC.

9 References

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