**California Energy Commission**
**DRAFT STAFF REPORT**

# ANALYSIS OF SMALL DIAMETER DIRECTIONAL LAMP AND LIGHT EMMITING DIODE LAMP EFFICIENCY OPPORTUNITIES

**California Energy Commission**

**2014 Appliance Efficiency Pre-Rulemaking**

**Docket Number 14-AAER-1**

CALIFORNIA
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# CALIFORNIA ENERGY COMMISSION


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# PREFACE

On March 14, 2012, the California Energy Commission issued an Order Instituting Rulemaking (OIR) to begin considering standards, test procedures, labeling requirements, and other efficiency measures to amend the Appliance Efficiency Regulations (California Code of Regulations, Title 20, Sections 1601 through Section 1608). In this OIR, the Energy Commission identified a variety of appliances with the potential to save energy and/or water. The goal of this pre-rulemaking is to develop the proposed appliance efficiency standards and measures to realize these energy savings opportunities.

On March 25, 2013, the Energy Commission released an “Invitation to Participate” to provide interested parties the opportunity to inform the Energy Commission about the product, market, and industry characteristics of the appliances identified in the OIR. The Energy Commission reviewed the information and data received in the docket and hosted staff workshops on May 28 through 31, 2013, to vet this information publicly.

On June 13, 2013, the Energy Commission released an “Invitation to Submit Proposals” to seek proposals for standards, test procedures, labeling requirements, and other measures to improve the efficiency and reduce the energy or water consumption of the appliances identified in the OIR.

The Energy Commission reviewed all information received to determine which appliances were strong candidates for the development of efficiency standards and measures. Based on its assessment, the Energy Commission will proceed with appliances in phases for the remainder of the rulemaking. The second phase of rulemaking commences with the development of staff reports and proposed regulations for small diameter directional lamps and general service light emitting diode (LED) lamps.

# ABSTRACT

This staff report focuses on two types of lamps. The first type is small-diameter directional lamps include lamps of 2.25 inches or less in diameter, which include multifaceted reflector lamps and parabolic aluminized reflector lamps (PAR16s and PAR11s). Currently, no Title 20 standard for small-diameter directional lamps exists, nor is there a federal standard for such lamps of less than or equal to 2.25 inches. (Federal standards exist for incandescent reflector lamps with diameters greater than 2.25 inches.) A large majority of the small diameter directional lamps currently installed in California buildings are the most energy-consumptive Incandescent, halogen and HIR lamps. Due to directional lamps ability to illuminate certain the work area in a particular direction for demanding visual tasks, it was technically unfeasible to substitute incandescent, halogen, and HIR lamps. Recently LED small diameter directional lamps have become available in the market. LED small-diameter directional lamps provide comparable utility as incandescent lamps, however these lamps are highly energy efficient. LEDs are cost-effective and technically feasible, and use significantly less energy than incandescent, halogen, and halogen infrared lamps. By replacing the existing inefficient, energy-wasting incandescent lamps with energy-efficient LED lamps, California will save approximately 1,535 GWh annually. Sales of cost-effective, energy- saving LED lamps are low, but growing. Regulations will transform the market towards more cost-effective and energy-efficient LED lamps.

Second, this staff report proposes requirements for white light LED replacement lamps and retrofit kits with E12, E17, E26, or GU-24 bases, including omni-directional, directional, and decorative lamps. LED lamps are relative newcomers to the replacement lamp market. They are dramatically more efficient than incandescent lamps, and their efficacy continues to improve raidly. (Efficacy is the relationship between light produced (lumens) and energy used (in watts). Average LED efficacy has outpaced that of compact fluorescent lamps as well. Today, LED lamps are only a small portion of the lighting market in terms of overall sales. Currently there are federal standards for general service incandescent lamps (GSIL), large diameter directional incandescent lamps, and general service CFL lamps. However, there are no Title 20 or federal standards for GSL LED lamps. To save significant energy in California it is necessary to develop cost effective energy efficiency standards for LED lamps. Furthermore, to encourage faster adoption of these energy savings lamps and save significant energy in California, there is a need to ensure a minimum level of quality and performance from these lamps to prevent consumer dissatisfaction.

**Keywords:** Appliance Efficiency Regulations, energy efficiency, LEDs, LED lamps, Lighting, MR16, General Service Lamps, Light Quality, Incandescent, Halogen, HIR, and Small Diameter Directional Lamps

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**PART B**

# EXECUTIVE SUMMARY

The California Energy Commission's Appliance efficiency Program has developed a staff report analysis of small diameter directional lamp and light emitting diodes (LED) lamps with proposals that address energy efficiency opportunities through Title 20 standards. The staff report analysis provides basis for the proposed standards. Staff's analysis shows that proposed small diameter directional lamps and LED lamp standards are technically feasible, cost effective to consumers, and would save significant energy. Specifically, the small diameter directional lamps and LED lamp standard are estimated to save 1600 GWh/year and 2,194 GWh/year statewide respectively.

Small diameter directional lamps are often used in retail, hospitality, residential, and museum applications. However, their popularity in residential applications is also growing. Incandescent based small diameter directional lamps are practical and relatively inexpensive, but higher efficacy LED lamps are dramatically more efficient and their efficacy continues to improve. The proposed standard for small diameter directional lamps covers lamps of diameter 2.25 inches or less, which include some multi-faceted reflector (MR) lamps (MR16s and MR11s) and parabolic aluminized reflector (PAR) lamps (PAR16s and PAR11s). Staff's proposal requires small diameter directional lamps to have an efficacy of 80 lumens per watt or greater and a minimum lifetime of 25,000 hours. The small diameter directional lamps proposal does not include other quality standards such as color rendering Index (CRI).

The installed stock of small diameter directional lamps in California is comprised of the poor efficiency incandescent, halogen, and HIR lamps. Small diameter directional LED lamps are relative newcomers to the lighting market, but can be used as replacements and provide large energy savings. The staff's proposed standard would transform the market to more cost-effective and energy efficient small diameter directional lamps.

This staff report also proposes LED lamp standards for general-purpose lighting. The scope of the standards includes the E12, E17, E26, or GU-24 bases, including omni-directional, directional, and decorative lamps. The LED lamp standard also includes LED lamps designed for retrofitting the covered socket types. There are about 540 million general-purpose lamps installed in residential buildings in California.

Staff proposes a standard that requires improvements to lamps currently on the market, yet allows for tradeoffs between a lamp's efficiency and color rendering index. The proposed Tier I standard will take effect January 1, 2017 and Proposed Tier II standard will be effective on January 1, 2019. The proposed standards also require omni-directional lamps to produce a light distribution pattern that aligns with requirements adopted by the US Environmental Protection Agency's (EPA) ENERGY STAR(R) program for lamps. The staff also proposes labeling standards that require manufacturers to meet minimum thresholds before making claims about dimmability, and applicability to retrofits of traditionally incandescent sockets.

# CHAPTER 1: Legislative Criteria

Section 25402(c)(1) of the California Public Resources Code[1] mandates the California Energy Commission reduce the inefficient consumption of energy and water by prescribing efficiency standards and other cost-effective measures[2] for appliances that require a significant amount of energy and water to operate on a statewide basis. Such standards must be technologically feasible and attainable and must not result in any added total cost to the consumer over the designed life of the appliance.

In determining cost-effectiveness, the Energy Commission considers the value of the water or energy saved, the effect on product efficacy for the consumer, and the life-cycle cost to the consumer of complying with the standard. The Energy Commission also considers other relevant factors, including but not limited to the effect on housing costs, the total statewide costs and benefits of the standard over the lifetime of the standard, the economic impact on California businesses, and alternative approaches and the associated costs.

In addition, the California Lighting Efficiency and Toxics Reductions Act of 2007[3] requires the Energy Commission to adopt minimum energy efficiency standards for general purpose lighting. These standards, in combination with other programs and activities, must be structured to reduce average statewide electrical energy consumption by not less than 50 percent from 2007 levels for indoor home lighting and not less than 25 percent from the 2007 levels for indoor commercial and outdoor lighting by 2018.

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[1] Cal. Pub. Resources Code § 25402(c)(1), available at http://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?lawCode=PRC&sectionNum=25402; Warren-Alquist State Energy Resources Conservation and Development Act, Division 15 of the Public Resources Code, § 25000 et seq available at http://www.energy.ca.gov/2014publications/CEC-140-2014-001/CEC-140-2014-001.pdf.

[2] These include energy and water consumption labeling, fleet averaging, incentive programs, and consumer education programs.

[3] Assembly Bill 1109 (Huffman, Chapter 534, Statutes of 2007), codified in relevant part at Pub. Resources Code, § 25402.5.4.

# CHAPTER 2:
# Efficiency Policy

The Warren Alquist Act[4] establishes the California Energy Commission as California's primary energy policy and planning agency and mandates the Commission reduce the wasteful and inefficient consumption of energy and water in the state by prescribing standards for minimum levels of operating efficiency for appliances that consume a significant amount of energy or water statewide.

For nearly four decades, appliance standards have shifted the marketplace toward more efficient products and practices, reaping large benefits for California's consumers. The state's appliance efficiency regulations saved an estimated 22,923 gigawatt hours (GWh) of electricity and 1,626 million therms of natural gas in 2012[5] alone, resulting in about $5.24 billion in savings to California consumers in 2012 from these regulations.[6] Since the mid-1970s, California has regularly increased the energy efficiency requirements for new appliances sold and new buildings constructed in the state. In addition, the CPUC in the 1990s de-coupled the utilities' financial results from their direct energy sales, facilitating utility support for efficiency programs. These efforts have reduced peak load needs by more than 12,000 MW and continue to save about 40,000 GWh per year of electricity.[7] The recently adopted appliance standards for battery chargers are expected to save 2,200 GWh annually, which is enough energy to power 350,000 California households each year.[8] Still, there remains huge potential for additional savings by increasing the energy efficiency and improving the use of appliances.

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[4] The Warren-Alquist State Energy Resources Conservation and Development Act, Division 15 of the Public Resources Code, § 25000 et seq available at http://www.energy.ca.gov/2014publications/CEC-140-2014-001/CEC-140-2014-001.pdf.

[5] California Energy Commission. California Energy Demand 2014-2024 Revised Forecast, September 2013, available at http://www.energy.ca.gov/2013publications/CEC-200-2013-004/CEC_200-2013-004-SD-V1-REV.pdf.

[6] Using current average electric power and natural gas rates of: residential electric rate of $0.164 per kilowatt-hour, commercial electric rate of $0.147 per kilowatt-hour, residential gas rate of $0.98 per therm and commercial gas rate of $0.75 per therm. This estimate does not incorporate any costs associated with developing or complying with appliance standards.

[7] *Energy Action Plan II*, available at http://www.energy.ca.gov/energy_action_plan/2005-09-21_EAP2_FINAL.PDF, page 3.

[8] *Staff Analysis of Battery Chargers and Self-Contained Lighting Controls*, available at http://www.energy.ca.gov/2011publications/CEC-400-2011-001/CEC-400-2011-001-SF.pdf, page iii; California Energy Commission, *Energy Efficiency Standards for Battery Charger Systems Frequently Asked Questions*, January 2012, available at http://www.energy.ca.gov/appliances/battery_chargers/documents/Chargers_FAQ.pdf.

## Reducing Electrical Energy Consumption to Adress Mitigate Climate Change

Appliance energy efficiency is identified as a key to achieving the greenhouse gas (GHG) emission reduction goals of Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006)[9] (AB 32), as well as the recommendations contained in the California Air Resources Board's *Climate Change Scoping Plan*.[10] Energy efficiency regulations are also identified as key components in reducing electrical energy consumption in the Energy Commission's *2013 Integrated Energy Policy Report (IEPR)*[11] and the California Public Utilities Commission's (CPUC) 2011 update to its *Energy Efficiency Strategic Plan.*[12]

## Loading Order for Meeting the State's Energy Needs

California's loading order places energy efficiency as the top priority for meeting the state's energy needs. Energy Action Plan II continues the strong support for the loading order, which describes the priority sequence for actions to address increasing energy needs. The loading order identifies energy efficiency and demand response as the State's preferred means of meeting growing energy needs.[13]

For the past 30 years, while per capita electricity consumption in the United States has increased by nearly 50 percent, California electricity use per capita has been nearly flat. Continued progress in cost-effective building and appliance standards and ongoing enhancements to efficiency programs implemented by investor-owned utilities (IOUs), customer-owned utilities, and other entities have significantly contributed to this achievement[14]

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[9] Assembly Bill 32, California Global Warming Solutions Act of 2006, available at http://www.leginfo.ca.gov/pub/05-06/bill/asm/ab_0001-0050/ab_32_bill_20060927_chaptered.html.

[10] California Air Resources Board, *Climate Change Scoping Plan*, December 2008, *available at* http://www.arb.ca.gov/cc/scopingplan/document/adopted_scoping_plan.pdf.

[11] California Energy Commission, *2013 Integrated Energy Policy Report*, January 2014, available at http://www.energy.ca.gov/2013publications/CEC-100-2013-001/CEC-100-2013-001-CMF.pdf.

[12] California Public Utilities Commission, *Energy Efficiency Strategic Plan*, updated January 2011, *available at* http://www.cpuc.ca.gov/NR/rdonlyres/A54B59C2-D571-440D-9477-3363726F573A/0/CAEnergyEfficiencyStrategicPlan_Jan2011.pdf.

[13] *Energy Action Plan II*, available at http://www.energy.ca.gov/energy_action_plan/2005-09-21_EAP2_FINAL.PDF, page 2.

[14] *Energy Action Plan II*, available at http://www.energy.ca.gov/energy_action_plan/2005-09-21_EAP2_FINAL.PDF, page 3.

## Zero-Net-Energy Goals

The *California Long-Term Energy Efficiency Strategic Plan*,[15] adopted in 2008 by the CPUC, and developed with the Energy Commission, the California Air Resource Board, the state's utilities, and other key stakeholders, is California's roadmap to achieving maximum energy savings in the state between 2009 and 2020, and beyond. It includes four "big bold strategies" as cornerstones for significant energy savings with widespread benefit for all Californians:[16]

- All new home construction in California will be zero-net-energy by 2020.
- All new commercial construction in California will be zero-net-energy by 2030.
- Heating, ventilation, and air conditioning (HVAC) will be transformed to ensure that the energy performance is optimal for California's climate.
- All eligible low-income customers will be given the opportunity to participate in the low-income energy efficiency program by 2020.

These strategies were selected based on the ability to achieve significant energy efficiency savings and bring energy-efficient technologies and products into the market.

On April 25, 2012, Governor Edmund G. Brown Jr. further targeted zero-net-energy consumption for state-owned buildings. Executive Order B-18-12[17] requires zero-net-energy consumption for 50 percent of the square footage of existing state-owned buildings by 2025 and zero-net energy consumption from all new or renovated state buildings beginning design after 2025.

To achieve these zero-net-energy goals, the Energy Commission has committed to adopting and implementing building and appliance regulations that reduce wasteful power and water consumption. The *Long-Term Energy Efficiency Strategic Plan* calls on the Energy Commission to develop a phased and accelerated "top-down" approach to more stringent codes and

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[15] California Energy Commission and California Public Utilities Commission, *Long-Term Energy Efficiency Strategic Plan,* updated January 2011, available at http://www.cpuc.ca.gov/NR/rdonlyres/A54B59C2-D571-440D-9477-3363726F573A/0/CAEnergyEfficiencyStrategicPlan_Jan2011.pdf.

[16] California Energy Commission and California Public Utilities Commission, *Long-Term Energy Efficiency Strategic Plan*, available at http://www.cpuc.ca.gov/NR/rdonlyres/14D34133-4741-4EBC-85EA-8AE8CF69D36F/0/EESP_onepager.pdf, page 1.

[17] Office of Edmund G. Brown Jr., Executive Order B-18-12, April 25, 2012, available at http://gov.ca.gov/news.php?id=17506.

standards.[18] It also calls for expanding the scope of appliance standards to plug loads, process loads, and water use. The Energy Commission adopted its detailed plan for fulfilling these zero-net-energy objectives in its *2013 IEPR*.[19]

## Governor's Clean Energy Jobs Plan

On June 15, 2010, as a part of his election campaign, Governor Brown proposed a *Clean Energy Jobs Plan*,[20] which called on the Energy Commission to strengthen appliance efficiency standards for lighting, consumer electronics, and other products. Governor Brown noted that energy efficiency is the cheapest, fastest, and most reliable way to create jobs, save consumers money, and cut pollution from the power sector. He stated that California's efficiency standards and programs have triggered innovation and creativity in the market. Today's appliances are not only more efficient, but they are cheaper and more versatile than ever.

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[18] California Energy Commission and California Public Utilities Commission, *Long-Term Energy Efficiency Strategic Plan*, p. 64.

[19] California Energy Commission, *2013 IEPR*, pp. 21-26.

[20] Office of Edmund G. Brown Jr., *Clean Energy Jobs Plan,* available at http://gov.ca.gov/docs/Clean_Energy_Plan.pdf.

# PART A

## CHAPTER 3:
## Small Diameter Directional Lamps Background

### Product Description

Application of lighting can be categorized as general, directional, or aesthetic etc. General lighting is designed to produce consistent level of illumination over an entire area; general lighting consists of ambient light, which provides uniform light over an area. Directional lighting is used in illuminate the work area in a particular direction. Directional lighting provides more light on a particular object than the surrounding area and is used when high levels of light are required for accenting purposes or for demanding visual tasks. Directional lighting includes accent lighting, down lighting, and track lighting.

Small diameter directional lamps is a class of general service lamps that are less than or equal to 2.25 inches in diameter. The following paragraphs describe the wide variety of types of these lamps studied in this Staff Report. Filament base directional lamps are the most common source of light found in homes and commercial buildings. Filament base lamps include incandescent, halogen, and halogen-infrared (HIR) lamps. There are two types of small diameter directional lamps available in filament base technology: (a) Multifaceted Reflector (MR) lamps; and (b) Parabolic Aluminized Reflector (PAR) lamps. IOUs CASE study estimates that 95 percent of the small diameter directional lamps installed the California buildings are MR types and only 5 percent lamps are PAR type.[21]

MR lamps are typically designed for low-voltage operation using shorter, thicker, and more robust filaments which allow the lamp to generate high luminous intensity. More robust filaments can accommodate higher currents, while thinner filaments are needed to limit current higher voltage applications. In combination with lamp reflector design, the short filament also allows more precise control of light distribution and beam intensity, otherwise known as beam angle and center beam candle power (CBCP).

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[21] *IOU CASE Report: Small Diameter Directional Lamps*, July 29, 2013 available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Small_Diameter_Directional_Lamps_2013-07-29_TN-71763.pdf page 3

## Incandescent, Halogen, and HIR MR and MRX Lamps

MR lamps are used for accent, task, and display lighting in museums, art galleries, retail stores, residential settings, and entertainment venues.

One of the most common type of MR lamp is the MR 16 which is short for Multifaceted Reflector with a 16/8" (16 x 1/8) diameter or 2 inches. The MR 16 lamp contains a light source consisting of a single-ended quartz halogen filament capsule mounted within a pressed glass reflector. The reflective coating of MR 16 lamps can either be dichroic [22]or aluminum. Typical bases for these lamps are 2-pin GU 5.3 for low voltage applications and GU 10 base for line voltage applications. [23]

Typically, MR lamps are available in different base types, such as pin base and screw base, and are sold in different wattage ranges, such as 20W, 35W, or 50W conventional wattages, and comprise the majority of the market. HIR lamps come in lower wattages (for example, 37W) intended to replace higher wattages (for example, 50W), but have a lower market penetration.

Halogen and HIR low voltage lamps have thicker and shorter filaments and accommodate higher current, at low voltage while thinner filaments lamps produce light at low current and high voltage. Shorter filaments allow precise control of the light distribution and beam intensity, known as beam angle and Center Beam Candle Power (CBCP). CBCP is performance parameters that characterize the beam appearance and the maximum beam intensity of a directional lamp.

Halogen, HIR, or incandescent MR lamps provide optical control by collecting the light from the filament to create a concentrated beam of light. This is usually done through faceted surfaces within the lamp, although some MR lamps contain smooth rather than faceted surfaces. As described previously, the light source of halogen MR lamps is a single-ended quartz halogen filament capsule. MR lamps have a reflective coating to capture light produced by the quartz halogen filament capsule. The reflective coating of MR16 lamps can be either dichroic or aluminum.

- A dichroic coating is a thin, multi-layer dielectric (non-metallic film) that allows infrared radiation (heat) from the filament capsule to pass through the reflector while it reflects visible radiation (light) forward
- An aluminum coating is a thin film of aluminum that, unlike the dichroic coating, reflects both infrared and visible radiation.

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[22] Dichoric coating will causes visible light to be split up into distinct beams of different wavelengths (colors). or the coating will cause light rays of different polarization are absorbed by different amounts.
[23] Low voltage lamps operate with a low voltage transformer of voltage 6-24 volts, whereas line voltage lamps operate at 110 volts.

Some low voltage MR16 lamps have a cover glass on the front end of the reflector. This cover is a safety measure designed to contain any broken fragments in case the lamp shatters when it fails. [24]

Halogen MR lamps offer a variety of light distribution ranging from narrow pin spots with a beam angle of 7° to beam angles of 60° or greater (wide flood distribution). MR lamps with greater range offerings are continuously reaching the market.

The quartz halogen filament capsule in MR lamps is designed to operate at significantly higher pressure than a standard incandescent lamp. Because the capsule can rupture under certain end-of-life conditions, MR 16 lamps must have either an integrated cover glass or be used in an enclosed fixture. The majority of MR 16 lamps are designed for low voltage operation (12 or 24 volts) and use shorter and thicker filaments, which allow lamps to generate high luminous intensities. Large number of MR lamps use 12 volts; however, some operate using 6 or 24 volts. Low-voltage MR 16 lamps require a transformer to step down supply voltage to an appropriate voltage level.

Since small diameter directional lamps operate at a low voltage (typically 12 V, but can be 6 V or 24 V), a transformer is used to reduce a line voltage (typically 120 V or 277 V) to an appropriate level that small diameter directional lamps can withstand. There are two major types of low-voltage transformers, magnetic and electronic. Transformers generally need to meet a minimum load requirement to work properly without flickering. Electronic transformers can achieve lower minimum load requirements, as low as 2.5 watts.

In small diameter directional lamps beam angle is critical in delivering the light at the precise point to illuminate the desired object. Beam angle is the angle at which the beam intensity is 50 percent of the Center Beam Candle Power (CBCP). Beam angle for MR 16 range from less than 10° to greater than 50°.[25] Another factor that determines the beam intensity is field angle: the angle at which the beam intensity is 10 percent of the CBCP. Typical MR lamp beam angles range from 10° to 60°.

In many cases, the brightness of the object to be highlighted needs to be 3-10 times brighter than the surrounding area. High levels of light are needed to accentuate dark colored objects. To increase the brightness from general area to accent area, the CBCP of the lamp becomes a critical factor in providing the necessary object illumination. CBCP is the intensity in candelas emitted at the center of a directional lamp beam (0°). CBCP values for halogen MR 16 lamps range from

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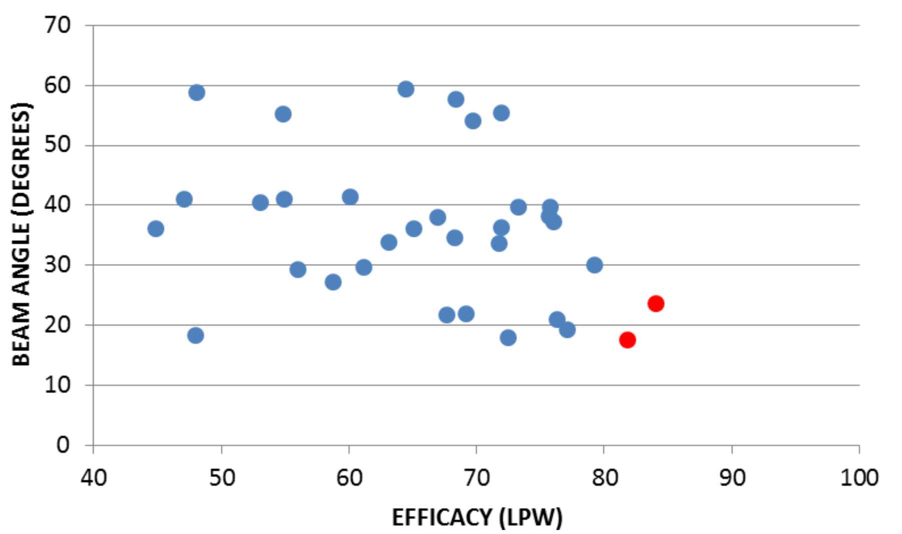
[24] Rensselaer Lighting Research Center, available at http://www.lrc.rpi.edu/programs/nlpip/lightingAnswers/mr16/whatAreMR16.asp.

[25] *Performance of Halogen Incandescent MR16 Lamps and LED Replacements* Prepared for the U.S. Department of Energy by Pacific Northwest National Laboratory, available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/mr16_benchmark_11-08.pdf, page 3.

230 to 16,000 candelas and these values are affected by lamp wattage and the beam angle of the lamp. A lamp with a large beam angle will have a lower CBCP than a lamp with narrow distribution.

IOUs CASE team has plotted the beam angle against efficacy for currently listed lighting facts data for LED SDDLs. While there is a limited data set for reported beam angle, the data shows that 80 LPW are capable of achieving narrow beam angles.

**Figure 1: Beam Angele Vs Efficacy**




## Incandescent, Halogen, and HIR PAR and R Lamps

Reflector (R) and PAR (Parabolic Anodized Reflector) lamps are another type of small diameter directional lamps. A small diameter directional PAR lamp is a halogen, HIR or incandescent spot light that uses a parabolic (U-shaped) reflector to collect and reflect the light from the front of the bulb. Small diameter directional PAR lamps come in two sizes: PAR 11 and PAR 16. PAR lamps have less control over beam angle, shape, and sharpness relative to MR lamps. Though small diameter PAR lamps (including PAR 16 lamps) are far less common than MR lamps, they are still available and used in entertainment and venue lighting. PAR lamps operate at line voltage and generally have medium screw bases, medium-screw bases, or GU-10 bases. PAR 16 lamps are sold in three conventional wattage categories: 20W, 35W, and 50W.

## LED MR, MRX, PAR, and R Lamps

Small diameter LED directional lamps are similar in shape and size to conventional MR and PAR incandescent, halogen, and HIR lamps, and can be used in most fixtures designed for halogen MR lamps. There are a wide variety of designs, varying significantly with regard to beam width, light color, efficiency and luminous power. Some LED-based MR compatible lamps rely on the optics of the LED(s) to control the beam width. Some designs may have simple cut-off apertures that limit beam width, or even individual reflectors for each LED.[26] A few LED MR 16 lamps with the multifaceted surface are available in the market.[27] The following paragraphs provide more detail on the types of LED lamps studied in this Staff Report.

LED MR lamps provide uniformity across the beam, have fewer hotspots, have no filament images, and have no ragged edges.[28] These attributes make LED directional lamps better products than halogen and HIR.

In terms of beam angle, LED manufacturers are continuously working to provide lamp options with narrow spot, spot, narrow flood, and flood angles. Many LED manufacturers now offer MR 16 lamps with 10° and 60° beam angles and the range of beam angles in between.

LED Small diameter directional lamp beam angles use different optics than MR, PAR, and R lamps to provide narrow spot and wide flood beams. The optics have a limited effect on the efficacy of the lamp, due to relatively thin optical thicknesses and clear lenses. Since technical feasibility does not appear to be a barrier, consumers can anticipate a variety of products with spot and flood beam angles as LED lamp demand grows in the market.

## Flicker and Dimmablity

Replacing high wattage small diameter directional halogen lamps with low wattage LED lamps can result in flicker in some existing low voltage applications. This flicker is caused by incompatibility of the existing transformer with the replacement LED lamp. LED lamps are extremely energy efficient when compared to incandescent, halogen, or HIR lamps they are replacing. The reduction in power consumption by LED lamps can result in some of the electronic transformers entering into power saver mode or even shutting off (resulting in flickering or no light output). Transformers require a minimum power load for proper operation. If this minimum load requirement is not met, then the protection circuit will shut off the transformer. However, transformer technology has progressed substantially in the past few years. New transformers that are specifically designed for LED compatibility have the ability to run low voltage LEDs while avoiding flicker.

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[26] Global information Premium Market Research Reports, *LED Multifaceted Reflector (MR) Lamps Global Market Forecast*, available at http://www.giiresearch.com/report/el306109-led-multifaceted-reflector-mr-lamps-global-market.html.

[27] *Superbrightled.com 5 Watt MR16 LED bulb* - Multifaceted Lens with High Power Epistar COB LED, available at http://classic.superbrightleds.com/moreinfo/led-spot-flood/5-watt-mr16-led-bulb--multifaceted-lens-with-high-power-epistar-cob-led/1396/#.

[28] U.*S. Department of Energy, Building Technologies Program Solid-State Lighting Technology Fact Sheet*, available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led_mr16-lamps.pdf.

Electronic transformers typically require a higher minimum load in order for the LED lamps to maintain their dimming abilities, which is often higher than the minimum required load for a transformer to run. This minimum load can vary from as low as 2.5 W (low-wattage start) to as high as 20 W (for dimming capabilities). Switching to an LED-compatible transformer allows for LED dimming.

The price for these LED-compatible transformers is reasonable. Standard 12 V, 60 W transformers can be found in the market for less than $18, while some more powerful 300 W electronic transformers can be upwards of $120. LED lamps can save significant energy and money, and switching to a LED compatible transformer will be the easiest way to accommodate lamps with dimming capabilities. The Energy Commission is not requiring the use of a dimmer with small diameter directional LED lamps.

## Small Diameter Directional Lamp Systems

Small diameter directional lamp systems are designed to operate between1-10 lamps, however, about 60 percent of the systems use 3-5 lamps.

The system power requirements are based on the assumption that 15 percent of the lighting load is a transformer load. Use of highly efficient lamps would significantly reduce the system power consumption and reduce the energy used by the transformer. The U.S. Department of Energy (DOE) regulates transformers with rated wattages of 250 Watts or less. These transformers, or external power supplies, must meet level IV power supply requirements. Recently adopted power supply standard by U.S. DOE will cover transformers and external power supplies of all voltages.

## Overview of Transformer Compatibility Design Approaches

Transformer compatibility is occasionally an issue for low voltage LED lamps that are installed on some low voltage transformers, though these issues are increasingly less prevalent based on evidence from utility rebate programs that suggest that the incidence of compatibility issues is decreasing. Manufacturers recognize that transformer compatibility for low voltage lamps has been a concern and have therefore been investing resources to improve the LED driver and lamp designs. It is estimated that in most cases low voltage LED lamp/transformer compatibility challenges can be resolved by changing to a lamp with a different driver or circuitry design, while maintaining existing fixture, transformer, and wiring infrastructure. For remaining compatibility challenges, the low voltage transformer can be swapped out for another low voltage system, or the system could be converted to line voltage.

## Transformer Technologies

The following transformer technologies are being used to power low voltage small diameter directional lamp system.

1. Buck Converter: A buck converter is a voltage step down and current step up converter. Buck converters cause the stack voltage to be less than the input voltage. Buck converters are a good solution for non-dimmable lamps, but perform poorly when a dimmer is installed.

2. Boost Converter: A boost converter is a DC-to-DC power converter with an output voltage greater than its input voltage. Boost converters have slightly better performance than buck converters due to their ability to boost up to 21V. However, this design approach also performs poorly under dimming applications, but performs better than buck converters in non-dimming applications.

3. Single Stage Solution: A highly effective approach at reduced cost, with considerable flexibility. LEDs selected for the lamp can operate between 6V and 21V and should function properly. However, there are efficiency losses that could limit light output. Single stage solutions work properly with dimmers, so this solution is suitable for both dimming and non-dimming applications.

4. Diode Bridge: Diode bridges are applied most commonly in magnetic low voltage transformers, but due to space constraints, a capacitor large enough in capacitance to maintain operation of the diode bridge and small enough to fit inside the form factor of the lamp is difficult to design.

5. Dynamic Transformer Recognition: A dynamic transformer recognition system can be a two stage system, a single stage system, or an extra circuitry system. This solution allows the lamp to recognize an issue and add extra load, by providing some resistance across transformer. Dynamic transformer recognition systems aid in transformer compatibility with the lamp. Dynamic transformer recognition decreases lamp efficiency, but increases compatibility.

# CHAPTER 4: Regulatory Approaches

## Objectives

Based on a study conducted by Navigant Consulting, [29] staff estimates that there will be approximately 15.8 million small diameter directional lamps installed in residential and commercial buildings in California in 2018. Based on this quantity, staff estimates that these lamps will consume about 1883 GWh/year in 2018. Most small diameter directional lamps stock is energy inefficient filament-based incandescent, halogen, and halogen infrared (HIR) lamps[30]. Small diameter directional lamp sales and stock are increasing, leading to an increase in statewide energy consumption.

Currently, consumers do not have sufficient information related to the energy consumption of small diameter directional lamps. These lamps are not regulated by the State of California, the U.S. Department of Energy (DOE), or the Federal Trade Commission. There are no energy guide labeling requirements for these lamps, and manufacturers of small diameter directional lamps are not required to disclose energy consumption information. Moreover, there is no mandatory test procedure prescribed to disclose the energy rating of these lamps.

It is the Energy Commission's objective to ensure that the 15.8 million small diameter directional lamps expected to be installed in 2018 and those installed thereafter, are as energy efficient as possible, and require the least amount of effort by purchasers to identify the small diameter directional lamps with the desired characteristics. As discussed below, regulations which set an efficiency floor are the best method for achieving these objectives.

Small diameter directional lamps are available in three technologies, Halogen, HIR and LED. The following table provides the summary of performance characterizations for halogen and LED:

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[29] These numbers are calculated based on the Navigant Consulting. 2011, "*Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications,*" available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/nichefinalreport_january2011.pdf

[30] *Codes and Standards Enhancement (CASE) Initiative For PY 2013: Title 20 Standards Development Small Diameter Directional Lamps* available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Small_Diameter_Directional_Lamps_2013-07-29_TN-71763.pdf (page 11)

**Table 1: Summary of Ranges for Typical Performance by Lamp technology**

| Lamp Performance Characterization | Halogen Non Infrared | LED Replacement Lamps |
|---|---|---|
| Lumen Output | 200-950 | 200-650 |
| Wattage Availability | 20W, 35W. 50W | 3-10 watts |
| Beam Angle Availability | 10-60 | 10-60 |
| Efficacy LPW | 5-25 | 35-90 |
| Average Lifetime Hours per lamp | 1,500-3,000 hours | 25,000-35,000 |
| Low an line voltage | 12 V & 120 V | 12 V & 120 Volt |

Sources: GE 2013a/b, Phillips 3a/b, Sylvania 2013a/b, Energy Star QPL 2013, PG&E 2010

Investor-owned utilities (IOUs) conducted through research and have analyzed the small-diameter directional lamps in detail and have submitted Codes and Standards Enhancement (CASE) studies to the Energy Commission in July 2013.[31] Their research found a large variation in the energy efficiency and price of small diameter directional lamps in the market shown in Figure 2, below. Data in the CASE study confirmed that inefficient incandescent, halogen lamps, and HIR lamps have a shorter life compared with LED lamps.[32] A shorter life results in more replacement costs, due to more frequent replacements. Furthermore, inefficient lamps result in higher power draws. Higher operating costs for these lamps. Many consumers may not be aware of the cost of operation and short life cycle of these lamps.[33]

Line and Low voltage small diameter directional lamp system:

There is a marked difference in efficacy between low and line voltage lamps[34]

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[31] *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative* August 6, 2014 available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Small_Diameter_Directional_Lamps_Addendum_to_CASE_Report_2014-08-06_TN-73551.pdf

[32] *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative* July 30, 2013 available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Small_Diameter_Directional_Lamps_2013-07-29_TN-71763.pdf page26

[33] *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative* August 6, 2014 available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Small_Diameter_Directional_Lamps_Addendum_to_CASE_Report_2014-08-06_TN-73551.pdf Page 26

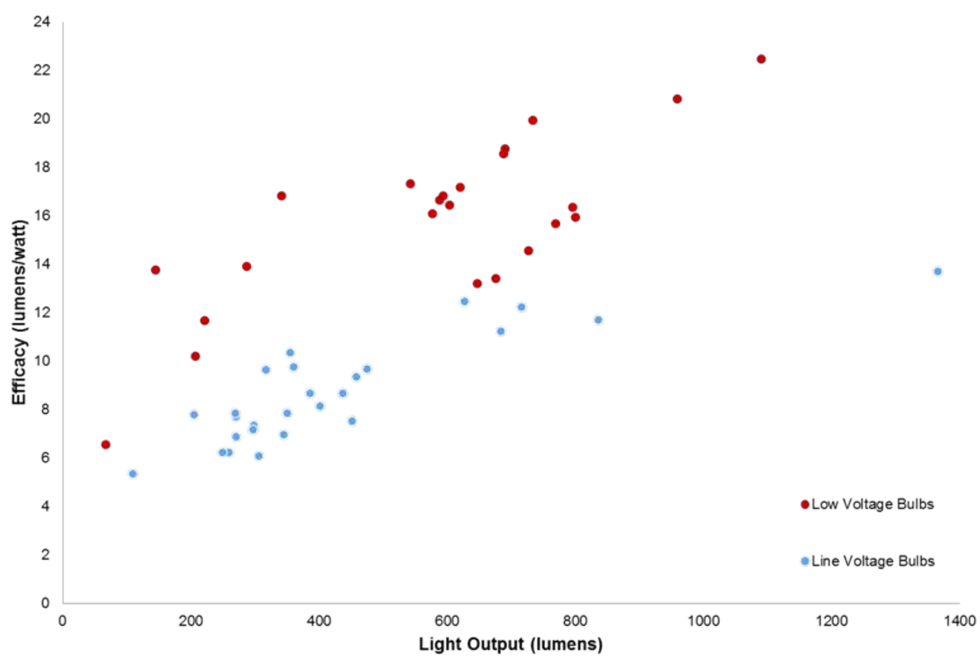
[34] *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative*, August 6, 2014, available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Small_Diameter_Directional_Lamps_Addendum_to_CASE_Report_2014-08-06_TN-73551.pdf, page 5.

-  Low voltage systems: Low voltage systems require a transformer to convert line voltage to low voltage. The power loss of the transformers, however, is not part of the lamp wattage. Transformer size and wattage is dependent on the number of lamps in the system. Market share for these low voltage lamps is 80 percent. There is significant variance in performance between low voltage and line voltage products as show in Figure 2 above.

-  Line voltage systems: In a line voltage system, lamps are directly connected to 110/120 volt line voltage. Twenty percent of the market share is for line voltage small diameter directional lamps.

Figure 2 below shows difference between the low and line voltage lamp efficacy and light output. this figure is taken from the IOU's CASE study

**Figure 2: Line and Low voltage Products**




Source: *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative August 6, 2014*

Because the efficiency of low-voltage systems is constant with some variability in the efficiency of the transformers in use, the efficiency of small-diameter directional lamp systems depends on the efficiency of the lamps installed. However, both of these systems use significant energy because filament-based lamps are inefficient and have a low lumen-per-watt rating. Figure 2 also shows that low-voltage lamps have slightly better efficiency than line voltage lamps, but the IOUs' test and analysis of these lamps show a significant variance in performance among low- and line voltage lamps with a similar lumen.[35]

Recently, manufacturers introduced LED small diameter directional lamps into the market; these lamps are highly efficient and have a very long life. Initial cost of purchasing an LED lamp is higher than the standard incandescent, halogen, or HIR lamp, however, the energy-cost savings over the lamp's lifetime make these a highly cost-effective substitute for halogen, HIR, and incandescent lamps. LED lamps are a better choice for two reasons:

LED lamps have an estimated life of more than 25,000 hours, while filament lamps have a life span of only 2,000-4,000 hours. On average, the life of one LED lamp is about 7 times greater than the life of one halogen, HIR, or incandescent lamp. However, the average price of an LED lamp is about $20 whereas halogen lamps sell for about $6. Although the bulb is more expensive, consumers will in fact save money over the lifetime of the bulb. For example, when a consumer replaces a halogen lamp with an LED lamp, consumers will save a minimum of ($6*7)-$20=$22 in lamp replacement costs alone due to the longer life of these LED bulbs.

The majority of filament based small diameter directional HIR or halogen lamps produce 10-20 lumens of light per watt of power consumed whereas an average LED small diameter directional lamp produces more than 80 lumens of light per watt of power. LED lamps consume 75-80percent less power than a halogen, HIR, or incandescent lamp, resulting in a lower operating cost, which means more monetized energy savings for consumers.

Filament–based, low-efficiency lamps which have been prevalent for decades, dominate the market. However, they are a less cost-effective option for consumers. Inefficient halogen, HIR, or incandescent lamps, when replaced with efficient small diameter directional lamp LED lamps, will save 1,535 GWh/year in electricity and California consumers will save millions of dollars per year.[36] To avoid further waste of electricity, environmental damage associated with the building and operation of power plants, increases in greenhouse gas emissions, and to save water used in power generation, it is necessary to transform the small diameter directional lamp market by setting energy cost effective and feasible efficiency standards for small diameter directional lamps. Standards will ensure that Californians purchase efficient and cost-effective lamps.

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[35] *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative,* August 6, 2014, available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Small_Diameter_Directional_Lamps_Addendum_to_CASE_Report_2014-08-06_TN-73551.pdf, pages 3 & 4 of Appendix.

[36] The energy savings are shown in the Appendix A

# CHAPTER 5: Other Energy Efficiency Programs

## DOE's Activity and Status

There are no existing DOE standards for small diameter directional lamps. DOE has started conducting a rulemaking on small diameter directional lamps, but MR 16s, MR 11s, PAR 16s, and PAR 11s are outside the scope of its rulemaking. DOE has established HIR performance standards for Incandescent Reflector Lamps (IRLs) of diameter greater than 2.25 inches that use 40 watts or more.

## ENERGY STAR® Specifications and Wattage Equivalency Criteria

ENERGY STAR® established specifications for LEDs in Version 1.4, including MR and PAR lamps.[37] For lamps with a diameter less than or equal to 2.25 inch (for example MR 16 or PAR 16), efficacy must be at least 40 lumens per watt. ENERGY STAR® provides a tool for PAR and MR lamps to calculate minimum CBCP requirements based on the replacement lamp's beam angle and claims about wattage equivalency. Based on the data and information staff has reviewed, staff finds that the 40 lumens per watt efficiency level to low and not reflective of the state of lighting technology or the potential cost savings.

## Australian Lamp Standard

The Australian commission for lighting standards established lighting standards for low voltage MR 16 lamps by establishing a wattage cap at 37W, which became effective on April 14, 2012. This cap effectively banned 50W halogen lamps from being sold in the market, leaving the 37W HIR lamp (a 50W equivalent) and LED replacements to compete (Australian Government Department of Resources Energy and Tourism AGDRET 2012).

## Proposals for Small Diameter Directional Lamp Efficiency Standards

## Seoul Semiconductors' Proposal

Seoul Semiconductors proposed that California should harmonize with ENERGY STAR® specifications. The Energy Star program provides a framework of standards and testing that California can adopt. Harmonizing with ENERGY STAR® would mean manufacturers would need to test only their equipment once and therefore reduce testing cost.

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[37] *ENERGY STAR® Program Requirements for Integral LED Lamps*, available at http://www.energystar.gov/ia/partners/product_specs/program_reqs/Integral_LED_Lamps_Program_Requirements.pdf.

## IOU and Natural Resources Defense Council Proposals

The IOUs and Natural Resources Defense Council (NRDC) proposed a two-tiered approach to performance standards for small diameter directional lamps. This approach would require replacing inefficient halogen, HIR, and incandescent lamps with efficient small diameter directional technologies, such as LED lamps that produce at least 80 lumens per watt.

IOUs and NRDC state that their proposal would result in immediate energy savings in California as well as greater energy savings in the future and prime the market for an LED standard. The table below shows the recommended standard levels for this measure.[38]

**Table 1: Recommended Standard Levels by the IOUs and NRDC**

| Tier Level | Voltage (V) | Energy Efficiency Standard (x = lumens) | Minimum Rated Life (hours) |
|---|---|---|---|
| Tier 1 (effective 1 year after adoption) | ≥50 | LPW > 0.50 * x $^{0.49}$ | 2,000 |
| | <50 | LPW > 1.15 * x $^{0.44}$ | 4,000 |
| Tier 2 (2018) | All voltages | LPW > 80 | No Standard |

Source: *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative August 6, 2014*[39]

Energy Commission staff believes that implementation of the Tier I standards proposed by the IOUs and NRDC may not save significant energy during the interim before the 80 lumen/watt standard comes into effect and may create confusion among the small-diameter directional lamp manufacturers and in its market. Manufacturers are investing resources on improving the efficiency, CRI and CBCP of lamps. Staff believes an 80 lumen per watt standard effective January 1, 2018 give manufacturers sufficient time to implement the emerging technologies to improve quality and efficacy of lampsA good quality 80 lumen watt lamp will strengthen consumer acceptance. Based on the above rationale, staff decided to drop the IOUs' proposed Tier I proposal.

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[38] *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative*, July 29, 2013, available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Small_Diameter_Directional_Lamps_2013-07-29_TN-71763.pdf.

[39] *IOU Standard Proposal Addendum: Small Diameter Directional Lamps* August 6, 2014 avaialble at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Small_Diameter_Directional_Lamps_Addendum_to_CASE_Report_2014-08-06_TN-73551.pdf page 4.

## Energy Commission Staff's Proposed Standards

Energy Commission staff has analyzed the small diameter directional lamp market data, conducted research on the design and technology development and staff noted significant improvement in the LED lamp efficacy, quality, beam angel, and color temperature. Based on the data and information provided by stakeholder and staff research of numerous studies and reports, staff concludes that proposed small-diameter directional lamps standards are cost–effective, technically feasible. There are many high efficacy quality lamps available in the market today. Staff proposes that Energy Commission to adopt and implement an 80-lumen-per-watt minimum standard for small-diameter directional lamps effective January 1, 2018. The staff-proposed standards for small-diameter directional lamps would result in significant energy savings in California in 2018 and beyond. Current trends in wattage and efficacy for LED small-diameter directional lamps are outlined in Table 3 below in Chapter 6.

Staff also propose that manufacturer use IES LM-79-08, to test efficacy of the state-regulated LED lamps.

## CHAPTER 6:
## Energy Savings and Cost Analysis

Staff conducted an energy savings and cost benefit analysis that justifies the proposed standard. Staff finds that the proposed small diameter directional lamp requirements represent a significant energy and cost savings opportunity for commercial and residential buildings in California. The common wattage incandescent, halogen, and HIR lamps that are sold on the market are 50-watt, 35-watt, and 20-watt lamps. A 50 watt lamp produces 750 lumens of light, a 35-watt lamp produces 500 lumens, and a 20 watt lamp produces 385 lumens of light. Table 3 below shows lamp wattage, light intensity, and lumens per watt for filament based lamps:

**Table 3: Wattages, Light Output and Efficacy**

| Lamp Wattage | Light Output (Lumens) | Efficacy (Lumens/Watt) |
|---|---|---|
| 50 Watt | ≥500≤.750Lumens | 10-25 |
| 35 Watt | ≥385≤.499 Lumens | 11-21 |
| 20 Watt | ≥240≤.384Lumens | 8-15 |

Source*: Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative July 29, 2013*[40]

Table 4 shows the equivalent wattages of 80 lumens per watt lamps.

**Table 4: Wattages and lamp efficacy**

| Lamp Wattage | Light Output | Efficacy (Lumens/Watt) |
|---|---|---|
| 50 Watt equivalent ≥6.25 W ≤9.375 W | ≥500≤.750Lumens | 80 |
| 35 Watt equivalent ≥4.8 W ≤6.25 W | ≥385≤.499 Lumens | 80 |
| 20 Watt equivalent ≥3.0 W≤.4.8 W | ≥240≤.384 Lumens | 80 |

Source: California Energy Commission

[40] *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative* July 29, 2013 available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Small_Diameter_Directional_Lamps_2013-07-29_TN-71763.pdf Page 21 Table 5.1

## Stock and Sales

## Existing Stock and Market Share and Future Stock Projections

IOUs estimated that there were about 14.6 million small-diameter directional lamps installed in California in 2012.[41] The 2012 stock estimate is based on the total national installed stock and the assumption that California stock is about 12 percent of the national installed stock. IOUs report further estimated that 70 percent of the California stock is 50-watt lamps, 20 percent are 35-watt lamps, and 10 percent are 20-watt lamps. Based on the market, IOUs also estimated that the current stock is growing at a compound annual growth rate (CAGR) of 1.3 percent. Staff used 2012 California stock and a CAGR of 1.3 percent per year to calculate total California stock for 2018 through 2028, as shown in the table below.

**Table 5: Low Voltage and Line Voltage Stock and Projections**

| Existing Low Voltage and Line Voltage Stock | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
| Low voltage stock= 80percent | 12.6 | 12.8 | 13.0 | 13.1 | 13.3 | 13.5 | 13.6 | 13.8 | 14.0 | 14.2 | 14.4 |
| Line Voltage Stock 20percent | 3.2 | 3.2 | 3.2 | 3.3 | 3.3 | 3.4 | 3.43 | 3.5 | 3.5 | 3.5 | 3.6 |
| Total Stock | 15.8 | 16.0 | 16.2 | 16.4 | 16.6 | 16.8 | 17.0 | 17.3 | 17.5 | 17.7 | 18.0 |

Source: California Energy Commission

## Annual Operating Hours/Duty Cycle

The IOUs CASE study assumptions for annual operating hours are based on a 2011 Navigant Study on MR lamps.[42] This study estimated annual operating hours to be 840 hours in residential applications, and 3,720 hours in commercial applications. According to the same study, the residential sector accounts for roughly 35 percent of sales, while the commercial

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[41] *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative,* August 6, 2014, available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Small_Diameter_Directional_Lamps_Addendum_to_CASE_Report_2014-08-06_TN-73551.pdf , Appendix Overview of small diameter directional lamp class, page 2.

[42] *Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications* Prepared for: Building Technologies Program Office of Energy Efficiency and Renewable Energy U.S. Department of Energy, available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/nichefinalreport_january2011.pdf.

sector accounts for 65 percent of sales.[43] Applying a weighted average to these values, staff estimates that a typical small diameter lamp is used on average 2,712 hours per year.[44]

## Incremental Cost

The IOUs have conducted a survey of small-diameter directional LED lamp price data and results of that data show LED lampretail price drop from 2013 to 2014. IOUs also conducted a price drop analysis based on the learning curves using methodology used by the DOE. The average lamp price in the data set of LED MR 16 and PAR 16 replacements is $24.67. It is exclusively based on online sales data collected between November 2013 and March 2014. Price data show that lamps that are in a 300 lumen or less than 300 lumens bin are the most expensive, and the prices range from $26 to $28. According to a DOE report, Internet pricing is the most expensive sales channel – its analysis suggested a 27.5 percent decrease in price in stores.[45] Applying this decrease, the anticipated lamp price average would decrease to $17.88 in today's dollars. Applying experience curves, the price is expected to decrease further by 2018.

The "experience curve approach" for appliance price forecasting describes a method to account for historical changes in product prices and energy efficiency in product price forecasting. Figure 3, below, illustrates the inflation-adjusted price histories of various products over the past four decades. All prices are normalized to the 2008 value, with the prices for computers and compact fluorescent bulbs presented on a separate axis to accommodate scale differences. Specifically, this report describes how *experience curve* (aka *learning curve*) analysis can be used in price forecasting and how energy efficiency changes over time can be incorporated into that analysis.

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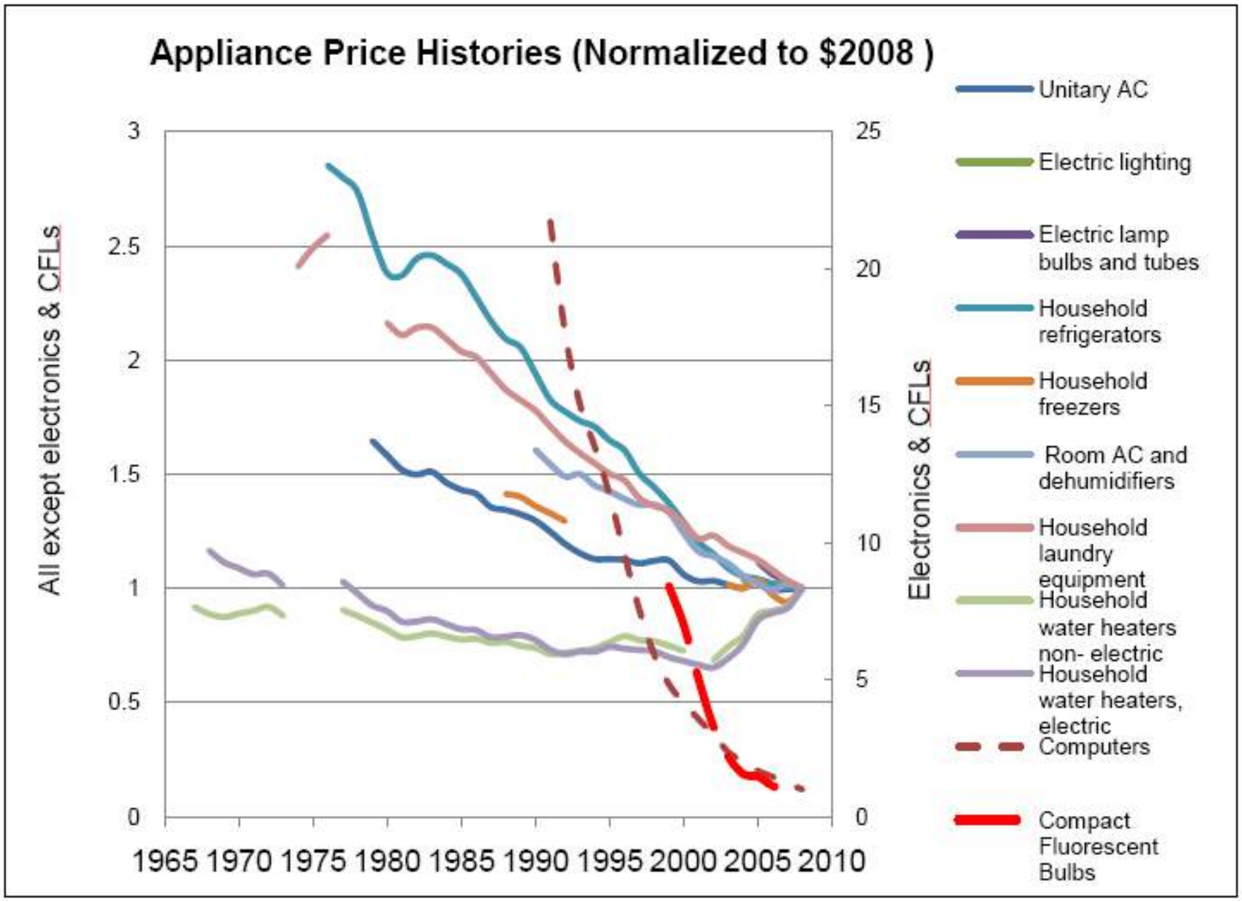
[43] Ibid.

[44] *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative*, July 29,2013, available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Small_Diameter_Directional_Lamps_2013-07-29_TN-71763.pdf, page 22.

[45] *Using the Experience Curve Approach for Appliance Price Forecasting*, February 2011, available at http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/experience_curve_appliance_price_forecasting_3-16-11.pdf.

**Figure 3: Product Price Histories**




Sources: Producer Price Index (PPI) data from Bureau of Labor Statistics, except Compact Fluorescent Lamp (CFL) Bulbs (Pulliam, R., 2008).

IOUs have provided assumptions that lamp costs change over time with learning curves. For the baseline and Tier 1 products (Filament based), IOUs assumed a slower learning curve than for LED technology, since LED technology is newer and innovation is still taking place to bring prices down. IOUs used DOE methodology to derive the learning curves.[46]

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[46] *Using the Experience Curve Approach for Appliance Price Forecasting*, February 2011, available at http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/experience_curve_appliance_price_forecasting_3-16-11.pdf.

**Table 6: Price Drop Based on Learning Curve**

| Lamp Cost w/ Learning curves | Baseline | 80 lumens/watt |
|---|---|---|
| 2014 | $6.68 | $30.25 |
| 2015 | $6.64 | $23.22 |
| 2016 | $6.59 | $18.78 |
| 2017 | $6.55 | $15.74 |
| 2018 | $6.51 | $13.52 |
| 2019 | $6.48 | $11.84 |
| 2020 | $6.44 | $10.52 |
| 2021 | $6.40 | $9.45 |
| 2022 | $6.37 | $8.58 |

Source: *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative August 6, 2014*

Staff has reviewed the IOU's price survey and data and agrees with the predicted experience curve analysis The IOU's assumptions on price drop trend is conservative; therefore, it is reasonable to assume the average price of LED small diameter directional lamps in 2018 will be about $13.52.

The average price of a filament-based incandescent, halogen, and HIR lamp is from $6.00 to $8.00. Estimated incremental cost for replacing a filament-based lamp with a LED lamp in 2018 will be about $13.52.00-$6.00 = $7.52. LED lamp price of $13.52 is based on the learning curve.

Figure 4 below was plotted by the staff to illustrate the lamp life expectancy for incandescent, halogen, HIR, and LED lamps. Staff collected lamp price data from the Internet and used pricing information from the IOUs' CASE study.[47]

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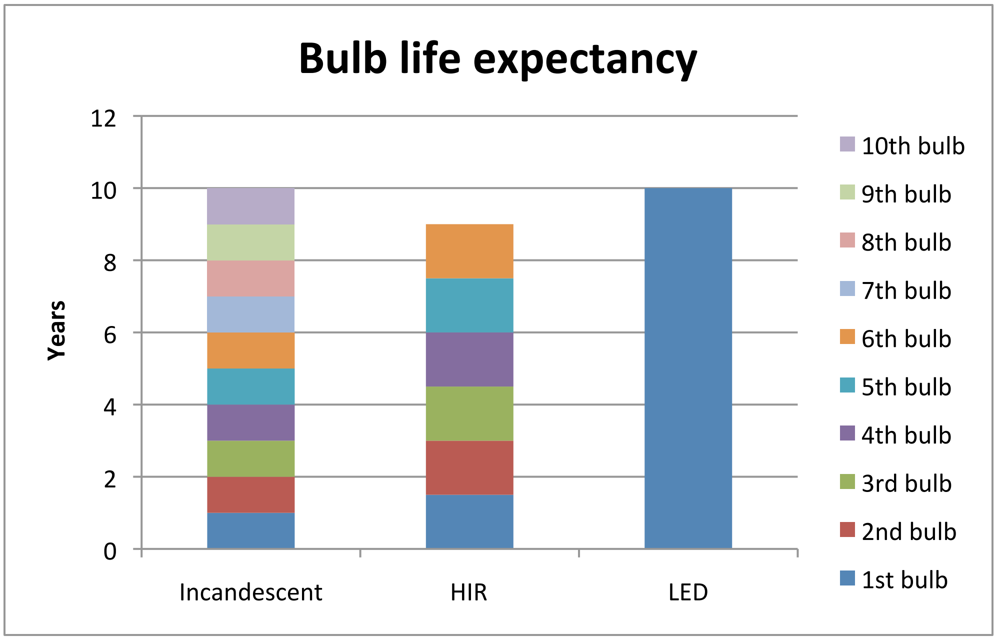
[47] *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative*, August 6, 2014, available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Small_Diameter_Directional_Lamps_Addendum_to_CASE_Report_2014-08-06_TN-73551.pdf, page 2.

**Figure 4: Bulb Life Expectancy Comparison and Price Over Time**




Source: California Energy Commission

The life expectancy is calculated based on the average duty cycle or hours of usage in businesses and homes and manufacturer-rated lifetime hours. Hours of usage assumptions are based on the Navigant consultant study.[48] The figure below illustrates that the life cycle of one LED lamp is roughly equal to 6 halogen or HIR lamps and 10 incandescent lamps. The predicted price for a LED lamp in 2018 would be about $13.52 and would last for about 10 years; incandescent, halogen, or HIR lamp cost about $8.00 and would last only a year to one and half years. Lamp replacement savings can be calculated by multiplying the price of halogen or HIR lamps by the number of replacement over the lifetime of an LED lamp as shown below:

Price of halogen lamp $6 * 6 replacements in 10 years = $36

Price of LED lamp .13.52 * 1 replacement in 10 years = $13.52

Savings in replacement costs = $36-$13.52 = $22.48.

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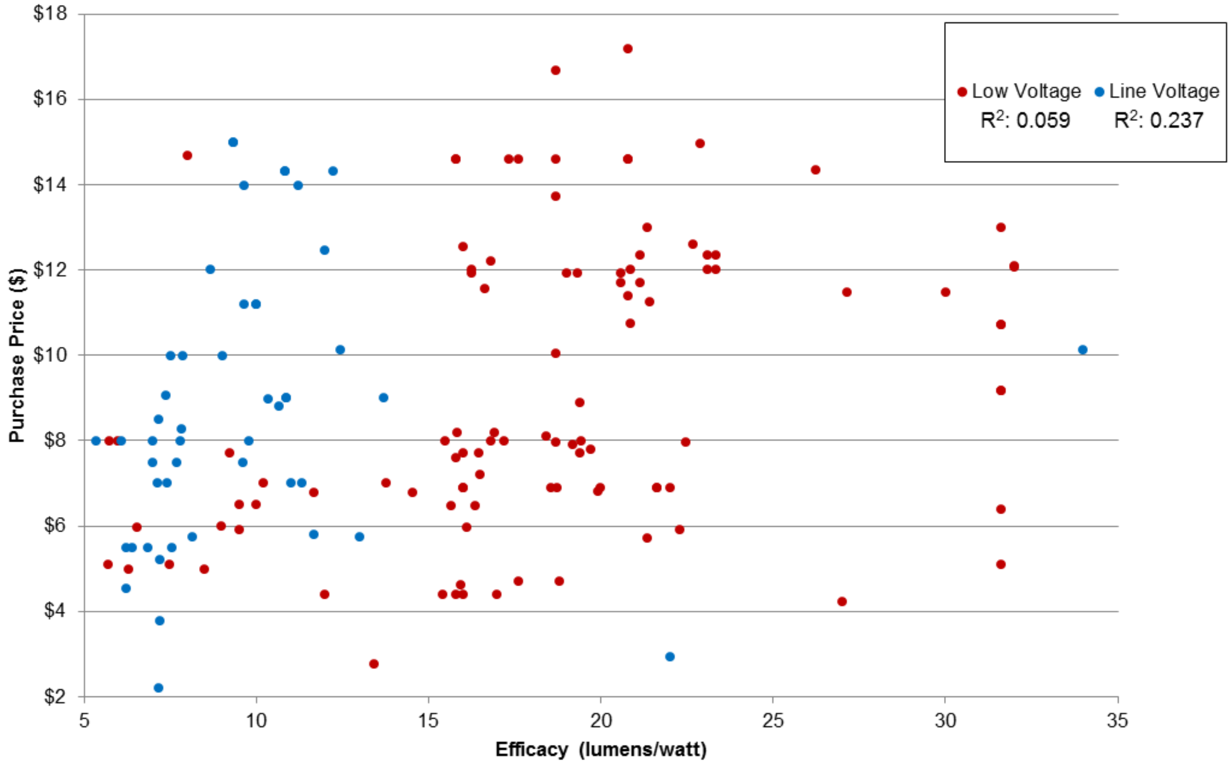
[48] *Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications* Prepared for: Building Technologies Program Office of Energy Efficiency and Renewable Energy U.S. Department of Energy, available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/nichefinalreport_january2011.pdf**.**

This shows that LED replacement saves at least $22.48 over the lifetime of the lamp in replacement costs alone. Staff analysis of energy savings shows that an LED lamp will save, on average, $126.52 per lamp over the lifetime of the lamp in conserved electricity. The total savings to consumer after replacing an incandescent, halogen, or HIR bulb with an LED lamp is about $126.52+$22.48= $149.00.

Figure 5 below provides cost data that IOUs have collected from various large national brick-and-mortar stores, as well as specialized online retailers. Sales data in Figure 5 below are plotted between the purchase price and efficacy for low- and line voltage lamps.

**Figure 5: Purchase Price and Efficacy for Low and Line Voltage Lamps**




Source: *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative addendum to July 2013 submission August 6, 2014*.

Market data in Figure 5 show that high-efficacy lamps are cheaper than low-efficacy lamps, but there is no clear relationship between efficacy and price of small-diameter directional lamps.

## Energy Savings

The energy savings achieved by moving from an inefficient incandescent, halogen, or HIR bulb to an efficient LED bulb depend on power draw, hours of use, and lifetime of the bulb. Staff conducted calculations for cost analysis, and the results of the calculations are presented in the tables in Appendix A.

## Incremental Cost

There is little to no correlation between efficacy and the retail cost of a lamp, example staff-collected sales data on pricing and efficacy (lumens/watt). The data shows a 50 lumens/watt, a 63 lumens/watt, a 72 lumens/watt lamp, and an 80 lumens/watt lamp selling at $23.00 each. Staff has researched and collected LED cluster data from the DIGIKEY, an LED component manufacturer and distributor. The LED price and efficacy analysis shows that there is no cost difference between a high-efficacy LED cluster and low-efficacy LED cluster. As newer LED clusters and efficient drivers come into the market, the prices of older components drop due to decrease in demand, and newer components are then sold at the lower, older rate. Because there is no price correlation between high- and low-efficacy lamps staff assumes $0 incremental cost between the base case and a lamp that could meet the proposed 80 lumen per watt standard.

## Cost-Effectiveness

**Table 7: Lamp Cost & Cost Effectiveness**

| Lamp cost in 2018 based on price drop learning curve in Table 6. | Avoided replacement savings | Annual Energy Savings per unit per year | Total energy savings per unit over the life time of the unit | Per unit savings over the life time of the lamp=NPV |
|---|---|---|---|---|
| $13.52 | $36.00- $13.52= $22.48 | 97 KWh | 973 KWh | $134.39 |

Source: California Energy Commission

## Statewide Energy and Cost Impact

Staff conducted statewide energy savings calculations and cost impact analysis and the conclusions are in Table 8.

**Table 8: Statewide Energy & Cost Impact**

| Proposed Standard | Design Life Hours | Annual Energy Savings/Unit kWh/year | Incremental Cost of Improvement Per Unit | Fist year Unit Energy Cost Savings |
|---|---|---|---|---|
| 80 lumens/ Watt | 10 years | 97kWh/year | $7.52 | $12.65 |
| Total savings per unit over the design life($) | | Simple payback period | Stock in millions | 1st year statewide energy savings after stock replacement |
| Energy Saving $134.39+Avoided Replacement Cost 22.48= 156.87 | | <1.5 years | 15.8 | 1535 GWh |

Source: California Energy Commission

# CHAPTER 7: Technological Feasibility

Electric power consumption for residential lighting in California is about 20 percent of the total electricity consumed in the state[49] and lighting power in commercial buildings is 29 percent.[50] Inefficient incandescent and halogen lamps consume significant electric power. Most of the power consumed is wasted as heat in the filament that produces the light. To reduce lighting power consumption in the state, inefficient incandescent, halogen, HIR small diameter directional lamps must be replaced with highly efficient small diameter directional lamps that are cost effective and are available in the market. LED small diameter directional lamps have the advantages of increased efficiency, color specificity, size, response time, and lifetime. The electricity used over the short lifetime of a single incandescent or halogen lamp costs 5 to 10 times the original purchase price of the lamp itself. The electricity savings over the lifetime of LED small diameter directional lamps is six to seven times more than the lamp purchase price and lamp replacement costs of LED small diameter directional lamps.

## Lumen Output and Efficacy

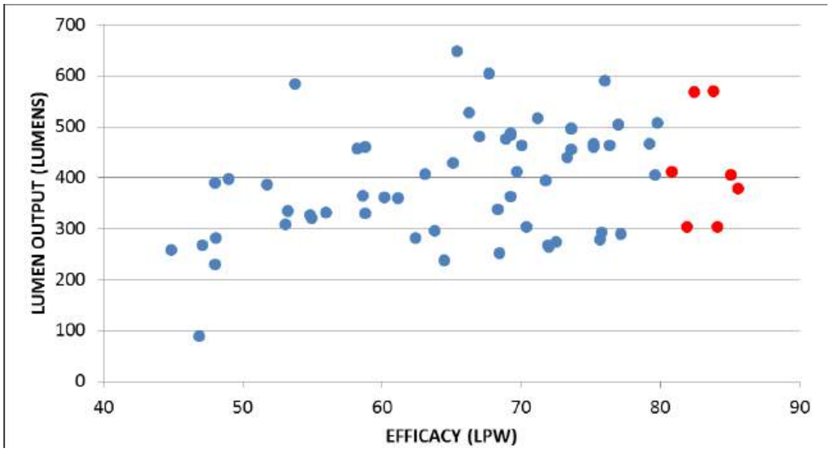
In terms of lumen output, LED small diameter directional lamps are steadily increasing in output as efficacy increases. Based on a May 2014 Lighting Facts Database (LFD) analysis, 80 LPW lamps (shown in red color in Figure 6, below) are able to achieve at least 550 lumens in output, which is equivalent to 50W halogen lamps based on European Union lighting requirements (EU 2012) for LED small diameter directional lamps. According to a recent DOE CALiPER report, LED small diameter directional lamps producing up to 600 lumens are widely available (CALiPER 2014).[51]

[49] *2009 California Residential Appliance Saturation Study*, available at http://www.energy.ca.gov/2010publications/CEC-200-2010-004/CEC-200-2010-004-ES.PDF, page 3.

[50] *2006 California Commercial End-Use Survey*, available at http://www.energy.ca.gov/2006publications/CEC-400-2006-005/CEC-400-2006-005.PDF, page 9.

[51] *CALiPER Application Summary Report 22 LED MR 16 Lamps*, June 2014, *available at* http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_22_summary.pdf Lighting/CaliforniaIOUs_Response_to_the_Invitation_for_Standards_Proposals_for_Small_Diameter_Directional_Lamps August 6, 2014 available at 2B_Lighting/California_IOUs_Small_Diameter_Directional_Lamps_Addendum_to_CASE_Report_2014-08-06_TN-73551.pdf Page 10.

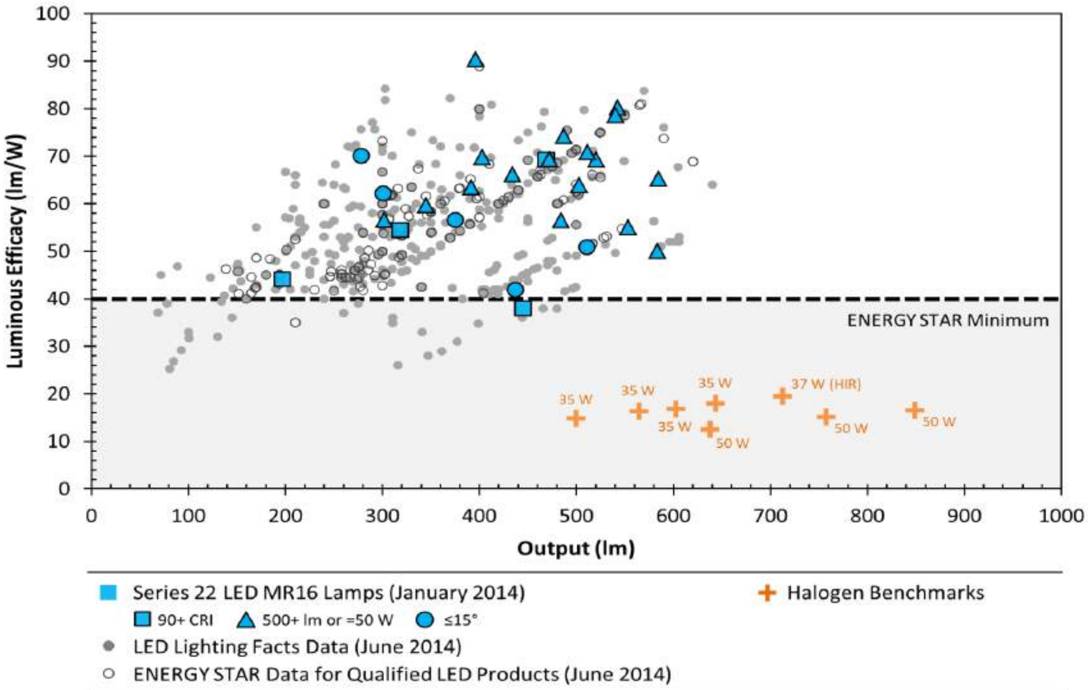
**Figure 6: Lumen Output vs. Luminous Efficacy**




Source: *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative August 6, 2014*

The U.S. DOE-issued CALiPER report studied Series 22 LED MR16 lamps that had measured output ranging from 197 to 585 lm, with a mean of 436 lm. The study shows a more general trend of increasing lumen output and increase in the LED market. Both the lumen output and efficacy of the Series 22 CALiPER products represent the higher end of the LED Lighting Facts and ENERGY STAR datasets, although the CALiPER dataset is much smaller, but it illustrates the rapid improvements in the lamp light out and gains in the lamp efficacy. Efficacy versus lumen output is shown in Figure 7.

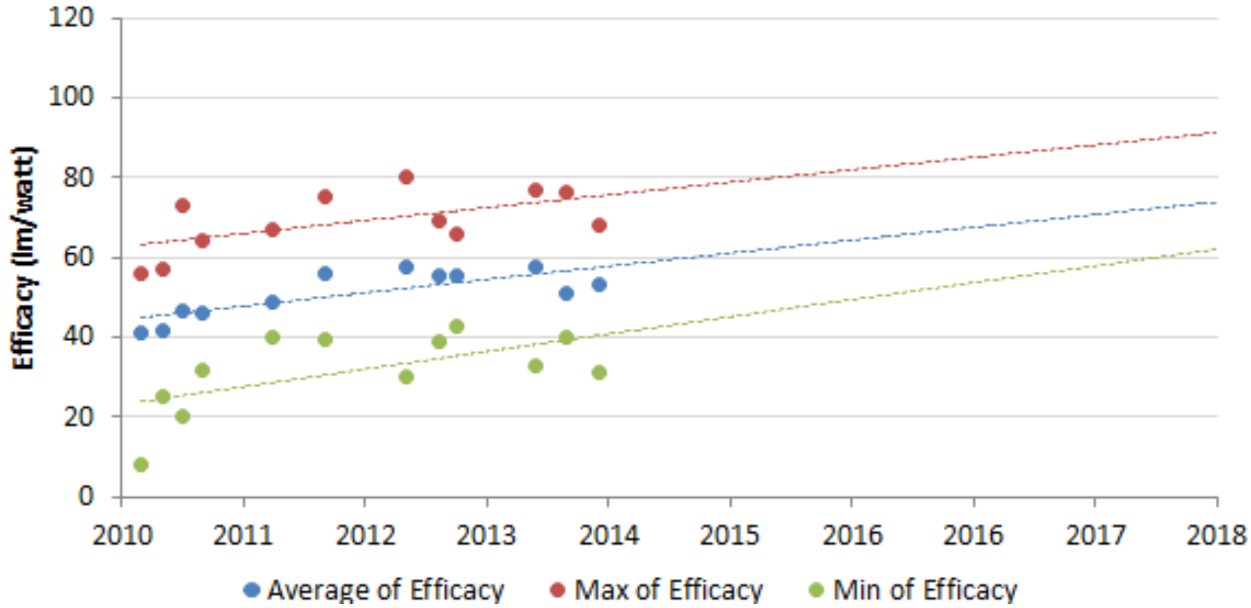
**Figure 7: Luminous Efficacy vs. Lumen Output**




Efficacy continues to increase for LED small diameter directional lamps. The gains in efficiency are resulting from use of better phosphors, efficient driver design, better chip design, packaging, and heat dissipation. The average efficacy of small diameter directional LED MR 16 lamps measured by Lighting Facts is plotted in figure 8 below.[52] Figure 8 shows that the efficiency of majority of small diameter directional LED lamps far exceeds 45 lumens per watt (lpw).

**Figure 8: Efficacy over Time**

[52] *Lighting Facts* is a program of Department of Energy. http://www.lightingfacts.com/.




Source: *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative August 6, 2014*

## LED Efficacy vs. Cost

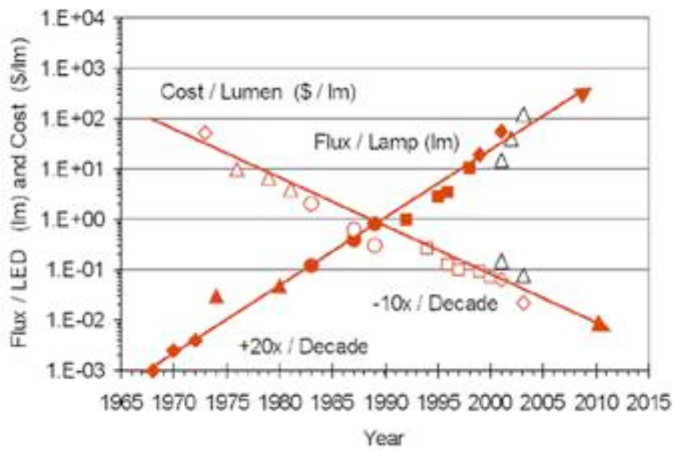
LED lighting is closely tied with the semiconductor industry, which makes the design, production, and innovation on a time scale and flexibility that is far different from traditional lamps. LED chip-on-board architecture serves as the basis for improving light quality and color control, lowering the production cost and time to market for a wide variety of lighting applications. LED lamps have a lifespan and electrical efficiency that is several times better than incandescent lamps and halogen lamps, and significantly better than most compact fluorescent lamps. Many LED chips are able to emit more than 100 lumens per watt.

LEDs in conjunction with a phosphor produce general purpose white light. White light produced by LEDs have the color rendering index (CRI) value range from 70 to more than 90, and color temperature of the light produce by LED lamps range from 2700 K up to 7000 K. The color rendering index (CRI) is a measurement of how true object color appears under a light in comparison to how it would look in sunlight. The score ranges between 0 and 100, with 100 representing a very good approximation of the color rendering of sunlight. There are LEDs available that can produce 200 lumens per watt, have a CRI of 90, and color temperatures ranging from 2700 K to 8300 K.[53]

[53] *CREE LED lighting News and Events*, available at http://www.cree.com/News-and-Events/Cree-News/Press-Releases/2014/May/XPL-intro.

The cost of LED lamps has been improving rapidly according to what has been called Haitz's law, analogous to Moore's law for semiconductor devices.[54] Haitz's Law asserts LEDs will become exponentially more efficient and more affordable over time.

**Figure 9: Increase in LED lumens/watt and decrease in cost per year**




Source*: Elemental LED, Haitz's law asserts LEDs will become exponentially more efficient and more affordable over time*

The implications of Haitz's Law for LED retailers and consumers are significant: LEDs will continue to get brighter and more efficient; LEDs will continue to get cheaper; LEDs will eventually dominate the lighting market and over time will completely replace the less-efficient counterparts, incandescent lights and CFLs. Despite this trend, effective policy coupled with appropriate efficiency regulations are needed to accelerate the energy- and money-saving potential of energy efficient lamps.

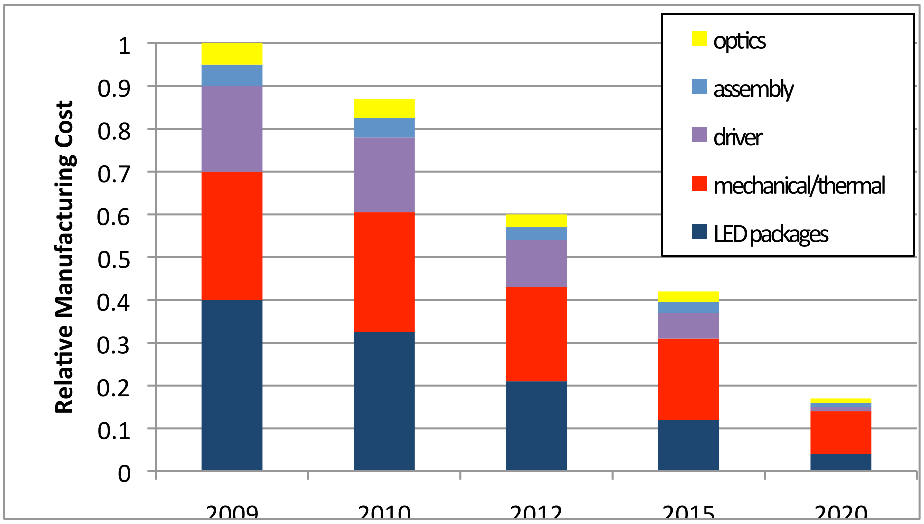
The following figure shows that the relative manufacturing cost of LED packages is on a continuous decline.[55]

**Figure 10: Relative Manufacturing Cost Per Year**

---

[54] *Elemental LED, Haitz's law asserts LEDs will become exponentially more efficient and more affordable over time*, available at
http://www.elementalled.com/academy/blog/led-news/haitzs-law-asserts-leds-will-become-exponentially-more-efficientpercente2percent80percent94and-more-affordablepercente2percent80percent94over-time/.

[55] *Solid-State Lighting Research and Development: Manufacturing Roadmap*, July 2010, Prepared for: Lighting Research and Development Building Technologies Program Office of Energy Efficiency and Renewable Energy U.S. Department of Energy, available at
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_manuf-roadmap_july2010.pdf.




Source: California Energy Commission

Manufacturers have developed highly efficient LED lighting technologies, and great achievements and breakthroughs have been made in this area. LED manufacturers have made claims to develop LEDs of light intensity tenfold, that is, from 50 lumens per watt to 500 lumens per watt.[56]

LEDs as MR lamps are ideal for track lighting because of directionality. A significant feature of LEDs is that the light is directional, as opposed to halogen or incandescent lamps, which spread the light more spherically. This is an advantage with recessed lighting or under-cabinet lighting and directional lighting. LED lamp designs address the directional limitation by using more diffuse lenses and reflectors to disperse the light more like a halogen or incandescent lamp.

LEDs do not contribute to heat buildup in a room because no matter how long they remain on, they do not get hot to the touch.

There are no major barriers in the path of LED technology. Many LED directional lamps are already available in the market that have similar center beam candle power compared to halogen and HIR lamps. LED directional lamp manufacturers have many different types of lens technology designs that are available to them. Moreover, designers are continuously making improvements to directional lamps. Most manufacturers have resolved the low-voltage LED

[56] *"Seoul Semi quintuples LED brightness with new technology," EE Times,* available at http://www.ledlighting-eetimes.com/en/seoul-semi-quintuples-led-brightness-with-new-technology.html?cmp_id=7&news_id=222908002.

transformer compatibility issues, once considered a barrier. As shown in Figure 6 above, LED lamp technology with 80 lumens per watt is already available and quite cost-effective.

LEDs are no longer available from just specialty retailers. Dozens of LED lamps for hundreds of applications are easily found at major retail stores. California utilities also have an aggressive rebate program for high efficacy and high quality LED lamps.

## LEDs and Power Factor

Power factor is the ratio of real power to apparent power. A LED lamp driver can collect the energy it needs by drawing power from the grid while perfectly in sync with the utility waveform, or larger bursts of energy while only partially in sync with the utility waveform. Many appliances draw a large amount of power from the grid, store it, use it, and then draw another surge of power. While the power consumption within the LED driver (referred to as *real power*) is the same in the each case, the power draw from the grid (apparent power) is very different. Shorter, but more intense current draws increase energy losses in building wiring. These wire losses are proportional to the square of the current. Therefore, an appliance that draws double the current would result in quadruple the wiring loss of power.

Low power factor in non-linear LED drivers send power back to the grid and generate harmonic waves in the power line. As the number of LED lamps increases these harmonics cause issues in electrical transmission and require expensive utility equipment to correct. Sometimes the harmonics remain uncorrected and the quality of a building's power is reduced, potentially interfering with other electronic equipment.  The most common SDDL lamps are incandescent and halogen technologies which have a power factor of 1, which is ideal. To get to the root of this problem, high-power LED drivers must come with a power factor of 0.9 or greater.

# CHAPTER 8: Safety and Environmental Issues

Staff could not identify any safety or negative environmental impacts of improving small diameter directional lamp efficiency. While the technical feasibility section acknowledges the use of different, more efficient components, and perhaps some additional control circuitry, those improvements would not create a particular waste hazard.

The proposed standards will however, lead to improved environmental quality in California. Saved energy translates to fewer power plants built and less pressure on the limited energy resources, land, and water use associated with it. Saved energy also relieves pressure on transmission infrastructure, thereby enhancing grid reliability. In addition, lower electricity consumption results in reduced greenhouse gas and criteria pollutant emissions, primarily from lower generation in hydrocarbon burning power plants, such as natural gas power plants. Reduction in emissions translates to improved health and safety to the people who depend on it. The energy saved by this proposal would reduce greenhouse gas emissions by 0.480 MMTCO2e.[57]

[57] Million metric tons of carbon dioxide equivalents. Conversion of 690 pounds per MWh to metric scale, using the rate estimated by the *Energy Aware Planning Guide,* CEC-600-2009-013, February 2011, Section II: Overview, page 5.

# CHAPTER 9:
# Staff Proposal for small diameter directional lamps

Based on the facts, data, and analysis regarding aggregate energy consumption of small diameter directional lamps and the availability of cost–effective, low-energy products, Energy Commission staff has found that efficiency standards for small diameter directional lamps are the most cost-effective and least burdensome means of achieving the state goals of energy savings, pollution reduction and cost savings. Staff proposes that, effective January 1, 2018, all small-diameter directional lamps shall have an efficiency minimum of 80 lumen per watt and a rated life of 25,000 hours.

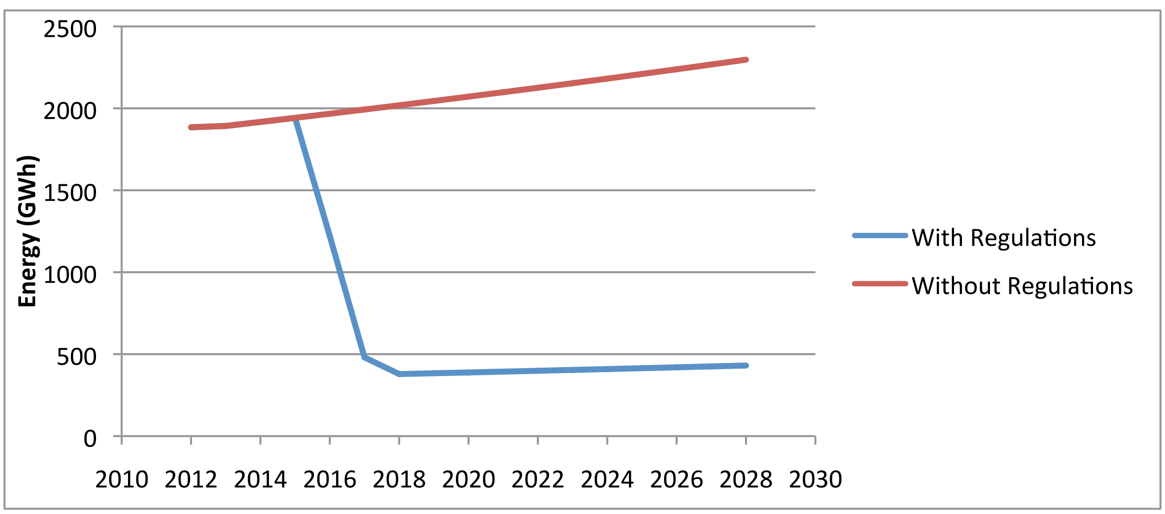
**Table 8: Proposed Standards**

| Effective date | Voltage (V) | Energy Efficiency Standard (x = lumens) | Minimum Rated Life (hours) |
|---|---|---|---|
| January 1, 2018 | All voltages | 80 LPW | 25,000 |

Source: California Energy Commission

Figure 11 below shows estimated energy use decrease with and without the proposed LED regulations (in California).

**Figure 11: Energy Consumption vs. Time**




Source: California Energy Commission

Legend: The red line shows the energy consumed by small diameter directional lamps without regulations, in other words, business as usual, for Incandescent, halogen, and HIR lamps and the blue line shows the energy consumed after stock replacement with 80 lumens/watt lamps.

Figure 11 shows the estimated reduction in energy consumption by adopting 80 lumens/watt small diameter directional lamps standard.

# CHAPTER 10:
# Regulatory Language

Proposed new language appears as underline (example) and proposed deletions appear as strikeout (~~example~~). Existing language appears as plain text. Three dots or "…" represents the substance of the regulations that exist between the proposed language and current language.

**Section 1601. Scope**

…

**(k)** Lamps, which are federally-regulated general service fluorescent lamps, federally-regulated incandescent reflector lamps, state-regulated general service incandescent lamps, general service lamps, and includes GU-24 base lamps, small diameter directional lamps of diameter less than or equal to 2.25 inches and operate on low voltage and line voltage.

(1) This also includes halogen, halogen-infrared, and LED technologies, as well as any other lighting technology that falls within the definitions outlined for this standard. This standard establishes minimum performance levels for efficacy and lamp lifetime.

…

**Section 1602, Definitions:**

…

**(k) Lamps**

"Beam angle" means the angle within which the lap produces 50percent of the maximum luminous intensity. This is also an important lighting design consideration, particularly in the commercial market, and should be measured and reported according to industry practice.

…

"Center beam candle power (CBCP)" means luminous intensity at the center of the beam of a reflector lamp, measured in candelas (cd), and is a particularly important performance indicator in the commercial market, and should be measured and reported according to industry practice.

…

"Efficacy" means the measure of how efficiently a light source produces visible light, in Lumens per Watt, which is the ratio of lumen output to power and the basis for the minimum performance standard.

…

“Lamp Shape and Size” means for specification purposes for test and list, manufacturers shall indicated lamp shape and size in terms of (MR 16, PAR 16, R 16, MR 11, PAR 11, R 14), which is consistent with reporting practices for Energy Star and Lighting Facts.

“Lifetime” means the useful effective life of a lamp as measured in hours in which the lamp is left on, regardless of whether or not it is being dimmed. Halogen lamps shall adhere to LM-49 standards for lifetime determination.

“Line voltage system” means a lamp that operates on voltage that is greater than or equal to 50 volts.

“Low voltage system” means a lamp that operate on voltage less than 50 volts

“Lumen Output” means the total amount of light projected forward, measured in Lumens, to be measured in accordance with the proposed test procedure accompanying the measurement. This is the numerator in the calculation of efficacy for minimum performance standards in small diameter directional lamps.

…

“Power” means the total amount of power required, measured in Watts, to operate the lamp, as measured at the base of the lamp in accordance to the proposed test procedure accompanying the measurement. This is the denominator in the calculation of efficacy for minimum performance standards in small diameter directional lamps.

…

“Small Diameter Directional Lamp (small diameter directional lamps)” means multi-faceted reflector (MR) lamps, parabolic aluminized reflector (PAR) lamps, reflector (R) lamps, and directional LED replacement lamps that are less than or equal to 2.25 inches in diameter, also commonly sold as MR 16, MR 11, PAR 16, PAR 11, R 16, R 14 lamps and their LED replacement equivalents that include all wattage, lumen-output, center beam candle power, and color temperature offerings. These include both line and low voltage lamps that fit the aforementioned definition.

…

**Section 1604. Test Method for Specific Appliances**

**…**

**(k) Lamps**

…

IES LM-79-08 “IES Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting.”

IES LM-80-08 “Approved Method: Electrical and Photometric Measurement of Lumen Maintenance of LED Light Sources “

…

**Section 1605.3 State Standards for Non-Federally Regulated Appliances.**

…

**(k) Lamps**

<u>(6) Effective January 1, 2018, all small diameter directional lamps must have a luminous efficacy of 80 lumens per watt or greater, a power factor of 0.9 or greater, and a minimum rated life of 25,000 hours.</u>

…

# PART B

# CHAPTER 11:
# LED Lamps Background

## Product Description

LED lamps such as general service, reflector, and decorative lamps are those used to provide general illumination in buildings. These lamps produce white light and are designed to either emit light in every direction or have built-in reflectors to provide directional light. Primarily the light is generated using incandescent, fluorescent, or light-emitting diode (LED) technologies.

LED lamps are the most efficient general service lamps available in the market today, reaching efficacies as high as 100 lumens per watt. This efficiency is far superior to incandescent lamps, which are around 14 lumens per watt. This shows the potential for a greater than 700 percent improvement in efficiency. The screw-base market has been shifting and continues to shift from traditional incandescent lamps toward more efficient halogen-incandescent lamps, compact fluorescent lamps (CFLs), and LEDs. This has a large effect on residential electricity use in particular, but LED technology can also benefit businesses, which tend to have more efficient lighting than homes. Lighting is estimated to consume 22 percent of residential electricity, according to the *2009 Residential Appliance Saturation Survey* (RASS)[58], and moving to high-efficiency LED lamps could cut that consumption to less than half.

LED lamps are sold in a variety of shapes and sizes just like the CFL and incandescent counterparts. The LEDs within the scope of this section of the report are limited to those that have a candelabra, intermediate, medium, GU-24 base or that are meant to retrofit these sockets without removing the socket itself. LEDs can produce white light but also can produce colored light and even transition between the two. The regulations considered in this report are meant to cover LED lamps as that produce white light, thereby focusing on general purpose lighting.

## Existing Standards

There are several standards for LED lamps in the United States. These standards are under development and maintained by the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency's ENERGY STAR® program, and the U.S. Federal Trade Commission (FTC).

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[58] KEMA, Inc. 2010. *2009 California Residential Appliance Saturation Study.* California Energy Commission. Publication Number: CEC-200-2010-004-ES.

There are also LED-specific regulations in the Energy Commission's regulations for portable luminaires. In addition, there is a voluntary LED performance specification created by the Energy Commission and recognized by the California Public Utilities Commission (CPUC).

The DOE has two rulemakings underway that will affect LED lamps, one for a new test procedure and one for mandatory performance standards. The test procedure is in the "supplemental notice of proposed rulemaking" phase, which was published June 26, 2014. This test procedure will eventually preempt any energy efficiency measurement procedure for LED lamps adopted by the Energy Commission. In addition, the DOE is in the framework stage of a "general service lamp" performance standard that would, as currently proposed, cover medium screw-base LED omnidirectional lamps. The performance standards that would be finalized through this process would also eventually replace state-specific standards where the scopes overlap. However, the standards are not likely to take effect until 2020, leaving a significant amount of energy and cost savings opportunity untapped in the meantime. Lastly, the DOE has also sponsored an LED certification and information website called "Lighting Facts," which makes available the efficiency of a large number of LED lamps.[59]

The ENERGY STAR program has specifications for lamps with a scope that includes medium screw-base, candelabra, intermediate, and GU based CFLs and LEDs. The most recent version of the specification is version 1.1. The number of criteria that a LED lamp must meet to qualify with ENERGY STAR is large: color-correlated temperature (CCT), color maintenance, color rendering index, warranty, power factor, minimum operating temperature, LED operating frequency, electromagnetic and radio frequency interference, audible noise, transient protection, operating voltage, safety requirements, package language, equivalency claims, efficacy, minimum lumen output, lumen maintenance, and rapid-cycle stress testing. As of April 28, 2014, there were 3,575 LED lamp models certified in the ENERGY STAR-qualified product database. The efficacy of qualified lamps ranges from 26 lumens per watt to 100 lumens per watt.

The FTC has mandatory labeling for general service lamps requiring disclosure of lamp brightness, estimated annual energy cost, lamp life, color temperature, and power. These are required to be provided on product packaging and available through online retailers.

The Energy Commission also has existing standards and specifications for LED lamps. The Energy Commission has specified minimum performance levels for LEDs that are sold with portable luminaires (for example, table or floor lamps) that have been effective since 2010. In addition, the Commission released a voluntary performance specification for quality LEDs in

[59] Lighting Facts is a program of the Department of Energy. http://www.lightingfacts.com/.

December 2012.[60] This specification built upon the ENERGY STAR specification and further enhanced quality. The specification has since become the fulcrum of residential LED lamp utility rebates in California.

## Lessons Learned From the CFL Market

The history of competition between higher-efficiency CFL lamps and lower-efficiency incandescent lamps provide important lessons that are applicable to the LED marketplace. Efforts to drive consumers to CFL lighting have met significant resistance mainly driven by factors beyond first cost and operating costs. These factors include aesthetic quality of the illumination (such as harshness), humming, dimming issues, flicker, slow start, hazardous mercury contained in CFLs with associated health risks to humans and pets upon accidental breakage, poor product performance (such as reduced lifespan in situations where CFLs are turned on and off frequently.[61] In fact, despite very low CFL costs, market penetration appears stagnant.[62] The relatively stable line between incandescent/halogen and LED/CFL market penetration implies that the large amount of momentum in the LED market is from the replacement of CFLs, not incandescent lamps.

The resistance to moving from lower-efficiency lamps to higher-efficiency lamps is tied to incremental costs, real and perceived differences in utility, and familiarity. Trends in LED lamps, as was also true in CFL lamps, are that incremental costs are dropping over time due to increased sales in both absolute dollars and inflation adjusted dollars. Buyers' familiarity with CFLs and LEDs is also improving through typical market adoption curves. However, in CFLs the early adopter curve was heavily frustrated by poor product performance. Product performance and utility have a large effect on the technology adoption curve.

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[60] Flamm, Gary, Owen Howlett, Gabriel D. Taylor, 2012. *Voluntary California Quality Light-Emitting Diode (LED) Lamp Specification*. California Energy Commission, High Performance Buildings and Standards Development Office. Publication Number: CEC-400-2012-016-SD.

[61] *LED Lamp Quality Codes and Standards Enhancement (CASE) Initiative,* available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/PG_and_E_and_SDG_and_Es_Responses_to_the_Invitation_for_Standards_Proposals_for_LED_Quality_Lamps_2013-07-29_TN-71758.pdf, page 10-11.

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

# CHAPTER 12:
# Analysis of LED Characteristics and Regulatory Potential

## Test Procedures

The primary test procedure for the proposed mandatory requirements is IES LM 79 (2008). This procedure gathers the necessary data to calculate CCT, CRI, and efficiency. Adopting LM 79 as the test procedure aligns with other Energy Commission lighting regulations, the voluntary specification, ENERGY STAR, and the proposed DOE test procedure. To calculate the CCT and CRI, the Energy Commission proposes CIE 15.2004 and CIE 13.3 (1995), respectively which are also referenced in IES LM 79.

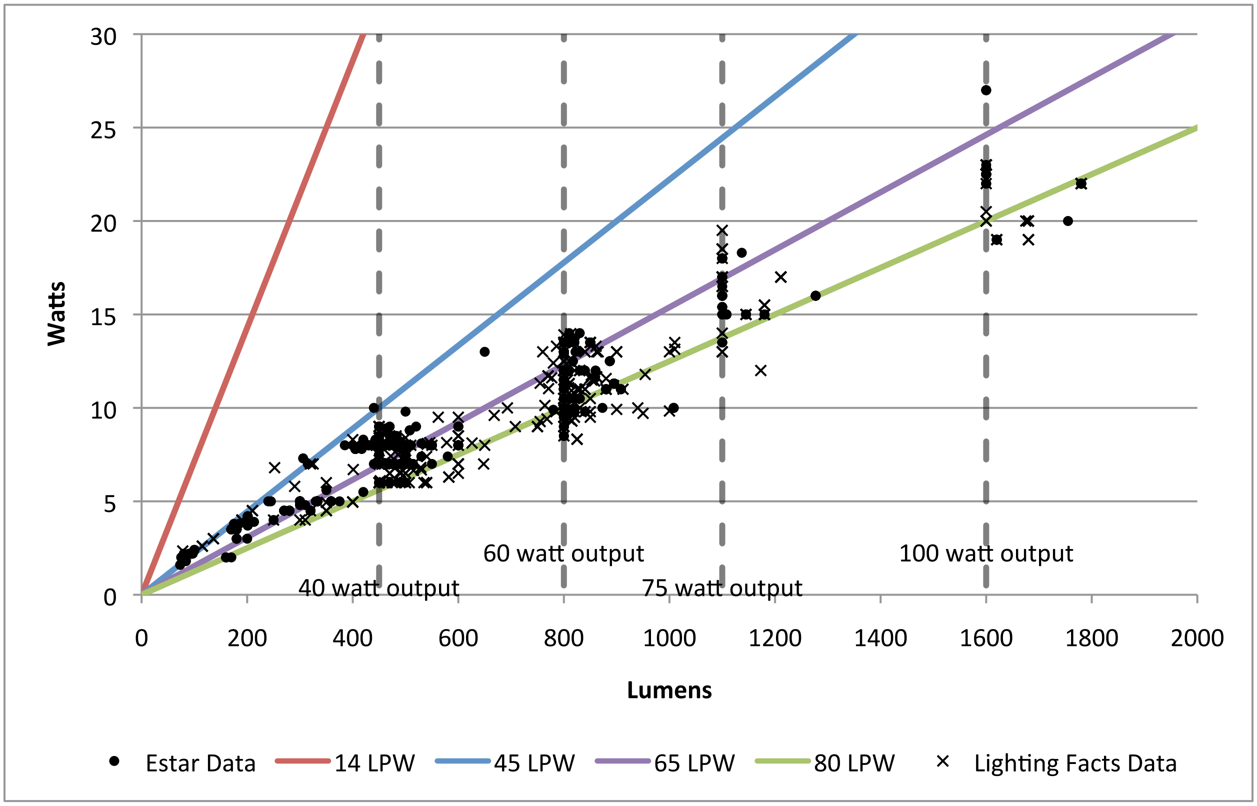
Staff has identified some concern with the current CIE calculation method for CRI in relation to LED lamps. Specifically, the CRI is an arithmetic average of eight color samples. This average allows for a high score on most samples to yield a generally high score despite a very poor result on a single sample. That leads to a deceptively high CRI, where the color rendering of a particular room could be fairly poor.

Staff is therefore proposing a minimum CRI score for each color of 75. Staff has also become aware of several efforts to improve upon the CRI calculation method and will continue to monitor progress throughout the process.

## Lamp Efficiency

The efficiency of an LED lamp is described by a rating of lumens per watt, or the amount of light output for an amount of electrical input. Improving lamp efficiency will lead to direct energy savings in baseline to efficient LED replacements as well as in LED replacements for other technology lamps. The efficacy of LED lamps in the current market varies widely. It is possible to purchase LED lamps that use almost double the power than that of others while producing the same amount of lumens.

**Figure 12: ENERGYSTAR and Lighting Facts medium screw base and GU-24 base lamp data**




Source: Energy Commission staff

The data are made up of 869 Lighting Facts and ENERGY STAR medium screw-base and GU-24 omnidirectional lamps. About 537 (62 percent) of those models have an efficacy of 65 lumens per watt or better. A total of 127 (15 percent) of them have an efficacy of 80 lumens per watt or better. [63]

While a snapshot of today's efficiencies is interesting, it is also important to understand the trajectory and potential efficacy of LED lamps over time. General service LED lamps have been on an upward efficiency trend and the future is likely to hold models that regularly surpass 100 lumens per watt.[64]

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[63] Source: Energy Commission

[64] US DOE, *"CALiPER Snapshot 'Lightbulbs',"* October 1, 2013, http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/snapshot2013_a-lamp.pdf

## Color Rendering Index

The color rendering index (CRI) measures how true the color of an object appears under a light in comparison to how it would look under natural light of the same color temperature. The score ranges between 0 and 100, with 100 representing a very good approximation of the color rendering of natural light. The incumbent incandescent lamp in screw base sockets typically have a CRI of 100 or close to 100. LED lamps are available at a broad range of CRI. High CRI is important to people who want the color of objects to look the same color as it would under natural light and who desire the same colors produced by incandescent light sources.

A nexus occurs between CRI and efficacy in several ways. For lamps using phosphors, a higher CRI requires a minimum amount of light in the red portion of the spectrum. Because the excitation wavelength is in the blue or UV spectrum, the efficiency of converting to red light is relatively poor when compared to shorter wavelengths such as yellow or blue. Furthermore, a high CRI requires a fairly even spectral distribution, which requires a larger variety of phosphors, some of which are less efficient than others.

## Correlated Color Temperature

The correlated color temperature (CCT) measures how “warm” or “cool” a light appears to be. CCT is based around white light. CCT is used in the proposed regulation to determine scope (colored lights are not within the scope). For products within the scope, CCT is used to ensure lamps are producing consistent white light and to improve brand to brand compatibility.

# CHAPTER 13: Staff Proposal

The standards are designed to improve the efficiency of LED lamps and ensure that they produce a certain grade of white light. For the standards, staff proposes a scope of coverage that includes all LED lamps that produce light within seven steps of the black-body curve,[65] and that have an E12, E17, E26, or GU-24 socket or are integrated LED lamps that include trims and are designed to be retrofitted within existing recessed can housings that contain one of the preceding bases.

## Mandatory Standards

Staff proposes three aspects of lamps to be regulated on a mandatory basis: the efficiency, color rendering index, and color correlated temperature. The efficiency and CRI requirements will allow for tradeoffs between one another, and proposed implementation is in two tiers, with more stringent requirements in Tier 2. Each tier is composed of a minimum compliance equation and bounding conditions on how low efficiency and CRI can be.

Tier 1 standard: $3 \times CRI + Efficiency \geq 335 \text{ and } CRI \geq 82,\ Efficiency \geq 55\ lp$[illegible]

Tier 2 standard: $3 \times CRI + Efficiency \geq 350 \text{ and } CRI \geq 84, Efficiency \geq 65\ lpw$

Each sample component of the CRI must also be greater than 75 and lamps must be within four steps of the black-body curve.

In addition, staff is proposing requirements for a subset of covered lamps that are traditionally expected to produce light in all directions (omni-directional). Staff proposes that omni-directional lamps meet the light distribution specified in the ENERGY STAR lamp specification version 1.1.

### Labeling Standards

The proposed labeling standards encompass three labels, most of which are conditional for access to the California market. The proposed regulations would require manufacturers to

[65] The "black-body curve" is a reference to the radiation spectra of a body at different temperatures. This curve lies at the core of the standardization of white light because most of the light from the sun is generated along this curve.

demonstrate performance before making claims about dimmability, incandescent equivalence, and meeting the Voluntary California Quality LED Lamp Specification.

To make claims of being "dimmable," lamps must pass a flicker test and must be dimmable to 10 percent. Further, they must not exceed a threshold of audible noise. Lamps may claim to be dimmable if the lamp can pass the test using a standard phase-cut dimmer. Alternatively, lamps may claim to be "dimmable with LED dimmer" if the lamp cannot be dimmed using a standard phase-cut dimmer but can be dimmed with another dimmer such as one that complies with NEMA SSL7. Lamps that are "dimmable with LED dimmer" must include instructions with the lamp describing the compatible/recommended dimmers.

To make claims of being an "incandescent equivalent" lamps must have a color temperature at or under 3000K, must be dimmable, must have a lumen output of 450 lumens or greater for a medium screw base, and 200 lumens or greater for intermediate or candelabra base. Claims of equivalence for 40W, 60W, 75W, 100W, and 150W incandescent lamps must have lumen outputs in the following ranges:

**Table 6: Incandescent equivalences**

| Incandescent equivalence | Lumen minimum |
|---|---|
| 40 W | 310 |
| 60 W | 750 |
| 75 W | 1050 |
| 100 W | 1490 |
| 150 W | 2601 |

Source: Lumen ranges contained in table K-6 of the current Appliance Efficiency Regulations

To make claims of meeting the Voluntary California Quality LED Lamp Specification a lamp must be certified as such with the California Energy Commission.

Finally, any lamp that provides less than 200 lumens for lamp bases other than a candelabra, and 150 lumens for candelabra bases, must be labeled as "for decorative purposes only."

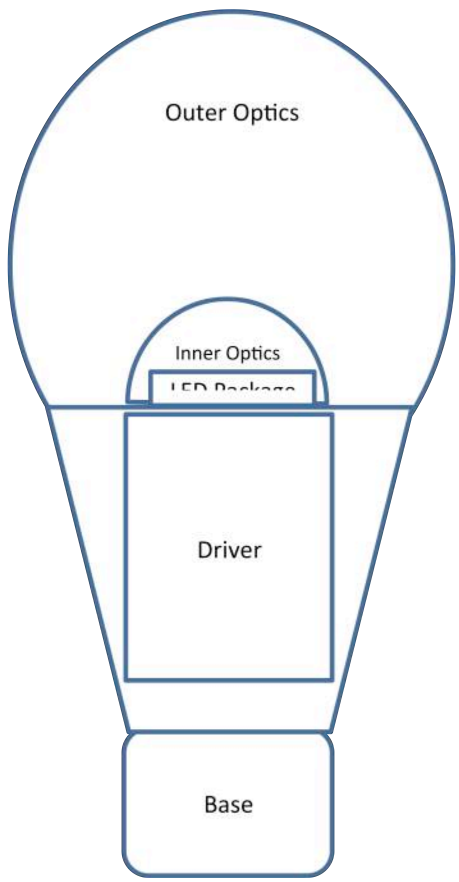
## Voluntary California Quality LED Lamp Specification

For manufacturers to be considered as having met the specification, lamps must be certified to comply to every one of the specification requirements. The specification will be updated as necessary to reflect this change.

# CHAPTER 14: Technical Feasibility

The proposed mandatory standards are feasible as there are already products in the marketplace today that comply with and meet both tiers of the proposed standards. The efficiency of a lamp is driven by three primary components: the lamp driver, the LED chip(s), and the optics. The location of these components can be seen in Figure 13 below.

**Figure 13: Typical Layout of an LED lamp**




Source: California Energy Commission

The efficiency can also be driven to some extent by the thermal management of the lamp, depending on how quickly the waste heat can be rejected from the lamp. The products that lead in efficiency are not LED lamps, but rather LED products incorporated into mobile equipment, such as mobile phones and tablets. The relatively high percentage of energy required to light mobile displays means that efficiency is one of the most critical drivers of product battery life.

The driver of an LED lamp converts AC power provided in the distribution and wiring system of a building to a voltage and waveform that is suitable for LED lamps. This conversion comes at an efficiency cost, but the amount can vary by how efficient the design and subcomponents are. The AC-DC power conversion efficiency of the driver is determined by the topology and parts incorporated. The DC power is then passed to the lamp controller, which adjusts the power (often using a PWM scheme) that powers the LED package.

The efficiency of drivers can vary and staff found performances at 85percent,[66] 90percent,[67] 95percent.[68] One strategy to improve the efficiency of a LED lamp would therefore be to improve the efficiency of the lamp driver from 85percent to 95percent. That level of driver efficiency improvement would increase the efficiency of a lamp from 55 lpw to 62 lpw. The driver has little, if any, effect on the CRI of an LED.

The LED package also plays a critical role, if not the most critical role, in the performance of the lamp. The LED package contains a series of LED devices that handle all of the conversion of electrical energy into photonic energy. LED devices are monochromatic, with the photonic energy released equal to the band gap caused by the junction of dissimilarly doped semiconductors. To achieve a white light, which includes a full spectrum of colors, an array of LEDs of many different colors must be used, or a secondary emission/conversion must be achieved through a series of phosphors.

In phosphor based LEDs, the monochromatic light selected is of short wavelength in the deep blue, violet, or ultraviolet wavelength. The efficiency of the device is driven by the diode efficiency, the difference between the diode wavelength and the phosphor wavelength, and the phosphor characteristics.

The efficiency of an LED device itself can be very high, and devices have been demonstrated at performance levels above 200 lpw. The device efficiency can be improved through material science engineering, selection of semiconductor, selection of dopants, and by making the LED thinner. A large contribution to energy loss in the device is the recombination of photons before

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[66] Marvell Single-Stage Flyback (A19) TRIAC-Dimmable LED Driver Evaluation Kit For Evaluation of the Marvell 88EM8183 LED Driver IC, available at http://www.marvell.com/led-lighting/assets/Marvell_Flybackpercent20LED_Driverpercent20Eval_Kit-04_PB_v1.pdf.

[67] Marvell 88EM8187 Shimmerless, Flicker-free, Deep Dimming Single-Stage AC/DC LED Driver IC for Replacement LED Lamps and Luminaires, available at http://www.marvell.com/led-lighting/assets/Marvell_88EM8187_IC-02_product_brief_final.pdf.

[68] Marvell 88EM8803 Dual-string Intelligent PWM Dimming DC/DC Buck LED Driver Integrated I2C Interface for LED Lighting with Wireless Network, available at http://www.marvell.com/led-lighting/assets/Marvell_88EM8803_IC-01_product_brief_final2.pdf; See also Fairchild Single stage fly back boundary mode PFC controller for lighting, available at http://www.fairchildsemi.com/ds/FL/FL7930C.pdf.

they are able to escape from the material, particularly in the junction area that is beneath the surface of the device.

The CRI is driven by the LED device and, if applicable, the phosphors. To improve CRI, the phosphor types and relative amounts of phosphors must be changed relative to a low CRI lamp. For LED lamps that do not use phosphors, additional band-gap LED devices must be added to the LED chip to better fill the visible light spectrum. High-efficiency and high-CRI-led chips are commercially available today.

# CHAPTER 15: Savings and Cost Analysis

## Stock and Sales

The total stock of general service and reflector lamps in California was about 622 million sockets in 2010[69]. At that time, LED lamps made up less than 1percent of the total stock of general service lamp sockets, but this value is predicted to increase over the next 10 years as manufacturing processes and technology continue to improve. The majority of the stock consists of incandescent/halogen lamps or CFL's.

## Incremental Cost

There is little to no correlation between efficacy and the retail cost of a lamp; for example, staff found a 50 lumens/watt, a 63 lumens/watt, a 72 lumens/ watt lamp, and an 80 lumens/watt lamp selling at $23.00 each. This lack of correlation in retail prices versus efficiency is further supported by market research conducted by DOE that shows poor correlation between efficacy, quality, and price, as well as overall downward trends in the cost of attributes.[70] Furthermore, staff has conducted collected LED chip data from the DIGIKEY, a major distributor of electronic devices with more than 15,000 white LED chip offerings. The DIGIKEY data are plotted in Figure 14. This figure shows no relationship between cost and efficacy. This same relationship seems to hold for cost versus CRI as well.

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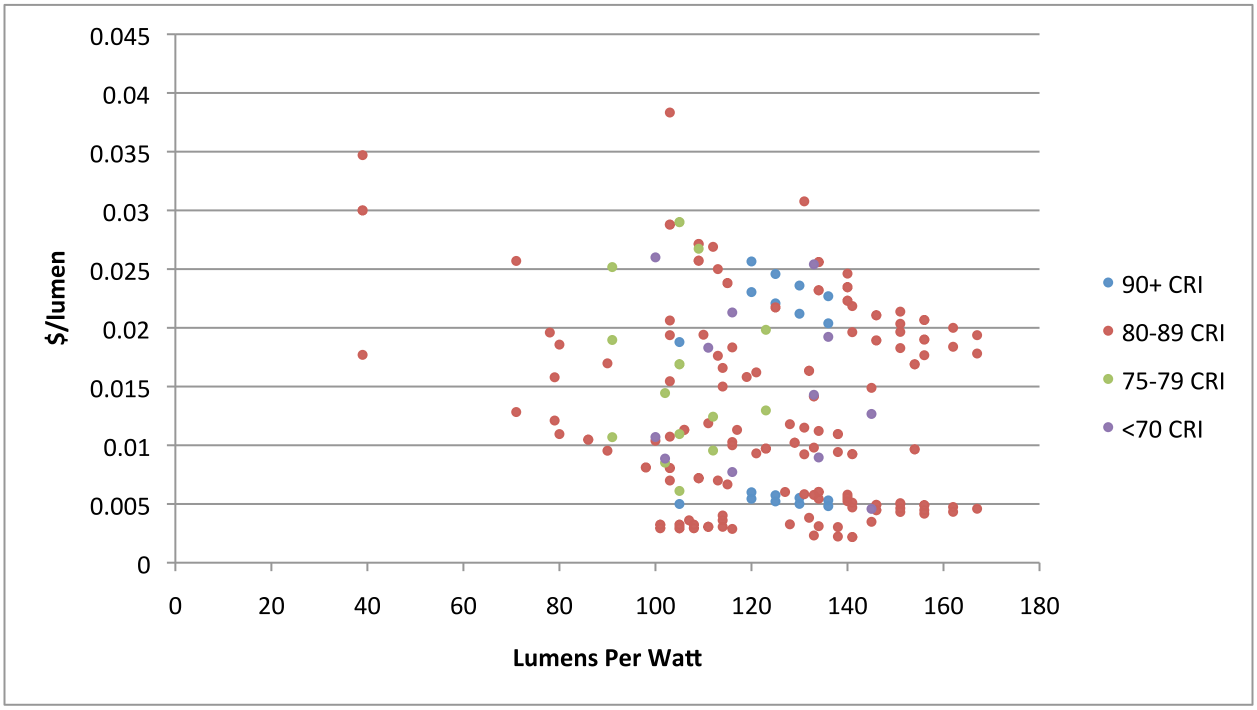
[69] Analysis of US DOE's *2010 U.S. Lighting Market Characterization* study table 4.1 using a population scaling factor of 12percent across appropriate incandescent, halogen, and CFL categories. This figure does not include linear fluorescent general service lamps as those are outside of the scope of the proposed regulation available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf

[70] U.S. DOE, *CALiPER Retail Study 3*, February 2014, available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_retail-lamps-study3.pdf.

**Figure 14: Efficacy vs. Cost of Light**




Source: California Energy Commission. Only products that had quantities available of 5,000 units or greater are plotted.

As newer LED chips and efficient drivers come into the market the price continues to decrease even further. This trend is well characterized by the DOE[71] as well as analysis contained in the California IOU's analysis.[72] All of this information suggests that the incremental cost for compliance with the proposed regulations is very small relative to the life cycle savings.

Staff found several estimates relating to the potential incremental cost of a standard. The California IOUs submitted incremental costs to improve general service LED lamps CRI to 90 at $1.84 per unit.[73] While the IOU proposal differs from staff's proposal, this improvement would

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[71] US DOE, *Manufacturing Roadmap Solid-State Lighting Research and Development*, August 2014, available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mfg_roadmap_aug2014.pdf

[72] California IOUs, *Codes and Standards Enhancement Initiative for LED Lamp Quality*, July 29, 2013, available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/PG_and_E_and_SDG_and_Es_Responses_to_the_Invitation_for_Standards_Proposals_for_LED_Quality_Lamps_2013-07-29_TN-71758.pdf

[73] California IOUs, *Codes and Standards Enhancement Initiative for LED Lamp Quality*, July 29, 2013, available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-

move a large number of products into compliance with the standard. Staff expects that improving the efficacy will be even less expensive than improving the CRI of LED lamps because of existing strong trends of improved efficacy in the industry, and because improvements in efficacy have counterbalancing cost savings in thermal dissipation components such as heat-sinks and LED drivers. In either the IOU estimate or the Staff's expectation of even lower incremental costs, the proposed regulations are cost-effective to the consumers.

## Energy Savings

Staff calculated energy savings by adjusting products that do not comply with the proposed standard to a point where they would just barely meet the standard. This forms a conservative estimate of the savings from improvements because, in reality, those products would most likely improve at least slightly beyond compliance. Savings include those from non-compliant LED's to compliant LED's. For detailed information about assumptions and calculations used to determine energy savings, see Appendix B of this report. The savings results are summarized in Table 8.

**Table 8: Energy Savings Summary**

| Lamp Type | LED Stock (Millions) | Average Baseline Efficacy | Average Tier 2 Efficacy | Energy Savings (GWh for the year 2030) |
|---|---|---|---|---|
| General Service | 308.1 | 65 | 97.2 | 1,372 |
| Directional | 47.8 | 50 | 97.2 | 380.9 |
| Decorative | 110.6 | 50 | 97.2 | 440.7 |
| Total | - | - | - | 2,194 |

Source: California Energy Commission, specifically calculations contained in Appendix B

## Cost-Effectiveness

According to staff analysis, the proposed standards are cost-effective, as the energy savings greatly outweigh both the incremental cost of improvements, and the price of compliant product with payback within a few years. The cost-benefit ratios of simple lifetime dollar savings are shown in Appendix B.  Table 9 summarizes the costs, benefits, and cost-benefit ratio of improved efficiency in general service, directional, and decorative LED lamps.

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2B_Lighting/PG_and_E_and_SDG_and_Es_Responses_to_the_Invitation_for_Standards_Proposals_for_LED_Quality_Lamps_2013-07-29_TN-71758.pdf

**Table 9: Energy Savings Summary**

| Lamp Type | Incremental Cost[74] | Lifetime Savings[75] | Cost to Benefit Ratio |
|---|---|---|---|
| General Service | $1.84 | $10.57 | 5.8 |
| Directional | $3.15 | $22.67 | 7.2 |
| Decorative | $2.47 | $11.33 | 4.6 |

Source: California Energy Commission, specifically calculations contained in Appendix B

[74] California IOUs, *Codes and Standards Enhancement Initiative for LED Lamp Quality*, July 29, 2013, available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/PG_and_E_and_SDG_and_Es_Responses_to_the_Invitation_for_Standards_Proposals_for_LED_Quality_Lamps_2013-07-29_TN-71758.pdf

[75] Lifetime savings were calculated using a 3% annual discount to the value of bill savings.

# CHAPTER 16:
# Safety and Environmental Issues

Staff could not identify any safety or negative environmental impacts of improving general service lamp efficiency. While the technical feasibility section acknowledges the use of different, more efficient components, and perhaps some additional control circuitry, those improvements would not create a particular waste hazard.

The proposed standards will, however, lead to improved environmental quality in California. Saved energy translates to fewer power plants built and less pressure on the limited energy resources, land, and water use associated with it. In addition, lower electricity consumption results in reduced greenhouse gas and criteria pollutant emissions, primarily from lower generation in hydrocarbon burning power plants, such as natural gas power plants. The energy saved by this proposal would reduce greenhouse gas emissions by 0.687 $MMTCO_2e$.[76]

[76] Million metric tons of carbon dioxide equivalents are calculated by Using conversion of 690 pounds per MWh to metric scale, using the rate estimated by the *Energy Aware Planning Guide,* CEC-600-2009-013, February 2011, Section II: Overview, page 5.

# CHAPTER 17:
# Regulatory Language

All language below that would be new to the appliance efficiency regulations are provided in underline with the exception of section headers.

## 1601 Scope.

…

**(k) Lamps**

…

(2) LED lamps that produce light within 7 MacAdam steps of the black-body curve, and that have an E12, E17, E26, or GU-24 socket or are integrated LED lamps that include trims and are designed to be retrofitted within existing recessed can housings that contain one of the preceding bases.

…

## 1602 Definitions.

…

### (k) Lamps

"State-regulated Light Emitting Diode (LED) lamp" means any LED lamp within the scope of 1601(k)(2).

## Section 1604 Test Methods for Specific Appliances

### (k) Lamps

…

(4) The test method for state-regulated LED lamps is IES LM-79-08.

…

(6) [Placeholder for flicker test]

…

### 1605.3 State Standards for Non-Federally-Regulated Appliances

### (k) Lamps

…

(2) Standards for State-Regulated General Service Incandescent Lamps, General Service Lamps, and Modified Spectrum Incandescent Lamps. The energy consumption rate of state-regulated general service incandescent lamps, general service lamps, and modified spectrum general service incandescent lamps manufactured on or after the effective dates shown in Tables K-10, K-11, ~~and~~ K-12, and K-13 shall meet the standards shown in these Tables.

…

(C) State-regulated LED lamps must have a correlated color temperature that falls within four MacAdam steps of the black-body curve.

…

(D) State-regulated LED lamps that have an ANSI standard lamp shape of A, C, CA, or G shall meet the respective omnidirectional light distribution requirements of ENERGY STAR's Product Specification for Lamps Version 1.1

…

**Table K-13**
**Standards for State-regulated General Service LED Lamps**

| *Effective Date* | *Minimum Compliance Score* | *Minimum Efficacy* | *Minimum CRI* |
|---|---|---|---|
| January 1, 2017 | 335 | 55 | 82 |
| January 1, 2019 | 350 | 65 | 84 |
| The compliance score shall be calculated as the sum of the efficacy and 3 times the CRI of a lamp.<br>*Each individual color components R1 through R8 shall not be less than 75 | | | |

…

### 1607 Marking of Lamps.

…

(12) State regulated LED lamps shall meet the criteria below before making any of the relevant claims in marketing materials, including retail packaging, or on the lamp itself.

…

(A) The following shall be demonstrated before making an unqualified claim of being "dimmable."

...

(i) The lamp shall be dimmable to 10percent of its full light output.

(ii) The product shall pass a flicker test as described in section 1604(k)(6) using a standard phase-cut dimmer, or;

(iii) if the product cannot pass the flicker test using a standard phase-cut dimmer, but can pass the flicker test using another type of dimmer, references to dimmability shall be qualified with the phrase "dimmable with LED dimmer." These lamps shall also be packaged with instructions that describe the type of dimmers that are compatible or recommended for use with the lamp.

...

(B) The following requirements shall be met before making any comparisons to incandescent lamps:

...

(i) The lamp shall have a color correlated temperature of 3000k or less.

(ii) The lamp shall be "dimmable" as described in 1607(d)(12)(A).

(iii) Must have a lumen output of 450 lumens or greater for medium-screw base lamps or 200 lumens or greater for intermediate and candelabra bases, and

(iv) Claims of equivalence to 40 watt, 60 watt, 75 watt, 100 watt, and 150 watt incandescent lamps shall have lumen outputs in the respective ranges contained in Table K-14 below.

...

Table K-14
Incandescent equivalences

| Incandescent equivalence | Lumen minimum |
|---|---|
| 40 W | 310 |
| 60 W | 750 |
| 75 W | 1050 |
| 100 W | 1490 |
| 150 W | 2500 |

...

(C) A lamp that is certified with a light output of less than 150 lumens for candelabra bases, or less than 200 lumens for other bases, shall be marked as “for decorative purposes only.”

…

(D) Lamps shall certify that each and every portion of the California Quality LED Lamp Specification is met before making any marketing, label, or mark regarding a model’s qualification for the specification.

…

# APPENDIX A

## Model for Small Diameter Directional Lamps

Appendix A discusses the information and calculations used to characterize small diameter directional lamps in California, their current energy use impact, and potential savings.

## Existing Stock and Market Share and Future Stock Projections

The IOUs' CASE Study estimates that in 2012 there were about 14.6 million small-diameter directional lamps installed in California.[77] This estimate is based on the assumption that California stock is about 12 percent of the national installed stock. The IOUs further estimated that 70 percent of the California stock is of 50-watt lamps, 20 percent are 35-watt lamps and 10 percent are 20-watt lamps. The 3rd row in the table below shows the existing stock of 50 watt lamps, the 4th row in the same table shows existing stock of 35 watt lamps, and the 5th row shows the 20 watt lamp stock. Total stock is the sum of all the existing stock in the 6th row of the table below.

Based on the market, IOUs also estimated that the current stock is growing at a compound annual growth rate (CAGR) of 1.3 percent. Calculations for total stock for years 2016 through 2028 are shown in the table below.

Variables for calculations are as follows:

ES=Existing Stock

LW50=Wattage Bin 70 Percent

LW35=Wattage Bin 20 Percent

LW20= Wattage Bin 10 Percent

CAGR= Compound Annual Growth Rate=1.3

Existing Stock and Stock Projections=ES*(LW50 or LW35 or LW20)*CAGR

77 *Small Diameter Directional Lamps Codes and Standards Enhancement (CASE) Initiative*, August 6, 2014, available at http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/California_IOUs_Small_Diameter_Directional_Lamps_Addendum_to_CASE_Report_2014-08-06_TN-73551.pdf, page 2.

**Table A-1: Existing Stock and Stock Projections**

| Existing Stock | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
| 50 Watt stock is 70percent | 11.04 | 11.19 | 11.33 | 11.48 | 11.63 | 11.78 | 11.93 | 12.09 | 12.25 | 12.40 | 12.57 |
| 35 Watt Stock is 20percent | 3.16 | 3.20 | 3.24 | 3.28 | 3.32 | 3.37 | 3.41 | 3.45 | 3.50 | 3.54 | 3.59 |
| 20 Watt Stock is 10percent | 1.58 | 1.60 | 1.62 | 1.64 | 1.66 | 1.68 | 1.70 | 1.73 | 1.75 | 1.77 | 1.80 |
| Total Estimated Stock | 15.8 | 16.0 | 16.2 | 16.4 | 16.6 | 16.8 | 17.0 | 17.3 | 17.5 | 17.7 | 18.0 |

Source: California Energy Commission

The IOUs' CASE report also estimated that 80 percent of the existing stock is low-voltage lamps, and 20 percent of the stock is line voltage. Low-voltage lamps are connected via a transformer, whereas line voltage lamps directly connect to 110 volts. The IOUs' CASE report also estimates that low-voltage transformers consume an additional 10 percent of power.

Formula for calculating the low voltage lamps:

Low Voltage Stock=ES*LO*CAGR

LO= Low wattage Bin=80 percent of the total stock

Formula for calculating the line voltage lamps:

Line Voltage Stock=ES*LN*CAGR

LN= Line wattage Bin=20 percent of the total stock

**Table A-2: Low Voltage and Line Voltage Stock and Projections**

| Existing Low Voltage and Line Voltage Stock | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
| Low voltage stock= 80percent | 12.6 | 12.8 | 13.0 | 13.1 | 13.3 | 13.5 | 13.6 | 13.8 | 14.0 | 14.2 | 14.4 |
| Line Voltage Stock 20percent | 3.2 | 3.2 | 3.2 | 3.3 | 3.3 | 3.4 | 3.43 | 3.5 | 3.5 | 3.5 | 3.6 |
| Total Stock | 15.8 | 16.0 | 16.2 | 16.4 | 16.6 | 16.8 | 17.0 | 17.3 | 17.5 | 17.7 | 18.0 |

Source: California Energy Commission

## Annual Energy Consumption

Annual operating hour estimates are based on the weighted averages of residential and commercial sectors. The annual operating hours are based on the 2002 lighting market characterization study conducted by Navigant, which states that the commercial low-voltage lamps operate roughly 3,720 hours per year, while residential general service halogen lamps operate 840 hours per year.[78] The study also estimates that commercial lamps make 65 percent of the total installed stock, whereas 35 percent of the stock is residential lamps.

**Table A-3: Annual operating hours**

| Annual Energy Consumption | Hrs/year | Market share |
|---|---|---|
| Commercial | 3720 | 65percent |
| Residential | 840 | 35percent |
| Average Operating Hours | 2712 | 100percent |

Source: California Energy Commission

Table A-4 below shows the total yearly energy consumption for small diameter directional lamps without any standards. The annual energy consumption after the standard is also shown in Table A-4.

LN Consumption=2712*(LW50 or LW35 or LW20)*0.2/1000 KWh

LO Consumption= 2712*(LW50 or LW35 or LW20)*0.8/0.9/1000 KWh

BECPL= LN Consumption + LO Consumption KWh

Baseline Energy Consumption per Lamp=BECPL

[78] Operating hours are calculated based on the Navigant Consulting 2011 report *Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications*," available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/nichefinalreport_january2011.pdf, page 17.

**Table A-4: Annual Energy Consumption per Lamp**

| Annual Energy Consumption Per Lamp: | | |
|---|---|---|
| No Standard | 80 lumens/watt | Savings |
| 119 KWh/year | 22 KWh/year | 97 KWh/year |
| **Annual Operating Cost** | | **$ Savings/year** |
| No Standards | 80 lumens/watt | |
| $15.51 | $2.86 | $12.65 |

Source: California Energy Commission

Calculated Baseline energy consumption per lamp is as follows:

## Baseline Energy Consumption

Statewide Base line energy consumption without standard

**SBEC=ES*BECPL*CAGR KWh**

Statewide Baseline Energy Consumption=SBEC

Statewide Energy Consumption with 80 lumens per watt with standard in effect:

**LN Consumption=2712*(LW50 or LW35 or LW20)/80*0.2/1000 KWh**

**LO Consumption= 2712*(LW50 or LW35 or LW20)/80*0.8/0.9/1000 KWh**

**BECPL= LN Consumption + LO Consumption KWh**

**Table A-5: Baseline Annual Energy Consumption**

| **Annual Energy Consumption (GWh/yr)** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| year | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
| Energy Consumption Without Standards (GWh) | 1883 | 1907 | 1932 | 1957 | 1982 | 2008 | 2034 | 2061 | 2088 | 2115 | 2142 |
| **Annual Energy Consumption after standard is fully implemented (GWh/yr)** | | | | | | | | | | | |
| Energy Consumption with Standard (GWh) | 347 | 352 | 356 | 361 | 366 | 370 | 375 | 380 | 385 | 390 | 395 |

Annual energy consumption per lamp is calculated by multiplying annual operating hours with the average lamp wattage of low voltage and line voltage lamps.

Source: California Energy Commission

## Energy Savings

Table A-6 below shows the total annual cost savings per year from 2018 to 2028. These savings are calculated by multiplying the total statewide energy savings with the average per KWh rate of 13 cents. The 13 cents rate is the average rate derived by multiplying 65 percent of the commercial market rate of 11 cents and 35 percent of the residential rate of 16 cents. The total NPV savings over the lifetime of a small-diameter directional LED lamp at a discount rate of 3 percent is $2,358 million or nearly $2.4 billion..

**Table A-6: Annual $ cost Savings**

| Annual $ savings | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
| $ savings (in Millions) | 223 | 220 | 216 | 212 | 208 | 205 | 201 | 198 | 194 | 191 | 187 |

Source: California Energy Commission

**Table A-7: Statewide Energy and Cost Impact**

| Proposed Standard | Design Life Hours | Annual Energy Savings/Unit KWh/year | Incremental Cost of Improvement/Unit | First year Unit Energy Savings | Reduced Total savings over the design life($) | Simple payback period | Annual sales in millions | 1st year statewide energy savings |
|---|---|---|---|---|---|---|---|---|
| 80 lumens/ Watt | 10 years | 97KWh/year | $13.52 | $12.65 | 156.87 | <1.5 years | 15.8 | 1535 GWH |

Source: California Energy Commission

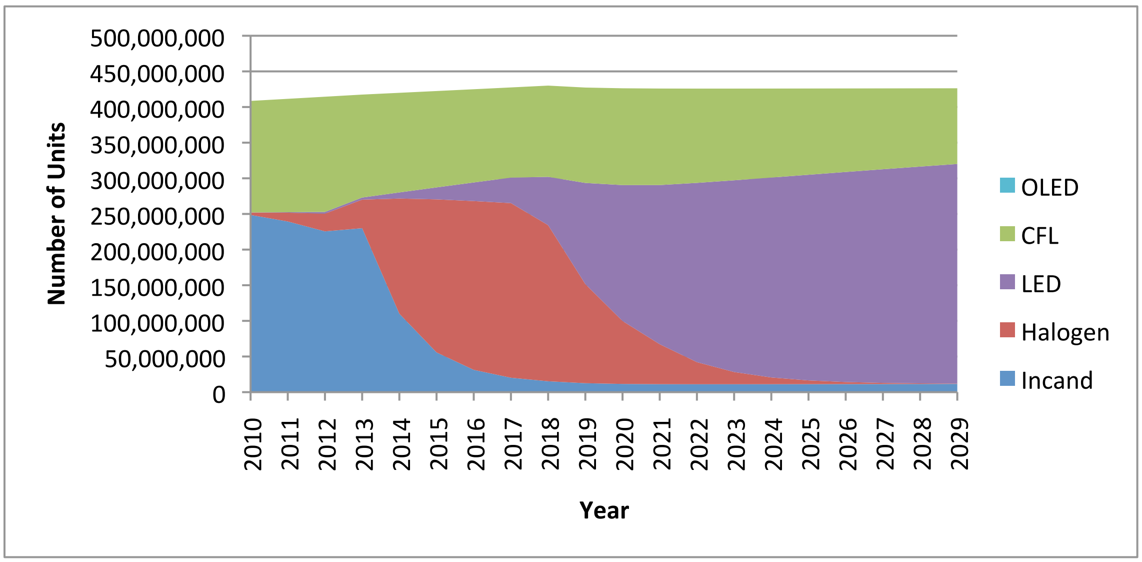
# APPENDIX B

Appendix B discusses the information used to characterize LED lamp energy use and potential savings.

## Existing Stock, Market Share, and Future Stock Projections

Energy Commission staff constructed a complex model of omni-directional medium screw base market share based on NEMA and DOE data.[79] [80] [81] The model also incorporated EISA standards for incandescent general service lamps and the 45-lumen per watt backstop standard adopted by the Energy Commission and effective on January 1, 2018. The stock and shipment distributions were generated are shown in figures B-1 and B-2 below. The model currently does not incorporate population or building stock growth rates.

**Figure B-1: Medium Screw Base A-lamp Stock Projections**




Source: California Energy Commission

**Figure B-2: A-lamp Shipment Projections**

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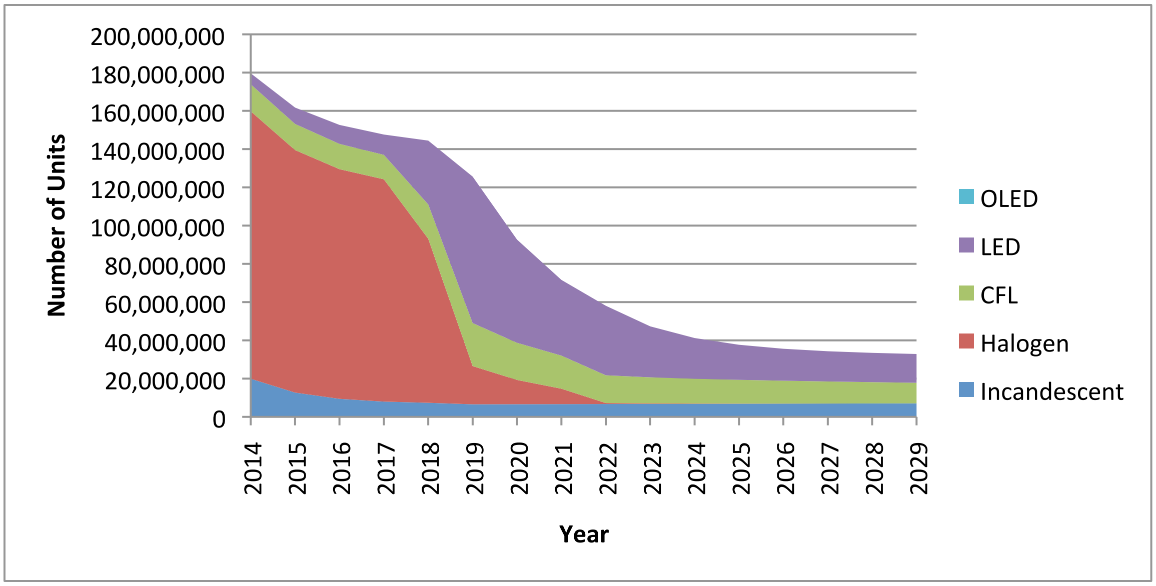
[79] NEMA, "LED A-line Replacement Lamps Begin Making Inroads into the Market," December 20, 2013, available at http://www.nema.org/news/Pages/LED-A-line-Replacement-Lamps-Begin-Making-Inroads-into-the-Market.aspx

[80] DOE, *2010 U.S. Lighting Market Characterization*, January 2012, available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf

[81] DOE, *Adoption of Light-Emitting Diodes in Common Lighting Applications*, May 2013, available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-adoption-report_2013.pdf




Source: California Energy Commission

Staff used the same DOE studies to estimate the stock of medium screw-base reflector lamps and decorative lamps. Staff aligned LED market share with DOE forecasts.[82] The results are summarized in Table B-1.

**Table B-1: Directional and Decorative Lamp Stock 2030**

| Baseline | Stock (lamps) | % LED 2030 |
|---|---|---|
| Directional | 95,537,880 | 50% |
| Decorative | 117,606,480 | 94% |

Source: California Energy Commission

## Energy Savings

Average LED lamp efficacy would increase in both Tier I and Tier II, saving energy in the process. The quality aspects of the regulation in additional to the reduced operating costs would also accelerate market share growth of LED lamps relative to less efficient technologies such as halogen lamps and CFLs. Table B-2 summarizes the energy savings potential of general service, directional, and decorative LED lamps.

[82] DOE, *Energy Savings Forecast of Solid-State Lighting in General Illumination Applications*, August 2014, see tables 3.3 and figure 3.8 available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energysavingsforecast14.pdf

**Table B-2: Stock Energy Savings**

| Lamp Type | LED Stock (Millions) | Average Baseline Efficacy | Average Tier 2 Efficacy | Energy Savings (GWh for the year 2030) |
|---|---|---|---|---|
| General Service | 308.1 | 65 | 97.2 | 1,372 |
| Directional | 47.8 | 50 | 97.2 | 380.9 |
| Decorative | 110.6 | 50 | 97.2 | 440.7 |

Source: California Energy Commission

The annual savings of the proposed regulations in 2030 would be 2,194 GWh. Even greater savings are at risk from the failure of LED lamps to penetrate the incandescent, halogen, and CFL markets. The reduced electricity cost to consumers in 2030 would be $351 million dollars.

## Yearly Savings for the Lifetime of One Lamp

**Table B-3: Single Lamp Savings, Directional Lamp**

| Year | Energy Savings | Value Of Kwh | $ Savings | Lifetime Savings | Lifetime Cost |
|---|---|---|---|---|---|
| 2017 | 8.0 | $0.160 | $1.28 | $1.28 | $3.15 |
| 2018 | 8.0 | $0.155 | $1.24 | $2.51 | $3.15 |
| 2019 | 8.0 | $0.151 | $1.20 | $3.71 | $3.15 |
| 2020 | 8.0 | $0.146 | $1.16 | $4.88 | $3.15 |
| 2021 | 8.0 | $0.142 | $1.13 | $6.01 | $3.15 |
| 2022 | 8.0 | $0.137 | $1.10 | $7.10 | $3.15 |
| 2023 | 8.0 | $0.133 | $1.06 | $8.17 | $3.15 |
| 2024 | 8.0 | $0.129 | $1.03 | $9.20 | $3.15 |
| 2025 | 8.0 | $0.125 | $1.00 | $10.20 | $3.15 |
| 2026 | 8.0 | $0.122 | $0.97 | $11.17 | $3.15 |
| 2027 | 8.0 | $0.118 | $0.94 | $12.11 | $3.15 |
| 2028 | 8.0 | $0.114 | $0.91 | $13.02 | $3.15 |
| 2029 | 8.0 | $0.111 | $0.89 | $13.90 | $3.15 |
| 2030 | 8.0 | $0.108 | $0.86 | $14.76 | $3.15 |
| 2031 | 8.0 | $0.104 | $0.83 | $15.60 | $3.15 |
| 2032 | 8.0 | $0.101 | $0.81 | $16.40 | $3.15 |
| 2033 | 8.0 | $0.098 | $0.78 | $17.19 | $3.15 |
| 2034 | 8.0 | $0.095 | $0.76 | $17.95 | $3.15 |
| 2035 | 8.0 | $0.092 | $0.74 | $18.69 | $3.15 |
| 2036 | 8.0 | $0.090 | $0.72 | $19.40 | $3.15 |
| 2037 | 8.0 | $0.087 | $0.69 | $20.09 | $3.15 |
| 2038 | 8.0 | $0.084 | $0.67 | $20.77 | $3.15 |
| 2039 | 8.0 | $0.082 | $0.65 | $21.42 | $3.15 |
| 2040 | 8.0 | $0.079 | $0.63 | $22.05 | $3.15 |
| 2041 | 8.0 | $0.077 | $0.61 | $22.67 | $3.15 |

Source: California Energy Commission

**Table B-4: Single Lamp Savings, Decorative Lamp**

| Year | Energy Savings | Value Of Kwh | $ Savings | Lifetime Savings | Lifetime Cost |
|---|---|---|---|---|---|
| 2017 | 4.0 | $0.160 | $0.64 | $0.64 | $2.47 |
| 2018 | 4.0 | $0.155 | $0.62 | $1.26 | $2.47 |
| 2019 | 4.0 | $0.151 | $0.60 | $1.86 | $2.47 |
| 2020 | 4.0 | $0.146 | $0.58 | $2.44 | $2.47 |
| 2021 | 4.0 | $0.142 | $0.56 | $3.00 | $2.47 |
| 2022 | 4.0 | $0.137 | $0.55 | $3.55 | $2.47 |
| 2023 | 4.0 | $0.133 | $0.53 | $4.08 | $2.47 |
| 2024 | 4.0 | $0.129 | $0.52 | $4.60 | $2.47 |
| 2025 | 4.0 | $0.125 | $0.50 | $5.10 | $2.47 |
| 2026 | 4.0 | $0.122 | $0.48 | $5.58 | $2.47 |
| 2027 | 4.0 | $0.118 | $0.47 | $6.05 | $2.47 |
| 2028 | 4.0 | $0.114 | $0.46 | $6.51 | $2.47 |
| 2029 | 4.0 | $0.111 | $0.44 | $6.95 | $2.47 |
| 2030 | 4.0 | $0.108 | $0.43 | $7.38 | $2.47 |
| 2031 | 4.0 | $0.104 | $0.42 | $7.80 | $2.47 |
| 2032 | 4.0 | $0.101 | $0.40 | $8.20 | $2.47 |
| 2033 | 4.0 | $0.098 | $0.39 | $8.59 | $2.47 |
| 2034 | 4.0 | $0.095 | $0.38 | $8.97 | $2.47 |
| 2035 | 4.0 | $0.092 | $0.37 | $9.34 | $2.47 |
| 2036 | 4.0 | $0.090 | $0.36 | $9.70 | $2.47 |
| 2037 | 4.0 | $0.087 | $0.35 | $10.05 | $2.47 |
| 2038 | 4.0 | $0.084 | $0.34 | $10.38 | $2.47 |
| 2039 | 4.0 | $0.082 | $0.33 | $10.71 | $2.47 |
| 2040 | 4.0 | $0.079 | $0.32 | $11.03 | $2.47 |
| 2041 | 4.0 | $0.077 | $0.31 | $11.33 | $2.47 |

Source: California Energy Commission

**Table B-5: Single Lamp Savings, General Service Lamp**

| Year | Energy Savings | Value Of Kwh | $ Savings | Lifetime Savings | Lifetime Cost |
|---|---|---|---|---|---|
| 2017 | 3.7 | $0.160 | $0.59 | $0.59 | $1.87 |
| 2018 | 3.7 | $0.155 | $0.58 | $1.17 | $1.87 |
| 2019 | 3.7 | $0.151 | $0.56 | $1.73 | $1.87 |
| 2020 | 3.7 | $0.146 | $0.54 | $2.27 | $1.87 |
| 2021 | 3.7 | $0.142 | $0.53 | $2.80 | $1.87 |
| 2022 | 3.7 | $0.137 | $0.51 | $3.31 | $1.87 |
| 2023 | 3.7 | $0.133 | $0.50 | $3.81 | $1.87 |
| 2024 | 3.7 | $0.129 | $0.48 | $4.29 | $1.87 |
| 2025 | 3.7 | $0.125 | $0.47 | $4.76 | $1.87 |
| 2026 | 3.7 | $0.122 | $0.45 | $5.21 | $1.87 |
| 2027 | 3.7 | $0.118 | $0.44 | $5.65 | $1.87 |
| 2028 | 3.7 | $0.114 | $0.43 | $6.07 | $1.87 |
| 2029 | 3.7 | $0.111 | $0.41 | $6.48 | $1.87 |
| 2030 | 3.7 | $0.108 | $0.40 | $6.88 | $1.87 |
| 2031 | 3.7 | $0.104 | $0.39 | $7.27 | $1.87 |
| 2032 | 3.7 | $0.101 | $0.38 | $7.65 | $1.87 |
| 2033 | 3.7 | $0.098 | $0.37 | $8.02 | $1.87 |
| 2034 | 3.7 | $0.095 | $0.35 | $8.37 | $1.87 |
| 2035 | 3.7 | $0.092 | $0.34 | $8.71 | $1.87 |
| 2036 | 3.7 | $0.090 | $0.33 | $9.05 | $1.87 |
| 2037 | 3.7 | $0.087 | $0.32 | $9.37 | $1.87 |
| 2038 | 3.7 | $0.084 | $0.31 | $9.68 | $1.87 |
| 2039 | 3.7 | $0.082 | $0.30 | $9.99 | $1.87 |
| 2040 | 3.7 | $0.079 | $0.30 | $10.28 | $1.87 |
| 2041 | 3.7 | $0.077 | $0.29 | $10.57 | $1.87 |

Source: California Energy Commission