Small Diameter Directional Lamps

Response to California Energy Commission
2013 Pre-Rulemaking Appliance Efficiency
Invitation to Participate

Docket Number: 12-AAER-2B; Lighting

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Summary

The information below is a direct response to the California Energy Commission's (CEC) Invitation to Participate (ITP) for the 2013 Appliance Efficiency Pre-Rulemaking, regarding Small Diameter Directional Lamps, including performance data, test procedures, market indicators, and cost data, and reference several primary sources, some of which are attached separately (see References for more details). This document includes all of the questions asked in the ITP, even those for which we do not provide response.

In summary, there is a significant opportunity to reap large energy savings from an energy performance standard for small diameter directional lamps sold in California. Not only is there a large variance in energy performance among commercially available products, but there is a sizeable market in terms of product availability and stock/shipments. These products are not federally covered, and thus we do not expect to see federal standards for these products in the foreseeable future. Moreover, consumers lack detailed product labeling for some higher efficiency products to be able to understand the energy cost consequences of their choices, and thus market adoption of more efficient products has been slow.

We commend the CEC for initiating a rulemaking on this measure, and look forward to working with both the CEC and other stakeholders to arrive at a cost-effective measure that maximizes energy savings for California consumers.

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1 Basic Information

1.1 Category definition and scope

We propose the scope to encompass small diameter directional lamps (diameter less than or equal to 2.5 inches), which include some multi-faceted reflector (MR) lamps (MR16s and MR11s) and parabolic aluminized reflector (PAR) lamps (PAR16s and PAR11s), which include low voltage lamps (typically MRs), and line voltage lamps (typically PARs and some MRs). These lamps are widely used for accent, task, and display lighting in museums, art galleries, retail stores, residential settings, and entertainment venues. MR lamps comprise the very large majority (approximately 95 percent[1]) of the small diameter lamp market, while small diameter PAR lamps comprise the remaining portion of the market (personal communication with a lighting designer).

1.1.1 MR Lamps

MR lamps are typically designed for low-voltage (V) operation (12V), allowing for shorter, thicker, and more robust filaments, which allow the lamps to generate high luminous intensity[2]; however, a small percentage operate on line voltage (120V). More robust filaments can accommodate higher currents, while thinner filaments are needed to limit current in 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). For directional lamps, CBCP is often a more useful metric than total lumen output (CALiPER 2012).

Typical bases for these lamps include the two-pin (GU5.3) base for low-voltage applications and a turn-and-lock (GU10) configuration for applications in which line voltage is used; some MR lamps developed and marketed in the last few years include an integral transformer, which provides low voltage performance while using line voltage supply.

Like typical halogen lamps, MR lamps have very high (close to 100) Color Rendering Index (CRI), and Correlated Color Temperature (CCT) ranging from 2600 to 3200 Kelvin (LRC 2002).

1.1.2 Small Diameter PAR Lamps

PAR lamps have less control over beam angle, shape, and sharpness relative to MR lamps, and are still widely used in entertainment and venue lighting. The small diameter PAR lamps, which include the class of PAR16 & PAR11 lamps, are much less common, though still available. Similar to MR lamps, small diameter PAR lamps also come in the same range of beam angles (7 degrees to 60 degrees) (LRC 2002). Additionally, CBCP and lumen output are typically considered in the selection of a PAR16. They operate at line voltage and generally have medium screw bases, medium-skirted bases, or GU-10 bases (LRC 2002). PAR16 lamps are sold in three conventional

[1] Based on phone interviews with lighting experts
[2] Luminous intensity is a measure of the amount of light that a point source radiates in a given direction, which is particularly relevant to small diameter directional lamps since light is emitted within a specified beam angle. (IES TM-1-12)

wattage categories: 20W, 35W, and 50W; they are very rarely found in 60W and 75W configurations (GE 2013a, Philips 2013a, Sylvania 2013a).

1.2 Standards (existing or under development)

At present there is no Title 20 standard for small diameter directional lamps, nor is there a federal standard for small diameter directional lamps less than or equal to 2.5 inches (federal standards exist for incandescent reflector lamps with diameters greater than 2.5 inches).

1.2.1 DOE Established HIR Performance Standard for Incandescent Reflector Lamps (IRLs)

DOE conducted a standards rulemaking on standard spectrum and modified spectrum IRLs with diameters and wattages exceeding 2.5 inches and 40 watts, respectively. The rulemaking, finalized on July 14, 2009, and effective on July 14, 2012, established minimum performance level (efficacy) that can be achieved by halogen infrared (HIR) lamps incorporating improved reflectors, coatings, and filaments. Improved HIR technologies will increase average baseline efficacy from about 14 lpw to 19 lpw, dropping average IRL wattage from 75W to 55W (ASAP 2011).

DOE conducted a full energy and cost-savings analysis, which demonstrated that (in the case of IRLs) HIR lamps provided maximized benefits at minimized costs. DOE made the following claims in the Final Rule:

- DOE indicated that it believed manufacturers could maintain production capacity levels and continue to meet market demand at the proposed IRL standard (TSL 4- HIR). DOE stated that manufacturers could install additional coaters, purchase infrared burners from a supplier, and use existing excess capacity.
- DOE did not receive comments that indicated that the energy conservation standards would result in the unavailability of standards-compliant products.
- DOE does not believe manufacturers will have to obtain proprietary technology to meet the energy conservation standards set forth by the final rule.
- DOE did not receive additional information or comments that would indicate that the identified alternative technologies necessary to meet energy conservation standards set forth by the final rule will lead to any lessening of competition.

In the rulemaking process, DOE received one petition for exemption from the IRL standard on the basis that the HIR lamps did not provide the same quality of light as the halogen lamps that would be eliminated by the proposed standard. DOE responded indicating that it was unaware of any specific light quality of halogen lamps that would necessitate their usage instead of halogen infrared reflector lamps. Although infrared reflector coating causes a reduction in the infrared region of the electromagnetic spectrum, these wavelengths are largely invisible to the human eye. Ultimately, DOE did not grant an extension on the basis that halogen lamps do not present a distinct utility when compared to HIR lamps (DOE 2012).

DOE has started a rulemaking on small diameter directional lamps, but MR16s and PAR16s are outside the scope of the rulemaking.

1.2.2 European Union (EU) Lamp Standards

The EU established standards for low voltage filament lamps[3], including low voltage and line voltage halogen lamps. They established performance standards according to an energy efficiency index (EEI), which takes into account lamp wattage and lumen output.[4] The intent of the standards was to establish that by 2014 only the best quality halogen reflectors would be available on the market (as depicted in Table 1).

Table 1: EU Standards for Low Voltage Filament Lamps

	Low Voltage Filament Lamps	Description
Stage 1 (2013)	≤450 lm, EEI ≤ 1.2	<450: Quality conventional low voltage halogens
	>450 lm, EEI ≤ 0.95	**Best low voltage halogen reflectors (infrared & xenon coated)**
Stage 2 (2014)	All lm, EEI ≤ 0.95	
Stage 3 (2016	All lm, EEI ≤ 0.95	

Source: Energy Solutions, adapted from EU Proposal; EEI is a proprietary energy efficiency index developed by the EU (EUC 2012)

1.3 Test procedures (existing or under development)

For efficacy measurements of incandescent reflector lamps, the most relevant test method is IESNA LM-20-1994, "IESNA (Illuminating Engineering Society of North America) Approved Method for Photometric Testing of Reflector-Type Lamps." For lifetime testing, the most relevant test method is IESNA LM-49-12. DOE released a final rule on test procedures for incandescent reflector lamps (IRL), general service incandescent lamps (GSIL), and general service fluorescent lamps (GSFL) on January 27, 2012 (DOE 2009a). In the final rule, DOE adopted LM-20-1994, the IES-approved[5] method for the electrical and photometric measurement of reflector type lamps. It should be noted that while a test procedure is in place, DOE does not have standards for small diameter directional lamps.

For measurement of LED lamp performance, the most relevant test methods are IES LM-79-08, "IES Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products," IES LM-80-08, "IES Approved Method for Measuring Lumen Maintenance of LED Light Sources", and TM-21-11 for "Projecting Long Term Lumen Maintenance of LED Light Sources".

- *IESNA LM-20-1994,* "IESNA Approved Method for Photometric Testing of Reflector-Type Lamps"

[3] The EU also established standards for mains voltage and LED lamps, but they are not discussed in this ITP since they are less relevant.
[4] The CA IOU C&S has attempted to reverse engineer efficacy from these calculations, and could not conclusively do so given the complicated nature of the formula.
[5] The Illuminating Engineering Society (IES) is the recognized technical authority for lighting test methods in the U.S., and works through a consensus process with related organizations to produce jointly published documents and standards.

- *LM*-49-12, "IES Approved Method for Life Testing of Incandescent Filament Lamps"
- *IES LM-79-08*, "IES Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting"
- *IES LM*-80-08, "IES Approved Method for Measuring Lumen Maintenance of LED Light Sources"
- *TM*-21-11, "Projecting Long Term Lumen Maintenance of LED Light Sources"

1.4 Sources of test data (confidential or public)

1.4.1 LED Test Data

The California Lighting Technology Center (CLTC) conducted testing to understand the extent to which LEDs achieve lumen output and CBCP equivalency when compared to incumbent technologies. Approximately 20 LED lamps were tested for CBCP, lumen output, beam angle, some color quality considerations, and compatibility with prevalent transformers, dimmers, and occupancy sensors. The LED lamps chosen for testing represent a range of types by wattage equivalency and beam angle, with preference given to high lumen output lamps and those with very narrow or wide beam angles. Testing was conducted with lamps in multiple housing types (e.g. open-air, closed, partially-open) and on multiple transformers. Test results from this study are forthcoming and will be submitted as an addendum to this submittal.

1.4.2 Halogen Performance Data

Halogen performance data was collected from Osram Sylvania, Philips, and GE publicly available online catalogs (Energy Solutions 2013a). Additional testing is in process, which will serve to complement this data set and test prototypes of very high performing halogen infrared products; we anticipate results will be available summer to fall 2013.

1.5 Energy use metrics

No response.

1.6 Relevant Performance Indicators

In the commercial lighting sector, one way of comparing the efficiency of two different light sources is by their luminous efficacy, a term which refers to the ratio of the amount of light produced by a lamp, measured in lumens, to the amount of power drawn, measured in watts. As seen in the DOE Rulemaking on Incandescent Reflector Lamps, a standard for efficacy as a function of light-output (lumens) would likely be needed.

Other performance metrics applicable to small diameter directional lamps include CBCP per watt and beam lumens per watt. Since lighting designers often use CBCP (instead of lumens) for selecting MR lamps, it could be more appropriate to evaluate lamp efficiency in terms of this metric. However, since CBCP is a function of beam angle and wattage, a CBCP per watt performance metric would necessitate a standard specification for each beam angle and wattage, for which there are many; additionally, CBCP is not a conventionally reported value for PAR lamps.

We believe CBCP, while an important design consideration, would be overly complicated for lighting designers and consumers and would be difficult to enforce.

Evaluating efficiency of lamps in terms of beam lumens per watt may be more appropriate than either CBCP per watt or lumens per watt. Beam lumens measure only the lumen output within the lamp's designated beam angle. Little data is available for beam lumens, thus additional lamp data would need to be evaluated to propose a performance standard using beam lumens per watt as a metric. Like lumens per watt, beam lumens per watt would likely need to be written as a function of beam lumen output.

1.7 Range of typical performance for each indicator

The small diameter directional lamp market is comprised of three main technologies, with widely varying efficacy levels, without a trade-off in utility in switching among these different performance levels. These include, from most to least energy intensive, and from largest to smallest market share: (1) conventional halogen lamps, (2) conventional halogen infrared (HIR) lamps, (3) higher performing HIR lamps, and (4) LED small diameter lamp replacements and their higher performing LED counterparts. These categorizations are grouped according to the mean efficacy of a given lamp design, which consists of the technology employed, filament design, capsule design, reflector design, and lens.

1.7.1 Conventional Halogen Lamps

Conventional halogens are the least efficacious directional lamps, achieving a range of about 5–13 lumens per watt (lpw), in three primary wattages: 50W, 35W, and 20W (GE 2013a, Philips 2013a, Sylvania 2013a & ECEEE 2011).With respect to lamp design, halogen filament lamps are usually coiled or double-coiled and oriented vertically, parallel to the center-beam axis of the lamp. Vertical axial orientation makes it easier to direct the light with reflectors and improves optical control. Variance in performance across the spectrum of halogen small diameter lamps is influenced by the filament, Quartz capsule (also called a burner), and reflector design.

1.7.2 Halogen Infrared (& Higher Performing Halogen Infrared) Lamps

Halogen infrared (HIR) lamps contain an infrared reflective coating on the outside of the halogen capsule which reflects infrared energy back onto the filament, causing it to burn at a higher temperature and generate more light. Typical HIR lamps use infrared (IR) coatings with alternating layers of two materials, SiO_2 and either Ta_2O_5 or Nb_2O_5 (DOE 2009b). They are more efficacious than standard halogen lamps (Sylvania 2011), and achieve approximately 12-19 lpw (ECEEE 2011).

There is also a growing presence of high performing (HP) HIR lamps, which are achieving higher efficacy in the range of 17 to 26 lpw (GE 2013a, Philips 2013a, Sylvania 2013a). To this end a 37W HIR lamp produces equivalent lumen output to a 50W conventional halogen; a 20W HIR lamp produces about the same lumen output as a 30W and some 35W conventional halogen lamps. We are unaware of any HIR lamps that are designed to replace 20W conventional halogens on lumen output basis (i.e., there are no HIR products that are less than 20W), however, this may be because consumers do not distinguish between 20W halogen and 20W HIR in terms of their lumen output.

1.7.3 LED Replacement Lamps

There is a wide range of LED performance with efficacy ranging between 35 - 70 lumens per watt (Energy Star 2013). On a lumen output basis, there are a large number of LED products that already achieve 20W equivalency, and a growing number that achieve 35W equivalency. Several manufacturers have recently released LED replacements for 50W equivalency; these LEDs are currently likely to match 50W small diameter lamps on a CBCP basis.

1.7.4 Summary of range of typical performance for lamp technology

Table 2 presents ranges of typical performance by lamp technology.

Table 2: Summary of Ranges for Typical Performance by Lamp Technology

Lamp Performance Characteristics	Halogen - non IR	Halogen Infrared Lamps	LEDs Replacement Lamps
Lumen Output	200-950	200-950	200-650
Wattage Availability (most predominant)	20W, 35W, 50W	20W, 30W, 37W	3-10W
Beam Angle Availability	10-60	10-60	10-60
Efficacy (lpw)	5 to 13	12 to 30	35 to 70

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

1.8 Incremental costs of energy efficiency features

See below under Section "Other Information Relevant to this Proceeding" regarding retail price data for these products. Note that incremental retail prices between products can be higher than the incremental cost of efficiency improvements only, as incremental retail prices can include the costs of non-efficiency related components.

1.9 Product development trends

No response.

1.10 Market barriers to energy efficiency

No response.

1.11 Number of California small businesses associated with manufacture, sale, distribution, or installation

No response.

1.12 Commercial vs. residential sector sales & operating hour data

Navigant published a report in 2011 summarizing various lighting markets. They estimated total U.S. stock, market share breakdown for commercial and residential, and their respective typical operating hours. We assume that California represents 12 percent of the country and annual growth in this market to be around 1.3 percent per year increase in installed base (WSDOT 2012 & LA Times 2012). Tables 3 and 4 present estimated operating hours and estimated stock and shipments, respectively.

Table 3: Operating hours and market share are based on a Navigant 2011 Report.

65%	Commercial Market Share
3720	Commercial hours of operation/year
35%	Res Market Share
840	Res hours of operation/year
2712	**Annual Operating hours**

Table 4: Stock & Shipments are based on Navigant 2011 Report.

122.20	US Stock (Millions) in 2011
12%	% California
14.66	California Stock (Millions) in 2011
1.3%	Annual Growth
14.85	Annual Shipments (Millions) in 2012

1.13 How do consumers identify efficient products on the market

A number of programs including the EPA Energy Star Program, the DOE LED Lighting Facts Program, manufacturer websites, and utility programs (e.g., PG&E LED Accelerator Program) are sources of information that customers could use to identify more efficient products. Largely, with the exception of manufacturer websites/brochures, these serve to educate consumers about higher performing LEDs (e.g., PG&E 2010, ENERGY STAR 2013). There is less available information, including no Federal Trades Commission label, for consumers to use to discern energy performance differences between halogen and HIR. In fact, they may not know that there are efficiency considerations associated with HIR lamps that would reduce the product's energy consumption.

2 Other Information Relevant to this Proceeding

2.1 Logical product categorization for analysis

As discussed broadly in section 2.7 (Range of typical performance for each indicator), we believe that the market, segmented by efficiency in terms of distinct ranges in lamp efficacy, would fall into six levels: (1) conventional halogen lamp performance, (2) conventional HIR, (3) higher performing HIR, (4) conventional LED replacements, and (5) high performing LED replacements. The market and other performance characteristics associated with these lamps are discussed in Section 3.3.

2.2 Test data for halogen, halogen-IR, and LED lamps

See Section 1.4.

2.3 Market share estimates for wattage categories (e.g., 50W, 35W, 20W), voltage (e.g. 12V vs. 120 V), transformer types (e.g., electronic vs. magnetic and associated performance considerations), technology type (e.g., halogen, halogen-IR, LEDs, and others), and use-case (residential vs. commercial)

2.3.1 Market share estimates for wattage categories (e.g., 50W, 35W, 20W)

No Response.

2.3.2 Transformer types

The installed base of transformers is characterized by magnetic low voltage transformers (MLVTs) and electronic low voltage transformers (ELVTs). MLVTs, the older technology, are believed to constitute the majority of the installed base in the United States, while ELVTs, the newer technology, are believed to constitute the majority of new shipments (LEDs 2011). Hatch and Lightech are the two largest manufacturers of transformers and comprise the lion's share of shipments within the US, providing hundreds of different models and designs (Reynolds 2012).

2.3.3 Conventional halogen lamps

Conventional halogen lamps, the least efficacious lamps in the market, achieve the full range of beam angles and are compatible with magnetic and electronic transformers in low voltage applications, as well as with dimmers. These lamps have the shortest lifespans of available technology types on the market (~1,500–3,000 hours), but also have the lowest upfront cost, ranging from $2 to $5 (CA IOUs 2012) per lamp. This type of lamp constitutes the lion's share of the market (approximately 93 percent) (personal communication with a manufacturer).

2.3.4 Conventional & higher performing HIR lamps

Conventional HIR and higher performing HIR lamps come in a full range of beam angles and are compatible with magnetic and electronic transformers and dimmers. Lifetimes for conventional HIR lamps range typically between 3,000-6,000 hours (CA IOUs 2013). There is also a growing presence of high performing (HP) HIR lamps, which even greater efficacy, and on average longer lifetimes, ranging upwards of 5,000 hours. Conventional HIRs range in price from $4-$10 (CA IOUs 2012), and the higher performing HIR lamps range from $7-$14.

While HIR lamps have increased in market share over the past 10 years, the natural market transition from conventional halogen to HIR is occurring slowly. Philips, GE, Osram Sylvania, and other manufacturers already have positions in this market. HIR lamps constitute about 5% of the market based on discussions with industry contacts.

2.3.5 Conventional and higher performing LEDs

LED replacement lamps on the market offer a wide range of products with CRI above 80, and CCT in the range of 2600 to 3000 Kelvin, which is typical of small diameter directional lamps. LEDs, likewise, come in a range of commercially available beam angle options from "spot" (typically understood to be < 16 degrees), "narrow flood and flood" (typically understood to be between <16- 40 degrees), and "wide flood", >40 degrees), on the market (ENERGY STAR 2013). There is little data available on transformer and dimmer compatibility, however, there have been reports of LEDs, in some instances, either creating failing, creating flicker, and having shortened lifetimes on some types of electronic and magnetic transformers. There are also an increasing number of available LED replacements for 50W equivalent products; trends in lumen output are discussed in greater detail in 3.3.8 (trends in LED replacement lamps). Lamp life can range from 25,000 to upwards of 35,000 hours.

LED replacement lamps range in cost from $16 to $45, and typically last around 25,000 lumen hours (CA IOUs 2012, 2013). These lamps constitute the majority of the 2 percent of the market that represent LED penetration in the small diameter directional lamp market (Navigant 2011).

2.3.6 Summary of market indicators

Table 5 below serves to provide a summary of market indicators relevant to the three main lamp technologies. Ranges for conventional and higher performing HIR and conventional and higher performing LEDs are aggregated within the columns "Halogen Infrared Lamps" and "LED Replacement Lamps", respectively. Information provided in section 2.7 ("Range of typical performance for each [energy efficiency] indicator"), is also included in the table.

Table 5: Summary of Ranges for Typical Performance by Lamp Technology

Lamp Performance Characteristics	Halogen - non IR	Halogen Infrared Lamps	LEDs Replacement Lamps
Lumen Output	200-950	200-950	200-650
Wattage Availability (most predominant)	20W, 35W, 50W	20W, 30W, 37W	3-10W
Beam Angle Availability	10-60	10-60	10-60
Efficacy (lpw)	5 to 13	12 to 25	35 to 70
Cost per Unit	$4	$4-14	$16-45
Average Lifetime Hours per Lamp	1,500 - 3,000	3,000 - 8,000	25,000 – 35,000
Low & Main Voltage	12V & 120V	12V & 120V	12V &120V
Current Market Share	93%	5%	2%

Source: CA IOUs 2012, 2013, ENERGY STAR 2013, Industry Contacts (market share)

2.3.7 Factors influencing luminous efficacy of halogen lamps

Infrared Coating in HIR lamps can dramatically improve a lamp's efficacy, but other factors also influence the performance of halogen lamps. Some of these factors include the following (DOE 2009c):

- Fill gas composition and pressure
- Capsule geometry (relevant to IR coated lamps)
- Filament composition, orientation, and placement
- Reflective coatings applied to the inner surface of the reflector portion of the lamp
- Use of double-ended burners

Fill gas, such as xenon, can improve efficacy. Increasing the pressure of any fill gas used can also improve efficacy, however, this approach also increases explosion hazard. Capsule design (elliptical), filament orientation (vertically oriented), and filament type (double-coiled) have positive effects on efficacy in HIR lamps. The most efficient capsules use a double-ended design with an ellipsoidal capsule shape. Higher reflectance coatings on the inner surface of the reflector, such as aluminum, silver, and gold affect efficacy as well. Silver and gold have higher reflectivity, and thus efficacy, but aluminum is the most commonly used due to lower costs. Silver reflective coatings used in conjunction with Tungsten filaments are also more efficacious than conventional halogens. Figure 1 below illustrates some of these design strategies.

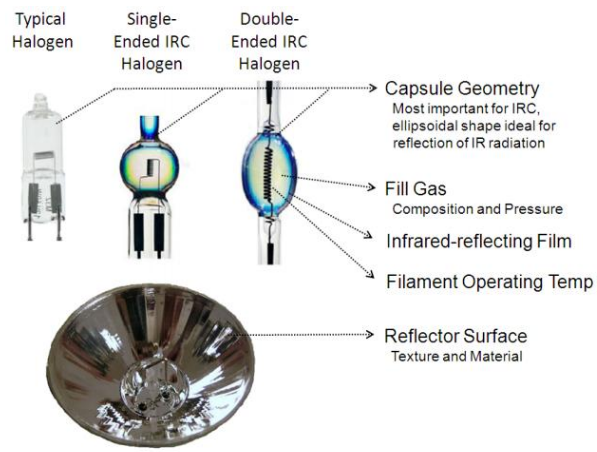

Figure 1: Design Strategies for Improving Halogen Performance

Source: ECEEE 2011

2.3.8 Trends in LED replacement lamps

New products continue to show increased lumen output and CBCP. While LED products claiming to be 50W equivalents are only recent additions to the market (and their performance should be verified with further testing), indications are that LED technology is improving quickly, and that 50W equivalent lumen output and CBCP are both within reach for LED manufacturers. The primary issue is that heat dissipation is limited by the small form factor; higher wattage lumen equivalencies will be achieved as efficacies increase further.

ENERGY STAR has qualified over 175 individual LED MR replacement lamps, and the DOE Lighting Facts Program has identified over 434 LED MR replacement lamps (ENERGY STAR April 2013 & DOE April 2013).

Figures 2 and 3 below show trends in efficacy and lumen output over time using historical LED Lighting Facts (LFD) database information and ENERGY STAR (ES) data. Trend lines were graphed to depict average performance over time, which was extrapolated out to 2015.

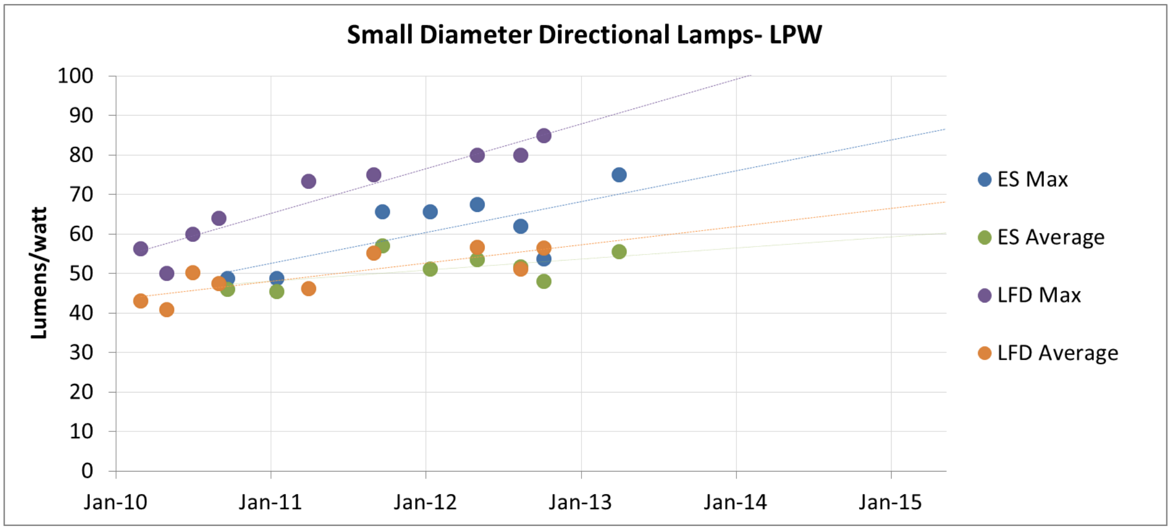

Figure 2: Efficacy Trends for Small Diameter Directional LED Lamps

Source: Energy Solutions analysis adapted from Lighting Facts Database (LFD) historical records and ENERGY STAR (ES) historical records. Each data point represents max and average (accordingly) lpw from unique records pulled from ES and LFD lists dating back to March 2010.

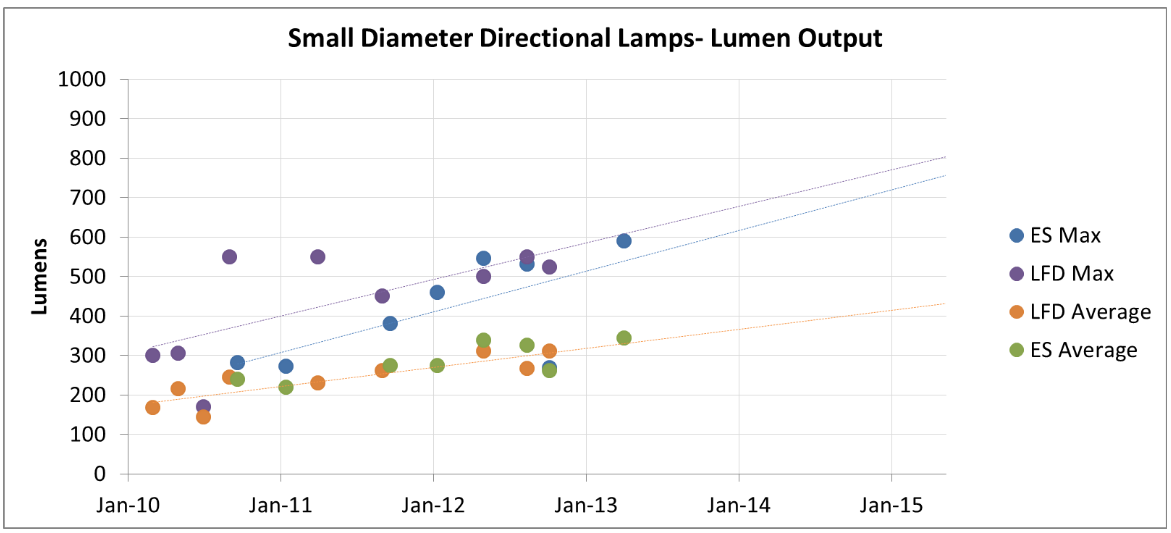

Figure 3: Lumen Output Trends for Small Diameter Directional LED Lamps

Source: Energy Solutions analysis adapted from Lighting Facts Database historical records and ENERGY STAR historical records. Each data point represents max and average (accordingly) lumen output from unique records pulled from ES and LFD lists dating back to March 2010.

2.4 Cost of halogen, halogen-IR, and LED lamps

See Section 3.3 & CA IOUs 2012 (see attached).

2.5 Comment on energy-use metrics (e.g. efficacy in lumens per watt vs. beam lumens per watt)

See Section 2.5.

3 References

(References attached separately are highlighted in grey)

[CA IOUs] Pacific Gas and Electric Company, Southern California Edison, Southern California Gas, San Diego Gas & Electric. 2013. "Halogen & Halogen IR Catalog Analysis." Microsoft Excel. Prepared by Energy Solutions. This document also references:

[CA IOUs] Pacific Gas and Electric Company, Southern California Edison, Southern California Gas, San Diego Gas & Electric. 2012. "Raw Cost data for SDDLs". Microsoft Excel. Prepared by Energy Solutions.

[CALiPER] CALiPER. 2012 "CALiPER Exploratory Study of Retail Replacement Lamps – 2011". http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_retail-replacement_2011.pdf.

[DOE] Department of Energy. 2012. "Energy Conservation Program: Test Procedures for General Service Fluorescent Lamps, General Service Incandescent Lamps, and Incandescent Reflector Lamps." 10 CFR Parts 429 and 430, January 27, 2012. http://www1.eere.energy.gov/buildings/appliance_standards/pdfs/gsfl_gsil_irl_tp_finalrule_frnotice.pdf.

[DOE 2009a] Department of Energy. 2009. "Energy Conservation Standards and Test Procedures for General Service Fluorescent Lamps and Incandescent Reflector Lamps; Final Rule." Federal Register, 74 FR 34080, July 14, 2009. http://www.gpo.gov/fdsys/pkg/FR-2012-01-27/pdf/2012-1770.pdf.

[DOE 2009b] Department of Energy. 2009. "Fluorescent and Incandescent Lamps Energy Conservation Standard Final Rule Technical Support Document- Chapter 3: Market & Technology Assessment." http://www.regulations.gov/#!documentDetail;D=EERE-2011-BT-STD-0006-0022.

[DOE 2009c] Department of Energy. 2009. "Appendix 5D. Advanced IR Coatings."

[ECEEE] European Council for Energy Efficient Economy. 2011. "Evaluating the Potential of Halogen Technologies". http://www.eceee.org/Eco_design/products/directional_lighting/halogen_technologies_report/eceee_report_halogen_technologies.

[EERE] Energy Efficiency & Renewable Energy. 2011. "Special Summary Report: Retail Replacement Lamp Testing." http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_retail-replacement_summary.pdf.

[ENERGY STAR] 2013. Energy Star Qualified Products List May 2013.

[EUC] European Union Commission. 2012. Commission Regulation (EU) No 1194/2012.

[GE 2013a] GE Lighting Catalog. 2013. http://www.gelighting.com/LightingWeb/emea/images/Lamp_Products_Spectrum_Catalogue_EN_tcm181-12550.pdf.

[GE 2013b] GE Lighting Catalog. 2013. http://catalog.gelighting.com/lamp/halogen/halogen-reflector-low-voltage.

[LA Times] California economic reports forecast modest growth. http://articles.latimes.com/2012/feb/15/business/la-fi-california-economy-20120215.

[LRC] Lighting Research Center. 2002. "MR16 Lamps." http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/mr16/abstract.asp.

[NC] Navigant Consulting. 2011. "Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications." http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/nichefinalreport_january2011.pdf.

[NLPIP] National Lighting Product Information Program. 1994. Specifier Reports: Reflector Lamps. http://www.lrc.rpi.edu/programs/NLPIP/PDF/VIEW/SRReflect.pdf.

[NS] National Semiconductor. 2011. "LM3401 MR16 Reference Designs for Non-Dimming & Dimming LED Applications." http://www.national.com/rd/RD/NSC_LM3401_MR16_V1.1.pdf.

[PG&E] Pacific Gas and Electric Company. 2010. "Business Fact Sheet: LED Replacement Lamps." http://www.pge.com/includes/docs/pdfs/mybusiness/energysavingsrebates/rebatesincentives/ref/lighting/lightemittingdiodes/led_fact_sheet.pdf.

[Philips 2013a] Philips Lighting Catalog. 2013. http://www.usa.lighting.philips.com/pwc_li/us_en/connect/tools_literature/downloads/SG100_Halogen_section2012_2013.pdf.

[Philips 2013b] Philips Lighting Catalog. 2013. http://www.ecat.lighting.philips.com/l/lamps/halogen-lamps/20951/cat/#filterState=FG_LP_BULB%7CMR16%3Dtrue.

Royner, Michael (Pacific Northwest National Labs). 2012. Personal Communication. April 4.

Sanderson, Susan., Kenneth Simmons, and Judith Walls. 2008. Lighting Industry: Structure and Technology in the Transition to Solid State. http://www.cireonusa.com/pdf/Lighting_Industry,_Structure_and_Technology_Transisiotn,_RPI.pdf.

[Sylvania 2013a] Sylvania Lighting Catalog. 2013. http://assets.sylvania.com/assets/documents/complete-catalog.b176dbb1-d6e0-40f0-ab92-e768e58f5dc1.pdf.

[Sylvania 2013b] Sylvania Lighting Catalog. 2013. http://ecom.mysylvania.com/sylvaniab2b/b2b/start.do;jsessionid=(J2EE18927600)ID1900487350DB12000748659345447327End;saplb_*=(J2EE18927600)18927650?browsername=mozilla%2F5.0%2520%2528windows%2520nt%25206.1%2529%2520applewebkit%2F537.17%2520%2528khtml%252C%2520like%2520gecko%2529%2520chrome%2F24.0.1312.52%2520safari%2F537.17&browsermajor=5&browserminor=5.

[WSDOT] Washington State Department of Transportation. 2012. Population Growth. http://www.wsdot.wa.gov/planning/wtp/datalibrary/population/WSPopulationGrowth.htm.