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Small Diameter Directional Lamps

Codes and Standards Enhancement (CASE) Initiative
For PY 2014: Title 20 Standards Development

Analysis *of* Standards Proposal for
Small Diameter Directional Lamps

ADDENDUM TO JULY 2013 SUBMISSION

Docket #12-AAER-2B

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Acknowledgements

The CASE Team would like to acknowledge Ecova for their contributions to this addendum, and in particular Chris Calwell, David Thomsen, Paolo Clavijo, and Brian Spak.

With funding from PG&E and SDG&E, the Ecova Team oversaw and implemented the test effort to support Tier 1 refinement. They helped to aggregate a larger data set of publicly available, industry-reported lamp data. They also conducted testing to complement this data set, and better characterize the range of market performance and refine, validate the updated standards proposal. They also conducted industry outreach to understand test methodology and rating practices, which support the refined test procedure proposal.

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Executive Summary

The Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), Southern California Gas (SoCalGas), San Diego Gas & Electric (SDG&E) Codes and Standards Enhancement (CASE) Initiative Program seeks to address energy efficiency opportunities through development of new and updated Title 20 standards. Individual reports document information and data helpful to the California Energy Commission (CEC), and other stakeholders in the development of these new and updated standards. The objective of this Program is to develop CASE Reports that provide comprehensive technical, economic, market, and infrastructure information on each of the potential appliance standards.

This Addendum updates the following topics associated with the original case proposal for Small Diameter Directional Lamps (SDDL):

Main Body:

1. Updated Scope for SDDL
2. Updated Standards, Test Procedure, and Labeling Proposals
3. Summary of Updated Savings and Economic Analysis
4. Updated Proposed Code Language
5. References

Appendix:

6. Overview of SDDL Class
7. Updated information on Filament-based SDDLs
8. Updated Information on LED SDDLs

Consistent with our July 2013 Proposal, we recommend a two-tiered approach to performance standards for SDDL that will allow California to realize significant savings in the near-term, as well as greater energy savings in 2018 and beyond.

The Tier 1 performance standards for low and line voltage lamps were updated as exponential curves to define minimum efficacy that mimic the physical properties and efficacy potential of filament lamps. Separate minimum rated life standards for Tier 1 line and low voltage lamps are proposed; we do not propose lifetime requirements for Tier 2, since the LED quality specification addresses lifetime separately.

The Tier 2 proposal was modified to reflect the anticipated technology leap frogging in this market as LED SDDLs increasingly become ideal substitutes in this lamp class. We believe a two-tiered approach will yield a successful market transformation of high efficacy, high performing SDDLs for consumers. The Tier 2 proposal also assumes that the LED Quality CASE measure with a minimum CRI standard of at least 90 is applicable to SDDL LEDs.

We are also proposing standardizing Illuminating Engineering Society (IES) approved test methods for filament-based and LED SDDLs with modifications to reduce ambiguity, increase accuracy and representativeness of SDDL operation in the field, and ensure that lamps are similarly measured and fairly compared.

Finally, we are proposing mandatory package labeling requirements for SDDLs in order to help ensure that consumers have a positive experience with SDDLs since they are not covered by the Federal Trade Commission (FTC) Lighting Facts Program. We propose including metrics such as wattage equivalency (relevant to the LED market), wattage, efficacy, lumen output, center beam candle power (CBCP), correlated color temperature (CCT), color rendering index (CRI), and voltage.

In total, this approach would yield a net savings of 1,486 gigawatt-hours (GWh) after stock turnover and a reduction of 552 megawatts (MW). The economic analysis revealed that savings were cost effective for the residential and commercial sectors for both Tiers 1 and 2.

1 Updated Scope for Small Diameter Directional Lamps

In the previous CASE Proposal submitted in July 2013, we reported that this lighting class included directional lamps less than or equal to 2.5 inches in diameter, which are not federally regulated. We would like to make a correction to this statement; this lamp class includes directional lamps **less than or equal to 2.25 inches in diameter** since anything larger could be subject to federal preemption. Table 1 summarizes the propose scope of coverage. An overview of the SDDL market is provided in Section 1 of the Appendix.

TABLE 1.1 PROPOSED SCOPE OF COVERAGE FOR SDDL

Characteristic	Description
Size	≤ 2.25 inches in diameter
Lamp Shapes	MR, PAR, R lamps and their LED replacements (e.g., MR16, MR11, PAR16s, PAR11, R16s, R11s)
Voltage (V)	Line (e.g., 120 V) and Low (e.g., 12 V)

2 Updated Standards, Test Procedure, & Labeling Proposal

The CA IOUs are proposing a two-tiered minimum efficacy performance standard for this lighting class with lifetime requirements for Tier 1 and labeling requirements for Tiers 1 and 2 as well as modifications to IES approved test methods for filament-based and LED SDDLs.

Given the large variance in efficacy among low and line voltage halogen products for similar lumen and CBCP output, we are proposing a Tier 1 standard that would disallow low and average performing filament-based products from being sold in California. Given that there may be a trade-off between efficacy and lifetime, we propose a minimum lifetime standard that will help ensure cost-effectiveness and prevent manufacturers from compromising lamp life. Since this standard would be set to a level achievable by commercially available halogen and halogen-infrared (HIR) SDDLs for every major lumen output range, we believe manufacturer impact will be limited. We propose that Tier 1 become effective one year after adoption to allow California to reap energy savings in the near term while the market prepares for an LED standard for SDDL in 2018. A review of the filament-based test effort and justification of the Tier 1 standards proposal is provided in Section 2 of the Appendix.

The CA IOUs propose a Tier 2 standard equivalent to 80 lumens per watt (LPW) effective in 2018. Based on a market analysis of commercially available LED SDDLs as well as projections for future performance, we believe LEDs will be able to provide equivalent performance to their filament-based counterparts in terms of CBCP, lumen output, beam angle, and CCT. The Tier 2 proposal also assumes that the LED Quality CASE measure with a minimum CRI standard of at least 90 is applicable to SDDL LEDs. Given the significant increase in efficacy and substantially longer lamp lifetimes, LEDs are already highly cost-effective substitutes for filament-based SDDLs.

Table 2.1 shows the recommended standard levels for this measure. We welcome comment by interested stakeholders on the recommended standards proposal. A more detailed analysis of current and predicted projections of performance, as well as a characterization of transformer and dimmer compatibility of LED SDDLs, is provided in Section 3 of the Appendix.

TABLE 2.1 RECOMMENDED STANDARD LEVELS FOR SMALL DIAMETER DIRECTIONAL LAMPS

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

[1] Most low voltage SDDLs are rated at 12-24V, while most line voltage SDDLs are rated at 110-120 volts. To account for some variability in voltage, 50V represents the threshold that should sufficiently partition these lamps types for standards purposes.

The unregulated small diameter directional lamp market has no definitive test procedure, and as such a standardized test procedure is needed to regulate this market. Separate test procedures are warranted for filament-based and LED lamps.

For filament based lamps, we recommend a procedure similar to Illuminating Engineering Society (IES) LM-20, the approved method for photometric testing of reflector type lamps, with modifications to reduce ambiguity associated with its interpretation and increase repeatability of results. These recommendations take into account manufacturer feedback on testing and field conditions under which these lamps regularly operate. For LED SDDLs we recommend adoption of LM-79, the approved method for electrical and photometric measurements of Solid-State Lighting.

Table 2.2 below outlines our recommendations for a test procedure for SDDLs. We welcome comment by interested stakeholders on the recommended test procedure. Section 2 of the Appendix discusses our conversations with manufacturers, which informed the proposed modifications below.

TABLE 2.2 RECOMMENDED TEST PROCEDURES FOR SDDLS

Technology	Base Test Procedure	Proposed Modifications
Filament-based SDDL	*IES LM-20-13:* "Photometric Testing of Reflector Lamps" *IES LM-45-09*: "Electrical and Photometric Measurement of General Service Incandescent Filament Lamps" – as referenced in Section 5 of LM-20-13	• Specify regulation of voltage at reference socket across the lamp base, not at voltage source to mitigate losses in voltage across wiring placed between the voltage source and the lamp. These losses are typically minimal at line voltage, but can be more significant when testing lamps at 12 volts. For lamps intended to operate on low voltage, as specified by packaging and base types (e.g., GU4, GU5.3, GU10, E26, E17), voltage should be regulated at 12V +/- 2 percent. For

	IES LM-54-12: "Guide to Lamp Seasoning" *IES LM-49-12* (Life Testing for filament lamps)	all products intended to operate on line voltage, voltage should be regulated at 120V +/- 1 percent. • Allow for either integrating sphere or goniophotometer measuring equipment. • Specify directional setup.
LED SDDL	*IES LM-79-08:* "IES Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting"	• Specify regulation of voltage at reference socket across the lamp base. For lamps intended to operate on low voltage, as specified by packaging and base types (e.g., GU4, GU5.3, GU10. E26, E17), voltage should be regulated at 12V +/- 2 percent. All products intended to operate on line voltage, voltage should be regulated at 120V +/- 1 percent. • Allow for either integrating sphere or goniophotometer measuring equipment. • Specify directional setup.

Given that SDDLs are not regulated by the Federal Trade Commission (FTC) and as such have no labeling requirements, we are proposing package labeling requirements for SDDLs sold in California to help consumers make informed purchasing decisions. This is particularly important since there will be a significant wattage reduction and consumers will likely need guidance on wattage equivalency (as a proxy for expectations for light output and CBCP) associated with a market shift from filament-based lamps to LEDs. Moreover, we believe a labeling requirement will help ensure consumers have a favorable experience with LED SDDLs.

Table 2.3 below summarizes our recommendation for package labeling requirements. We welcome comment by interested stakeholders on the recommended labeling requirements.

TABLE 2.3 RECOMMENDED LABELING REQUIREMENTS FOR SDDLS

Metric	Test Method	Reporting Directions
Wattage Equivalency (W_e)	Proposed Test methods in this Addendum	The Energy Star CBCP tool should be the basis for wattage equivalency based on beam angle and CBCP inputs.
Wattage (W)		Report value as fractional integer rounded to one decimal place (e.g., 7.5)
Efficacy (LPW)		Report value as a whole integer (e.g., 85)
Lumen Output (lumens)		Round to nearest 5 lumens, report as a whole integer
Center Beam Candle Power (CBCP)		Round to nearest 25 candela, report as a whole integer
Beam Angle (Degrees)		Report value as a whole integer
Correlated Color Temperature (CCT)		Report using Lighting Facts[1] Light Color Graphical illustration (see Figure 2.1 below)
Color Rendering Index (CRI)		Report value as a whole integer
Voltage (V)	Manufacturer Reported	Report value as a fractional integer rounded to one decimal place

[1] Light Color specification outlined in the Lighting Facts Label for LEDs: http://www.lightingfacts.com/Library/Content/Label

For illustrative purposes, we propose manufacturers consolidate this information onto a single label similar to the Lighting Facts Label used by the FTC, with which consumers are already familiar.

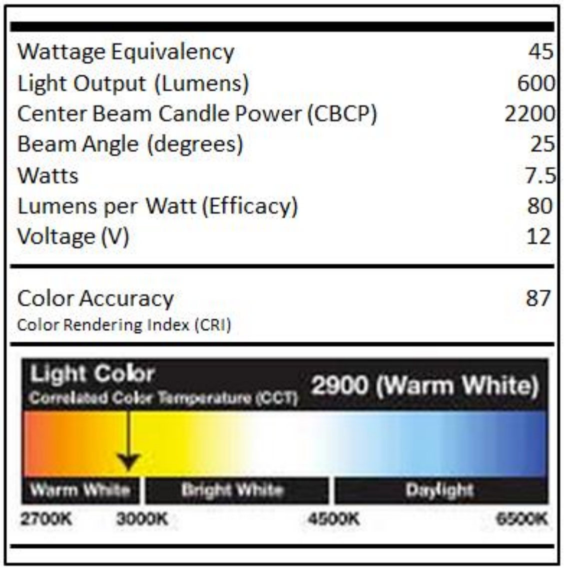

FIGURE 2.2 RECOMMENDED LABELING FOR SDDL PACKAGES

3 Updated Summary of Savings and Economic Analyses

The CA IOU CASE team conducted an updated savings analysis for this standards proposal. On an average per lamps basis, Tier 1 qualifying lamps will save 48 kWh per year in energy savings and Tier 2 qualifying lamps will save an additional 62 kWh per year. Tier 1 qualifying lamps will yield, on average, a 17 W power reduction; Tier 2 qualifying lamps will yield an additional 23 W reduction. The assumptions underlying this savings analysis are outlined in Section 1 of the Appendix, and summarized in Table 3.1 below.

TABLE 3.1 STATEWIDE SAVINGS FROM TIER 1 AND TIER 2

	Statewide Savings Potential		
	Tier 1	Tier 2	Total
1^{St} Year Savings (GWh)	568	688	1,088
Annual Savings after Stock turnover (GWh)	755	731	1,486
Coincident peak demand reduction (1st year in MW)	186	216	401
Coincident peak demand reduction (after stock turnover in MW)	278	274	552

Source: Author created 2014

The CA IOU CASE team also conducted an updated economic analysis for this standards proposal to evaluate cost-effectiveness to the consumer for Tiers 1 and 2.

Tier 1 assumes no incremental cost to the consumer, as justified in Section 2 of the Appendix. We recognize that there may be some incremental cost associated with material cost and production of higher efficacy filament based lamps. Nonetheless, the savings are large enough to justify some incremental costs and still be cost-effective.

For Tier 2, LED costs are based on LED SDDLs online pricing collected by the CASE team in 2014 (i.e., ~$25 per lamp average). This analysis assumes in the base case lamps are replaced every year in the commercial sector and every 4 years in the residential sector. This is a conservative estimate for cost-effectiveness since we do not take into consideration a reduction in LED lamp cost over time due to learning nor the costs associated with reduced maintenance.

The results of this cost-effectiveness analysis are summarized in Table 3.2 below.

TABLE 3.2 COSTS AND BENEFITS PER UNIT FOR QUALIFYING PRODUCTS WITHOUT LEARNING CURVES APPLIED TO LAMP COST

Tier	Sectors Evaluated	Energy Savings	Incremental Cost	Avoided Replacement Cost	NPV
Tier 1	**Commercial** *Years of Operation:* 1 year	$5.74	$0	$0	$5.75
	Residential: *Years of Operation: 2.5 years*	$3.75	$0	$0	$3.74
Tier 2	**Commercial** *Years of Operation:* 7 years	$109.84	$17.99	$41.60	$133.45
	Residential: *Years of Operation: 15 years*	$67.15	$17.99	$27.36	$75.30

Source: Author created 2014

4 Proposed Language for Code Adoption

This section contains proposed language for the Title 20 Appliance Efficiency Regulations, specifically for the sections on Scope, Definitions, and State Standards.

The sections on Test Procedures and Labeling will be developed after the CA IOUs obtain feedback on the test procedure modifications and labeling proposals at forthcoming workshops on this measure.

Section 1601. Scope

(x) All small diameter directional lamps, which meet the definitions outlined in Section X (Definitions), including both low voltage and line voltage lamps. 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

"Small Diameter Directional Lamp" (SDDL) refers to multi-faceted reflector (MR) lamps, parabolic aluminized reflector (PAR) lamps, reflector (R) lamps, and LED SDDLs that are less than or equal to 2.25 inches in diameter, also commonly sold as MR16, MR11, PAR16, PAR11, R16, R14 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."

"Efficacy": For the purposes of this performance standard 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.

"Lumen Output for SDDL": Refers to the total lumens associated with an SDDL on a directional setup.

"Wattage for SDDL": Refers to the power required to operate the device, measured at the base of the lamp.

"Center Beam Candle Power (CBCP)": The luminous intensity at the center of the beam of a reflector lamp, measured in candelas, typically corresponding to a vertical angle of 0°.

"Beam Angle": Refers to the angle between two directions opposed to each other over the beam axis for which luminous intensity is half that of the maximum luminous intensity.

"Correlated Color Temperature (CCT)": The actual color of the LED is called the color temperature and is defined in terms of the spectral tri-stimulus values (color coordinates) according to the recommendations of IESNA LM-16-93. For color coordinates near the blackbody loci, the correlated color temperature, measured in Kelvin (K), is used.

"Color Rendering Index (CRI)": A measure of color fidelity that characterizes the general similarity in color appearance of objects under a given source relative to a reference source of the same CCT, based on a scale of 100.
"Low voltage": Refers to lamps that operate on voltage less than 50 volts.

"Line voltage": Refers to lamps that operate on voltage that is greater than or equal to 50 volts.

Section 1605.3 State Standards for Non-Federally Regulated Appliances.

(x) Small Diameter Directional lamps

Effective one year after adoption, minimum efficacy performance standards shall apply to SDDLs per accordance with Table X, below. Efficacy should be expressed as lumens per watt, per the definition, and rounded to one decimal place (e.g. 65.1), whose value must be greater than 80 lumens per watt.

TABLE X. STANDARDS FOR SMALL DIAMETER DIRECTIONAL LAMPS

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

The manufacturer shall publish rated values for wattage equivalency, beam angle, CCT, CBCP, and lumen output clearly on packages in which SDDL are sold. Wattage equivalency shall be based on the ENERGY STAR© CBCP Tool.

5 References

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

[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.

European Union Law. Commission Regulation (EU) No 1194/2012 of 12 December 2012 implementing Directive 2009/125/EC of the European Parliament and the Council with regard to ecodesign requirements for directional lamps, light emitting diode lamps and related equipment. http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32012R1194&from=EN

[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

Appendix

1 Overview of Small Diameter Directional Lamp Class

The table below provides a summary of the market of SDDL as well as many of the characteristics underlying the savings analysis.

TABLE 1.1 SUMMARY OF SMALL DIAMETER DIRECTIONAL LAMP CLASS CHARACTERISTICS

Characteristic	Description
Size	≤ 2.25 inches in diameter
Lamp Shapes	Small diameter MR, PAR, R lamps and their LED replacements (e.g., MR16, MR11, PAR16, PAR11, R16, R11)
Voltage (V)	Line (e.g., 120 V) and Low (e.g., 12 V)
Common Use	Commonly used for accent, task, and display lighting in art galleries, retail stores, restaurants, museums, and residential settings
Technologies	• *Filament based lamps:* Includes incandescent, halogen, and halogen-infrared lamps (HIR). The large majority of these are sold as 50W, 35W, or 20W conventional wattages. Some HIR lamps come in lower wattages (e.g., 37W) intended to replace higher wattages (e.g., 50W), and are more commonly used in commercial applications. • *LED SDDLs*: The most efficacious, are often less than or equal to 10W. In 2011, LED market share was estimated to comprise about 2.5% of the market. By 2018, we estimate that 18% of the market will convert to LEDs via naturally occurring market adoption. • *Wattage category characterization*: We estimate that 70% of the market is comprised of 50W lamps and their replacements (e.g., HIR 37W and 10W LEDs), 20% of is comprised of 35W lamps and their replacements, and 10% is comprised of 20W lamps and their replacements.
Residential Use	• Estimated to comprise 35% of the market (Navigant 2011); a recent CALiPER report suggested that 43% of the market is residential (2014) • Typically operate on line voltage (fixtures are line voltage) • Lamps often utilize GU10 base, compatible with line voltage • Typically have shorter operating hours (~ 840 hours/ year) • Consumers typically care more about lumen output (using wattage as a proxy) and beam angle • Lamps may be lower in quality than the commercial/professional market, and have shorter lifetimes
Commercial Use	• Estimated to comprise 65% of the market (Navigant 2011); a recent CALiPER report suggested that 56% of the market is commercial (2014) • Typically operate on low voltage • Lamps often utilize GU5.3 base, compatible with low voltage • Typically have longer operating hours (~3720 hours/year) • Lighting professionals may put more weight on characteristics such as

	center beam candle power (CBCP), and more extreme beam angles (e.g., 10 degrees) • Lamps are likely to be higher in quality and designed with longer lifetimes to decrease maintenance costs
Operating Hours	• Annual operating hours assumed for this CASE analysis were 2,712 hours per year, based on a 65%/35% split between commercial and residential use.
Lamp Costs	• According to an analysis of low and line voltage halogen, HIR, and incandescent lamps, average lamp price from a sample of 195 lamps was $7.99 per unit, based on online and big-box retail listings. • Based on web-crawled price data from various online retailers, average LED SDDLs were $24.67 per lamp.
Stock	14.6 million in stock estimated in California
Characterization of Current Market Regulation	SDDLs are not federally regulated by the Department of Energy (DOE) (e.g., standards for energy performance) or the Federal Trade Commission (FTC) (e.g., labeling requirements). This also means that manufacturers are not required to disclose lamp performance characteristics such as lumens. There is also no mandatory test procedure for reporting or rating of these types of lamps.

NOTE: Assumptions about residential use, commercial use, operating hours, and stock were based on a Navigant 2011 report

2 Overview of Filament-based SDDL Test Effort and Results

With support from Ecova, the CA IOUs conducted testing of halogen, halogen-infrared, and incandescent lamp performance with the following goals in mind to support a Tier 1 proposal.

1. Characterize existing publicly available, industry-reported lamp data to understand data gaps.
2. Conduct testing to complement existing industry published data set and for proposal refinement.
3. Vet test procedure proposal with manufacturers.

To gain an understanding of the market performance of small diameter directional lamps, additional research was conducted on several large online retailers and national brick and mortar retail chains. The search returned a total of 251 small diameter directional lamps, 116 (46.2%) of which had published lumens data readily available, for which we could calculate efficacy. Approximately 80% of lamps in the data set were low voltage (20% were line voltage); lamp shape and size was predominantly MR16, comprising 80% of the dataset.

We selected 50 lamp models for testing, some of which overlapped with the data set of 251 lamps, referenced above. Selected lamps were both featured prominently at national brick and mortar retail chains and from online catalogs, chosen for their high efficiency ratings. The selection process was done so as to reflect a diverse dataset of manufacturers, bulb shape and size, underlying bulb technology, operating voltages and a broad range of light output. Two samples were tested per lamp model and the average performance was considered for lumen output, wattage, and efficacy. Ecova performed testing using IES LM-20, which references IES LM-45.

2.1 Analysis & Findings from Test Effort

This section serves to highlight the main, conclusive findings associated with the test effort, which we number 1 through 7.

1. There is significant variance in performance between low and line voltage products, warranting separate standards for each (See Figure 2.1). This is consistent with the July 2013 proposal that separate standards are warranted for line voltage lamps.

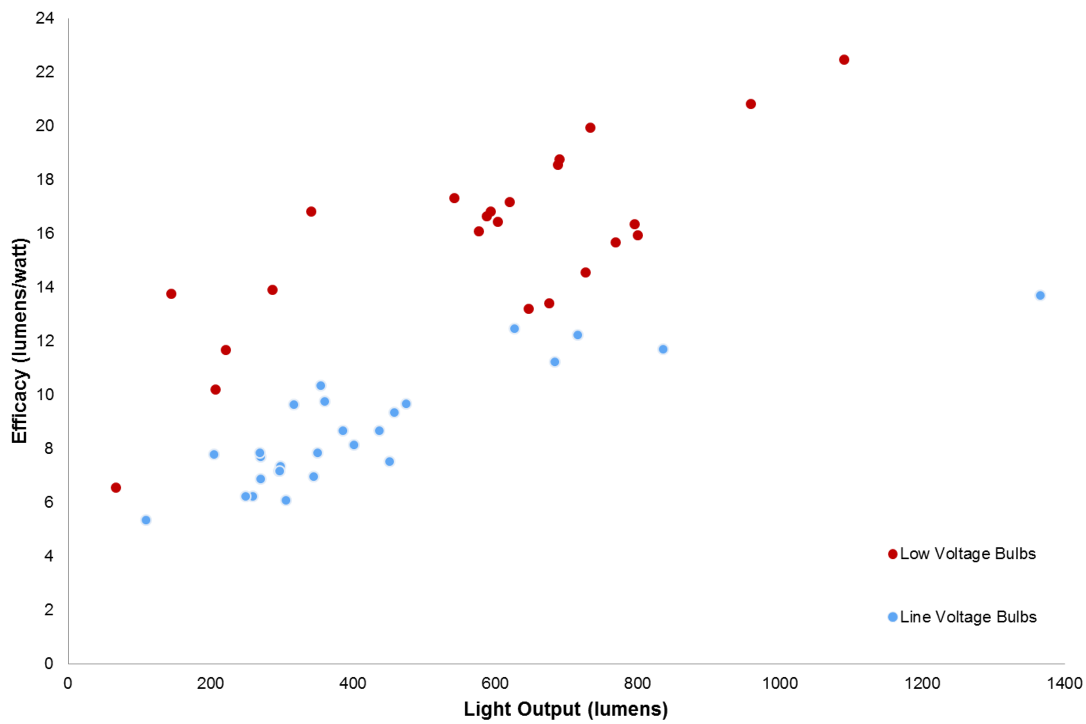

FIGURE 2.1 MEASURED PERFORMANCE OF LOW VOLTAGE AND LINE VOLTAGE LAMPS

2. There is significant variance in performance among **low voltage lamps** with similar lumen output, warranting an investigation for standards among low voltage lamps (See Figure 2.2).

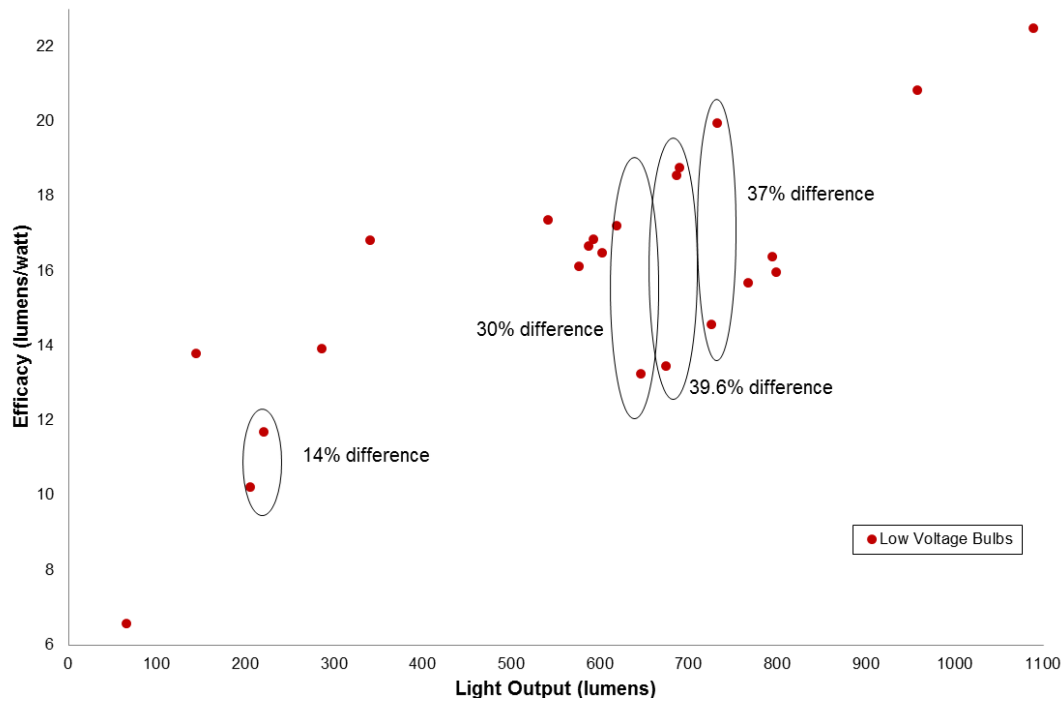

FIGURE 2.2 MEASURED PERFORMANCE OF LOW VOLTAGE LAMPS

3. There is significant variance in performance among **line voltage lamps** with similar lumen output, warranting a standard among line voltage lamps (See Figure 2.3).

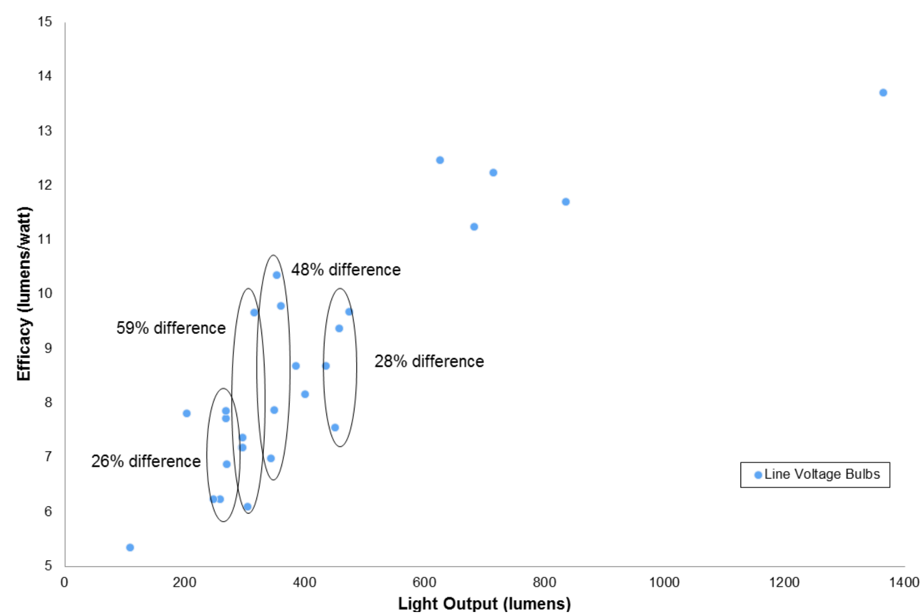

FIGURE 2.3 MEASURED PERFORMANCE OF LINE VOLTAGE LAMPS

4. We found no correlation between efficacy and the retail cost to the consumer for price for both line and low voltage lamps based on data collected by Ecova from various online retail

sources (See Figure 2.4). We recognize that manufacturer costs may be different for different lamps; for instance fill gas, reflector type, filament type, and capsule could all have varying production costs based on material choice/quality that influence efficacy. We have not collected information on manufacturer costs to produce different types of lamps. The cost data we collected came from various large national bricks and mortar stores as well as specialized online retailers. Figure 3.4 below plots purchase price against efficacy for low and line voltage lamps.

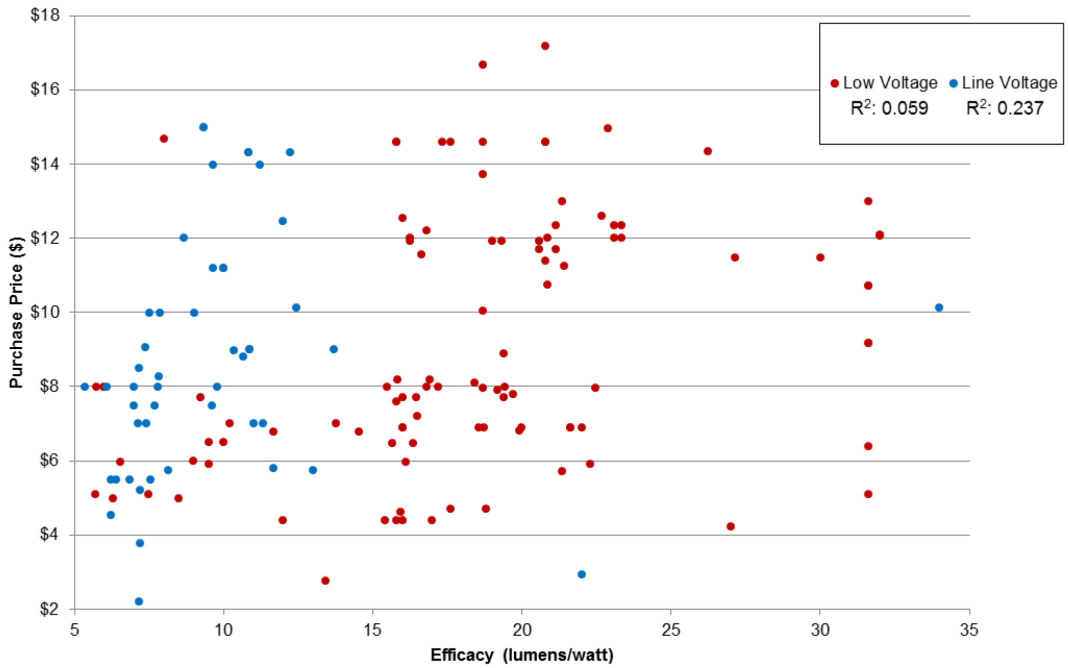

FIGURE 2.4 CORRELATION BETWEEN PRICE AND EFFICACY

5. There is variance in lamp lifetime between low and line voltage lamps, warranting separate standards for both (See Figure 2.5). This analysis is based on data collected since our July 2013 effort, and takes into account many more lifetime data points for low and line voltage lamps. With this larger sample set, one can more clearly recognize a difference in lifetime between low and line voltage lamps across a range of efficacies. Thus, we are proposing updated lifetime standards in this addendum.

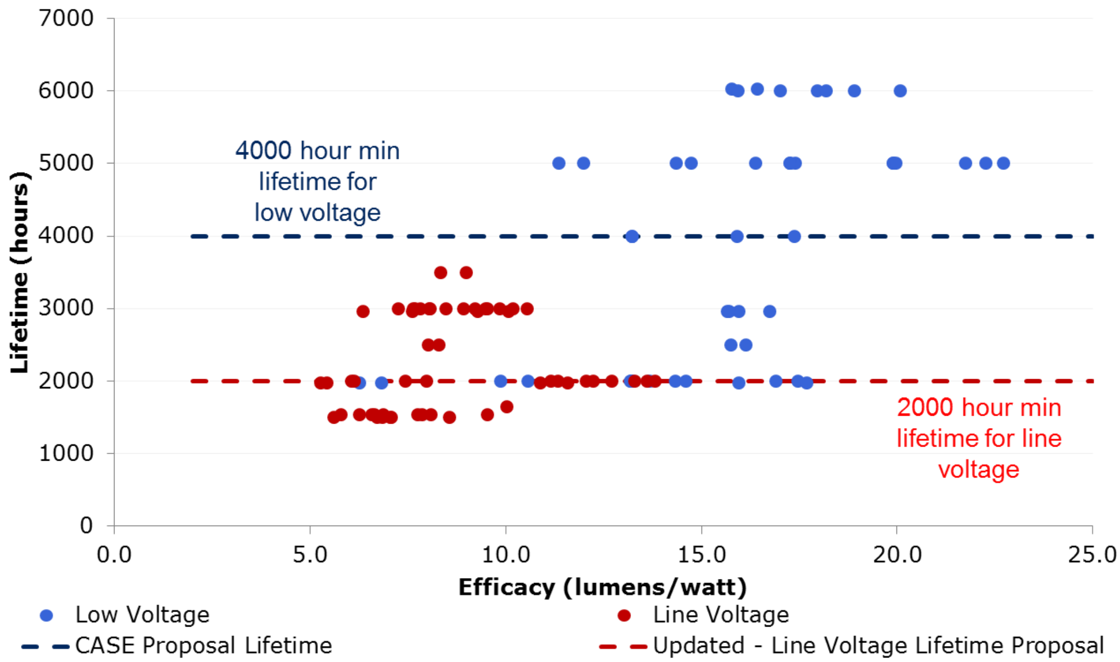

FIGURE 2.5 RATED LIFETIME VERSUS MEASURED EFFICACY FOR LAMPS

6. Test results indicated some variance between manufacturer reported values and test results; based on manufacturer outreach we believe this is largely attributable to differences in reporting techniques (See Figure 2.6). Two manufacturers we spoke with rounded the mean downwards, one rounded upwards, and two others did not provide comment.

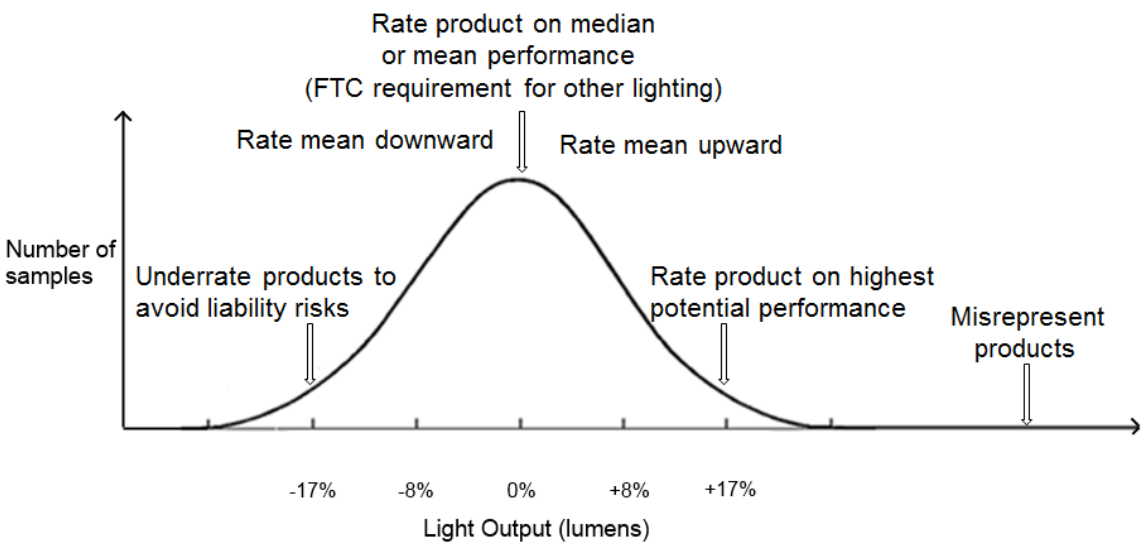

FIGURE 2.6 HOW MANUFACTURERS COULD CHOOSE TO RATE PRODUCTS & FEEDBACK FROM OUTREACH

2.2 Findings from Outreach to Manufacturers

As part of the test effort, we vetted the industry proposed test procedure and reporting practices by conducting manufacturer outreach to understand how Tier 1 and Tier 2 manufacturers test and rate their products. We learned that manufacturers used different equipment ranging from goniophotometers, integrating spheres, to photometrical bench setups; controlling for everything else, the difference in measured lumens on a goniophotometer versus integrating sphere should be minimal. Most manufacturers reported that they use a directional setup, which measures forward-projected lumens. In general the vast majority of lumens are projected forward, so the difference between an omnidirectional and directional setup would be modest. However, because many MR16s are intentionally designed to spill some light through the back of their reflectors, it is important to specify which method shall be used in the test procedure. With respect to regulation of current versus voltage, most manufacturers interviewed stated that they regulate voltage for line and low voltage lamps; however, a couple of the manufacturers interviewed stated that they regulate current when testing MR16s. The Department of Energy (DOE) specifies regulation of voltage in the test procedure for incandescent reflector lamps (IRL). With respect to rating products using measured data, manufacturers had different preferences for rating above, on, or below the mean performance. For lighting products covered by the Federal Trade Commission (FTC), FTC requires that light output of each lamp included in the package, be expressed as "Brightness" in average initial lumens rounded to the nearest five.

The unregulated small diameter directional lamp market has no definitive test procedure, efficacy or lifetime standards. A standardized test procedure is the first step in regulating this market. Separate test procedures are warranted for filament-based and LED lamps. Our recommendations are outlined in Section 2 of the main report.

2.3 Graphical Depiction of Tier 1 Proposal

Figure 2.8 graphically illustrates the proposed standard for Tier 1 low voltage SDDLs (i.e., those with lamps operating less than 50 volts (V), and more typically at 12V). The proposal (i.e., the green curve, which is equivalent to the standard proposal in Table 2.1) is plotted against publicly available rated data as well as Ecova measured test results. The standards proposal was designed to allow some commercially available lamps, based on some rated and measured data to exceed the proposed standard at all major lumen bin ranges. Design options for improved efficiency include use of infrared coatings, higher quality fill gas such as xenon, improved reflector and filament design.

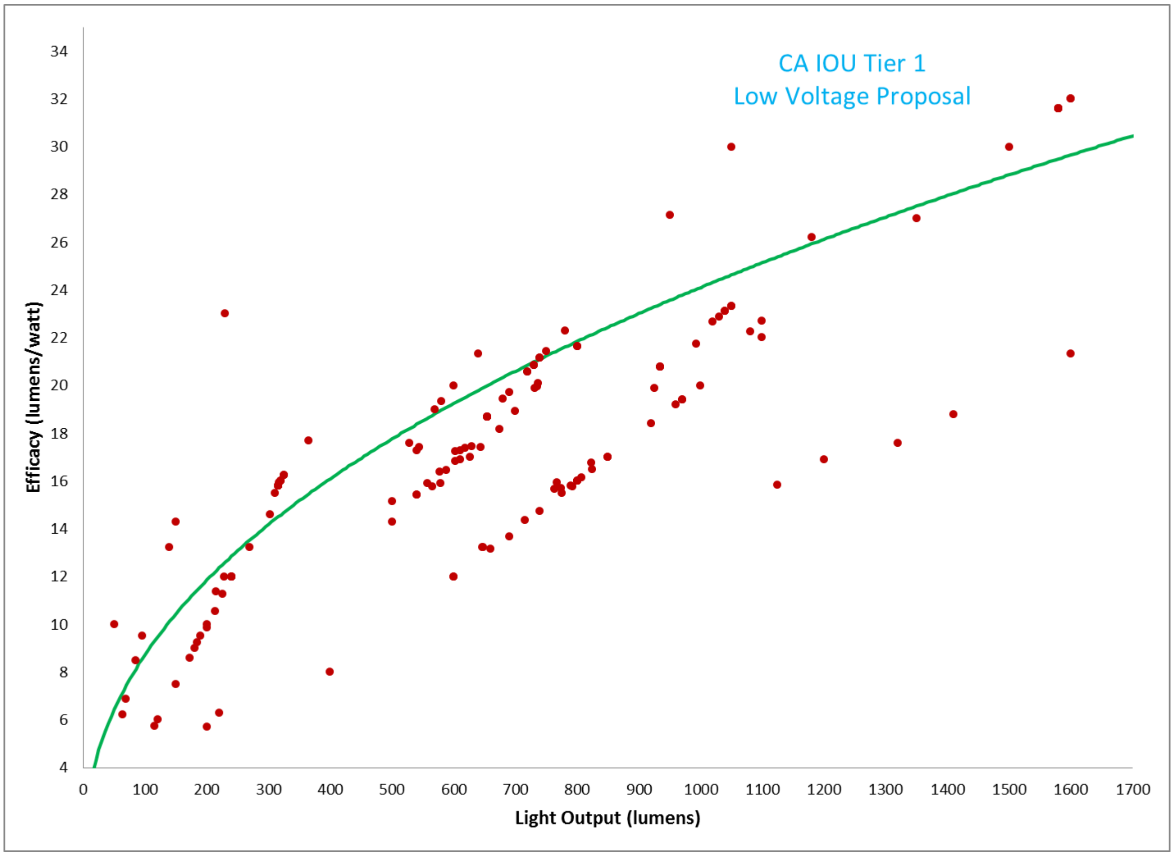

FIGURE 2.8 TIER 1 LOW VOLTAGE PROPOSAL

Figure 2.9 graphically illustrates the proposed standard for Tier 1 line voltage SDDLs (i.e., lamps operating at or above 50, or conventionally at or around 120V). The proposal (i.e., the green curve, which is synonymous to the standards proposal in Table 2.1) is plotted against publicly available rated data as well as Ecova measured test results. This proposed standard allows for commercially available lamps at all lumen ranges to meet the proposed standard. Design options for improved efficiency include the use of higher quality reflectors, better filament and capsule design, use of higher quality fill gas.

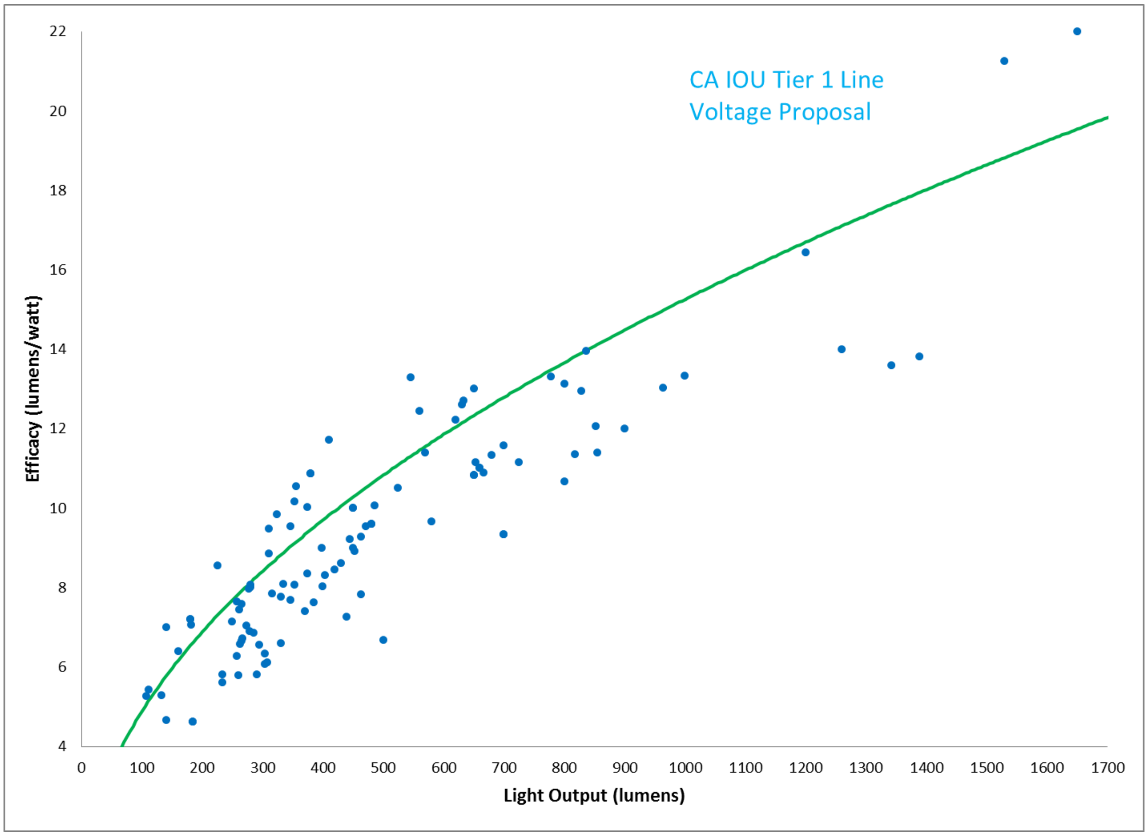

FIGURE 2.9 TIER 1 LINE VOLTAGE PROPOSAL

3 Updated Information on LED SDDLs

This section serves to provide an update to the July 2013 proposal with new findings on the following topics, which support an 80 LPW standard:

1. Lumen Output
2. Center Beam Candle Power
3. Beam Angle
4. Compatibility with Transformers & Dimmers
5. Color Rendering Index
6. Efficacy

3.1 Lumen Output

In terms of lumen output, LED lamps are steadily increasing in output as efficacy increases. Based on a May 2014 Lighting Facts Database (LFD) analysis, 80 LPW lamps (in red in Figure 3.1, 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 SDDLs[2]. According to a recent DOE CALiPER report, LED SDDLs producing up to 600 lumens are widely available (CALiPER 2014).

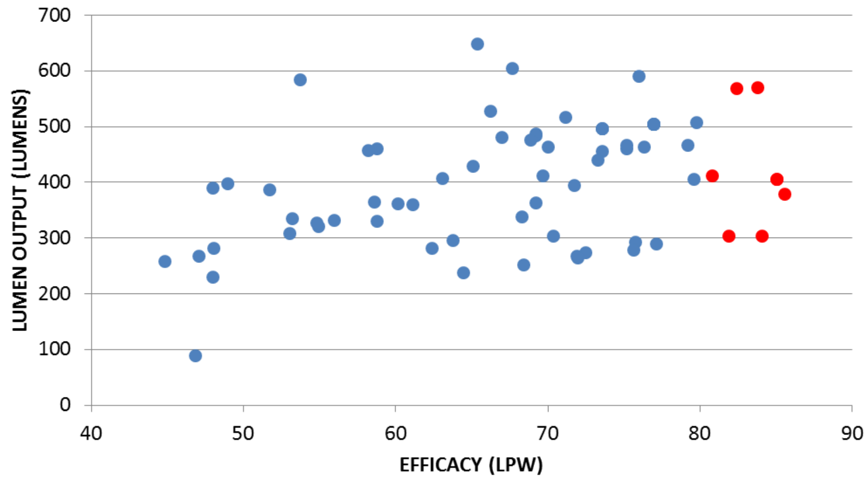

FIGURE 3.1 LIGHTING FACTS MR LAMP PERFORMANCE

One consideration for equivalency between filament based lamps and LEDs, based on reported values, is that the CALiPER report also notes that most halogen low MR16s yield lower light output than reported (2014). The report suggests that many luminaire manufacturers try to prolong halogen lamp life by delivering 11.5V (these lamps are typically tested at 12V), which has the effect of dimming the lamp (i.e., reducing CBCP and lumen output) as well as lowering its color temperature (CALiPER 2014). Additionally, most halogen lamps are paired with a protective glass in front of the aperature, which can reduce output by about 10% (CALiPER 2014). Thus, measured comparisons of LED performance to filament-based performance may not be indicative of their compared performance in the field.

The CASE team also conducted a regression analysis on LFD records over time, which suggests that lamps will increase in lumen output over time. Figure 3.2 below forecasts this trend in improvement over time; note that the average and minimum values take into account lamps specifically designed specifically for lumen ranges equivalent to 20W and 35W equivalency.

[2] Incandescent lamps operated on 240V in Europe tend to be less bright than their lamp counterparts that operate on 12V or 120V. Nonetheless,we believe comparing the U.S. and European Union markets is appropriate for this product class for basic benchmarking purposes.

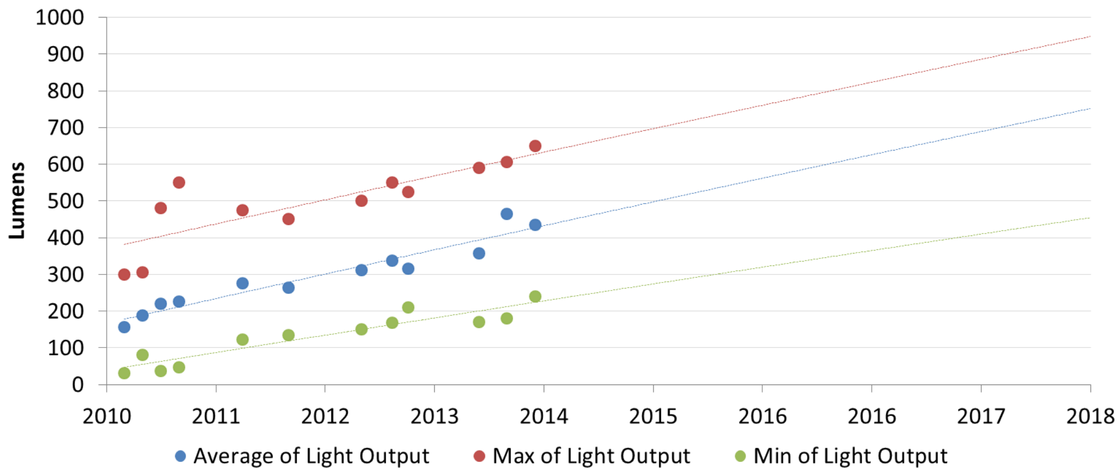

FIGURE 3.2 LIGHTING FACTS MR LAMP PERFORMANCE OVER TIME

3.2 Center Beam Candle Power

In terms of Center Beam Candle Power (CBCP), the wattage equivalency metric that ENERGY Star utilizes to compare wattage equivalencies between filament based MR16s and LED SDDLs, CBCP is predicted to continue to increase over time for the range of beam angles applicable to this market. The California Lighting Technology Center (CLTC) conducted testing of LED performance for the CA IOUs in 2012 and 2013. Approximately 20 LED MR16 replacement models were selected from commercially available 2012 Q3 and Q4 products, and lumen output and CBCP were measured for these lamps. While none of the 2012 tested lamps meet 50 W equivalency on a measured basis, almost all of them were able to achieve 35 W equivalency. Additionally, given the consistent increase in brightness the market has shown since then, we expect a wide variety of lamps will be meeting CBCP 50 W equivalency well in advance of 2018.

Additional testing was conducted at CLTC in Q2 of 2014 to evaluate wattage equivalency of 5 LED SDDLs released in either 2013 or 2014. Preliminary results, highlighted in Table 3.1 below show that 2 of the 5 were able to meet 50W equivalency, and all could meet 35W equivalency.

TABLE 3.1 CLTC TEST RESULTS FOR 2013-2014 LED SDDL REPLACEMENTS

Test ID	Beam Angle	CBCP	Lumen Output	Meets 35W equivalency	Meets 50W equivalency
MR16-21	20.8	3258	660	yes	yes
MR16-22	22.5	2428	581	yes	no
MR16-23	23.7	3294	562	yes	yes
MR16-24	20.4	2509	445	yes	no
MR16-25	17.3	3860	618	yes	no

3.3 Beam Angle

In terms of beam angle, LED manufacturers are increasingly working on providing lamp options with narrow spot, spot, as well as narrow flood, and flood angles. LED manufacturer Soraa now offers LED SDDL with 10 degree and 60 degree beam angles and the range of beam angles in between. Manufacturers are exploring different optical solutions to provide narrow spot beam angles. In a recent CALiPER report, DOE observed lamps with measured beam angles of 4°, 7°, 10°, and 15° within the narrow spot category (2014). Ultimately, technical feasibility does not appear to be a barrier, and we anticipate seeing a variety of products with spot and flood beam angles as demand in the LED market grows.

Figure 3.4 below plots beam angle against efficacy for currently listed LFD 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.

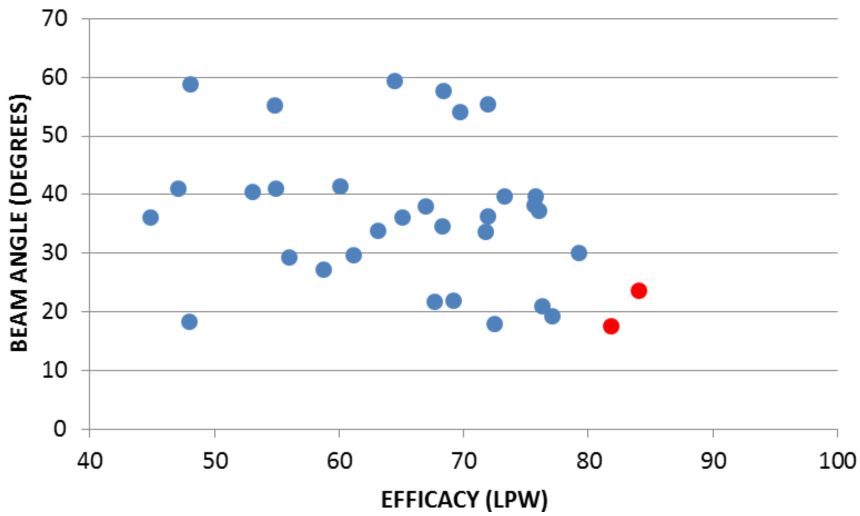

FIGURE 3.3 LFD REPORTED BEAM ANGLES BY EFFICACY

3.4 Color Rendering Index (CRI)

Color Rendering Index (CRI) is a quantitative measure of the ability of a light source to render the colors of objects as natural light would. Higher CRI lamps can more accurately render the true colors of objects. While halogen lamps yield close to 100 CRI, LED lamps average currently around 80-85 CRI (see Figure 3.5 below). The highest performing LED lamps achieve CRI above 95; in the recent CALiPER report, one LED yielded a measured CRI of 98 (2014).

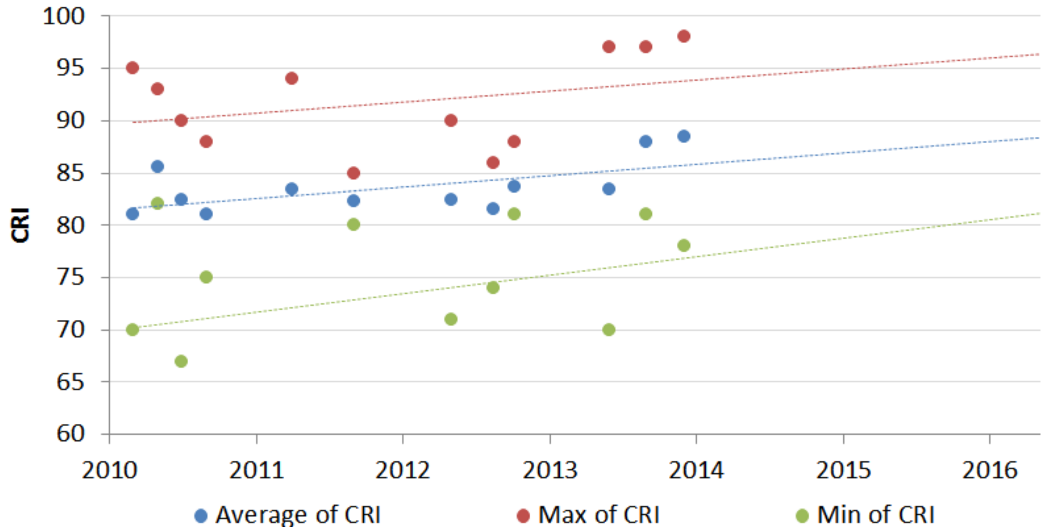

FIGURE 3.4 SDDL LED CRI PREDICTIONS TO 2016

3.5 Transformer & Dimmer Compatibility

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 anecdotal evidence from utility rebate programs that suggest that the incidence of incompatibility is decreasing. Based on conversations with some LED manufacturers, manufacturers recognize that transformer compatibility for low voltage lamps has been a concern and have therefore been investing in improvements to their 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.

While the majority of LED SDDLs report dimming ability in the Lighting Facts Database and on ENERGYSTAR, we recognize that dimming compatibility is not fully resolved. Flicker and the inability to achieve a full range of dimming have been reported. These issues are more prevalent in retrofit scenarios in which existing dimming systems are already installed; new dimming systems designed for LEDs tend to have few compatibility issues. Manufacturers are vetting various solutions for compatibility in these retrofit scenarios. We predict that as these lamps become more efficient, smaller heat sinks can be utilized, which will provide more space for electronics to support all types of dimming systems. The CA IOU CASE team is conducting testing of LED SDDLs on various dimmers to better characterize these issues and potential solutions.

3.6 Efficacy

Efficacy continues to increase for these products. As shown in the time series graph below (based on analysis of the Lighting Facts Database) the highest efficacies of available LED MR16 lamps already exceeds 75-80lpw, while the average efficacy of MR16 LED replacements is already at 60 lumens per watt (LPW). By 2018, we anticipate that there will be ample lamp choice in the market with an 80 LPW standard. Table 3.6 below depicts these efficacy trends and forecasts. The highest efficacy reported in the recent CALiPER report was 90 lumens per watt (2014).

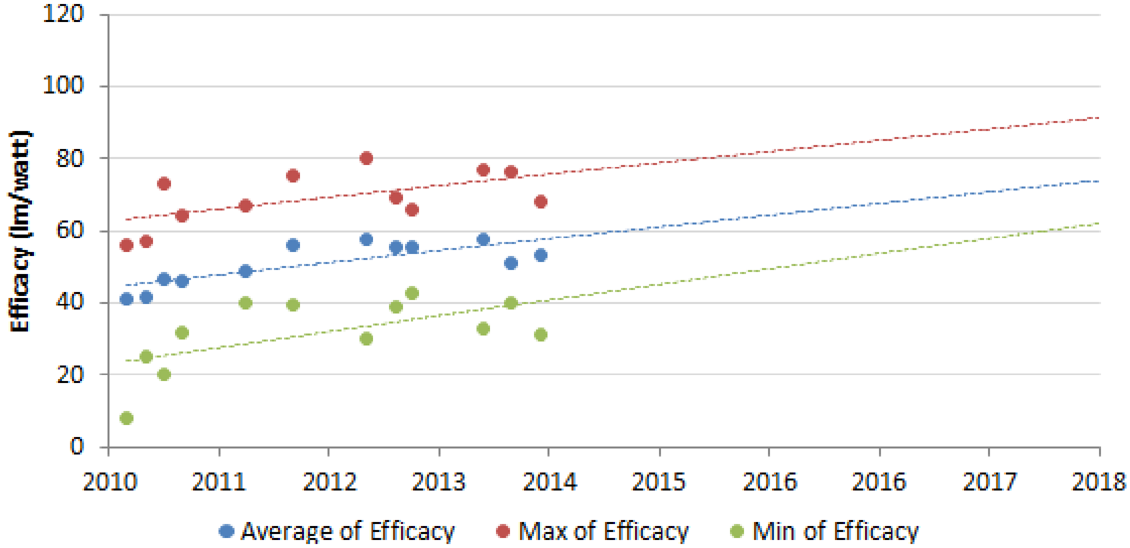

FIGURE 3.5 SDDL LED EFFICACY PREDICTIONS TO 2018