# Proposal Information Template for:
# **Non-Federally Preempted General Service, Directional, and Linear Lamps**

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**Please note: all savings estimates and information in this document are preliminary and are based on data available to the authors at the time of the report. If the CEC moves forward with this topic, we anticipate updating our estimates and recommendations based upon additional input from stakeholders.**

**Proposal Information Template – Non-Federally Regulated Lamps**

*2011 Appliance Efficiency Standards*

Prepared for: Pacific Gas and Electric Company

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## Purpose

This document is a report template to be used by researchers who are evaluating proposed changes to the California Energy Commission's (Commission) appliance efficiency regulations (Title 20, Cal. Code Regulations, § 1601 – 1608) This report specifically covers certain non-federally preempted lamp types within the following three lamp categories: general service lamps (GSLs), linear lamps, and directional lamps. Covered in this proposal are lamps in those three categories that are non-fluorescent and non-incandescent. Currently, the only technology that is not federally regulated for these lamp types is light emitting diode (LED).

**This proposal focuses on exploring the lamp properties we believe to be most critical to providing consumer value, but does not aim to set specific performance levels at this point. We understand that LED technology is only beginning to penetrate these markets and that the technology's performance is improving at a very rapid rate; we therefore expect to engage in a robust stakeholder process to develop appropriate standard level recommendations for each of the lamp properties identified in this proposal.**

## Background

LED technology has improved dramatically in the past several years, and is forecasted to continue to improve in efficacy while decreasing in cost. For many common lighting applications, manufacturers have already developed suitable LED products which can be used in place of less efficient incumbent technologies. This standard focuses specifically on LED GSLs, LED directional lamps, and tubular, linear LED replacement lamps for standard fluorescent tube lamp fixtures.

### *General Service Lamps*

GSLs, for example "A-type" lamps, are used for general service lighting applications where the light is designed to be distributed in all directions. GSLs are especially common in the

residential sector, and comprise the largest installed stock of any lighting type. Nationally, DOE estimated that GSLs consumed almost 120 TWh of electricity in 2010. The GSL market has continued to change since the introduction of compact fluorescent lamps (CFLs) and is on the verge of another revolution with LED replacements quickly becoming more and more market available. The figure below presents three common technologies used in general service lamps.

**Figure 1. Incandescent, compact fluorescent, and LED general services lamps. Source: Google Images**

### *Directional and Linear Lamps*

Directional lamps, such as parabolic aluminized reflector (PAR) or multifaceted reflector (MR) lamps are commonly used in retail applications, while linear lamps are typically found in the ceilings of offices and commercial buildings. DOE estimated that national energy consumption by linear lamps in 2010 was on the order of 12 TWh[1]; national energy consumption by directional lamps in 2010 was estimated to be on the order of 56 TWh.[2] Figures 2 and 3 below illustrate different types of directional and linear lamps.

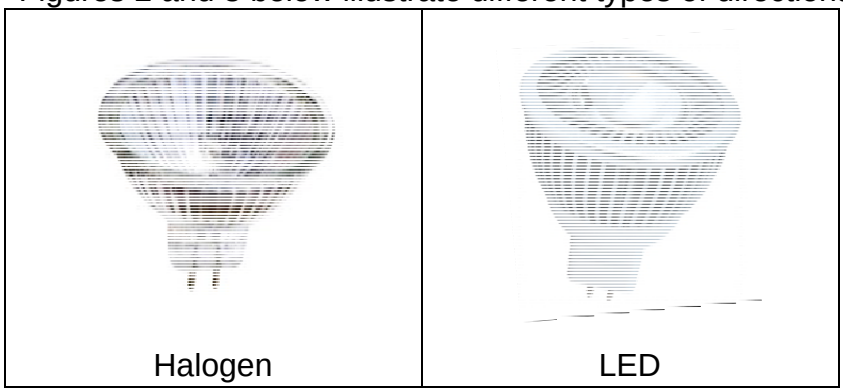


**Figure 2. Halogen and LED directional lamps. Source: Google Images**

[1] Assumed to be equal to the estimated consumption of 2 ft by 2 ft troffer fixtures.
[2] Assumed to be equal to the sum of MR16 lamp consumption plus PAR, BR, and R-shaped lamps.

| | |
|---|---|
| | |
| Fluorescent | LED |

**Figure 3. Fluorescent and LED linear lamps. Source: Google Images**

**Overview**

| | |
|---|---|
| Description of Standards Proposal | The proposed standard aims to ensure LED lamp quality in order to build and maintain consumer satisfaction with LED's. This standard would require LED lamps to meet minimum performance requirements addressing the following key specifications: color, dimmability, longevity, flicker/noise, and efficacy. The ENERGY STAR Program Requirements for Integral LED Lamps specification (version 1.4) defines specific requirements for these main criteria and provides a useful foundation for this standard; however, further market research and industry collaboration will be required to develop an appropriate set of specifications in the Title 20 context. |
| California Stock and Sales | LED GSLs:<br>Stock in 2014: 13.9 million<br>Annual Sales in 2014: 2.6 millions<br>Stock and sales estimates are derived from past CASE reports and assumptions for market share of LED GSLs in 2014.<br><br>Directional and linear lamps:<br>TBD |

| | |
|---|---|
| Energy Savings and Demand Reduction | LED GSLs:<br><br>Energy use in 2014: 165 GWh<br>Peak demand in 2014: 94 MW<br>Energy savings in 2014: 2.7 GWh<br>Peak demand reduction in 2014: 1.5 MW<br><br>In terms of first order savings from efficacy requirements, we anticipate a modest reduction in energy use; however, by preventing low quality LED lamps from entering the market and eroding consumer confidence in LED technology, this standard will achieve significant "second order" savings as LED adoption rates ultimately increase more rapidly and beyond what would happen in a no standards scenario.<br>Directional and linear lamps:<br><br>TBD |
| Economic Analysis | LED GSLs:<br><br>Incremental cost per unit: $4-8<br>PV lifetime savings per unit: $6.54<br>Annual avoided energy costs in 2020: $45 million<br><br>Directional and linear lamps:<br><br>TBD |
| Non-Energy Benefits | This proposed standard will result in higher customer satisfaction with LED products due to improved lamp color and dimming performance. Additionally, improved lamp lifetimes would decrease labor and maintenance costs related to replacing burnouts. |
| Environmental Impacts | None |
| Acceptance Issues | Consumer education and proper labeling of LED lamps will be necessary to educate the consumer on the specific operating characteristics of LEDs versus incumbent technologies. The consumer must be provided enough information to make true "apples to apples" comparisons between products. |

| | |
|---|---|
| Federal Preemption or other Regulatory or Legislative Considerations | General Service LEDs<br><br>EISA 2007 defines "general service lamp (GSL)" as (1) General Service Incandescent Lamps (GSILs), (2) Compact Fluorescent Lamps (CFLs), and (3) and GSLEDs, but it did not set standards for GSLEDs. The Act then directed the DOE to initiate a rulemaking by 2014 to reassess current GSIL standards and to consider broadening the scope to cover other types of GSL's. If DOE does broaden the scope of coverage to include GSLED's, those standards would likely not take effect until 2019 or later. It is therefore our understanding that states are not pre-empted from setting GSLED standards, though pre-emption may apply if and when DOE standards become effective.<br><br>LED directional lamps and Linear LEDs<br><br>No Federal standards have been explicitly set for either of these product types, nor has Congress directed DOE to set standards for these products. Federal standards do exist for incandescent directional lamps and for linear fluorescent lamps, but LED alternatives for them are clearly outside the scope of those standards, so state standards would not be preempted. |

**Methodology and Modeling used in the Development of the proposal**

Currently, LED lamps that can be used to replace general service, linear fluorescent, and directional lamps are not subject to State or Federal minimum performance requirements. We believe that absent standardization, as LED prices drop significantly over the next several years, cheaper, lower-quality products are likely to dominate sales, especially when consumers are not well educated on the general operating characteristics of this new technology. As a result, consumers will in many cases be unsatisfied with their first round of LED purchases and will therefore hesitate to rely on LED technology in the future. A similar trend occurred in the development of CFL products, and the consumer dissatisfaction with early CFL products has greatly limited the market adoption of CFLs in the United States. Applying lessons learned from the relative failure of CFLs to successfully, comprehensively infiltrate the general service lighting market, we aim to define minimum specifications that ensure consumer satisfaction for newer technology and higher efficiency products that are meant to replace incumbent lamps. This proposal will leverage the numerous market studies that have identified and ranked consumer preferences for lamp performance and light quality, and will develop standards to ensure that LED lamps provide the minimum performance characteristics deemed critical by consumers. Considering the cost-implications and technical feasibility of all proposed specifications, this proposal will aim to set LED performance specifications to equal or surpass the performance of the existing technologies that have already gained consumer acceptance. Drawing from the ENERGY STAR Program Requirements for Integral LED Lamps specification, we have focused this proposal on the following key lamp properties: light color, dimmability, longevity, flicker/noise, and efficacy.

### *Light color*

Past studies of consumer lighting preferences indicate that the "naturalness" of general service lighting is of very high concern. We believe that it will be important to ensure that all LED lamps can meet minimum light color specifications designed to mimic the performance of incandescent lamps. ENERGY STAR uses the table below to specify the acceptable criteria for lamps that fall within pre-defined correlated color temperature (CCT) bins to maintain color consistency among lamps designed for the same CCT.

**Table 1. ENERGY STAR's specifications for LED CCT**

| | | | | |
|---|---|---|---|---|
| Correlated Color Temperature (CCT) and Duv | Lamp must have one of the following designated CCTs (per ANSI/NEMA/ANSLG C78.377-2008) consistent with the 7-step chromaticity quadrangles and Duv tolerances listed below (see Appendix A for more information). | | | IES LM-79-08<br><br>ANSI/NEMA/ ANSLG C78.377-2008 |
| | Nominal CCT | Target CCT (K) and tolerance | Target Duv and tolerance | |
| | 2700 K | 2725 ± 145 | 0.000 ± 0.006 | |
| | 3000 K | 3045 ± 175 | 0.000 ± 0.006 | |
| | 3500 K | 3465 ± 245 | 0.000 ± 0.006 | |
| | 4000 K | 3985 ± 275 | 0.001 ± 0.006 | |

We believe this table can generally serve as a starting model for our light color standards. We plan for more than four nominal CCT bins, however, as this allows for a greater variety of differentiated products to be developed and supports greater consumer choice.

We also propose to vary from the ENERGY STAR color specification by requiring greater color consistency among lamps of a given nominal CCT. Should a consumer retrofit all of the existing lights in a room with lamp models of the same labeled color, this specification can ensure that there is no discernable difference in lamp color between any one lamp and the others.

Additionally, we propose to set color rendering index (CRI) requirements to ensure high light quality for all LED lamps. As a point of reference, ENERGY STAR currently requires a minimum CRI of 80, but we believe that it may be possible to set a higher minimum level, particularly when considering expected improvements in LED technology in the near future.

### *Dimmability*

The incumbent technologies that LEDs are seeking to replace in each of the three product classes in this standard are able to achieve certain levels of dimming. This standard proposes to require dimmability in LED lamps and to ensure that key lamp characteristics are not adversely affected when the lamp is dimmed down to a certain minimum (TBD) level. The specification would set requirements to define allowable changes in lumen output, CCT, and flicker/noise, as well as potential impacts on lamp reliability.

Currently, ENERGY STAR does not require LED lamps to be dimmable, but rather that they be clearly marked as such if they are dimmable. We are not yet aware of a test procedure designed specifically to measure the dimmability of LED lamps while tracking the parameters outlined in the previous paragraph; however, we believe that a suitable test

method can be derived from existing industry accepted test procedures to apply in this situation.

***Longevity***

This standard will set minimum lamp life requirements in order to meet consumer expectations for LED lamps. ENERGY STAR currently requires lamps to last 25,000 hours[3], and also provides a methodology for determining the lifetime that LED products are allowed to claim, presented in detail in Appendix B. We believe that it will be very important for actual LED lamp lifetimes to meet claimed lifetimes, particularly in the near term when consumers are expected to be paying a significant price premium for the LED products.

***Flicker/noise***

Some LED lamps in certain applications may flicker or buzz. Consumers accustomed to incandescent lamps which do not exhibit these annoyances will expect similar performance from LED lamps, at all levels of dimming. ENERGY STAR currently requires lamps to have a Class A sound rating, and attempts to address problems with flicker by preliminarily specifying a minimum LED operating frequency of 120Hz. We currently are not yet aware of any industry standard lamp test procedures specifically designed to measure LED flicker and/or noise, but we believe that existing test procedures can be easily modified to appropriately measure these lamp properties.

***Efficacy***

We also propose modest efficacy requirements (likely in the form of minimum lumens per watt) to capture first order energy savings through improved energy efficiency of LED lamps. This efficacy requirement is designed to be relatively easy to meet, though would still represent a significant improvement over incandescent technologies. Our rationale for not pushing for stringent efficacy standards is to allow the manufacturers more flexibility in achieving the desired price points for lamps that are able to meet the other quality specifications in the standard.

**Data, Analysis, and Results**

As previously mentioned, GSLs comprise the vast majority of stock and shipments of the products considered in this standards proposal. Therefore, at this time, our preliminary stock and savings analysis focuses on this lamp product class.

First order savings from the efficacy requirements to be specified in this standard proposal are expected to be modest. Initial estimates for savings from the efficacy requirement for LED GSLs are provided in the tables below. Note that first order savings in 2020 are expected to be very low as a result of expected cost effective advancements in efficacy in the next several years.

[3] This is defined as $L_{70}$, or 70% lumen maintenance at 25,000 hours.

**Table 2. First order savings from standards for GSLs**

| Year | Annual energy savings (GWh) | Peak demand savings (MW) |
|---|---|---|
| 2014 | 165 | 94 |
| 2020 | 7 | 4 |

We believe that the true value in this standard is derived from second order savings. For our savings calculations, we assume that the base case LED market penetration in 2018 will be on the order of 5%. We have seen a range of LED market share estimates for different lighting applications and expect that our baseline assumption of 5% is likely to be conservative, on the low end. This value is less critical to the impact of the standard than our assumptions on how LED market share is expected to increase as a result of the standard. To account for uncertainty, we created three scenarios to determine second order savings resulting from changes in eventual LED market share, as shown in the table below.

**Table 3. Second order savings from standards for general service LED lamps**

| Standards case market share | Savings in 2020 (GWh) |
|---|---|
| 7% | 80 |
| 12% | 281 |
| 20% | 602 |

These savings estimates rely on a number of assumptions which will require additional industry data and input to refine. Further market data will also be necessary to develop savings estimates for linear and directional lamps.

## Proposed Standards and Recommendations

As previously stated, this plan focuses on a few key properties which can be used to benchmark lamp performance. By building from existing specifications, including the current ENERGY STAR Program Requirements for Integral LED Lamps and the CLTC's Super-lamp spec, we intend to define acceptable ranges and parameters for CCT, dimming, lifetime, flicker/noise, and efficacy. At this time, we have not yet determined the precise standard levels for each of these properties, and plan to coordinate with industry moving forward to develop feasible specifications that will not be cost-prohibitive.

**Bibliography and Other Research**

[CLTC] California Lighting Technology Center. 2009. Specification for "Super Lamp"-designated Lamps. University of California, Davis.

[DOE] U.S. Department of Energy. 2011. Solid-State Lighting Research and Development: Multi Year Program Plan.

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Grover, Steve. 2006. *SDG&E Small Business Energy Efficiency SoCal Gas Non-Residential Financial Incentives Program 2004-2005 Evaluation Results*. Presentation to CALMAC/MAESTRO.

[PG&E] Pacific Gas and Electric Company. 2008. *Analysis of Standards Options for General Service Incandescent Lamps*. Codes and Standards Enhancement (CASE) Initiative for PY2008: Title 20 Standards Development.

## References and Appendices

### *Appendix A: ANSI Chromaticity Specification and Tolerance Quadrangles (as referenced by ENERGY STAR)*

This chromaticity specification below was developed by ANSI to be as consistent as possible with existing fluorescent lamp standards, and to reflect the current (and near future) state of SSL technology and color binning capabilities. Each of the eight quadrangles as defined below overlap the six current the ANSI 7-step MacAdam ellipses (consistent with the current ENERGY STAR lighting criteria), and thus have the same nominal CCT as ENERGY STAR fluorescent lamps. Two additional CCTs (4500 and 5700K) are included to encompass the additional CCTs available in SSL. Each quadrangle is defined by the range of CCT and the distance from the Planckian locus on the chromaticity diagram. Refer to ANSI/NEMA/ANSLG C78.377-2008for the details of these definitions. Figure 1 shows the plot of these chromaticity quadrangles and the table below shows (x,y) coordinates of the center points and the corners of each quadrangle.

| | 2700 K | | 3000 K | | 3500 K | | 4000 K | | 4500 K | | 5000 K | | 5700 K | | 6500 K | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | x | y | x | y | x | y | x | y | x | y | x | y | x | y | x | y |
| Center point | 0.4578 | 0.4101 | 0.4338 | 0.4030 | 0.4073 | 0.3917 | 0.3818 | 0.3797 | 0.3611 | 0.3658 | 0.3447 | 0.3553 | 0.3287 | 0.3417 | 0.3123 | 0.3282 |
| Tolerance quadrangle | 0.4813 | 0.4319 | 0.4562 | 0.4260 | 0.4299 | 0.4165 | 0.4006 | 0.4044 | 0.3736 | 0.3874 | 0.3551 | 0.3760 | 0.3376 | 0.3616 | 0.3205 | 0.3481 |
| | 0.4562 | 0.4260 | 0.4299 | 0.4165 | 0.3996 | 0.4015 | 0.3736 | 0.3874 | 0.3548 | 0.3736 | 0.3376 | 0.3616 | 0.3207 | 0.3462 | 0.3028 | 0.3304 |
| | 0.4373 | 0.3893 | 0.4147 | 0.3814 | 0.3889 | 0.3690 | 0.3670 | 0.3578 | 0.3512 | 0.3465 | 0.3366 | 0.3369 | 0.3222 | 0.3243 | 0.3068 | 0.3113 |
| | 0.4593 | 0.3944 | 0.4373 | 0.3893 | 0.4147 | 0.3814 | 0.3898 | 0.3716 | 0.3670 | 0.3578 | 0.3515 | 0.3487 | 0.3366 | 0.3369 | 0.3221 | 0.3261 |

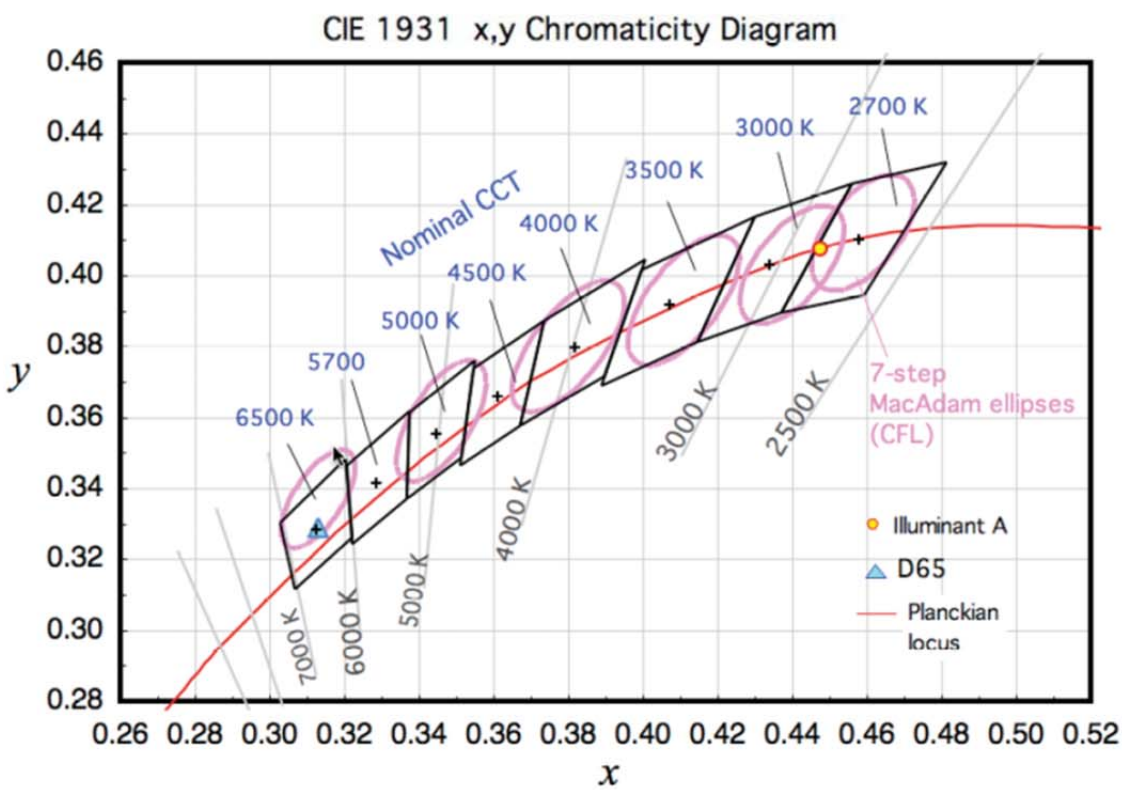


Figure 1. CIE 1931 Chromaticity Diagram Showing the Eight Nominal CCT Quadrangles

## *Appendix B: ENERGY STAR's Lumen Maintenance Testing and Life Claims*

Minimum life requirement: 15,000 hours to 70% lumen maintenance ($L_{70}$) for Decorative lamps (section 7B); 25,000 hours for all other lamp types. At least 6,000 hours of lumen maintenance testing of the full integral lamp is required of all lamp types. Lumen maintenance cannot be claimed on the basis of component testing alone. Life claims associated with early initial qualification are limited to the minimum life requirement values stated above, though longer $L_{70}$ life may be claimed based on verified lumen maintenance levels after 6,000 hours of lumen maintenance testing, as follows:

**Table 1. 6000-Hour Lumen Maintenance Thresholds**

| | Minimum lumen maintenance at end of 6000 hours (% of initial lumens; -3% tolerance) | Maximum $L_{70}$ Life Claim (hours) | ENERGY STAR Approval Available After 6000-hour test |
|---|---|---|---|
| Minimum for Decorative | 86.7% | 15,000 | **Full approval** (no additional lumen maintenance testing required) |
| Optional for Decorative | 89.9% | 20,000 | |
| Minimum for Non-standard, Omnidirectional, and Directional<br>Optional for Decorative | 91.8% | 25,000 | |
| Optional for All Lamp Types | 93.1% | 30,000 | **Initial approval**, pending completion of total required test period (see Table 2 below) |
| | 94.1% | 35,000 | |
| | 94.8% | 40,000 | |
| | 95.4% | 45,000 | |
| | 95.8% | 50,000 | |

Longer life claims are allowed, based on longer required test periods and associated lumen maintenance thresholds, as shown in Table 2.

**Table 2. Total Required Test Periods for Life Claims >25,000 Hours**

| Minimum cumulative test period (hours) | Minimum lumen maintenance at end of test period (% of initial lumens; -3% tolerance) | Maximum $L_{70}$ Life Claim (hours) |
|---|---|---|
| 7,500 | 91.2% | 30,000 |
| 8,750 | 91.5% | 35,000 |
| 10,000 | 91.5% | 40,000 |
| 11,250 | 91.5% | 45,000 |
| 12,500 | 91.8% | 50,000 |

Lumen maintenance operation is conducted at specific ambient temperatures shown in Table 3 below, for each lamp category. Periodic photometric tests are conducted at room temperature (25°C).

**Table 3. Lumen Maintenance Required Minimum Ambient Temperature Between Measurements**

| Lamp category | Lamp subcategory | Minimum ambient temperature |
|---|---|---|
| Non-standard lamps<br>Omnidirectional lamps<br>Directional lamps | LED lamp power <10W | 25°C |
| | LED lamp power ≥10W | 45°C |
| Decorative lamps | All | 25°C |