California Energy Commission

FINAL STAFF REPORT

VOLUNTARY CALIFORNIA QUALITY LIGHT-EMITTING DIODE (LED) LAMP SPECIFICATION

A Voluntary Minimum Specification for “California Quality” LED Lamps

CALIFORNIA
ENERGY COMMISSION

Edmund G. Brown Jr., Governor

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ABSTRACT

This *Voluntary California Quality LED Lamp Specification* "California Specification" final staff report outlines a voluntary quality specification that is intended to support energy policy makers and the lighting industry in their collective goal to move consumers away from the inefficient incandescent lighting of the past century and toward more efficient light-emitting diode (LED) lighting technology. Achieving this goal will require more than just efficient lamps; it will require lamps that meet consumers' expectations for lighting quality and performance.

California Energy Commission staff worked with technical experts, utilities, and industry to determine the level of performance necessary to achieve a lighting product that would meet or exceed customer expectations for lighting, with a particular focus on homes because the majority of incandescent light bulbs are used in the residential sector. The California Specification represents the Energy Commission staff's minimum requirements for an LED light to be considered "California Quality."

The concept of the *California Quality LED Lamp Specification* and many of the original arguments for its necessity arose from discussions with Professors Michael Siminovitch and Konstantinos Papamichael, of the California Lighting Technology Center, and from ideas they developed in a report titled *Relighting American Homes with LEDs*, published as an editorial in *Lighting Design and Application*, August 2012.

The first draft of this staff report was used as the basis for discussion at a public workshop held at the Energy Commission in October 2012. The workshop solicited input from the lamp industry, the utilities, and other interested stakeholders, regarding the voluntary specification. The Energy Commission staff considered all comments received and recommends this final staff report for adoption and publication.

Keywords: Light-emitting diodes, LED, LED replacement lamps, *Voluntary California Quality LED Lamp Specification.*

Lighting Terminology: There is lighting industry terminology used in this report for which some readers may not be familiar. Please see the Glossary for helpful definitions of some of the lighting terminology used in this document.

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OVERVIEW

California Energy Commission staff worked with technical experts, utilities, and the lighting industry to determine the appropriate level of performance necessary to achieve a light-emitting diode (LED) lighting product that would meet or exceed customer expectations for general purpose lighting in residences. Such an LED product would be functionally indistinguishable from equivalent incandescent lamps.

This voluntary quality specification is intended to inform energy policy makers and the lighting industry in their collective goal to move consumers away from the inefficient incandescent lighting of the past century and toward more efficient LED lighting technology. The California Specification represents the Energy Commission staff's recommendation for minimum requirements an LED light should meet to be considered "California quality."

The *Voluntary California Quality LED Lamp Specification* applies only to LED lamps that are intended to be installed directly into incandescent luminaires ("light fixtures") as an alternative to incandescent lamps ("light bulbs"). As such, the specification does not apply to many LED products that are now available on the market. For example, it does not apply to colored LED lamps, LED light strips, linear LED pin-based lamps, LED rope lights, LED fully integrated luminaires, LED luminaire housings, or LED light engines not having American National Standards Institute (ANSI) standardized screw bases.

History

On New Year's Eve, 1879, Thomas Edison gave his first public demonstration of his new invention, the electric filament lamp, at Menlo Park, New Jersey. Within four years there were more than 300 electric power stations, feeding more than 70,000 incandescent lamps, each with an average life of 100 hours. This dramatic success established the "Edison screw" as the standard for residential light bulb sockets up to the present day.

In California there are now an estimated 530,000,000 general service "Edison Screw" lamp sockets in homes and places of work[1]. The majority of these sockets contain incandescent lamps that have not changed significantly from Edison's original filament lamp. Despite lighting codes promoting pin-based sockets in newly constructed buildings, screw-base sockets are expected to remain in the existing building stock for the foreseeable future. To meet California's energy policy goals, there is a need for consumers to have readily available high-efficacy screw-base lamps for these millions of existing Edison screw-base sockets.

Opportunity

Because LED lamps can now achieve comparable brightness and color quality to incandescent lamps, with instant-on and dimming capability, while using a fraction of the power, California is at the beginning of one of the largest energy savings opportunities in the history of the

1 http://www1.eere.energy.gov/buildings/ssl/tech_reports.html

lighting market. The *2011 Integrated Energy Policy Report (IEPR)* recognized this and recommended that "the Energy Commission and CPUC should collaborate to develop voluntary LED quality performance standards."[2]

Need for a Voluntary Quality Specification

Most California consumers still choose a variation on the Edison electric filament lamp over compact fluorescent lamps (CFLs) (See Chapter 1 below). For LED lamps to achieve significant market share, consumers must be confident that LED lamps can give them the light quality they need or want. This voluntary specification would help accelerate demand by establishing LED performance criteria that reflect consumer expectations.

Though CFLs have improved steadily over the past decade, for many consumers, their opinions and perception of CFLs have been established by their experiences with poor quality early products. In the words of Ed Crawford, the head of the North American Lighting Division at Philips, the world's largest lighting company, "Some of the early compact florescent products, they were not ready for prime time. They buzzed, they had lousy color, and they made everything kind of grayish, green[3]." Early experiences with these lamps were enough to ruin many consumers' confidence in CFLs. Though modern products have improved color properties, many consumers have not bothered to continue to seek out these lamps. The poor public image of CFLs has added to the challenge researchers face as lighting manufacturers introduce LED lamps into the market and attempt to convince consumers that LED lamps can deliver the quality, performance, and efficacy that both consumers and designers want.

The slow and incomplete market adoption of CFLs in the residential market (compared to the commercial market) demonstrates that just because a product produces enough light, is cost-effective, and is supported by millions of dollars in persuasive marketing, the market adoption of that technology is not ensured. In 2006, just as CFLs sales began to increase (more than 20 years after they had been introduced), the U. S. Department of Energy commissioned a study of "lessons learned" from the introduction of CFLs[4]. Among its key recommendations:

- Manufacturers and energy-efficiency groups should coordinate to establish minimum performance requirements.
- Shift consumer focus from product price to product value.
- Delay launch rather than introduce inferior product; first impressions are long-lasting.
- Accurate incandescent equivalency on packaging is critical.

2 California Energy Commission, 2011. *2011 Integrated Energy Policy Report*.
Publication Number: CEC-100-2011-001-CMF.

3 http://www.cbsnews.com/8301-3445_162-57344798/let-there-be-leds/?tag=contentMain;contentBody.

4 U.S. Department of Energy and Pacific Northwest National Laboratory, *Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market*, June 2006,
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/cfl_lessons_learned_web.pdf.

A voluntary specification is a way of moving toward the first of these four recommendations while fulfilling the second through an increased market penetration of high quality products. The third and fourth recommendations are beyond the scope of the California Specification.

At present, LED efficacy is not much higher than CFL efficacy for applications that involve omnidirectional light. In the short term, LED lamps that simply replicate the color quality and overall user experience of bare spiral CFLs are unlikely to gain much market share over incandescent lamps, especially since at the time of writing their retail price is typically $20-$50. To persuade consumers to purchase LEDs instead of incandescent lamps, LEDs must be seen as a high-quality product worth the high price differential. Therefore LEDs must provide performance that is measurably better than CFLs, for instance, dimming ability, higher color rendering, or more predictable color appearance.

The primary intent of the California Specification is to encourage the market penetration of high-quality LED lamps that meet customer expectations regarding performance and light quality. The California Specification focuses on six quality attributes for LED lamps:

- Color temperature
- Color consistency
- Color rendering
- Dimmability
- Rated life/warranty
- Light distribution

Cost and luminous efficacy are also important but are not the key priorities of the California Specification. Cost is not discussed in detail in this report because the cost of fully compliant LED lamps cannot be known until manufacturers bring them to market. However, the research and outreach conducted by the Energy Commission staff suggest that it will be possible within a few months for utilities to provide a rebate that reduces the cost of compliant lamps to a level at which consumers will purchase them in numbers large enough to influence the market. Luminous efficacy is not a priority in strategic terms because the difference in energy use between high- and low-efficacy LED products is small. Therefore, a persistent and growing adoption of moderate efficacy lamps that meet consumer expectations will provide significantly more energy savings than a limited adoption of the highest efficacy lamps.

Status and Use of the California Specification

This specification is intended to serve as a resource for the Governor and the Legislature in establishing new or expanded energy conservation measures involving LED lamps; for the California Public Utilities Commission (CPUC) in setting ratemaking policies for California investor-owned utilities; and for the public when considering the purchase of lighting products.[5] It supports the goals of the State of California and the California Energy

5 See Pub. Resources Code, §§ 25216, subd. (a), 25216.5, subd. (c), 25218, subd. (e), 25496; see also *id*. at § 25218.5.

Commission by promoting energy conservation through increased market penetration of high quality, highly efficient LED lamps for replacing traditional incandescent lamps, both up to and beyond 2018 (when major changes will take place to lighting standards in California).

The California Specification is voluntary. It does not establish a framework for the California Energy Commission to certify or take enforcement action in regard to LED lamps, and it does not authorize the labeling of any product in any way as to claim compliance with the California Quality Specification.

Relationship Between the California Specification and ENERGY STAR®

ENERGY STAR has improved the quality and performance of CFL lamps and other lighting products in the 15 or so years since its introduction. For many years the State of California, through the CPUC, has supported ENERGY STAR by requiring utility-rebated lamps to be certified to ENERGY STAR. The California Specification seeks to continue to support and make use of ENERGY STAR by taking an "ENERGY STAR plus" approach. This approach has two key components:

- This specification is designed to work alongside (rather than replace) the applicable ENERGY STAR standards. The Energy Commission anticipates that the California Public Utilities Commission (CPUC) will continue to use ENERGY STAR along with the California Specification to inform its decisions about which lamps to rebate .
- The requirements in this specification that go beyond ENERGY STAR (for instance, for color, dimmability, light distribution, warranty) are based on the same test procedures and performance metrics that ENERGY STAR uses. The Energy Commission anticipates that manufacturers will be able to use the same test procedures to determine the performance of the lamp in relation to both ENERGY STAR and the California Specification.

In some cases, it is possible that a given class of lamps may not be able to meet both the requirements of ENERGY STAR and the California Specification. The Energy Commission anticipates that any conflicts between ENERGY STAR and the California Specification will be both minor and temporary. However, the Energy Commission also recommends that, pending resolution of those conflicts, the California Specification be viewed as vitally important to ensuring that consumers' have a positive first experience with LED lamps, which is a necessary precursor, as demonstrated by the CFL experience, to driving the market toward LED lamps which are inherently more efficient than incandescent lamps.

Furthermore, there is a potentially symbiotic relationship between the California Specification and ENERGY STAR, if the California Specification can act as a reach standard for ENERGY STAR and thereby maintain upward pressure on lamp quality standards.

Relationship Between the California Quality Specification and Statewide Lighting Standards

The three lamp standards used in California (EISA, Title 20, ENERGY STAR), along with the California Quality Specification in some sense create "tiers" of performance and must be carefully structured and explained to regulators and manufacturers. The Energy Commission will continue to seek to establish clear boundaries and definitions to ensure that these standards and the Specification support one another and do not conflict.

Several commenters on the first draft of this report suggested establishing different tiers of performance within the California Quality Specification itself. A tiered approach within the specification has been rejected because the intent of the specification is to make the performance of LED lamps functionally indistinguishable from incandescent lamps, and there are not different tiers of "indistinguishable". The current performance of LED lamps already on the market is very close to the Specification's level of performance, so the staff believes a temporary transition period (see section below) to allow manufacturers and retailers to adapt to the full California Specification will be sufficient. Using a transition period rather than permanently establishing different tiers of performance is a way to reconcile the limitations of currently-available lamp performance with the goal of establishing an absolute performance specification.

CPUC Implementation Timeline

The CPUC issued decision 12-11-015 on November 8, 2012, which is relevant to the California Specification. The CPUC decision requires the utilities to rebate only LED lamps that are compliant with the California Specification, but it establishes a "transition period" of up to one year during which non-compliant lamps may still be rebated. The current performance of LED lamps already on the market is very close to the Specification's level of performance, but there are only a handful of lamps that currently meet all the performance requirements. Therefore the CPUC decided that a temporary transition period to allow manufacturers and retailers to adapt to the full performance Specification would be appropriate. The CPUC decision orders that:

> 30. Pacific Gas and Electric Company, San Diego Gas & Electric Company, and Southern California Edison Company shall only offer incentives for light-emitting diode (LED) bulbs to products that are in the top half of quality on the market and that meet the Energy Star requirements prior to the adoption of a California quality specification for LEDs by the California Energy Commission (CEC). Once the CEC quality specification is adopted, the utilities shall design a transition period of less than one year, in consultation with the CEC and Commission staff, after which they shall only offer incentives to LED bulbs that meet the California quality specification.[6]

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6 California Public Utilities Commission, Decision 12-11-015 (Nov. 8, 2012) http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M033/K171/33171249.PDF at p. 140.

CHAPTER 1:
Lessons From the Introduction of Compact Fluorescent Lamps (CFLs)

Efforts to move California homes to high-efficiency light sources have been underway since at least 1992, when California utilities launched full-scale CFL rebate programs.

In California, 21 percent of all residential lamp sockets are now fitted with CFLs, and 29 percent of all *medium screw-base* sockets (residential plus nonresidential) are fitted with CFLs[7,8]. While this compares favorably with the national average of 11 percent of residential sockets[9], it is a low rate of penetration compared to the size of the full market potential of the technology. From 2004-2008, 30 percent of screw-based lamps sold in California were CFLs[7], indicating that the market share may have stabilized. This stabilization is consistent with national data[9]. Because CFLs have a longer rated life than incandescent lamps, a market share of 30 percent should result in more than 30 percent of sockets being fitted with CFLs, so these numbers suggest that the number of installed CFLs may still be increasing. Nevertheless, evaluators have speculated that the residential CFL market has reached saturation. That is to say, current CFL owners have bought as many CFL lamps as they ever intend to and are simply replacing the CFLs in their home as they burn out. Consumers are not switching from incandescent lamps to CFLs at a significant rate. Based on these findings, the CPUC has significantly reduced the number of bare-spiral CFLs that utilities are allowed to rebate for the 2013-2014 program cycle.

Market adoption of CFLs has been slower and less complete in California than in the Northwest (where incentives were lower), and much slower and less complete than in other industrialized countries[10]. These statistics raise the question of why California's 20-year effort to promote CFL lamps, and the national effort to achieve the same goal, were not more successful; and what can be done differently to achieve more success with LED lamps. A comprehensive attempt to answer this question was made by the U. S. Department of Energy (DOE) in 2006[11].The DOE

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7 The Cadmus Group and Quantec, *Compact Fluorescent Lamps Market Effects Final Report* (California Public Utilities Commission, Energy Division, April 12, 2010), http://www.calmac.org/publications/CFL_ME_Final_Report_04-12-10_3.pdf.

8 At the time of writing, the penetration of LED lamps has not been measured by any study as being more than 1 percent, that is, too low to evaluate.

9 U.S. Department of Energy, "CFL Market Profile 2009", March 2009, http://www.energystar.gov/ia/products/downloads/CFL_Market_Profile.pdf.

10 ECOS Consulting, *Lighting the Way to Energy Savings: How Can We Transform Residential Lighting Markets? Volume 1: Strategies and Recommendations.* (Natural Resources Defense Council, n.d.).

11 U.S. Department of Energy and Pacific Northwest National Laboratory, *Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market*.

report suggests a number of lessons from the CFL market effort that should be learned before the widespread promotion of LED lamps (See Appendix D).

Price

Price has consistently been identified by program evaluations as the main factor in market adoption, and indeed CFL market penetration over time has correlated closely with price reductions. However, the average retail price of a CFL has been under $2 per lamp since 2004[7], yielding a payback period of less than one year[12]. This shows that, even with a very fast payback, many consumers are still not willing to use CFLs for the majority of lighting in their homes. Cost-effectiveness may be necessary for market adoption, but has not been sufficient to increase the market share of CFLs to the level of incandescent lamps.

Consumer Preference

Most of the effort spent on promoting the adoption of CFLs in the market has been aimed at reducing their price to be comparable with incandescent lamps. In comparison, the amount of effort and research spent on understanding what product characteristics consumers wanted, and whether and how CFLs should be improved, has been very small.

In California, consumer preference studies have been limited to telephone surveys and shopper-intercept surveys. While these studies are useful in understanding consumers' decisions to purchase one lamp over another in a given transaction, they do not provide enough depth to reveal the reasons why consumers decide to purchase or not purchase CFLs in the long run.

In fact, the studies conducted in California have indicated that consumers have had a consistently *high* opinion of CFLs since the beginning of utility incentive programs, and that a majority (81 percent) of consumers would like to use either CFL or LED lighting rather than incandescent as their preferred lighting solution[13]. These findings are clearly at odds with the fact that CFLs have not achieved wider acceptance, which suggests that the surveys used to date have been unsuccessful in accurately identifying areas for product or marketing improvement. This is not surprising in the context of the general inaccuracy of consumers' self-reported behavior. For instance, a study by Energy Market Innovations[14] found that consumers were not even aware of how many CFLs they had in their home (they underestimated the number of lamps by more than 40 percent). The same study found that consumer estimates of how many CFLs they would install in their home varied by a factor of three, depending on

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12 U.S. Department of Energy, "CFL Market Profile 2009."

13 EcoAlign, *EcoPinion+Lighting+Survey+Report+10+vf.pdf*, EcoPinions, March 30, 2010, http://www.ecoalign.com/system/files/EcoPinion+Lighting+Survey+Report+10+vf.pdf.

14 Energy Market innovations, *Puget Sound Area Residential Compact Fluorescent Lighting Market Saturation Study* (Puget Sound Energy, n.d.), http://www.emiconsulting.com/assets/pdf/CFL%20Saturation%20Study.pdf.

whether they were asked the question on a written survey or asked in person by a utility representative.

The few in-depth studies on consumer purchasing and use of CFLs conducted in the United States have shown that consumers are much less satisfied with CFLs than is suggested by the many telephone surveys and shopper-intercept studies that have been conducted as part of utility program evaluations. A thorough in-home study conducted by the Lighting Research Center[15] found that among consumers who said that they were "satisfied" with CFLs, only 60 percent said that the color of the lamps was satisfactory, and among those who were not satisfied, 57 percent thought the color was satisfactory.

ENERGY STAR®

ENERGY STAR performance criteria for CFLs was introduced in 1999 and revised in 2001 and 2003. The performance criteria include correlated color temperature, color consistency (MacAdam ellipses – defined in Appendix A), and color rendering. Although it is not possible to establish that the ENERGY STAR performance criteria were responsible for the strong increase in CFL sales around 2004, CFL sales surged after the introduction of the ENERGY STAR performance criteria.

Lamp Life

Consumer surveys have found lamp life to be a comparatively minor complaint among CFL purchasers, and the only quantitative study of CFL returns (that is, consumers returning CFLs to a store due to early failure) found only 47,000 returns from 2.1 million product sales (2.2 percent). However, lighting experts consistently complain about the unpredictable and sometimes short life of CFLs. Therefore, lamp life remains an under-researched and unsolved question.

One early evaluation of the CFL market[16] paints a telling picture of both consumers' and evaluators' perceptions. The evaluation focused on whether consumers understood the advantages of CFLs. They were asked how long a CFL lasts, and most guessed that it was between two and five times as long as an incandescent lamp, whereas the "correct" answer (as deemed by the evaluators) was "more than ten times as long." Given the many anecdotal reports of short CFL life outside the laboratory environment, the consumers were probably closer to the real answer than the evaluators.

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15 Lighting Research Center, *Increasing Market Acceptance of Compact Fluorescent Lamps* (U.S. Environmental Protection Agency, September 30, 2003), http://www.lrc.rpi.edu/programs/lightingTransformation/colorRoundTable/pdf/MarketAcceptanceOfCFLsFinal.pdf.

16 Decision Sciences Research Associates, *Residential Lighting Market Transformation Study*, September 1998, http://www.calmac.org/publications/19980901SCE0003ME.PDF.

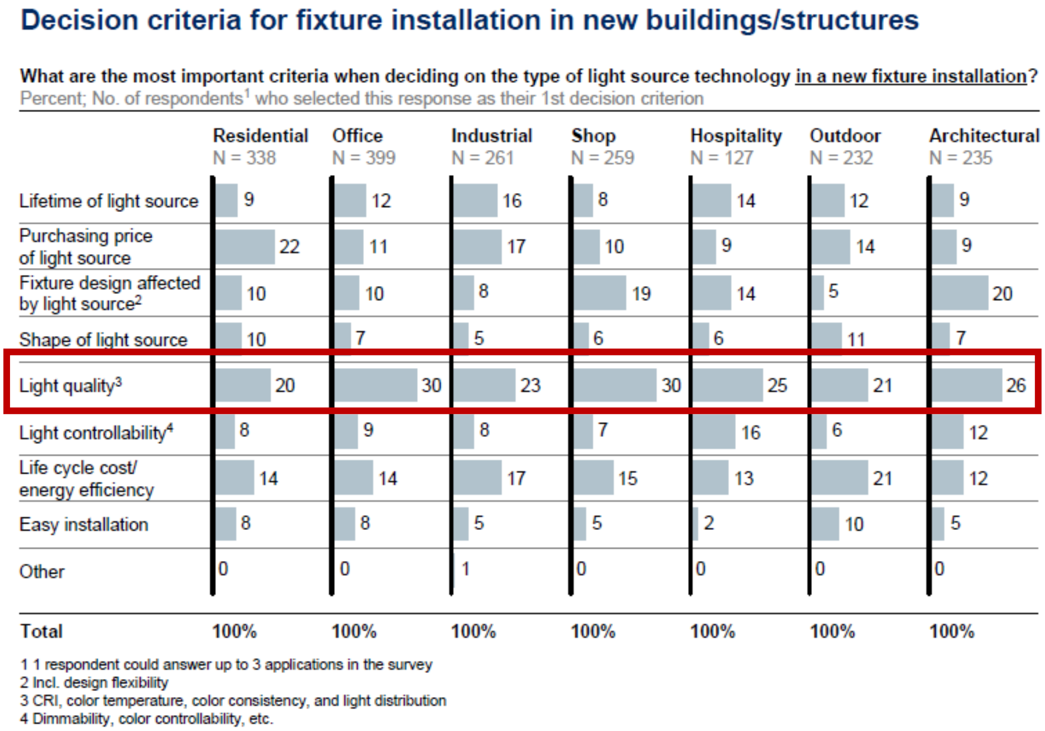
The failure of CFLs to meet their claimed lamp lifetimes in practice may be one of the important underlying reasons why consumers have become disillusioned with CFLs. Many CFLs failed to reach their rated lifetimes because of heat-related failure of the electronics that drive them, such as in downlights with vertical sockets that trap heat in the area of heat-sensitive electronics.

Summary of Lessons Learned From CFLs

The Energy Commission staff believes that the introduction of CFLs to the residential market has been disappointing primarily due to consumer dissatisfaction with color quality (color rendering, color consistency), lack of dimming capabilities, and unpredictable lamp life of CFLs. Recent research, such as that from McKinsey's 2011 *Lighting the Way* report, suggests that consumer lighting purchase decisions are driven as much by light quality, as they are by the cost of the light bulb. As shown in the figure below, 20 percent of residential respondents rated light quality as the most important decision criterion for lamp installation – which is on par with the 22 percent who rated purchase price as the most important factor. In all other market segments, light quality was by far the most important factor. A similar recent study found that "quality of light" was the most important of eight lamp attributes[17], and that 67 percent of consumers were in favor of phasing out incandescent lamps over time (with 21 against, and 13 percent undecided).

17 Other attributes were overall performance, energy efficiency, price, ease of use, maintenance, appearance/color, and disposal.

Figure 1: McKinsey Study, *Lighting the Way*[18]



Source: McKinsey Global Lighting Professionals & Consumer Survey

18 McKinsey & Company. *Lighting the Way: Perspectives on the Global Lighting Market*. July 2011.

CHAPTER 2: Attributes of the Voluntary California Quality LED Lamp Specification

The *Voluntary California Quality LED Lamp Specification* is built upon an "ENERGY STAR Plus" approach, designed to enable manufacturers to voluntarily meet the specification and, in parallel, achieve ENERGY STAR certification for those same lamps.

The Voluntary California Specification uses the same metrics as the ENERGY STAR standard and refers to the same test procedures, to make its use as easy and straightforward as possible. However, there are six key quality attributes in the specification that exceed those specified in ENERGY STAR:

- Color temperature
- Color consistency
- Color rendering
- Dimmability
- Rated life/warranty
- Light distribution

This section provides context on each of these attributes, including the metric used to quantify them and the standard performance typically exhibited by other lighting products and/or demanded by consumers.

See Appendix A for a comparison of the Specification to the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2.

Color Temperature

The color temperature of a light source describes the apparent coolness or warmness of the light coming from the lamp. This color is associated with a unique location on a "chromaticity diagram", which shows all the possible colors of a light source. The axes of the color space are the CIE[19] x and y chromaticity coordinates; these are mathematical constructs used to describe color.

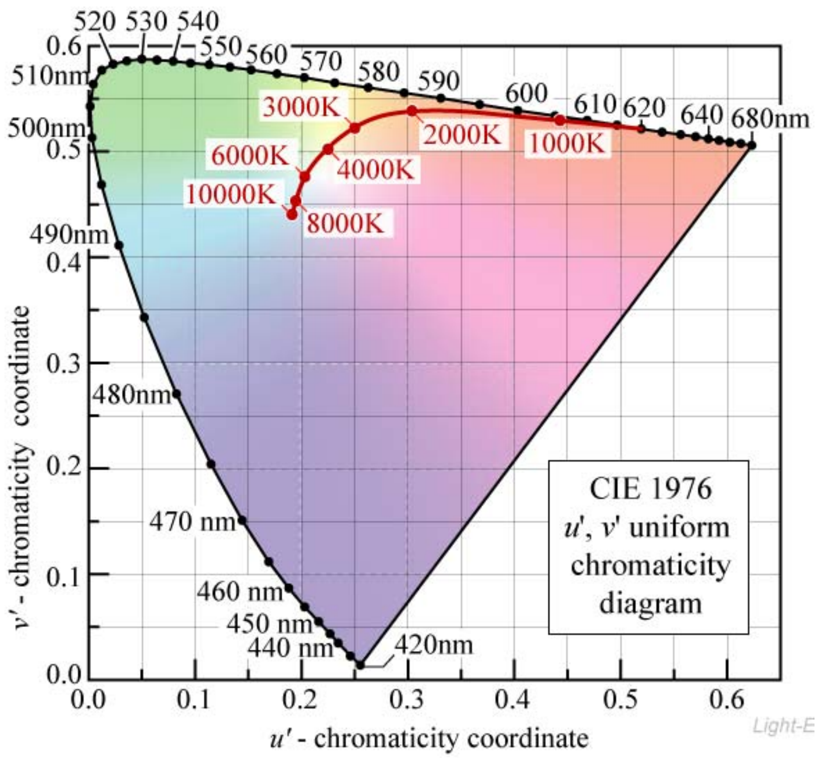
The color of incandescent lamps falls on the "Planckian Locus," which represents the range of colors of a theoretical "black body" or perfect emitter, when heated to various temperatures (measured in degrees Kelvin). Figure 2 demonstrates the 1976 CIE chromaticity diagram, and the curved black line represents the Planckian Locus. At the right end of the locus are "warmer" lamps with lower color temperatures, while at the left end are "cooler" lamps with higher color temperatures. Note the counterintuitive use of "warmer" for lamps with *lower* temperatures.

[19] Commission Internationale de l'Eclairage, the international body that sets underlying standards for the measurement of light and color.

Unfortunately, lamps such as fluorescents and LEDs do not usually lie exactly on the Planckian Locus. Lamps that lie above the locus have a green tint, while lamps below the locus have a pink or purple tint. Their deviation from the locus gives rise to the concept of "correlated color temperature" (CCT), that is, the nearest point on the Planckian Locus to the chromaticity coordinate of the lamp. The lamp's chromaticity coordinate can be linked to its CCT point on the locus by lines that run roughly perpendicular to the locus. These CCT lines are shown in Figure 2.

Most general service lamps have CCTs between 2700K and 6500K (degrees Kelvin), and different CCTs are appropriate for different applications; so there is no "ideal" CCT. That said, most consumers are used to 2700K or 3000K in their homes because incandescent lamps at these color temperatures have been the predominant residential light source for many decades. Therefore, the California Specification assigns two specific color temperature ranges, which will make compliant LEDs consistent in color with most of the other light sources in people's homes.

Figure 2: 1976 CIE u,v Chromaticity Diagram



Note: the red line shows the black body (or "Planckian") locus; the black line shows the spectral (monochromatic) colors.

Source: www.lightemittingdiodes.org, Chapter 18.[20]

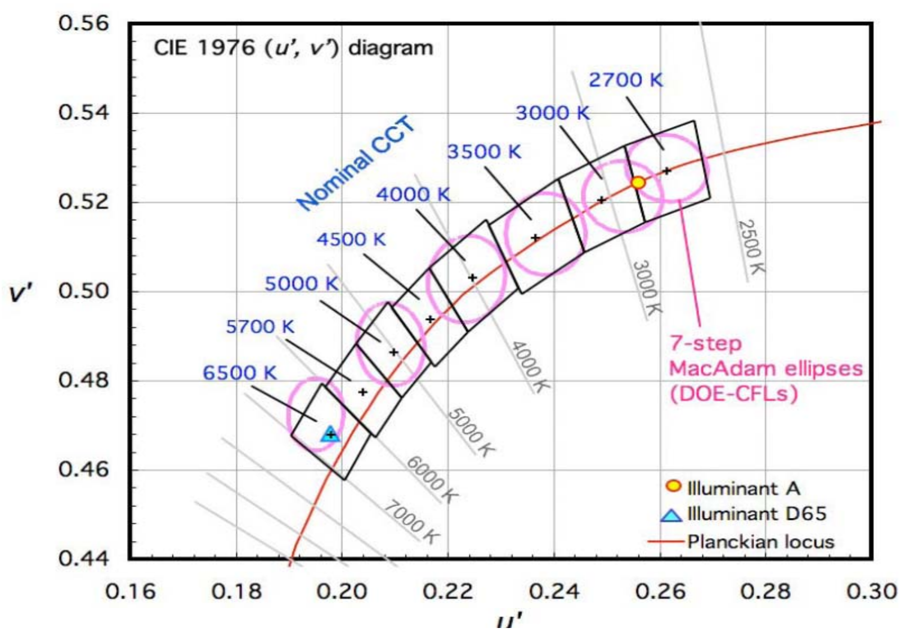
To set a requirement for color temperature, there has to be a limit on how far a lamp is allowed to be away from the Planckian locus. The human eye is very good at discriminating even small

20 Fred Schubert, "Light-emitting diodes-dot-org Home Page," *Www.lightemittingdiodes.org*, 2006, http://www.ecse.rpi.edu/~schubert/Light-emitting diodes-dot-org/.

light color variations between lamps; so to ensure consumer satisfaction with LED lamps, the ENERGY STAR standard and the California Specification both set limits on the range of allowable color bins (rectangular regions of the chromaticity chart, as shown in Figure 3 below). The system used to describe the size of these bins is named after David MacAdam, whose research in the 1930s and 1940s led to an understanding of the amount of color change, starting from an initial point in the color space, which was indistinguishable to the average human observer. Because these shapes were ellipses in the color space, they are now commonly known as MacAdam ellipses.

As shown in Figure 3, the current American National Standards Institute (ANSI) standard for LED color binning, ANSI C78. 377, 2008, contains a specification for a 7-step ellipse (meaning that lamps with very different color appearances can be claimed to be of the same CCT). In the diagram below, pink ovals have been used by CFL manufacturers, while the black shapes represent 7-step Macadam "quadrangles" for use by LED manufacturers.

Figure 3: ANSI Standard 7-Step MacAdam Ellipse



Source: ENERGY STAR Program Requirements for Integral LED Lamps.[21]

Based on a research project conducted by the Lighting Research Center (LRC)[22], somewhere between a two-step and a four-step MacAdam ellipse would be the suitable tolerance for LED color, depending on whether the lamps are viewed directly adjacent to each other (two-step

21 "ENERGY STAR® Program Requirements for Integral LED Lamps" (U.S. Department of Energy, n.d.), http://www.energystar.gov/ia/partners/manuf_res/downloads/IntegralLampsFINAL.pdf.

22 Nadarajah Narendran, Lei Deng, and Jean Paul Freyssinier, *Developing Color Tolerance Criteria for White LEDs* (Lighting Research Center, January 2004), http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/ColorDiscriminationStudy.pdf.

ellipses) or whether illuminated patches of wall are viewed without the lamp being visible (four-step ellipses). Further human factors research and product testing are being done in 2012 by the California Lighting and Technology Center.

Based on the study by the LRC, on initial assessment of available products, manufacturer claims, and on the noted rate of improvement for color consistency, the California Specification sets the color binning requirement at a four-step MacAdam ellipse; this is significantly tighter than the ENERGY STAR requirements. However, the California Specification does not set the color bins at the high end identified by the LRC study (two-step ellipses), because this is not technically achievable in a cost-effective manner using current technology. This would be a desirable improvement in performance for future LED lighting.

Color Consistency Within Lamp Batches

Another way of looking at the issue of color is in terms of the variations in color between lamps from the same batch, or between one batch and another. It would be possible to set a requirement for this "color consistency" in addition to the color temperature requirements described above. This would be a logical approach, based on the findings of the LRC paper cited above, because lamps from the same batch are very likely to be viewed side-by-side, for instance in a bath bar or in a line of recessed fixtures.

Based on the LRC study, the correct requirement to set for color consistency would be a two-step MacAdam ellipse. However, as this is not technically feasible for LEDs at this time (discussed above), the Energy Commission staff, in response to stakeholder comments, decided not to pursue a requirement for color consistency in this version of the California Specification.

Color Rendering

Color rendering is a measure of how true the colors of objects look under a light source, as compared to how they look under a reference light source of the same (or similar) color temperature. The two most common reference sources are an incandescent lamp at 2700K and a typical spectrum of daylight at 6500K (known as "D65").

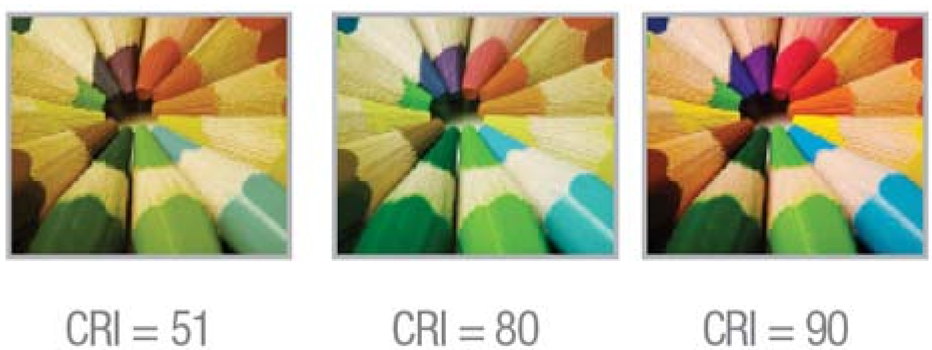
The most common metric of color rendering is the Color Rendering Index (CRI). A CRI of 100 indicates that a light source renders a particular palette of eight colors in exactly the same way as the reference light source to which it is being compared. A light source with a CRI significantly less than 100 typically makes one or more of the eight standard palette colors appear more gray (less saturated) than the reference source, although a low CRI can also arise because a light source renders certain colors as being *too* saturated. An incandescent lamp is considered the "reference" light source for all lamps with color temperatures less than 4000K, so by definition incandescent lamps achieve a CRI of 100 because they are being compared to themselves.

It is important to realize that color rendering is *not* necessarily a measure of "naturalness" or "saturation" or "quality". The CRI metric was developed for industrial purposes, when color checking was carried out by human observers, to prevent observers confusing one color with another ("metamerism"). The CRI metric was *not* optimized to describe viewers' subjective preferences for color balance or saturation. Other metrics have been and continue to be explored to quantify viewers' subjective preferences for different light sources and for the colors of rendered objects, though none has replaced CRI as the primary metric. In particular, the National Institute of Standards and Technology (NIST) is continuing work on the Color Quality Scale (CQS), though at the time of writing there is no specific schedule for development of a new metric.

Despite the various minor shortcomings of the CRI metric that have been noted by researchers, it is a reliable and meaningful scale toward the top end (that is, at values approaching 100 CRI). This is because the only way to achieve such high values is by using a nearly continuous spectrum, by using multiple phosphors or LED chips to give almost-equal weighting to all spectral colors. Natural daylight also has a continuous spectrum. Therefore, a light source that approaches 100 CRI will be perceived by consumers as being colorful and natural, as well as rendering colors accurately.

The images in Figure 4 demonstrate the difference between low CRI and high CRI. In the picture on the left, which represents a 50 CRI light source, the pink, red, and orange pencils are hard to distinguish from one another. In the image on the right, representative of a 90 CRI light source, the colors are much more easily distinguished. (These images are for illustration only and should not be taken to accurately represent the actual appearance of objects.)

Figure 4: Comparison of Color Rendering Index of Different Light Sources



Source: Lighting Matters' LED Blog, lightingmatters.com.au/blog/ledlight-quality-cri/

In addition to quoting CRI, LED manufacturers have begun to quote the performance of their products in terms of how they render a ninth color ("R9"—a saturated red color). This is, in part, because a high R9 value indicates improved rendition of important common materials (skin tones, earth tones, woods and vibrant red colors). It is also because manufacturers wish to distinguish "good" LEDs from "bad" LEDs, and from typical triphosphor T8 lamps, which do not render the R9 color well. R9 performance is defined on the same scale as the CRI, although values are often much lower, or even negative, because manufacturers have historically not optimized their lamps for R9 performance. Typically the R9 value for T8 lamps is 10-20, whereas LEDs are currently available that achieve over 50.

Because CFL program evaluations did not identify color as a key factor, improved color performance was not demanded or encouraged and was therefore abandoned in favor of lower cost. Innovation and new investment in color were hard to justify and largely not pursued by mainstream manufacturers.

However, color rendering has become a more widely discussed lamp attribute, and some manufacturers in the blossoming LED lamp industry are already striving for improved CRI in their products. As of May 30, 2012, the U. S. Department of Energy's SSL Lighting Facts product database contained 123 replacement lamp products with a CRI of 90 or better. Because the LED market already includes a large number of products with high CRI, and because color quality has been identified as a key opportunity for improvement, the specification includes a minimum requirement for color rendering index.

Dimmability

One of the performance attributes of incandescent lamps expected and taken for granted by consumers is that they are all readily dimmable over their full range of output without flicker. Consumers expect this attribute when they screw incandescent lamps into these sockets, and do not expect to have to search for lamps that are specially labeled as "dimmable" when purchasing lamps. If LED lamps fail to meet this high standard of dimming performance, consumers are likely to be dissatisfied.

A significant number of existing incandescent sockets are already controlled with dimmer switches. DOE's *2010 Lighting Market Characterization* study found that 12 percent of residential sockets in the United States are controlled by dimmers[23]. This number is likely to be higher in California. A 2008 study of residential newly constructed buildings found that 29 percent of screw-based sockets were attached to dimmers (Wilcox 2008). The number of dimmable sockets is increasing quickly due to the state's aggressive *Building Energy Efficiency Standards, Title 24, Part 6* (the *Building Energy Efficiency Standards*). Starting with the 2005 residential lighting requirements of the *Building Energy Efficiency Standards*, many rooms in newly constructed residential buildings, additions, and alterations are required to install either high-efficacy lighting or incandescent luminaires controlled with dimmer switches. The *Building Energy Efficiency Standards 2008*, which are updated every three years, now require most screw-base sockets in residential newly constructed buildings to be on dimmer switches.

Indeed, it is not just in the residential sector that California is moving toward dimmable controls on all incandescent lighting. For many years, the *Building Energy Efficiency Standards* have required nonresidential buildings to have multilevel lighting controls on all types of lighting. Typically this could be accomplished with "checkerboard" switching (that is, switching some luminaires off in a checkerboard pattern) or with dimming. Starting with the

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23 Navigant Consulting, *2010 U.S. Lighting Market Characterization* (U.S. Department of Energy, January 2012), http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf.

2013 update to the *Building Energy Efficiency Standards*, most lighting in nonresidential buildings will need to be dimmable, from 10 percent to 100 percent.

Compatibility between lamps and dimmer controls is another major issue of concern because consumers expect lamps to be compatible with existing dimmers. Some LED lamps may experience flicker or cause dimmers to make noise, or simply not work on certain existing residential dimmers. To have both dimmable and nondimmable LED lamps available on the market, or "dimmable" lamps that are incompatible with most residential dimmers, runs the risk of further confusing and disappointing consumers.

The California Specification requires LED replacement lamps to be dimmable, using the dimmability requirements in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (See Appendix A). Note that although there is a requirement for lamps to be dimmable without visual flicker there is, as yet, no quantitative test procedure to quantify visual flicker.

When incandescent lamps are dimmed, they become redder, or "warmer," but LED lamp manufacturers continue to wrestle with providing color shift for dimmed LED lamps as an added amenity to satisfy consumer expectations.

Rated Life and Warranty

The ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2, standard already includes extensive and detailed requirements for rated life of lamps. The California Specification does not impose additional requirements because there is no evidence that extended lamp lifetimes beyond ENERGY STAR would significantly increase consumer acceptance of LED lamps.

However, because consumers are much more likely to understand a warranty (in years) than a rated lifetime (in thousands of hours) and are likely to be reassured by an enforceable warranty, the California Specification requires that lamps be supplied with a minimum five-year free replacement warranty. This warranty should not depend on any assumptions about the hours of use of the lamp.

Light Distribution

There are many LED lamps today that are marketed as "omnidirectional" but perform optically more like a directional lamp than an omnidirectional lamp. In other words, they provide very little side light and virtually no downlight when used base-down, for instance, in a table lamp. When such lamps (identified as "semidirectional" and "nonstandard light output" by ENERGY STAR) are installed in a typical table base-up lamp, virtually all of the luminous flux is directed at the ceiling. These lamps do not perform in the way consumers expect.

To ensure that LED lamps will perform according to consumers' expectations, the California Specification distinguishes among three broad types of light distribution:

Omnidirectional Lamps

These lamps emit light almost equally in all directions, that is, over a complete sphere. They are sometimes used in portable luminaires such as "table lamps," as well as in many other luminaires that use shades. They are also used in luminaires that use diffusers, such as ceiling-mounted diffusing glass domes. General service incandescent lamps provide an omnidirectional distribution of light. In other words, when a general service incandescent lamp is screwed into a portable luminaire, the light is projected in all directions including upward onto the ceiling, sideways on to the lamp shade, and to a lesser extent downward on to the table. Many LED lamps that are being classified as general service LED lamps today project very little light to the side, and almost no light downward. It is critical that consumers have omnidirectional lamps that meet their expectations and provide the same distribution of light as the incandescent lamps they are replacing.

The California Specification will not recognize "semidirectional" or "nonstandard light output" lamps as being omnidirectional lamps.

The California Specification will use the omnidirectional lamp specifications in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (see Appendix A).

Floodlamps

These lamps emit no light "backward" toward the lamp base, but emit forward light somewhat evenly over a hemisphere. They are mostly reflector lamps such as reflector lamps that are 30/8 inch in diameter (R30) and parabolic aluminized reflector lamps that are 38/8 inch in diameter (PAR 38), and are ideal for use in recessed downlights. In most recessed downlights, if omnidirectional lamps are installed, much of the available light gets trapped inside the downlight, reducing the overall efficiency of the lighting system.

The "floodlamp" light distribution is not defined in ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2, but, for convenience, the definition of "floodlamp" used in the California Specification uses the same photometric test data that is used to define the photometric requirements of ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2.

Spotlights

Spotlights have narrower beams than floodlamps and are intended to illuminate objects at a distance. They are typically used for outdoor lighting and in directional luminaires used to illuminate wall displays, art, plants, or other objects of interest. Retail lighting systems are commonly made up of directional lamps to create contrast illuminance on merchandise.

Lamps that fulfill these requirements will have a light distribution (beam angle) that is too narrow to meet the light distribution requirements for a "floodlight" defined in the California Specification. Therefore the California Specification uses the luminous intensity distribution requirements defined for PAR and MR lamps in the ENERGY STAR Product Specification for

Lamps, Version 1.0, DRAFT 2 as the basis for the definition of "spotlight" in the California Specification.

CHAPTER 3: Voluntary California Quality LED Lamp Specification

Following are the key minimum requirements for the *Voluntary California Quality LED Lamp Specification*. The full list of requirements is shown in Appendix A. The specification is intended to be "ENERGY STAR plus," that is, the specification refers to the ENERGY STAR requirements when those are sufficient for the California Specification. However, in some cases alternative or additional requirements (or no requirements) are made. These requirements are consistent with the ENERGY STAR standards as much as possible; that is, they draw on the same test data or use similar metrics. If test procedures are updated in ENERGY STAR, the California Specification will refer to the same updated test procedures.

In terms of their equivalent requirements in ENERGY STAR, the the California Specification includes the following four categories:

A) The California requirement is based on the same test procedures as the ENERGY STAR requirement, but requires a different level of performance.

B) The California requirement is the same as the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2, and will change in line with ENERGY STAR when a revised version of the ENERGY STAR specification is released.

C) The California requirement is the same as the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2, and will <u>not</u> change in line with ENERGY STAR when a revised version of the ENERGY STAR specification is released.

D) There is no California requirement for that performance metric.

In those cases where the California Specification will update in line with future revisions of ENERGY STAR, this is explicitly set out below. In all other cases, the California Specification will <u>not</u> update in line with ENERGY STAR.

In those cases where there is no California requirement, that performance metric is not included in this section, although it is included in the full list of requirements in Appendix A. Appendix A contains a detailed point-by-point comparison of the California specifications and the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2.

Eligible Lamp Bases and Lamp Shapes

LED lamps must be classified as either "omnidirectional", "floodlamps," or "spotlights"; the California Specification does not recognize any other types of lamp.

Figure 5 shows which combinations of LED lamp bases and lamp shapes are eligible for this specification. Each cell of the table shows which light distribution(s) are allowed for that particular combination of lamp base and shape.

Figure 5: Eligible Lamp Bases and Lamp Shapes

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="7">Lamp shape</th></tr>
<tr><th>A, B,BA,C,CA, F</th><th>G,</th><th>B,BA,C,CA, FF,</th><th>MR</th><th>PAR16, R16, PAR20, R20, BR20BR20,</th><th>PAR30, R30, BR30, PAR38. R40, BR40</th><th>JC Bi-pin, wedge, t</th></tr>
<tr><td rowspan="5">Lamp base</td><td>E12, E17,</td><td>X</td><td rowspan="2">Omnidirectional</td><td>Omni-directional</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>E26, GU-24 (120V)</td><td>Omni-directional</td><td>X</td><td>X</td><td>Spotlight</td><td>Spotlight or Floodlamp</td><td>X</td></tr>
<tr><td>GU-10 (120V)</td><td>X</td><td>X</td><td>X</td><td>Spotlight</td><td>Spotlight</td><td>X</td><td>X</td></tr>
<tr><td>GX5.3 (12V)</td><td>X</td><td>X</td><td>X</td><td>Spotlight</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>G8, G9 (120V)</td><td>X</td><td>X</td><td>X</td><td>Spotlight</td><td>X</td><td>X</td><td>Omni-direct-ional</td></tr>
</table>

Also, integrated LED lamps that include trims and are designed to be retrofitted within existing recessed can housings, and which contain one of the lamp bases listed above, are eligible as floodlamps.

Color Temperature

To meet the specification, LED lamps shall fall within a 4-step Macadam ellipse of the 2700K or 3000K points on the Planckian Locus.

Color Consistency Within Lamp Batches

Color consistency quantifies how closely clustered the chromaticity coordinates of a sample of LED lamps of a given model number are to each other. Research discussed in Chapter 2 supports a requirement for color consistency, but due to the technical limitations of the LED lamps currently on the market, the California Specification does not include a requirement for color consistency.

The Energy Commission staff supports additional research to see if a 2-step Macadam ellipse or similar requirement for color consistency would be appropriate for a future version of the California Specification. This would require lamps of the same model number to fall within a 2-step Macadam ellipse of the average chromaticity of the tested sample.

Color Rendering

To meet the specification, LED lamps shall have a minimum color rendering index (CRI) of 90. Lamps shall have an R9 value greater than 50, measured under the same conditions as the CRI.

Color Maintenance

To meet the specification, LED lamps shall comply with the color maintenance requirements in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2.

If a revised version of the ENERGY STAR specification is released, LED lamps shall meet the equivalent requirements in the revised version.

Color Angular Uniformity

To meet the specification, LED lamps classified as "spotlights" shall comply with the color angular uniformity requirements in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2.

If a revised version of the ENERGY STAR specification is released, LED lamps shall meet the equivalent requirements in the revised version.

Light Distribution

Lamps shall meet one of the following distribution requirements, and the type of photometric distribution shall be shown on the packaging, as follows:

- "Omnidirectional"
- "Floodlamp, [beam angle]° beam angle"
- "Spotlight, [beam angle] ° beam angle"

Omnidirectional Lamps

To meet the California Specification, LED lamps classified as omnidirectional shall meet the specifications for omnidirectional lamps in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2.

If the ENERGY STAR requirements are updated the California Specification will still refer to the omnidirectional requirements in ENERGY STAR Version 1.0 DRAFT 2.

The *California Quality LED Lamp Specification* does *not* recognize "semidirectional" or "nonstandard light output" lamps as being omnidirectional lamps.

Floodlamps

All LED lamps classified as floodlamps shall have a light distribution that meets the following requirements:

- Luminous intensity shall not increase from any given angle of elevation to the next, over the range 0° to 90°, for each of the azimuthal planes.
- Beam angle shall be between 45° and 110°. Beam angle is defined as two times the elevation angle at which the intensity falls to half the peak (center-beam) intensity.
- At least 10 percent of the total flux (lumens) must be emitted in the 60°-90° zone.
- Distribution shall be vertically symmetrical as measured in three vertical planes at 0°, 45°, and 90°.

Spotlights

All LED lamps classified as spotlights shall meet the requirements for center-beam intensity and luminous intensity distribution for “PAR shapes and low voltage MR lamps” in the ENERGY STAR Product Specification for Lamps, Version 1.0 DRAFT 2 (See Appendix A).

If a revised version of the ENERGY STAR specification is released, LED lamps classified as spotlights shall meet the equivalent requirements in the revised version.

Semidirectional and Nonstandard Light Output Lamps

The ENERGY STAR Product Specification for Lamps, Version 1.0 DRAFT 2 defines the “semidirectional” and “nonstandard light output” lamp classifications. The California Specification does not recognize there classifications.

Dimmability

To meet the specification, LED lamps shall be capable of continuous dimming, without flicker or noise, from 10-100 percent. For these lamps, the *California-Quality LED Lamp Specification* will use the test procedures (e.g., for flicker and noise) cited in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 (see Appendix A). The test procedures used in the California Specification will update in line with future revisions to ENERGY STAR, but the requirement for dimming down to 10% will not update .

There is currently no quantitative test procedure for visual flicker or audible noise, but nevertheless we recommend that utilities conduct flicker and noise testing as part of the approval procedure for lamp rebates, because flickering lamps would seriously compromise user acceptance. At present, conformance with the California Specification must be judged using a subjective test, i.e., by direct observation. Observers have different levels of sensitivity to flicker; some observers are unable to detect line frequency flicker while others detect it in their peripheral vision. Flicker sensitivity is mostly independent of the observer’s age. Flicker testing should be conducted by observers who are flicker sensitive. Similarly, noise at different frequencies may be audible to some people and not to others, so noise testing should be done by people who are able to hear high frequencies. Because sensitivity to high frequency sounds declines with age, the best test subjects are likely to be younger people.

As described below, to meet the specification, lamps must include information about dimmer compatibility on their packaging. This information may be a URL or QR code that links to a regularly updated list of compatible dimmers.

Rated Life

To meet the specification, LED lamps shall comply with the minimum lamp life requirements in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2 as shown in Appendix A.

If a revised version of the ENERGY STAR specification is released, the California Specification will not be updated.

Power Factor

To meet the specification, LED lamps shall have a power factor ≥ 0.9 when tested at full output.

Lamp Labeling

Labeling on the lamp itself shall be compliant with the requirements under the "lamp labeling" section of ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2. The requirement for the California Specification will update in line with future revisions to ENERGY STAR.

Lamp Packaging

The packaging on the lamp shall be compliant with the requirements under the "lamp packaging" section of ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2. The requirement for the California specification will update in line with future revisions to ENERY STAR.

To meet the Specification, lamps must also include information about dimmer compatibility on their packaging. This information may be a URL or QR code that links to a regularly updated list of compatible dimmers.

Lamps must also include information about their luminous intensity distribution on their packaging. One of the following three descriptions must be printed on the exterior of the packaging, in ≥ 8 point type:

- "Omnidirectional"
- "Floodlamp, [beam angle]° beam angle"
- "Spotlight, [beam angle] ° beam angle"

As an alternative to the luminous intensity descriptions above, for floodlamps and spotlights, the exterior of the lamp packaging may carry the "non-standard light output diagram" from the lamp labeling requirements of ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2. The option to carry the non-standard light output diagram will update in line with future revisions to the non-standard lighting output diagram in ENERGY STAR.

Warranty

To meet the specification, LED lamps shall carry a minimum five-year, free-replacement warranty for indoor and outdoor use in homes only (both single-family and multifamily). The warranty shall be marked on the lamp packaging in the manner set out by the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2. The labeling requirement (but not the warranty requirement) will update in line with future revisions to ENERGY STAR.

Future Development of the California Specification

The Energy Commission staff anticipates that for the investor-owned utilities' 2015-2016 program cycle, this specification may be updated. The staff expects that the update will include some or all of the following elements:

- The color appearance and color consistency requirements may be tightened to a three-step ellipse or to a different requirement, based on research.
- The color rendering requirement may be changed to different CRI and R9 values, or to a different metric, based on research.
- Color change (to warmer CCTs) during dimming may be required, based on research.
- Quantitative flicker testing may be required, based on research.
- Other lamp bases.
- Other envelope shapes, such as globe lamps for bath bars.
- Other light sources such as Organic Light Emitting Diodes (OLED).
- The specification will likely refer to the new IESNA Lighting Measurement (LM) document on the lifecycle testing of LED lamps, expected to be published in 2012 or 2013.
- Consumer needs, wants, reactions, and satisfaction with LED lamps derived from market research, reports, or analyses.

Future Work Needed

To improve future versions of the California Specification, the Energy Commission staff supports the following research activities:

- Development of a practical measure of visual and nonvisual flicker and noise from LEDs and other light sources, including a measure of color flicker in addition to brightness flicker.
- Development of an improved color quality metric, to be based on studies of residential consumers. General Electric and NIST are doing some work on color metrics.
- Development (if necessary) of an LED life-testing method that emulates the power quality found in homes (low power quality test), along with typical residential switching patterns and thermal environments.

- Agreement on how LED life testing (using the IES LM-80 and TM-21 methods) should account for early failure and midlife failure of LED sources. These methods do not provide adequate guidance on how to include failure data in L50 and L70 estimates.
- Development of a standard for color shift of LEDs when they are dimmed, to replicate the color shift that consumers are accustomed to for incandescent lamps.
- Ongoing market surveys and consumer research to determine if a future specification shall require lamps of the same model number to fall within 2-step Macadam ellipse points on the Planckian Locus.

GLOSSARY

Lighting industry terms are used in this report for which some readers may not be familiar. Lighting terminology used in this report includes the following:

"**ANSI**" is the American National Standards Institute. ANSI is a nonprofit organization that oversees the development (by others) of voluntary standards in the United States. It coordinates with international bodies such as the International Electrotechnical Commission (IEC) and Commission International de l'Eclairage (CIE).

"**ANSI Standard Shapes**" are the standard lamp (light bulb) envelope shapes defined by ANSI standards. These standards ensure that lamps from many different manufacturers will physically fit within luminaires.

"**Directional lamp**" refers to an LED lamp having at least 80 percent light output within a solid angle of π (pi) steradians (corresponding to a cone with an angle of 120 degrees) and intended to function as a direct replacement for reflector lamps, including ANSI Standard Shapes classified as R, BR, ER, and PAR. LED spotlights and recessed cans are usually "directional" lamps.

> Steradian is a measure of solid angle, that is, an angle in three dimensions. For small solid angles, the solid angle subtended by a surface from a given point is equal to the area of the surface divided by the square of the distance between the surface and the point. A complete sphere subtends 4 pi steradians.

"**Efficacy**" for lamps is defined as how many lumens (quantity of light) are delivered for each watt of electricity that is consumed. This is analogous to miles per gallon for a car.

"**General service lamp**" refers to lamps used to satisfy a wide range of nonspecialized, primarily residential lighting applications that have traditionally been serviced by general service incandescent lamps. The Federal Energy Information and Security Act of 2007 defines general service lamps as typically designed for a light output between 310 and 2600 lumens and capable of operating at a voltage range at least partially within 110 and 130 volts. Examples include incandescent A-lamps, compact fluorescent lamps, and screw-based LED lamps.

"Goniophotometer" refers to a device used for measurement of the light emitted from an object at different angles. The use of goniophotometers has been increasing in recent years with the introduction of LED-light sources, which are mostly directed light sources, where the spatial distribution of light is not homogeneous.

"**Integrated lamp**," when used for LED lamps, refers to an LED device with an integrated driver and a standardized base that is designed to connect to the electrical branch circuit via a standardized lampholder/socket. For example, replacement of incandescent lamps with screw-base LED lamps. Integrated LED lamps can be designed for a variety of input voltages, but the California Specification covers only those lamps designed to work at line voltage (120V).

"**Lamp**" refers to the source that creates optical radiation, also known as a "light bulb".

"**Luminaire**" refers to the housing within which the lamp is held, which provides mechanical support and electrical power to the lamp, and reflects or diffuses the light. This is also referred to as a "light fixture" in commercial applications. Many consumers refer to luminaires as "lamps", such as "floor lamps" or "desk lamps".

"**Macadam ellipse**" refers to the region on a chromaticity diagram that contains all colors that are indistinguishable to the average human eye, from the color at the center of the ellipse. The contour of the ellipse. Therefore, represents the just noticeable differences of chromaticity.

"**Omnidirectional lamp**," when used for LED lamps, refers to a lamp intended to function with isotropic light distribution (that is, to distribute light evenly in all directions) and intended to function as a direct replacement for incandescent A-lamps, including ANSI Standard Shapes classified as A, B, C, F, G, P, PS, S, and T.

"**Planckian Locus**" refers to the path or locus that the color of an incandescent black body would take in a particular chromaticity space as the black body temperature changes. It goes from deep red at low temperatures through orange, yellowish white, white, and finally bluish white at very high temperatures.

"**Solid-state lighting (SSL)**" is used by ENERGY STAR to mean LED. As used by ENERGY STAR, the term "solid-state" refers to the fact that the light is produced by solid-state electroluminescence, (that is, as a direct result of the passage of electricity through a semiconductor). This differs from fluorescence (used in fluorescent lamps) and incandescence (used in incandescent lamps).

APPENDIX A

COMPARISON OF THE VOLUNTARY CALIFORNIA QUALITY LED LAMP SPECIFICATION TO ENERGY STAR PRODUCT SPECIFICATION FOR LAMPS, VERSION 1.0, DRAFT 2

These tables show the detailed requirements of *Voluntary California Quality LED Lamp Standard* (left column) and the ENERGY STAR requirements (Version 1.0, Draft 2). For easy comparability, the tables are ordered according to the structure of the ENERGY STAR Version 1.0, Draft 2 requirements and not according to the structure of this report. The voluntary requirements of the California Quality Specification are shown in the left column, while the ENERGY STAR requirements are shown in the right column.

California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Application

California Quality LED Lamps Specification applies only to LED Lamps, including LED lamps that include trims and are designed to be retrofitted into recessed can housings.	Applies to compact fluorescent and Solid State Lighting.

California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Specification Scope and Lamp Classification

Same as ENERGY STAR Draft 2. Will not update in line with revisions to ENERGY STAR. California EXCEPTIONS: 1. The California Specification uses a reduced list of allowable lamp bases and lamp envelope shapes (see chapter 3). 2. Semidirectional lamps and decorative lamps shall not qualify as California Quality LED Lamps. 3. Defines an additional lamp type: "floodlamp," which must meet the ENERGY STAR requirements for directional lamps, along with additional photometric requirements (see chapter 3)	Screw Bases: E26, E26d, E17, E12. Multiple pin bases: GU-24, GU10, GU5.x, GX5.3. ANSI Standard Shape Directional R, BR, MR, PAR ANSI Standard Shape Omnidirectional A, BT, G, P, PS, S, T. Decorative B, BA, C, CA, F.

Effective Date

As a voluntary specification, immediately upon approval of this staff report by the California Energy Commission. If the specification is used by others, they may use other effective dates for their own purposes.	Still to be determined by ENERGY STAR in accordance with information in Draft 2.

Future Specification Revisions

The California Energy Commission reserves the right to change the California Quality LED Lamp Specifications, including adopting selected provisions from Draft 2, or selected provisions from later version of the ENERGY STAR specifications.	EPA reserves the right to change the ENERGY STAR specifications.

California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Definitions

Same as ENERGY STAR Draft 2. California ADDITION: Will not update in line with revisions to ENERGY STAR. An additional light distribution ("floodlamp") is defined in the Light Distribution section.	ENERGY STAR definition for Decorative Lamps: Lamps with a lamp shape B, BA, C, CA, DC, and F as defined in ANSI C79. 1-2002.

Test Criteria

Same as ENERGY STAR Draft 2. Will update in line with revisions to ENERGY STAR	Still to be determined by ENERGY STAR in accordance with information in Draft 2.

Product Qualification

Same as ENERGY STAR Draft 2. Will update in line with revisions to ENERGY STAR.	Product variations as listed in Draft 2.

Methods of Measurement and Reference Documents

Same as ENERGY STAR Draft 2. Will update in line with revisions to ENERGY STAR.	As listed in Draft 2.

Luminous Efficacy Requirements—All Lamps

California	ENERGY STAR	
The California Specification does not include a requirement for luminous efficacy	**Luminous Efficacy Requirements: All Lamps**	
	Lamp Input Power (Watts)	Lamp Efficacy (initial lm/W)
	Omnidirectional <10	55
	Omnidirectional ≥10	60
	Directional <10	40
	Directional ≥10	45

	Decorative <10	45
	Decorative ≥10	50
	Methods of Measurement and Reference Documents as listed in Draft 2 for SSL.	
The California Specification does not include a requirement for luminous efficacy.	**Supplemental Testing** For dimmable/2-way/3-way products, measurements shall be made at the highest wattage setting listed for the model. Sample Size: 10 units per model: 5 units tested base-up and 5 units tested base-down unless the manufacturer restricts specific use or position. If position is restricted, all units shall be tested in restricted position. Passing Test: Average of unit values shall meet the requirement, and ≥9 units individually shall meet the required value. If units are tested both base-up and base-down, averages shall be calculated for both subsets, and the efficacy shall be the lesser of the two averages.	

Elevated Temperature Light Output Requirements—All Lamps

The California Specification does not include any requirement for light output ratio at elevated temperature.	Light Output Requirements as listed in Draft 2. Lamp shall maintain ≥ 90% of initial rated light output (total luminous flux) when tested in the elevated temperature condition.

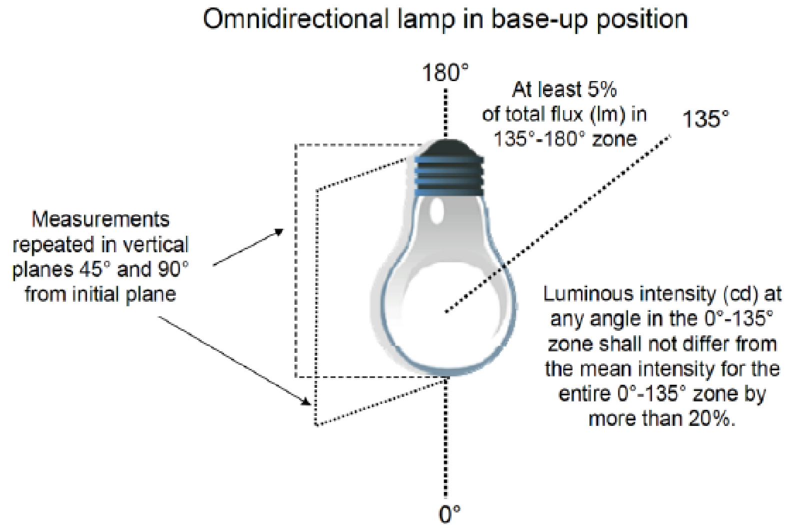
Center Beam Intensity Requirement—PAR and MR Shapes

The California Quality Specification refers to the PAR and MR lamp center-beam intensity distribution requirements in ENERGY STAR as the "spotlight" photometric distribution. Center beam intensity requirements for "Spotlights" same as the center-beam intensity requirements for PAR and MR lamps in ENERGY STAR Draft 2. If a revised version of the ENERGY STAR specification is released, LED lamps classified as "spotlights" shall meet the equivalent center-beam intensity requirements in the revised version of ENERGY STAR.	Center Beam Intensity Requirements as listed in Draft 2.

Luminous Intensity Distribution Requirements—Omnidirectional Lamps

Luminous Intensity Distribution Requirements for Omnidirectional Lamps same as ENERGY STAR Draft 2. If the ENERGY STAR requirements are updated, the California Specification will still refer to ENERGY STAR Version 1 DRAFT 2.	Lamp luminous intensity distribution shall emulate that of the referenced incandescent lamp as follows: • Each luminous intensity measured value (candelas) shall vary by no more than 20% from the average of all measured values. • No less than 5% of total flux (lumens) shall be emitted in the 135° to 180° zone. See diagram below. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

ENERGY STAR Draft 2 Luminous Intensity Distribution Diagram for Omnidirectional Lamps



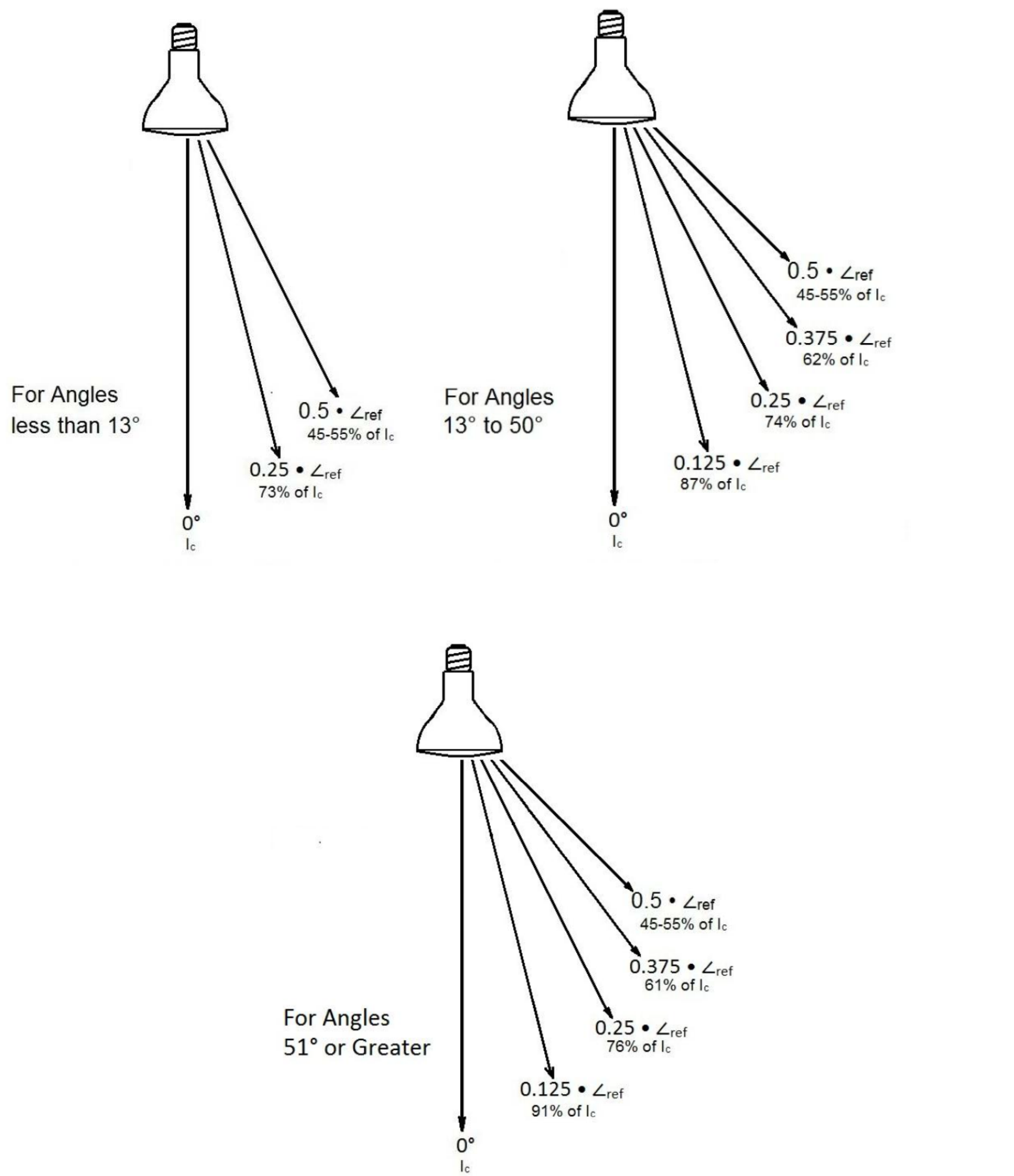
Source: ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2.

Luminous Intensity Distribution Requirements—PAR and MR lamps

The California Quality Specification refers to the PAR and MR lamp luminous intensity distribution requirements in ENERGY STAR as the "spotlight" photometric distribution. Luminous intensity distribution requirements for "Spotlights" same as the luminous intensity distribution requirements for PAR and MR lamps in ENERGY STAR Draft 2. If a revised version of the ENERGY STAR specification is released, LED lamps classified as "spotlights" shall meet the equivalent luminous intensity distribution requirements in the revised version of ENERGY STAR.CALIFORNIA ADDITION: Also, the California Specification recognizes "floodlamp"-style lamps, defined as follows: • Luminous intensity shall not increase from any given angle of elevation to the next,	Lamp luminous intensity distribution shall emulate that of the referenced incandescent lamp, including its nominal beam angle ("reference angle" or $\angle_{ref}$), as follows: Measured on two rotational planes 90° from each other around and through the beam axis, lamp luminous intensity within each plane shall measure no less than 45% and no greater than 55% of the center beam intensity (I_c) on each edge of the beam (0.5 • $\angle_{ref}$). For reference angles less than 13°, on each side of the beam axis at (0.25 • $\angle_{ref}$), lamp luminous intensity within each plane shall measure no less than 73% of I_c. For reference angles of 13° to 50°, on each side of the beam axis: • at (0.125 • $\angle_{ref}$), lamp luminous intensity within

over the range 0° to 90°, for each of the azimuthal planes. • Beam angle shall be between 45° and 110°. Beam angle is defined as two times the elevation angle at which the intensity falls to half the peak (center-beam) intensity. • At least 10 percent of the total flux (lumens) must be emitted in the 60°-90° zone. • Distribution shall be vertically symmetrical as measured in three vertical planes at 0°, 45°, and 90°.	each plane shall measure no less than 87% of I_c ; and, • at (0.25 • $\angle_{ref}$), lamp luminous intensity within each plane shall measure no less than 74% of I_c ; and, • at (0.375 • $\angle_{ref}$), lamp luminous intensity within each plane shall measure no less than 62% of I_c. For reference angles 51° or greater, on each side of the beam axis: • at (0.125 • $\angle_{ref}$), lamp luminous intensity within each plane shall measure no less than 91% of I_c ; and, • at (0.25 • $\angle_{ref}$), lamp luminous intensity within each plane shall measure no less than 76% of I_c ; and, • at (0.375 • $\angle_{ref}$), lamp luminous intensity within each plane shall measure no less than 61% of I_c. Comparing the two rotational planes, each of the corresponding aforementioned values shall not vary by more than 20%. See diagrams on next page. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

ENERGY STAR Draft 2 Luminous Intensity Distribution Diagrams for Directional Lamps



California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Correlated Color Temperature (CCT) Requirements—All Lamps

Correlated Color Temperature (CCT) requirements and test methods same as ENERGY STAR Draft 2. Will update in line with revisions to ENERGY STAR. California Exception: • Only lamps with correlated color temperatures of 2700K and 3000K are recognized. • Lamps must fall within a 4-step MacAdam ellipse from the designated CCT.	Correlated Color Temperature (CCT) Requirements: SSL. Lamps shall meet one of the following nominal CCT's: 1. 2700K 2. 3000K 3. 3500K 4. 4000/4100K 5. 5000K Methods of Measurement and Reference Documents as listed in Draft 2 for SSL. Supplemental Testing as listed in Draft 2 of SSL, including:. All units shall fall within a 7-step MacAdam ellipse for the designated CCT, with ellipses constructed per ANSI C78.376-2001 sections 2 and 4, and table 2.

Color Rendering Requirements—All Lamps

Correlated Color Temperature (CCT) requirements and test methods same as ENERGY STAR Draft 2. Will update in line with revisions to ENERGY STAR. California Exception: • Lamps shall have color rendering index ≥ 90, and $R_9 > 50$.	Lamps shall have color rendering index ≥ 80, and $R_9 > 0$. Methods of Measurement and Reference Documents as listed in Draft 2 for SSL. Supplemental Testing as listed in Draft 2 of SSL.

Color Maintenance Requirements—All Lamps

Color maintenance requirements same as ENERGY STAR Draft 2. Will update in line with revisions to ENERGY STAR. Methods of Measurement, Reference Documents, and Supplemental Testing same as Draft 2. Will update in line with revisions to ENERGY STAR.	Lamp change in chromaticity from 0-hour measurement, at any measurement point during the first 6,000 hours of lamp operation, shall be within a total distance of 0.007 on the CIE 1976 u'v' diagram. Methods of Measurement and Reference Documents as listed in Draft 2 for SSL. Supplemental Testing as listed in Draft 2 of SSL.

Color Angular Uniformity Requirements—Spotlights Only

Color Angular Uniformity Requirements same as ENERGY STAR Draft 2. Will update in line with revisions to ENERGY STAR.	Variation of chromaticity across the field angle of the lamp shall be within a total distance of 0.004 from the weighted average point on the CIE 1976 (u'v') diagram. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

Lumen Maintenance and Rated Life Requirements

The California Specification does not include a requirement for lumen maintenance.	Lamp shall maintain 80% of initial lumen output at 40% of rated life. Lamp shall maintain minimum percentage of 0-hour light output after completion of the test duration corresponding to lamp's life claim (hours to 70% lumen maintenance or L70) per the table(s) below. Lamp may earn optional early interim qualification after 3,000 hours, with a rated life claim ≤ 35,000 hours, per the provisions below. Lamps to be marketed as commercial grade shall satisfy requirements for no less than 35,000 hour rated life claims. (Table same as Draft 2). **For Extended Lifetime Claims:** For lamp life claims > 25,000 hours, lamp shall

	maintain ≥ 91.5% of 0-hour light output after completion of the test duration corresponding to lamp's life claim per the table below. (Table same as Draft 2). **To Qualify for Early Interim Qualification After 3,000 Hours**: Lamp shall maintain minimum percentages of 0-hour light output corresponding to the lamp's life claim per the table below, and shall meet all other requirements in this specification. A lumen maintenance projection calculation using the applicable LM-80-08 test report for the employed LED package/module/ array model (―device‖), the in situ temperature of highest temperature TMPLED, and the forward drive current applied to each device shall support a rated lumen maintenance life greater than or equal to the lamp rated life value to be claimed on product packaging. (Table same as Draft 2). Methods of Measurement and Reference Documents as listed in Draft 2 for SSL. Supplemental Testing as listed in Draft 2 for SSL.

Rated Life Requirements—All Lamps

Rated Life Requirements same as ENERGY STAR Draft 2 for SSL. Will <u>not</u> update in line with revisions to ENERGY STAR.	Decorative lamps shall have a rated life ≥ 15,000 hours. All other lamps shall have a rated life of ≥ 25,000 hours. Lamps to be marketed as commercial grade shall have a rated life ≥ 35,000 hours. All tested units shall be operational at 3,000 hours. ≥ 90% of the tested units shall be operational at 6,000 hours. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Rapid Cycle Stress Test—All Lamps

The California Specification does not include a requirement for rapid cycle stress testing.	Lamp shall survive cycling once per hour of rated life, at 5 minutes on, 5 minutes off, for no more than 15,000 cycles. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

Electrical Safety Requirements—All Lamps

The California Specification does not include a requirement for electrical safety.	Lamp shall comply with ANSI/UL 1993-2009, ANSI/UL 8750-2009 and ANSI/UL 8750-2009 as applicable. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

Power Factor Requirements—All Lamps

All California Quality LED lamps shall have a power factor ≥ 0.9.	Lamp shall have a power factor ≥ 0.7 for residential applications, or ≥ 0.9 if marketed as commercial grade. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

Operating Frequency Requirements—All Lamps

The California Specification does not include a requirement for operating frequency.	This does not apply to LED lamps, within ENERGY STAR Version 1.0, DRAFT 2.

California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Start Time Requirements—All Lamps

The California Specification does not include a requirement for start time.	This does not apply to LED lamps, within ENERGY STAR Version 1.0, DRAFT 2

Dimming Requirements--All Lamps

All California Quality LED lamps shall be capable of continuous dimming, flicker and noise free, from 10-100 percent. For these lamps, the specification uses the dimmability requirements in the ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2. The test procedures (e.g., for flicker and noise) used in the California Specification will update in line with future revisions to ENERGY STAR, but the requirement for dimming down to 10% will not update .	All Lamps Marketed as Dimmable: Lamp shall meet each of the following requirements if noted as capable of dimming on the lamp, its base or packaging, product literature or point-of-purchase materials, either printed or electronic: • Dimming level: TBD. • Flicker: TBD. • Audible noise: TBD. • Compatibility: TBD. • Methods of Measurement and Reference Documents: TBD. • Supplemental Testing: TBD. The above criteria are yet to be determined by ENERGY STAR in accordance with information in Draft 2.

Transient Protection Requirement—All Lamps

The California Specification does not include a requirement for transient protection.	Lamp shall survive 7 strikes of a 100 kHz ring wave, 2.5 kV level, for both common mode and differential mode. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

Noise Requirements—All Lamps

All LED lamps shall be free of noise over the full range of operation from 10%-100% output.	Noise Requirements for dimmable lamps TBD in accordance with Draft 2.

Lamp Toxics Reduction Requirements—All Lamps

The California Specification does not include a requirement for lamp toxics. Note that lamps must meet the toxics requirements of the California Title 20 appliance standards and ROHS legislation.	Lamp Toxicity Reduction Requirements as listed in Draft 2, as applicable.

Lamp Shape Dimensional Requirements—All Lamps

All ANSI Standard Lamps same as ENERGY STAR Draft 2. Will update in line with revisions to ENERGY STAR. California EXCEPTIONS: • The California Specification uses a reduced list of allowed lamps shapes and lamp bases, as shown in the staff report.	Lamp Shape Dimensional Requirements as listed in Draft 2 Methods of Measurement and Reference Documents as listed in Draft 2 Supplemental Testing as listed in Draft 2.

Lamp Thermal Requirements—All Lamps

The California Specification does not include a thermal requirement.	Lamp shall have a minimum ambient operating temperature of 0°F (-18°C) or below. Methods of Measurement and Reference Documents as listed in Draft 2. Supplemental Testing as listed in Draft 2.

California Quality LED Lamps	ENERGY STAR Version 1.0, DRAFT 2

Lamp Labeling, Packaging, and Warranty Requirements—All Lamps

Lamp Labeling Requirements same as ENERGY STAR Draft 2. Will update in line with revisions to ENERGY STAR.	Each of the following shall be printed on the lamp: • Lamp manufacturer or brand name • Lamp model number as will appear on the ENERGY STAR qualifying product list. • Lamp nominal correlated color temperature including ―Kelvin‖ or ―K‖. • Rated wattage in watts (lamps not covered by FTC requirements). • Lamp rated lumen output in lumens (lamps not covered by FTC requirements).

Lamp Packaging Requirements same as ENERGY STAR Draft 2. Will update in line with revisions to ENERGY STAR California Additions: To meet the specification, lamps must also include information about dimmer compatibility on their packaging. This information may be a URL or QR code that links to a regularly updated list of compatible dimmers. Lamps must also include information about their luminous intensity distribution on their packaging. One of the following three descriptions must be printed on the exterior of the packaging, in => 8 point type: • “Omnidirectional” • “Floodlamp, [beam angle]° beam angle” • “Spotlight, [beam angle] ° beam angle” As an alternative to the luminous intensity descriptions above, for floodlamps and spotlights, the exterior of the lamp packaging may carry the “non-standard light output diagram” from the lamp labeling requirements of ENERGY STAR Product Specification for Lamps, Version 1.0, DRAFT 2. The option to carry the non-standard light output diagram will update in line with future changes to the non-standard lighting output diagram in ENERGY STAR.	Lamp Packaging Requirements as listed in Draft 2.

Warranty Requirements All California Quality LED Lamps shall be backed by a minimum five-year warranty, from date of purchase. Lamp packaging shall state: "Warranty: This lamp has a [warranty term]-year, free replacement warranty", and a phone number or website address for consumer complaint resolution. The complete written warranty shall be printed on the exterior of the packaging and be included within the lamp packaging. Manufacturer is solely responsible for honoring the warranty; intermediate parties (e.g. showrooms, electrical distributors, retailers) are not responsible for honoring warranty requirements.	Warranty per table in Draft 2 Lamp package shall state "Warranty" or "Limited Warranty", the warranty period (in years) per the above table, and a phone number or website address for consumer complaint resolution. The complete written warranty shall be printed on packaging exterior or included within lamp packaging. [ENERGY STAR] Partner is solely responsible for honoring warranty; intermediate parties (e.g. showrooms, electrical distributors, retailers) are not responsible for honoring warranty requirements.

APPENDIX B

ANALYSIS FOR DIRECTIONALITY REQUIREMENTS

This section describes the analysis that supports the directionality requirements of the California Specification. For omnidirectional lamps, the ENERGY STAR LED Product Specification for Lamps, Version 1.0, DRAFT 2 requirements already contain a definition of "omnidirectional" light output, but the ENERGY STAR requirements do *not* contain a definition for the type of directional output given by floodlamps that are often used in recessed can luminaires. Therefore, this analysis has two goals:

- To determine whether the ENERGY STAR definition of "omnidirectional" successfully distinguishes truly omnidirectional lamps from "snow cones".
- To develop a luminous intensity distribution requirement for floodlamps that distinguishes these lamps from both omnidirectional lamps and narrow-beam floodlights/spotlights.

To visualize the direction of light output from each lamp, the graphs below show elevation angle vs. measured relative luminous intensity (cd/klm). Staff compared several currently available LED lamps with their incandescent equivalents. This graph is similar to the standard "polar curve" commonly used in the lighting industry, but this format provides better visual resolution of small intensity values.

Intensity can be measured either as *absolute* intensity (candelas) or *relative* intensity (candelas per thousand lumens of lamp output); of these two, relative intensity is usually the most useful because it allows lamps of different lumen outputs to be directly compared on the same scale.

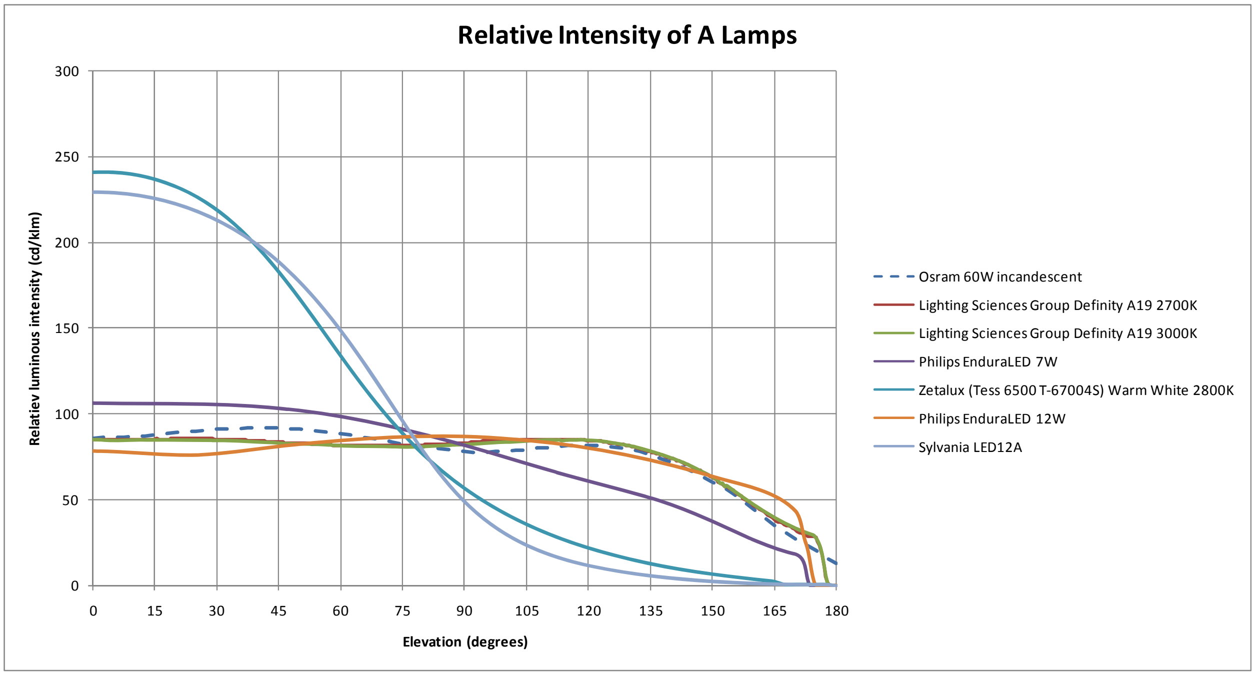
Omnidirectional Lamps

The ENERGY STAR requirement for omnidirectional lamps is as follows:

> *Products shall have an even distribution of luminous intensity (candelas) within the 0° to 135° zone (vertically axially symmetrical). Luminous intensity at any angle within this zone shall not differ from the mean luminous intensity for the entire 0° to 135° zone by more than 20%. At least 5% of total flux (lumens) must be emitted in the 135°-180° zone. Distribution shall be vertically symmetrical as measured in three vertical planes at 0°, 45°, and 90°.*

The graph below shows that several of the LED lamps tested are very similar to a reference 60W incandescent A-lamp (dashed line). The four LED lamps that closely follow the incandescent curve meet the ENERGY STAR criteria for omnidirectional. The lamp shown in purple (which gives a small amount of light backwards) follows the incandescent curve somewhat closely, but it fails the ENERGY STAR criteria because its intensity falls below the minimum allowed value at elevations above about 105 degrees. The two "snow cone" lamps fail to meet the omnidirectional criteria by a long way. Based on this analysis, the ENERGY STAR criteria distinguish omnidirectional lamps from snow cones very effectively, and the criteria can be met by commercially available lamps.

Figure 6: Relative Intensity of Various A-Lamps



Source: California Energy Commission, staff analysis conducted for this report.

Floodlamps

Since there is no ENERGY STAR definition for a floodlamp, staff analyzed the beam shapes of several models of incandescent lamp (including a reference lamp, the GE 56W R30 flood, shown by the dashed line). The various incandescent beam shapes show that the narrower-beam spotlights have high intensities in the center of the beam and low intensities outside the half-beam angle.

The goal for the luminous intensity distribution requirements is that they should:

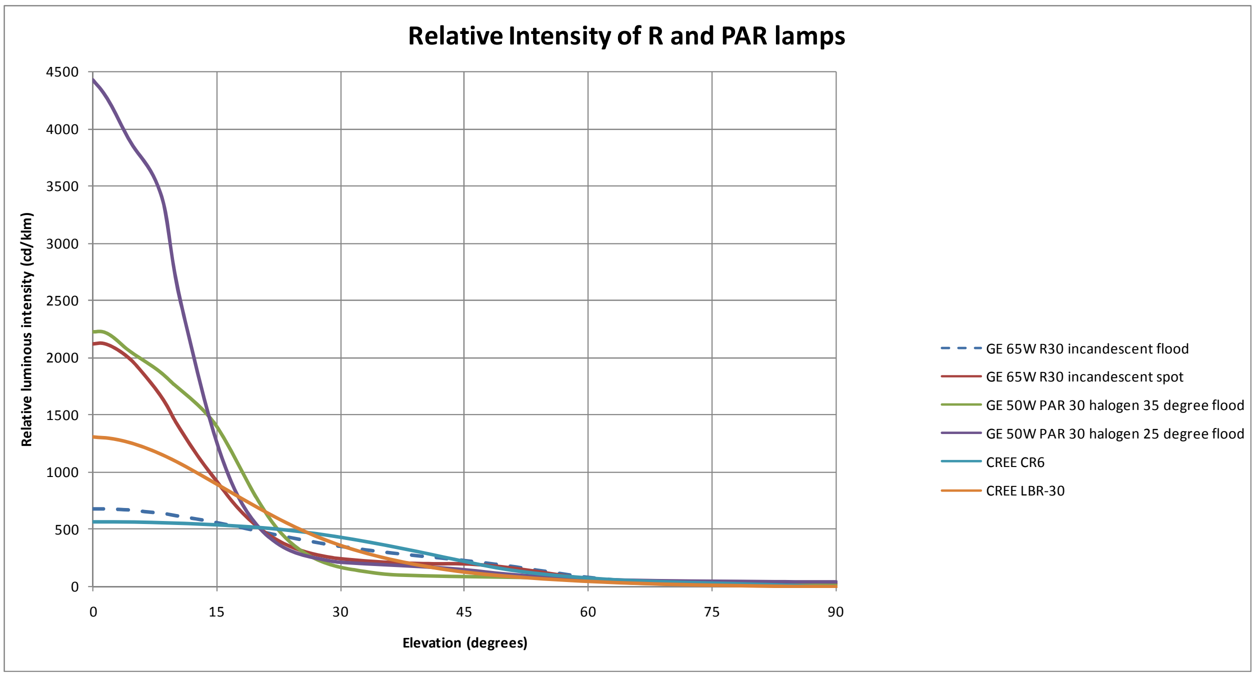
- Ensure that lamps do not have sudden changes in intensity at different viewing angles, that is, they should avoid sudden cutoffs or other unexpected changes.
- Set boundaries for diffuse vs. focused light beams. A beam that is either too diffuse or too focused would not give the kind of light distribution a consumer would expect from a floodlight.
- Ensure that lamps have at least some apparent brightness when viewed at angles close to horizontal, for instance from across a room.

The luminous intensity requirements for floodlamps are therefore in four parts:

- Luminous intensity shall not increase from any given angle of elevation to the next, over the range 0° to 90°, for each of the azimuthal planes.
- Beam angle shall be between 50° and 90°.
- At least 10 percent of the total flux (lumens) must be emitted in the 60°-90° zone.
- Distribution shall be vertically symmetrical as measured in three vertical planes at 0°, 45°, and 90°.

Two of the lamps in the graph below meet these requirements: the reference incandescent and the CREE CR6. The CREE LBR-30 falls just outside the acceptable beam angle range.

Figure 7: Relative Intensity of Various R and PAR Lamps



Source: California Energy Commission, staff analysis conducted for this report.

APPENDIX C

CODES AND STANDARDS CONTEXT

Energy Independence and Security Act of 2007 (EISA)

The Energy Independence and Security Act of 2007 (EISA) − passed by Congress and signed by President George W. Bush − created new energy efficiency standards for general service lamps. The law is designed to reduce energy use and greenhouse gas emissions and make the United States less dependent on foreign sources of energy. The entire country started phasing in this standard on January 1, 2012. EISA allows California to implement the national standard on a timeline that starts one year earlier.

The EISA lamp requirements, as implemented in California, are shown in the table below:

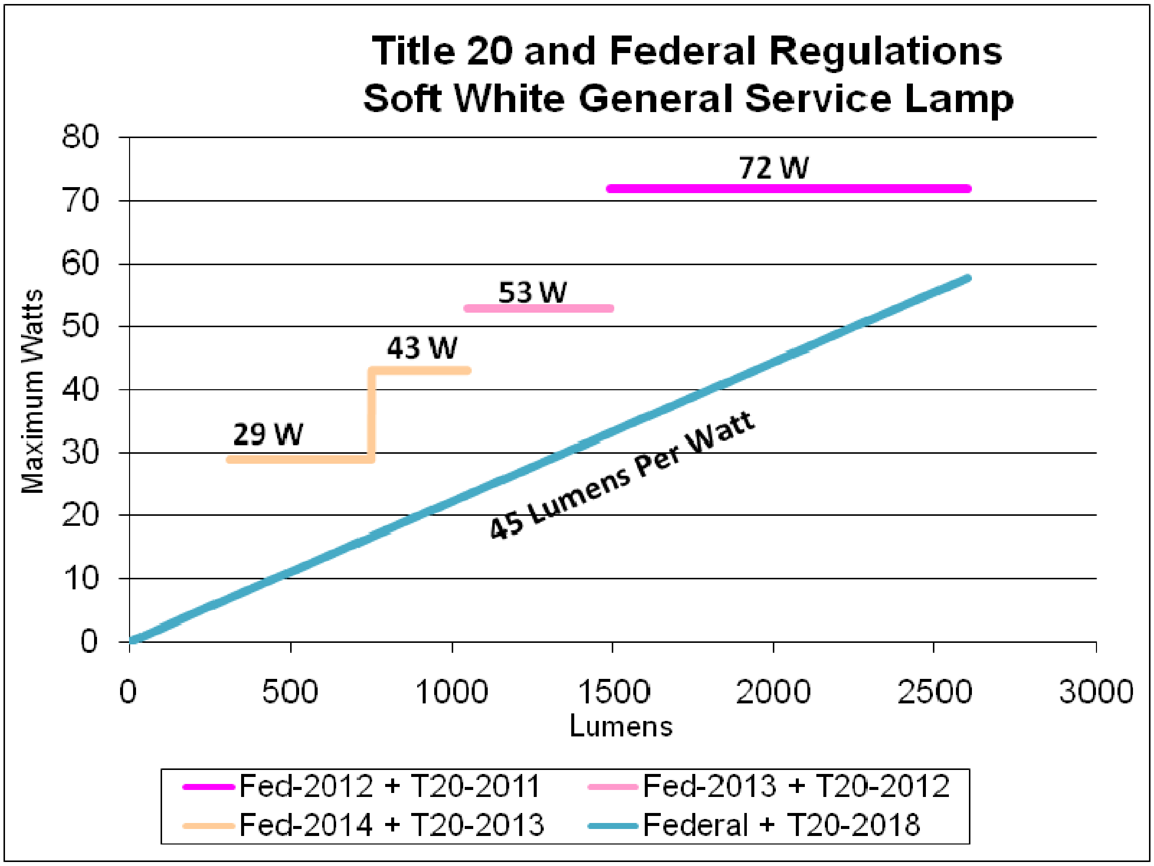
Figure 8: EISA Requirements for General Service Lamps in California

Rated Lumen Ranges	Maximum Rated Wattage	Minimum Rated Life	California Effective Date	What this means relative to traditional wattage lamps
1490-2600	72	1,000	1/1/2011	What was once a 100 watt lamp must provide the same light output but consume no more than 72 watts.
1050-1489	53	1,000	1/1/2012	What was once a 75 watt lamp must provide the same light output but consume no more than 53 watts.
750-1049	43	1,000	1/1/2013	What was once a 60 watt lamp must provide the same light output but consume no more than 43 watts.
310-749	29	1,000	1/1/2014	What was once a 40 watt lamp must provide the same light output but consume no more than 29 watts.

Source: California Appliance Efficiency Regulations, 2010.

These standard levels can generally be met by halogen incandescent lamps, as well as CFLs and LEDs. Starting on January 1, 2018, the EISA requirements for all general service lamps will increase further to a minimum efficacy of 45 lumens per watt. It is not clear whether manufacturers will make halogen incandescent lamps to meet this second tier of EISA standards in 2018. Regardless, it is anticipated that the EISA general service lamp requirements are going to significantly increase consumer demand for quality, high-efficacy lamps.

Figure 9: Power Consumption and Luminous Flux Requirements for General Service Lamps in Title 20 and EISA



Source: California Appliance Efficiency Regulations, 2010; Section 1605; Federal Energy Independence and Security Act, 2007, Section 321.

There are already California regulations on lamps that have GU-24 bases. GU-24 is an ANSI-defined pin-based socket designed to replace the Edison screw-based socket for certain applications. The California Appliance Efficiency Regulations (Title 20) do not allow any incandescent GU-24 base lamps, luminaires with GU-24 sockets that are rated for incandescent lamps, or adaptors that convert GU-24 sockets to screw-based sockets to be sold or offered for sale in California. This means that all GU-24 lighting products sold or offered for sale in California must be high-efficacy products such as LED lamps, self-ballasted fluorescent lamps, or self-ballasted high-intensity discharge (HID) lamps.

California Public Utilities Commission

The California Public Utilities Commission's (CPUC) *Decision Providing Guidance on 2013-2014 Energy Efficiency Portfolios and 2012 Marketing, Education, and Outreach*[24] supports the establishment of minimum California performance specifications for LED lamps that will

24 California Public Utilities Commission. *Decision Providing Guidance on 2013-2014 Energy Efficiency Portfolios and 2012 Marketing, Education, and Outreach (Decision 12-05-015)*. Page 227. May 10, 2012.

ensure ratepayer funds support only quality products that consumers will desire. The development and implementation of the California Specification will be necessary to avoid the prior experience with CFLs, in which early rebates for CFLs incentivized inferior products that permanently hampered public perception of this product.

The CPUC's plans for the investor-owned utilities (IOUs) call for them to shift their incentive funding from basic compact fluorescent lamps to more advanced products, such as dimmable compact fluorescent lamps and LEDs. At the same time, CPUC plans a phase-out of basic compact fluorescent lamp incentives to consumers. As indicated in the *Draft 2011 California IOU Potential Study*, the technical potential for LED lighting, starting in 2013, is significantly higher than the current market potential.

ENERGY STAR

The California Specification is constructed to allow LED lamp manufacturers to meet both the ENERGY STAR and the California Quality LED Lamp Specification. An LED lamp that meets the Specification for color quality, dimmability, rated life, and light distribution can also meet the remaining ENERGY STAR Product Specification for Lamps, thus meeting both requirements.

Appendix A compares the Specification to the ENERGY STAR Product Specification for Lamps, Version 1.0, and DRAFT 2.

APPENDIX D

COMPACT FLUORESCENT LIGHTING IN AMERICA: LESSONS LEARNED ON THE WAY TO MARKET

In 2006, Pacific Northwest National Laboratory authored a report for the U. S. Department of Energy, on the lessons learned from the introduction of CFLs into the U. S. market[25]. One section of this report dealt specifically with lessons that could be applied to the introduction of new technologies, for example, LEDs. The report contained a summary of those lessons, which is presented below in the original language of the report with additional explanations:

Application to LED and Other New Lighting Technologies

- Much consumer research is needed to determine what the consumer does and does not know before the initial product launch so that the launch is done right the first time.
- Accurate incandescent equivalency on packaging is critical.
- Rely as much as possible on retailers for customer education. Product packaging can also be a very powerful way to convey product benefits.
- Industry collaboration, perhaps through NEMA, would be helpful, though difficult to achieve given the large number of manufacturers.
- Coordinate with energy efficiency programs once products are available but don't start before products are ready (for reliable mass-production at high volume).
- Don't rely on giveaways and coupons or other programs that confuse consumers about the actual retail price (that is, sales information should show the original and rebated price).
- Avoid market introduction programs that distribute products outside normal retail channels, for example, utility mail-order programs.
- Performance claims must be accurate. Don't launch a product until performance issues are ironed out.
- Initial education and performance issues will be more difficult to iron out if many manufacturers are involved in the initial introduction of LEDs.
- Pricing is critical but tricky − low enough to encourage consumer demand, high enough to generate profit for the retailer and manufacturer.
- Education of both consumers and retailers is critical.
- Understand that many people will not try a new product until price drops to a range near that of existing products providing similar functionality.
- Niche marketing is the best approach for now (that is, during early market penetration).

25 Department of Energy and Pacific Northwest National Laboratory, *Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market*.