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CA IOU Comments on LED Lamps

Additional submitted attachment is included below.

LED Lamps

Codes and Standards Enhancement (CASE) Initiative
For PY 2015: Title 20 Standards Development

RESPONSE TO CEC'S EXPRESS TERMS 45-DAY LANGUAGE PROPOSALS

December 7, 2015

Prepared for:

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1 Overview

The Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), Southern California Gas (SoCal Gas), San Diego Gas & Electric (SDG&E) Codes and Standards Enhancement (CASE) Initiative Program seeks to address energy efficiency opportunities through development of new and updated Title 20 standards.

This document outlines the California Investor-Owned Utilities' (IOUs) CASE team response to the California Energy Commission's (CEC) Express Terms (45-day language) published in October 2015, "Small Diameter Directional LED Lamps and General Purpose LED Lamps" (herein referred to as the 45-Day Language) and discussion in the subsequent CEC workshop on November 18, 2015. The comments in this document focus on the proposed standards for state-regulated light emitting diode (LED) lamps.

We are supportive of the CEC's proposals to set minimum efficacy, performance and quality requirements for LED lamps to help ensure consumer satisfaction and thus increase market adoption of LEDs. As we saw with Compact Fluorescent Lamps (CFL), an initial sales surge is not indicative of complete market transformation. CFL market share skyrocketed from below 1% to over 30% in approximately 5 years in the late 2000's as soon as their price dropped below $5-10, but market share plateaued after that, even as prices continued to decline below $2. This experience proved that low prices alone are not enough – product performance is an important aspect of consumer acceptance and complete adoption. Fortunately, we've seen a trend towards improved LED performance over the last several years, resulting from the great innovation of the LED industry, in concert with California's recent work in this area of LED quality standards and specifications. The market has responded to the CEC's 2012 Voluntary LED Quality Specification with a steady stream of high quality products, at ever dropping prices, and ever improving efficacy. Lamps have been introduced with extremely high color rendering, with great dimming capability, long life, etc. The CA IOUs' rebate programs have been supporting these products for the last two plus years.

While the CEC's Voluntary Specification and the associated rebates helped to incentivize these high performing products, it cannot prevent products that don't render colors well, that flicker or buzz when dimmed, or that mislead consumers with their packaging from undercutting these products. Another simultaneous recent trend in the LED market is a "race to the bottom" in terms of product quality and performance, with manufacturers cutting corners wherever possible and competing on price alone for early market share and early adopters. These products may be good replacements for CFLs, but they do not provide the level of service and amenity needed to compete with incandescent lamp performance and fully transform the market.

The CEC's Title 20 proposal in the 45-day language goes a long way towards preventing products like these from "poisoning the well" and resulting in a loss of consumer confidence in LEDs. The CEC's Title 20 proposal does not require LED lamps to be "best-in-class" – it is not as strong as the CEC Voluntary Specification for example, nor is it as strong as the original CASE proposal from the CA IOUs. But it does require a solid foundation for a minimum performance standard, and it establishes a level playing field upon which manufacturers can compete.

This rulemaking is California's opportunity to drive the market transformation to LED lamps by ensuring that LED lamps provide a minimum level of amenity and efficiency. If CA can convert the

remaining low efficacy sockets[1] to LEDs, the annual statewide savings would be on the order of 30,000 GWh, enough to achieve the State's AB 1109 goals.

Below is a summary of the specific comments and recommendations made in this document regarding the CEC's proposed LED lamp standards.

1.1 Specific Comments in Support of the CEC's 45-day Language

- There is a wide variety of products available today that meet all of the proposed standards, at reasonable prices. Products are available from Philips, Feit, Osram, Cree, Cooper, Green Creative, and many others.
- We support the CEC's proposal to require lamps to provide white light within a 4 MacAdam step tolerance from either the black body locus or the ANSI white curve defined in ANSI C78.377. The vast majority of LED products available today (about 90 %) already meet this specification, and this will ensure that products with a noticeably pink or greenish hue will not be sold as white lights.
- We support the CEC's proposal to set minimum requirements for the individual color rendering scores R_1-$R_8 \geq 72$. Without requirements set for these individual color samples, products with a Color Rendering Index (CRI) in the low 80's can significantly distort specific colors and will not reliably provide consumers with accurate color rendition. However, products with an R1-R8 score of at least 72 reliably provide adequate light across a wide range of color samples, including the pinkish R8 color sample (red is usually the deficiency in low CRI LED lighting).
- We support the minimum efficacy requirements proposed in the 45-day language: 65 lpw in 2017 and 80 lpw in 2019. We also support the concept of the efficacy/CRI trade-off equation proposed by the CEC as this acknowledges that higher CRI products may not need to provide as many photopic lumens to generate equivalent perceived brightness.
- We support the CEC's proposed standby power requirement of 0.2 W maximum. Testing has shown this level to be feasible and given how much time lamps spend in the off or standby state, it is critical that we limit standby power draw.
- We support the CEC's proposal to require lamps marketed as incandescent replacements or equivalents to be capable of providing a Color Correlated Temperature (CCT) of 3000K or less and to provide other performance features that are comparable to incandescent (minimum light output, dimmability, etc.) to make sure customers are not mislead into thinking a product is "equivalent" to an incandescent lamp if that product does not perform like an incandescent lamp.

[1] Halogen and incandescent lamps still represent over 50% of NEMA lamp sales nationally as of Q1 2015. https://www.nema.org/news/Pages/First-Quarter-Proves-to-be-a-Mixed-Bag-for-Consumer-Lamp-Indexes.aspx

1.2 Specific Recommended Changes to the CEC's 45-day Language

- We support the CEC's proposal to limit flicker and noise in dimmable LED lamps but recommend that CEC extend these requirements to non-dimming lamps as well (tested at full output, no dimmer). Flicker and noise could be a major source of consumer disappointment whether it occurs in dimming or non-dimming lamps.
- We recommend that lamps designed for use with forward phase cut dimmers (the majority of LED replacement lamps) be compliant with NEMA SSL7A, the industry's phase-cut dimmer compatibility standard. This standard addresses dimming performance aspects such as improved dimming range, reduced dead travel (switch is adjusted but no change in light), pop-on (when adjusting dimmer from the lowest setting upward, light turns on suddenly in the middle of the range, rather than gradually, from a very low light level), drop-out (light source drops out prematurely as lights are being dimmed), ghosting (light source is at a low-level "on" state when switch is in "off" position), and premature failure of LEDs. Compliance with NEMA SSL7A has already been adopted in Title 24 for lamps and dimmers, with the support of industry stakeholders. Adopting this requirement would not limit design options for dimming strategy, because it would only be required for lamps designed for forward phase cut dimmers. Lamps designed to work on other less common dimmer types would not have to meet SSL7A.
- We recommend that CEC provide more specificity around the test procedure for verification of dimming performance, including the selection of dimmer types and dimmer samples to be used in testing. The current language seems to imply that manufacturers are only required to test lamps on one dimmer of their choosing, but this is not clear. Specifically, we recommend that CEC refer to the dimming test procedure methodology already adopted in Joint Appendix JA8 of Title 24, which specifies the dimmer selection process based on manufacturer claims. Additionally, we recommend that CEC clarify what is meant by the phrase "standard phase-cut dimmer" in Section 1607 (12).
- We recommend that all lamps be required to be dimmable. However, if CEC does not adopt this recommendation, we recommend that lamps not meet the dimming requirements be required to include text on the front of the package clearly stating that the lamp is "NOT DIMMABLE."
- We recommend that CEC include a minimum power factor requirement of 0.9 at full light output. Improving power factor has significant financial and greenhouse gas benefits for California consumers. Our research suggests it has minimal or negligible incremental manufacturer cost, and our analysis of thousands of online retail price points did not suggest any link between increased power factor and increased end user prices. Lastly, there is already a preponderance of products that meet this proposed level.
- We recommend that all lamp packaging include a label indicating the product's CRI, and that the date of manufacturer be permanently marked on all products in the format: MM/YYYY.
- In the data collection table format for product certification, the 45-day language appears to allow manufacturers to submit only a "yes/no" response to indicate whether they meet the flicker requirements. We urge the CEC to modify this field in the table to require products to list their specific measured performance. Collecting the specific flicker performance results at 100% light output and 20% light output is a very important aspect of the flicker

standard because currently there is no public database of LED flicker data. This data will be extremely helpful for the lighting design community and to distinguish products with the lowest levels of flicker.

- We recommend CEC classify products with the shape ST as decorative and require them to meet the decorative light distribution requirements. These products are used for decorative purposes.

2 Supporting Comments and Data

2.1 Color Appearance (Duv)

We support CEC's proposal to require lamps to provide white light within a 4 MacAdam step tolerance (i.e. +/-0.0033) from either the black body locus or the ANSI white curve defined in ANSI C78.377. The 4 step tolerance was introduced to the ANSI specification in 2011 as LEDs were introduced to the market with much tighter color binning than had historically been provided with by fluorescent sources. The Duv standard will help ensure that products provide a true white light with better color consistency between products (tightening the tolerances helps to prevent the wide variation of different shades of white among different lamps installed in the same space).

2.2 Color Rendering

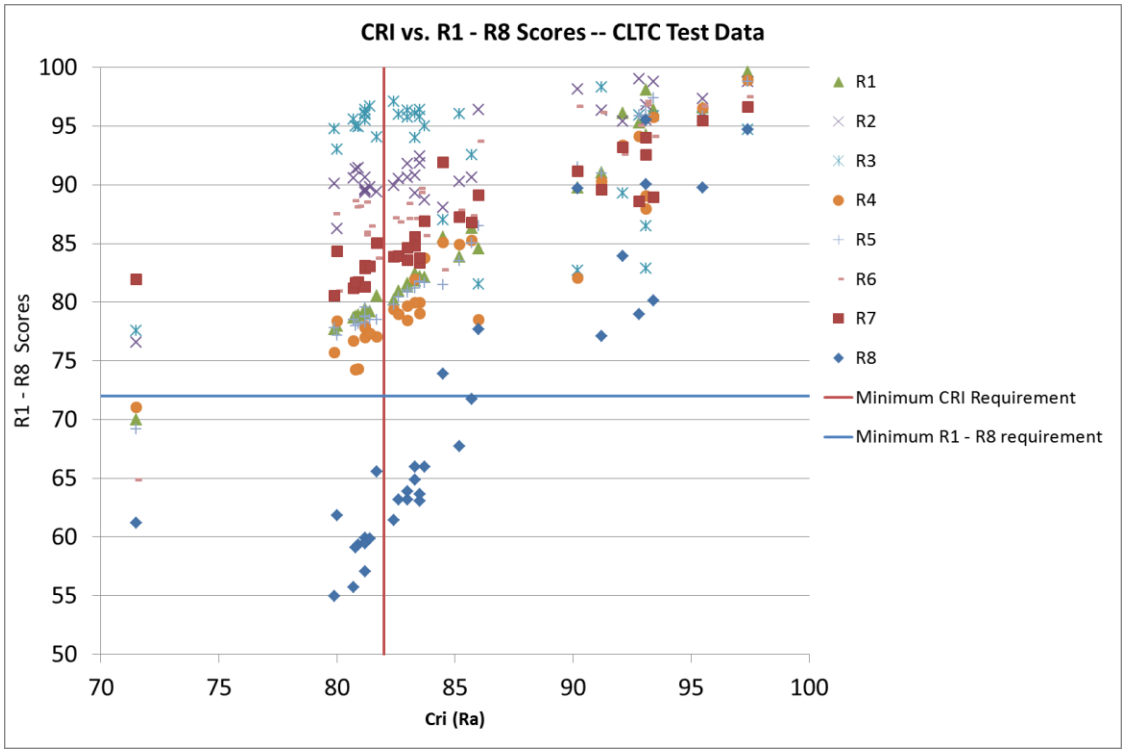
We support the CEC's proposal to set minimum requirements for both the CRI (Ra) score *and* for the individual color rendering scores R1-R8 ≥72. This recommendation is based on the following findings.

2.2.1 Significance of the individual R1-R8 requirements

Because the CRI score is calculated as a simple average of performance across eight color samples, light sources with CRI in the low 80's can distort certain colors, while making up ground by providing decent rendition of other color samples. In this way, products in the low 80's will not reliably provide consumers with accurate color rendition. Specifically, many LED products with CRI in the low 80's offer significantly distorted color rendering in one of the color samples in the CRI metric, R8, which is a pinkish/red hue (often R8 scores are in the 50's or 60's).

Figure 1 below demonstrates test data from the 2012-2013 LED lamp testing at the California Lighting Technology Center (CLTC) that was commissioned by PG&E. The figure shows the individual R1 through R8 scores plotted against CRI (Ra) for all products. It demonstrates that R8 scores are typically the lowest scores for any given lamp, regardless of CRI.

Figure 1. CRI vs. R1 through R8 scores in CLTC test data



By requiring the R_1 through R_8 scores to be at least 72, the CEC's proposal is essentially requiring that products provide improved R8 performance, which is associated with improved level of red rendition. The proposal ensures that lamps cannot simply meet a given Ra score by off-setting poor performance in the red region with better performance in other colors.

We reiterate our past comments submitted to CEC regarding the importance of red content in LED lighting and the importance of improved color accuracy in general. Strong rendition of reds and pinks, which is often missing in high efficacy lighting, is a critical element of lighting performance, as it relates to accurate rendition of skin tones, food, furniture, and other natural objects. Though CFLs have achieved about 40% market share, they have not successfully replaced incandescents in more color sensitive applications such as bathrooms (where people see themselves in the mirror, apply make-up, etc.) and dining rooms and living spaces where families spend much of their time. For more detail on the importance of color rendering, and design strategies for improved color rendering, we refer CEC to the detail provided in the 2013 CASE report[2] and in our November, 2014 comments.[3]

[2] http://www.energy.ca.gov/appliances/2013rulemaking/documents/proposals/12-AAER-2B_Lighting/PG_and_E_and_SDG_and_Es_Responses_to_the_Invitation_for_Standards_Proposals_for_LED_Quality_Lamps_2013-07-29_TN-71758.pdf

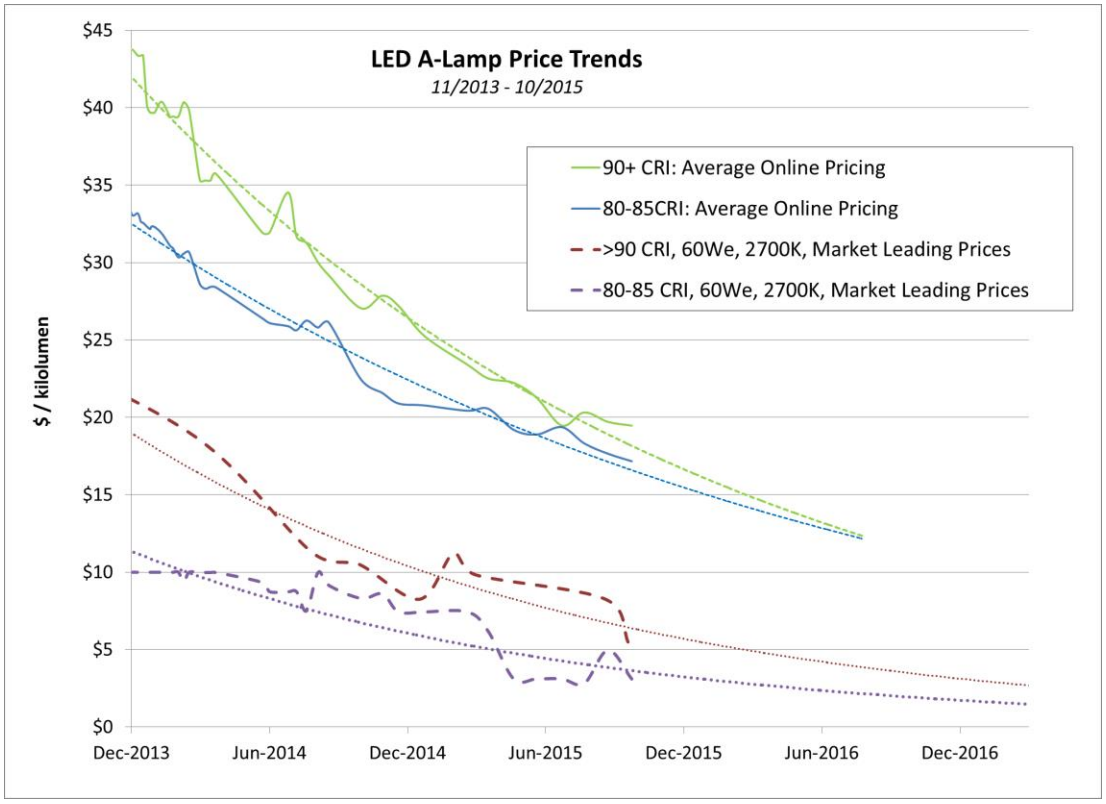
[3] http://www.energy.ca.gov/appliances/2014-AAER-01/prerulemaking/documents/2014-09-29_workshop/comments/California_IOUs_Response_to_the_CECs_Draft_Regulations_regarding_LED_Lamps_2014-11-18_TN-73993.pdf

2.2.2 Price Trends for high CRI products

Prices are falling quickly for all LEDs, but they are falling more rapidly for higher CRI products. The CASE team has been monitoring LED pricing, regularly obtaining thousands of price points from online retailers, as well as tracking individual price points of high CRI products, including those that meet the CEC Voluntary Specification.

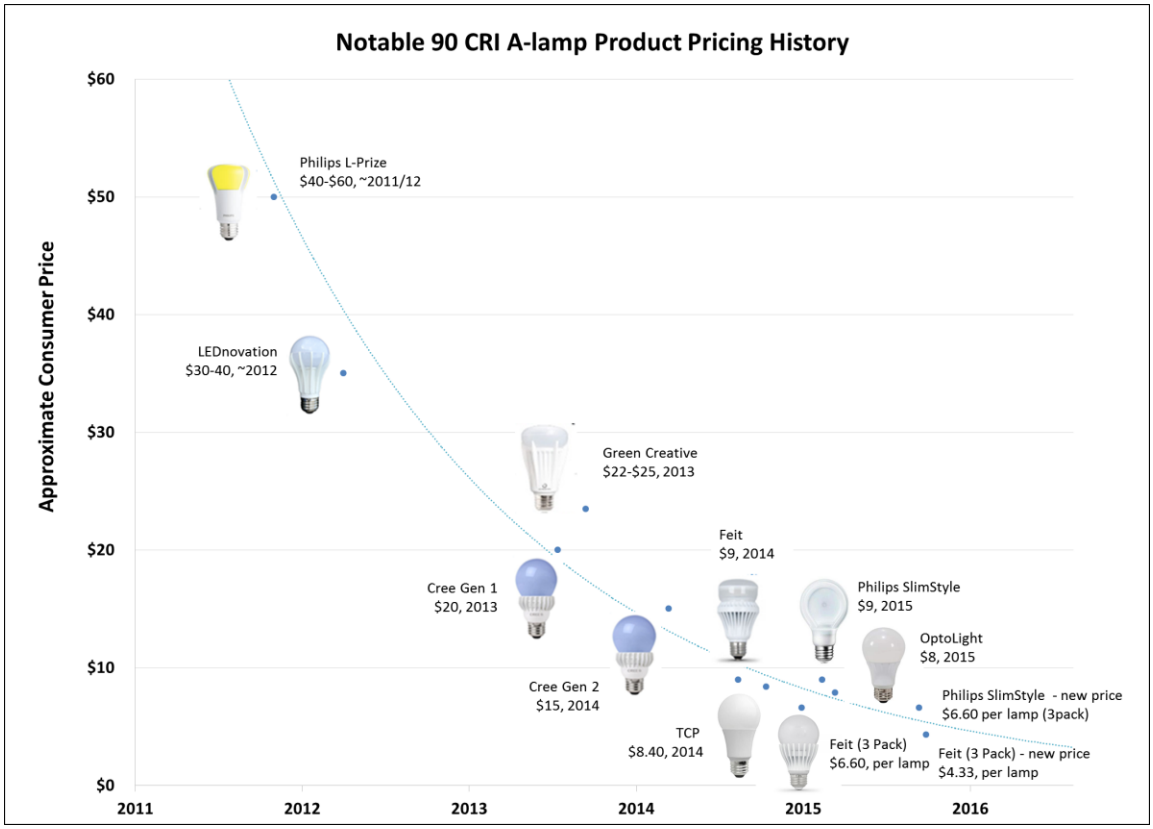
Figure 2 below shows average online pricing per kilolumen based on A-lamp prices collected from nine online retailers between late 2013 and fall 2015. In less than two years, average pricing of low CRI products came down by about 47%, but the average pricing of high CRI A-lamps came down by about 58%. The graph also shows market-leading price trends for low and high CRI products. Again, the best high CRI prices have come down more quickly and continue to catch up to the best lower CRI prices. Exponential trend lines (dotted lines) provide a possible forecast.

Figure 2. Average Online per Kilolumen Price Trends for A-lamps



These macro-level results are corroborated by specific product launches from the past several years. Figure 3 below highlights many of the notable high CRI A-lamp product releases and new price point offerings. Since late 2014, a number of products have been released from multiple manufacturers below $10. The latest pricing as of late 2015 includes multiple products below $7, including one as low as $4.33.

Figure 3. High CRI A-lamp Price History



2.3 Feasibility of Meeting CEC's Proposed Standards

The CASE team has conducted an analysis to assess product availability and to demonstrate feasibility of meeting the proposed standards. To do this, our team has relied on publically available product performance data in the ENERGY STAR Qualified Product List (QPL) and the DOE Lighting Facts Database, in addition to product testing completed by the CLTC. The public data sources are much larger in terms of the number of products listed (thousands), however they do not provide data for all metrics included as part of the CEC's proposed standards (specifically, they do not include R1-R8 data or Duv data). The CLTC test reports, on the other hand, provide performance data for all of these metrics, but for a much smaller set of products (approximately 50 A-lamps and directional lamps, most of which were obtained in 2012-2013, but several more recently). Both of these analyses show that there are products available that meet all of the CEC's proposed mandatory requirements, including Duv, CRI, R1-R8, efficacy, CRI/efficacy compliance score, lifetime, power factor, light distribution, and standby power.

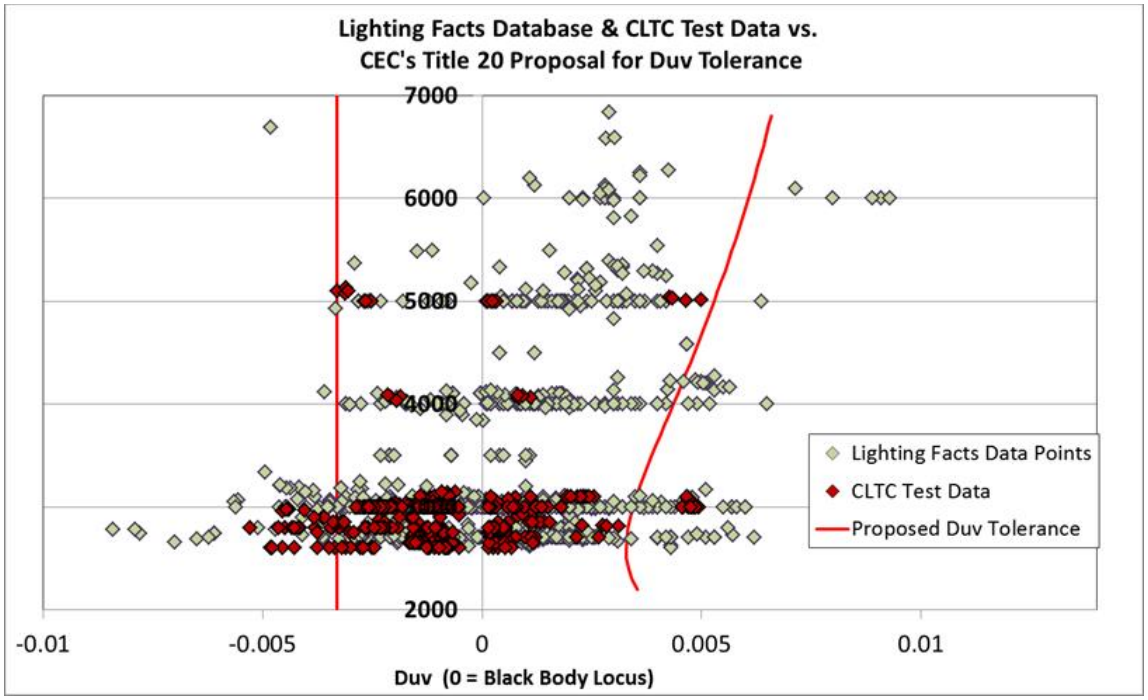
This analysis found that products are available across all lamp type categories; there are omnidirectional, directional, downlight, and decorative lamps that meet the requirements. Hundreds of products meet the Tier 1 requirements, available from over 60 different manufacturers, including Civilight, Cree, Eaton Cooper, Feit, Green Creative, Greenlight, Halco, Home Depot Brand, Lowe's Brand, Maxlite, Nora, Optolight, Philips, Satco, Wal-Mart Brand, and

many more. These products are available in a wide variety of shapes and sizes, including A19, A21, BR30, BR40, PAR20, PAR30, PAR38, PAR38L, R20, Globe, Candle, and others. These products are available in a range of color temperatures from 2700K to 6500K, and range in light output from 200 lumens up to 1,650. There are also already products available that meet the Tier 2 requirements, across all lamp type categories, from over 12 manufacturers, despite not taking effect for over three years. The following sections explain the analysis conducted to arrive at these conclusions.

2.3.1 Color Appearance (Duv)

The vast majority of LED products available today already meet this specification. Our analysis of the thousands of products reporting Duv in the Lighting Facts Database, shown in the Figure 4 below, found that 89% of covered products fall within this range. Testing completed by California Lighting Technology Center for PG&E, incidentally also found that 89% of products meet this specification. In fact, most products pass this requirement by a significant margin. Even if the requirement were tightened by 33% (to Duv +/- 0.0022), ~75% of products would still meet the proposal. Notably, among products with a CRI listed above 82 in the Lighting Facts Database, the passing rate for Duv is even higher at 91%.

Figure 4. Market Analysis of CEC's proposed Duv Tolerance Requirements



2.3.2 R1-R8

R1-R8 data are not available in public databases such as the ENERGY STAR Qualified Product List (QPL) or the DOE Lighting Facts Database. These resources provide only CRI (Ra) and R9 (a deep saturated red color). Because R8 performance tends to be the limiting factor for LED products, we have conducted analysis of many products, including those tested by CLTC, as well as over 100 other products with LM79 test reports available, to better understand the relationships between R8

and CRI, and between R8 and R9. Understanding these relationships helps us to better analyze the publically available data using proxy data for R8. Figures 5 and 6 below provide this analysis.

Figure 5. Comparison of R8 to CRI (Ra) in LED Lamps

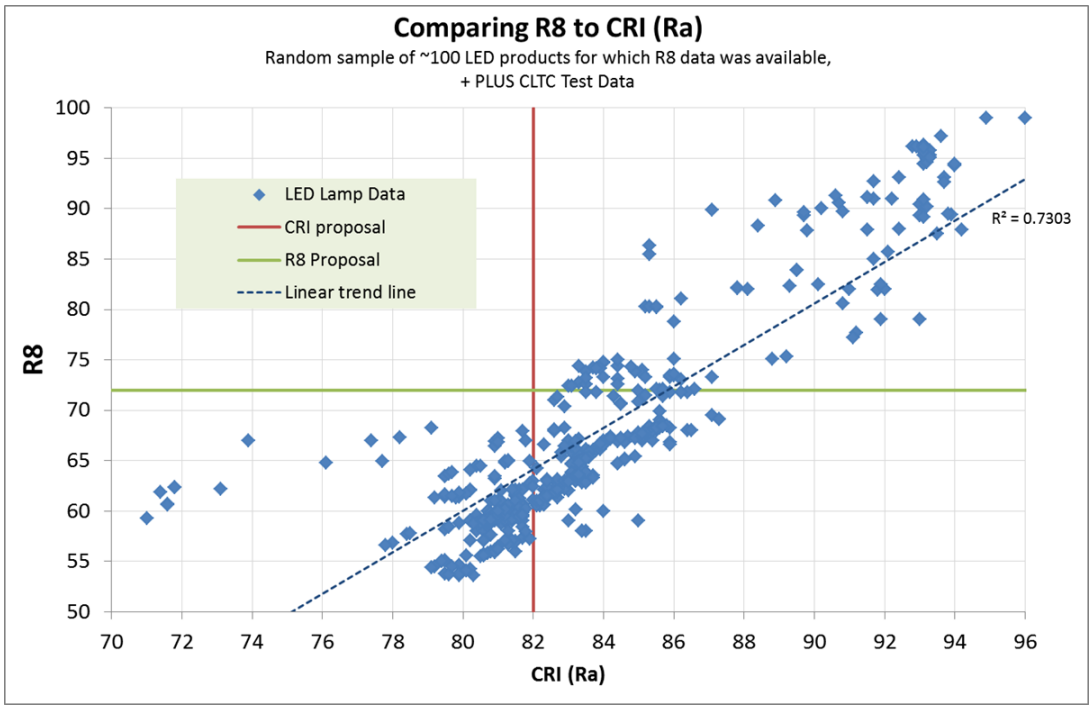


Figure 6. Comparison of R8 to R9 in LED Lamps

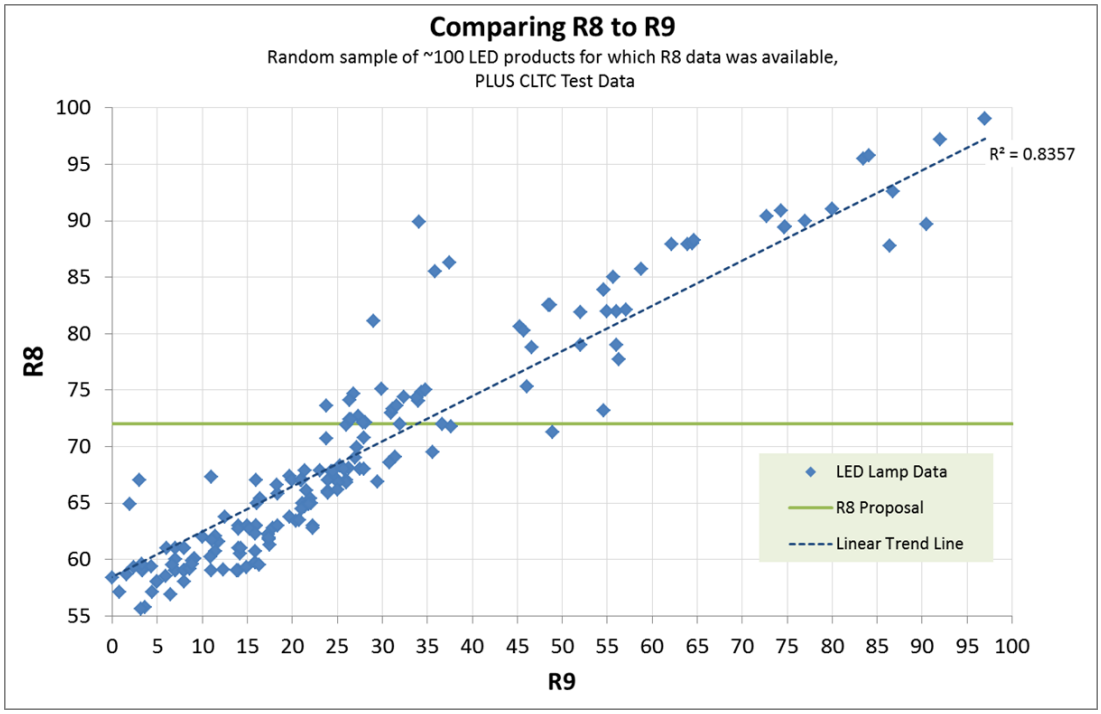


Figure 5 demonstrates that the relationship between R8 and CRI is not perfect, but it is good, with an R^2 value of 0.73. The figure also shows that among products with a CRI of 85, about half have an R8 value above 72, and above 88 CRI, all products have an R8 above 72.

Figure 6 shows that the relationship between R8 and R9 is even stronger, with an R^2 value of 0.84. This graph shows that among products with an R9 score of 30-35, most products (about 75%) have an R8 above 72.

These analyses have helped us to interpret Lighting Facts Database and the ENERGY STAR QPL. For our purposes, we have used an R9 score of 32 as an approximate comparison for an R8 score of 72, since that is the intercept of the trend line and above that point we see that most products meet an R8 of 72. However, to be certain, and to take a conservative approach to analysis of compliant products, we also know that products with a CRI above 88-90 will more definitively meet the proposed R1-R8 requirement.

2.3.3 ENERGY STAR Data: Products that Meet all the Proposed Mandatory Requirements

The following graphs in this section (Figures 7 through 13) show data from the ENERGY STAR qualifying product lists (both the Lamps and Luminaires Specifications, which houses the downlight retrofit kits). Products represented in the graphs have been certified to U.S. EPA with their performance values across a wide range of metrics, usually by 3rd party test labs, and following ENERGY STAR's testing guidance. ENERGY STAR recently conducted verification testing; results have not yet been published, but early reports are that they found 95% passing rate for LED lamps. Given this high level of confidence in the ENERGY STAR data, the following sections provide an assessment of performance against all of CEC's proposed mandatory requirements.

- **Lifetime:** The ENERGY STAR lifetime requirements range from 15,000 to 25,000 hours, so all of the products in the ENERGY STAR QPL have a longer rated life than the CEC's proposed 10,000 hour life requirement. Therefore, all of the products shown in the graphs below meet the proposed Title 20 lifetime requirement.
- **Light distribution:** CEC's proposed light distribution requirements for omnidirectional lamps and decorative lamps are the same as ENERGY STAR's. The CEC did not propose light distribution requirements for directional lamps. Therefore, all the products shown in the graphs below meet the CEC's proposed light distribution requirements.
- **Power factor:** CEC's proposed power factor requirement of 0.7 is the same as ENERGY STAR's requirement for LED lamps. Therefore, all the products shown in the graphs below meet the CEC's proposed power factor requirement.
- **CRI, efficacy, CRI/efficacy compliance score:** The graphs below plot CEC's proposed requirements for efficacy, CRI, and minimum compliance score, for both Tier 1 (red line) and Tier 2 (purple line), so product data points shown to the right and above these plotted standards lines meet all three of these requirements.
- **R1-R8:** The ENERGY STAR QPL does not provide R1-R8 data. However, separate analysis (shown earlier in Section 2.3.2) found that an R9 score above 32 is approximately equivalent to an R8 score of 72, and that R8 is the limiting factor among all the R1-R8 scores. Therefore, the data represented in the following graphs has been filtered to show only products that have a listed R9 value above 32, as a proxy for R8 above 72. This

indicates that the products in the graphs below with a CRI in the range of 82-86 are very likely meet the R1-R8 >72 proposal. However, to take an even more conservative view, one could consider that above 90 CRI, all products are believed to meet the R1-R8 proposal.

- **Duv:** The ENERGY STAR QPL does not include Duv data. However, separate analysis (shown on earlier in Section 2.3.1) found that the vast majority (89%) of products on the market meet the CEC's proposed Duv requirement. Among products with a CRI >82, the value is even higher: 91% meet the proposed Duv requirement. We therefore assume that about 90% of the products shown in the following slides meet the Duv requirement.

Figure 7. Omnidirectional ENERGY STAR Lamps

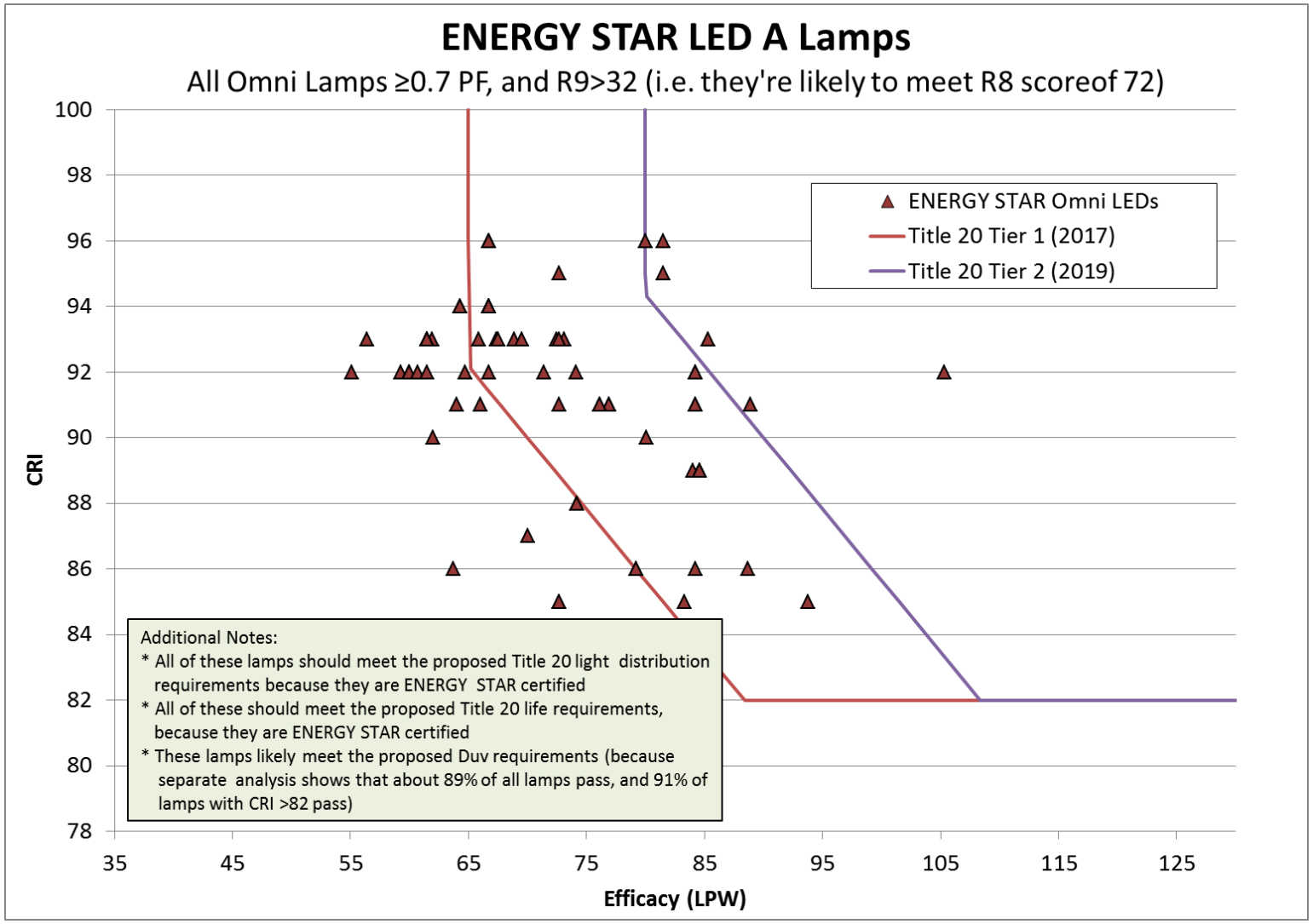


Figure 8. Omnidirectional ENERGY STAR Lamps with Pricing and Notes Inserted for Various Products

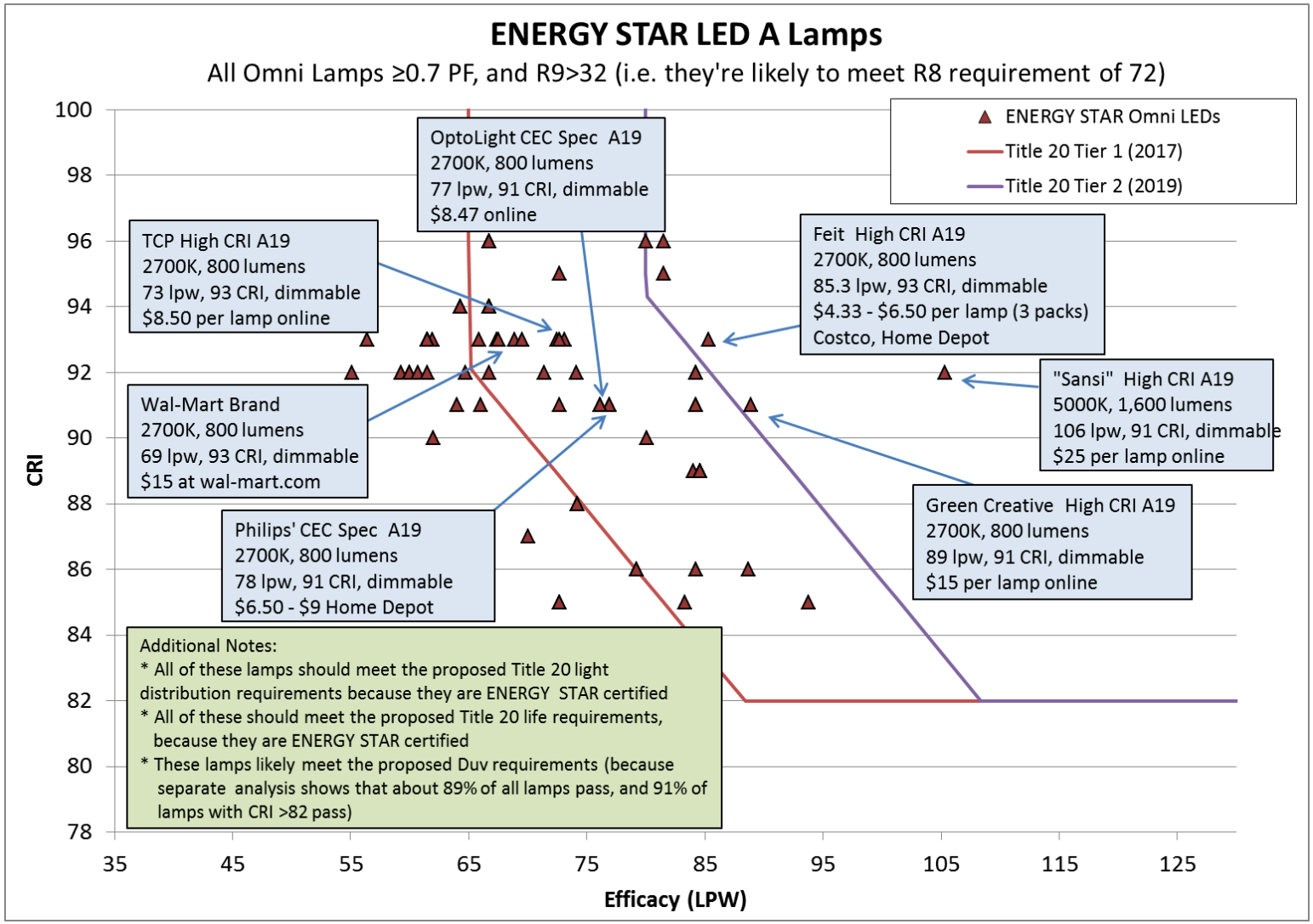


Figure 9. Directional ENERGY STAR Lamps

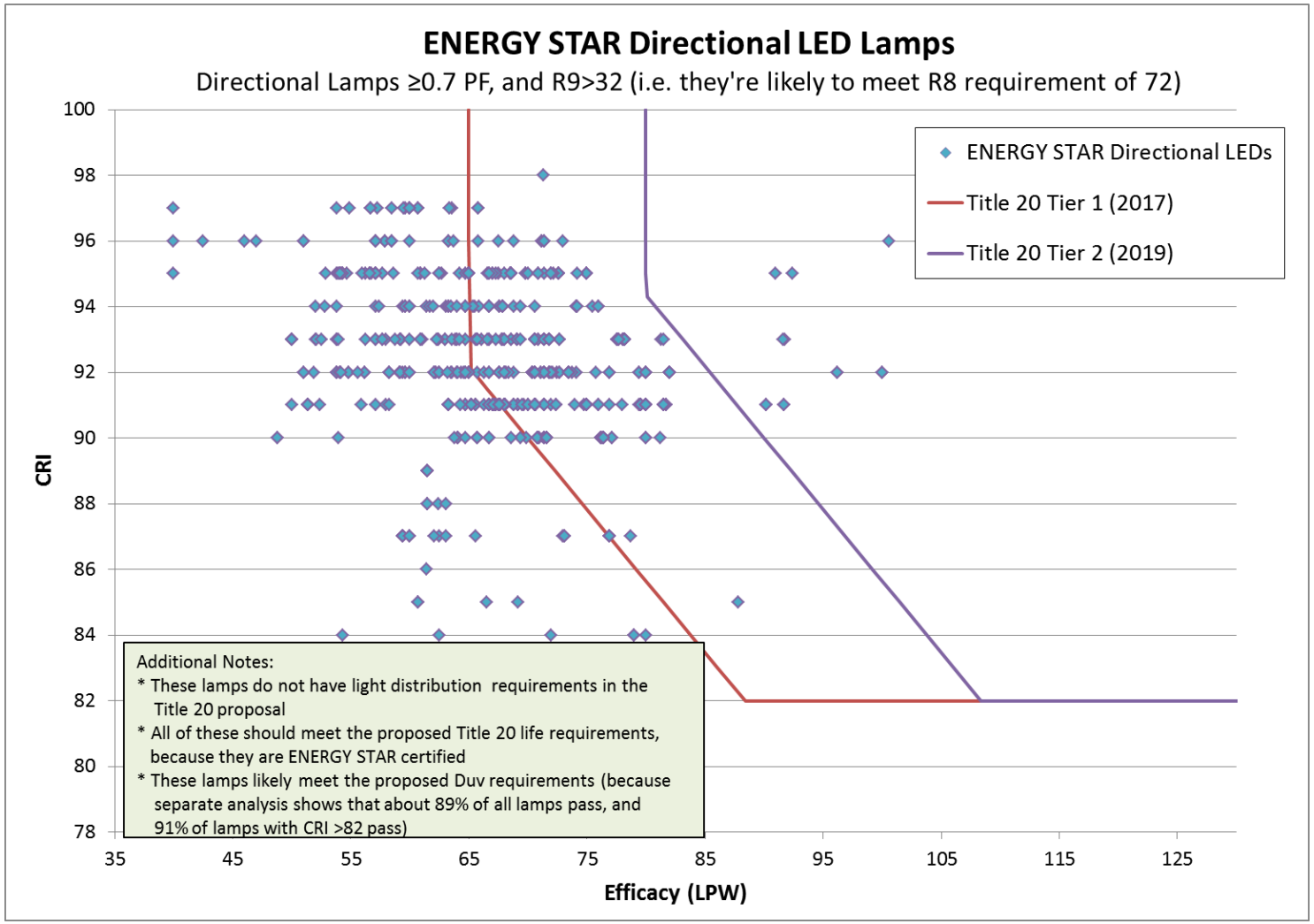


Figure 10. Directional ENERGY STAR Lamps with Pricing and Notes Inserted for Various Products

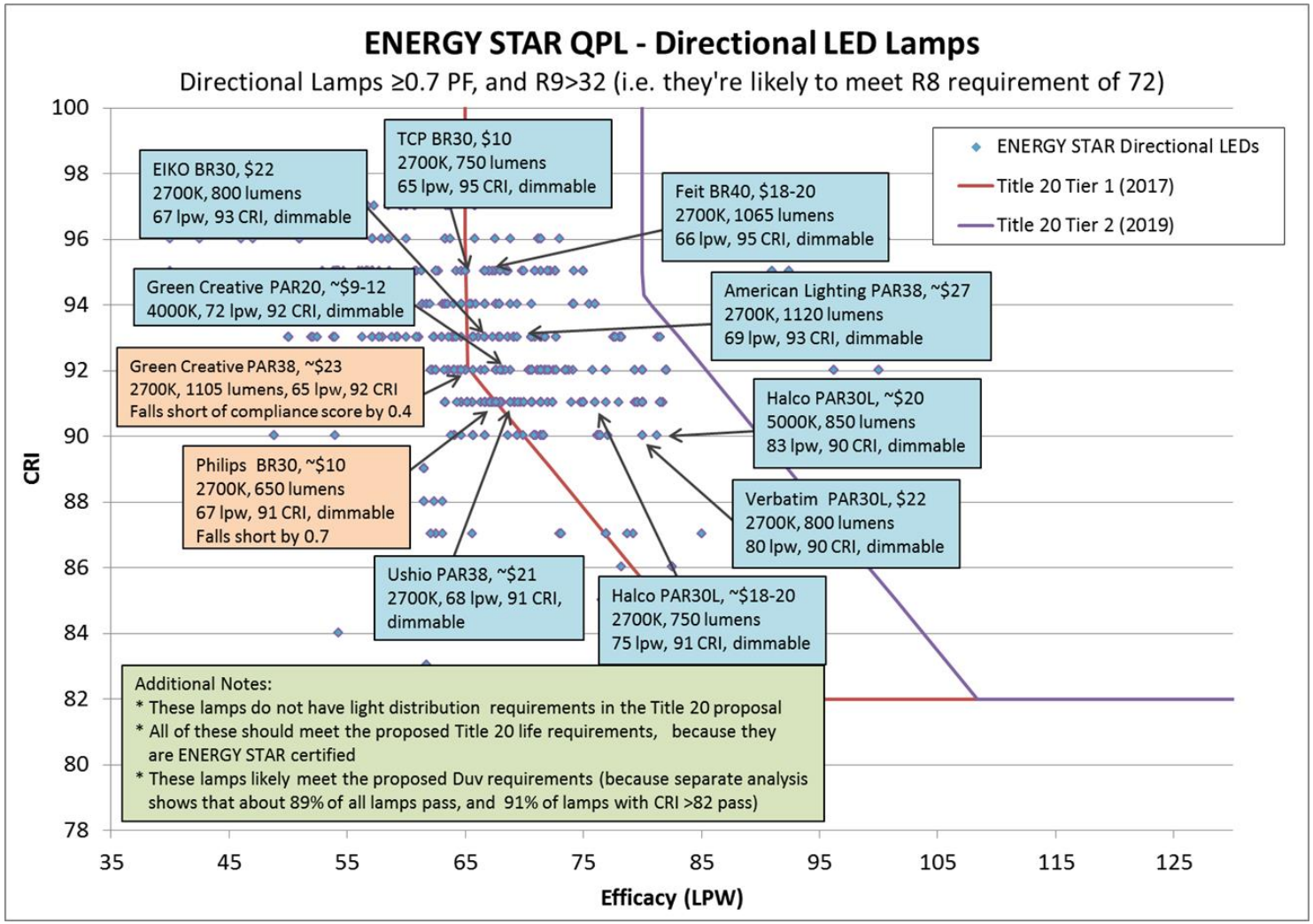


Figure 11. Decorative ENERGY STAR Lamps with Pricing and Notes Inserted for Various Products

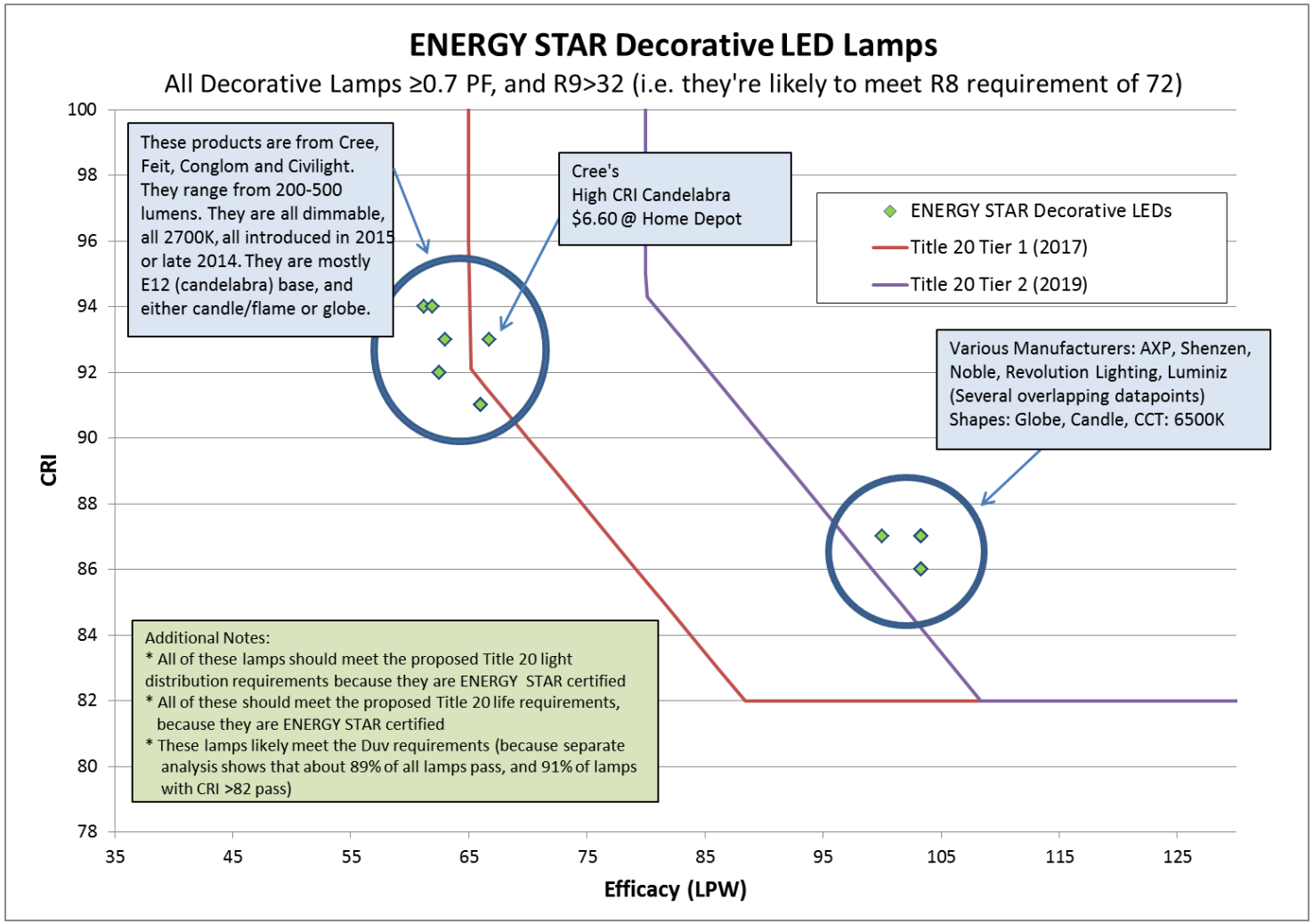


Figure 12. ENERGY STAR Retrofit Downlights, using R9>32 as a proxy for R8>72

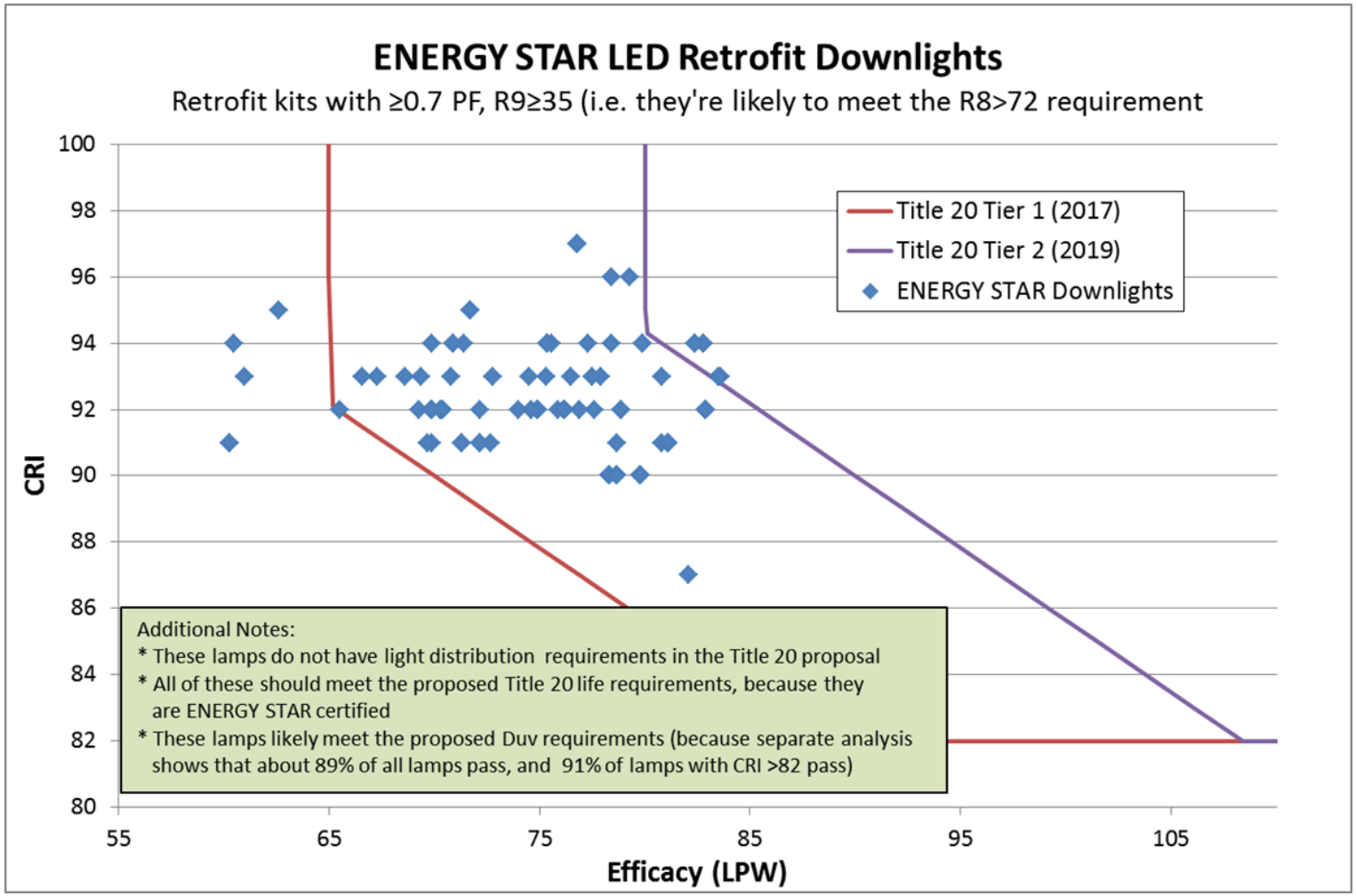
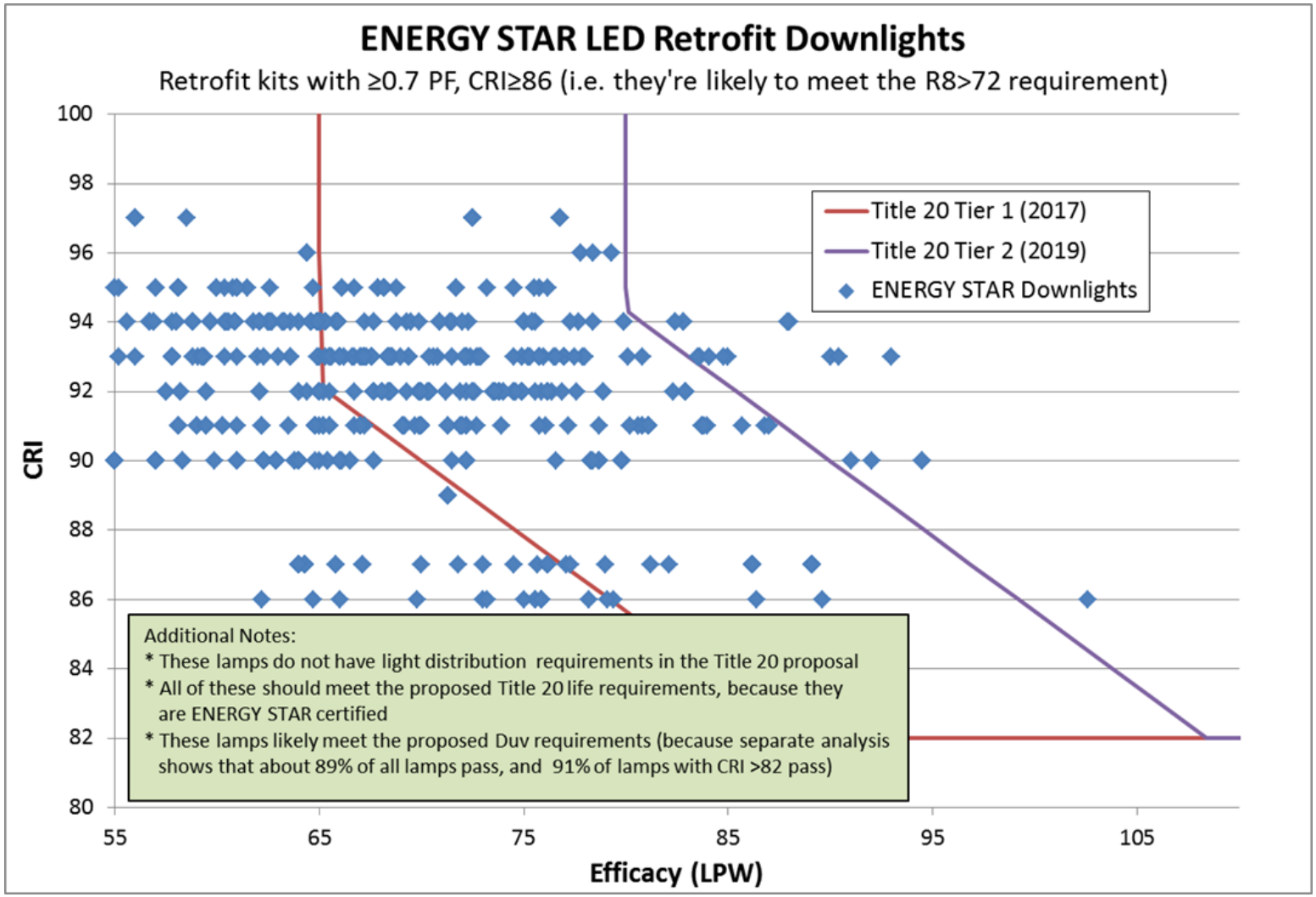


Figure 13. ENERGY STAR Retrofit Downlights, using CRI>86 as a proxy for R8>72



2.3.4 CLTC Test Data: Products that Meet all the Proposed Mandatory Requirements

In addition to the hundreds of products that appear to meet the proposed mandatory requirements based on the publically available data about them, testing completed by the CLTC has confirmed additional products that meet CEC's proposal. Table 1 below contains a list of products that meet the proposed standards, and their scores in each of the metrics. The first four are products that were tested through funding from PG&E[4] and the make and model have been kept confidential in that study. Products FF and GG are certified ENERGY STAR products, so they pass the light distribution requirements. The last two products have been tested outside the scope of PG&E's project funding, and CLTC has made the make and model available. The Civilight product passes all requirements but light distribution testing has not yet been completed. The Philips SlimStyle product has had only one sample go through the test protocol so far.

Table 1. LED A-lamp test data from CLTC demonstrating products expected to meet the Title 20 proposal

Lamp	Efficacy (≥65)	CRI (≥82)	Compliance Score (≥277)	R1 (≥72)	R2 (≥72)	R3 (≥72)	R4 (≥72)	R5 (≥72)	R6 (≥72)	R7 (≥72)	R8 (≥72)	Duv (+/- 0.0033)	PF (≥0.7)	Rated Life (≥10,000 hrs)	Omni-Distribution (Same as Estar v1.1)
Product J	104	93	318	94	97	83	88	97	97	94	96	-0.00002	0.83	25,000	Pass
Product EE	65	96	285	97	97	96	97	96	97	95	90	0.0003	0.94	25,000	Pass
Product FF	82	91	292	91	96	98	90	91	96	90	77	0.0002	0.84	25,000	Pass - ENERGY STAR Certified
Product GG	77	93	291	95	99	96	94	96	95	89	79	-0.0030	0.93	25,000	Pass - ENERGY STAR Certified
Civilight A19	86	97	310	100	99	95	99	99	98	97	95	0.0005	0.73	25,000	Testing Underway
Philips SlimStyle	79	92	290	92	98	97	90	92	97	89	78	0.0015	0.899	25,000	Pass - ENERGY STAR Certified

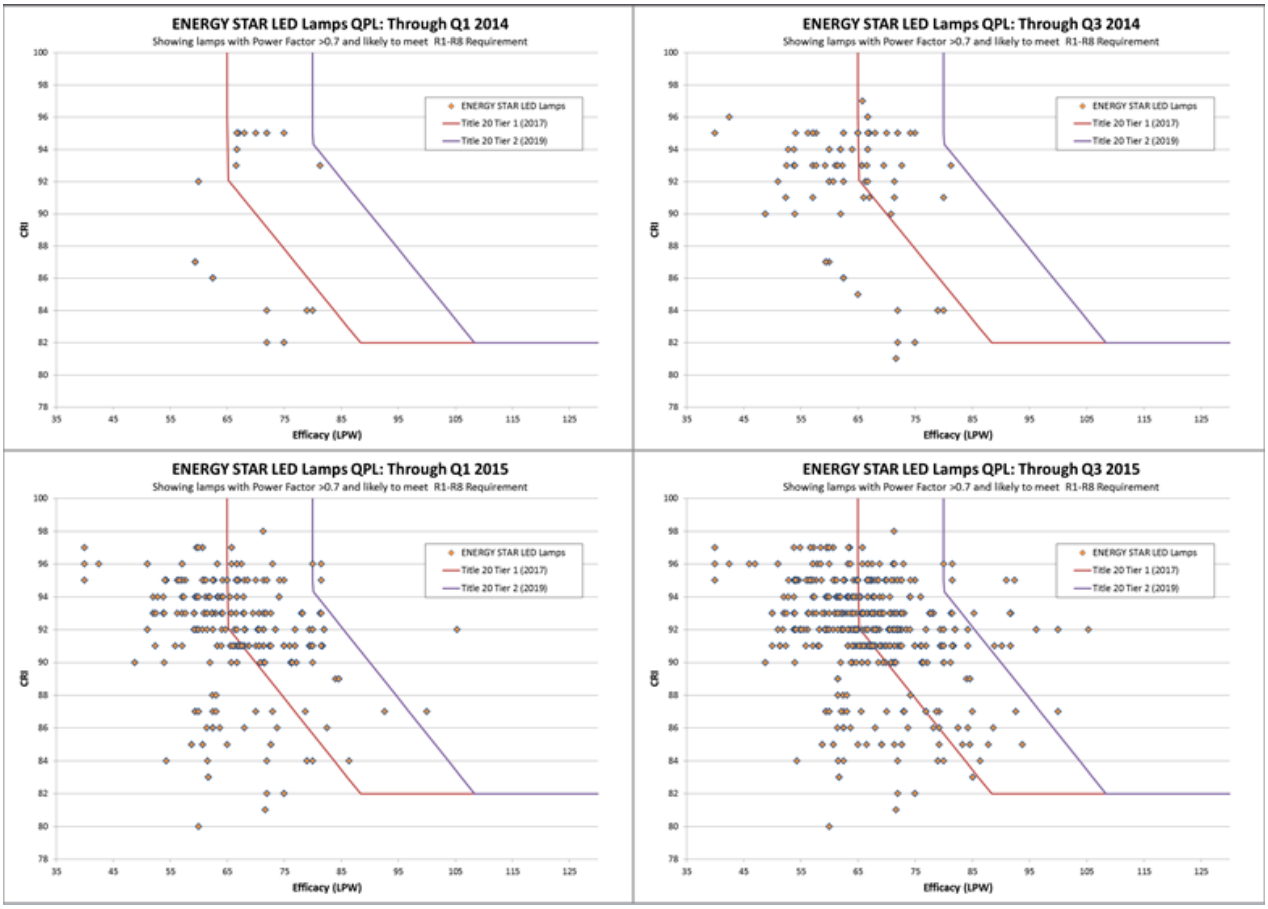
2.3.5 Performance Improvement Trends

In addition to the data indicating that current products are available that meet the proposed standards, the trends in the LED market suggest that more products will be available by the time the standard takes effect in 2017. The market is expected to experience even more significant improvement before Tier 2 standards take effect in 2019. Assuming current trends continue, omnidirectional lamps will increase in efficacy by 30% between now and 2019; directional lamps will increase by 23%. Decorative lamps are experiencing the fastest efficacy improvement; if their current improvement trends continue, decorative lamps will be 33% more efficient by 2019.

[4] Testing of the first 26 products (Product A through Z) completed in ~2013, is available here: http://cltc.ucdavis.edu/sites/default/files/files/publication/140609-report-omni-directional-led-replacement-lamps_rev140807.pdf The complete database of for this testing, including products tested more recently is available here: http://www.ledperformancedatabase.org/products

Figure 14 below highlights the rate of improvement over the last two years, in terms of the total number of products in the ENERGY STAR QPL that meet all the proposed requirements. The four graphs show progress updates on a 6 month schedule, starting with Q1 2014 in the top left.

Figure 14. Time Series Analysis of Availability of Products that Meet the Proposed Standards: January 2014 – August 2015



2.4 Dimming

We recommend that CEC require all LED lamps to be dimmable down to 10% of full light output (or lower) and that lamps designed for phase-cut dimming (the majority of LED replacement lamps) be compliant with NEMA SSL7A, the recently developed phase-cut dimmer compatibility standard. However, if CEC does not adopt this recommendation, we recommend that lamps not meet the dimming requirements be required to include text on the front of the package clearly stating that the lamp is "NOT DIMMABLE." This will help inform consumers by making it more clear which products they can expect to work in their dimming sockets, and significantly reducing consumer dissatisfaction. Additional analysis on our dimming-related recommendations is provided in this section, below.

Lack of dimmability was a major cause of consumer dissatisfaction with CFLs, and as dimming sockets become more and more prevalent in California due to building code requirements, the ability of LED lamps to dim well will be crucial for their mass adoption. The Northwest Energy

Efficiency Alliance (NEEA) Residential Building Stock Assessment,[5] the first phase of which was published in late 2012, found that across their study of 1,850 homes in the Pacific Northwest, only 6.6% of the sockets controlled by dimmers had CFL lamps installed in them. For example, in dining rooms, where fixtures are commonly controlled by dimmers, CFL adoption rates were appreciably lower than in other rooms. Considering that total CFL market share is 30-40%, these results indicate that sockets on dimmers have not been converted to high efficacy sources at nearly the rate that non-dimming sockets have. Though dimming CFLs are now available, many consumers had negative early experiences when trying to install non-dimmable CFLs on dimming sockets. Distinguishing between dimmable and non-dimmable LED lamps will only create unnecessary labeling confusion for consumers and will impede the adoption of LED lamps.

Most LED lamps are already dimmable but some are not. Among the thousands of LED lamp products for which we are collecting online price data, about 85% are labeled as dimmable. In the ENERGY STAR database, over 2,000 products (about 65% of the total) are labeled as dimmable. About 75% of those are dimmable to a level of 10% or lower. Over 400 products are listed as dimmable below 5%.

Section 5.4.2. of the 2013 CASE Report presented an analysis documenting savings potential for standards compliant dimmable lamps installed on dimmers (savings ranged from 4 to 14 kWh per year), and the weighted average savings for standards compliant LED lamps across the state (assuming 25% of lamps get installed on dimmers). Those tables are provided again here.

Table 2. Per Unit Energy Savings by Lamp Type (for lamps installed in dimming sockets)

	Per Unit Energy (dimming sockets)		
Lamp Type	Non-Qualifying kWh/yr	Qualifying kWh/yr	Savings (kWh/yr)
General Service A-lamp	13.8	7.6	6.2
Large Diameter Directional	37.9	24.1	13.8
Small Diameter Directional	23.2	14.8	8.4
Decorative	8.7	4.8	3.9

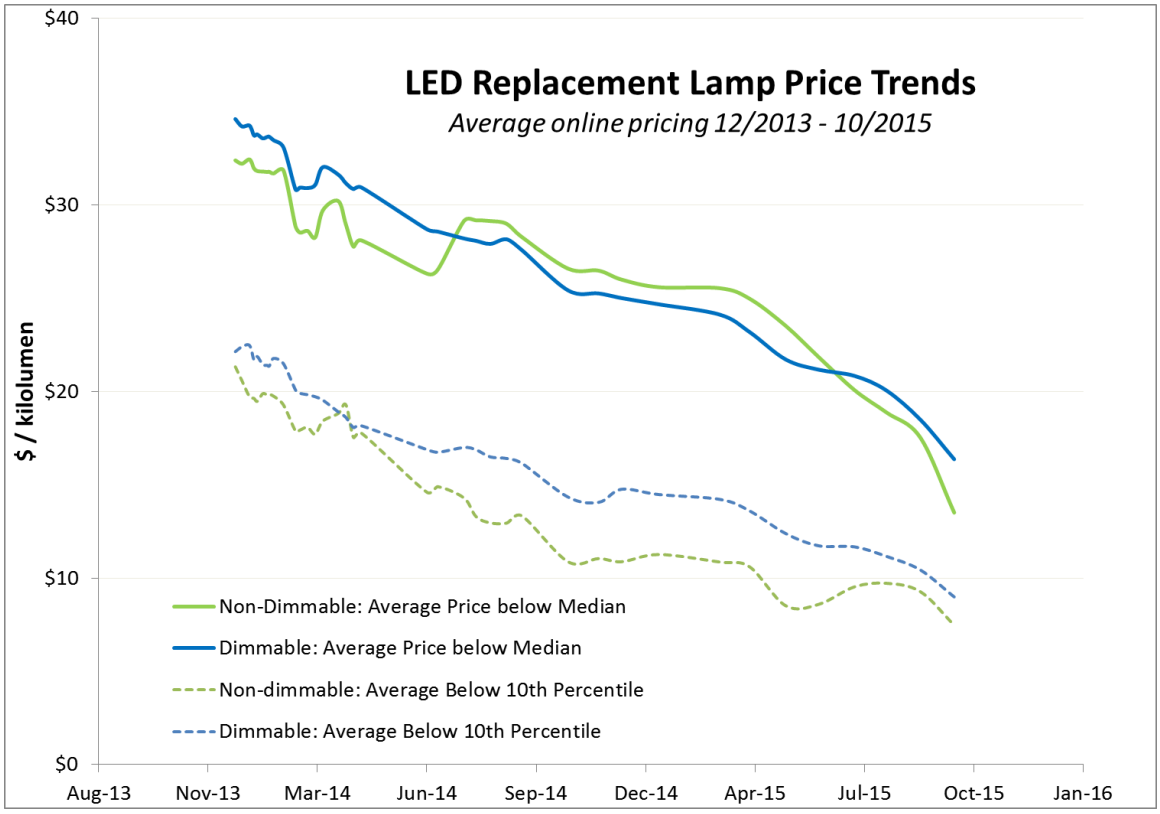
[5] Northwest Energy Efficiency Alliance; 2011 Residential Building Stock Assessment: Single Family Characteristics and Energy Use, 2012. http://neea.org/docs/reports/residential-building-stock-assessment-single-family-characteristics-and-energy-use.pdf?sfvrsn=8

Table 3. Weighted Average per Unit Annual Energy Savings by Lamp Type (for lamps installed in all CA sockets)

		Annual Energy Savings (kWh)			
		General Service A-lamp	Large Diameter Directional Lamp	Small Diameter Directional Lamp	Decorative Lamp
Not Installed on Dimmer	75%	2.1	5.5	3.4	2.2
Installed on Dimmer	25%	6.2	13.8	8.4	3.9
Weighted Average Per Unit Annual Energy Savings		**3.1**	**7.6**	**4.6**	**2.6**

Off-the-record comments from industry contacts who are either in the driver manufacturer community or who have conducted research into dimming driver ICs suggests that the incremental cost for an LED driver to be dimmable is small and shrinking. Estimates range from $0.15 to $0.20 incremental manufacturer cost, dropping to 5 cents or less in the next few years. To verify that the incremental manufacturer cost to add dimmability is indeed small, the CASE team has conducted an analysis of thousands of retail prices collected from 9 online retailers. Based on statistical analysis of that data, there is no statistical relationship between dimmability and retail prices for A-lamps. Additionally, as shown in the figure below, online prices for dimmable LED replacement lamp products (based on price points from hundreds of products) are occasionally slightly lower than prices for non-dimmable products. This suggests that any incremental manufacturer cost associated with making a product dimmable is negligible. It also stands in stark contrast to the CFL market, where historically few products were dimmable and they carried significant incremental retail prices.

Figure 15. 2014 Average Online Pricing for Dimmable vs. Non-Dimmable LED Lamps



We also recommend that lamps designed for use with forward phase cut dimmers (the majority of LED replacement lamps) be compliant with NEMA SSL7A, the industry's phase-cut dimmer compatibility standard. This standard addresses dimming performance aspects such as improved dimming range, reduced dead travel (switch is adjusted but no change in light), pop-on (when adjusting dimmer from the lowest setting upward, light turns on suddenly in the middle of the range, rather than gradually, from a very low light level), drop-out (light source drops out prematurely as lights are being dimmed), ghosting (light source is at a low-level "on" state when switch is in "off" position), and premature failure of LEDs. Compliance with NEMA SSL7A has already been adopted in Title 24 for lamps and dimmers, with the support of industry stakeholders. Adopting this requirement would not limit design options for dimming strategy, because it would only be required for lamps designed for forward phase cut dimmers. Lamps designed to work on other less common dimmer types would not have to meet SSL7A.

2.5 Dimming Test Procedure

We recommend that CEC provide more specificity around the test procedure for verification of dimming performance in Title 20. The CEC has already specified a dimming test procedure in Joint Appendix JA8 of Title 24, which provides guidance on what dimmers should be used for testing. Title 24 JA8 requires manufacturers certifying a lamp to specify which dimmer types are compatible with the lamp. The lamp must be listed as compatible with at least one type (e.g. forward phase cut, reverse phase cut, 0-10V, etc.). JA8 also requires that the lamp be tested on at

least one dimmer of any type claimed as compatible. For example, if the product claims to be dimmable using a forward phase cut dimmer, it must pass the dimming, flicker and noise requirements when tested on at least one forward phase cut dimmer. If a product claims to be dimmable on other dimmer types, it must pass these requirements on at least one of each of them.

Because this has already been adopted in Title 24, and the data certification efforts are now going to overlap for products certifying to either Title 24 or Title 20, this should be straightforward for CEC to align Title 20 with Title 24. This change should be made by adding "dimmability" to the test procedures listed in Table K1, along with a reference to Section 8.3.7 of Joint Appendix JA8. Additionally, in Section 1606, Table X, the CEC should require lamps being certified to Title 20 to provide the same information that lamps being certified to Title 24 are required to provide (i.e. which dimmer types they have been tested with).

2.6 Flicker

We support CEC's proposal to require reduced flicker operation in dimmable LED lamps, but if non-dimmable lamps are allowed, we recommend that CEC broaden flicker requirements to apply to those too (at full light output only). The main component of photometric flicker arising in LED lighting at frequencies below 200Hz is primarily generated by full-wave rectification of the AC mains, and which occurs at the second harmonic of the mains frequency (120 Hz). While it is the case that this flicker component can, in the case of many LED lighting products, be exacerbated by dimming, it is not caused by dimming. Objectionable levels of flicker can occur among products that do not claim to be dimmable, and/or are not operating on a dimmer, and we therefore strongly suggest that the reduced flicker operation requirements apply to all LED lamps covered by Title 20 regulations.

The CA IOU team has completed a significant amount of flicker testing on a number of different product types, at several different labs, in 2014-2015. This testing has found that the test procedure proposed and adopted in Reference Joint Appendix 10 of Title 24 is repeatable. It also found that there are products available that provide reduced flicker operation in every product category being considered in this rulemaking: A-lamps, directional lamps, decorative lamps, and downlights.

Lastly, in the data collection table format for product certification, the 45-day language appears to allow manufacturers to submit only a "yes/no" response to indicate whether they meet the flicker requirements. We urge the CEC to modify this field in the table to require products to list their specific measured performance. Collecting the specific flicker performance results at 100% light output and 20% light output is a very important aspect of the flicker standard because currently there is no public database of LED flicker data. This data will be extremely helpful for the lighting design community and to distinguish products with the lowest levels of flicker.

2.7 Labeling, Marking, and Reporting

We support CEC's proposal to require lamps marketed as incandescent replacements or equivalents to have a CCT of 3000K or less. Typical incandescent lamps provide a CCT in the range of 2700K to 2900K, and most consumers expect this warm quality of light from a light bulb. While some consumers may prefer and seek out high CCT lamps, it is misleading to market a product as a replacement for an incandescent if it provides a light color that is dramatically

different. This is likely to lead to consumer dissatisfaction, similar to that experienced in the CFL market where many consumers objected to CFLs providing light that was too "cold" and "harsh." However, we recommend that the CEC require lamps *to be capable of* providing a CCT of 3000K, to accommodate color changing lamps.[6]

For the same reason, we also support CEC's proposal to require lamps marketed as incandescent replacements or equivalents to provide a minimum light output corresponding to the claimed wattage equivalency. However, the values in the table provided by CEC should apply only to omnidirectional A lamps. Separate lumen equivalency values should be provided for directional and decorative lamps. CEC should use the ENERGY STAR values provided for lumen equivalencies for each lamp type, and should also utilize the ENERGY STAR center beam candle power equivalence tool for MR and PAR lamps.

Lastly, we encourage CEC to consider using the "equivalency" claims or any lamp marketing comparisons to incandescent to enforce other aspects of the CEC Voluntary Specification that are not being required of all lamps. As an example, if the CEC does not require all lamps to provide 90 CRI, it should at least require lamps claiming to be incandescent replacements to meet this level of performance. This would be consistent with the proposal to require a minimum light output (in terms of lumens) and a specific color temperature range to provide light that is similar to incandescent.

There are several additional marking / labeling requirements that we recommend that CEC adopt. First, we recommend that all lamp packaging include a label indicating the product's CRI, and for directional lamps, a label indicating the product's beam angle. These two metrics are not included in the Federal Trade Commission (FTC) Lighting Facts Label but they are extremely important product attributes that will help consumers. Though CEC does not have authority to revise or add to the FTC label, we recommend that California require these two product attributes be added elsewhere on the product package, for example directly below the FTC label.

Lastly, we recommend that the date of manufacturer be permanently marked on all products in the format: MM/YYYY. The Warren-Alquist Act already requires date of manufacturer be marked on covered products in Title 20, but there appears to be either low compliance with this requirement or alternate date formats/codes used that cannot be interpreted by average consumers. Having a clearly marked date of manufacturer will help consumers follow up on product warranties in the event of product failures. Date of manufacture markings will also help with standards enforcement and compliance improvement for regulators in the State.

[6] Conversely, CEC could consider exempting color changing lamps from several of the specific aspects of this standards proposal.