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Soraa comments on NOPA - Docket # 15-AAER-6

Additional submitted attachment is included below.

Docket Unit
California Energy Commission
Docket No. 15-AAER-6
1516 9th Street, MS-4
Sacramento, CA 95814

Fremont, December 7th, 2015

SUBJECT: Comments to the Notice of Proposed Action on “PROPOSED AMENDMENTS TO APPLIANCE EFFICIENCY REGULATIONS” (Docket # 15-AAER-06)

Dear Sir, Dear Madam,

It is with great appreciation for the California Energy Commission’s efforts to increase the adoption of efficient lighting technologies, that we offer our comments to the Notice of Proposed Action on “PROPOSED AMENDMENTS TO APPLIANCE EFFICIENCY REGULATIONS”.

We present comments on two aspects of the proposal:

Comments on efficiency limits (page 2)

Comments on standby mode consumption (page 12)

Yours sincerely,

Aurelien David
Sr. Principal Scientist

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COMMENT ON EFFICIENCY LIMITS

Introduction

First, we would like to express our support of the CEC's approach to provide a CRI-dependent efficiency limit. By doing so, CEC Staff recognizes that there exists a fundamental trade-off between lamp efficiency and CRI, and that manufacturers may want to operate at various points in this trade-off. CEC staff has made a careful effort to quantify this trade-off and include it in its proposal. This choice will enable high color quality products, which is crucial for adoption in some markets.

We would also like to acknowledge CEC Staff for engaging with Soraa in defining a small-diameter lamp spec; the current proposal rightly takes into account the additional difficulty to optimize such lamps. Small-directional lamp form factors are crucial in some applications, and the fact that the CEC's proposal differentiates them from larger form factors is important to allow these products to exist.

By making these important distinctions, the CEC sets a healthy general framework for discussing efficiency limits. However, we find two main issues with the proposal on efficiency limits as it stands.

First, the CEC did not thoroughly extend its analysis of the trade-off between efficiency and quality: other aspects of product quality have not been fully taken into account in the current proposal. Each of these aspects also comes at a slight, but fundamental, cost in efficiency. It is important for manufacturers to be able to balance efficiency and quality in product design; this is only possible if efficiency limits are not too stringent.

In addition, upon careful study of the CEC's feasibility analysis, we have found flaws in its conclusions, in large part caused by inaccuracies in product databases. Once such inaccuracies are corrected, very different conclusions emerge regarding feasibility.

Therefore, we find that for some products, the current proposal is very aggressive and would make it challenging to achieve the required efficiency limits – in such cases, the only option for manufacturers will be to worsen some aspects of product quality to gain efficiency, and phase out high-quality products from California. This would undoubtedly hurt adoption in certain markets. Therefore, we suggest that the CEC should mitigate its requirements for certain products.

In the following, we discuss these quality/efficiency trade-offs in more technical details; we point out inaccuracies in the CEC's feasibility analysis; and we make a revised proposal for efficiency limits.

Trade-offs between quality and efficiency

Below, we review some properties of light sources which can be desirable but can only be improved at a slight cost in energy efficiency.

a) Directional sources, beam quality

Controlling the emission pattern of a light source is done through optics. Diffuse sources (such as A-lamps) only require an optical diffuser – whose optical efficiency is typically ~95%. On the other hand, directional lamps (such as MR and PAR lamps) require directional optics to direct the beam.

Directional optics have limited optical efficiency, typically ~85%. Furthermore, tighter beams (e.g. 4^o, 10^o) are more challenging to design: indeed they require small, bright LED sources (due to the fundamental limit of *etendue conservation*) which tend to be less efficient and more thermally-constrained.

It is crucial to realize that for directional sources, *more lumens can be bad for quality*. Especially for sources with beams of 25^o and below, it is undesirable to have lumens in the spill of the beam (e.g. large-angle light) because it causes glare. Therefore, a good optical designer will strive to remove spill lumens. However, spill lumens are especially beneficial to efficiency. Thus, given a stringent efficiency limit, it can be tempting for a manufacturer to add spill lumens in order to artificially meet requirements, even though this loophole causes an overall decrease in product quality.

We note that the efficiency 'cost' of directional sources is readily apparent in the CEC's analysis of market data (with directional sources being overall less efficient than omnidirectional sources). The CEC, to some extent, already recognizes this limitation: indeed it places small-diameter directional lamps in a separate category. Surprisingly however, this analysis is not applied to large-diameter directional lamps such as PAR30 or PAR38 lamps. While slightly less challenging to design than small-diameter lamps, these lamps still suffer from a fundamental efficiency penalty versus diffuse lamps.

b) Color rendition

Two well-known aspects of color rendition are considered by the CEC: source chromaticity and CRI Ra. However, color rendition is a complex topic with many aspects. Among these, two crucial aspects are not considered by the CEC:

- *Deep-red rendering*, quantified by the CRI index R9, is known to have a strong influence on perceived quality of light (arguably even more than the average CRI Ra score), as documented in [Wei15]. A high R9 value requires long-wavelength photons in the spectrum, which has a fundamental efficiency cost. Some manufacturers, including Soraa, make sure that their high-CRI sources also have a high R9 value (for instance, R9>90). However, other manufacturers design sources with a high CRI (say 90) but a moderate R9 (50 or less). Decreasing R9 from 90 to 50 can raise efficiency by ~8%, however it degrades product quality.

- *Whiteness rendering*. Many white products require violet light or ultra-violet radiation (both present in natural light) to produce a pleasant, bright white rendering. Unfortunately, the vast majority of existing LED products have a spectrum of emission which starts with blue light. They are therefore unable to render white objects properly – an effect which is completely ignored by the CRI, but is very easily perceived [Houser14]. Adding violet light in the spectrum of an LED product is a simple way to restore whiteness rendering, however it costs ~3-4% efficiency. Studies have shown that such proper white rendering elicits a pronounced preference from users [Wei15]. In our experience, this feature is essential for adoption by some customers, including commercial applications.

The CEC proposal ignores both of these aspects. Therefore, it places manufacturers in an uncomfortable position: to increase efficiency, an easy choice is to remove whiteness rendering and reduce deep-red rendering. These two steps can boost efficiency by 10% or more, but again hurt product quality.

c) Driver quality, flicker

LED drivers provide rectification of AC current. Basic drivers provide limited rectification, which leads to stroboscopic flicker (especially upon dimming). Better-quality drivers provide a smoother waveform and less or no flicker, but this negatively impacts efficiency and product cost. Furthermore, high-end drivers tend to require larger electronic components. Thus such drivers are especially challenging to implement in sources with high heat generation and limited space – namely in directional lamps, and especially so in small form factor lamps.

Some drivers can have efficiencies as high as 90%. However, the size constraints of directional lamps (especially small-diameter) lead to typical efficiencies of about 80-85%. Furthermore, improving the quality of the driver to reduce flicker can have an efficiency cost of about 5%.

d) Form factor

Products having a restricted form factor are more difficult to design, because they offer less room for heatsinking (which impacts both performance and lifetime). This is especially relevant for small-diameter directional sources, which must fit all elements of the system (LED, optics, driver, heatsink) in a small lamp envelope. It can be tempting for manufacturers to sidestep this challenge by designing products which don't conform to this standard envelope (for instance the ANSI for factor of an MR16 lamp). In fact, a review of product by major manufacturers reveals that very few existing MR16 LED lamps conform to the ANSI form factor – due to protrusions of the heatsink and/or optics. These products are therefore not compatible with all standard fixtures – a problematic situation for customers.

Soraa has strived to offer products ANSI-compliant lamps, and has accepted to deal with the associated design challenges. We are intent on maintaining this aspect of product quality. However it is important to realize that not all manufacturers follow this spirit, and that higher-efficiency products sometimes suffer from non-compliant form factors.

Comments on the CEC's feasibility analysis

The CEC's approach is data-driven, which is a sound choice. However, we have founds flaws in the implementation of this approach. Namely, the CEC finds some products which nominally meet the proposed limit (in the Energy Star and LightingFacts databases) and concludes that this establishes feasibility. However, none of the quality aspects mentioned above (beam quality, color rendering beyond CRI, flicker, form factor) are considered. Furthermore, in many cases, the qualifying products do not seem to actually exist.

A detailed discussion of the CEC's feasibility analysis can be found in Annexes A and B. Our high-level conclusions are as follows (we use the term medium-size for general-service directional lamps which are not in the small-size category):

- For directional medium-size lamps, a plurality of lamps meet Tier 1. However, only a very small number (seven) meet Tier 1 with high color rendering (Ra>90, R9>90). None of these have a PAR30 form factor, none have a beam angle <15^{o}, and none have whiteness rendering.
- For directional medium-size lamps, very few lamps (six) nominally meet Tier 2. None are from major lamp manufacturers, and none seem to actually exist.
- For directional small-size lamps, very few low-CRI products meet the proposed spec and only three of those are from a major manufacturer; they lack narrow beam angles and whiteness rendering. Not a single high-CRI lamp meets the proposed spec, due to the weaker CRI-efficiency derating in small-size lamps.

This stands in sharp contrast to the CEC's report, which concluded that a large number of products already meet the proposed specs.

As it stands, the CEC proposal would lead to a drastic reduction in directional lamp availability. For medium-size directional lamps, very few high-color-quality lamps and no narrow-beam lamps (10^{o} and less) qualify for Tier 1; none qualify for Tier 2. For small-diameter lamps, no high-color-quality lamp qualifies whatsoever. In short, the highest-quality products would be phased out from the California market.

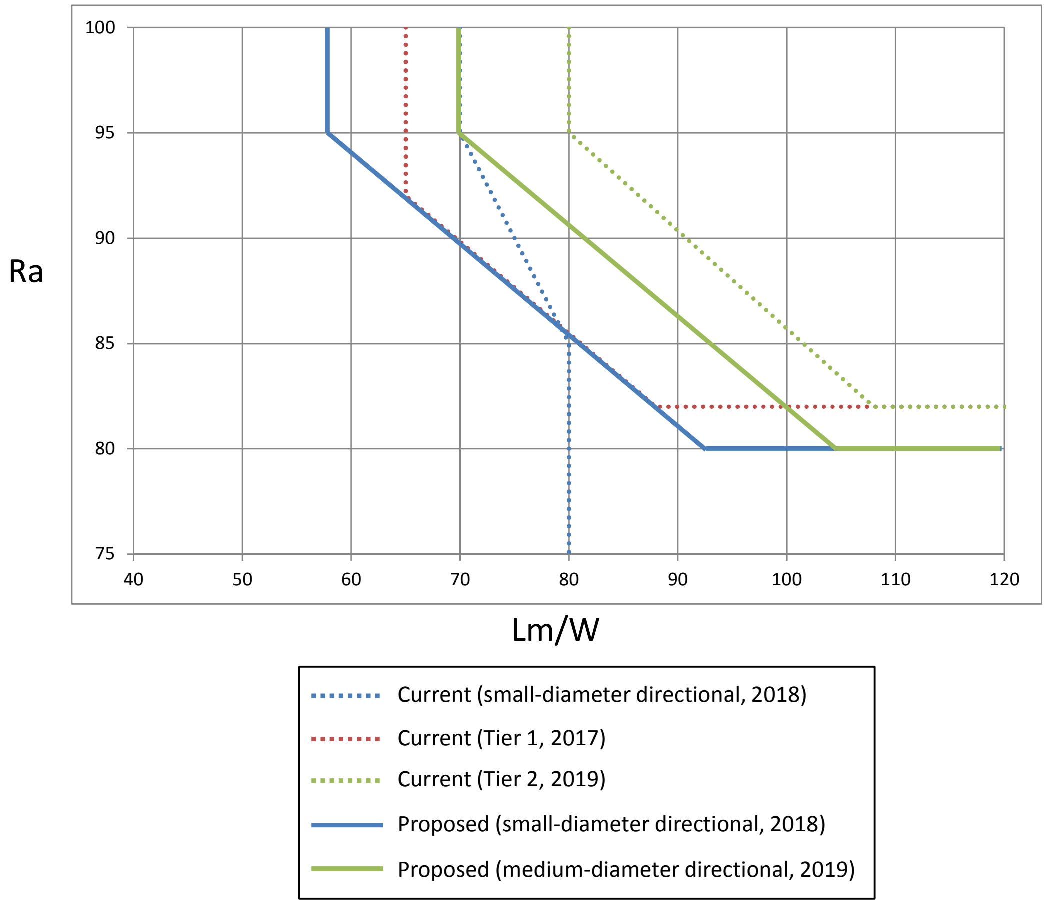
We understand that the CEC might expect that future technology improvements will help meet these objectives. Certainly, manufacturers (including Soraa) strive to constantly improve their technology. However, it is important to realize than intrinsic efficiency improvements have been nearly non-existent for most manufacturers over the last two years (the wall-plug efficiency of LEDs is unchanged within a few %). Rather, improvements in applications have been obtained by increasing the number of LED chips per lamp. This workaround, however, can no longer be applied in directional lamps where the emitting area is constricted and now reaching its limit value.

Proposal

We believe that the CEC proposal for efficiency limits is too aggressive for directional lamps in general. We realize that including corrective factors for each aspect of product quality may be too complex. Rather, we propose that efficiency limits be somewhat relaxed in order for manufacturers to keep the ability to sell their highest-quality products in California.

Therefore, we propose that the CEC create a separate category for medium-size directional lamps, with lower standards than those currently proposed. In addition, we suggest that the CRI-efficiency trade-off should be harmonized to have the same magnitude for all lamp types, as this trade-off is fundamental and does not depend on the product type.

Specifically, we propose the following limits:



This proposal remediates various flaws found in the current CEC proposal. Namely:

- It harmonizes the CRI-efficiency trade-off for all lamps sizes, as should be the case
- It makes it possible to design high-quality directional products (including color rendering and spot beams)
- It recognizes that medium-size directional products are fundamentally less efficient than omnidirectional lamps, and thus slightly relaxes their spec. At the same time, it recognizes that they are somewhat easier to design than small-diameter products.

We also note that this proposal is somewhat consistent with (although more demanding than) the latest Energy Star 2.0 proposal for high-CRI lamps.

Annex A – feasibility analysis for medium-size directional lamps

We use the most recent data form Energy Star and LightingFacts (November 2015). We consider warm-white (CCT=2700 or 3000) directional lamps (PAR and BR). More than 3.000 lamps meet these criteria.

Tier 1

A fair number of products meet the Tier 1 requirement; most have either low Ra or low R9.

However, if we focus the analysis on products with high color rendering (e.g. Ra>=90, R9>=90), conclusions are very different. Only fourteen lamps (all PAR38 lamps) meet such requirement. No PAR30 meets the requirement. Only two products have a beam angle of 15° and no product has a tighter beam angle. No product has whiteness rendering.

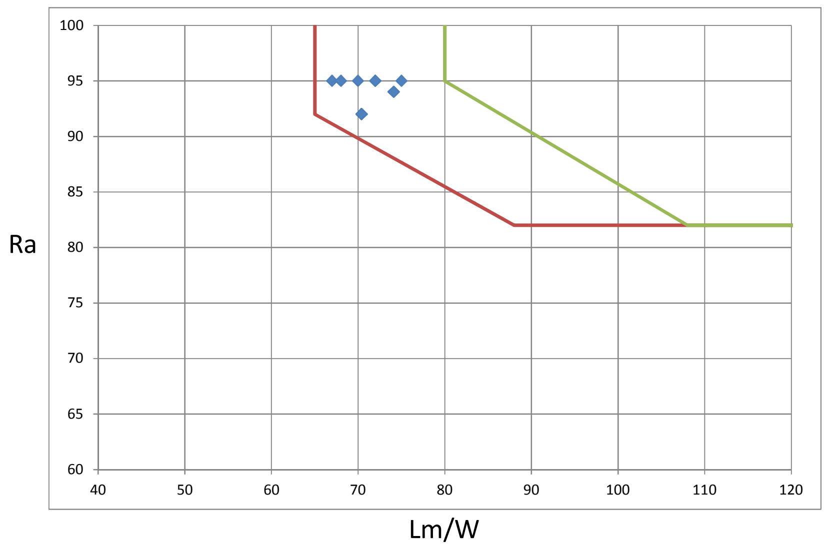


Figure 1: Warm-white directional products meeting Tier 1, with high color rendering (Ra>90, R9>90).

This indicates that the CEC Tier 1 proposal is already very challenging, considering its timing. Only a handful of products with high color rendering (including R9) are able to meet it. It is unclear how this situation can improve significantly by January 2017. Thus the current proposal would allow only a handful of lamps with high color rendering, none of which have whiteness rendering or spot beam angles.

Tier 2

When considering all directional lamps (either low or high CRI), only four lamps **nominally** meet the CEC Tier 2 requirement. However the actual existence of these products is unclear. Namely, the qualifying products are from:

- Dongguan City Lemark Lighting, a Chinese manufacturer. The qualifying products found on the E* database do not seem to exist on their website. The company's PAR38 spec sheet claims

66lm/W, versus the E* value of 92 (http://lemarklighting.gmc.globalmarket.com/products/par-lamp-3550-1-38.html).

- Lihgting Investments LTD, a division of Epistar. The qualifying lamps are shown on the LightingFacts database as "not available". The products cannot be found online. To the best of our knowledge, Epistar only sells components and not lamps. (http://www.epistar.com.tw/_english/01_product/01_overview.php)

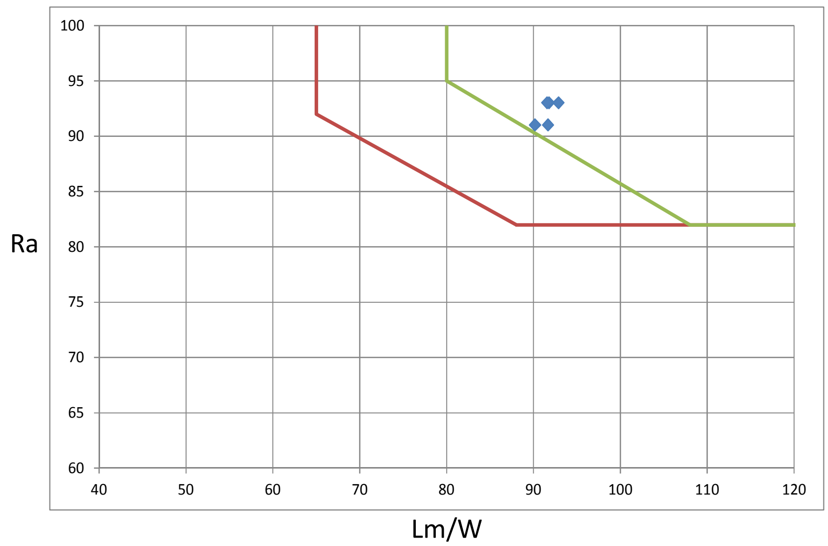


Figure 2: Warm-white directional lamps nominally meeting Tier 2. None of these products appear to actually be available.

Thus none of the qualifying products are from recognized lamp manufacturers, nor do they appear to actually be commercially available. In summary **we cannot find any existing product meeting the Tier 2 requirement**.

Annex B – feasibility analysis for small-size directional lamps

We use the most recent data form Energy Star and LightingFacts (November 2015). We consider warm-white (CCT=2700 or 3000) directional lamps (16-diameter). More than 600 lamps meet these criteria.

Among low-CRI lamps (Ra<90), 35 products nominally meet the CEC requirement. We did not pursue an in-depth study of each. However, we note that all are products from minor manufacturers, for which availability and existence are unclear – except for three lamps from Philips Lighting.

Among high-CRI lamps (Ra>90), nine products **nominally** meet the CEC requirement. However upon inspection of the database, the efficiency data is incorrect for all of these. Namely, the qualifying lamps are from:

- Dauer Mfg (http://dauerled.com/product/mr16-7-watt/), whose products have an actual efficiency 65lm/W rather than 77lm/W
- ESLVision (http://www.eslvision.com/) which does not appear to be offering any MR16 (or retrofit lamp) products
- LightingScience Group, whose LSPro model has an efficiency of 62.5 lm/W rather than 75.5lm/W (https://www.lsgc.com/collections/professional/products/lspro-mr16-gu10?variant=7315524677)
- Tospo Lighting (http://www.tospolighting.com/proDetail.aspx?proId=132) whose products have an actual efficiency 65lm/W rather than 71lm/W
- Turolight (http://www.turolight.com/product/VIV-MR16-CC-7W-30-FL25-GU10-D) whose products have an actual efficiency 66lm/W rather than 78lm/W

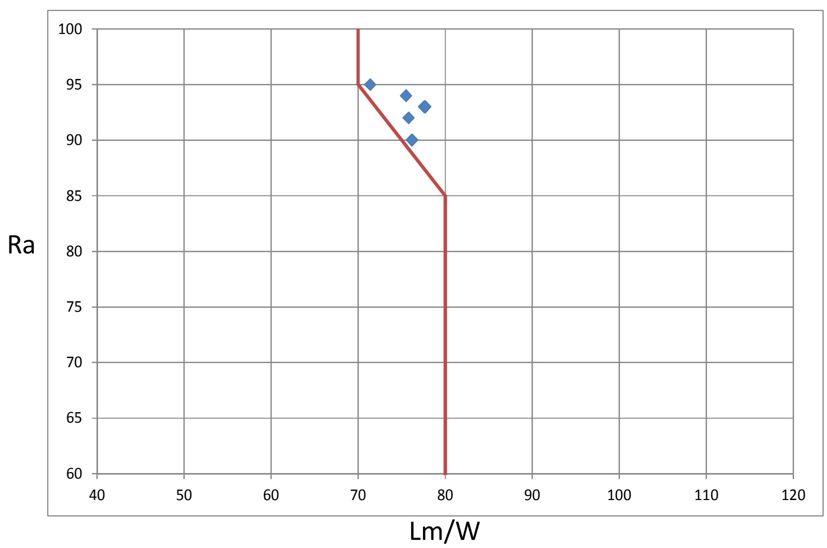


Figure 3: Small-diameter lamps with Ra>90 nominally meeting the CEC proposal. None of these products appear to actually be available.

Therefore we conclude that no single existing small-diameter lamp with high CRI actually meets the proposal. This is in large part due to the CRI-dependent efficiency derating, which is much weaker for small-diameter lamps than other lamps. This, in practice, makes high CRI products more challenging to design in small-diameter lamps than in other form factors – an inappropriate situation, since there is a clear call for such products in applications like retail. The trade-off between efficiency and CRI is fundamental, and it should be the same for all lamps.

Surprisingly, the CEC report does not justify feasibility by considering data on small-diameter lamps but medium-diameter lamps instead, and states (see p.40) "*Figure 13 below shows the number of general service, medium screw base directional lamps with high CRI and high efficacy, demonstrating that the LED chips, drivers, and controllers exist and simply need to be included in small-diameter directional lamps.*"

Of course this reasoning does not hold: the smaller size of small-diameter lamps makes it impossible to include as many LED chips, and to use the same optics and electronics as in larger lamps (otherwise, manufacturers would have done so long ago) – especially while conforming to a standard form factor. This is precisely the reason why they belong in a separate category, as recognized by the CEC, and why using data from larger lamps to demonstrate technical feasibility makes no sense.

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Bibliography

Houser14 Houser K et al, "Whiteness Perception under LED Illumination", LEUKOS 10 (2014).

Wei15 Wei M et al, "Perceptual responses to LED illumination with colour rendering indices of 85 and 97", Light Res. Tech 47 (2015)

COMMENT ON STANDBY MODE CONSUMPTION

The CEC proposes that connected lamps have a maximum standby consumption of 0.2 watts. There is widespread agreement in the industry that this value is too stringent, as it doesn't enable modern data communication protocols to be monitored. In the study cited by the CEC, only one lamp model meets this requirement – and this lamp requires a bridge, thus increasing its actual consumption. Therefore, this value does not seem practical.

We also note that various entities are proposing a more reasonable limit of 0.5W (including the latest Energy Star proposal, and the upcoming European Union's Ecodesign proposal).

We propose that the current value be raised to 0.5 watts – a value met by a fraction of the existing products, and in line with proposals by other regulatory bodies and with technological needs.