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California Energy Commission

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Mr. Andrew McAllister
Commissioner
California Energy Commission
1516 Ninth Street
Sacramento, California 95814

NEMA Comments on Staff Analysis of Small Diameter Directional Lamp and Light Emitting Diode Lamp Efficiency Opportunities

Dear Commissioner McAllister,

The National Electrical Manufacturers Association (NEMA) appreciates the opportunity to provide the attached comments on the California Energy Commission's staff analysis for Small Diameter Directional Lamp and Light Emitting Diode Lamp Efficiency Opportunities. These comments are submitted on behalf of NEMA Light Source, Ballast and Driver and Lighting Controls Product Sections.

As you may know, NEMA is the association of electrical equipment and medical imaging manufacturers, founded in 1926 and headquartered in Arlington, Virginia. Its approximately 400 member companies manufacture a diverse set of products including power transmission and distribution equipment, lighting systems, factory automation and control systems, and medical diagnostic imaging systems. The U.S. electroindustry accounts for more than 7,000 manufacturing facilities, nearly 400,000 workers, and over \$100 billion in total U.S. shipments.

Please find our detailed comments below. We look forward to working with you further on this important project. If you have any questions on these comments, please contact Alex Boesenberg of NEMA at 703-841-3268 or alex.boesenberg@nema.org.

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NEMA Comments on Staff Analysis of Small Diameter Directional Lamp and Light Emitting Diode Lamp Efficiency Opportunities

NEMA thanks the Commission for the opportunity to comment on and participate in their efforts to develop and adopt energy standards for Small Diameter Directional Lamps and Light Emitting Diode Lamps. NEMA supports practical, feasible energy performance requirements for electrical products and shares the Commission's desire to save energy in the State of California.

LED Lamps:

1. At the outset, NEMA appreciates the acknowledgement at page 44 of the Staff Analysis that "the DOE is in the framework stage of a "general service lamp" performance standard that would, as currently proposed, cover medium screw-base LED omnidirectional lamps. The performance standards that would be finalized through this process would also eventually replace state-specific standards where the scopes overlap." At this time, NEMA believes it is probable that an energy conservation standard for general service LED lamps will be promulgated by the Department of Energy by December 31, 2016, in which case state standards would be preempted under 42 USC §6297 and the Energy Independence and Security Act of 2007 §321(a)(3), 42 USC §6295(i)(6)(A)(vi)(I). If that occurs as we expect, then California is permitted to adopt those federal standards and make them effective as early as January 1, 2018. This point ties into our separate comment immediately below about a single effective date, which makes far more sense to NEMA and its members than a two-tier effective date proposal.
2. Comments on Effective Dates/Tiers: we appreciate the CEC's attempt to lessen compliance burden by establishing two tiers to be phased in over two-year's time, but in practicality this will not reduce manufacturer's burdens. We suggest a single 2018 effective date harmonized with the MR proposals and only a single tier, with early compliance/listing allowed.
3. While we appreciate the desire of the CEC to encourage maximum energy savings, the CEC should recognize the billions of dollars already being invested in LED technology by producers and CEC should not add unnecessarily to this investment challenge. Innovation with this new lighting technology is occurring rapidly and product obsolescence (less than a year) is equally rapid. At this stage in the development of solid-state lighting products, Title 20 Regulations should be minimum performance requirements. There are attributes of the proposal in the Staff Analysis that go beyond minimum efficiency and efficacy performance requirements that would only add to product cost and risk delaying market adoption. And the Staff Analysis contains inadequate evaluation of these manufacturer and consumer burden and cost impacts. These are important, because the Warren-Alquist Act requires the Commission to consider "impact on product efficacy for the consumer," Cal. Public Resources Code §25402(c)(1), and if there are no alternative products capable of conveniently replacing

the product that the proposed standards will eliminate there is a substantial negative impact on product efficacy for the consumer. Additionally, as manufacturing industry investments are forced to increase, this leads to direct impacts on consumer product purchase prices. Initial purchase price has again and again been cited as the number one hurdle to widespread adoption¹, it is the very reason that rebate programs already exist in dozens of states for high-efficiency products. The CEC should not mandate high-performance as the State minimum, only to increase the primary obstacle to adoption, i.e. cost.

4. Flicker requirements: NEMA reaffirms its opposition to the CEC establishing mandatory flicker test procedures and minimum performance levels ahead of numerous industry working groups examining this phenomenon and working to identify repeatable objective tests to evaluate it. Additionally we note that the CEC has proposed a Flicker Test Procedure in the Title 24 rulemaking. There is no clear reason why this Test Procedure has been drafted for the CA Building Energy Efficiency Regulation, and it is out of place there. Furthermore, we caution against adopting this draft test procedure because it has not been adequately tested. The number of devices tested by the IOU/CASE team is woefully inadequate and the CEC is taking a significant risk by relying on such a small, unrepresentative data set. Work has already begun in the ENERGY STAR Lamps program, and the CEC should allow the data gathering and analysis begun there to reach some conclusions.
5. We wish to point out that the CEC in the staff report incorrectly interprets a claim of 500 lpw LEDs from the Seoul Semiconductor Corporation, footnote 56 page 46/84. The actual article states "Currently, the brightness of a power chip LED in mass production is around 100 lumen but this new product, introduced by Seoul Semiconductor, produces 500 lumen which is 5 times better than a conventional product."² The claim is for a product with 5 times higher lumens than their current product, not 5 times higher efficiency or 500 lumens per watt.
6. In regards to the proposed approach of using an Efficiency Equation as the method of certifying products, we disagree with this proposal. The realities of designing reliable, repeatable Color Rendering Index (CRI) performance at economies of scale demands overdesign in the approach, effectively eliminating tradeoffs. Instead the CEC should use mandatory minimums of 80 CRI and 60 lpw. These are achievable with today's technology, an important legal requirement for CEC. Different applications require different color quality and efficiency and consumers demand options and choices in product performance. Likewise CEC should not hamper innovation by making overly restrictive minimum performance requirements. CRI is a faulty metric, and should not be overly relied upon. It is not a guarantee of consumer satisfaction. Studies have shown

¹ http://www.mckinsey.com/client_service/semiconductors/latest_thinking/led_at_the_crossroads LED penetration roadblock #1

http://www.calmac.org/publications/LED_Market_Characterization_Report_-_Final.pdf Market Barriers item #1, p53/71

² <http://www.ledlighting-eetimes.com/en/seoul-semi-quintuples-led-brightness-with-new-technology.html?cmpid=7&newsid=222908002>

that CRI of 80 is acceptable to most consumers³, and lower CRI is less costly. Setting a minimum CRI of 80 does not preclude manufacturers and specifiers from pursuing higher CRI levels where that makes sense, but it allows for more cost-effective options.

7. Minimum lifetime: NEMA recommends 10,000 hours for LED lamps in this proposal, which is consistent with our NEMA Standard SSL-4⁴ and is a fair minimum requirement.
8. NEMA suggests that CEC allow lamps qualified and listed with the ENERGY STAR program be waived from any additional durability testing in the Title 20 regulation. There is no need to duplicate testing.
9. NEMA disagrees with the CEC and IOU proposals to require a 4-step MacAdam ellipse. There is no evidence to suggest this is important to consumers or market acceptance. In fact, a study performed by the Lighting Research Center (LRC), Troy, NY⁵ notes that color off the black body curve can be just as acceptable if not more acceptable to consumers. This research calls for caution in setting overly-prescriptive regulatory requirements until the topic is more understood scientifically. The requirement should be set consistent with the ENERGY STAR Lamps Specification which requires a 7-step MacAdam ellipse. This will eliminate confusion and reduce unnecessary cost burden. Similar to our discussion above about CRI, the black body curve is an evaluation of how well a lamp mimics incandescent light. We contend it is not essential, and could be detrimental to innovation to closely copy this centuries old technology. Additionally, we note that the scope of Title 20 includes Modified Spectrum products, which are outside the 4-step by their very nature, another reason why a 7-step ellipse is needed.
10. We continue to disagree with the IOU proposals that a State-specific label or labeling requirements be established. The additional costs and difficulty of assuring proper distribution are not justified in the intangible benefits pursued by the proposals. CEC has routinely stated their intent to set a trend for other States to follow, and should keep in mind that a State-specific label is not in keeping with their attempts to set a standard that can be adopted at the national level. This also respects manufacturer's tendencies to produce and label products for sale in multiple regions. It is costly to produce lamp packaging for sale in a single State and challenging to assure proper distribution therein. Additionally, existing labeling is strictly challenged to meet Federal and other disclosure and marking requirements while being simple to read and understand. A State label only complicates this situation.
11. We disagree with establishing a dimming requirement to 10% of full light output. This is extremely difficult to verify and assure in the field due to the extremely varied designs in the installed base of dimmers. We understand CEC's desire to assure compatibility and satisfactory performance, and we share that desire. However, standards are still being developed and these are for current and future dimmer designs. It is not feasible to estimate and replicate legacy dimmer performance in a laboratory setting for repeatable certification, especially when the CEC is about to begin enforcement of Title 20 to include potentially substantial fines. To establish an unrepeatable dimmer to lamp

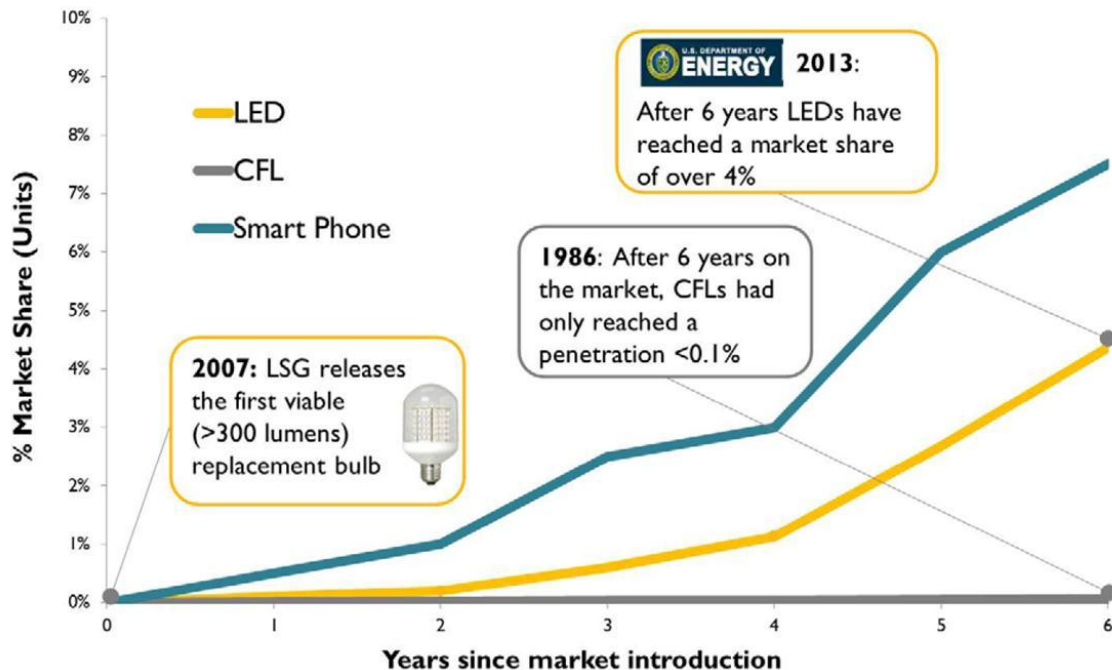
³ <http://www.consumerreports.org/cro/lightbulbs/buying-guide.htm>

⁴ <http://www.nema.org/Standards/Pages/Retrofit-Lamps-Minimum-Performance-Requirements.aspx>

⁵ https://www.jstage.jst.go.jp/article/jlve/37/2_3/37_IEIJ130000501/article

compatibility requirement would negatively affect certification and compliance enforcement. As to labeling, manufacturers handle that as best they can today with packaging and website information. Product labels are also heavily regulated Federally. Also in progress are uniform marking and testing requirements for the dimmers themselves, so the CEC proposal only deals with half of the issue and is therefore incomplete as proposed. The ENERGY STAR Lamp program is experiencing reasonable success with their 20% dimming requirement and we propose the CEC maintain this same level as a minimum requirement, allowing this larger national working group to address the topic.

12. We note that the CEC LED and MR Lamps staff report proposals vary greatly in their approach to dimming and compatibility requirements. This inconsistency should be repaired, and we suggest leaning towards the MR Lamps approach which accepts that dimming compatibility issues will sometimes have to be sorted out in the field.
13. The staff report on page 46/84 states “LEDs do not contribute to heat buildup in a room because no matter how long they remain on, they do not get hot to the touch.” This is a misleading statement. While it is true LEDs do not radiate heat outwardly in the same direction as their emitted lumens, LEDs do generate significant amounts of heat at their junction. High heat at the junction is a leading contributor to early demise of LEDs and cooling of LEDs is a significant technical concern. The LED lamps shown in pictures in the CEC workshop presentation clearly show cooling fins. LED Lamps do contribute to space heating, though it is less than legacy lighting products. We believe the CEC should perform Space Heating analyses. Current LED Lamp designs do conceivably add some measurable heat to spaces and this should be evaluated as for any other light source in Title 20. LEDs consume fewer watts for a given level of illuminance, but they still consume power, some of which is unavoidably heat.
14. In response to the routine retrospective comments regarding challenges with early CFL designs, we note that the DOE has clearly demonstrated that SSL is being adopted radically faster than CFL was (see figure below). There is simply no comparison between the two adoption rates. It no longer makes sense, in light of this high adoption rate, to persist in thinking that there is an overwhelming need to put in place strict requirements for CRI and other characteristics based on old arguments that the CFL story will repeat itself. There is little to suggest that the adoption of LED will suddenly reverse itself, nor a reason to fear it.



DOE report: "Solid-State Lighting: Early Lessons Learned on the Way to the Market" Published January 2014
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_lessons-learned_2014.pdf

Some stakeholders in the September 29 workshop made statements that fewer lumens might be required with a high CRI source than with a low CRI source. This is used as an argument that cost will not go up as much as expected, because fewer lumens are needed. This argument was made with no supporting evidence and without regard to Federal and State minimum lumens requirements based on incandescent equivalency, which force lumens output to remain flat, as it were. High CRI is therefore not an eligible tradeoff for lumens.

15. R factors and CRI: CRI is a test which gauges the ability of a given light source to mimic a reference light source. In practical application, CRI is a method of determining how similar a light source is to incandescent light, since incandescent sources are usually considered to be at a CRI of 100. It has been proposed by CEC that the 8 individual R factors, which are averaged to yield CRI, each rate at least 75 on a 100 scale. With typical LED formulations of today, R_1 - R_8 will only reach 75 consistently and reliably when the light source design in question yields an overall CRI at or near 90. In addition to the 8 standard color "factors", an additional factor, R_9 , is proposed by CEC to be added to requirements. R_9 is an evaluation of the light source's ability to render deep red tones and is often mistakenly focused on by regulators. Other R factors, R_8 in particular which gauges light reddish purple hues, sometimes referred to as vividness, have been demonstrated to affect consumer perception as much or more than R_9 . There are many performance features of incandescent light that the CEC and other advocates vocally wish to see eliminated in future light sources: high heat generation, low shock resistance, short lifetime, and fragility. There is no more reason to insist on a replication

of incandescent performance in color rendering than there is to mandate the LED Lamps have heaters in them to increase their power consumption by 300% or that LED lamps last 1 year or less under general use.

- a) R Value Manufacturing Variation: R_1 - R_8 values can and do vary from lot to lot. Manufacturers Nichia, Lumileds, CREE, and LG specification note a potential variation of up to ± 2 in CRI. OSRAM specifies ± 3 in CRI for the LED package itself. Note that the variations in a single R_i may be considerably larger, because 8 values are averaged to get the CRI.
- b) R Value Measurement Variation: Additionally, R value determinations can vary due to inevitable operator and equipment variation. We refer the CEC to CIE 13.3, which is referenced by Energy Star Lamps V1.1:

7.2 Uncertainties in the determination of R

Experience has shown that *Colour Rendering Indices* depend on the choice of reference illuminants and therefore, on the value of the correlated colour temperature, T_c (to calculate correlated colour temperature see [20 ... 33]), of the reference illuminant. The corrected value of R should be regarded as that obtained when this value of T_c is made equal to the correlated colour temperature of the lamp to be tested.

Experience has shown that differences in spectral power distribution due to present methods of measurement (see section 5.5) may cause uncertainties of the order of 1 to 3 units in R_a .

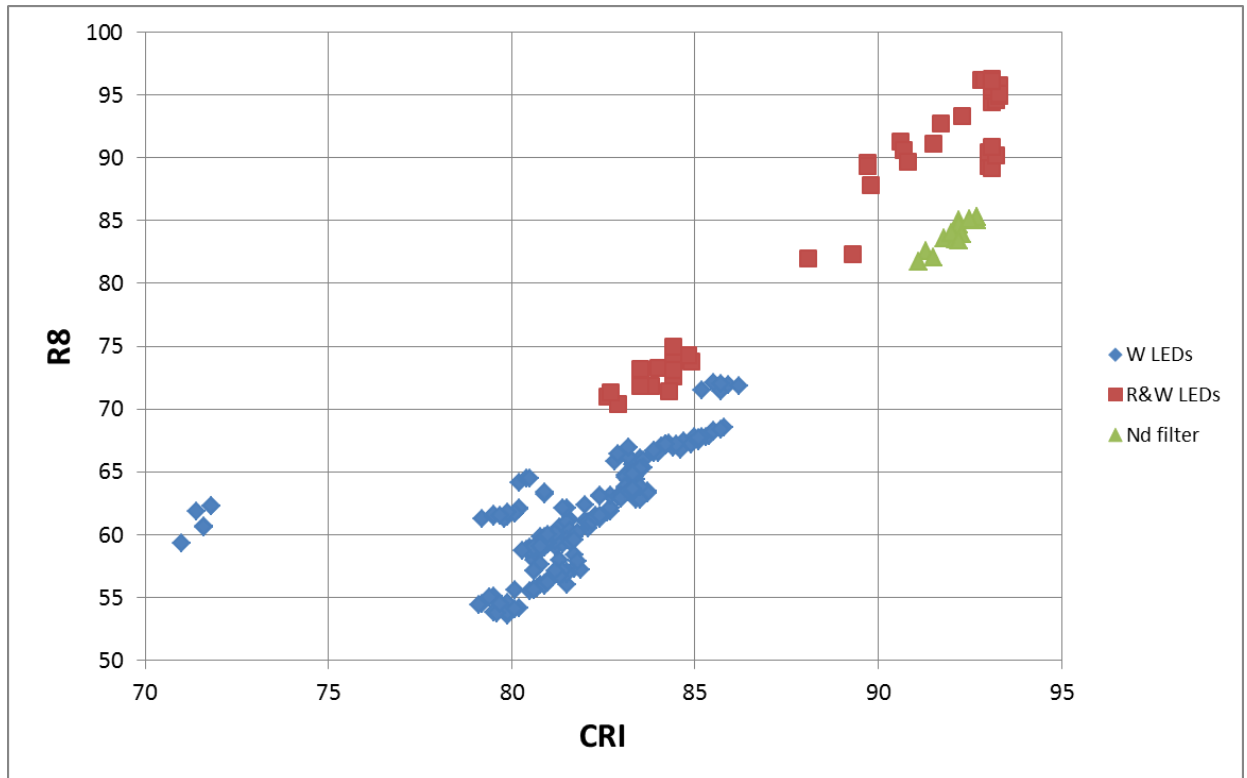
Particular attention should, therefore, be paid to the precise determination of the spectral power distribution of the light source to be tested.

It has been found that the value of R may be influenced by the spectrum range taken to represent the visual spectrum (e.g. 400 ... 700 nm, 380 ... 830 nm), and also by the spectral intervals employed in the computation.

- c) Overdesign: For a given minimum CRI of 80, what must the R numbers then be? The value of R_8 with typical LED products now depends on the CCT. R_8 tends to be the lowest of the 8 R_i 's at common CCTs, because it contains the greatest amount of red. CCTs on the black body line contain different amounts of red, however, so R_8 tends to be low for low CCTs (2700K), if CRI is kept constant. For example, R_8 is 58-59 for two of a NEMA member's 2700K lamps with CRI 80.5. A 3000K lamp with CRI 83 has an R_8 of 65, and a 4000K lamp with CRI 83 has R_8 70. One NEMA member's popular lamp with CRI 92.9 and CCT 3000K has an R_8 of 84. An unintended consequence of specifying that all R's be 75 or above is that manufacturers will tend to make higher CCT lamps to more readily meet the specification. The figure below plots R_8 for all of the lamps in CLTC's report, "OMNI-DIRECTIONAL LED REPLACEMENT LAMP PERFORMANCE TESTING"⁶. This plot shows data from lamps of three different types. The results labelled "R&W" are for lamps that contain both Red and White LEDs. The results labelled "Nd filter" are for lamps that contain white LEDs and a filter that removes part of the spectrum from the white LEDs to yield > 90 CRI. The results labelled "W LEDs" are for lamps that

⁶ http://cltc.ucdavis.edu/sites/default/files/files/publication/140609-report-omni-directional-led-replacement-lamps_rev140807.pdf

contain white LEDs only. In principal, all of the “R&W LEDs” should be capable of $CRI > 90$. Some of the tested “R&W LEDs” lamps are clearly poorly designed and not realizing their CRI potential, despite the complication of adding R LEDs. The “W LEDs” data is for the most practical approach to achieving higher CRI, as explained in the appendix. Projecting the “W LEDs” data to an R_8 of 75 yields a CRI in the high 80’s. For a CRI of 80, R_8 averages about 60. Therefore, a requirement that all R_i ’s be greater than 75, is effectively a requirement that CRI be greater than 88-90, rejecting the proposed compliance equation which combines CRI and Efficiency.



- d) Overdesign revisited: To design a product as close as possible to the 75 minimum R values, allowing for both the tolerance in the LED manufacturing process (2-3 units) and the measurement error (1-3 units), one would need to design for 3-6 extra units in CRI to be certain of meeting a specified minimum level. This would mean designing for 85-88 CRI, in order to get 82, or 93-95 CRI to assure 90.
- e) Addressing color through an R_9 requirement: The ENERGY STAR Lamps program requires $R_9 \geq 0$, and there is no indication that this is a problem in the market. There is no reason to make Title 20’s minimums stricter than ENERGY STAR. As stated above, acceptance of SSL is going very well, without stricter requirements.

See the Appendix to this document for more details on CRI.

16. Conclusion for CRI and Efficacy: Different applications require different color quality and efficiency. We suggest that CEC simply specify a minimum for each parameter for Omnidirectional Lamps; $CRI \geq 80$, $Efficacy \geq 60\text{lpw}$, $R_9 \geq 0$, align with the ENERGY STAR

specification for color accuracy at 7 McAdam steps. This will simplify certification and reporting, and it will acknowledge the importance of lower market prices, which will increase market adoption. By specifying minimum performance parameters this will better enable freedom in design and innovation and allow customers to choose products for a range of applications and prices. It is perhaps worth noting that a review of the ENERGY STAR Lamps qualified products list reveals less than 3% of these lamps are 90 CRI or greater. A further filtration of these results for an efficiency ≥ 60 lpw yields less than 1%. Even at these levels, lower than proposed by CEC, the Commission risks difficulties in legal review to satisfy their mandates that products specified in the regulation be commercially available at time of adoption.

MR Lamps:

1. **SCOPE:** The current scope definition proposes to put all small diameter directional lamps types, LED, Halogen, Halogen-IR and Incandescent, with all shapes, sizes, voltages and base-types into one category including products sold for general lighting applications as well as all specialty or niche applications. Despite this broad inclusion, the analysis narrowly focuses on general lighting applications where the majority of power is consumed. However, the scope, as proposed, inappropriately regulates niche product types with no justification, and NEMA urges the CEC to avoid regulating these niche products.

Because the scope of the proposed regulation is written too broadly and inadvertently covers many niche products that have very low sales, use very little energy, and have no LED replacement options, the scope should be significantly modified to cover only products intended for general lighting applications. The current proposal includes many specialty lamp types used in photo lamp, projector lamp, medical equipment, or other niche product applications. If the proposed regulation included these niche lamp types, it would ban the sale of these products producing seriously negative consequences for those who rely on such products to operate equipment and buildings while saving no meaningful energy. As some of this specialized equipment is quite expensive, banning individual lighting products and therefore obsoleting this equipment is not economically justifiable.

The IOU proposal provided an incomplete analysis that did not properly analyze all uses of small diameter lamps. These niche types of lamps operate at a variety of voltages, can have light output much higher than any LED product produced today, and can have unusual base types with no LED alternative. To address covering niche products with no technically feasible or economically feasible replacement, the scope of the regulation must be limited to the types of small diameter lamps that are used in most general lighting applications and that fit into most existing fixture types. Regulating niche products will produce no meaningful energy savings, produces severe user problems, and has not been financially or technically justified in the IOU proposal.

Examining potential energy savings potential for small diameter reflector lamps:

The vast majority (an estimated 90% or greater) of products sold in this category are MR16, PAR 16, or small medium screw-based Reflector lamps sold for use in General Lighting Applications. Most (an estimated 60%) of these are two pin MR16 lamps operated on 12 volt magnetic or electronic transformers. An estimated 20% are MR16 lamps with GU10 bases that operate on 120 volts. Of the remaining small diameter reflector lamps, approximately 5-6% of lamps are PAR16 lamps with medium screw bases that operate on line voltage and another 5-6% of lamps are small reflector lamps with medium screw-bases that operate at 120 volts. The remaining products are dozens of different low volume niche products sold in specialty applications that have either very small size, unusual bases, operate at unusual voltages, or have very high light output and short lives. As a group, this specialty category does not have LED options and is unlikely to have LED options in a few years due to their very small sales volumes and short operating times. The 90+% of the products sold for general lighting applications would consume well over 95% of the power in this category due to their much longer operating hours.

LED options exist for 2-pin and GU10 MR16 lamps, as well as PAR16 and R16 lamps - the high volume categories. Since the Commission's charter under the Warren-Alquist Act, Cal. Public Resources Code §25402(c)(1), is directed at "standards for minimum levels of operating efficiency . . . [for] appliances whose use, as determined by the commission, requires a significant amount of energy . . . on a statewide basis," the only justifiable focus of the scope in this category is MR16 lamps, either 2-pin GU-5.3 12 volt or 120 volt GU-10 based lamps designed and marketed for general lighting applications, and medium screw-based PAR16 or medium-screw-based R16 or R14 small reflector lamps that are designed and marketed for general lighting service applications. Due to the short operating times of specialty lamps, this type of scope would cover over 95% of all possible energy savings in this category without producing significant problems for users of specialty lamps.

Recommended Scope 1:

(k) Lamps, which are federally-regulated general service fluorescent lamps, federally-regulated incandescent reflector lamps, state-regulated general service incandescent lamps, general service lamps, and includes GU-24 base lamps, small diameter directional lamps of a diameter less than or equal to 2.25 inches, and that operate satisfactorily at 120 volts or 12 volts, and that have an MR16 or MRX 16 lamp shape with a GU-5.3 bi-pin or GU-10 lamp base, or have a PAR16, R16 or R14 lamp shape with a medium screw-base.

2. TECHNICAL FEASIBILITY: we submit that it is NOT technically feasible to regulate all MR16 12 volt and 120 volt, and Small PAR screw-based 120 volt lamps to LED efficiency levels and therefore eliminate all Halogen Technology in these high volume product areas.

The IOU studies did not accurately analyze technical feasibility. Given the very significant technical issues raised at the recent workshop and summarized below, the proposal falls far short of justifying that such technical hurdles can be overcome in as little as 2 to 3 years, if ever. There are no technical solutions to many of the issues raised and no guarantees presented that such technical issues have a solution or will have a solution the next few

years. In short, the proposal completely fails to justify a standard which would entirely eliminate Halogen MR16 options in favor of only LED options.

Since the proposal in the Staff Analysis relies entirely on a single technology to meet the proposed performance requirement, the burden of proof is on the Commission to demonstrate that there is a viable LED solution for each and every halogen lamp type on the market today used in all applications. In fact, the proposal makes no attempt to indicate LED availability for the dozens of specialty lamp types. In reality, there are no LED options for most of these lamps types and none expected to be developed in the near future due to very low sales volumes. As already noted, this can be addressed by focusing the scope of the regulation on small diameter reflector lamps designed for general service lighting applications.

a) DIMMING

Small diameter reflector lamp types for general service lighting applications are primarily used by Restaurants, Museums, Hospitality, Residences and Retailers. In commercial applications, these products are often used on sophisticated lighting control or energy management systems. High end homes also often use sophisticated lighting control dimming systems. Typical homes use more conventional dimmers.

According to the DOE Lighting Characterization report, dimmers are used in approximately 25% of all applications using Halogen lamps to change and provide varying moods, to provide for varying activities, for daylight compensation, for energy savings, or for other reasons. Use of dimmers is considered critical in many of these applications and is not a “nice to have”. Therefore, in order to determine the technical feasibility of a regulation that would only allow LED lamps to be sold, a very high hurdle must be crossed. CEC must prove that all dimmable LED MR16 lamps on the market today will work smoothly with all existing dimming systems. Due to the extreme nature of the Staff Analysis proposal, the CEC should assure backwards compatibility to move forward with such a proposal.

The dimmers designed to work with halogen sources provide seamless and smooth dimming in all applications. Dimmers designed to work with 12 volt MR16 lamps are more complicated as they must dim the magnetic or electronic transformer that operates the MR16 lamps. GU-10 or screw-based PAR16 Line voltage Halogen lamps can run smoothly on standard dimmers.

The proposal fails to prove the technical feasibility for LED MR16 lamps on the dozens of dimming systems in use today and there is no justification provided for the post-proposal backward compatibility with existing systems. Many of the dimming systems installed in today's buildings are no longer manufactured. These dimming systems were designed to work with halogen reflector lamps and did not take LED technology into account when designed.

When evaluating DOE studies on dimming low voltage MR16 lamps, research shows numerous challenges to LED product's technical feasibility on existing dimming systems.⁷ In particular, the research indicates that "dimmable LED" lamps can and do exhibit the following behaviors when dimming is attempted on existing systems:

- 1) Limited dimming range
- 2) Unusual dimming curve
- 3) Dead Travel
- 4) Pop-on of different lamps at different times
- 5) Drop-out of different lamps at different times
- 6) Flashing
- 7) Flickering
- 8) Ghosting when turned Off
- 9) Premature Failure
- 10) Audible noise from the lamp, or the dimmer, or the transformer
- 11) Complete inoperability
- 12) Complete unpredictability

These behaviors vary depending on the number and type of light sources on each circuit.

Even if the dimmable LED MR16 lamps can be dimmed on existing systems, the existing dimmer can potentially:

- 1) Degrade the lamp efficiency
- 2) Shift (or not Shift) the LED Chromaticity.
- 3) Degrade Power Factor
- 4) Increase Total Harmonic distortion.

The probability of these problems greatly increases with low voltage systems. This is because the dimmer not only has to be compatible with the electronics driving the lamp, but additionally, the electronics of the LED source have to be compatible with the electronics of the transformer which has to be compatible with electronics in the dimmer. Chances of all three electronic circuit designs being 100% compatible are very unlikely because LED dimming performance is dependent on the source capability, the transformer-source capability and the dimmer-transformer-source capability.

The conclusion that can be reached from the available research is that dimming LED lamps is not technically feasible on all of today's existing dimming systems the proposal would have them fill. As this represents 25% of all applications being regulated, a total LED lamp replacement standard is not technically feasible for this reason alone and it is not cost effective.

⁷ Caliper Report 20.2 and Gateway Demonstration – Dimming LEDs with Phase-Cut dimmers – DOE reports can be found at www.ssl.energy.gov/led_mr16_lamps.html

These same DOE studies show that dimming LED systems is technically possible, but typically requires replacement of the entire lighting system, entire dimmer system and multiple mock-ups of varying technology to assure success.

In addition to significant dimming issues, there are also optical and thermal problems.

b) OPTICAL

MR16 lamps were originally designed to provide precise optical control for equipment such as slide projectors. To precisely direct most of the light through a slide, a very small 12 volt filament was used to create a point source of light. This point source was then surrounded by a multi-faceted elliptical reflector creating a second focal point of light in front of the lamp at the second focal point of the ellipse. When these lamp types started to be used in general lighting applications, fixture manufacturers took advantage of this unusual precise control to create recessed monopoint fixtures with very small openings, or recessed track fixtures with very small slits. This type of precise control was never possible before because it is not possible to get such precise control by simply using lenses on the front of the lamp. LED lamps also are not capable of this precise control and will not work very well in recessed fixtures with very small openings. If attempted, most of the LED light will never get out of the fixture. The fixture will need to be replaced to work properly. Many of these types of fixtures are permanently installed in finished ceilings, thus requiring the entire ceiling to be replaced. The cost would be enormous.

Many MR16 surface mounted track lighting systems allow some of the light to be emitted from the back of the fixture creating a pleasant glow of light on the ceiling. Designers often use this technique to minimize the cave effect and minimize the contrast between the ceiling and the light source. LED lamps are not capable of throwing light out of the back of the fixture to reproduce this effect.

These two major optical flaws with LED MR16 lamps will not allow them to be used in all halogen MR16 applications. An all LED standard cannot be technically justified due to optical issues.

c) THERMAL

Recessed fixtures in finished ceilings, surrounded by insulation, operate at a relatively high temperature. LED lamps require cooling to obtain long lamp life. LED Lamp life will be significantly shortened if the fixture operates the lamp at a high temperature. These fixtures exist because existing Halogen MR16 lamps operate fine in very high temperatures. Again, the only solution is to replace the entire fixture, and if the ceiling is a finished ceiling, the entire ceiling. Again, the cost would be enormous.

Conclusion: for dimming, optical and thermal reasons, an all-LED conversion for MR lamps cannot be technically justified and is not cost effective. The current Staff Analysis does not technically justify complete conversion that it *claims* is technically possible. Even if the CEC

came to the conclusion that it were technically possible, it must be assessed in terms of economic feasibility and cost effectiveness.

- 5) **ECONOMIC FEASIBILITY:** The IOU analysis falls far short in assessing the true cost to end-users of implementing an all LED standard. Dimming systems are used in nearly 25% of the applications. Per numerous studies⁸ this will often require the purchase of new and compatible dimmers, new and compatible transformers and new and compatible LED lamps. We note that during workshops some entities disagreed with the DOE study in favor of citing gathered Internet performance claims. We expect the CEC to place greater faith in a credible study, as provided by the DOE. As to the practicality of an LED-only MR lamps environment, at the commercial level studies indicate that multiple mock-ups using several different products will likely be required before acceptable dimming and visual performance is obtained for a given installation. This will require the hiring of a lighting designer or consulting engineering firm. While this is possible in a new construction or major renovation, it would never be cost effective if the only reason for considering LED was the unavailability of halogen MR16 lamps. The considerable costs of this exercise would never be paid back by the meager energy savings from a few lamps especially considering the existing halogen MR16 system was already being dimmed and already operating below the nominal lamp wattage.

LED lamps that do not work properly with the optical needs of the fixture will require the fixture and, in some cases, the entire ceiling to be replaced. The Warren-Alquist Act requires the Commission to consider the “impact on product efficacy for the consumer,” Cal. Public Resources Code §25402(c)(1), and the current Staff Analysis does not adequately address this consideration for the reasons explained above.

LED lamps that do not achieve proper lamp life due to very hot thermal conditions either will require the purchase of many LED replacement lamps over very short periods of time, or the replacement of the entire fixture, and in some cases, the tearing down and replacement of the ceiling.

In all of these common situations, the only conclusion that can be reached is that the proposed standard, only allowing LED MR16 lamps to be sold, and eliminating all Halogen MR16 lamps, is not technically and economically feasible, nor is it cost effective.

- 6) **EFFICIENCY LEVELS:** it is clear the efficiency level proposed is inappropriate for Halogen, Halogen-IR or Incandescent Technology. In fact, the proposed level is too high and not even appropriate for LED lamps.

⁸ See footnote 2, and also this DOE paper which cites several sources
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/cfl_lessons_learned_web.pdf

The LED options for all of these categories operate at an efficiency level that is much lower than 80 LPW today and is not projected to reach 80 LPW in the next couple of years. In fact, in recent DOE testing⁹ of MR16 LED technology, DOE states that *“market available [MR16 LED] products still do not produce the lumen output and Center Beam intensity of typical 50 watt halogen MR16 lamps. In fact, most of the 18 lamps in this category had lower lumen output and center beam intensity than a typical 35 w halogen MR16 lamp!”* Also worth noting is that no LED MR16 lamp sold today is even close to producing the lumen output and Center Beam Candlepower of a 75 watt MR16 lamp.

According to the Caliper report, the average efficacy of the MR16 LED lamps tested was 62 lumens per watt. If CA set a standard at 60 LPW they would eliminate approximately 50% of all LED MR16 lamps sold today. A standard where all lamps had to be over 80 LPW would eliminate all but one of the lamps tested by DOE, however this lamp had a very low CRI of 63 suggesting it had moved most of its light output into the green part of the spectrum to achieve a high lumen rating. Placing the LPW level at this extremely high level is unacceptable for all technologies.

Proposal: NEMA proposes a more reasonable efficiency of 60LPW for these products

Concerning efficiency equations/considerations; we note that some entities have suggested an equation approach. For the reasons we note above regarding LED lamps, we do not agree with an equation approach.

Proposed new regulatory language:

(k) Lamps

(6) Effective January 1, 2018, all small diameter directional lamps of a diameter less than or equal to 2.25 inches, and that operate satisfactorily at 120 volts or 12 volts, and that have an MR16 or MRX 16 lamp shape with a GU-5.3 bi-pin or GU-10 lamp base, or have a PAR16, R16 or R14 lamp shape with a medium screw-base must have a luminous efficiency of 60 LPW per watt or greater, a CRI \geq 80, a power factor of 0.7 or greater, and a minimum rated life of 10,000 hours.

- 7) HALOGEN MR16 LAMPS: Halogen MR16 lamps need to remain on the market to address existing applications that would be either practically (from a consumer impact point of view), technically and economically infeasible to convert to LED lamps. Since the majority of MR16 lamps operate at 50 watts, 30% energy savings can be obtained in this category by exempting lamps that operate at less than 37 watts, and requiring lamps over 37 watts to meet Halogen-IR efficiency levels of at least 18 LPW. Typical 50 watt MR16 halogen lamps today operate at 10 to 12 LPW. It should be noted that Halogen lamps are 100 CRI

⁹ Caliper Summary Report 22 – June, 2014
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_22_summary.pdf

sources and they have a Power Factor of 1.0, thus completely meeting the CEC's and IOU's goals for those characteristics.

- 8) Preemption and Incentives: It may be worth noting that the DOE has no tasking at present to set minimum Federal standards for Halogen MR lamps, so they will continue to be available nationally, and that EPA does not allow them in the ENERGY STAR Lamps program. We submit that these two factors will work in balance to still provide Halogen MR16 for those who need it, but those purchase paths which historically encourage high-efficiency products by specifying ENERGY STAR will still discourage their use otherwise.
- 9) ENERGY SAVINGS ANALYSIS: The energy savings projections shown in the IOU proposal are overstated, greatly exaggerating expected energy savings.

While NEMA believes it is not an unreasonable estimate that California's stock is 12% of the National installed stock, the total estimated stock assumption is incorrect. The IOU study greatly overestimates the size of this market, and therefore greatly overstates the expected energy savings. Based on the above referenced DOE CALiPER study on LED MR16 lamps, approximately 46 million MR16 lamps are installed in the United States. This estimate correlates well with the industry's sales for these lamps and expected replacement rate. Estimating that 12% of these 46 million lamps are installed in California would produce 5.5 million installed lamps.

MR16 are approximately 80% of all small diameter reflector lamps sold today. The total number of small diameter lamps installed in CA today is approximately 6.8 million lamps, not 15.8 million. This is almost 57% less than the 15.8 million lamps estimated in the IOU study.

According to the May 2013 DOE report on the *Adoption of LED Lamps in Common Lighting Applications*,¹⁰ LED MR16 lamps had the highest penetration rate, approximately 10%, of all LED lamps in 2012. The adoption rate is certainly even higher today, especially in CA with robust utility rebate programs and high electric rates. DOE estimates the MR16 LED category is activating faster than any other lamp category. This is especially true for non-dimmed retailer applications operating 16 hours per day where the economics are very good. The CA market is easily at a 15% penetration rate today for LED MR16 lamps. This existing penetration was not considered in the analysis reducing the number of halogen or incandescent small diameter lamps to around 5.8 million lamps, 63% lower than the IOU analysis.

The power use is lower than projected. The IOU analysis estimates that 50 watt MR16 lamps are 70% of the Market, 35 watt lamps are 20% and 20 watt lamps are 10%. Initial

¹⁰ http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-adoption-report_2013.pdf

industry data¹¹ indicates that the market share is closer to 60% 50 watt lamps, 20% 35 watt lamps and 20% 20 watt lamps, lowering the average estimated power use.

Further lowering power consumption is the estimated 25% of lamps uses on dimmers. According to a reduce CEE study on Residential Lighting Controls, January 2014¹², when dimmers are used, they reduce power from 34% to 73% with an average being approximately 50%. The majority of dimmers would be used with the 50 watt MR16 lamps, which means a 50% power reduction for 25% of these lamps.

The IOU study estimates that 65% of these lamp types are used in commercial applications at 3720 hours while 35% are used in residences at 840 hours. Short life specialty applications were not considered in the energy analysis even though they are covered by the proposed scope. However, the aforementioned DOE studies indicate that 43% of MR16 lamps are used in households, while 56% are used in commercial applications also lowering total operating hours and potential energy savings. The existing LED MR16 penetration is nearly all in commercial applications with long operating hours.

All told, the actual energy use in this category in 2018 will only be about 20% of the total energy use incorrectly calculated in the IOU analysis estimating sales of LED MR16 lamps continuing to increase each year until 2018. In addition, the analysis incorrectly shows the energy use increasing in this category beyond 2018 if there is no standard, while increasing market sales of LED MR16 lamps will clearly reduce energy use in this category.

Because the energy use is so much lower than predicted, in the final analysis, the energy savings difference between going to an all LED standard and a LED standard plus a Halogen standard are not that large. Only an approach which yields an LED standard combined with an appropriate Halogen standard is technically and economically feasible. Once corrections are made to the analysis, we believe the CEC will agree with this conclusion.

¹¹ Percentages based on review of multiple external sources, which can be provided upon request. Further detail may be possible through a special NEMA member market survey to delineate existing market data which is gathered without distinction of wattage.

¹² <http://www.cee1.org/content/savings-strategy-residential-lighting-controls>

Appendix

Why can't CRI 90 be as inexpensive and efficient as CRI 80?

It is possible to make lamps that provide CRI 90. It has been done in many products (many of which have subsequently been discontinued). Lamps with CRI 90 are presently receiving rebates according to the CEC Quality LED Lamp Specification. It is possible to make CRI 90 lamps with high efficacy, but there are major challenges to widespread creation and adoption of such lamps.

CRI 90 is obtainable in three distinct ways:

1. The simplest way (and the way used in most white CRI 80 LED products today) is to use a blue LED to excite a yellow phosphor. Some of the blue light from the LED is mixed with the light emitted by the phosphor to produce white light of the desired color temperature (CCT). The phosphor formulation must be modified to produce light with CRI 90. In order to obtain 90 CRI, phosphor that produces more red light must be used. This approach inevitably results in lower LED efficacy, because more energy is lost in converting a blue photon to a red photon, than to a green or yellow photon. Also, some of the broad band emission from the phosphor is in the infrared spectral region. Because high CRI LED efficacy is lower, in order for a lamp to produce the same amount of light, more power is needed. Typically, the extra power required is about 15-20%. This means more LEDs are needed, the electronics must provide more power, and the heatsinking must dissipate more power. Depending on the exact lamp design and LED selection/configuration, the optics may also need to be larger. This approach results in higher cost, both for initial lamp purchase and for the ongoing electricity use to power the lamp. There are research efforts to produce narrow band red phosphors, which, if successful, will reduce the amount of light lost in the infrared, but will still lose energy relative to typical CRI 80 LEDs, because more photons must still be converted from blue to red.

2. The second way is to use two (or more) colors of LEDs (e.g. phosphor-converted white + red). The advantage of this approach is that the extra red light is generated directly by a red LED, so efficacy is higher than with approach 1. (It is no longer necessary to generate red light by converting a blue photon to a red photon.) The difficulty with this approach is that color consistency is more difficult to maintain with two LED colors. Both colors must be controlled separately, requiring two channels in the driving electronics. Because of the inevitable different temperature dependence of the two colors of LEDs, if fixed currents are provided to the two colors, then color will change as the lamp warms up, and color will vary at different ambient temperatures. The other difficulty, even if two channels are used, is that the two colors of LEDs, which are built from different materials systems, degrade differently over time. Inevitably, color will drift much more over time than with approach 1, leading to unsatisfying color performance. There are ways to avoid this differential degradation:

- a. Add more complicated (and expensive) electronics that perform both optical and thermal feedback to maintain constant color.

- b. Use the approach used in the L Prize lamps. In this case, the LEDs are substantially underdriven to reduce degradation. However, this requires many more LEDs to reach the necessary light output, and therefore much higher cost.

Approach 2 may yield efficacy for CRI 90 products that is nearly equal to that of CRI 80 products. However, much more complicated electronics, sensing, and different optics are also required. If these measures are not taken, color maintenance and reliability issues will be much bigger issues than with approach 1. Initial cost will inevitably be higher and hinder adoption of LED installations.

3. The third way is to filter out some of the non-red light from phosphor-converted LEDs so that the remaining light meets the CRI and R_9 specifications. This is the least efficient approach, because it starts with a CRI 80 LED and completely discards a portion of the light. At least one CA-qualified lamp uses this method. The 80 CRI version of that lamp uses 9.5W, in its 60W incandescent equivalent. The 90 CRI version uses 13.5W or 42% more energy than the 80 CRI version. Approach 3 results in the poorest lamp efficacy of the three approaches.

It is to be expected that the cost of CRI 90 products will go down, and the efficacy will go up. However, the percentage difference between CRI 90 and CRI 80 products will remain, because CRI 80 products will also improve. In fact, because CRI 80 products are being well-accepted in the rest of the world, and CRI 90 is not an attractive feature, the difference is more likely to worsen the argument for CRI 90 as time goes by, and greater effort is dedicated to higher-volume CRI 80 products.