Proposal for Standards – MR Lamps

Appliance Efficiency Standards and Measures

for California Energy Commission's Invitation to Submit Proposals

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Submission to California Energy Commission 2013 Rule Making (by email)

Re: Docket No. 12-AAER-2B – Lighting – MR Lamps

Soraa expresses its gratitude for the opportunity to submit supporting material for considered energy measures related to lighting appliances.

The proposal for MR lamps follows the format provided.

We look forward to provide clarification and further information if desired, to support the 2013 rule making.

Best regards,

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[Date]

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1 Executive summary

Soraa thanks the California Energy Commission for the provided opportunity to submit proposals for the 2013 Appliance Rulemaking.

Soraa Inc. is a California based manufacturer and developer of lighting products, using a GaN substrate based lighting-emitting diode (LED) technology, called GaN on GaN™. Being a young company with limited resources, we provide a short proposal focusing on a few key elements.

Soraa recommends keeping regulations open to innovative products with respect to form and size, output, controllability and connectivity. The regulations should not be limited to or constrained today's lamp shapes, sizes, form and functionality.

Our proposal focuses on two key factors to maximize end user expectation. When end user expectations are met, the LED lamps can be adopted broadly with accompanying benefits of energy savings and economic advantages.

Soraa proposes the use of *field lumens* as an appropriate measure for output of MR16 lamps and field-based lumens-per-Watt (lm/W) as their efficacy measure.

Soraa further proposes to differentiate LED lamp efficacy requirements (lm/W) in relation to quality of light. The required field lm/W for greater than 90CRI products with an R9 greater than 50, should be 30 and the required field lm/W for products with a CRI less than 90 should be 37.5. This is a valuable trade-off, because higher CRI products address a substantial segment of end users who state that quality of light is of primary concern when considering adopting energy saving lighting technology. The positive effect that increased light quality has on adoption of energy saving lamps outweighs the lower efficiency that is inherently associated with higher color rendering products.

Soraa further proposes a lifetime requirement of 10,000 hours for LED lamps, based on operating conditions that correspond to enclosed or poorly ventilated fixtures. LED lamps operate at higher temperatures in these types of fixtures and as a result life time expectations are shorter. The current practice to specify lamp life on open fixture conditions is not in line with many real life applications and has the potential to disappoint end users.

In line with a life requirement of 10,000 hours, Soraa proposes lamp qualification test requirements to be limited to 3,000 hours. On the one hand, long test durations increase the confidence that products are durable and reliable. On the other hand, long testing hours delays the market availability of more efficient products. Also, with energy efficiency of LED lighting products increasing at a significant rate, locking in today's products with very long lifetimes actually serves to reduce the potential energy savings compared to the case wherein lamps are replaced at a reasonable cycle.

2 Product Description and Proposal Scope

2.1 Technical Description

[Multi-faceted reflector, MR, lamps are lamps of 2" (MR16 16/8th) or 11/8th" (MR11) diameter. They provide directional light in a range of beam angles (5 degrees to over 60 degrees).(Refer to whitepaper Benya).

Halogen MR filaments are contained in a small capsule filled with halogen gas. The capsule can be coated (IR lamps) for higher efficiency and higher filament temperatures. Light is emitted from the filament in all directions.

The multi-faceted reflector around the filament-containing bulb directs a portion of the light in forward direction. A range of reflector coatings are available. Some let a small portion of the light pass through, which results in light emission in the direction of the lamp base ("backlight").

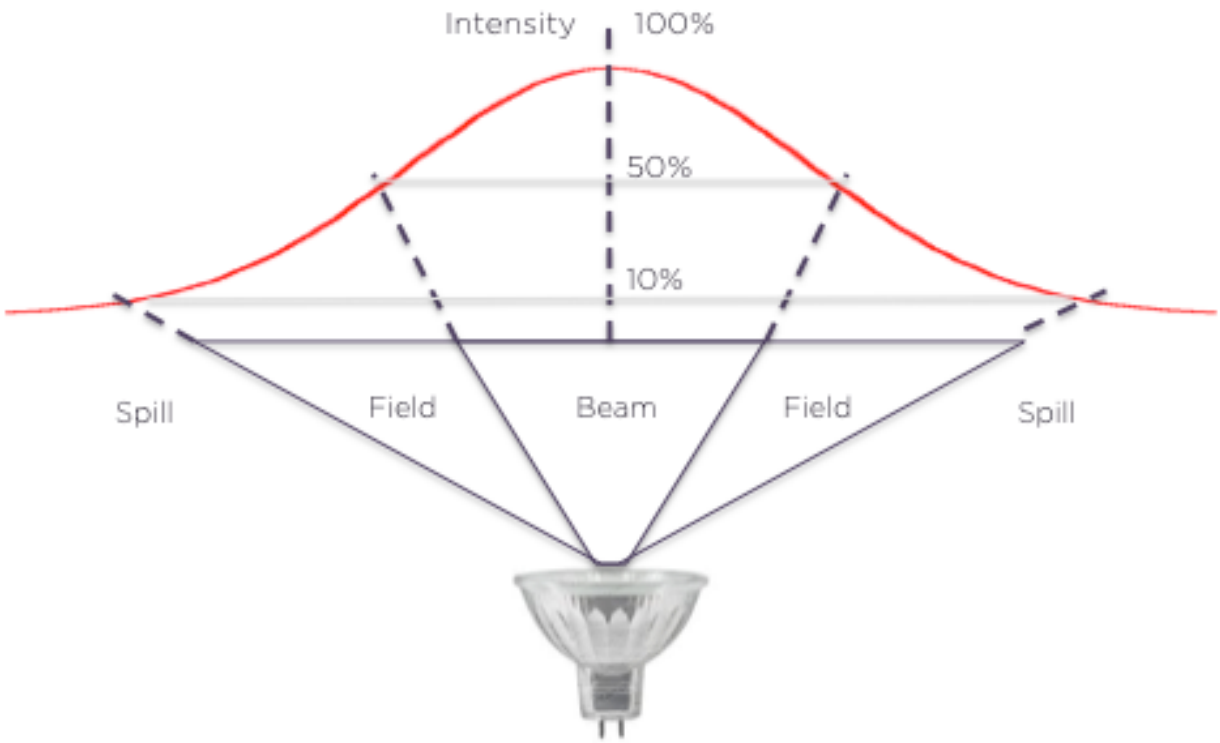
MR lamps are typically driven of 12V AC or DC transformers and have a 2-pin base (GU5.3). The wattage that they draw can range from 20W to over 50W. A mains voltage version of the lamp is also available (120VAC) with typically a GU10 base.

Lamp size and base are defined in ANSI / CIE standards.

An alternative to halogen lamps are those based on LED technology. Light from a single or multiple LED emitters is typically re-directed with the use of a secondary optic, which can be a lens or a reflector or a combination. LED MR lamps have an internal driver to control the current to the LEDs. LED MR lamps are available in mains voltage and 12V AC/DC compatible versions, with the same bases as the halogen lamps that they intent to replace.

The output of a MR lamps is typically characterized by its peak intensity (or Center Beam Candle Power – CBCP). Peak Intensity for lamps with a narrow beam is typically higher than for lamps with a wide beam.

The light distribution of the lamp can be divided in three zones: *beam*, *field* and *spill*. Beam is the zone where the directional intensity is between 50% and 100% of peak intensity. Field is the zone where the intensity is above 10% of peak intensity. The remaining zone is often referred to as spill, as the light is not considered useful in the application, and can lead to issues such as glare. Beam and field are referred to by the angles at which the 50% and 10% of peak intensity occurs.



2.2 Technologies and Best Practices for Energy Efficiency

MR lamps, being directional lamps, are best characterized by their intensity distribution. Energy efficiency is determined by two key factors. The first factor is the efficacy with which the light is generated. This can be measured in lm/W. Second, the effectiveness with which the generated light is used to create a beam and field of the desired intensity. This can be expressed in % lm in the beam or % lm in the field. There are substantial differences between halogen MR16 and different types LED MR16 in both base lm/W and beam efficiency.

	Mains voltage halogen MR16	Low voltage halogen MR16	IR halogen MR16	LED MR16
Lm	350	600	600	500
W	50	50	37	10
Lm/W	7	12	16	50
% lm in beam	33%	33%	33%	50%
% lm in field	70%	70%	70%	85%
Beam lm/W	2.3	4.0	5.4	25.0
Field lm/W	4.9	8.4	11.4	42.5

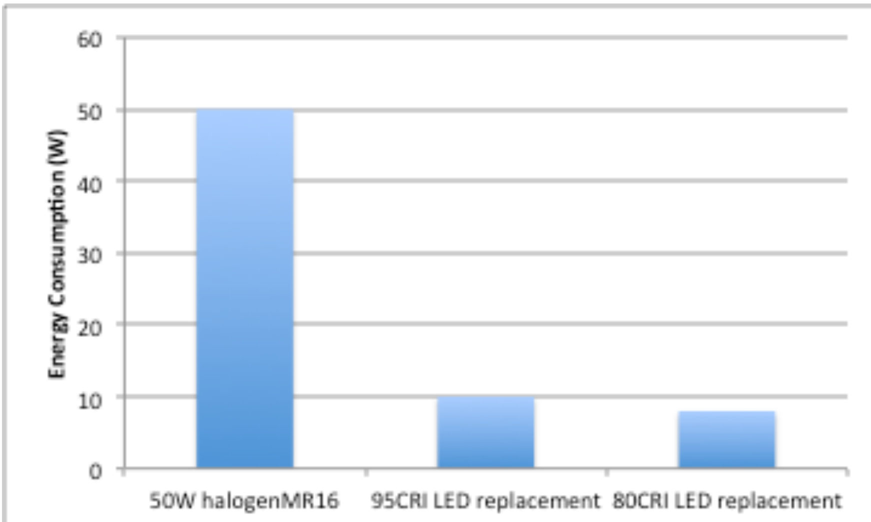
Table I. Comparison of lm/W, Beam lm/w and Field lm/W for different MR16 variants. Narrow flood lamps (~ 25 degree beam angle) compared. Data on various commonly used MR16 types, from Soraa docket submission for Appliance Rulemaking 2013, May 2013.

Beam lm/W for LED MR16s is between 5x and 10x higher than halogen MR16. LED MR16s have between 3.5x and 8x higher Field lm/W.

The percent distribution of field lm and beam lm tends to be higher for all lamp types for wider all beam angles. However, the most common MR16s are narrow flood types.

For total energy consumption, the energy use of transformers should be taken into account as well. Soraa is not able to provide comprehensive data on transformer efficiencies at this moment. An advantage of mains voltage MR lamps is that they do not require a transformer at all. On the other hand, mains voltage halogen lamps have lower output and limited beam control compared to low voltage MR16 because constraints on the filament. With LED MR16, the lower performance level of mains voltage MR16 is resolved. Soraa is of the opinion that mains voltage MR16 lamps can have the same efficiency as low voltage LED MR16 lamps, with the added advantage of no transformer losses whatsoever. Thus the mains voltage LED MR16 system has the potential of achieving overall lower energy consumption, in addition to reduced installation costs, overall lower bill of materials, and reduced electronic waste generation.

LED lamps with high color rendering tend to have lower efficiency than parts with worse color rendering properties, under comparable conditions, due to a fundamental tradeoff between color rendering and luminosity. Specifically, for high color rendering, large red emission content is required, for which the eye is less sensitive to compared to yellow or green emission. For a 50W halogen MR16 replacement, the difference between a 95CRI lamp and 80CRI lamp is 10W vs. 8W, a 20% difference. The percent difference in energy saved between these two lamps is of course much smaller, only 4% (80% savings vs. 84% savings).



A separate minimum energy efficiency requirement for 90CRI LED lamps means they can be offered at a comparable price to the end user (refer to section 8.1) as 80CRI lamps. With both options available side-by-side, it is expected that overall adoption will increase, as certain applications demand high color rendering that is today provided by halogen (100CRI). As a result, more energy inefficient incandescent and halogen lamps will be replaced and energy savings will increase.

Shorter qualification cycles for LED lamps can have a net positive effect on overall energy consumption. If for example a product improvement that results in 20% less energy consumption can be released after 3,000h (proposal) instead of 6,000h (Energy Star), an overall reduction of energy consumption of 8% of the lamps sold in a particular year can be achieved.

2.3 Design Life

The following key elements form the basis of lamp life

- Maintenance of light output
- Maintenance of light color
- Likelihood of occurrence of failures

Typically for all lamps, lifetime expectation according these three elements is shortened at elevated temperatures.

Halogen lamp life is determined by the occurrence of failures. Typically life expectation for halogen lamps is based on the operating hours at which 50% of the products are expected to fail. Halogen MR16 is available in different configurations with substantial differences in expected life, ranging from 1,000h to over 5,000h to 50% failures. Soraa does not have data on what the share is of lamps with different life expectancies.

References regarding LED lamp lifetime tend to emphasize light output maintenance with little attention for lamp failures. Soraa proposes that LED lamp qualification requirements include testing to validate failure levels.

Most LED lamps on the market today meet long life claims in terms of lm and color maintenance (25,000h to 50,000h), but are recommended not to be used in enclosed or poorly ventilated fixtures. It is expected that they do not reach their life claims when operated at the substantially higher temperatures that can occur in a fully enclosed or poorly ventilated fixture.

Many MR16 fixtures are of enclosed type or have limited ventilation because of a narrow neck around the fitting or because of the requirement of a cover glass (to protect against possible halogen lamp explosion). Soraa believes that lamp life should be rated based in these fixture conditions to ensure that product life meets end user expectations.

Examples of poorly ventilated or fully enclosed fixtures currently installed

2.4 Manufacturing Cycle

The perspective from Soraa is that innovations in LED performance (lm/W) can be delivered to the market in an annual cycle. These improvements are typically delivered within existing lamp models. These improvements can be reductions in power consumption while maintaining the same light output, or increases in light output while maintaining the same power consumption. Soraa has no data available on the manufacturing cycle for halogen lamps.

2.5 Product Classes

Products classes covered in the proposal include:

MR16 halogen, IR halogen and LED MR16 equivalents

Lamp bases: GU5.3, GU10 and other commonly used bases

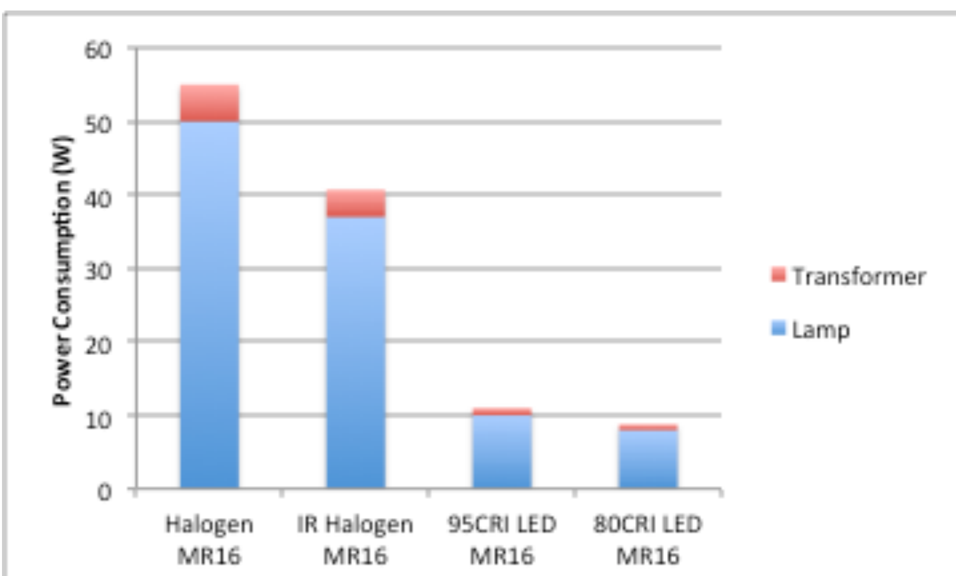
Input voltage: 12V AC and DC and 120V AC

3 Unit Energy Usage

[Provide as much detail as possible about unit energy/water usage by product class, efficiency level, capacity or any other characteristic that drives energy/water use.]

To achieve a similar level of lm in the field, 90 or 95CRI LED MR16 require 20% of energy of a standard 50W halogen MR16 and 27% of the power of so called IR MR16 lamps. IR halogen lamps require 74% of the power of a standard 50W MR16. (See Table I.)

Mains voltage halogen MR16 lamps provide substantially lower field lm than their low voltage halogen counterparts of equal wattage. Soraa estimates that mains voltage MR16 power usage to achieve the same lm level is 74% higher than low voltage halogen MR16. IR halogen requires 43% of the energy of mains voltage halogen MR16 lamps and 95 CRI LED MR16 lamps require 12% of the energy of mains voltage halogen MR16 lamps.



A good summary of Energy use for LED lamps is giving in the Report on LED lamps by McGaraghan, May 2013, that was prepared in response to CEC invitation to participate in 2013 appliance rulemaking.

Additional up to date sources are Energy Star qualified lamps listing and Lighting Facts full product list.

3.1 Duty Cycle

Different states that lamps can be in:

- Off
- Standby
- On in dimmed mode (0-100%)
- On at nominal output (100%)

Estimates on duration in each state are largely dependent on lamp use and are not available to us.

Energy use in dimmed conditions is determined by the energy consumption of the dimming system, the transformer and the lamp. Soraa has no information on the energy consumption of the dimming systems.

Halogen MR16 lamps operate at lower efficacy under dimmed conditions. This is due to the shift of the emission spectrum at lower filament temperatures. Soraa cannot present data on halogen lamp efficacy under dimming at this moment.

LED MR16 lamps have fairly stable to slightly increasing lm/W efficacy under dimming.

3.2 Efficiency Levels

Energy use in dimmed conditions is determined by the energy consumption of the dimming system, the transformer and the lamp. Soraa has no information on the energy consumption of the dimming systems.

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LED MR16 lamps have fairly stable to slightly increasing lm/W efficacy under dimming.

3.3 Energy Consumption

Lamp Type	Energy	Normalized
Mains voltage halogen MR16	87W	100%
Low voltage halogen MR16	50W	58%
Low voltage IR halogen MR16	37W	43%
95CRI LED MR16	10W	12%
80CRI LED MR16	8W	9%

Table II. Estimated Energy consumption to generate 450 field lm.

Soraa does not have information average annual operating hours.

4 Market Saturation and Sales

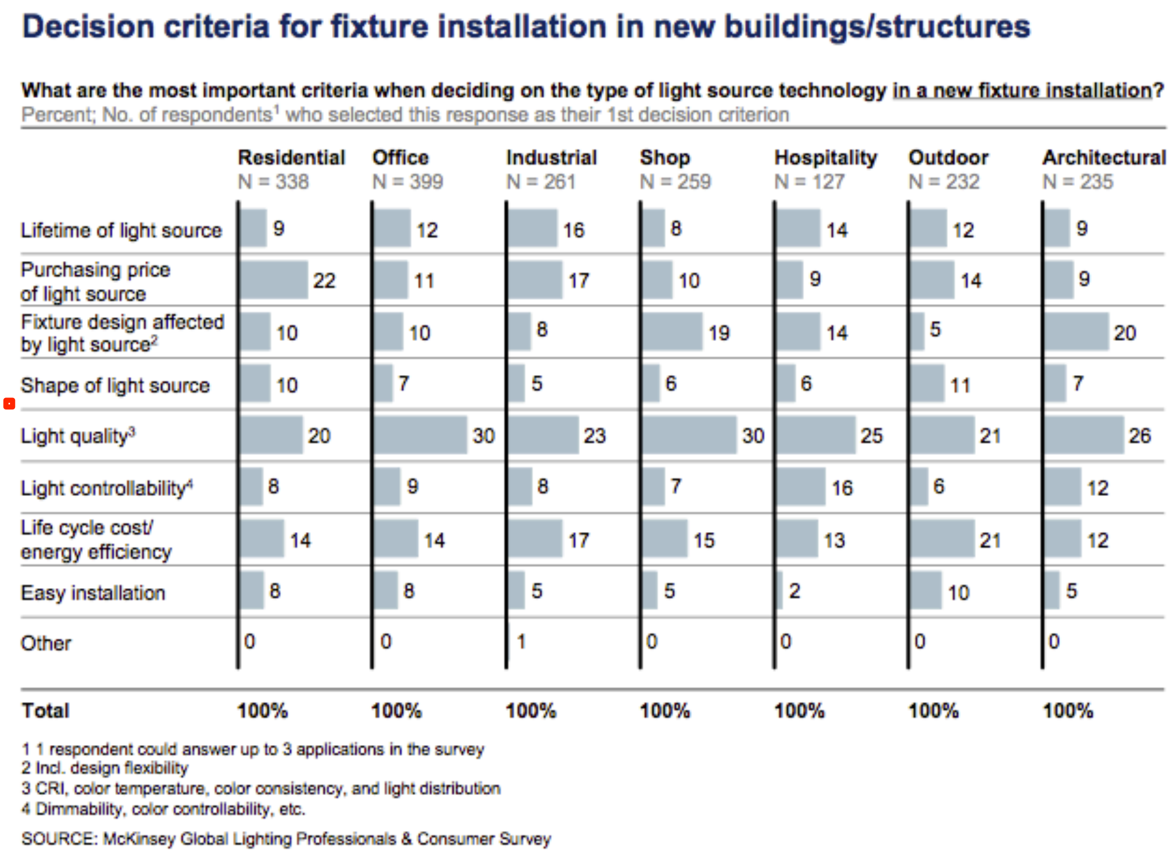
4.1 California Stock and Sales

Refer to Navigant reports for DOE on LED market adoption in common lighting applications and US 2010 lighting market characterization, update 2012. No specific California data is available to us.

4.2 Efficiency Options: Current Market and Future Market Adoption

Soraa does not have data about the adoption of the various halogen MR16 lamp types. Refer to the Navigant report on LED adoption for LED lamp types, including MR16. Soraa does not have California specific data on market adoption.

High efficiency compact fluorescent with a CRI around 80, have been available for sale for many years and have seen limited adoption of around 20% (Relighting American Homes with LEDs, Siminovitch). It is documented that the modest adoption of CFLs is in part due to their poor light quality. For adoption of LED lighting, quality of light is a top concern for both commercial and residential lighting (McKinsey, Lighting the Way)



In addition to poor quality of light, many CFL's exhibit shortened life spans, particularly when they are used in a warm environment like a fully enclosed or poorly ventilated fixture.

California's own LED lamp quality specification is in place to address the concern of poor quality of light as a barrier to broader adoption of energy efficient lighting.

5 Statewide Energy Usage

Soraa does not have data on number of lamps used in California.

6 Proposal

6.1 Summary of proposal

Soraa proposes an efficacy standard for all MR16 lamp types based on field lm/W which represents the true efficiency relevant for directional lighting applications. The efficacy requirement should be differentiated depending on the color rendering properties of the lamp, due to the fundamental tradeoff between color rendering and luminosity.

	80 ≤ CRI < 90 0 ≤ R9 < 50	CRI ≥ 90 R9 ≥ 50
MR16 field lm/W requirement	30lm/W	37.5lm/W

This requirement applies to mains voltage as well as low voltage MR16 lamps.

The benefit of using field lm is that it quantifies the directional aspect of the lamp and it is the right measure for the quantity of light for directional lamps.

With a separate energy efficiency requirement for 90CRI LED lamps, they can be offered at a comparable price to the end user (refer to section 8.1) as 80CRI lamp (since compensating for lower efficiency requires increased light-source costs to achieve the same lumen level). With both options available side-by-side, it is expected that overall adoption will increase. As a result, more energy inefficient incandescent and halogen lamps will be replaced and energy savings increase.

Soraa proposes lamp life requirement of 10,000h based on fully enclosed fixture conditions. Lamp life based should be based on a requirement on color shift, reduction in light output and a drift in color point. Related qualification requirements can be 3,000h. If lamp life of 10,000h is ensured in fully enclosed fixtures, a substantially longer life in open or well ventilated fixtures can be expected

Shorter qualification cycles for LED lamps can have a net positive effect on overall energy consumption. If for example a product improvement that results in 20% less energy consumption can be released after 3,000h (proposal) instead of 6,000h (Energy Star), an overall reduction of energy consumption of 8% of the lamps sold in a particular year can be achieved.

6.2 Implementation Plan

- Lamp manufacturers – submitting data for products
- Validation by independent qualified test laboratories
- Submission and keeping of records – appointed by CEC.

6.3 Proposed Test Procedure(s)

Soraa proposes a substantially shortened test procedure. Details of the test procedure and required results have to be worked out. The requirements should be related to meeting low lamp failure levels and maintaining sufficient light output and color stability of the lamp over its life. The test conditions must correspond to the operating conditions of the lamp in fully enclosed or poorly ventilated fixture.

6.4 Proposed Regulatory Language

To be proposed at a later point in time.

7 Technological Feasibility

As can be seen from the Energy Star qualified products lists and the Lighting facts products list, many products meet the minimum 80CRI requirements (refer also to LED Replacement lamps, Mc Garaghan May 2013). The proposed difference between 80CRI and 90CRI required minimum efficacy is in line with corresponding LED efficacy difference for 80 and 90CRI. Hence, it is feasible that the proposed minimum efficacy requirements can be met with today's 90CRI LED components.

LED lamps capable of running in fully enclosed fixtures, without compromising lifetime, are currently available on the market. In addition, LED products and the electronics that are required to drive them are becoming widely used in high temperature applications like automotive headlamps and have proven to be durable and reliable in those conditions.

Finally, there are LED MR16's lamps available on the market that meet the full light output requirement while being truly size compatible with retrofit halogen fixtures.

8 Economic Analysis

8.1 Incremental First Costs

Considering incremental first cost, it is important to take the longer life of LED lamps into account. Comparing halogen products with LED lamps, a 10x longer life for the latter can be assumed.
Soraa is not able to provide a good data set for cost comparisons between different lamp technologies, across multiple lamp types.

Incremental cost of high CRI: Soraa MR16 lamps of 80CRI and 95CRI are offered on Amazon and 1000bulbs.com for the same price, with a differentiated efficacy level and light output.

8.2 Incremental Operating Costs and Savings

Table III. Energy cost and replacement cost based on 4,000 operating hours

Lamp Type	No of lamps	Energy Cost	Lamp Cost	Relamp cost	Total cost
50W Halogen	3	31.20	6.00	12.00	$49.20
37W Halogen IR	2	17.60	12.00	6.00	$35.60
10W LED	1	6.00	25.00	0	$31.00
8W LED	1	4.80	25.00	0	$29.80

Cost shown here do not include energy costs related to cooling.

Higher LED MR16 initial cost is offset by lower energy cost within 4,000 hours, when comparing to both standard and IR halogen MR16. The cost savings is $160 - $210 over 25,000 hours, the claimed life of many LED MR16 lamps. (See Table VI.)

Lamp Type	Total ownership cost over 25,000h
50W Halogen	$268.50
37W Halogen IR	$225.75
10W LED	$62.50
8W LED	55.00

Table VI. Estimated total ownership cost over 25,000h

8.3 Infrastructure Costs and Savings

LED MR16 lamps are available with different lamp bases (GU5.3, GU10) and in mains voltage and low voltage configuration. They can replace a halogen MR16 without the need to replace the transformer, or the modifications or replacement of the fixture.

In new construction, LED MR16 lamps contribute to a lower building heat load. Consequently, energy consumption related to cooling can be reduced and possibly the capacity of the cooling system.

Mains voltage LED MR16s do not require a transformer, which simplifies the lighting system, lowers its cost, and increases energy savings. It is expected that mains voltage LED MR16 will have the same performance levels as low voltage MR16.

8.4 State or Local Government Costs and Savings

Soraa does not have the information required for a comment.

8.5 Business Impacts

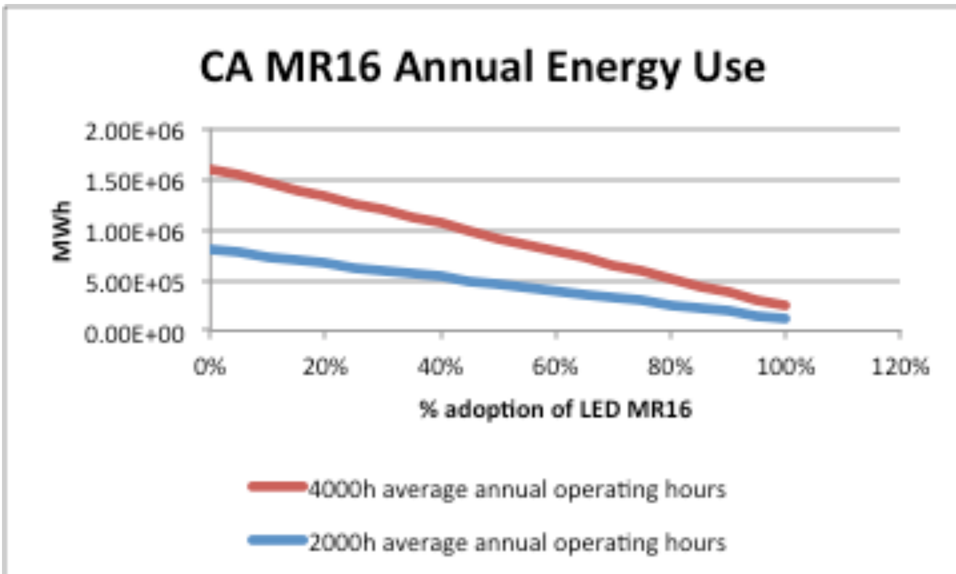
Longer lamp life, lower total cost of ownership and lower energy cost are beneficial for businesses.

8.6 Lifecycle Cost and Net Benefit

Refer to Table III.

9 Savings Potential

Soraa does not have accurate estimates of number of sockets filled with MR16 and their average annual operating hours. Based on an estimated 10 million MR16 sockets with an average annual operation of 4,000 hours (majority of MR16's are used commercially), it is estimated that energy consumption by MR16 alone can be reduced by approximately 1.4 million MWh per year, when all MR16 sockets are fully converted to LED MR16. The equivalent potential for energy cost reduction is estimated to exceed USD 200M.



10 Acceptance Issues

11 Environmental and Societal Impacts

12 Federal Preemption or Other Regulatory or Legislative Considerations

13 Methodology for Calculating Cost and Savings

14 Bibliography and Other Research

MR16 Lamps – Lighting Research Center – September 2002 – www.lrc.rpi.edu/programs/nlpip/lightinganswers/mr16/abstract.asp

A Critical Advance in MR16 Lamps – Jim Benya – May 6, 2012 – www.soraa.com/public/docs/A_Critical_Advance_in_MR16_Lamps-Benya.pdf

Soraa Submission to invitation to participate in 2013 rulemaking for MR lamps May 2013

Lighting the Way – Perspectives on the global lighting market – McKinsey Company

LED replacement lamps, Michael McGaraghan, May 9 2013, prepared in Response to CEC 2013 Pre-Rulemaking Appliance Efficiency Invitation to Participate

Adoption of Light-Emitting Diodes in Common Lighting Applications, April 2013, Prepared by Navigant for DOE

2010 U.S. Lighting Market Characterization, January 2012, Prepared by Navigant for DOE

Relighting American Homes with LEDs, Siminovitch

Energy Star specification draft 4

Energy Star qualified Lamps: downloads.energystar.gov/bi/qplist/Lamps_Qualified_Product_List.xls

Lighting Facts listed products: http://www.lightingfacts.com/content/products

APPENDIX: Cost Analysis Assumptions

[The Energy Commission used the following rates to evaluate initial proposals received in response to the August 31, 2011 scoping workshop.

The cost of electricity: $0.15 per kWh

The cost of natural gas: $1 per therm

The cost of water: $0.0052 per gallon

Discount rate: 3%

The Energy Commission is investigating whether to update these figures over the course of the rulemaking. Stakeholders are welcome to suggest appliance-specific rates, or alternates to these flat rates to support cost-effectiveness of their proposals. If stakeholders choose a different rate, they should describe the analysis and rationale for the different rate.]