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Proposal Information Template for:
Multifaceted Reflector Lamps

Submitted to:
California Energy Commission
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Prepared for:
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Please note: all savings estimates and information in this document are preliminary and are based on data available to the authors at the time of the report. If the CEC moves forward with this topic, we anticipate updating our estimates and recommendations based upon additional input from stakeholders.

Proposal Information Template – Multifaceted Reflector Lamps

2011 Appliance Efficiency Standards

Prepared for: Pacific Gas and Electric Company, San Diego Gas & Electric, Southern California Edison, Southern California Gas Company

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Purpose

This document is a report template to be used by researchers who are evaluating proposed changes to the California Energy Commission's (Commission) appliance efficiency regulations (Title 20, Cal. Code Regulations, §§ 1601 – 1608) This report specifically covers Multifaceted Reflector Lamps (MRs).

Background

Multifaceted reflector (MR) lamps are widely used for accent, task, and display lighting in museums, art galleries, retail stores, residential settings, and entertainment venues because of their well-controlled, high-intensity beam (LRC 2010). These types of lamps are typically designed for low-voltage operation, requiring shorter, thicker, and more robust filaments, which allow them to generate high luminous intensity. In combination with lamp reflector design, the small filament also allows more precise control of light distribution and beam intensity, otherwise known as beam angle and center beam candle power (CBCP). MRs are typically sold as MR16s and MR11s; the number refers to the diameter in eights of an inch. While they fulfill a niche need, the market opportunity is significant with over 14 million installed MRs in California with approximately 9 million annual shipments. The market is generally split between halogen MRs and their more efficient counterpart, halogen-infrared (halogen-IR) MRs; LED MR replacements have also begun to penetrate the market. Conventional halogens are the least efficacious MR lamps, achieving a range of about 8-18 lumens per watt (lpw), in three primary wattages: 50W, 35W, and 20W (Walercyzk 2006 & CALiPER 2008). Halogen-IRs contain an infrared-reflective coating on the halogen capsule which reflects infrared energy back onto the filament, causing it to burn at a higher temperature and generate more light. Halogen-infrared lamps are therefore more efficacious than standard halogen lamps (Sylvania 2011), and achieve approximately 18-23 (lpw) (Walercyzk 2003).

LED MR lamps, which are currently achieving 33–73 lpw, averaging around 47 lpw, (with rapid and significant improvement forecasted), can be an ideal MR replacement given the requirements for small form factor, dimmability, and optical control. The currently available LED MR replacements for 20W and 35W conventional halogens, and soon-to-be available LED MR replacements for 50W[1] conventional halogens are significantly more energy efficient, can produce similar lumen output, and last over 5 to 8 times as long as their halogen and halogen-IR counterparts. ENERGY STAR has qualified over 37 individual LED MR replacements, and the Department of Energy (DOE) Lighting Facts Program has identified over 200 LED MR replacement lamps (ENERGY STAR 2010 & DOE 2010). Based on the DOE Lighting Facts database, Table 1 describes performance and other specification ranges for commercially available LED MR replacements; Table 2 describes performance and other specifications for halogens and halogen-IRs.

Table 1. Range of performance specifications for commercially available LED MR replacements

		Luminosity (lumens)	Power (watts)	Efficacy (lumens/watt)	Correlated color temperature (K)	Rated Life (hrs.)	Price ($)
LED Replacement	*Average*	-	-	47	3097	29,595	$18
	Max	380	6.5	74	4000	-	$35
	Min	151	3.3	41	2700	-	$16

SOURCE: Energy Star (2011)

Table 2. Range of performance specifications for halogen and halogen-IRs

		Luminosity (lumens)	Power (watts)	Efficacy (lumens/watt)	Correlated color temperature (K)	Rated Life (hrs.)	Price ($)
Halogen-IR	*Average*	-	-	20	3000	5000	$6
	Max	1,080	50	23	-	-	-
	Min	370	20	18	-	-	-
Halogen	*Average*	-	-	16	3000	3000	$3
	Max	1,320	70	19	-	-	-
	Min	200	20	10	-	-	-

SOURCE: PG&E (2010), Walercyzk (2006), Phillips (2009), & Sylvania/OSRAM (2010)

Two other performance parameters pertinent to MRs are beam angle and center beam candle power (CBCP), which characterize the beam appearance and the maximum beam intensity of directional lighting (LRC 2010). Based on a survey of manufacturers' catalogs, typical beam angles of MR16 lamps range from 7 to 60 degrees, and their CBCP ranges from about 230 up to 16,000 candelas, depending on the wattage and beam angle combination (CALiPER 2008). Beam angles less than 20 degrees are known as “narrow spot”, those between 20-35 degrees are commonly referred to as “narrow flood”, and those that are greater than 35 degrees may be referred to as “wide flood” (CALiPER 2008).[2] There is limited current data available on CBCP for given beam angles for LEDs since ENERGY

[1] Philips recently introduced a product being marketed as a 50 Watt equivalent LED MR16. Another manufacturer announced plans to release such a product in Fall 2011

[2] Some manufacturers within the lighting industry have recognized upwards of 9 classifications of beam angles, and design MRs to be able to achieve this broad spectrum (7 degrees to more than 56 degrees). The classifications proposed in CALiPER are simplified, and referenced here to introduce this important concept. There is no industry standard for beam angle specifications; however the Illuminating Engineering Society (IES) Handbook from 2010 specifies 9 classifications.

STAR does not require specifications for CBCP, and neither ENERGY STAR nor the DOE Lighting Facts Database provide data on CBCP for LED MR replacements.[3] However, the following CBCP and beam angle combinations were taken from one LED MR16 manufacturer catalog (Table 2). In comparing these CBCP values to those for Halogen MRs (Table 3), there is continued need for improvement, particularly for beam angles classified as "Spot".

Table 3. Center beam candle power (CBCP) and beam angles for LED MR replacements

Lamp Type	Beam Angle	CBCP (candelas)
Spot	20°	1700
Narrow Flood	26°	1200
Wide Flood	38°	500

SOURCE: CRS (2010)

Table 4. Center beam candle power (CBCP) and beam angles for Halogen MRs

Lamp Type	Beam Angle	CBCP (candelas)
Spot	10°	3000 – 15000
Narrow Flood	25	2000 – 5700
Wide Flood	35	510 - 2850

SOURCE: Survey of CBCP ranges from Sylvania/OSRAM (2010)

LED compatibility with existing low-voltage transformers and existing dimmers has been an issue with some LED MR retrofits because LEDs draw significantly less power than halogens and halogen-IRs; this can cause flickering or random shut down. However, there have been and continue to beimprovement in this area. If it is Energy Star qualified, manufacturers will supply compatibility lists for power supplies and dimmers. In cases where compatibility issues remain, LED savings are so significant that it may be cost effective to retrofit the entire transformer/fixture.

[3] ENERGY STAR developed an excel tool for lighting designers that provides guidance on what the proper CBCP ought to be for an LED replacing a halogen MR of a specified wattage and beam angle. A screen shot of this tool is provided in Appendix B; a link to this file is provided in the bibliography.

Overview

Description of Standards Proposal	LED MR replacements are an ideal replacement for halogen-incandescent MRs given their significantly higher efficacy, longer useful lives, comparable lumen output, and improving compatibility to operate with existing low voltage transformers. We recommend establishing a performance standard based upon the current ENERGY STAR Integral LED lamp specifications, which provide performance specifications for LED MR replacements. MR efficacy should be at least 40 lpw.
California Stock and Sales	We estimate current stock in California to be about 14.8 million, with annual sales around 8.9 million. Given the longevity of LED lamps, annual sales under this standard would drop to approximately 1.4 million. The market is split between commercial and residential applications by 66% and 34%, respectively; increases in sales from growth in CA population and the retail industry should be incorporated into any future sales projections.
Energy Savings and Demand Reduction	*Per unit annual energy savings:* 49 KWh/lamp[4] *First-year savings:* 436 GWh *Annual energy savings after stock turnover*: 713 Gwh/yr *Peak demand reduction:* 114 MW
Economic Analysis	*Lifecycle cost:* $14.809 *Lifecycle net benefit:* $63.76[5] *Benefit/cost Ratio*: *4.31* Given the increased lifespans of the LED products, annual sales of MRs could decrease from 8.9 million down to 1.4 million. However, this is not likely to negatively affect California jobs since the manufacturing centers for the three largest lighting companies – GE, Sylvania, and Philips – are not located in California.
Non-Energy Benefits	In general, a market shift to LEDs has environmental benefits both upstream and downstream, particularly in terms of embedded energy and greenhouse gas reduction at the power generation source, helping California to meet its AB 32 goals (1990 levels by 2020).

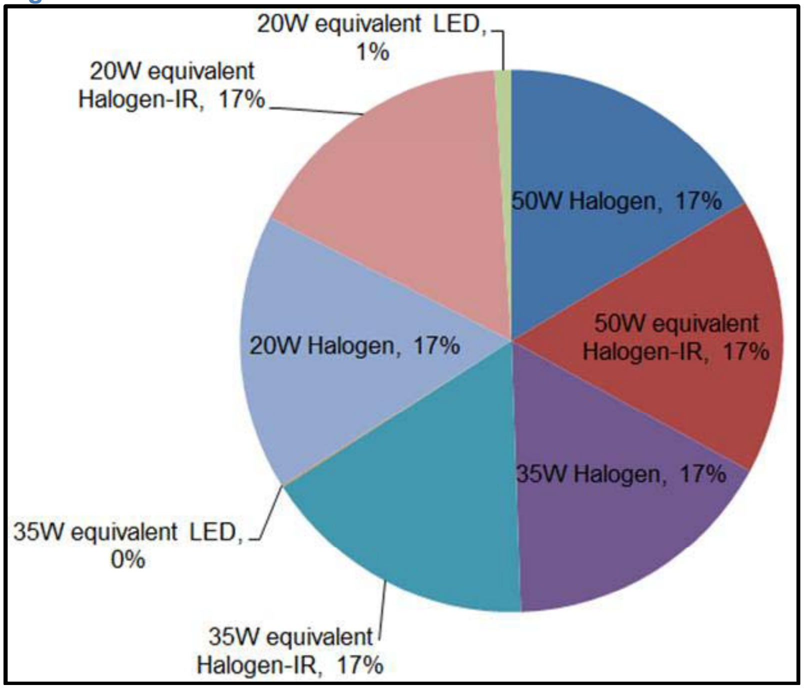
[4] This savings per unit calculation represents a market share weighted average of savings from LED MR replacements for 20W, 35W, and 50W Halogens. See table 7 for individual per unit energy savings.

[5] The lifecycle net benefit and benefit/cost calculations represents represent a market share weighted average of savings from LED MR replacements for 20W, 35W, and 50W Halogens. A 20W, 35W, and 50W LED equivalent will save annually, approximately $46.52/lamp, $81.16/lamp, and$108.03/lamp, respectively. We assume the market share for 20W, 35W, and 50W Halogens is split 33%: 33%: 33%

Environmental Impacts	Further research and analysis is needed to weigh the full life-cycle costs and benefits of the environmental impacts of the manufacturing, distribution, use and disposal of the lighting technologies as a result of this proposed standard.
Acceptance Issues	Some states, including California, have created LED rebate programs for MRs. The LED Accelerator Program is a PG&E program that offers a per kW rebate to qualified LED lamps, including MR replacements. Various rebates are offered for efficacies ranging between 50 – 100 lm/watt. ENERGY STAR has prescribed various labeling requirements for their LED MR replacement specifications; we recommend that California adopt those or similar labeling requirements.
Federal Preemption or other Regulatory or Legislative Considerations	Federal standards exist for incandescent reflector lamps, but the scope of coverage is for larger diameter lamps. MR16s are not covered by these federal standards. The DOE recently opened a rulemaking for "luminaires", whose scope is not yet decided upon, but could include multifaceted reflectors. The earliest that this DOE standard would go into effect would be 2017/2018.

Methodology and Modeling used in the Development of the proposal
Using a 2011 Navigant report, the DOE lighting facts database for LED MR16 replacements, manufacturer lighting catalogs, and Energy Solutions' lighting expertise, we developed a basic excel model to evaluate the savings potential from an LED standard for MRs in California. Below describes some of our basic market assumptions:

Figure 1. California market share of installed MRs



Total Installed Base in California = 14,806,540

SOURCES: Navigant (2011) & Energy Solutions (2011)

NOTES: Our assumption about total installed base is an extrapolation of U.S market data onto California based on the 2011 Navigant study. Our assumptions about the relative market breakdown are based on internal Energy Solutions expertise, and will be supplemented by additional market research.

Table 5 below describes our assumptions about annual operating hours, average useful life, and average market prices for the baseline technologies (halogens and halogen-IRs), and the standards case technology (LEDs).

Table 5. Assumptions about operating hours, life span, price and average wattage reduction from Standard

Avg. Annual Operating Hours	2,447
Avg. life hours – Halogen Avg. life hours – Halogen-IR Avg. life hours – LED	3,000 hours 5,000 hours 25,000 hours
Avg. price – Halogen Avg. price – Halogen-IR Avg. price – LED	$3 $6 $35

SOURCES: PG&E (2010) & DOE (2010)

We factored the current market split between halogens and halogen-IRs into our baseline assumptions about wattage, efficacy, and market share. [6] In table 6 below, the "Baseline Assumptions used in calculations" reflects this market share weighted average. We established a standards case by calculating the wattage needed to achieve specified lumen outputs that mimic halogen lumen output for the baseline power ranges, at typical LED efficacy levels.

Table 6. Average baseline and standard cases

Average Baseline Wattage, Efficacy, & Market Share			**Proposed Standard Case Efficacy and Wattage**
Halogen	Halogen-IR	Baseline Assumptions used in Calculations	LED Replacement
50 W 17 lpw ~37%	39 W 22 lpw 37%	**45 W** 19 lpw ~74%	**17 W** 50 lpw
35 W 15 lpw ~6%	28W 19 lpw ~6%	**31 W** 17 lpw ~12%	**11 W** 50 lpw
20 W 11 lpw ~6%	14W 16 lpw ~6%	**17 W** Lpw ~12%	**5 W** 44 lpw

SOURCE: Energy Solutions (2011) & Navigant (2011)

NOTES: For market shares, we assume that LEDs have already penetrated ~1.7% of the market based on a 2011 Navigant Report. We factor this into our savings calculations. Market share numbers here are rounded for simplicity.

[6] We also factor into our calculations the ~1.7% market penetration by LEDs.

Table 7 below describes the wattage reduction and annual energy savings on a per lamp basis from shifting from the baseline scenario to the standard case scenario.

Table 7. Wattage reduction and energy savings from shifting from the baseline scenario to the standards case scenario

Per Lamp Wattage Reduction & Annual Energy Savings	
Wattage reduction from Standard – 45W baseline Wattage reduction from Standard – 31W baseline Wattage reduction from Standard – 17W baseline	28 W 20W 12 W
Annual Energy Savings per lamp from Standard – 45W baseline Annual Energy Savings per lamp from Standard – 31W baseline Annual Energy Savings per lamp from Standard – 17W baseline	67 kwh/lamp 51kwh/lamp 29 kwh/lamp

SOURCE: Energy Solutions (2011)

Data, Analysis, and Results

Using the data described in the methodology section, we were able to calculate energy, power, and life cycle cost figures. The savings opportunity associated with this measure is described in the table below.

Table 8. Model savings outputs

1st Year Energy Savings	436 GWh
Energy Savings after Stock Turnover	713 GWh/yr
Peak Demand Reduction	114 MW
Incremental Cost/unit	$30.50[7]
PV Lifetime Energy Savings/unit	$78.57
Annual Avoided Energy Costs after Stock Turnover	$123 Million

SOURCE: Energy Solutions (2011)

Proposed Standards and Recommendations

We recommend that California adopt ENERGY STAR performance specifications for LED MR replacements as the standard for MRs in California. ENERGY STAR uses a thoroughly vetted process to establish standards based on commercially available lamp technology. Current research and market data have shown vast improvements in LED MR replacements over a short period of time, and we should continue to expect more improvement in performance, specifically with respect to CBCP and compatibility issues, in the future.

[7] Incremental cost per unit is based on the difference between the cost of an LED replacement and the weighted average cost of a halogen and halogen-IR, using market share.

Moreover, our economic analysis suggests a significant savings opportunity on an energy, power, and cost basis.

Please see Appendix A for the ENERGY STAR specifications for LED MR replacements.

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References and Appendices

APPENDIX A. Energy Star Criteria for LED MR replacements

7C) Directional Lamps

Applicable lamp types BR, ER, K, MR, PAR, R (per ANSI C79.1-2002)
For MR and PAR lamps, the following lamp diameters are included at this time: MR16, PAR16, PAR20, PAR30S (short neck), PAR30L (long neck), PAR38

Criteria Item	ENERGY STAR Requirements	Reference Standard/Test Procedure	Sample Size/Specific Requirements
Definition	Directional lamp means a lamp having at least 80% light output within a solid angle of π sr (corresponding to a cone with angle of 120°)	EC No 244/2009; IES LM-79-08, Section 10	1 unit per model
Minimum luminous efficacy		IES LM-79-08	10 units per model - 5 base-up - 5 base-down 9 of 10 lamps must meet specification
- Lamp diameter ≤ 20/8 inch	40 lm/W		
- Lamp diameter > 20/8 inch	45 lm/W		
Color Spatial Uniformity	The variation of chromaticity within the beam angle shall be within 0.006 from the weighted average point on the CIE 1976 (u',v') diagram.	IES LM-79-08 ANSI C78.379-2006, section 5	1 unit per model - Angular chromaticity measurements shall be made at the center and edge of the beam. The measurements shall be made in at least two vertical planes 90° apart. Results shall be averaged from the different vertical planes.

Criteria Item	ENERGY STAR Requirements	Reference Standard/Test Procedure	Sample Size/Specific Requirements
Maximum lamp diameter	Not to exceed target lamp diameter	ANSI C78.21-2003 ANSI C78.24-2001	1 unit per model
Maximum overall length (MOL)	Not to exceed MOL for target lamp	ANSI C78.21-2003 ANSI C78.24-2001	1 unit per model
Minimum light output ***– BR, ER, K, and R lamps***	Lamp shall have minimum light output (total luminous flux) equal to the target wattage of the standard incandescent lamp to be replaced multiplied by 10.	IES LM-79-08	10 units per model - 5 base-up - 5 base-down 9 of 10 lamps must meet specification
Minimum center beam intensity[4] ***– PAR and MR16 lamps***		IES LM-79-08, Section 10	1 unit per model
- PAR lamps	Link to online tool at: http://www.energystar.gov/ia/products/lighting/iledl/IntLampCenterBeamTool.zip Enter the following information into the online tool: PAR diameter in eighths of an inch (i.e., 16, 20, 30, 38) Target lamp nominal wattage Target lamp beam angle in degrees (Note: maximum allowable beam angle = 65°.)		
- MR16 lamps	Link to online tool at: http://www.energystar.gov/ia/products/lighting/iledl/IntLampCenterBeamTool.zip Enter the following information into the online tool: Target lamp nominal wattage Target lamp beam angle in degrees (Note: maximum allowable beam angle = 50°.)		
Lumen Maintenance	≥ 70% lumen maintenance (L_{70}) at 25,000 hours of operation	IES LM-79-08 Elevated Temperature Test per ENERGY STAR CFL version 4.0 and technical clarifications in Appendix E IES LM-80-08 (for early initial qualification option)	10 units per model - 5 base-up - 5 base-down - LED lamp power <10W must operate at 25°C between measurements. - LED lamp power ≥10W must operate at 45°C between measurements. -Average of 10 samples must be ≥ 91.8% at 6000 hours
Rapid-Cycle Stress Test	Cycle times must be 2 minutes on, 2 minutes off. Lamp will be cycled once	ANSI C78.5-2003	10 units per model - 5 base-up

APPENDIX B. Energy Star Integral Lamp Center Beam Tool

A1 ENERGY STAR® Integral LED Lamp Center Beam Intensity Benchmark Tool

ENERGY STAR® Integral LED Lamp Center Beam Intensity Benchmark Tool

PAR Lamps

Target Incandescent/Halogen Lamp Parameters

Enter PAR type/value:	30	lamp diameter in ⅛ of inch
Enter Nominal Lamp Wattage:	75	watts
Enter Beam Angle:	10	degrees
Minimum Center Beam Intensity:	9561	cd

Term	Coefficient	PAR Type	Nominal Wattage	Beam Angle	Predicted Log CBCP	Log CBCP Two-sigma Lower Bound	Predicted CBCP	CBCP Two-sigma Lower Bound
Intercept	5.5102112	30	75	10	9.468	9.165	12936	9561
PAR	0.1395448							
Watts	0.0448725							
Beam Angle	-0.083493							
PAR*Watts	-0.000521							
PAR*Beam Angle	-0.000719							
PAR^2	-0.001192							
$Watts^2$	-0.00005981							
$Beam Angle^2$	0.0008786							
Root Mean Square Error	0.151113							

Sheet1

MR-16 Lamps

Target Halogen Lamp Parameters

Enter Nominal Lamp Wattage:	35	watts
Enter Beam Angle:	10	degrees
Minimum Center Beam Intensity:	5079	cd

Term	Coefficient		Watts	Beam Angle	Predicted Log CBCP	Log CBCP One-sigma Lower Bound	Predicted CBCP	CBCP One-sigma Lower Bound
Intercept	8.5850833		35	10	8.875	8.533	7147	5079
Volts	-0.010502							
Watts	0.0533632							
Beam Angle	-0.120216							
Volts*Beam Angle	0.0002857							
$Watts^2$	0.000312							
$Beam Angle^2$	0.0009782							
Root Mean Square Error	0.341548							