Work Paper PGECOLTG140
LED MR-16
Revision 7

Pacific Gas & Electric Company

LED MR-16

Measure Codes LD196-LD203

06/29/2017

At-a-Glance Summary

Applicable Measure Codes:	LD196-LD203 LED MR16 Lamps
Measure Description:	LED MR-16 lamp replacing halogen MR-16 lamp.
Energy Impact Common Units:	Lamp.
Base Case Description:	Halogen MR-16 lamp Source: Based on WRR from 2011 DEER
Base Case Energy Consumption:	Various. Refer to .xlsx file attached Source: DEER 2016 (wattage reduction ratio of 4.24)
Measure Energy Consumption:	Various. Refer to .xlsx file attached
Energy Savings (Base Case – Measure)	Various. Refer to .xlsx file attached Source: DEER 2016
Costs Common Units:	$ per lamp.
Base Case Equipment Cost ($/unit):	Various. Refer to .xlsx file attached
Measure Equipment Cost ($/unit):	Various. Refer to .xlsx file attached
Measure Incremental Cost ($/unit):	Various. Refer to .xlsx file attached
Effective Useful Life (years):	Various. Refer to .xlsx file attached Source: DEER 2016
Program Type:	ROB
Net-to-Gross Ratios:	NTGR ID / Sector / NTGR NonRes-sAll-mLEDSpcl / NonRes / 0.6 Res-sAll-mLEDSpcl / Com / 0.6 Source: DEER 2017
Important Comments:	

Document Revision History

Revision #	Date	Description	Author (Company)
Revision 0	06/01/11	PGECOLTG140R0-LED MR16	Alina Zohrabian (PG&E)
Revision 1	05/30/12	PGECOLTG140R1-LED MR16 Updated for 2013-14	Alina Zohrabian (PG&E)
Revision 1	8/29/12	OTR explanation is added in the workpaper, The “Com” and "RES" building types are the weighted up value from DEER building types, For Vintage AV is changed to EX and For Climate Zone All is changed to IOU	Alina Zohrabian (PG&E)
Revision 2	7/13/13	Revised Savings values per ED Workpaper Disposition for Lighting Retrofit, issue March, 2013. For updated savings values, see file PGECOLTG140 R2-Calcs.xlsx For measure L097 PG&E used 5 watts for the measure wattage this went down to 3 watts. For measure L098 PG&E used 7 watts for the measure wattage this went down to 6.1 watts. For measure L046 PG&E used 10 watts for the measure wattage this went down to 8.1 watts.	Alina Zohrabian (PG&E)
Revision 3	9/23/13	Measure wattages are broken down into more refined wattage ranges. Please refer to PGECOLTG140 R3-Calcs.xlsx for savings values.	Alina Zohrabian (PG&E)
Revision 4	3/21/14	Added DI values from (PGE3PLTG177-R2) and Revised savings values per ED Workpaper Disposition for lighting Retrofit, December 14, 2013. For updated savings values, see file PGECOLTG140 R4.xlsx	Alina Zohrabian (PG&E)
Revision 5	1/1/2016	Updated NTG, annual hours of operation, IE, CDF, EUL, per DEER 2016. Costs have also been updated.	Linda Wan (PG&E)/ Alina Zohrabian (PG&E)
Revision 6	11/28/2016	Updated Residential Interactive Effect(IE) per DEER 2017	Mini Damodaran (PG&E)/Alina Zohrabian (PG&E)
Revision 7	6/29/17	Updated NTG ID based on the 2017ScrewInLampDisposition	Henry Liu (PG&E)

Table of Contents

List of Tables

Section 1. General Measure & Baseline Data

1.1 Product Measure Description & Background

This work paper details the replacement of existing halogen MR-16 lamps with LED MR-16 lamps.

Requirements:

- Must replace a halogen MR16 lamp (for a retrofit case)

Table 1 Measure Codes

Product Code	Description
LD196	LED MR-16: <6 Watts
LD197	LED MR-16: 6 to <7 Watts
LD198	LED MR-16: 7 to <8 Watts
LD199	LED MR-16: 8 to <9 Watts
LD200	LED MR-16: 9 to <10 Watts
LD201	LED MR-16: 10 to <11 Watts
LD202	LED MR-16: 11 to <12 Watts
LD203	LED MR-16: ≥12 Watts

Program Restrictions and Guidelines

The delivery method is Upstream/Midstream Programs for commercial customers and the Upstream Lighting Program for residential customers. For Multifamily customers, this product is also available through the downstream program. Certain 3rd party contractors may also be delivering these lamps using Direct Install channels.

In support of the transition to the California Energy Commission's Voluntary California Quality Light-Emitting Diode (LED) Lamp Specification (CEC Spec), to qualify for a rebate in the program, the replacement LED lamps must fall into one of the categories shown in the table below. Only lamps that fully meet the CEC Spec will be supported in the Upstream Lighting Program after Dec 1, 2013.

Table 2 Lamp Specification

Residential: Upstream Lighting Program	Residential: Downstream & Direct Install Commercial: Midstream / Upstream & Direct Install
Must meet CEC specification 3.0[1] and Energy Star 2.0[2] and be listed on both Energy Star and Modernized Appliance Efficiency Database System (MAEDBS) databases. The lamps in MAEDBS must be listed on the "State-regulated Light Emitting Diode Lamp" list[3].	Must be on THE ENERGY STAR Qualified Products List.

Terms and Conditions
The customer must be a residential or commercial PG&E electric customer.

Market Applicability
Single and multi-family installations are eligible. MR-16 lamps are primarily used in the retail market sector; however, this measure applies to all commercial buildings and to the residential market as well.

Please refer to the table below for applicable delivery types, building types, and application types:

Table 3 Delivery Method and Applicable Building Types

Delivery Type	Applicable Building Types	Application Type
Upstream	"Com" & "Res"	ROB
Downstream	DEER Building Types	ROB
Direct Install	DEER Building Types	ROB

1.2 Product Technical Description

Light emitting diode (LED) sources have improved over the past decade making them an efficient and reliable lighting technology. Many LED products successfully replaced other lighting sources and made their way into the market by continuing to improve to be able to compete in any application.

Comparing the results of the CALiPER test summaries[6], starting in Round 3 where they included the testing of the MR16 lamps, with the results of the later CALiPER tests, the LED MR16 lamps improved not only in their lumen output and efficacy but also in their correlated color temperature, color rendering index, power factor, heat control and lamp beam directivity. These improvements are seen in many of the LED lighting products and make this technology promising for the near future in most lighting applications.

1.3 Measure Application Type

The DEER Measure Cost Data Users Guide found on www.deeresources.com under *DEER2011 Database Format* hyperlink, DEER2011 for 13-14, spreadsheet *SPTdata_format-V0.97.xls*, defines the terms as follows:

Table 4 Measure Application Type[4]

Identifies the measure application type in the Measure Implemenation table in DEER2011.

Code	Description	Comment
ER	*Early retirement*	*measure applied while existing equipment still viable, or retrofit of existing equipment*
ROB	*Replace on Burnout*	*measure applied when existing equipment fails or maintenance requires replacement*
NC	*New Construction*	*measure applied during construction design phase as an alternative to a code-compliant standard design*

All the measures within this workpaper are ROB.

1.4 Product Base Case and Measure Case Data

The most common base case wattages of the halogen MR-16 are 20, 35, and 50 watts, based on the "Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications" report, prepared for DOE[5]. The base case is calculated based on the wattage reduction ratio (WRR) methodology. The measure case is the associated LED wattage.

1.4.1 DEER Base Case and Measure Case Information

The base case wattage is calculated using the wattage reduction ratio (WRR). The base case wattage is calculated using the approved WRR of 4.24 from the July 22, 2016 disposition (LED-WRR-WorkpaperDisposition_22Jul2016-Final). The measure case is the associated LED wattage.

Hours of Operation

The DEER 2017 hours of operation and interactive effects are used for the savings calculations.

Net-to-Gross Values
The NTG values are from DEER 2016. The table below summarizes all applicable Net-to-Gross ratios for programs that may be used by this measure.

Table 5 Net-to-Gross Ratios

NTGR ID	Description	Sector	BldgType	Measure Delivery	NTGR
NonRes-sAll-mLEDSpcl	All nonresidential specialty LED lamps (other than A-lamp and screw-in reflector), all delivery mechanisms	NonRes	Any	Any	0.6
Res-sAll-mLEDSpcl	All residential specialty LED lamps (other than A-lamp and screw-in reflector), all delivery mechanisms	Res	Any	Any	0.6

Spillage Rate
Spillage rates are not tracked in work papers; they are tracked in an external document which will be supplied to the Commission Staff.

Installation Rate
The IR values were obtained using the DEER READI tool. The relevant IR values for the measures in this work paper are in the table below:

Table 6 Installation Rate

GSIA ID	Description	Sector	BldgType	ProgDelivID	GSIAValue
Def-GSIA	Default GSIA values	Any	Any	Any	1
Com-LED-PGE	Non-Res LED; Non-Upstream Program; Annual Installation Rate	Com	Any	NonUpStrm	1

Effective Useful Life / Remaining Useful Life
Although the minimum lamp life in Energy Star is 25,000 hours and most products show a lamp life of 25,000 or 35,000 hours, the Energy Division recommended a lamp life of 20,000 hours. Since the effective useful life (EUL) is dependent on the hours of operation, the EUL varies by building type. The Energy Division also recommended using a maximum value of 12 years for EUL, which is the life of a pin-based CFL fixture in commercial application.

The EUL is calculated using the following equation:

EUL = (Lamp Life (20,0000 hours)) / (Average Operating Hours Per Year)

Table 7 Effective Useful Life/Remaining Useful Life

EUL ID	Description	Sector	UseCategory	EUL (Years)	RUL (Years)
ILtg-Com-LED-20000hr	LED Lamp - Indoor-Commercial	Com	Lighting	Varies (max of 12 years)	Varies
ILtg-Res-LED-20000hr	LED lamp - Indoor - Residential	Res	Lighting	16	5.33

1.4.2 Codes & Standards Requirements Base Case and Measure Information

Title 20: These measures do not fall under Title 20 [2015] of the California Energy Efficiency Regulations.

Title 24: These measures do not fall under Title 24 [2013] Non-Residential Building Energy Efficiency Standards.

Federal Standards: These measures do not fall under Federal DOE Energy Regulations.

1.4.3 EM&V, Market Potential, and Other Studies – Base Case and Measure Case Information

There are many demonstration projects and reports such as DOE Solid-State Lighting CALiPER Program's Summary of Results[6] that could be addressed. However this workpaper is using the disposition for integral LED lamp replacement guidelines from Energy Division to calculate the savings. As the LEDs improve and the efficacy increases the wattage reduction ratio methodology should be revisited since it will not be an appropriate method to calculate savings going forward.

1.4.4 Assumptions and Calculations from other sources—Base and Measure Cases

This workpaper follows the LED-WRR-Workpaper Disposition from the California Public Utilities Commission; Energy Division dated July 22, 2016.

Section 2. Calculation Methods

2.1 Electric Energy Savings Estimation Methodologies

The energy savings calculation is using the wattage reduction ratio (WRR) of 4.24 on the LED wattages in the measures case. The operating hours and interactive effects for Commercial were taken from DEER 2016 data. The operating hours and interactive effects for Residential were taken from DEER 2017. Refer to the equation below for the energy savings calculation:

$$Annual\,Energy\,Savings\left[\frac{kWh}{unit}\right] = (\Delta kW/unit) * (Annual\,hours\,of\,operation) * (Energy\,Interactive\,Effects)$$

$$\Delta kW/unit = \left[\frac{(Measure\,case\,wattage * WRR) - Measure\,case\,wattage}{1000}\right]$$

Sample calculation for LD196 LED MR-16 <6 Watts for an Assembly:

$$Annual\,Energy\,Savings = \left[\frac{kWh}{unit}\right] = (0.003 * 4.24 - 0.003) * (1160) * (1.04) = 11.7$$

"OTR"-This code stands for "Other" building type and it is only used when the customer doesn't select a building type in the application or the building type doesn't fall under any of the DEER approved building types. "OTR" building type savings are calculated using the "minimum kwh savings row" of valid DEER building types. If all kwh are zero, use minimum kw row. If all kwh and kw are zero, use minimum therm. For a lighting measure with all building types, the "MTL" building type will be equivalent to OTR because it is the lowest hours of operation.

2.2. Demand Reduction Estimation Methodologies

The lighting demand difference (Watts per unit) is simply the difference between the electric demand of the base unit and the electric demand of the energy efficient unit. The operating hours and interactive effects for Commercial were taken from DEER 2016 data. The operating hours and interactive effects for Residential were taken from DEER 2017. The Demand savings is calculated based on the formula below:

$$Demand\ Savings\left[\frac{kW}{unit}\right]=(\Delta kW/unit)\times(lightingCoincidentDemand)\times(DemandInteractive\ Effects)$$

Sample calculation for Assembly:

$$Demand\ Savings\left[\frac{kW}{unit}\right]=(0.003*4.24-0.003)*(0.221)*(1.18)=0.00253$$

2.3. Gas Energy Savings Estimation Methodologies

There is no gas energy savings associated with this measure. However, the negative impacts are calculated based on the formula below. The operating hours and interactive effects for Commercial were taken from DEER 2016 data. The operating hours and interactive effects for Residential were taken from DEER 2017.

$$Annual\ Gas\ Savings\ [Therm/Unit]=(\Delta kWatts/unit)\times(AnnualHoursOfUse)\times(GasInteractive\ Effects)$$

Sample calculation for Assembly:

$$Annual\ Gas\ Savings\ [Therm/Unit]=(0.003*4.24-0.003)*(1160)*(-0.0099)=-0.112$$

Section 3. Load Shapes

Load Shapes are an important part of the life-cycle cost analysis of any energy efficiency program portfolio. The net benefits associated with a measure are based on the amount of energy saved and the avoided cost per unit of energy saved. For electricity, the avoided cost varies hourly over an entire year. Thus, the net benefits calculation for a measure requires both the total annual energy savings (kWh) of the measure and the distribution of that savings over the year. The distribution of savings over the year is represented by the measure's load shape. The measure's load shape indicates what fraction of annual energy savings occurs in each time period of the year. An hourly load shape indicates what fraction of annual savings occurs for each hour of the year. A Time-of-Use (TOU) load shape indicates what fraction occurs within five or six broad time-of-use periods, typically defined by a specific utility rate tariff. Formally, a load shape is a set of fractions summing to unity, one fraction for each hour or for each TOU period. Multiplying the measure load shape with the hourly avoided cost stream determines the average avoided cost per kWh for use in the life cycle cost analysis that determines a measure's Total Resource Cost (TRC) benefit.

3.1 Base Case Load Shapes

The base case load shape would be expected to follow a typical residential and commercial lighting end use load shape.

3.2 Measure Load Shapes

For purposes of the net benefits estimates in the E3 calculator, what is required is the load shape that ideally represents the difference between the base equipment and the installed energy efficiency measure. This difference load profile is what is called the Measure Load Shape and would be the preferred load shape for use in the net benefits calculations.

The measure load shape for this measure is determined by the E3 calculator based on the applicable residential and commercial market sector and the lighting end-use.

Table 8 Building Types and Load Shapes

Building Type	Load Shape	E3 Alternate Building Type
All Commercial Building Types	PGE:DEER:Com:Indoor_CFL_Ltg	NON_RES
All Residential Building Types	PGE:DEER:Indoor_CFL_Ltg	RES

Section 4. Base Case & Measure Costs

A joint effort was made between SCE and PG&E to update base case and measure costs for DEER 2016 affected measures. Please refer to the LED lamp cost workbook for detailed information.

4.1 Base Case(s) Costs

The base case costs are 100% incandescent/halogen. Incandescent/halogen costs are calculated from WO017[7] workbook. The base case wattages are mapped to individual LED wattages using a table from the Energy Star Calculator.

4.2 Measure Costs

Most costs for LED lamps were provided by Navigant as part of a study on LEDs. Several were interpolated or extrapolated from the Navigant data. The California LED Workpaper Update Study[8] recommends using 25 percentile utilizing CA specific data.

4.3 Incremental & Full Measure Costs

Table 9 Full and Incremental Measure Cost Equations

Installation Type	Incremental Measure Cost	Full Measure Cost	
		1st Baseline	2nd Baseline
ROB	(MEC + MLC) – (BEC + BLC)	(MEC + MLC) – (BEC + BLC)	N/A
NEW/NC			
RET/ER	(MEC + MLC) – (BEC + BLC)	MEC + MLC	(MEC + MLC) – (BEC + BLC)
REF	(MEC + MLC) – (BEC + BLC)	MEC + MLC	N/A
REA	MEC + MLC	MEC + MLC	N/A

MEC = Measure Equipment Cost; MLC = Measure Labor Cost
BEC = Base Case Equipment Cost; BLC = Base Case Labor Cost

4.3.1 Full Measure Cost

Full Measure Cost is the cost to install an energy efficient measure per the CPUC calculators. This definition implies a different meaning depending on the Measure Application type.

The Full measure cost is used for Direct Install Measures. A labor cost of $4.48 is used from WO017. For full measure costs please refer to the LED lamp cost spreadsheet.

4.3.2 Incremental Measure Costs

The labor required installing base case or measure case is equivalent. Therefore, labor cost is not considered in incremental measure costs. For incremental measure costs please refer to the LED lamp cost spreadsheet.

References

[1] CEC Spec v3.0: http://www.energy.ca.gov/business_meetings/2016_packets/2016-12-14/Item_09.pdf

[2] EnergyStar v2.0: https://www.energystar.gov/sites/default/files/asset/document/ENERGY%20STAR%20Lamps%20V2%20Revised%20Spec.pdf

[3] MAEDBS, State-regulated Light Emitting Diode Lamp list, https://cacertappliances.energy.ca.gov/Pages/ApplianceSearch.aspx

[4] The DEER Measure Cost Data Users Guide found on www.deeresources.com under *DEER2011 Database Format* hyperlink, DEER2011 for 13-14, spreadsheet *SPTdata_format-V0.97.xls*.

[5] Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications, Jan 2011, section 2.2.3, page 17 of document

[6] DOE CALiPER *Summary Reports:* http://www1.eere.energy.gov/buildings/ssl/reports.html

[7] 2010-2012 WO017 Ex Ante Measure Cost Study Final Report. Submitted by: Itron, Inc. May 27, 2014.

[8] California LED Workpaper Update Study. Navigant Consulting. August 28, 2015.