Work Paper PGECOLTG141
LED PAR Lamps
Revision 8

Pacific Gas & Electric Company

LED PAR16, PAR20, PAR30 and PAR38 Lamps

Measure Codes LD03, LD167-LD195, LT064-LT066

6/7/2017

At-a-Glance Summary

Applicable Measure Codes:	LD03, LD167-LD195 LED, LT064-LT066 PAR Lamps
Measure Description:	LED PAR lamps replacing halogen PAR lamps.
Energy Impact Common Units:	Lamp.
Base Case Description:	Halogen PAR lamp Source: Energy Star, DOE and PG&E Calculations.
Base Case Energy Consumption:	Various. Refer to .xlsx file attached Source: DEER 2016(wattage reduction ratio of PAR16=4.70, PAR20=4.70, PAR30=3.42, PAR38=3.81)
Measure Energy Consumption:	Various. Refer to .xlsx file attached Source: Energy Star and Lighting Facts
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** / **NTGR** NonRes-sAll-mLEDARefl / 0.91 Res-sAll-mLEDARefl / 0.91 Source: 2017 Disposition for Screw-In Lamps
Important Comments:	PAR16 measure codes are added with the same WRR as PAR20. "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.

Document Revision History

Revision #	Date	Description	Author (Company)
Revision 0	07/21/11	PGECOLTG141R0-LED PAR Lamps	Alina Zohrabian (PG&E)
Revision 1	06/17/12	PGECOLTG141R1-LED PAR Lamps Note: updated for 2013-2014	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 PGECOLTG109 R4-Calcs.xlsx For measure L037 PG&E used 7 watts for the measure wattage this went down to 5.5 watts. For measure L038 PG&E used 11 watts for the measure wattage this went down to 8 watts. For measure L039 PG&E used 15 watts for the measure wattage this went down to 14 watts. For measure L045 PG&E used 17 watts for the measure wattage this went down to 16 watts. For measure L040 PG&E used 13 watts for the measure wattage this went down to 8 watts. For measure L041 PG&E used 18 watts for the measure wattage this went down to 16 watts. For measure L044 PG&E used 21 watts for the measure wattage this went down to 20.1 watts.	Alina Zohrabian (PG&E)
Revision 3	10/09/13	Measure wattages are broken down into more refined wattage ranges. Please refer to PGECOLTG141 R3-Calcs.xlsx for savings values.	Alina Zohrabian (PG&E)
Revision 4	3/21/14	Added DI values from (PGE3PLTG178) and Revised savings values per ED Workpaper Disposition for lighting Retrofit, December 14, 2013. For updated savings values, see file PGECOLTG141 R4.xlsx	Alina Zohrabian (PG&E)
Revision 5	1/1/2016	Updated NTG, EUL, CDF, IE, hours of operation per DEER 2016. Costs have also been updated.	Linda Wan (PG&E)/ Alina Zohrabian (PG&E)
Revision 6	6/10/2016	PAR16 measure codes are added with the same WRR as PAR20. IOU’s further evaluation of the whole WRR methodology and the suggestions would apply to the whole workpaper in the future when the new methodology gets accepted by ED. Cost for PAR16 is done by web search.	Alina Zohrabian (PG&E)
Revision 7	11/28/2016	Updated residential interactive effect (IE) per DEER 2017.	Mini Damodaran (PG&E)/ Alina Zohrabian (PG&E)
Revision 8	6/7/2017 8/10/2017	Updated WRR, base case percentages and NTG as per 2017 Disposition for Screw-In Lamps; Used PAR20 WRR for PAR16; Base costs changed based on base case %; NTG changed to 0.91; Updated Program Restrictions and Guidelines. The EnergyImpactID for the PAR16 measures were corrected to “Res-Iltg-dWatt-CFL” for residential sector and “Com-Iltg-dWatt-CFL” for Commercial sector as per “Review of Resubmitted workpapers for 2017 Screw-In Lamp Disposition”, July 31st, 2017	Alina Zohrabian (PG&E)/ Mini Damodaran (PG&E) Mini Damodaran (PG&E)

Table of Contents

List of Tables

Section 1. General Measure & Baseline Data

1.1 Measure Description & Background

This work paper details the replacement of existing halogen Parabolic Aluminized Reflector (PAR) PAR16, PAR20, PAR30 and PAR38 lamps with LED PAR16, PAR20, PAR30 and PAR38 lamps.

Requirements:

- Must replace a halogen PAR lamp

Table 1 Measure Codes and Description

Product Code	Description
LT064	LED PAR16: <6 Watts
LT065	LED PAR16: 6 to < 7 Watts
LT066	LED PAR16: ≥7 Watts
LD03	LED PAR20: ≤11 Watts
LD167	LED PAR30: <10 Watts
LD168	LED PAR30: 10 to <11 Watts
LD169	LED PAR30: 11 to <12 Watts
LD170	LED PAR30: 12 to <13 Watts
LD171	LED PAR30: 13 to <14 Watts
LD172	LED PAR30: 14 to <15 Watts
LD173	LED PAR30: 15 to <16 Watts
LD174	LED PAR30: 16 to <17 Watts
LD175	LED PAR30: 17 to <18 Watts
LD176	LED PAR30: 18 to <19 Watts
LD177	LED PAR30: 19 to <20 Watts
LD178	LED PAR30: ≥20 Watts
LD179	LED PAR38: < 12 Watts
LD180	LED PAR38: 12 to <13 Watts
LD181	LED PAR38: 13 to <14 Watts
LD182	LED PAR38: 14 to <15 Watts
LD183	LED PAR38: 15 to <16 Watts
LD184	LED PAR38: 16 to <17 Watts
LD185	LED PAR38: 17 to <18 Watts
LD186	LED PAR38: 18 to <19 Watts
LD187	LED PAR38: 19 to <20 Watts
LD188	LED PAR38: 20 to <21 Watts
LD189	LED PAR38: 21 to <22 Watts
LD190	LED PAR38: 22 to <23 Watts
LD191	LED PAR38: 23 to <24 Watts
LD192	LED PAR38: 24 to <25 Watts
LD193	LED PAR38: 25 to <26 Watts
LD194	LED PAR38: 26 to <27 Watts
LD195	LED PAR38: ≥27 Watts

Program Restrictions and Guidelines

This workpaper is configured to accommodate any additional program changes to address higher efficacy lamps, if necessary. Currently the lamps rebated through the residential program must meet both Energy Star and the CEC Voluntary California Quality Light-Emitting Diode (LED) Lamp Specification (CEC Spec) requirements. These lamps meet higher quality product performance criteria as defined by CEC. The CEC Spec has added new efficacy requirements.

For lamps rebated through the commercial programs the minimum efficacy requirements have increased due to stricter Energy Star requirements. IOU's program staff will work with CPUC program staff to make sure all the rebated lamps meet the appropriate program rules and to reach towards the same common goals.

- The delivery method is Upstream/Midstream Programs for commercial customers and the Upstream Lighting Program for residential customers. This workpaper also covers Direct Install delivery channel. For Multifamily customers this product is also available through the downstream program.
- 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 Specifications

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. Single and multi-family installations are eligible.

Market Applicability
PAR lamps are primarily used in the retail market and grocery stores for display lighting; however, this measure applies to all commercial buildings and to the residential market as well.

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

Table 3 Delivery Method and Applicable Building Types

Delivery Type	Applicable Building Types
Upstream/Midstream	"Com" & "Res"
Downstream	DEER Building Types
Direct Install	DEER Building Types

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[4], starting in Round 3 where they included the testing of the LED Parabolic Aluminized Reflector (PAR) lamps, with the results of the later CALiPER tests, the LED PAR 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 Database for Energy Efficiency Resources (DEER) developed by the California Public Utilities Commission defines the measure application type. The Support table "Measure Application Type" in the "Measure Catalog" can be found using the latest version of the Remote Ex-Ante Database Interface (READI) on the Database for Energy-Efficient Resources (DEER) website[5].

Table 4 Measure Application Type

Code	Description	Comment
ROB	Replace on Burnout	*Measure technology applied instead of Code/Standard technology at the time of replacement, Single baseline (above code), incremental or full costs*
NC	New Construction	*Measure technology applied instead of Code/Standard technology during new construction, Single baseline (above code), incremental or full costs*
ROBNC	ROB or NC	*Measure technology applied instead of Code/Standard technology at the time of replacement or new construction, Single baseline (above code), incremental or full costs*

All the measures within this work paper are ROB.

1.4 Product Base Case and Measure Case Data

The base case wattages of the halogen PAR lamps are calculated based on the Energy Division wattage reduction ratios (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). WRR is the ratio of the deemed baseline wattage to the deemed LED wattage. Table below shows the approved WRR from July 1st, 2017 based on 2017 "Comprehensive Workpaper Disposition for: Screw-In Lamps" Disposition from the California Public Utilities Commission; Energy Division, dated May 26, 2017[6].

Table 5 Wattage Reduction Ratios

Lamp	WRR
PAR16	4.04
PAR20	4.04
PAR30	2.94
PAR38	3.28

Hours of Operation

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

Net-to-Gross Assumption

Table below shows the approved NTG values from the July 1st, 2017 based on 2017 Disposition for Screw-In Lamps. The table below summarizes all applicable Net-to-Gross ratios for programs that may be used by this measure.

Table 6 Net-to-Gross Ratios

NTGR ID	Description	Sector	BldgType	Delivery Method	NTGR
NonRes-sAll-mLEDARefl	Nonresidential LED A-lamp and screw-in reflector, all delivery mechanisms	NonRes	Any	Any	0.91
Res-sAll-mLEDARefl	Residential LED A-lamp and screw-in reflector, all delivery mechanisms	Res	Any	Any	0.91

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 7 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 EUL is calculated using the following equation:

$$EUL = \left[\frac{Rated\ Lamp\ Life}{Hours of\ Operation} \right]$$

Table 8 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[4] that could be addressed. However this workpaper is using the disposition for integral LED lamp replacement guidelines from Energy Division (ED) to calculate the savings. As the LED's 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

The base case is split into 40% CFL and 60% halogen/incandescent. This workpaper complies with the 2017 "Comprehensive Workpaper Disposition for: Screw-In Lamps" Disposition from the California Public Utilities Commission; Energy Division, dated May16, 2017.

Section 2. Calculation Methods

Wattage Reduction Ratio (WRR) savings estimation methodology is used per 2017 "Comprehensive Workpaper Disposition for: Screw-In Lamps" Disposition from the California Public Utilities Commission; Energy Division, dated May 26, 2017, based on values in Table 5 to calculate the energy savings. The demand difference (Δ Watts/lamp) is simply the difference between the electric demand of the base case lamp and the electric demand of the measure case lamp. The base case wattage of the lamp is calculated by applying the WRR multiplier to the lowest measure case wattage within the measure case range.

$$\Delta Watts/lamp\left[\frac{Watts}{lamp}\right] = (Measure\ Case\ Watts/lamp\ x\ WRR) - (Measure\ Case\ Watts/lamp)$$

$$\Delta Watts/lamp\left[\frac{Watts}{lamp}\right] = (Base\ Case\ Watts/lamp) - (Measure\ Case\ Watts/lamp)$$

2.1 Electric Energy Savings Estimation Methodologies

The energy savings calculation uses the wattage reduction ratio (WRR) methodology. Energy savings vary by market sector and building type because of differences in operating hours and interactive effect multipliers. 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:

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

$$\text{Where } \Delta kW/unit = \frac{(Measure\ case\ wattage * WRR) - Measure\ case\ wattage}{1000}$$

Sample calculation for LD03 PAR 20 for Assembly building type:

$$Energy\ Savings\left[\frac{kWh}{unit}\right] = (0.006 * 4.04 - 0.006) * (1160) * (1.04) = 22$$

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 Demand savings is calculated based on the formula below:

$$Demand\ Savings\left[\frac{kW}{unit}\right] = (\Delta kW/unit) * (lighting\ coincident\ diversity\ factor) * (Demand\ Interactive\ Effects)$$

Sample calculation for LD03 PAR 20 for Assembly building type:

$$Demand\ Savings\left[\frac{kW}{unit}\right] = (0.006 * 4.04 - 0.006) * (0.221) * (1.18) = 0.00476$$

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.

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

Sample calculation for LD03 PAR 20 for Assembly building type:

$$Energy\ Savings\left[\frac{kWh}{unit}\right] = (0.006 * 4.04 - 0.006) * (1160) * (-0.0099) = -0.21$$

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.

These measures will use the Residential lighting and Commercial indoor lighting load shapes based on the E3 calculator and the applicable residential and commercial market sector.

Table 9 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. To comply with the May 26th, 2017 disposition we used the same cost information but changed the percentages in the base cost as per the disposition. Please refer to the LED lamp cost workbook for detailed information.

The cost for PAR16 is done by web search, since the previously used study for this workpaper doesn't have specific cost for PAR16.

4.1 Base Case(s) Costs

The base case costs are split into 40% CFL and 60% halogen/incandescent based on 2017 "Comprehensive Workpaper Disposition for: Screw-In Lamps" Disposition from the California Public Utilities Commission; Energy Division, dated May 26th, 2017. CFL costs are taken from the READI Tool v 2.3.0. Costs not available from READI have been interpolated. Halogen/incandescent 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 10 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] DOE CALiPER *Summary Reports:* http://www1.eere.energy.gov/buildings/ssl/reports.html

[5] The Support table "Measure Application Type" in the Measure Catalog can be found using the latest version of the Remote Ex-Ante Database Interface (READI) on the Database for Energy-Efficient Resources (DEER) website, http://www.deeresources.com/

[6] Non-DEER Work Papers and Dispositions (2013 – 2017), Screw In Lamps Disposition, http://www.deeresources.com/index.php/non-deer-workpapers

[7] 2010-2012 WO017 (work-Order-17) 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.