**Work Paper PGECOLTG151**

**LED Outdoor Parking Garage Lighting**

**Revision 9**

**Pacific Gas & Electric Company**

**LED Outdoor Parking Garage**

**Measure Codes: LT480 – LT487**

# At-A-Glance Summary

|  |  |
| --- | --- |
| **Applicable Measure Codes:** | LT480 to LT487 |
| **Measure Description:** | LED parking garage luminaires and kits greater than 120 lm/W (DLC v4.4 Premium Classification) |
| **Energy Impact Common Units:** | Per fixture. |
| **Base Case Description:** | Parking Garage: 30% LED fixture, 30% linear LED replacement lamp (TLED), 20% Linear Fluorescent, 20% Metal Halide (MH) |
| **Base Case Energy Consumption:** | Refer to PG&E Calculations  “PGECOLTG151 R9 LED Outdoor Ltg Calc\_Mar2019.xlsx” |
| **Measure Energy Consumption:** | Refer to PG&E Calculations  “PGECOLTG151 R9 LED Outdoor Ltg Calc\_Mar2019.xlsx” |
| **Energy Savings (Base Case – Measure)** | Refer to PG&E Calculations  “PGECOLTG151 R9 LED Outdoor Ltg Calc\_Mar2019.xlsx” |
| **Costs Common Units:** | $ per lumen |
| **Base Case Equipment Cost ($/unit):** | Varies  Refer to: “Copy of TLED Cost Data\_FEB2019.xlsx” and  “PGECOLTG151 R9 LED Outdoor Ltg Calc\_Mar2019.xlsx” |
| **Measure Equipment Cost ($/unit):** | Varies  Source: PG&E Program Data and online pricing  Refer to “PGECOLTG151 R9 LED Outdoor Ltg Calc\_Mar2019.xlsx” |
| **Measure Incremental Cost ($/unit):** | Varies  Source: PG&E Program Data and online pricing  Refer to “PGECOLTG151 R9 LED Outdoor Ltg Calc\_Mar2019.xlsx” |
| **Effective Useful Life (years):** | 12 years, OLtg-Com-LED-50000hr  LED Fixture – Outdoor - Commercial  Source: DEER2016 |
| **Measure Application Type:** | NR (Normal Replacement) |
| **Net-to-Gross Ratios:** | NTG = 0.91 per Disposition “2018OutdoorLightingPhase1-7May2018-Final” |
| **Important Comments:** | Revision 9 has parking garage measures only with the following revisions:  a). Added TLED in the baseline  b). Switched wattage bin structure to lumen bin structure  c). Updated cost |
| **Note 1:** | In the ED Report (Excel spreadsheet) the MAT is showing ROB because PG&E’s system is still in the process of adopting the new MATs. PG&E will revise ROB to NR at a later time when the system is ready. |
| **Note 2:** | Changing the Revision 9 workpaper (WP) title to “LED Outdoor Parking Garage Lighting” but keeping the same WP number. |

# Document Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| **Revision #** | **Date** | **Description** | **Author (Company)** |
| Revision 0 | 11/19/08 | Original work paper | Marc Theobald (EES)  Jack Howells (EES) |
| Revision 1 | 03/20/09 | PGECOLTG151 R1 | Jim Wyatt (PG&E) |
| Revision 2 | 01/15/2010 | PGECOLTG151 R2 | Jim Wyatt (PG&E) |
| Revision 3 | 06/15/2012 | PGECOLTG151 R3 | John Rossi (EES)  Jay Martin (EES)  Jim Wyatt (PG&E) |
| Revision 3 | 8/29/12 | For Building type changed COM to ANY, For Vintage AV is changed to ANY and For Climate Zone All is changed to ANY (Since this measure is for Exterior Lighting) | Alina Zohrabian (PG&E) |
| Revision 4 | 05/22/2014 | Added DI values and applied the 2014 IE and Hours from DEER (posted 2/20/14). For updated savings values, see file PGECOLTG151 R4.xlsx. | Tai Voong (PG&E) |
| Revision 5 | 1/1/2016 | Added NC for measure application type. Updated NTG values & EUL ID per DEER 2016. Updated base case costs and measure costs. | Linda Wan (PG&E) Alina Zohrabian (PG&E) |
| Revision 6 | 7/26/2016 | New measure codes LT067-LT073 to comply with leased street lamps requiring incentives refer to Advice Letter 4661-E. Retired LT016-LT017 because there is no uptake. Updated DI costs. | Henry Liu (PG&E) |
| Revision 7 | 12/14/2016 | -Changing measure application type from ROB and NC to ROBNC. | Henry Liu (PG&E) Mini Damodaran (PG&E)  Alina Zohrabian (PG&E) |
| Revision 8 | 1/1/2018 | Updates based on DLC version 4.2 and proposed new baseline percentage mix pending ISP study; Retiring the old measure structure (LT007 – LT015, LT18-LT024, LT067-LT073) and adding new measure codes LT282-LT324 effective 1/1/2018 that follow closely to DLC version 4.2 primary uses | Greg Barker (Energy Solutions)  Mini Damodaran (PG&E) |
| Revision 8 | 4/11/2018  5/14/2018 | -Updated baseline technology mix per disposition “2018OutdoorLighting-1March2018” as follows:  Street light, Roadway/Area, Wall-mounted and Canopy – 100% LED  Parking Garage - 60% LED, 20% metal halide, and 20% linear fluorescent  - Measure codes LT282-LT324 effective 1/1/2018 to follow DLC version 4.3 primary uses  - Cost is a temporary placeholder that uses IMC as a percentage of the rebate amount  -Updated NTG to 0.91 as per disposition “2018OutdoorLightingPhase1-7May2018-Final”  -Updated Measure IDs and Cost IDs | Greg Barker (Energy Solutions)  Mini Damodaran (PG&E)  Linda Wan (PG&E) James Liu (PG&E)  Mini Damodaran (PG&E) |
| Revision 9 | 12/10/2018  3/1/2019 | Added TLED in the baseline and updated cost for parking garage only, and sunset all other outdoor lighting measures. Switched wattage bin structure to lumen bin structure. Updated to Measure Codes LT480-LT487. Removed NC MAT. Measures effective 4/1/2019.  Changing the WP title to “LED Outdoor Parking Garage Lighting” but keeping the same WP number.  Revised TLED lamp efficacy to 111 lm/W, results in TLED fixture efficacy of 85.2 lm/W.  Revised TLED cost from $0.0042/lm to $0.0036/lm. | Greg Barker (Energy Solutions)  Randy Kwok(PG&E)  Randy Kwok(PG&E) |

# Table of Contents

[At-A-Glance Summary ii](#_Toc2803187)

[Document Revision History iii](#_Toc2803188)

[Table of Contents v](#_Toc2803189)

[List of Tables vi](#_Toc2803190)

[List of Figures vi](#_Toc2803191)

[Section 1. General Measure & Baseline Data 1](#_Toc2803192)

[1.1 Measure Description & Background 1](#_Toc2803193)

[1.2 Technical Description 4](#_Toc2803194)

[1.3 Installation Types and Delivery Mechanisms 4](#_Toc2803195)

[1.4 Product Base Case and Measure Case Data 4](#_Toc2803196)

[1.4.1 DEER Data 4](#_Toc2803197)

[1.4.2 Codes & Standards Requirements 6](#_Toc2803198)

[1.5 EM&V, Market Potential, and Other Studies – Base Case and Measure Case Information 7](#_Toc2803199)

[1.5.1 TLED Baseline 7](#_Toc2803200)

[1.5.2 CALiPER Snapshot Report June 17, 2016: 8](#_Toc2803201)

[1.5.3 Lighting Dispositions and DEER Resolutions 9](#_Toc2803202)

[1.5.4 California LED Pricing Analysis, Navigant 2018 10](#_Toc2803203)

[1.5.5 LED Workpaper Update Study, Navigant 2015 12](#_Toc2803204)

[1.5.6 Exterior Lighting Standard Practice Baseline and Workpaper Support, TRC Energy Services 14](#_Toc2803205)

[1.5.7 LED Non-Residential Lighting Market Characterization, Navigant – In Progress Update 14](#_Toc2803206)

[1.6 Data Quality and Future Data Needs 15](#_Toc2803207)

[1.6.1 Inclusion of Early Retirement (ER)/Accelerated Replacement (AR) Measure Application Type 15](#_Toc2803208)

[1.6.2 Product ID Collection Process 15](#_Toc2803209)

[1.6.3 LightingFacts LED Database 16](#_Toc2803210)

[1.6.4 Cost Data 16](#_Toc2803211)

[Section 2. Calculation Methods 17](#_Toc2803212)

[2.1 Electric Energy Savings Estimation Methodologies 23](#_Toc2803213)

[2.2 Demand Reduction Estimation Methodologies 23](#_Toc2803214)

[2.3 Gas Energy Savings Estimation Methodologies 23](#_Toc2803215)

[Section 3. Load Shapes 23](#_Toc2803216)

[3.1 Base Case Load Shapes 24](#_Toc2803217)

[3.2 Measure Load Shapes 24](#_Toc2803218)

[Section 4. Base Case & Measure Costs 24](#_Toc2803219)

[4.1 Base Case(s) Costs 24](#_Toc2803220)

[4.2 Measure Case Costs 25](#_Toc2803221)

[4.3 Incremental & Full Measure Costs 25](#_Toc2803222)

[Attachments 27](#_Toc2803223)

[References 28](#_Toc2803224)

# List of Tables

[Table 1: Measure Codes and Descriptions 3](#_Toc2803225)

[Table 2: Measure Application Type 4](#_Toc2803226)

[Table 3: Delivery Method and Applicable Building Types 4](#_Toc2803227)

[Table 4: DEER Difference Summary 4](#_Toc2803228)

[Table 5: DEER Net-to-Gross Ratios 6](#_Toc2803229)

[Table 6: Installation Rate 6](#_Toc2803230)

[Table 7: Effective Useful Life 6](#_Toc2803231)

[Table 8: Base Case Technology Mix 7](#_Toc2803232)

[Table 9: Lighting Facts 25th Percentile for Parking Garage luminaires by lumen bin 17](#_Toc2803233)

[Table 11: Lumen Maintenance Assumptions by Source Type 18](#_Toc2803234)

[Table 12: DLC v 4.4 and Zonal Lumens Distribution Requirements 19](#_Toc2803235)

[Table 13: Wattage Bin Method (Previous) 20](#_Toc2803236)

[Table 14: Lumen Bin Method (New with this revision) 21](#_Toc2803237)

[Table 15: Light Output Factors for Garage fixtures 21](#_Toc2803238)

[Table 16: Calculated Lumens 22](#_Toc2803239)

[Table 17: Measure Performance Actual vs. Deemed 22](#_Toc2803240)

[Table 18: Delta Watts for 8000 lm Garage Fixture 22](#_Toc2803241)

[Table 19: Building Type and Load Shape 24](#_Toc2803242)

[Table 20: Base case blend, including Watts and efficacy for 8000 lm Garage Fixture 25](#_Toc2803243)

[Table 21: Full and Incremental Measure Cost Equations 25](#_Toc2803244)

# List of Figures

[Figure 1: Web-based LED Price and Efficacy Data for Recessed Troffer/Panel 2’ x 4’ (Source: California LED Pricing Analysis, Navigant, January 2018) 11](#_Toc2803245)

[Figure 2: Willingness to replace equipment with LEDs before end of useful life, relative to other replacements (Source: California LED Workpaper Update Study, Navigant, August 2015) 14](#_Toc2803246)

# Section 1. General Measure & Baseline Data

## 1.1 Measure Description & Background

In 2017, the IOUs received dispositions on outdoor LED lighting which directed an update to the baselines used for outdoor LED lighting workpapers. Southern California Edison (SCE) was the lead on this effort and collaborated with the other IOUs to conduct a Standard Practice (SP) Baseline and Workpaper Update Study on outdoor lighting. The Study has, in December 2018, reported preliminary findings that are under review. The final report is expected to be completed by the end of December 2018.

PG&E submitted PGECOLTG151 Revision 8 in November 2017 as an interim solution to be used until the Standard Practice Baseline Study has been completed and was issued a 2018 Outdoor Lighting Phase 1 Disposition (filename: 2018OutdoorLighting-1March2018.pdf) on March 1, 2018. This disposition directed PG&E to perform the following:

1. Revise the baseline technology mix;
2. Revise the baseline LED efficacies, perform additional cost research; and
3. Re-analyze cost data.

Through cost research conducted via program data review and web scraping using existing measure wattage bins, negative incremental measure costs (IMC) were observed. The Commission Staff (CS) expressed that they did not want PG&E to eliminate measures or categories solely due to the cost issue recognizing the market barriers to LED fixture adoption still exist. CS therefore directed PG&E to work with the EAR team to resolve these issues. Multiple meetings were then conducted between the EAR team and PG&E from March to April to try to resolve the negative IMC issue. In late April, the EAR team accepted PG&E’s proposal of setting IMC at 110% of the rebate values as an interim solution to the issue. On May 7, 2018, Commission staff issued the disposition for PGECOLTG151 approving the interim solutions until 12/31/2018, with direction for PG&E to continue with cost research for inclusion in the next revision to the workpaper. On 10/11/2018 CPUC issued Resolution E-4952 extended the interim solution savings through 2019, but not the measure costs. PG&E’s recent research conducted through TRC in September/October showed the same negative IMC issue between LED fixtures of varying efficacies.

Upon additional research into previously completed CA market studies and from the preliminary findings of the Exterior Lighting SP Baseline Study conducted by TRC, it became evident that customers are facing multiple scenarios when choosing to upgrade their lighting. Customers who intend to upgrade their existing parking garage lighting from non-LED technologies to LED technology are faced with the following two scenarios: a full LED luminaire fixture/retrofit kit replacement or upgrading to tubular LED lamps (TLED). Cost-sensitive customers may choose the less expensive TLED option over the full fixture upgrade to achieve similar levels of service and energy savings. Evidence from SCE & PG&E participation data, NEMA (National Electrical Manufacturers Association) national sales data[[1]](#endnote-2), input from local distribution channels, and the California LED Pricing Analysis Study[[2]](#endnote-3) by Navigant all have suggested that TLEDs are a viable retrofit alternative to full fixture replacements. All other outdoor lighting measures besides parking garage measures have been sunset in revision R9 of this workpaper as TLEDs are not applicable to their baseline and the negative IMC challenge persists in a normal replacement scenario. PG&E has thus incorporated TLEDs in the baseline mix for parking garage lighting in this workpaper revision.

In addition, Revision 9 of this workpaper transitions the measure structure from wattage bins to lumen bins, with the intention to focus consumer purchasing choices on desired or equivalent levels of service.

PG&E has provided TLED cost and efficacy data collected in 2018 for this initial R9 workpaper update. Subsequently PG&E conducted additional online web-scraping on TLED cost and efficacy in February 2019 per CPUC ex-ante team’s recommendation. Based on the new data the average TLED cost and efficacy level were revised accordingly. See sections 2 and 4.1 below for details of the revision.

***Catalog Description***

LED Outdoor Area Lighting – Parking Garage

**Requirements:**

Only LED fixtures or LED retrofit kits on the list of prequalified LED fixtures available in the following DesignLights Consortium (DLC) product category qualify for these measures:

* **Parking Garage Luminaires** (fixtures and retrofit kits)
* Must replace a lumen equivalent lamp/fixture of higher wattage. (Please refer to Table 1)
* Must be on the DLC qualified product list (QPL)[[3]](#endnote-4)

**Exclusions:**

* Fixtures listed under specialty primary use designations on the DLC do not qualify for the measures.
* No other Exterior Primary Use Designations qualify for the rebate
* Street lighting applications for Pole/Arm-mounted Area and Roadway luminaires do not qualify for these measures. Please check with PG&E’s Government and Community Partnership team for LED street light rebates.
* Self-ballasted, screw-based or pin-based lamps do not qualify.
* Interior installations do not qualify for this rebate.
* Horticultural installations do not qualify for this rebate.
* Must meet the minimum efficacy and lumen ranges listed for the appropriate measure codes in Table 1.

The following table includes PG&E’s measure codes and measure descriptions:

Table 1: Measure Codes and Descriptions

|  |  |
| --- | --- |
| **Measure Code** | **Measure Name** |
| LT480 | LED Parking Garage Luminaire rated from 1800 to 2300 lumens and >= 120 LPW |
| LT481 | LED Parking Garage Luminaire rated > 2300 to 2900 lumens and >= 120 LPW |
| LT482 | LED Parking Garage Luminaire rated > 2900 to 3600 lumens and >= 120 LPW |
| LT483 | LED Parking Garage Luminaire rated > 3600 to 4500 lumens and >= 120 LPW |
| LT484 | LED Parking Garage Luminaire rated > 4500 to 5600 lumens and >= 120 LPW |
| LT485 | LED Parking Garage Luminaire rated > 5600 to 7000 lumens and >= 120 LPW |
| LT486 | LED Parking Garage Luminaire rated > 7000 to 8800 lumens and >= 120 LPW |
| LT487 | LED Parking Garage Luminaire rated > 8800 to 11000 lumens and >= 120 LPW |

***Program Restrictions and Guidelines***

To qualify for these measures, the following requirements must be met:

* Luminaires must be classified and listed under the Outdoor Category with a Primary Use Designation of either Parking Garage Luminaires or Retrofit Kits for Parking Garage Luminaires
* Luminaires must meet the DLC Technical Requirements version in effect at the time of installation, and be 120 lumens per watt or higher
* A product cut sheet and installation instructions must be provided.

***Terms and Conditions***

The customer must be a PG&E electrical customer served under a commercial/industrial rate schedule.

***Market Applicability***

These measures are offered via Midstream, Downstream and Direct Install delivery types.

## 

## 1.2 Technical Description

LED products are able to outperform discharge-lamp technologies across Outdoor lighting. The demanding photometric requirements of garage lighting, where fixtures must spread light as widely as possible from low overhead height, is well-suited for the improved optical control of LED products.

## 1.3 Installation Types and Delivery Mechanisms

The Database for Energy Efficiency Resources (DEER) developed by the California Public Utilities Commission defines the measure application type as shown in the table below.

Table : Measure Application Type[[4]](#endnote-5)

|  |  |  |
| --- | --- | --- |
| **Code** | **Description** | **Comment** |
| NR | Normal Replacement | *Measure technology applied instead of Code/Standard technology at the time of replacement, Single baseline (above code), incremental or full costs* |

The measure application type in this workpaper is identified as NR or “Normal Replacement.”

The workpaper supports Programs with downstream and direct install delivery channels with normal replacement application types. There are potential plans for a midstream expansion in the future.

Table : Delivery Method and Applicable Building Types

|  |  |  |
| --- | --- | --- |
| **Delivery Type** | **Applicable Building Types** | **Application Type** |
| Midstream, Downstream & Direct Install | DEER Building Types | NR (Normal Replacement) |

## 1.4 Product Base Case and Measure Case Data

This revision R9 of the workpaper only contains outdoor LED lighting measures for parking garage fixtures and retrofit kits.

### 1.4.1 DEER Data

Table : DEER Difference Summary

|  |  |
| --- | --- |
| **DEER Item** | **Used for Workpaper?** |
| Modified DEER methodology | Yes |
| Scaled DEER measure | No |
| DEER Base Case | No |
| DEER Measure Case | No |
| DEER Building Types | Yes |
| DEER Operating Hours | Yes |
| DEER eQUEST Prototypes | No |
| DEER Version | DEER 2019 |
| DEER Measure IDs Used | Propose new |

**Hours of Operation**

**Parking garages:**

Parking garages are assumed to be **2767.5** hours of use. This Equivalent Full-Load Hours (EFLH) is the average of the full power and lower-power usage at 35% power (the mid-point in the 20% to 50% range allowed) per CPUC’s disposition “2017ExteriorLEDFixturesDisposition-1Mar2017-FINAL”.

Operating hours with controls:

**Net-to-Gross Assumption**

The NTG value was specified in the Disposition “2018OutdoorLightingPhase1-7May2018-Final”. The NTG value for the measures in this work paper is listed below:

Table 5: DEER Net-to-Gross Ratios

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **NTGR ID** | **Description** | **Sector** | **BldgType** | **Delivery Method** | **NTGR** |
| Com-Out-Ltg-LEDFixt | Commercial Exterior LED Fixtures, For NR and NC Measure Application Types only. Not applicable to ER or AR | Com | Any | Any | 0.91 |

**Spillage Rate**

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

**Installation Rate**

The IR value was obtained using the DEER READI v2.4.7 tool. The relevant IR value for the measures in this workpaper is in the table below:

Table : Installation Rate

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **GSIA ID** | **Description** | **Sector** | **BldgType** | **ProgDelivID** | **GSIAValue** |
| Def-GSIA | Default GSIA values | Any | Any | Any | 1 |

**Effective Useful Life/Remaining Useful Life**

The EUL value was obtained using the DEER READI v2.4.7 tool. The relevant EUL value for the measurers in this work paper is listed in the table below:

Table : Effective Useful Life

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **EUL ID** | **Description** | **Sector** | **UseCategory** | **EUL (Years)** | **RUL (Years)** |
| OLtg-Com-LED-50000hr | LED Fixture - Outdoor- Commercial | Com | Lighting | 12 | 4 |

### 1.4.2 Codes & Standards Requirements

***Title 20***: These measure case products do not fall under Title 20 [2016] of the California Energy Regulations. The Metal Halide (MH) fixtures in the base case do fall under Title 20, and the wattages used for savings calculations are based on formulae from Table N-1 on page 283 and section 1605.3(n)(1)(B) on page 318.[[5]](#endnote-6)

***Title 24:*** Section 110.9 and 130.2 of Title 24 [2016] details the mandatory requirements for lighting control devices and systems, ballasts, and luminaires and outdoor lighting controls and equipment. Power consumption is prescribed through calculations at the site level. Individual fixture optical performance is restricted only in section 130.2. This section describes the number of lumens exiting the fixtures at upward angles and angles near-horizontal, which also depends on the lighting zone.

Title 24 Section 130.1(c)7B for parking garage controls:

In parking garages, parking areas and loading and unloading areas, general lighting shall be controlled by occupant sensing controls having at least one control step between 20 percent and 50 percent of design lighting power. No more than 500 watts of rated lighting power shall be controlled together as a single zone. A reasonably uniform level of illuminance shall be achieved in accordance with the applicable requirements in TABLE 130.1-A. The occupant sensing controls shall be capable of automatically turning the lighting fully ON only in the separately controlled space, and shall be automatically activated from all designed paths of egress. Interior areas of parking garages are classified as indoor lighting for compliance with Section 130.1(c)7B. Parking areas on the roof of a parking structure are classified as outdoor hardscape and shall comply with the applicable provisions in Section 130.2.

***Federal Standards:*** Department of Energy (DOE) regulates Fluorescent lamps and ballasts, and MH outdoor lamps via a MH Light Fixture standard enforced starting February 10, 2017.[[6]](#endnote-7)

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

LED quantitative and qualitative performance information came from two key sources: the Technical Requirements of the current DLC version, and the LightingFacts Program of the U.S. Department of Energy (for base case only).***[[7]](#endnote-8)***

The DLC Technical Requirements provided the minimum efficacy, as well as other important minimum requirements for color, lifetime, and light distribution for the measure case.3 The complete QPL listings of 7,680 garage fixtures and kits were used to determine actual lumen depreciation over the 33,210 hours in the 12-year measure life.4

The full LightingFacts list of 1,355 garage fixtures was used to determine a 25th percentile efficacy for each lumen bin, which set the base case LED fixture efficacy in line with the 2018 Interim Solution workpaper approved through 2019. This calculation can be seen in the attachment titled GarageBaseEfficacy\_LightingFacts\_201812.xlsx.

The base case technology mix is shown below in Table 8. The linear fluorescent and metal halide base case percentages follow the 2018 Interim Solution mix approved through 2019. The TLED percentage is new with this revision and explained in the following section.

Table : Base Case Technology Mix

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Workpaper version** | **Metal Halide**  **Base Case** | **Linear Fluorescent Base Case** | **LED Luminaire Base Case** | **TLED Base Case** |
| 2018 Interim Solution (R8) | **20%** | **20%** | **60%** | **0%** |
| 2019 workpaper (R9) | **20%** | **20%** | **30%** | **30%** |

### 1.5.1 TLED Baseline

Other than the conversion from Wattage Bin to Lumen Bin described below in Section 2, the other major change in Revision 9 of this workpaper is the inclusion of tubular LED replacement lamps (TLEDs) in the base case. Discussions during the development of the 2018 Interim Solution and additional research have made clear that TLEDs are an important component of the parking garage lighting replacement market.

Installing TLEDs is a simple and inexpensive upgrade to an existing fluorescent fixture. Type A TLEDs require no electrician skills and no tools other than a ladder, making them an easy option for garage maintenance staff. Cost-sensitive customers may choose the less expensive TLED option over the full fixture upgrade with benefits of energy savings. Evidence from SCE deemed and PG&E custom program participation, NEMA (National Electrical Manufacturers Association) national sales data[[8]](#endnote-9), input from local lighting distribution channels, and the California LED Pricing Analysis Study[[9]](#endnote-10) by Navigant all have suggested that TLEDs are a viable retrofit alternative to full fixture replacements. PG&E has thus incorporated TLEDs in the baseline mix with an assumption that they are equally popular to new luminaires and retrofit kits. The baseline share of LED tubular replacement lamps (TLEDs) is estimated at a significant share, 30%, which is half of the total LED share of 60%. Bonneville Power Administration (BPA) conducted a Non-Residential Lighting Market Characterization Study for the Pacific Northwest Region that indicated that LED sales continue to increase rapidly, accounting for 15% of all non-residential sales, with LED lamps and tubes representing the majority of the growth at 10% of total sales.[[10]](#endnote-11) The 30% TLED scenario is also a balance point which yields positive IMCs as well as enough savings for a cost-effective program. PG&E will review program data in mid-year 2019 along with other publicly available study data to determine if the TLED percentage requires update.

Even though the workpaper does not distinguish between the light distribution performance of TLEDs and new LED luminaires, this should not be taken as indication that they perform equally. TLED photometric distribution is unlikely to be equal to that of new fixtures and retrofit kits, but this workpaper assumes no difference given limited data availability. Full photometric distribution data for TLEDs are not readily available, neither the full TLED market nor the subset used in parking garage luminaires. DLC’s dataset of 5,190 TLEDs shows that, on average, less than 15.2% of light output is in the 60-80° zone, meaning they would fail the DLC’s parking garage distribution requirement of ≥30% zonal lumens in the 60-80° range. No more than 1.9% of DLC TLEDs would meet the DLC’s Parking Garage retrofit zonal lumen requirement, so TLED selection could have significant impact on performance. Most TLEDs in the market are designed for troffer and high bay applications where the majority of zonal lumens are needed 20-50° from nadir. Garage applications differ by requiring a broader spread, especially at 60-70°. Thus common TLEDs may underperform in garage applications by creating pools of higher illumination under each fixture with darker areas in between. In contrast, the measures in this workpaper are for entire new luminaires or retrofit kits that include complete new optical assemblies.

### 1.5.2 CALiPER Snapshot Report June 17, 2016:[[11]](#endnote-12)

Data from the most recent CALiPER snapshot report on TLEDs was used to inform the base case performance. The conclusions are as follows:

* Over 90% of the currently listed TLEDs exceed 100 lumens per watt (lm/W), which is roughly the efficacy of a bare linear fluorescent lamp, and near to the qualification threshold for the DesignLights Consortium™ Qualified Products List of 110 lm/W. In the broad LightingFacts database, the median efficacy is 113 lm/W and the 25th percentile efficacy is 105 lm/W.
* When evaluating TLEDs, it’s important to consider their efficacy when installed in a luminaire. As the number of lamps increases, the luminaire efficiency is slightly reduced. In order to appropriately compare the efficacy of TLEDs to that of other LED luminaires, this workpaper uses a fixture efficiency multiplier of 0.8 to represent the luminous efficiency of the luminaire, as suggested in this CALiPER report from the DOE

Based on the recent data collected in February 2019, the 25th percentile of the TLED efficacy is calculated at 111 lm/W (see section 2 for more details), and adopted for this workpaper revision.

In addition, many or most TLEDs operate with existing fluorescent ballast which increases wattage. CALiPER does not address the percentage of TLEDs operating with fluorescent ballast. Anecdotal market evidence suggests the plug-and-play, Type A, approach to TLEDs is the most popular, with no electrician requirement to plug in new lamps; this is also the most inefficient strategy because it leaves the fluorescent ballast powered. Without a thorough study available on TLED trends, the workpaper assumes a conservative 40.4% of TLEDs operate with fluorescent ballasts. This number was derived from all TLED listings in the DLC, which is the most comprehensive list that includes UL Type. 40.4% of products were Type A, so the workpaper makes that assumption for the market share of Type A in the absence of better market data. For the 40.4% Type A, fluorescent ballasts are assumed to consume 10% of system power, based on federal fluorescent ballast luminous efficiency standards cited above in section 1.5.2. The remaining 59.6% of TLEDs are assumed to have no ballast losses. Incorporating ballast wattage and fixture losses yields an 85.2 lm/W efficacy for TLEDs in fixtures (see section 2 for more details).

### 1.5.3 Lighting Dispositions and DEER Resolutions

The CPUC addressed exterior lighting as part of the 2018 Outdoor Lighting Phase I Disposition, and Final Resolution E‑4867 for DEER Updates, which generally re-affirmed the guidance that the CPUC had provided in previous dispositions. Highlights of the CPUC dispositions (in reverse chronological order) are included below. The Standard Practice Baseline and Workpaper Update Study currently being finalized, seeks to provide supporting data in response to this direction.

* 5/7/18 Disposition “2018OutdoorLightingPhase1-7May2018-Final” which approves the interim solution for measure savings and costs, with directions as follows:

1. Revise baselines for all but parking garage fixtures to be 100% LED technologies
2. Develop baseline LED fixture performance characteristics that are typical for fixtures with similar output to the measure fixture
3. Cost data submitted with the revised workpaper is approved on an interim basis for the period of January 1, 2018 through December 31, 2018. The PAs are directed to perform additional cost research on measure and baseline LED fixtures and re-analyze cost data to provide updated values for incremental measure costs with the next workpaper update.
4. The Net-to-Gross Ratio for all the covered measures, utilizing a normal replacement or new construction measure application type, is revised to 0.91.
5. SCE is the lead PA for a standard practice baseline study with a scope encompassing the measures covered by this disposition. Workpaper updates which propose any baseline revisions, shall consider (findings subject to approval by CPUC staff) the SCE baseline study which results are expected by fall of 2018.

* 3/1/18 (2018 Outdoor Lighting Phase 1 Disposition): “The Ex Ante Review (EAR) team review provides a strong indication from the cost analysis that the baseline, for the measure types and expected project types (not “one-off” fixture replacements) covered by the workpaper, should be 100% LEDs in many cases.

In addition, the disposition directed PG&E to revise the baseline LED efficacies, perform additional cost research; and re-analyze cost data.

* 2/15/17 (SCE-16-C-C-0073-0500804246\_Ext. LED Lighting (Second Review)”): “Commission believes the use of LED lighting is ISP for parking lot retrofits and likely also for other exterior and interior lighting retrofits…For exterior lighting projects, the PAs…shall…enumerate the situations where ISP is likely an LED technology and thus significantly different from current code or regulation requirements…The PAs (or SCE individually) shall proceed to immediately work collaboratively with CS to develop an ISP technology assignment appropriate for identified measures to be used in place of the code or regulation as the baseline for ROB / NR/ NC/CE and the second period baseline for ER.”
* 8/18/16 (Resolution E-4795): “DEER standard practice baseline for outdoor lighting early retirement measures has been revised to be LED technologies. The specific baseline technologies need to be developed through workpapers or custom project support documentation as new exterior lighting measures are introduced into programs. The second baseline will be applicable to all nonresidential measures covering outdoor general lighting measures. As a result of the change in standard practice baseline to LED technologies, all currently approved outdoor lighting measures (except screw-in CFLs) will no longer be approved for early retirement measures after December 31, 2017 ... PAs may submit workpapers where the measure technology meets or exceeds the current DEER code baseline (Pulse Start Metal Halide). For these, measure and code baseline technologies shall be identical, resulting [in] savings for [the] RUL period only. Note that this change only affects early retirement measures and that DEER code baselines would apply to normal replacement measures.”

### 1.5.4 California LED Pricing Analysis, Navigant 2018[[12]](#endnote-13)

This market study to evaluate LED product pricing was completed by Navigant Consulting, Inc. in January 2018. This study’s objectives included 1) identifying the range of current prices for DLC and ENERGYSTAR qualified LED products in the California non-residential lighting market for certain priority product categories selected by the IOUs including LED Outdoor lighting product categories, 2) determining what factors significantly influence LED price, 3) developing an incremental cost estimate relative to identified baseline technologies (MH, HPS, LF, CFL), and to 4) determine how, and at what rate LED price ranges are anticipated to change as the market matures 3 and 5 years out from 2017.

Price data from 2016 Q4 and 2017 Q2 was collected from California IOU Program data and from Navigant Research’s LED Price Tracker, which utilizes web-scraping software to collect data on product pricing and specifications online. Of the LED products, only those that met DLC’s technical requirements were included in the study analysis. To determine which factors significantly influence LED prices, a multiple variable regression was conducted to determine the correlation between various product specifications and price.

The results of the study initially showed that the biggest driver influencing LED price is lumen output, followed by manufacturer, DLC qualification, and CRI. Efficacy was not one of the significant price determining characteristics. Furthermore, even as DLC efficacy requirements have increased over time, prices have continued to decline. According to the study, price does not appear to scale with efficacy for any of the LED product categories evaluated, including LED Outdoor Lighting. LED deemed lighting measures have assumed that measure costs have scaled with efficacy, therefore this finding that efficacy may not be a key price driver implies that further analysis should be conducted to consider how to incorporate other price drivers in measure design to encourage the adoption of higher degrees of efficiency. PG&E is implementing in this revision a measure structure that is tiered by both lumen output and efficacy. Separate efficacy tiers were considered, but dropped due to the low number of DLC-listed parking garage products at 140 lm/W and above. Further research studies to explore and understand the barriers to market adoption other than pricing are needed for future workpaper updates.

Figure 1 below (Figure 3-5 in study) shows that the relationship between price and efficacy is highly randomized and there is a large spread in the dataset. Although the Figure shows LED troffers, this phenomenon can be seen across the other lighting categories as well.



Figure 1: Web-based LED Price and Efficacy Data for Recessed Troffer/Panel 2’ x 4’ (Source: California LED Pricing Analysis, Navigant, January 2018)

Lumen output and wattage have a direct relationship, increasing or decreasing proportionally. Therefore, the study’s indication that lumen output is a main driver of LED prices can also be interpreted that wattage may be a primary price driver. Since both factors could not be tested simultaneously due to their collinearity, only one was tested. Increasing lumen output in a product would also require increasing power load which could lead to eventually more drivers or more sophisticated drivers, which adds cost to the LED product. This supports traditional IOU Program rebate structure of offering higher incentives for higher wattage products because as wattage increases, so does product purchase price.

The study also noted that the cost to manufacture a product is separate from the consumer purchase price of that product. So, although it may cost more to increase the efficacy of a product, that additional cost is not being reflected in the purchase price the way lumen output/wattage and manufacturer affect product price. It could be that manufacturers are making trade-offs with other performance parameters to keep prices down as they improve efficacy, but that was not evaluated in this study and could be important future research to better understand the factors that influence LED price.

Another important finding of this study was that a larger portion of retrofit installations entail replacing lamps and ballasts only and not entire fixtures. This is due to the extremely long life of commercial baseline (MH, HPS, induction, linear fluorescent) fixtures, where steel fixture housings rarely fail. This finding has implications for this workpaper, and suggested that a base case mix other than 100% fixture-to-fixture is appropriate. In addition, the incremental measure cost in the two scenarios is very different. Since a common consumer purchasing scenario includes replacement lamps and ballasts only, this workpaper has been modified to consider that scenario in the baseline.

The study determined that prices will continue to decrease over the next 5 years; however, the rate of decline is slowing across all product categories. It will continue to be important to closely monitor LED prices and update workpapers at least annually.

### 1.5.5 LED Workpaper Update Study, Navigant 2015[[13]](#endnote-14)

The LED Workpaper Update Study, also conducted by Navigant Consulting Inc. from 2015 was similar to the study completed in 2018. Its objective was to develop findings and recommendations for updates to key parameters and methodologies used in the workpapers, program planning, and parts of the DEER database that target light-emitting diodes (LEDs), to ensure that IOU lighting programs can keep up with rapid changes in LED pricing and efficacy.

Three key research topics for high priority LED product categories were 1) LED pricing (for both residential and non-residential products), 2) Non-residential baseline wattages (which inform the selection of appropriate wattage reduction ratios or wattage ranges), and 3) the ability of the currently used savings estimation methods to predict non-residential baselines (e.g., wattage reduction ratio and wattage ranges).

Price data was collected through web-scraping, market-actor surveys of contractors, distributors, and commercial end users and through in-depth interviews with manufacturers and retailers. The study developed price estimates that were current for 2015, and it also looked at factors that affect pricing and how often workpapers need to be updated to include most current pricing.

The 2015 study found higher annual percentage price declines for LED products which have since slowed down as shown in the 2018 study. While annual decreases for LED luminaires were found to be 20% per year from 2015-2018, they are now expected to be 9% per year from 2017-2020 decreasing to 8% per year from 2020-2022 on average across all product categories (10% annual rate of decline from 2017-2020 for LED outdoor lighting and 9% annual rate of decline from 2020-2022. However, accuracy of these price projections may be limited due to the small dataset.

The study suggested price assumptions be updated annually using web-scraping until prices stabilize. This will help ensure projections of LED price remain useful to the IOUs.

The study also found that regional price differences in California are negligible and so all IOUs can use the same cost data in workpapers.

In terms of factors that influence the price of luminaires, no one factor was found to significantly affect pricing, but there were many: efficacy, lumens, watts, CRI, lifetime. This analysis was repeated in the 2018 pricing study and correlation factors were assigned and lumen output/wattage was determined to be the greatest influence on price. IOU LED deemed lighting measures have assumed that measure costs have scaled with efficacy, therefore this finding that efficacy may not be a key price driver implies that further analysis should be conducted to consider how to incorporate other price drivers in measure design to encourage greatest energy efficiency. For this workpaper, the available DLC-listed products pointed the way to a single-tier measure structure.

The projected LED price decline is expected to have a significant impact on LED adoption in California. The forecasted installed stock penetration of LEDs into the various outdoor applications was expected to increase from 11-19% in 2015 to 42-54% in 2018, and then increase further to 66-78% in 2020. IOU Programs can help accelerate this adoption curve and encourage the adoption of higher and highest efficiency products.

Market actors said that lumen equivalence was the single most important factor when selecting an LED. End users also considered light color and wattage equivalence when selecting an LED fixture. It will be important to research and understand how customers perceive lumen equivalence in LED fixtures and if there is bin jumping similar to what reportedly occurs with LED lamps – when market actors choose an LED that is not equivalent in light output to their baseline product. We hope the new measure structure change to lumen bins in this workpaper revision will help emphasize light output as the most important metric in product selection.

When Navigant considered the incidence of early retirement, the results showed that the majority of contractors and end users indicated that they are more likely to replace equipment before the end of useful life with LEDs. This suggests that LED decision making is unique and warrants additional research on ER and NR baselines. The IOUs are considering incorporating early retirement measures into future workpaper updates to capture the additional energy savings potential in the market.



Figure : Willingness to replace equipment with LEDs before end of useful life, relative to other replacements (Source: California LED Workpaper Update Study, Navigant, August 2015)

Survey data and specifications on existing fixtures also indicate that LEDs replacing metal halides and linear fluorescents are not near the upper end of the LED wattage ranges in the May 2014 disposition. The Navigant study results and IOU program data analysis point out that the majority of program activity happens in the lower wattage ranges for PG&E and it would be advisable for IOUs to break these measure codes into narrower wattage ranges to more accurately capture savings.

This revision of the workpaper breaks the measure codes into smaller bin sizes and separate outdoor lighting product categories to more accurately capture savings and going forward will also evaluate program data to better understand what wattage/lumen output products customers are buying. This program information can then be used to more accurately calculate energy savings.

### 1.5.6 Exterior Lighting Standard Practice Baseline and Workpaper Support, TRC Energy Services[[14]](#endnote-15)

The California Investor-Owned Utilities completed an Exterior Lighting Standard Practice Baseline and Workpaper Support Study in December 2018, per the 2017ExteriorLEDFixturesDisposition-BaselineClarifications-12Apr2017, Resolution E-4795, and SCE-16-C-C-0073\_0500804246\_Ext. LED Lighting, dated 02/15/2017. The results support the CPUC’s modification of the standard practice baseline for outdoor lighting to 100% LED technology, however per Resolution E-4952, the parking garage baseline technology mix (60% LED, 20% metal halide, 20% linear fluorescent) is effective through December 31, 2019, therefore this Revision 9 maintains that blended mix. PG&E will work with the other IOUs to submit a revised workpaper that incorporates the Exterior Lighting Standard Practice Baseline Study findings.

### 1.5.7 LED Non-Residential Lighting Market Characterization, Navigant – In Progress Update

This Statewide Non-Residential LED Market Characterization Study being conducted by Navigant Consulting, Inc. was initially scoped in response to a June 26, 2015 workpaper disposition for PGECOLTG179 LED Ambient Commercial Fixtures and Retrofit Kits, seeking additional clarification on qualifying LED technologies for the IOUs. Its expected completion date is Q1 2019. In that decision, Commission Staff thought it was unclear that the DLC QPL meets the requirements of incentivizing the top half of quality products in the non-residential lighting market. In that same disposition, Commission Staff wrote the following:

*“However, the products covered by this work paper are not covered by the CEC standard and therefore must still be “products that are in the top half of quality on the market.” As added guidance along with the more general guidance provided by the Commission in the text of the Decision (at 79) that “Our goal, as in D.12-05-015, is to avoid offering incentives for lighting products that do not meet consumer expectations and result in a poor lighting experience, discouraging customers from investing in energy efficient lighting in the future.” It is unclear that the DLC listed products meet this requirement. The work paper shall be revised to include the process utilized by the PAs that will ensure that products offered meet the direction from D.12-11-015.”*

This market share study is an effort to determine the size of the non-residential LED market and the relative market share of products on the DLC QPL. The study is also developing a proposed definition of “quality” for non-residential lighting and will work with Commission staff to finalize this quality definition for future use in PA’s lighting portfolio.

Until this study is completed, IOUs will use the DOE Lighting Facts database as a proxy for representing the LED market.

## 1.6 Data Quality and Future Data Needs

### 1.6.1 Inclusion of Early Retirement (ER)/Accelerated Replacement (AR) Measure Application Type

The IOUs are currently investigating ER/AR measure application type offering for the next iteration of the workpaper. The analysis will be derived from reviewing market studies and ER custom applications with a focus on customer segment(s) and geographical location(s). Resolution E-4818 begins to set a framework for deemed program level ER adoption for Preponderance of Evidence (POE).

Subsequently CPUC issued an E-4939 Draft Comment Resolution on October 11, 2018, addressing Track 2 Working Group related energy efficiency issues pursuant to D.16-08-019 and Resolution E-4818. In the draft Resolution E-4939’s section 3.2.3 Task 3 Conclusions stated “…..However, as to the proposal’s evidentiary requirements for demonstration of equipment viability and program influence, the POE requirement to demonstrate equipment viability and program influence for accelerated replacements shall meet the requirements in Task 2 to be addressed in a future resolution” (last paragraph on p.27).

### 1.6.2 Product ID Collection Process

As part of the IOUs’ future data needs, a more robust process to collect product information from program data is under consideration. It has been an ongoing challenge to run data analytics on existing Program data due to model number discrepancies from rebate application invoices and the DLC QPL. In order to address this challenge, IOUs propose to collect the unique DLC product ID in rebate applications. This unique identifier has no variation and can easily be used to match product information from program data to the performance metrics of these products listed on the DLC QPL. Collecting this additional information will be helpful for future workpaper updates.

### 1.6.3 LightingFacts LED Database

LightingFacts offers many benefits as a data source for a full characterization of the LED market:

* Large sample size (~30,000 outdoor products)
* Product performance data previously accepted by CalTF and Ex-Ante Review team in the LED Troffer workpaper and High-Bay and Outdoor 2018 Interim workpapers.
* Ability to filter by year, so that older products could be excluded from the efficacy samplingImportant distinctions by primary use: LightingFacts captures variation in efficacy by application type.

Unfortunately, the Department of Energy has ended funding for the LightingFacts label program. Other data sources will need to be considered for revisions beyond 2019 in lieu of LightingFacts, such as the data that will be collected for the Navigant LED Market Characterization study.

### 1.6.4 Cost Data

The cost analysis to develop the base case and measure case costs for this workpaper revision contemplated data from 2 sources:

1. PG&E Program Data
2. Price data collected from online web-scraping

**PG&E Program Data:** To perform cost analysis, one of the challenges with the data was acquiring the wattage, lumen output, and efficacy of the rebated fixture. Additionally, some applications did not contain a manufacturer and model number as it might be tracked elsewhere. Since the manufacturer and model number is inconsistent from application to application, only 30% of the rebated application fixtures matched with the DLC list. From there, the wattage, lumen output, and efficacy of the rebated fixtures were acquired. The fixtures in this subset did not provide representative products for each lumen bin, nor for both base case and measure case efficacy in each lumen bin. Previous data from the Navigant 2018 LED Pricing study had indicated that, in general, costs do correlate to lumens or wattage, so Measure and Base case LED pricing were determined based on the typical per-light-output price for each tier, multiplied by the midpoint light output of each lumen bin.

**Price Data Collected from Online Web-scraping**: PG&E initially conducted web-scraping on TLED cost and efficacy in 2018 for this R9 workpaper revision. Subsequently, PG&E performed additional online web-scraping on TLED costs and efficacy in February 2019 per the Ex-ante Review (EAR) team’s recommendation. Based on the new data the average cost for TLED is calculated at $0.0036 per lumen. See section 4.1 below for more details.

# Section 2. Calculation Methods

**Base Case Assumptions used in the Calculations**

**Technology Percentage Mix:** From the 2018 Outdoor Lighting Phase 1 Disposition, the base case technology mix is as listed in Table 8.

**Linear Fluorescent:** Standard Fixture Wattages from Appendix B are used for fluorescent base case.

**LED:** The LED base case power consumption was based on performance from the DOE LightingFacts database.[[15]](#endnote-16) The 25th percentile efficacy of the sample was used to estimate performance of the base case LED fixtures as a reasonable assumption when without efficiency incentive programs promoting higher-efficacy products customers are likely to select products from the non-certified lower-efficacy half of the market products. A sample of 1,355 garage products in the LightingFacts database was used to determine base case efficacies, in a very similar manner to the Interim Solution 2018 workpaper, but with updated numbers including 1) new LightingFacts listings since November 2017 and B) new lumen bin definitions. The disposition provided a percentile efficacy breakdown by lumen output bins as shown highlighted in the following table.

Table : Lighting Facts 25th Percentile for Parking Garage luminaires by lumen bin



Table 10: Lumen Bins with measure descriptions and efficacies

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure Description** | **Lumen Bin lower end** | **Lumen Bin upper end** | **Meas LPW minimum** | **Base LED Efficacy** |
| LED Parking Garage Luminaire rated from 1800 to 2300 lumens and greater than or equal to 120 LPW | 1,800 | 2,300 | 120 | 85 |
| LED Parking Garage Luminaire rated greater than 2300 to 2900 lumens and greater than or equal to 120 LPW | >2,300 | 2,900 | 120 | 80 |
| LED Parking Garage Luminaire rated greater than 2900 to 3600 lumens and greater than or equal to 120 LPW | >2,900 | 3,600 | 120 | 83 |
| LED Parking Garage Luminaire rated greater than 3600 to 4500 lumens and greater than or equal to 120 LPW | >3,600 | 4,500 | 120 | 84 |
| LED Parking Garage Luminaire rated greater than 4500 to 5600 lumens and greater than or equal to 120 LPW | >4,500 | 5,600 | 120 | 86 |
| LED Parking Garage Luminaire rated greater than 5600 to 7000 lumens and greater than or equal to 120 LPW | >5,600 | 7,000 | 120 | 86 |
| LED Parking Garage Luminaire rated greater than 7000 to 8800 lumens and greater than or equal to 120 LPW | >7,000 | 8,800 | 120 | 93 |
| LED Parking Garage Luminaire rated greater than 8800 to 11000 lumens and greater than or equal to 120 LPW | >8,800 | 11,000 | 120 | 90 |

**Measure Case Assumptions used in the Calculations**

The measure case for all parking garage lighting is 100% LED with 120 lm/W efficacy or greater. This is the highest of the Premium-classification efficacies in the Technical Requirements in the current version of the DLC QPL2.

**Basecase TLED Fixture Efficacy**

The data collected in February 2019 of the 63 new TLED models has an average calculated efficacy of 118 lm/W.  Resolution E4952 states that the code/standard practices baseline assumes performance equal to the 25% percentile. The 25% percentile of the 63 TLED models is 111 lm/W (see attached file “Copy of TLED Cost Data\_FEB2019.xlsx” for more details of the calculation). Using the 111 lm/W efficacy the TLED fixture efficacy is then calculated to be 85.2 lm/W (see attached file “PGECOLTG151 R9 LED Outdoor Ltg Calc\_ Rev 2.xlsx” for more details of the calculation).

**Representative Fixtures and Factors Used in Calculations**

LED fixtures were assigned an equivalent maintained, useful light output to the MH fixture in order to ensure equivalent level of service being achieved in the base case. A one-for-one relationship was also established for that comparison purpose. Fixture efficiency for both MH and fluorescent products, and light distribution information for LED, fluorescent and MH were taken from photometric data in the form of “.ies” files obtained from manufacturer websites. These standard report files were loaded into the online Visual Photometric Viewer software to produce uniform light distribution reports listing efficacy and lumens by zone. LED fixtures reported 100% efficacy in all ies reports, as is standard for absolute photometric measurements.

Light depreciation for LED fixtures (both base and measure case) was based on actual DLC reported lifetime data, interpreted by means of the DOE depreciation formula for percent depreciation at 33,210 hours, which is the exterior hours of use over the 12-year DEER measure life. Average LED lumen maintenance (assumed for Measure, Base Case luminaire, and Base case TLED) was 80.3%.

The Lumen Maintenance assumptions for fluorescent and MH fixtures were based on Pacific Northwest National Laboratories’ 2013 report, Lumen Maintenance and Light Loss Factors: Consequences of Current Design Practices for LEDs.[[16]](#endnote-17) Fluorescent fixtures were matched to MH fixtures of approximately similar light output due to the challenge of 1-to-1 matching, given fixed values for lamp light output.

Initial MH lamp light outputs for each of the lamp wattages chosen, and for primary use category were reduced by the following factors:

* Fixture efficiency based on actual manufacturer-published photometric data for sample products
* Lamp lumen maintenance: 58% for all MH based on end-of-life output and not mean lumen output, typical of quartz metal halide lamps.

Table : Lumen Maintenance Assumptions by Source Type

|  |  |  |  |
| --- | --- | --- | --- |
| **Fluorescent Base Case Maintenance** | **MH Base Case Maintenance** | **LED & TLED Base Case Maintenance** | **LED Measure Case Maintenance** |
| 91% | 58% | 80.3% | 80.3% |

**Zonal Lumen calculation**

Fluorescent, MH, and LED luminaire lumen equivalence was based on maintained Zonal Lumens in the DLC-designated garage fixture zone of 60 - 80°, as shown in the table below. This metric rewards fixtures for illuminating a broader area at higher angle from nadir, which spreads widely the illumination from fixtures mounted on low parking garage ceilings, allowing greater fixture spacing (and lower wattage consumption) and meeting the most significant challenge in garage lighting. Fixture lumens in the 0 - 60° zone, which is directly below the fixture and easiest to light, are not factored into equivalence, which prevents rewarding omnidirectional discharge lamp sources for producing a bright blob of light below each fixture. MH, fluorescent, and other omnidirectional sources have a common shortcoming: they are known for creating pools of light underneath the fixtures with much darker sections between. Using Zonal Lumens compensates for this tendency.

Table : DLC v 4.4 and Zonal Lumens Distribution Requirements

|  |  |  |
| --- | --- | --- |
| **Primary Use Designation** | **Zone Definition** | **Zonal Lumen** **Requirement** |
| Parking Garage Luminaires | 60-80⁰ | ≥30% |
| 70-80⁰ | ≤25% |

**Lumen Bin Measure Structure**

In this revision, PG&E transitions the measure structure for Parking Garage LED fixtures to lumen bins from the previous wattage bin structure. Although the lumen ranges were previously used on the back-end to match measure case solutions to base case products, as the industry shifts towards LED technologies, referencing solutions by wattages becomes outdated. Older incumbent technologies were referred to by wattages and not light output by the industry because the efficacies (lumens per watt, LPW) of these products were constant within the technology for a given light output and the level of service was understood through the wattage they consumed. With LEDs, products that provide a given light output are available along the entire efficacy & wattage spectrum.

When comparing an equivalent measure case product to the base case, using lumens is much more straightforward. Customers now speak about LED products’ level of service in terms of lumens rather than Watts. To match this shift in technology and industry communication & make it easier for customers to choose the right measure, PG&E proposes changing the workpaper measure structure to lumen bins rather than wattage bins.

The challenges with the wattage range methodology as the technology shifts to LED is further explained in the 2015 California Workpaper Update Study conducted by Navigant:[[17]](#endnote-18)

*“The original CA lighting disposition used the baseline wattages to bin lighting fixture categories. This technique is effective for capturing the baseline of older technologies, especially considering the explicit goal of determining what efficient wattage will replace the existing inefficient wattage. This follows the logic of a wattage range calculation, the goal being to determine the difference between the initial and final wattage.*

*In practice, the initial wattages of the bay fixtures existed over a wide range of values but the LED responses were contained in a small range. This aspect makes it difficult to create wattage bins based on LED alternatives. It is not possible to accurately measure the savings of a certain LED replacement if it could be replacing a wide range of baseline fixtures.”*

The benefit of the lumen bin methodology is illustrated below. Under the measure codes defined by wattage bins in Table 13, there is much greater overlap in measure case lumen ranges shown in the 2 right columns. A customer might pick a higher-wattage product to get a higher rebate, when the program would prefer to drive customers instead toward higher efficacy products, and because of efficacy variation, higher wattages do not always come with higher light outputs. In

Table 14, with Lumen Bins, they can decide the light output they need and it will match only a single measure code.

Table : Wattage Bin Method (Previous)

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Measure Code | Blended Base Case Watts | Blended Base Case Efficacy | Measure Case Efficacy Floor (LPW) | Measure Case Wattage (min) | Measure Case Wattage (max) | Measure Case Lumens (min) | Measure Case Lumens (max) |
| LT305 | 64 | 51 | 110 | 0 | 38.99 | 2,200 | 5,850 |
| LT306 | 89 | 58 | 115 | 39.00 | 56.99 | 4,485 | 8,550 |

Table : Lumen Bin Method (New with this revision)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Measure Code | Blended Base Case Watts | Blended Base Case Efficacy | Measure Case Efficacy Floor (LPW) | Measure Case Lumens (min) | Measure Case Lumens (max) | Measure Case Wattage (minimum Efficacy, Average Output) |
| LT480 | 41 | 50 | 120 | 1,800 | 2,300 | 17 |
| LT481 | 60 | 43 | 120 | >2300 | 2,900 | 22 |

**Delta Wattage Assumption (ΔW)**

This section describes the method used to match MH and Fluorescent base case fixtures to equivalent LED fixtures, as done in the previous interim solution. The LED fixtures being matched include both base case and measure case, and the calculations assume no difference in the light distribution, lumen maintenance, or fixture efficiency between the base and measure case LEDs. This is a particularly conservative approach to light distribution of base case TLED products, which tend to put out most of their light between 0 - 60° and are not typically well-configured to produce light at 60 - 80°. However, as no good model for typical base case TLED light distribution exists, they are assumed equivalent to LED fixtures in distribution in this workpaper.

The workpaper assumes 1-to-1 equivalence of maintained Zonal Lumens for each lumen bin. For lumen bin, the closest equivalent in fluorescent lamp quantity and MH lamp wattage are determined, accounting for Zonal Lumens, Lumen Maintenance, and Fixture Efficiency.

The LED measure case wattage values are determined by dividing the midpoint value of the lumen bins by the 120 lm/W minimum efficacy. The Delta Watts are simply the LED measure case minus the blended weighted average of base case LED, TLED, MH, and Fluorescent wattages.

**Calculation Method Process**

This section will provide an example calculation for a new LED parking garage luminaire with 8,000 initial lumen output at 125 lm/W. The various factors shown in the table below are used to calculate the equivalent light outputs for each light source.

Table : Light Output Factors for Garage fixtures

|  |  |  |  |
| --- | --- | --- | --- |
| **Fixture Light Source** | **Fixture Eff** | **Zonal Lumens** | **Lumen Maintenance** |
| LED | 100% | 33% | 80.3% |
| TLED | 85% | Same as LED | Same as LED |
| Fluorescent | 71% | 25% | 91% |
| Metal Halide | 73% | 23% | 58%19 |

Table : Calculated Lumens

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Fixture Light Source**  **most closely matching**  **8000 lm LED** | **System**  **Watts** | **Fixture Lumens** | **Initial Zonal**  **Lumens** | **Maintained Zonal Lumens** | **LED Initial**  **Zonal**  **Lumens** | **LED Initial Lumens** |
| 200W Metal Halide | 222 | 14,690 | 3,420 | 1,984 | 2,271 | 7,428 |
| 4-lamp F32T8 Fluorescent | 151 | 9,654 | 2,442 | 2,222 | 2,766 | 8,320 |

MH parking garage fixture with 200W Lamp

1. Typical 20,000 initial lamp lumens, limited by Title 24 to 222 system Watts [90% efficiency per section 1605.3(n)(1)(B)]
2. 73% fixture efficiency means that 14,690 lumens will exit the fixture
3. 23% zonal lumens means that 3,420 lumens are emitted between 60 and 80 degrees to illuminate the portions of the garage floor at the outer edge of the area under that fixture
4. 58% lamp depreciation means that 1,984 lumens will remain at end-of-life.
5. 1,984 is also the number of zonal lumens that are assumed for the end-of-life LED fixture
6. At 80.3% lumen maintenance at end-of-life, the initial zonal lumen output is assumed to be 2,271
7. 33% LED zonal lumens means that the initial fixture light output is assumed to be 7,428.

7,428 is the closest MH-equivalent LED light output to the 8,000 lumen fixture in our example.

The tables below compare actual and deemed measure performance for this fixture. Note that the measure deemed lumens are the midpoint of the lumen bin, so actual lumens may fall slightly above or below. The size of the lumen bins is much smaller than in the previous workpaper version, increasing the accuracy of these deemed values. The measure deemed efficacy of 120 lm/W is always less than or equal to the efficacy of the actual product, ensuring a conservative savings estimate.

Table : Measure Performance Actual vs. Deemed

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Measure Lumens** | **Measure Efficacy** | **Measure Watt** |
| Actual Value | 8,000 | 125 | 64 |
| Deemed Value | 7,901 | 120 | 66 |

The Delta Watts table below shows the blending of 4 base case fixture types to create a weighted average base case wattage and calculate the Delta Watts for our example fixture.

Table : Delta Watts for 8000 lm Garage Fixture

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **% in Base Case Blend** | **Wattage** | **Efficacy**  **(fixture lm/W)** | **Delta Watts** |
| Deemed Measure |  | 66 | 120 | 64 |
| Deemed Base Case Blend |  | 130 | 78 |
| LED Base Case | 30% | 85 | 93 |
| TLED Base Case | 30% | 94 | 85 |
| Fluorescent Base Case | 20% | 151 | 64 |
| Metal Halide Base Case | 20% | 222 | 66 |

## 2.1 Electric Energy Savings 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.

*∆watts/unit = Base watts/unit – Energy Efficient watts/ unit*

*Annual Electric Savings:*



The following example calculates the annual electric energy kWh savings for the “LED Parking Garage Luminaire rated greater than 7000 to 8800 lumens and greater than or equal to 120 LPW” measure:

For the savings of all other measures, see file “PGECOLTG151 R9 LED Outdoor Ltg Calc.xlsx” that accompanies this workpaper.

## 2.2 Demand Reduction Estimation Methodologies

There is no anticipated demand reduction associated with these measures since parking garage is classified as outdoor lighting.

## 2.3 Gas Energy Savings Estimation Methodologies

There is no gas energy saving associated with these measures.

# 

# 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 non-residential outdoor lighting end use load shape.

## 3.2 Measure Load Shapes

For purposes of the net benefits estimates in the Cost Effectiveness Tool (CET) 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 CET calculator based on the applicable non-residential market sector and the outdoor lighting end-use, since load shape will not alter with new technology.

Table : Building Type and Load Shape

|  |  |  |
| --- | --- | --- |
| **Building Type** | **Load Shape** | **E3 Alternate Building Type** |
| Any | PGE:COMMERCIAL:2 = Commercial Outdoor Lighting | COMMERCIAL |

# 

# Section 4. Base Case & Measure Costs

As discussed in Section 1.6.4 Cost Data , price data from PG&E programs in 2018 was used to determine base and measure LED fixture costs, and the distributor and online pricing gathered by TRC Solutions was not utilized due to costs significantly higher than shown in PG&E programs.

* **Advantages:** Deemed cost values may be more likely to correspond to typical program-incentivized product; product prices are up-to-date, having been gathered in the last 9 months of 2018.
* **Disadvantages:** Deemed cost values may be lower than the upper end of the price range.

## 4.1 Base Case(s) Costs

LEDfixture pricing was determined from deemed program applications reviewed from 3/1/2018 to 11/30/2018. Minimum efficacies were lower than 120 lm/W in the 2018 program year for many lower lumen output products, so the program data includes products that would be classified both as Base Case and Measure Case for this workpaper revision. Because application data does not cover every lumen bin in this workpaper, and 70% of applications were not conclusively matched to DLC products, the cost is based on the average cost per thousand lumens of light output for fixtures below 120 lm/W. LED base case costs for all measures are $17.86 per thousand lumens (kilolumens) of light output at the midpoint of the lumen bin.

Other Base Case cost sources:

1. TLED prices are taken from online list prices. Because TLEDs vary widely in wattage, price, and light output, the prices were normalized by light output at the midpoint of the lumen bin. Based on the February 2019 webscraped cost data the average TLED price was $9.23 with an average light output of 2,582 lumens, which yields a cost of $0.0036 per lumen. See attached file “Copy of TLED Cost Data\_FEB2019.xlsx” for details of the cost data and the calculations.
2. Metal Halide prices are taken from online sources gathered by the workpaper engineering team for specific fixture cases based on lamp wattage.
3. Fluorescent prices are taken from online sources gathered by the workpaper engineering team for specific fixture cases based on the number of F32T8 lamps.

The 4 base case types were blended according to the percentages below:

Table : Base case blend, including Watts and efficacy for 8000 lm Garage Fixture

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Blend %** | **Wattage** | **Efficacy**  **(fixture lm/W)** |
| **Deemed Base Case Blended Value** |  | 130 | 78 |
| LED Base Case | 30% | 85 | 93 |
| TLED Base Case | 30% | 94 | 85 |
| Fluorescent Base Case | 20% | 151 | 64 |
| Metal Halide Base Case | 20% | 222 | 66 |

## 4.2 Measure Case Costs

As with the base case LED costs above, Measure case LEDfixture pricing was determined from deemed program applications reviewed from 3/1/2018 to 11/30/2018, from products with efficacies of 120 lm/W and higher. Because application data does not cover every lumen bin in this workpaper, and 70% of applications were not conclusively matched to DLC products, the cost data is normalized by light output and is based on the average cost per thousand lumens of light output for fixtures at and above 120 lm/W. LED Base costs for all measures are $19.63 per kilolumens of light output at the midpoint of the lumen bin.

The labor cost used is $187.14 per WO017 for lift accessible fixtures[[18]](#endnote-19).

## 4.3 Incremental & Full Measure Costs

Incremental and full measure costs are determined using the Base and Measure case costs, as well as the labor cost, above.

Table : Full and Incremental Measure Cost Equations

|  |  |  |  |
| --- | --- | --- | --- |
| **Installation Type** | **Incremental Measure Cost** | **Full Measure Cost** | |
| **1st Baseline** | **2nd Baseline** |
| NR/ROB | (MEC + MLC) – (BEC + BLC) | (MEC + MLC) – (BEC + BLC) | N/A |
| NEW/NC |
| AR/ER | (MEC + MLC) – (BEC + BLC) | MEC + MLC | (MEC + MLC) – (BEC + BLC) |
| RET | (MEC + MLC) – (BEC + BLC) | MEC + MLC | N/A |
| AOE/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

For the complete list of incremental and full measure costs for all options, see the Workpaper calculations spreadsheet that accompanies this workpaper.

# Attachments

GarageBaseEfficacy\_LightingFacts\_201812.xlsx

PGECOLTG151 R9 LED Outdoor Ltg Calc\_Mar2019.xlsx

Copy of TLED Cost Data\_FEB2019.xlsx

# References

1. National Electrical Manufacturers Association (NEMA) 2Q 2017 Sales Data <https://www.nema.org/Intelligence/Indices/Pages/Linear-Fluorescent-Lamp-Indexes-Continue-to-Decline-in-Second-Quarter-2017-while-T-LED-Market-Penetration-Increases.aspx> [↑](#endnote-ref-2)
2. Navigant Consulting, [California LED Pricing Analysis, January 2018](http://calmac.org/publications/LED_Pricing_Analysis_Report_-_Revised_1.19.2018_FinalES.pdf) [↑](#endnote-ref-3)
3. https://www.designlights.org/search/ [↑](#endnote-ref-4)
4. The table “Measure Application Type” in the Measure Catalog can be found on the Database for Energy-Efficient Resources (DEER) website [www.deeresources.com](http://www.deeresources.com)*.* [↑](#endnote-ref-5)
5. California Energy Commission *Title 20: California Appliance Regulations* 2016. <http://www.energy.ca.gov/2016publications/CEC-140-2016-001/CEC-140-2016-001-REV3.pdf> [↑](#endnote-ref-6)
6. DOE *Energy Conservation Standards for Metal Halide Lamp Fixtures; Final Rule.* <https://www.regulations.gov/document?D=EERE-2009-BT-STD-0018-0072> [↑](#endnote-ref-7)
7. Electronic Code of Federal Regulations, Title 10, §430.32,

   <https://www.ecfr.gov/cgi-bin/text-idx?SID=2fed8aa79758a538d0878801f58a3312&mc=true&node=se10.3.430_132&rgn=div8>

   DOE Solid-State Lighting CALiPER Program. *Round 11 Summary Report* (October 2010)—includes roadway arm-mount and post-top luminaires. http://www1.eere.energy.gov/buildings/ssl/reports.html

   Detailed reports for 36 LED light sources for outdoor applications (as of June 15, 2012) are available at http://www1.eere.energy.gov/buildings/ssl/caliper/default.aspx [↑](#endnote-ref-8)
8. National Electrical Manufacturers Association (NEMA) 2Q 2017 Sales Data <https://www.nema.org/Intelligence/Indices/Pages/Linear-Fluorescent-Lamp-Indexes-Continue-to-Decline-in-Second-Quarter-2017-while-T-LED-Market-Penetration-Increases.aspx> [↑](#endnote-ref-9)
9. Navigant Consulting, [California LED Pricing Analysis, January 2018](http://calmac.org/publications/LED_Pricing_Analysis_Report_-_Revised_1.19.2018_FinalES.pdf) [↑](#endnote-ref-10)
10. [2016 Non-Residential Lighting Market Characterization, Bonneville Power Administration, July 2017](https://www.bpa.gov/EE/Utility/research-archive/Documents/Momentum-Savings-Resources/2017_NonResidential_Lighting_Final_Report.pdf) [↑](#endnote-ref-11)
11. CALiPER Snapshot Report Linear Lamps (TLEDs), June 17, 2017. Accessed at <https://www.energy.gov/sites/prod/files/2016/07/f33/snapshot2016_tleds.pdf> [↑](#endnote-ref-12)
12. Navigant Consulting. *California LED Pricing Analysis – Final Draft.* January 2018. [http://www.calmac.org/publications/LED\_Pricing\_Analysis\_Report\_-\_Revised\_1.19.2018\_Final.pdf](http://www.calmac.org/publiations/LED_Pricing_Analysis_Report_-_Revised_1.19.2018_Final.pdf) [↑](#endnote-ref-13)
13. Navigant Consulting. California LED Workpaper Update Study – Final Report. August 28, 2015. <http://www.calmac.org/publications/LED_Study_Report_FINAL_201510029.pdf> [↑](#endnote-ref-14)
14. TRC Energy Services, *Exterior Lighting Standard Practice Baseline and Workpaper Support – Final Report*, December 31, 2018. <http://www.calmac.org/publications/TRC_-_SCE_Ext_Lighting_SP_and_WP_Support_Final_Report.pdf> [↑](#endnote-ref-15)
15. DOE *Lighting Facts Database.* March 30th, 2018.<http://lightingfacts.com/Products> [↑](#endnote-ref-16)
16. DOE and Pacific Northwest National Laboratory (PNNL). *Lumen Maintenance and Light Loss Factors: Consequences of Current Design Practices for LEDs*, Figure 1, page 3. <http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22727.pdf> [↑](#endnote-ref-17)
17. [California LED Workpaper Update Study, Navigant Consulting, August 2015](http://www.calmac.org/publications/LED_Study_Report_FINAL_201510029.pdf) [↑](#endnote-ref-18)
18. 2010-2012 WO017 Ex Ante Measure Cost Study Final Report. Submitted by: Itron, Inc. May 27, 2014. Page 4-12. [↑](#endnote-ref-19)