**Work Paper PGECOLTG178**

**LED High-Bay and Low-Bay Fixtures**

**Revision 3**

**Pacific Gas & Electric Company**

**Customer Energy Solutions**

**LED High-Bay and Low-Bay Fixtures**

**Measure Codes: LT376 – LT393**

# At-a-Glance Summary

|  |  |
| --- | --- |
| **Applicable Measure Codes:** | LT376 – LT393 |
| **Measure Description:** | LED High-Bay and Low-Bay Fixtures, various wattages  Tier 1: Efficacy of 110 - 125 lumens per watt  Tier 2: Efficacy of 130 - 135 lumens per watt |
| **Energy Impact Common Units:** | Each fixture |
| **Base Case Description:** | Percentage mix of high performance Linear Fluorescent Fixtures with 2, 3, 4, 6, 8, and 10 lamps and LED – DLC v4.3+ Standard efficacy  Source: PG&E Calculations. |
| **Base Case Energy Consumption:** | Various. Refer to .xlsx file attached  Source: PG&E Calculations. |
| **Measure Energy Consumption:** | Various. Refer to .xlsx file attached  Source: PG&E Calculations. |
| **Energy Savings (Base Case – Measure):** | Various. Refer to .xlsx file attached  Source: PG&E Calculations. |
| **Costs Common Units:** | $ Per fixture. |
| **Base Case Equipment Cost ($/fixture):** | Various. Refer to .xlsx file attached.  Source: PG&E Program Data |
| **Measure Equipment Cost ($/fixture):** | Various. Refer to .xlsx file attached  Source: PG&E Program Data |
| **Gross Measure Cost ($/fixture)** | Various. Refer to .xlsx file attached  Source: PG&E Calculations |
| **Measure Incremental Cost ($/fixture):** | Various. Refer to .xlsx file attached  Source: PG&E Calculations |
| **Effective Useful Life (years):** | 12 years, ILtg-Com-LED-50000hr  Source: DEER 2014 |
| **Program Type:** | ROB/NC |
| **Net-to-Gross Ratios:** | NTG= 0.6, Com-Default>2yrs  NTG= approx. 0.91 (To be provided by CPUC as per discussion on 4/5/2018)  Source: DEER 2014 |
| **Important Comments:** | Revision 3 is a resubmittal and an interim solution until the next workpaper revision can address CS comments and the standard practice baseline for high/low bay lighting. |

# Document Revision History

|  |  |  |  |
| --- | --- | --- | --- |
| **Revision #** | **Date** | **Section by Section Description of Revisions** | **Author (Company)** |
| Revision 0 | 11/4/2013 | **PGECOLTG178 R0** LED High-Bay and Low-Bay Fixtures.doc  Original Workpaper | Author: Greg Barker (Energy Solutions)  Reviewer: Alina Zohrabian (PG&E) |
| Revision 1 | 5/27/14 | **PGECOLTG178 R1** LED High-Bay and Low-Bay Fixtures.doc  Added DI values from (PGE3PLTG192-R0) and Applied new hours of operation and IE factors. For updated savings values, see file PGECOLTG178 R1.xlsx | Alina Zohrabian (PG&E) |
| Revision 2 | 1/1/2016 | NC was added.  Updated NTG, EUL, IE, CDF, GSIA, and hours of operation per DEER2016. Base case and measure costs have also been updated. | Linda Wan (PG&E)/Alina Zohrabian (PG&E)/Tai Voong (PG&E)/Henry |
| Revision 3  (Not Approved) | 8/14/2017 | -Retired measures LD101 to LD113  -Updated Title 20 Ballast Efficiency minimums;  -Created new measure codes LT105 to LT120  -Included LED high bay fixtures to replace 100W & 150W MH as well as 2- and 3-lamp fluorescent fixtures; - Used Wattage range savings estimation method recommended by Navigant Study (average of LED wattage within the range is used to calculate savings)  -Updated cost | Mini Damodaran(PG&E)/ Greg Barker (Energy Solutions) |
| Revision 3  (Interim Solution) | 4/11/2018 | -Baseline percentage mixes include LEDs and remove Metal Halides  -Created Tier 1 and Tier 2, which aligns closely with Lighting Facts 50th percentile efficacies and DLC Premium minimum efficacies as efficacy floors  -Aligns technical requirements with DLC Technical Requirements update v4.3  -Cost is a temporary placeholder that uses IMC as a percentage of the rebate amount | Mini Damodaran(PG&E)  Linda Wan (PG&E)  Pauravi Shah (PG&E)  Greg Barker (Energy Solutions) |

# Table of Contents

[At-a-Glance Summary ii](#_Toc511244872)

[Document Revision History iii](#_Toc511244873)

[Table of Contents iv](#_Toc511244874)

[List of Tables iv](#_Toc511244875)

[List of Figures 5](#_Toc511244876)

[Section 1 General Measure & Baseline Data 2](#_Toc511244877)

[1.1 Measure Description & Background 2](#_Toc511244878)

[1.2 Technical Description 4](#_Toc511244879)

[1.3 Installation Types and Delivery Mechanisms 5](#_Toc511244880)

[1.4 Measure Parameters 6](#_Toc511244881)

[1.4.1 DEER Data 6](#_Toc511244882)

[1.4.2 Codes & Standards Analysis 7](#_Toc511244883)

[1.5 EM&V, Market Potential, and Other Studies – Base Case and Measure Case Information 2](#_Toc511244884)

[1.5.1 Lighting Dispositions 2](#_Toc511244885)

[1.5.2 California LED Pricing Analysis, Navigant 2018 2](#_Toc511244886)

[1.5.3 LED Workpaper Update Study, Navigant 2015 4](#_Toc511244887)

[1.5.4 LED Non-Residential Lighting Market Characterization, Navigant – In Progress 6](#_Toc511244888)

[1.5.5 CALiPER Application Summary Report 135: 7](#_Toc511244889)

[1.6 Data Quality and Future Data Needs 7](#_Toc511244890)

[1.6.1 Standard Practice Baseline Studies 7](#_Toc511244891)

[1.6.2 Inclusion of Early Retirement (ER)/Accelerated Replacement (AR) Measure Application Type 8](#_Toc511244892)

[1.6.3 Product ID Collection Process 8](#_Toc511244893)

[1.6.4 DEER Limitation on Non-linear Functions 8](#_Toc511244894)

[1.6.5 Lighting Facts LED Database 8](#_Toc511244895)

[1.6.6 Cost Data Quality 9](#_Toc511244896)

[Section 2 Calculation Methods 10](#_Toc511244897)

[2.1 Electric Energy Savings Estimation Methodologies 18](#_Toc511244898)

[2.2 Demand Reduction Estimation Methodologies 19](#_Toc511244899)

[2.3 Gas Energy Savings Estimation Methodologies 19](#_Toc511244900)

[Section 3 Load Shapes 20](#_Toc511244901)

[3.1 Base Case Load Shapes 20](#_Toc511244902)

[3.2 Measure Load Shapes 20](#_Toc511244903)

[Section 4 Base Case & Measure Costs 20](#_Toc511244904)

[4.1 Base Case Costs 21](#_Toc511244905)

[4.2 Measure Case Costs 21](#_Toc511244906)

[4.3 Incremental & Full Measure Costs 22](#_Toc511244907)

[Attachments 23](#_Toc511244908)

[References 24](#_Toc511244909)

# List of Tables

[Table 1 - LED High-Bay and Low-Bay Fixtures Base and Measure Wattages 3](#_Toc511244910)

[Table 2 - Measure Application Type 5](#_Toc511244911)

[Table 3 – Breakdown of ROB vs NC Measure Application Types for 2016, 2017, and All Program Years 5](#_Toc511244912)

[Table 4 - Delivery Method and Applicable Building Types 5](#_Toc511244913)

[Table 5 – DEER Difference Summary 6](#_Toc511244914)

[Table 6 - Net-to-Gross Ratios 6](#_Toc511244915)

[Table 7 - Installation Rates 7](#_Toc511244916)

[Table 8 - Effective Useful Life/Remaining Useful Life 7](#_Toc511244917)

[Table 9 – Base Case Technology Percentage Mix 7](#_Toc511244918)

[Table 10 – Manufacturer Cost Pair Matching 9](#_Toc511244919)

[Table 11 – Industrial Products Efficacy Percentiles from Lighting Facts 14](#_Toc511244920)

[Table 12 Using Kilolumen Structure Cost Impacts 15](#_Toc511244921)

[Table 13 – Variation in MH and LED Efficacies Across Wattage and Output Range 15](#_Toc511244922)

[Table 14 – Rebate Catalog Example if Using Lumen Bins and Efficacy 16](#_Toc511244923)

[Table 15 - LED High-Bay and Low-Bay Fixtures Base and Measure Wattages 17](#_Toc511244924)

[Table 16 Example of Photometric Data from “.ies” file 17](#_Toc511244925)

[Table 17 Example Calculation of Fixture Efficiency and Fixture Lumens 18](#_Toc511244926)

[Table 18 Equivalent LED Lumen Output for Similar Levels of Service 18](#_Toc511244927)

[Table 19 Lower Lumen Bin Measure Definition for the Next Measure Code 18](#_Toc511244928)

[Table 20 - Incremental and Full Measure Cost Equations 22](#_Toc511244929)

# 

# List of Figures

[Figure 1: Web-based LED Price and Efficacy Data for Recessed Troffer/Panel 2’ x 4’ 3](#_Toc511244930)

[Figure 2 – Example of Zonal Lumen in the 20 – 50 degrees 11](#_Toc511244931)

[Figure 3 – Example of Useful Lumens in the 0 – 50 degrees 12](#_Toc511244932)

[Figure 4 – HPT8/T5 Linear Fluorescent Highbay Fixture Program Data, 2013-2017 13](#_Toc511244933)

# Section 1 General Measure & Baseline Data

## 1.1 Measure Description & Background

PG&E was issued two relevant lighting dispositions:

* PGECOLTG178r3\_DetailedReview\_29Sep2017-final1.pdf (Issued September 29, 2017)
* High Bay Fixtures Disposition.pdf (Issued March 26, 2018)

In response to the disposition received on March 26, 2018, PG&E is resubmitting Revision 3 as an interim solution for PGECOLTG178 LED High-Bay and Low-Bay Fixtures. Details covering this revision and the next revision (to be submitted no later than August 31, 2018) are outlined below:

**Revision 3 Updates (considered as the Interim Solution):**

1. Baseline percentage mixes include LEDs and remove Metal Halides (MH)
   1. The baseline is a tiered mix of HPT8 linear fluorescent and LED (using 25th percentile efficacies from Lighting Facts) starting with a higher fluorescent % mix at lower lumen ranges and steadily decreasing to 0% fluorescent at the highest lumen ranges.
2. Tier 1 and Tier 2 align closely with Lighting Facts 50% percentile efficacies and DLC Premium minimum efficacies as efficacy floors.
3. Align technical requirements with DLC Technical Requirements update v4.3
4. Maintain the definition of level of service based on zonal lumen output in the solid angle range defined by the DLC for high bay products: 20 – 50 degrees from nadir.
   1. This Zonal Lumen method provides the benefit of simple, full data access via the DesignLights Consortium’s Qualified Product List.
5. Incremental measure costs are based on proposed rebate values to be effective upon approval of this workpaper. These rebate values are lower than those that were in place for Q1 2018. (Note: PG&E commits to maintain these rebate values for ROB measures until the next major revision that allows us to confidently update IMC data is approved).

**Revision 4 Planned Updates:**

1. Include Early Retirement/Accelerated Replacement as a Measure Application Type, and apply a different baseline for New Construction. With the addition of the ER/AR MAT, PG&E intends to offer higher rebates for qualified projects.
2. Transition to a lumen bin measure structure
   1. To promote higher efficacy and higher performance products, PG&E intends to offer measures tiered by efficacy, starting at a minimum efficacy level corresponding to DLC Premium Classification, in order to qualify for incentives.

**Revision 5 Planned Updates:**

1. Update the baseline mix with results from Standard Practice Baseline Study
   1. PG&E is conducting a standard practice baseline study through Navigant to update the baseline technology mix in the workpaper.
2. Collect program data to support annual updates to costs and efficacy levels
   1. PG&E will collect product data to help determine whether the median of the wattage/lumen range should be used to calculate savings in future workpaper updates and which measure case efficacy levels should be used to calculate savings.
3. Consider moving away from a 1-to-1 replacement savings calculation methodology and move towards a basis of design methodology.

***Catalog Description***

Light Emitting Diode (LED) High-Bay and Low-bay Lighting

**Requirements:**

* Must replace a lumen equivalent lamp/fixture of higher wattage. (Please refer to Table 1)
* Must be on the DesignLights Consortium (DLC) qualified product list (QPL)[[1]](#endnote-2)
* Fixtures listed under specialty categories on the DLC QPL do not qualify for the deemed rebate.
* Horticultural installations do not qualify for this rebate.
* Exterior installations do not qualify for this rebate.
* Self-ballasted screw-based lamps do not qualify.
* Must meet the minimum efficacy and wattage range listed for the appropriate measure codes in Table 1.

Table 1 - LED High-Bay and Low-Bay Fixtures Base and Measure Wattages

|  |  |  |  |
| --- | --- | --- | --- |
| **Measure Codes** | | | **Measure Description\*** |
| **PG&E** | **SCE** | **SDG&E** |  |
| LT376 |  |  | LED High/Low Bay: 110 LPW to <130 LPW, 0 to <48 W |
| LT377 |  |  | LED High/Low Bay: 110 LPW to <130 LPW, 48 to <71 W |
| LT378 |  |  | LED High/Low Bay: 110 LPW to <130 LPW, 71 to <90 W |
| LT379 |  |  | LED High/Low Bay: 120 LPW to <130 LPW, 90 to <125 W |
| LT380 |  |  | LED High/Low Bay: 120 LPW to <130 LPW, 125 to <153 W |
| LT381 |  |  | LED High/Low Bay: 125 LPW to <135 LPW, 153 to <187 W |
| LT382 |  |  | LED High/Low Bay: 125 LPW to <135 LPW, 187 to <212 W |
| LT383 |  |  | LED High/Low Bay: 125 LPW to <135 LPW, 212 to <246 W |
| LT384 |  |  | LED High/Low Bay: 125 LPW to <135 LPW, 246 to <283 W |
| LT385 |  |  | LED High/Low Bay: >=130 LPW, 0 to <42 W |
| LT386 |  |  | LED High/Low Bay: >=130 LPW, 42 to <60 W |
| LT387 |  |  | LED High/Low Bay: >=130 LPW, 60 to <82 W |
| LT388 |  |  | LED High/Low Bay: >=130 LPW, 82 to <113 W |
| LT389 |  |  | LED High/Low Bay: >=130 LPW, 113 to <140 W |
| LT390 |  |  | LED High/Low Bay: >=135 LPW, 140 to <174 W |
| LT391 |  |  | LED High/Low Bay: >=135 LPW, 174 to <194 W |
| LT392 |  |  | LED High/Low Bay: >=135 LPW, 194 to <227 W |
| LT393 |  |  | LED High/Low Bay: >=135 LPW, 227 to <262 W |

*\* +/-10% tolerance is applied on the minimum light output as per DLC technical requirements V4.3*

***Program Restrictions and Guidelines***

This work paper details the savings associated with implementation of energy efficient LED High-Bay/Low-Bay fixtures and retrofit kits. The delivery methods allowed include Downstream, Midstream, and Direct Install Programs for non-residential customers.

The LED fixture or retrofit kit must be listed in the technical requirements table (V4.3) by the Design Lights Consortium under the General Category “High Bay” and under the Primary Use Designations as follow: ***[[2]](#endnote-3)***

* High-Bay Aisle Luminaires
* High-Bay Luminaires for Commercial and Industrial Buildings
* Low-Bay Luminaires for Commercial and Industrial Buildings
* Retrofit Kits for High-Bay Luminaires for Commercial and Industrial Buildings
* Retrofit Kits for Low-Bay Luminaires for Commercial and Industrial Buildings

DLC Standard requirements for the high-bay and low-bay categories include:

* 5-year warranty
* 50,000-hour L70 Lumen Maintenance
* ≥ 70 Color Rendering Index (CRI)
* ≥ 105 lumens/Watt (LPW)\*
* ≤ 5700 Kelvin Correlated Color Temperature (CCT)
* ≥ 5,000 Lumen light output +/- 10%
* ≥ 30% of Lumen Output in the 20° - 50° zone (higher for Aisle Lighting)

DLC Premium requirements for the high-bay and low-bay categories include:

* 5-year warranty
* 36,000/50,000-hour L90/L70 Lumen Maintenance
* ≥ 70 Color Rendering Index (CRI)
* ≥ 130 Lumens/Watt (LPW)\*
* ≤ 5700 Kelvin Correlated Color Temperature (CCT)
* ≥ 5,000 Lumen light output +/- 10%
* ≥ 30% of Lumen Output in the 20° - 50° zone (higher for Aisle Lighting)

\*Specific measure case efficacy requirements listed in measure code descriptions in Table 1.

**Terms and Conditions:**

The customer must be a non-residential PG&E electric customer.

**Market Applicability:**

The customer must be a non-residential PG&E electric customer.

## 1.2 Technical Description

The following is a short excerpt from the CALiPER Snapshot for Industrial Luminaires[[3]](#endnote-4) that gives a high-level overview:

*“Industrial” luminaires are prevalent in both the commercial and industrial sectors, providing economical ambient lighting in large, open indoor spaces such as warehouses, manufacturing facilities, and big-box retail stores.  Industrial luminaires are divided into two categories: low-bay and high-bay. Typically, low-bay fixtures are used for heights up to 20 feet, whereas high-bay fixtures are used where ceilings exceed 20 feet. Given the space demands, high-lumen-output luminaires are required, with low-bay options typically emitting between 5,000 and 20,000 lumens per fixture and high-bay options emitting between 15,000 and 100,000 lumens per fixture.*

Historically, high-bay fixtures have used high-intensity discharge (HID) lamps (e.g., metal halide and high-pressure sodium) as the predominant light source, and low-bay fixtures have traditionally used both HID and fluorescent light source. Linear fluorescent high-output systems (e.g. T5/HO or F32T8 with VHLO ballasts) became a popular energy-efficiency measure in the early 2000’s for both high and low bay fixtures due to their superior lumen maintenance, lack of restrike delay, and ability to switch with occupancy sensors.

Light emitting diodes (LEDs) first entered this market circa 2009 but early-generation LED high-bay luminaires lacked the lumen output to compete in the market.  LEDs have since improved significantly making them an efficient and reliable lighting technology successfully replacing many lighting sources. Improvements in LED performance, makes LED an ideal replacement of HID and fluorescent light fixtures.

Though only 6% of all industrial luminaire installations were LED in 2015, market penetration is expected to grow to 86% by 20353. According to LED Lighting Facts, by 2014 LED efficacy had surpassed the HID and fluorescent technology with very competitive pricing.  LED Lighting Facts currently lists more than 8,000 industrial products, “41% of which emit between 5,000 and 15,000 lumens and 55% of which emit more than 15,000 lumens.” About “168 LED retrofit kits for these applications are currently listed with Lighting Facts.” A majority of listed industrial fixtures have comparable lumen output and higher luminous efficacy than their metal halide and fluorescent counterparts. “And in terms of color quality and power quality, LED industrial fixtures almost all offer the same performance as their metal halide and fluorescent counterparts.”

LED fixtures under this workpaper are assigned a measure code according to efficacy and wattage, which describes the energy savings associated with their replacement of linear fluorescent fixtures and less efficient LED fixtures.

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

|  |  |  |
| --- | --- | --- |
| **Code** | **Description** | **Comment** |
| *ROB* | *Replace on Burnout* | *measure applied when existing equipment fails or maintenance requires replacement* |
| *NC* | *New Construction* | *measure applied during construction design phase as an alternative to a code-compliant standard design* |

All the measures within this revision of the workpaper are ROB and NC. Analysis of historical program data shows a minimal portion of applications are claimed as NC. Table 3 shows the kWh percentage breakdown of measure application types in the program. Please see Attachment 1 – ROB vs NC.xlsx for more detailed information. For the interim solution, there is no differentiating baseline between NC and ROB, however, this will be examined for the next iteration of the workpaper.

Table 3 – Breakdown of ROB vs NC Measure Application Types for 2016, 2017, and All Program Years

|  |  |  |  |
| --- | --- | --- | --- |
| **Program Year** | **Measure Application Type** | **kWh** | **NC to ROB Percentage** |
| 2016 | ROB | 8,206,486 | 3.85% |
| NC | 328,312 |
| 2017 | ROB | 10,041,284 | 1.05% |
| NC | 106,357 |
| All Program Years (2015 – Present 2018) | ROB | 19,615,254 | 2.20% |
| NC | 442,036 |

Please refer to Section 1.6 Data Quality and Future Data Needs on efforts to include Early Retirement (ER) in the next iteration of the workpaper.

Historically, the workpaper supports Programs with a downstream and direct install delivery channel with replace-on-burnout and new construction measure application types. There are potential plans for a midstream expansion in the future.

Table 4 - Delivery Method and Applicable Building Types

|  |  |  |
| --- | --- | --- |
| **Delivery Type** | **Applicable Building Types** | **Application Type** |
| Downstream, Midstream, & Direct Install | DEER Building Types | ROB, NC |

## 1.4 Measure Parameters

The measure parameters are defined by the linear fluorescent base case. The linear fluorescent base cases are chosen by the code equivalent of the most common high performance T8 linear fluorescent fixtures. Therefore, 2, 3, 4, 6, 8, and 10-lamp linear fluorescent fixture arrangements were chosen as part of the base case. More information on the base case and measure case is provided in Section 2 Calculation Methods.

### 1.4.1 DEER Data

This revision of the workpaper is an update to the previous revision now found in the Database for Energy Efficient Resources (DEER).

The DOE Solid-State Lighting CALiPER Reports have examined 7 LED high-bay fixtures combined in application summary reports #13[[5]](#endnote-6). None of the 7 fixtures met the DLC minimums for efficacy and output. Given the small population relative to the full DLC QPL of 45,536 products as of 8/16/2017, CALiPER reports were not used for determining equivalency. Wattage equivalency was based on the full list of DLC products.

Table 5 – 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 2016 |
| Reason for Deviation from DEER | DEER does not contain these exact wattage ranges for the measure; DEER does not contain the percentage mix and efficacies for the base case. |
| DEER Measure IDs Used | N/A |

**Net-to-Gross Ratio**

The NTG values are from DEER 2014. 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** |
| Com-Default>2yrs | All other EEMs with no evaluated NTGR; existing EEM in programs with same delivery mechanism for more than 2 years | Com | Any | Any | 0.6 |

Per discussion with Commission Staff (CS) on April 5, 2018, the NTG value is expected to increase closer to 0.91 with the introduction of LED fixtures into the baseline. Since updated NTG values and IDs are not yet available, PG&E has been directed to use the current NTG value until CS issues a finalized update. After CS issues a final update, PG&E will resubmit workpaper with new NTG IDs.

**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 value was obtained using the DEER READI tool. The relevant IR value for these measures in this work paper is in the table below.

Table 7 - Installation Rates

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **GSIA ID** | **Description** | **Sector** | **BldgType** | **ProgDelivID** | **GSIAValue** |
| Com-HiBay-PGE | Non-Res High-Bay; Annual Installation Rate | Com | Any | NonUpStrm | 0.92 |

**Hours of Operation**

The DEER 2016 hours of operation and interactive effects are used in the savings calculations.

**Effective Useful Life / Remaining Useful Life**

The rated life for these products is assumed to be 50,000 hours, the minimum DLC specification. Rated life for DLC-listed products starts at 50,000 hours and extends much higher, but a minimum of 50,000 hours or 12 years is used here. Since the EUL is dependent on the hours of operation, the EUL varies by building type.

The EUL is based on 50,000 hours rated fixture life divided by average annual hours of operation for each building type:

EUL = (DLC-Minimum Fixture Life (hours)) / (Average Operating Hours per Year)

Table 8 - Effective Useful Life/Remaining Useful Life

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

### 1.4.2 Codes & Standards Analysis

***Title 20:*** The ballast efficiencies of these base case metal halide lighting systems are regulated under Title 20 of the California Energy Regulations, section 1605.3(n). The most broadly applicable ballast efficiency minimums are as follows:

1. 90 percent for 150 to 250 watt lamps; or
2. 92 percent for 251 to 500 watt lamps.

These minimums are assumed for the appropriate measures in the work paper.

***Title 24:*** Neither the source technology nor the fixture selection for these measures falls under Title 24 [2016] [[6]](#endnote-7) of the California Energy Regulations. However, the Lighting Power Densities (LPD) in watts/ square feet of both measure and base case are capped by Title 24. Given the enormous range in high bay spacing, with 25 and 30 foot spacing possible, any eligible fixture under this measure (capped at 571W/fixture) could meet appropriate LPDs listed in Table 140.6-C of Title 24. The bases of the 2016 standards for high and low bay occupancies are pulse start metal halide.  The 2019 Title 24 standards will be based on all LED designs.

***Federal Standards:*** These measure case fixtures do not fall under Federal DOE or EPA Energy Regulations. As amended by EISA 2007, EPCA regulates metal halide lamp fixtures designed to be operated with lamps rated greater than or equal to 150 watts (W), but less than or equal to 500 W, by prescribing performance requirements for the metal halide ballasts used in those metal halide lamp fixtures[[7]](#endnote-8). Both metal halide lamps and ballasts are energy-using components of metal halide lamp fixtures. For this MH lamp wattage range, metal halide lamp fixtures must contain the following:

1. a pulse-start metal halide ballast with a minimum ballast efficiency of 88 percent;
2. a magnetic probe-start ballast with a minimum ballast efficiency of 94 percent; or
3. a non-pulse-start electronic ballast with—
   1. a minimum ballast efficiency of 92 percent for wattages greater than 250 watts; and
   2. a minimum ballast efficiency of 90 percent for wattages less than or equal to 250 watts.

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

The following studies were used for the development of the workpaper and briefly described below:

### 1.5.1 Lighting Dispositions

There were two lighting dispositions that were issued relevant to the development of this workpaper:

* PGECOLTG178r3\_DetailedReview\_29Sep2017-final1.pdf (Issued September 29, 2017)
* High Bay Fixtures Disposition\_03262018.docx-1.pdf (Issued March 26, 2018)

As outlined in the “Disposition for Workpaper PGECOLTG178-REV3 Covering High and Low Bay LED Fixtures” dated September 29, 2017, the PAs will address the following:

1. *Develop a standard practice baseline that reflects the typical mixture of efficiency levels that are currently selected in normal replacement situations.*
2. *Define measure tiers in a way that assigns greater savings for higher performance products and place an efficacy floor on eligible products.*
3. *Due to the rapid changes in the marketplace, update the measures at least annually.*
4. *Revise measure definitions so that baseline and measure zonal lumen output levels represent similar levels of service.*

In the more recent lighting disposition, PG&E was directed to the following:

* *Required to work with Commission Staff over the course of next few days to develop interim ex ante values that will become effective April 1, 2018.*
* *Encouraged to continue to engage with Commission staff if there is continued uncertainty regarding how PG&E can meet the compliance requirements within the September 29, 2017, staff disposition.*
* *Shall work with Commission staff and their consultants to develop interim ex ante value ASAP over the next two weeks that allow a resubmission of R3 using those interim values until more robust standard practice baseline work can be completed.*

As a result of these dispositions, R3 of this workpaper reflects the agreed interim approach. Summarized details of R3 and R4 are listed in Section 1.1 Measure Description & Background.

### 1.5.2 California LED Pricing Analysis, Navigant 2018[[8]](#endnote-9)

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 the LED Highbay/Lowbay lighting product category, 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 Highbay/Lowbay 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 will consider a measure structure that is tiered by both lumen output and efficacy in future workpaper updates that may include separate efficacy tiers. 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 include 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. This may have implications for this workpaper since it currently assumes a fixture-to-fixture comparison between base case and measure case. The incremental measure cost in the two scenarios is very different. Since a common consumer purchasing scenario includes replacement lamps and ballasts only, workpapers should consider including that scenario in the baseline. This will be investigated for a future revision of this workpaper.

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.

### 1.5.3 LED Workpaper Update Study, Navigant 2015[[9]](#endnote-10)

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 2015-208, 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. 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 the adoption of higher degrees of efficiency.

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 highbay/lowbay applications is expected to increase from 3.4% in 2015 to 17% in 2018, and then increase to 34% 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 does not align with its rated wattage or lumen equivalent. This could have implications for measure structure and how lumen equivalency is defined between base case and measure case in future workpaper updates.

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 ROB baselines. The IOUs are considering incorporating early retirement measures into future workpaper updates to capture the additional energy savings potential in the market.



**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)**

Early retirement baseline according to contractors indicates closer to 50% for HID technology and 50% for T8 and T5 combined.

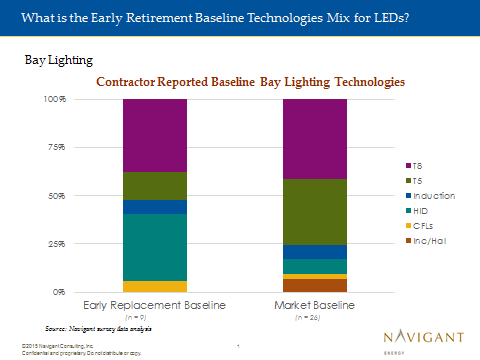


Figure 3: Early Retirement Baseline Technology Mix for LEDs as reported by Contractors

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 30, 2014 lighting 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. The three IOUs formed a statewide working group in February 2016 to address the Navigant recommendation. The analysis and IOU recommendations were presented to the Ex-Ante Review (EAR) team in July 2016. The final presentation was made to California Technical Form and the EAR team in October of 2016. This proposed methodology was submitted in June 2017 for an early review by the Ex-Ante Review team.

Upon further guidance from CS, the IOUs will need to collect program data to validate this savings calculation methodology. This revision of the workpaper breaks the measure codes into narrower wattage ranges to more accurately capture savings and going forward will also evaluate program data to better understand what wattage products customers are buying. This program information can then be used to more accurately calculate energy savings. Section **1.6.3 Product ID Collection Process** describes a data collection process to inform savings calculations in the future.

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

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 Q3 2018. In that decision, Commission Staff think it is unclear that the DLC QPL meets the requirements of incentivizing the top half of quality products in the non-residential lighting market. In that 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.

This study has been expanded to include distributor surveys to determine the standard practice baseline for interior LED categories. These surveys will ask distributors about their current sales/purchase mix by lighting technology, including LEDs. They will ask about the last 12 months and the projected sales mix by lighting technology for each of the next five years. The sales data is being collected separately for each interior product category and also attempts to collect efficacy data within LED products being sold.

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

### 1.5.5 CALiPER Application Summary Report 135:

A few of the conclusions that CALiPER reported in the most recent application summary report (#13) from tests of 5 LED high-bay fixtures:

* Two products tested significantly outperformed the benchmark products in terms of light output and efficacy
* Three products performed as claimed in product literature

## 1.6 Data Quality and Future Data Needs

### 1.6.1 Standard Practice Baseline Studies

**Indoor LED Lighting**

Previous revisions of this workpaper focused on the replacement of metal halide or linear fluorescent fixtures with LED technology. The baseline assumed 100% metal halide or 100% linear fluorescent in previous measure codes.

The September 2017 high-bay and low-bay disposition directed an update to reflect standard practice baseline for normal replacement situations. As such, the California Investor-Owned Utilities are leveraging a PG&E-led “Non-residential Lighting Market Characterization Study” that is currently underway by Navigant Consulting, Inc. to gather 2017 and projected (5 years) sales data that will inform the standard practice baseline for interior LED categories. This Study is targeted for completion by late 2018. Leveraging Navigant’s study is an effort to consolidate touch points with manufacturers and distributors.

The results gathered will address the base case technology percentage mix and efficacy levels, which will be used to update R5 of the workpaper. Therefore, PG&E has updated this workpaper (Revision 3) with an interim solution until the standard practice baseline results have been approved and published. The table below is the breakdown of technology use for the base case used in the savings calculations.

Table 9 – Base Case Technology Percentage Mix

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Meas Code** | **Measure Description** | **Meas Case Tier** | **Base Case**  **% Linear Fluorescent** | **Base Case**  **% LED** |
| LT376 | LED High/Low Bay: 110 LPW to <130 LPW, 0 to <48 W | Tier 1 | 20% | 80% |
| LT377 | LED High/Low Bay: 110 LPW to <130 LPW, 48 to <71 W | Tier 1 | 20% | 80% |
| LT378 | LED High/Low Bay: 110 LPW to <130 LPW, 71 to <90 W | Tier 1 | 20% | 80% |
| LT379 | LED High/Low Bay: 120 LPW to <130 LPW, 90 to <125 W | Tier 1 | 10% | 90% |
| LT380 | LED High/Low Bay: 120 LPW to <130 LPW, 125 to <153 W | Tier 1 | 10% | 90% |
| LT381 | LED High/Low Bay: 125 LPW to <135 LPW, 153 to <187 W | Tier 1 | 10% | 90% |
| LT382 | LED High/Low Bay: 125 LPW to <135 LPW, 187 to <212 W | Tier 1 | 0% | 100% |
| LT383 | LED High/Low Bay: 125 LPW to <135 LPW, 212 to <246 W | Tier 1 | 0% | 100% |
| LT384 | LED High/Low Bay: 125 LPW to <135 LPW, 246 to <283 W | Tier 1 | 0% | 100% |
| LT385 | LED High/Low Bay: >=130 LPW, 0 to <42 W | Tier 2 | 20% | 80% |
| LT386 | LED High/Low Bay: >=130 LPW, 42 to <60 W | Tier 2 | 20% | 80% |
| LT387 | LED High/Low Bay: >=130 LPW, 60 to <82 W | Tier 2 | 20% | 80% |
| LT388 | LED High/Low Bay: >=130 LPW, 82 to <113 W | Tier 2 | 10% | 90% |
| LT389 | LED High/Low Bay: >=130 LPW, 113 to <140 W | Tier 2 | 10% | 90% |
| LT390 | LED High/Low Bay: >=135 LPW, 140 to <174 W | Tier 2 | 10% | 90% |
| LT391 | LED High/Low Bay: >=135 LPW, 174 to <194 W | Tier 2 | 0% | 100% |
| LT392 | LED High/Low Bay: >=135 LPW, 194 to <227 W | Tier 2 | 0% | 100% |
| LT393 | LED High/Low Bay: >=135 LPW, 227 to <262 W | Tier 2 | 0% | 100% |

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

PG&E is currently investigating ER/AR measure application type offering for the next iteration of the workpaper. The analysis will be derived from reviewing ER custom applications with a focus on customer segment(s) and geographical location(s). Resolution E-4818 and Track 2 Working Group begins to set a framework for deemed program level ER adoption for Preponderance of Evidence. Further Commission Staff guidance on ER will be forthcoming and incorporated into the final development of ER measure application type for deemed.

### 1.6.3 Product ID Collection Process

As part of the IOUs’ future data needs, a more robust process to collect product information from program data is being implemented. 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 allow IOU Programs to analyze program data to for savings calculations as well as future workpaper updates.

### 1.6.4 DEER Limitation on Non-linear Functions

DEER currently can accept only a constant value of cost per unit of measure. Navigant’s LED Pricing Analysis Study has identified lumen output as the factor most correlated with price, but the relationship is neither linear nor without a constant term. The cost of the metal housing for a fixture might be constant, rather than scaling with light output. PG&E would like to explore in the longer term how DEER could accommodate a non-linear relationship such as a logarithmic relationship between light output and price. Linearly scaling prices, efficacies, and costs across such a wide range of lumens prove a limiting factor, until such time as DEER can accept values from functions that scale other than linearly with the defined unit.

### 1.6.5 Lighting Facts LED Database

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

* Up-to-date product offerings
* Large sample size (~12,500 industrial products)
* Product performance data previously accepted by CalTF and Ex-Ante Review team in the LED Troffer workpaper
* Ability to filter by year, so that older products could be excluded from the efficacy sampling
* Important distinctions by primary use: Lighting Facts captures the lower LPW values typical of Wall-mounted LEDs on the market.

Unfortunately, as of March 31, 2018, the Department of Energy has ended future funding for the Lighting Facts label program. Other data sources will need to be considered in lieu of Lighting Facts such as the data that will be collected for the Navigant LED Market Characterization study.

### 1.6.6 Cost Data Quality

The following data sources were consulted to develop the base case and measure case costs:

1. PG&E Program Data
2. SCE Program Data
3. Navigant Data
   1. Raw from the Price Tracker
   2. Values from the cost model
4. Online pricing

As detailed below, these cost determination approaches did not yield reliable incremental measure costs. Until further analysis can be conducted, incremental measure costs have been determined based on proposed deemed rebate levels that will be effective upon approval of this workpaper, and will be applied for this revision only as an interim solution. This option is described in further detail in Section 4 on Base and Measure Costs.

**PG&E Program Data:** The raw data file cleaned of customer information can be found as Attachment 2. There were 3403 applications received from 1/1/2016 through 3/29/2018. One of the challenges with the data was acquiring the wattage, lumen output, and efficacy of the rebated fixture because the unique Product ID that matches with the listed DLC fixture has not yet been implemented as part of application processing. Additionally, approximately 680 applications (20% of all received records) 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, an approximate logic was used to match with the rebated fixture with the DLC list. From there, the wattage, lumen output, and efficacy of the rebated fixtures was acquired. There were 2078 (61% of all received records) matches with the manufacturer and model number. Out of the 2078 matches, 1814 (53% of all received records) applications were used for the cost analysis. Some of the excluded applications had wattages out of the range of the measure definitions or had other cost data quality issues. Other known or possible cost data quality issues include setting the material cost per unit equal to the rebates, incorporating the labor costs in the material costs, misreported quantities, and incorrect DLC manufacturing and model number matching. Spot checking was conducted; however, it is a manual and time intensive task. Invoices or receipts are scanned into the database electronically.

From a general overview of the data, it was observed that costs do correlate to lumens or wattage as indicated in the Navigant 2018 LED Pricing study: as wattage increases, the cost per fixture also increases. The data also points that when comparing efficacy of LEDs, the price premium may not exist and as such, efficacy does not largely drive the cost of the fixture. From recent discussions with the Commission Staff (early April 2018), a suggestion of cost pair matching was made. The idea of cost pair matching is to find a group of similar fixtures in terms of fixture features in the base case as well as the measure case. For example, if stainless steel, shock absorbent, vibration resistant high bay fixtures were found in the measure case, the base case should also possess the same fixture features. This will drop variables in the cost of a fixture and leave a metric such as efficacy as the sole variable left contributing to the price delta. A first examination of pair matching was conducted based on manufacturers, and the results can be seen in Table 10:

Table 10 – Manufacturer Cost Pair Matching

|  |  |  |  |
| --- | --- | --- | --- |
| **Manufacturers** | **Premium** | **Standard** | **Adder for Premium** |
| ACUITY | $239.22 | $331.92 | -$92.70 |
| ALEO | $165.44 | $206.55 | -$41.11 |
| ATLAS | $248.09 | $185.76 | $62.33 |
| CREE | $138.23 | $344.96 | -$206.73 |
| All other MFRs | $181.45 | $186.60 | -$5.15 |

Unfortunately, the results did not yield in favor of a positive premium cost adder, indicating that further analysis is needed to determine the metrics driving price, and the parameters by which IOU Programs would design efficiency measures. Further in-depth investigation will be needed to research the spec sheets of the rebated fixtures. This is a time intensive and manual task, which can be evaluated for the next iteration of the workpaper.

**SCE Program Data:** The raw data file cleaned of customer information can be found as Attachment 3. There were 656 applications received from the end of 2016 through the end of 2017. The same approximate logic was used to match the manufacturer and model number to obtain the wattage, lumen output, and efficacy of the rebated fixtures. There were 405 (62% of all received records) matches with the manufacturer and model number. Out of the 405 matches, 207 (32% of all received records) applications were used for the cost analysis. Some of the excluded applications had wattages out of the range of the measure definitions.

A generalized trend of cost correlating with lumen output can be seen in the data set, however, when assigned into the wattage bins and two tiers, Tier 2 does not seem to follow this relationship. Due to the low amount of data points in each of the wattage bins, the SCE program data was only included as a comparison and not incorporated fully into the base case and measure case cost analysis.

# Section 2 Calculation Methods

**2.1 Equivalent Levels of Service**

This workpaper uses the current DLC QPL to choose the most appropriate LED base and measure case wattages. The fluorescent base case power consumption uses the Standard Fixture Wattages from Appendix B. The base case wattages have been developed from common configurations of high performance T8 linear fluorescent high-bay and low-bay fixtures.

The fixture lumen performance in the high-bay and low-bay categories of the DLC qualified product list as of March 2018 was analyzed to justify the wattage equivalency assumptions. The 7799 parent products in the DLC list in these categories were analyzed for equivalency to common linear fluorescent base case fixtures. Parent fixtures are the only entries listed with zonal lumen data. This is a much smaller list than the full DLC list.

Two calculation methodologies were investigated to address “measure definitions equivalent level of service” and to identify the base case wattage using the following:

1. Zonal Lumens
2. Useful Lumens

Beyond technical accuracy, other major considerations for the evaluation were the following:

* Ease of program implementation
* Ease of conceptual understanding

I. Zonal Lumens Methodology

The zonal lumen methodology analyzes useful light output in a specific zone to ensure equivalent performance between LED and linear fluorescent fixtures. PG&E’s previous workpaper introduced zonal lumens as a proxy for useful light output, and uses the definition from the DesignLights Consortium specified minimum requirement zone: 20 to 50 degrees from nadir.

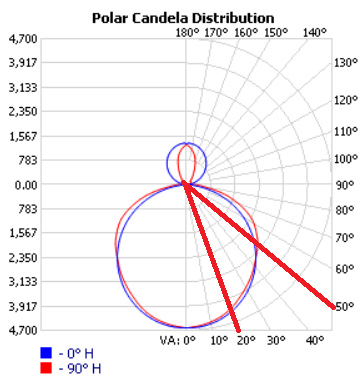


Figure 2 – Example of Zonal Lumen in the 20 – 50 degrees

(Source: Visual-3d <http://www.visual-3d.com/tools/photometricViewer/default.aspx?id=18586>)

II. Useful Lumens Methodology

While the zonal lumens between 20 to 50 degrees is the most important, the single number can be a more crude approximation than necessary if full information is available on fixture light distribution and the task plane shape. For example, it is important that fixtures provide some light between zero and 20 degrees: darkness would be unacceptable there. Furthermore, more lumens should be provided at 40 – 50 degrees than 20 – 30 degrees—4.57 times more, in fact—because of the following:

A) represents a larger area further away from the fixture, and

B) requires higher lumen output with the ten degree range to achieve the same horizontal illuminance.

These savings’ calculations expand on the zonal lumens concept to define equivalent performance in gradations of 10 degrees from 0 to 50 degrees from vertical and based on photometric division of lumen output. However, limitations in the assumptions required for uniformity-based calculations make this approach less desirable than the zonal lumens approach, namely:

A) the assumptions of a uniform task plane, especially horizontal-only, don’t capture indoor environments such as warehouses,

B) uniformity is much less of a limiting factor in indoor high-bay lighting than, for example, in outdoor lighting, and higher-illuminance areas may even be desirable,

C) the method brings complexity without clear, significant benefit.

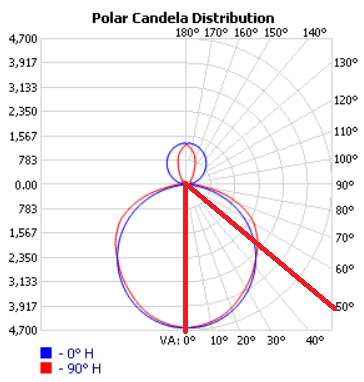


Figure 3 – Example of Useful Lumens in the 0 – 50 degrees

(Source: Visual-3d <http://www.visual-3d.com/tools/photometricViewer/default.aspx?id=18586>)

The savings calculations will continue to utilize Zonal Lumens, as this method approximates the level of service provided by the luminaires at least as well as the other method, and does so without unnecessary complexity.

Many Pulse Start Metal Halide HID and linear fluorescent fixtures commonly over-illuminate the area directly beneath the fixture (0° - 20°) simply because they lack the ability to direct light to where it is needed most. Pulse Start Metal Halide HID and linear fluorescent sources may achieve a higher average illuminance than an LED source (and have a correspondingly higher lumen output), however they achieve similar minimum illuminance because the LED fixture may be able to do a better job of directing light out to the edges of the illuminated space.

The analysis of lumen performance focuses on light distribution differences from HID, Fluorescent & LED technologies. HID & Fluorescent, as omni-directional sources, are not as successful in effectively spreading out light and avoiding pools of light below each fixture, which is sometimes seen in product data as a higher percentage of lumens in the 0 - 20° zone. This analysis estimates the degree to which LEDs with better directional light control can replace fluorescent and HID products with higher total light outputs. The same data from Revision 2 of the workpaper is used for this update as the fundamental relationships of light distribution have not changed.

This analysis compares fixtures based on the lumen output in the 20° - 50° range to ignore the hot spot of light that may appear directly under a fixture. Customers are often happy with the light output of LED fixtures with lower total light output than the Pulse Start Metal Halide HID or linear fluorescent fixtures replaced which further supports utilizing the zonal lumen method.

The lumens in the 20° - 50° range were calculated from the DLC QPL based on the measured light output of each fixture multiplied by the percent of lumens in that range labeled on the DLC QPL spreadsheet at ZL-HBLB: 20-50 or ZL-HBA: 20-50. The lumen output for base case fixtures in the 20° - 50° range was calculated from the zonal lumen summary tables of manufacturer photometric reports. These values were corrected for lamp lumens and ballast factor based on industry standards for HPT8 linear fluorescent lamps.

The lumen output in the 20° - 50° range is the basis for the division of LED products into appropriate measure codes. The LED products equivalent in lumen output in the 20° - 50° range were grouped to the base case fixtures as much as possible, given the limitation of varying LED fixture performance. The HPT8 linear fluorescent fixtures were compared to the group of DLC-approved LED fixtures that would best replace the linear fluorescent fixtures based on photopic lumens in the 20° - 50° zones. Measure codes were created by setting LED wattage ranges from the lumen equivalence of the base case fixture lumen output.

The DLC QPL was analyzed as of March 2018 to determine qualification of the applicable fixture population. 47,230 fixtures in these categories, 80% of the qualified products, are represented in the measure code offerings. There are no measures codes in the first efficacy tier above 203 W because the base case efficacy above that wattage approaches the measure case efficacy floor thereby generating minimal energy savings. Only DLC Premium products at or above 130 LPW create substantial savings above the base case in the higher wattage ranges.

**2.2 Assumptions Used in the Calculations**

**Base Case Technology Mix**

PG&E evaluated past program data to estimate a starting point for the base case technology mix. PG&E previously offered rebates for HPT8/T5 linear fluorescent highbay fixtures. The figure below shows program activity for these measures.

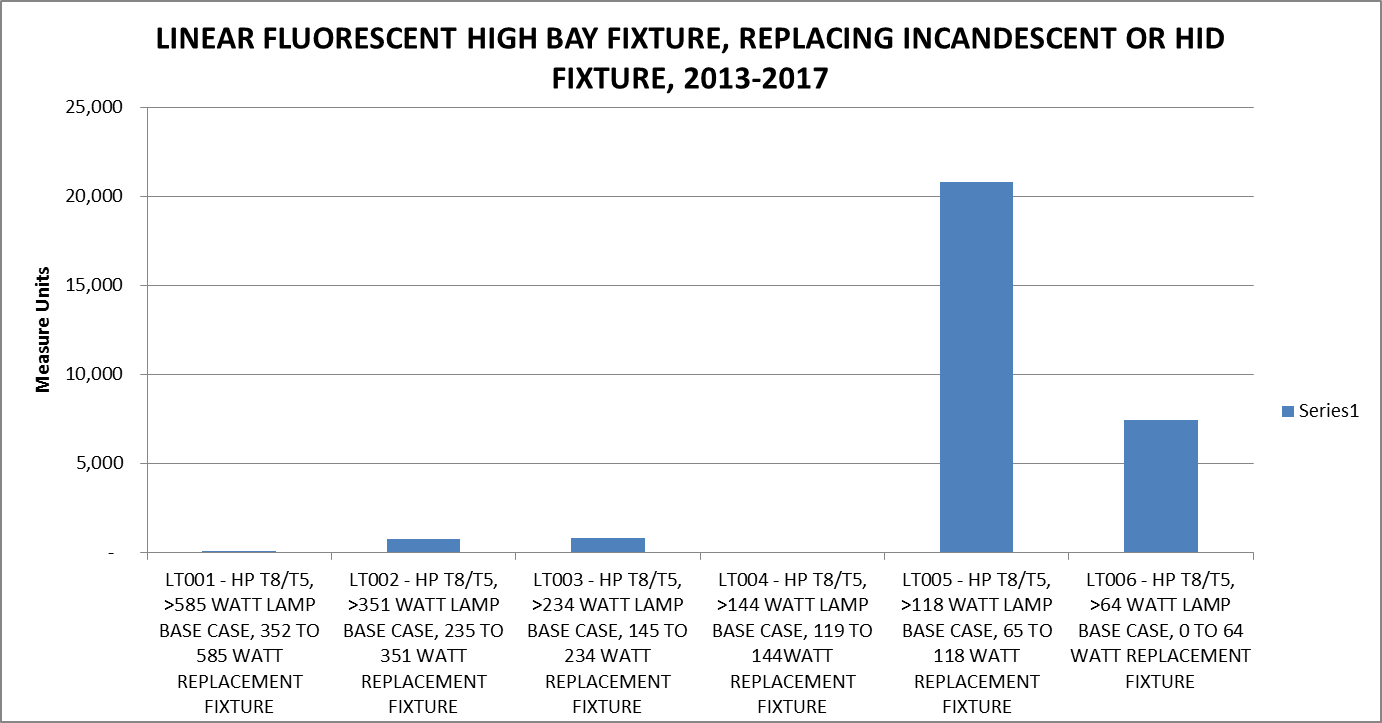


Figure 4 – HPT8/T5 Linear Fluorescent Highbay Fixture Program Data, 2013-2017

This data makes clear that the majority of purchases in this measure offering occur in the lower wattage ranges from 0-118 watts. This implies that when customers are selecting fixtures to purchase in an ROB scenario, it is more likely to be fluorescent in the lower wattage bins than higher wattage bins. This is the basis for the base case mix chosen in this revision of the workpaper – starting with higher percentage fluorescent fixtures in the lower wattage ranges and dropping that percentage of fluorescent fixtures as the wattage increases.

Although the measure codes are not separated for lowbay and highbay applications specifically, the measures are separated by lumens/watts and lowbay applications tend to occur in the 0-10,000 lumen range (the equivalent of 2,3, and some 4 lamp linear fluorescent fixture replacements) whereas highbay applications fall into the higher lumen ranges. The standard practice baseline for these lower wattage range measures are 20% linear fluorescent and 80% LED. For the 6, 8, and 10-lamp linear fluorescent equivalent measures, mostly high bay applications, the standard practice baseline technology mix shows 90% for LED and 10% for linear fluorescent. Measures above the 10-lamp linear fluorescent fixture assume 100% LED standard practice baseline as linear fluorescent fixtures are not common at all at this high lumen output. Historically, metal halide fixtures were used in these applications.

During discussions with the Commission Staff, it was made apparent that LED linear lamps (also known as TLEDs) should be acknowledged as a major part of the standard practice baseline. The interim workpaper still uses a fixture- to-fixture replacement to incorporate the influence of LED linear lamps in the standard practice baseline, as this issue is being investigated further for the next iteration of the workpaper. The base case technology mix used in the calculations are shown in Table 9 – Base Case Technology Percentage Mix.

**LED Base Case Efficacy:** The base case efficacy used was 25th percentile Lighting Facts for industrial luminaires. This is a similar approach taken in the workpaper PGECOLTG151 Outdoor and Street Lighting. This assumption is based on what customers would buy in the absence of utility programs.

Table 11 – Industrial Products Efficacy Percentiles from Lighting Facts

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Base Case**  **25 %ile efficacy** | **Tier 1 Floor**  **50 %ile efficacy** | **Tier 1 Meas Case**  **62.5 %ile** | **Tier 2 Floor**  **75 %ile efficacy** | **Tier 2 Meas Case**  **87.5 %ile** |
| 0.25 | 0.5 | 0.625 | 0.75 | 0.875 |
| 95.3 | 107.5 | 116.3 | 127.2 | 134.4 |
| 99.2 | 110.6 | 121.5 | 129.4 | 137.8 |
| 97.9 | 110.4 | 116.5 | 126.6 | 137.1 |
| 104.6 | 122.6 | 128.5 | 133.4 | 141.9 |
| 108.1 | 120.0 | 126.7 | 131.0 | 140.0 |
| 109.5 | 124.8 | 131.9 | 137.8 | 143.7 |
| 118.3 | 127.7 | 130.4 | 134.0 | 140.0 |
| 114.3 | 127.9 | 131.8 | 138.0 | 144.1 |
| 113.6 | 127.1 | 130.7 | 134.4 | 141.6 |
| 108.6 | 124.8 | 130.6 | 135.4 | 143.1 |

**Linear Fluorescent:** The wattages used are from Appendix B Standard Fixture Wattages. It is assumed to use HPT8 lamps (3050 lumens per Federal Standards) with a ballast factor of 1.15.

**Measure Structure:** The current measure structure uses the wattage bin as structured from the previous revision (R2) of the workpaper. For the future update of the workpaper, per kilolumen and lumen bins will be investigated. There are, however, challenges with the kilolumen structure:

1. **Setting constant per-kilolumen LED costs across a wide range from 4.5 to 160 kilolumens given market efficiencies of scale**

* High-bay products range across a light-output factor of 30, which makes for a poor fit with the per-kilolumen approach. The LED ambient fixtures workpaper (PGECOLTG179) was limited to a range of less than a factor of 3 in light output.
* The table of kilolumen measures below show a blended base cost of $18 per kilolumen. However, multiplying this by the extremes of the kilolumen range (4.5 and 90) to obtain yields base case costs at $80 and $1600 per fixture. Compared with actual fixture prices, these are too low and too high, respectively, due to the assumption of constant cost per kilolumen.

Table 12 Using Kilolumen Structure Cost Impacts

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Per Kilolumen Measure | Efficacy Tier | Base W/klm | Measure W | ΔW | Blended Base Cost [$/ kilolumen] | Measure Cost [$/ kilolumen] | **Fixture Cost at 4.5-90 Kilolumens**  **($/fixture)** |
| 1 | 130 LPW | 11.07 | 7.69 | 3.38 | $17.70 | $20.04 | **$90-$1800** |
| 2 | 140 LPW | 11.07 | 7.14 | 3.93 | $17.70 | $22.42 | **$101-$2018** |
| 3 | 150 LPW | 11.07 | 6.67 | 4.40 | $17.70 | $28.56 | **$129-$2570** |

* DEER currently can accept only a constant value of cost per unit of measure. The details have been described in Section 1.6.4 DEER Limitation on Non-linear Functions.

1. **(Pertinent for ER and 1-for-1 replacement) Scaling the metal halide fixtures and costs appropriately across the light output range**

Background: The Ex Ante Team recommended the kilolumen method utilized in PGECOLTG179 for LED troffers where energy impacts are normalized in terms of energy savings per unit of light output, or kilolumen. For fluorescent lighting, commonly found in office, retail, and other commercial spaces, the light source technology is predominantly the F32T8 four-foot fluorescent lamp. Other technologies exist, but this is the most common and highest-efficacy technology in use. Most importantly for scaling per lumen, the same exact fluorescent lamps (and thus the same efficacy) are used both for illuminating hallways to 10 foot-candles and for illuminating printing review spaces to 100+ foot-candles. Thus, the savings from a 125 lm/W LED over the ~95 lm/W fluorescent is the same across the measures.

* However, the scaling of metal halide light output presents a problem because all sizes of metal halide fixtures have 1 lamp each. *For high-bay lighting where metal halide products are a common light source, the base case efficacy is not constant per light output across the output range.* This is a significant issue that prevents establishing accurate energy impacts across a range of HID products in high/low bay applications on a per kilolumen basis.

This table[[10]](#footnote-2) demonstrates the significant variation in lamp efficacies across the wattage and output range:

Table 13 – Variation in MH and LED Efficacies Across Wattage and Output Range

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **MH Lamp Wattage** | **MH Initial Lamp Lumens** | **MH Lamp efficacy (lm/W)** | **LED DLC Premium efficacy (lm/W)** | **Delta Efficacy (lm/W)** |
| 100 | 8,213 | **65.90** | 130 | 64.10 |
| 150 | 12,360 | **67.90** | 130 | 62.10 |
| 200 | 20,000 | **90.00** | 130 | 40.00 |
| 250 | 23,183 | **83.46** | 130 | 46.54 |
| 320 | 30,473 | **87.61** | 130 | 42.39 |
| 400 | 42,250 | **97.18** | 130 | 32.83 |
| 750 | 75,000 | **91.69** | 130 | 38.31 |
| 1000 | 120,000 | **112.32** | 130 | 17.68 |

*The assumption of a constant base case luminous efficacy ignores a significant variation because the base case efficacies are not uniform as with fluorescents.* The delta efficacies between the LED and metal halide as seen in the last column are significantly higher for the 100W metal halide lamp than the 1000W metal halide lamp.

For the future update of the workpaper, it is likely that the measure structure will use lumen bins instead of wattage bins. It encourages customers to determine the most appropriate light output for the task.

* Comparing the Wattage Bin and Lumen Bin methods, the Lumen Bins method is more effective in recognizing the service provided in the volume of light output. In either case, the Wattage or Lumen value jumps by an average of 30% with each bin, but with the Wattage Bin method there is an added variation by efficacy between products at a given wattage: 7.3% for products within the 130 – 139.5 LPW tier. This means that some products in a lower wattage bin outperform products in a higher wattage bin due to the efficacy difference.
* Using lumen bins rather than binning by wattage encourages customers to directly compare a 130 LPW LED luminaire to higher efficacy tiers because the bins are the same in all tiers, rather than requiring comparisons across both efficacy and wattage-bin differences.
* In the Wattage Bin method, the range of wattages comparable to a 4-lamp fluorescent fixture might be 78W to 104W in the 105LPW tier, but 71W to 93W in the 150 LPW tier. This makes the tier structure using wattage as a primary reference more complicated for customers at first glance. The lumen bin structure makes it easier to see that rebates for a given output product will increase with efficacy.

Using the lumen bin approach that identifies a lumen range for each base case that LED products will replace and to create efficacy tiers, where the higher efficacy tiers will offer higher incentives. This approach is similar to the approach used for A-lamps in PGECOLTG165. The lumen bins will be sized according to fluorescent luminaire configurations offered in high-bay and low-bay lighting. The lumen bin approach is the most natural as we are asking customers to consider lumen equivalency in their choice to upgrade to more efficient technology.

For example, a customer considering a low-bay product from the rebate catalog will see the following:

Table 14 – Rebate Catalog Example if Using Lumen Bins and Efficacy

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measure Code** | **Min Lumen** | **Max Lumen** | **LED efficacy tier (lm/W)** | **Incentive available ($ / fixture)** |
| 1 | 4,500 | 6,510 | 130 | W |
| 2 | 6,511 | 10,230 | 130 | X |
| … |  |  |  |  |
| 9 | 4,500 | 6,510 | 140 | Y |
| 10 | 6,511 | 10,230 | 140 | Z |

The per-luminaire incentives listed and comparable across efficacy tiers will more easily provide support for higher-performing products.

**Measure Tiers:** The measures are structured with two tiers.

1. Tier 1 contains lower efficacies floors than Tier 2 to accommodate current projects in the pipeline. The efficacy floor for Tier 1 was derived from the 50th percentile of the Lighting Facts database to represent top half of the market and serves as an eligibility requirement. The measure case efficacy used in the savings calculations is the mid-point between the 50th and 75th percentile: 62.5th percentile.
2. Tier 2 is the goal and focus for Programs to drive higher efficiency products into the market for market transformation. The efficacy floor for Tier 2 is derived from the 75th percentile of the Lighting Facts database and serves as an eligibility requirement. The measure case efficacy used in the savings calculations is the mid-point between the 75th and 100th percentile: 87.5th percentile.

**Delta Wattage Assumption (ΔW)**

Revision 3 of this workpaper continues to use the difference between the lowest wattage in the baseline and the highest wattage within the measure wattage range as per the disposition “2013-2014\_LightingRetrofit\_Disposition-13March15”. The mid-points of 62.5 and 87.5 percentiles of Lighting Facts database was used to calculate the LED measure case wattage. The efficacy floors set from reviewing the 50 and 75 percentile Lighting Facts database for each wattage bin was used to calculate the LED base case wattage. Delta watts are the difference between the blended base case of fluorescent and LED wattages and the measure case wattages.

Table 15 - LED High-Bay and Low-Bay Fixtures Base and Measure Wattages

|  |  |  |  |
| --- | --- | --- | --- |
| **Meas Code** | **Base Case Blended System Wattage** | **Meas Case Wattage** | **Delta Watts** |
| LT376 | 53 | 47.99 | 4.8 |
| LT377 | 81 | 70.99 | 10.0 |
| LT378 | 105 | 89.99 | 15.4 |
| LT379 | 143 | 124.99 | 17.6 |
| LT380 | 177 | 152.99 | 23.7 |
| LT381 | 224 | 186.99 | 36.9 |
| LT382 | 220 | 211.99 | 8.3 |
| LT383 | 262 | 245.99 | 16.1 |
| LT384 | 303 | 282.99 | 20.4 |
| LT385 | 53 | 41.99 | 10.8 |
| LT386 | 81 | 59.99 | 21.0 |
| LT387 | 105 | 81.99 | 23.4 |
| LT388 | 143 | 112.99 | 29.6 |
| LT389 | 177 | 139.99 | 36.7 |
| LT390 | 224 | 173.99 | 49.9 |
| LT391 | 220 | 193.99 | 26.3 |
| LT392 | 262 | 226.99 | 35.1 |
| LT393 | 303 | 261.99 | 41.4 |

**Calculation Method Process for Defining Measures**

Below in Table 12 is an example of the type of information that can be obtained from photometric data:

Table 16 Example of Photometric Data from “.ies” file

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Type** | **Fluorescent Lamp Qty** | **IES Fixture Lumens** | **Average ZL-HB 20-50** | **Lamp Lumen on .ies file** |
| Fluorescent | 2 | 5026 | 44.71% | 2,900 |

1. 75.4% fixture efficiency was calculated by examining the IES Fixture Lumens divided by the lamp lumens emitted with a ballast factor of 1.15.
2. The fixture lumens of 5,286 are calculated by multiplying the lamp quantity, the ballast factor, lamp lumens for HPT8, and fixture efficiency. This is the amount of lumens exiting the fixture.
3. The LED zonal lumen percentage is the amount of lumens in the 20-50 degree zone from nadir compared to the total lumen output of the fixture. This was calculated using an average of all of the DLC QPL entries. The value is 53.6%.

Table 17 Example Calculation of Fixture Efficiency and Fixture Lumens

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Type** | **Fluorescent Lamp Qty** | **Ballast Factor** | **HPT8 Lamp Lumens** | **Fixture Efficiency** | **Fixture Lumens** |
| Fluorescent | 2 | 1.15 | 3050 | 75.4% | 5,286 |

1. To calculate the equivalent total lumens of service for LED, the fixture lumens are multiplied by the ratio of fluorescent zonal lumen percentage to LED zonal lumen percentage.

Table 18 Equivalent LED Lumen Output for Similar Levels of Service

|  |  |  |  |
| --- | --- | --- | --- |
| **Fluor ZL %** | **LED ZL %** | **LED Lumens** | **Rounded lumen bin value** |
| 44.71% | 53.6% | 4407.4 | 4500 |

1. The initial LED lumens is rounded to 4500 lumens.
2. For a 3-lamp linear fluorescent fixture base case, the corresponding LED fixture output is 7264.3 lumens.
3. The lower lumen bin is chosen by picking the midpoint between the two LED lumens and rounding to the nearest hundred. 5,800 lumens is chosen as the dividing point between LED equivalent of the 2-lamp linear fluorescent fixture and 3-lamp linear fluorescent fixture base case.

Table 19 Lower Lumen Bin Measure Definition for the Next Measure Code

|  |  |  |  |
| --- | --- | --- | --- |
| **Type** | **Lamp Qty** | **LED Lumens** | **Rounded Lumen Lower Bin Value** |
| Fluorescent | 3 | 7264.3 | 5800 |

Note: For the wattage bin calculations of all other measures, see the savings calculation spreadsheet that accompanies this workpaper.

## 2.1 Electric Energy Savings Estimation Methodologies

The electric demand difference is the delta watts (**∆**Watts/fixture) between the electric demand of the base case fixture and the electric demand of the measure case fixture (average wattage of the measure wattage range). Annual energy savings is obtained by taking the delta watts and multiplying by the annual hours of operation. Annual Energy savings vary by market sector (building type) because of differences in operating hours and interactive effect multipliers. The annual operating hours and energy interactive effects for each segment were taken from DEER 2016 data.



***Annual Energy Savings:***



**Example**:

The following example calculation demonstrates the annual electric energy savings in kWh, for the Assembly building type for the “LED High/Low Bay: 110 LPW to <130 LPW, 0 to <48 W” measure:



For the savings of all other measures, see the calculation spreadsheet that accompanies this report.

## 2.2 Demand Reduction Estimation Methodologies

Demand reduction varies by market sector (building type) due to different HVAC interactive effects and coincident peak demand multipliers for each type of building type. The demand interactive effects, and coincident diversity factors (CDF) for each segment were taken from DEER 2016 data.

***Demand Reduction:***

**Example**:

The following example calculation demonstrates the peak demand reduction, kW, for the Assembly building type, for the “LED High/Low Bay: 110 LPW to <130 LPW, 0 to <48 W” measure:



For the savings of all other measures, see the calculation spreadsheet that accompanies this report.

## 2.3 Gas Energy Savings Estimation Methodologies

Gas estimates are entirely based on the estimated increased gas use through calculated interactive effects. This measure includes HVAC interactive effects impacts.

**∆Watts/fixture:** The demand difference (watts per fixture) is simply the difference between the electric demand of the base case fixture and the electric demand of the measure case fixture.

∆Watts/fixture = Base Case Watts/fixture - Measure Case Watts/fixture

***Annual Gas Savings:***



**Example**:

The following example calculation demonstrates the annual gas savings in therms, for the Assembly building type for the “LED High/Low Bay: 110 LPW to <130 LPW, 0 to <48 W” measure:



For the savings of all other measures, see the calculation spreadsheet that accompanies this report.

# 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 closest load shape chosen for this measure is the “PGE:DEER:Com:Indoor\_Non-CFL\_Ltg” load shape.

## 3.2 Measure Load Shapes

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

The closest load shape chosen for this measure is the PGE:DEER:Com:Indoor\_Non-CFL\_Ltg load shape. See the KEMA report [31] for a more thorough discussion regarding the load shapes for this measure.

# Section 4 Base Case & Measure Costs

The following data sources were used to develop the base case and measure costs:

* PG&E Program Data
  + Applications received from 1/1/2016 – 3/29/2018
* SCE Program Data
  + Applications received from late 2016 through end of 2017
* Navigant Data
  + Raw data from the LED Price Tracker
  + Values from the cost model
* Online pricing
  + Accessed April 2018

Note that all program costs were projected to 2018 costs using the annual percent decline value given in the Navigant 2015/2018 LED pricing studies.

* From 2017 cost data to project forward to 2018 (Source: Appendix E-30 in Navigant 2018 California LED Pricing Analysis)
  + High/Low Bay – use 7%
* From 2016 cost data to project forward to 2018 (Sources:  Table 3-7 in Navigant 2018 California LED Pricing Analysis, Table 3-7 Navigant 2018, Table A-4 Navigant 2015, Appendix E-30 Navigant 2018)
  + High Bay/Low Bay – Use 22% annual price decline to project to 2017, then use -13% to correct the projection for 2017, and then use 7% annual decline to project for 2018 cost
  + Note: -13% represents an additional decrease of 13% in the price

Due to cost challenges listed in Section 1.6.5 Cost Data Quality, three cost options were evaluated. For the interim solution, cost option 3 was agreed upon with Commission Staff and until further research can be completed for cost pair matching. The options are listed below along with the advantages and disadvantages associated with each option:

* **Option 1:** The base case LED cost is calculated using an average of the DLC Standard fixtures obtained from PG&E Program Data.
  1. **Advantages:** The incremental cost values are all positive except for 1 measure.
  2. **Disadvantages**: LED Cost efficacy does not mirror the savings LED base case efficacy. Several Tier 2 LED base case costs are higher than the measure case cost. The range of incremental measure cost values range from $4 to $18 per fixture for Tier 1 and - $11 to $281 per fixture for Tier 2.
* **Option 2:** The base case LED cost is calculated using an average of the fixtures with an efficacy at or below the DOE Lighting Facts 25th percentile obtained from PG&E Program Data.
  1. **Advantages:** The efficacy mirrors the savings base case efficacy.
  2. **Disadvantages:** Data points with these relatively low efficacies are from earlier program years (2016 and 2017) when DLC Standard technical requirements had lower qualification requirements for efficacy. Even with a projected annual percent decline percentage applied, the cost is still high and therefore, creating negative incremental cost values. In all but two measures, the LED base case cost is higher than the measure case cost.
* **Option 3:** Acknowledges the traditional cost logic model should be re-evaluated and as an interim solution, establishes the IMC based on the proposed rebates for the program
  1. **Advantages:** Minimizes disruption to program participants enabling existing measures to continue, reflecting baseline and savings adjustments
  2. **Disadvantages:** Lack of supporting data

## 4.1 Base Case Costs

**Option 1 and 2**

The base case is blended using the technology mix from Table 9 – Base Case Technology Percentage Mix.

**Linear Fluorescent:** Costs for linear fluorescent came from online fixture vendors, and labor costs were calculated using WO017[[11]](#endnote-11). The labor cost used was $187.14.

**LED:** Costs for base case LED came from PG&E Program Data, and labor costs were assumed to be the same as linear fluorescent. The cost used was $187.14.

**Option 3**

The base case cost is set temporarily at $0.

## 4.2 Measure Case Costs

**Option 1 and 2**

The measure material costs were based on an average of PG&E program data depending on the DLC reported wattage. These prices were compared to SCE program data and to the Navigant pricing.

The quantity of fixture sales in each application (for downstream program data) is not factored in the weighted average. Instead, weighted average is done based on the number of price points recorded in each of the measure range.

The labor cost is assumed to be the same as the base case labor cost.

**Option 3**

The measure case cost is set equal to the incremental measure costs.

## Incremental & Full Measure Costs

**Option 1 and 2**

Establishing prices for each measure code presented a challenge, given the wide range of price, quality, and product characteristic in the high/low bay lighting market. The general approach used was to gather prices widely and look at overall trends in price.

**Option 3**

The incremental measure cost is set to 110% of the rebate amount.

Table 20 - Incremental and Full 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

Please refer to the savings spreadsheet for detailed base case and measure case cost information.

# Attachments

Attachment 1 – ROB vs NC.xlsx

Attachment 2 – ProgramCostData2016.01.01-2018.03.29\_cleaned.xlsx

Attachment 3 – SCE High Bay Pricing.xlsx

Attachment 4 – LF\_Efficacy and Output\_20180411.xlsx

Attachment 5 - HighLowBay-InterimSolution\_20180411.xlsx

PGECOLTG178 R3 EDReports\_4-11-2018.xlsx

# References

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    Also using data from *LRC Lighting Answers: Low-wattage Metal Halide Lamps*, table 2 and manufacturer website data. [↑](#footnote-ref-2)
11. 2010-2012 WO017 Ex Ante Measure Cost Study Final Report. Submitted by: Itron, Inc. May 27, 2014. Table 4-6. Page 4-12. *HID to T5 Fixtures high bay, lift accessible.* [↑](#endnote-ref-11)