California LED Pricing Analysis

Final Report

Prepared for:

Southern California Edison, Pacific Gas and Electric Company, and Sempra Energy

Submitted by:
Navigant Consulting, Inc.
1200 19th Street NW
Suite 700
Washington, D.C. 20036

202.973.2400
navigant.com

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EXECUTIVE SUMMARY

Navigant Consulting, Inc. (Navigant) was contracted by Southern California Edison (SCE), on behalf of California's electric investor owned utilities (IOUs), to help understand pricing trends in the light-emitting diode (LED) lighting market and their implications on the IOU's program. Due to requirements set forth by the California Public Utilities Commission (CPUC), the LED price analysis needed to include only products that are DesignLights Consortium (DLC) or ENERGY STAR® qualified. Given this directive, the Study was designed around five key research objectives:

1. **Current LED Pricing** – Identify the range of current prices for DLC and ENERGY STAR qualified priority LED products.
2. **CA IOU Program Data and Web-based Price Comparison** – Assess the relationship between online and CA IOU pre-rebated prices (provided by SCE and PG&E) for high priority non-residential LED products, and determine how this could be utilized for forecasting purposes.
3. **Factors that Significantly Influence LED Price** – Conduct a multiple variable regression to determine the correlation between various product specifications and price, focusing on metrics including lumen output, efficacy, CCT, CRI, dimmability, DLC qualification status, and manufacturer.
4. **Incremental Cost** – Develop incremental cost estimates for priority LED products relative to their baseline technologies.
5. **Projected LED Pricing** – Determine how, and at what rate, LED price ranges are anticipated to change as the market becomes more mature, looking forward 3 years and 5 years.

Table ES – 1 shows final list of priority product categories agreed upon by IOUs, as well as their dimensions and relative mapping to DLC or ENERGY STAR product eligibility.

Table ES - 1 LED Priority Product Categories

#	Priority Product Categories	Dimensions (if applicable)	Relevant DLC and ENERGY STAR Categories
1	Area/Roadway and High Wattage Retrofits		Relates to Outdoor Pole/ Arm-mounted Area and Roadway Luminaires (fixtures and retrofit kits) (DLC)
2	Downlight Fixture	Diameters 2” - 10”	Relates to Downlights: Recessed, Surface, Pendant or Retrofits (ENERGY STAR)
3	Recessed Troffer/Panel	1’x4’	Relates to Troffer 1x4, 2x4 and 2x2 Luminaires for Ambient Lighting of Interior Commercial Spaces (DLC)
4	Recessed Troffer/Panel	2’x4’	
5	Recessed Troffer/Panel	2’x2’	
6	Recessed Troffer Retrofit	2’x4’	Relates to Integrated and Linear Style and Retrofit Kits for 2x4 and 2x2 Luminaires for Ambient Lighting of Interior Commercial Spaces (DLC)
7	Recessed Troffer Retrofit	2’x2’	
8	Wall Pack		Relates to Outdoor Wall-mounted Area Luminaires (fixtures and retrofit kits) (DLC)
9	Canopy		Relates to Fuel Pump Canopy Luminaires (fixtures and retrofit kits) and to Parking Garage Luminaires (fixtures and retrofit kits) (DLC)
10	Parking Garage		Relates to Parking Garage Luminaires (fixtures and retrofit kits) (DLC)
11	Parking Lot		Relates to Outdoor Pole/ Arm-mounted Area and Roadway Luminaires (DLC)
12	Strip Light		Relates to Direct and Indirect Linear Ambient Luminaires (DLC)
13	High/Low Bay		Relates to High-Bay Luminaires (fixtures and retrofit kits), Low-Bay Luminaires (fixtures and retrofit kits) and High-Bay Aisle Luminaires (fixtures) (DLC)
14	Indoor Decorative		Includes Pendants, Kitchen Island Light, Ceiling Flush Mount, Decorative Ceiling Light, Flush Mount, Drum Lights (fixtures and retrofit kits) (ENERGY STAR)
15	Outdoor Decorative		Relates to Outdoor Pole/Arm-mounted Decorative Luminaires (fixtures and retrofit kits) (DLC)

The pricing and performance characteristics for DLC or ENERGY STAR qualified products were analyzed leveraging Navigant Research’s LED Price Tracker, which utilizes web-scraping software to collect data on product pricing and specifications. The following sections of the executive summary describe the key findings and results of the LED pricing analysis by research objective.

ES 1. Current LED Pricing

Using the LBNL 25th percentile price estimation method, the typical LED purchase price for each of the 15 priority product categories was determined for 2016 Q4 (data collected in December of 2016) and 2017 Q2 (data collected in June of 2017). Price estimates for this research objective are representative of LED products that are DLC or ENERGY STAR qualified. Key findings included:

- From 2016 Q4 to 2017 Q2, new DLC technical requirements[1] were implemented that changed the minimum efficacy threshold across all DLC product categories. Despite the increase in the

[1] DLC, “Technical Requirements Version 4.2”, Released April 28, 2017. https://www.designlights.org/default/assets/File/SSL/DLC_Technical-Requirements-V4-2.pdf

minimum efficacy for DLC qualification, the results suggest that this increase did not have a strong influence on the price of DLC qualified products.

- On average, there was a 21% decrease in price across all product categories from 2016 Q4 to 2017 Q2.
- Navigant conducted a statistical significance test to determine if there was a statistically significant price difference between DLC qualified LED products, and non-DLC LED products (which were tagged as not DLC qualified based on web-scraped data and manual verification) but met the DLC technical requirements for lumen output and efficacy. The results showed that there is no statistically significant price difference between DLC qualified products and non-DLC qualified products that still meet the DLC lumen and efficacy requirements. This allowed Navigant to utilize a larger sample of data in the analysis, so long as the LED products met the DLC technical requirements for lumen output and efficacy.
- Navigant conducted another statistical significance test to determine if there was a statistically significant price difference between LED products that meet the DLC Standard versus DLC Premium qualification. Overall the analysis showed that there is not a strong statistical difference in price between DLC Standard and Premium qualifying products.
- Continued monitoring and analysis of LED price trends will be important as the market and technology offering continues to mature and develop, thereby affecting LED product prices.

ES 2. CA IOU Program and Web-based Price Comparison

Navigant compared the estimated DLC and ENERGY STAR qualified pricing ranges to pre-incentivized sale-weighted pricing data provided by SCE and PG&E for the following product categories: High/Low Bay, Downlight, Recessed Troffer/Panel, and Recessed Troffer/Panel Retrofit. Key findings included:

- The IOU program sales data aligns well within the range of web-based LED pricing data for the product categories High/Low Bay, Downlight, Recessed Troffer/Panel, and Recessed Troffer/Panel Retrofits.

- The web-based LED price range estimates are representative of DLC and ENERGY STAR qualified purchase price for the evaluated priority product categories.

ES 3. Factors that Significantly Influence LED Price

Navigant conducted a multiple regression analysis to assess which factors affect LED luminaire price. To do so, a multiple regression of lumen output, CCT, CRI, dimmability, DLC qualification (ENERGY STAR in the case of the Downlight and Outdoor Decorative categories), and manufacturer were tested as variables that influence price. Key findings included:

- The biggest driver of LED luminaire price is lumen output, followed by manufacturer, DLC qualification, and CRI.
- There were no product categories, for either indoor and outdoor, that had CCT, dimmability, or efficacy as the most significant price determining characteristic.
- These results revealed that efficacy, which is often seen in industry as a price driver, is not measurably correlated to purchase price of LED luminaire products.

- A detailed investigation was also conducted to determine if the results of the multiple regression analysis hold under more controlled datasets – specifically, controlling for retailer/distributor and manufacturer. However, the controlled regression analysis showed that lumen output is still the most significant LED price determining characteristic, while efficacy does not correlate significantly to price.
- Although the analysis found lumen output is the most significant price determining characteristic, lumen output can be interchanged with wattage in the multiple regression analysis. While wattage and lumen output were not evaluated together due to multi-collinearity errors, the results must be interpreted to indicate that wattage could be the most significant price determining characteristic of an LED product, rather than lumen output.

ES 4. Incremental Cost Analysis

The incremental cost calculation describes the additional first cost incurred by purchasing an LED product over a baseline system. This Study evaluated the incremental cost of purchasing an LED product by comparing the typical price of LED retrofit kits and luminaires in each priority product category to the price of an equivalent baseline technology lighting system. Navigant evaluated incremental cost both with and without baseline fixture costs, in order to represent two distinct scenarios:

1. **Luminaire Market:** For the luminaire market incremental cost, the baseline system was assumed to comprise a lamp(s), ballast, reflector/diffusor, and the housing. Pricing for each of these system components was included in the baseline system cost. The incremental cost was then calculated relative to a complete LED luminaire. This scenario represented the new construction market where owners and facility managers are comparing technology options equally. It is important to note that this represents a small proportion of total installations.[2]
2. **Replacement Market:** For the replacement market, the baseline system comprised of just a lamp(s) and ballast. The replacement market baseline system does not include reflector/diffusors or housing. This scenario represented the replacement on lamp or ballast burn-out where owners and facility managers are not comparing technology options equally due to the long lifetime of commercial baseline fixtures (above 100,000 hours). This represents a relatively larger proportion of total installations.[3]

Key findings included:

- The incremental costs of DLC and ENERGY STAR qualified LED products to complete baseline luminaire systems (lamp(s), ballast, reflector/diffusor and fixture) for certain priority products, particularly in the outdoor groups, were negative. This indicates that LED products were sometimes less expensive than, or comparable to, baseline systems.

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[2] Between 2015 and 2017, new construction of commercial floorspace is estimated to grow at a rate of approximately 1.1% per year according to the Energy Information Administration's Annual Energy Outlook 2017 Table: Commercial Sector Key Indicators and Consumption, https://www.eia.gov/outlooks/aeo/data/browser/#/?id=5-AEO2017&cases=ref2017&sourcekey=0. In addition, the renovation cycle for commercial end-uses varies between 7 and 22 years according to a study conducted by Boston Consulting Group: http://image-src.bcg.com/Images/BCG-How-to-Win-in-a-Transforming-Lighting-Industry-Nov-2015_tcm79-88535.pdf

[3] In contrast to new construction and the renovation of commercial spaces, the lifecycle of baseline lighting products is much shorter. Based on lifetime data collected from product catalogs, the lifetime range in commercial end uses for incandescent and halogen products is 0.6 to 1.2 years, for compact fluorescent is 1.4 to 1.7 years, for linear fluorescent is 2.2 to 5.1 years and for high intensity discharge is 3.7 to 6.1 years. Commercial operating hour assumptions provided in the Department for Energy's 2010 U.S. Lighting Market Characterization (Table 4.6) report were used to develop these lifetime ranges: https://www1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf

- However, comparing fixture-to-fixture represents a small proportion of the market, accounting primarily for new construction installations. The replacement market, in which a complete DLC and ENERGY STAR qualified LED product is compared to a baseline lamp(s) and ballast, yields high incremental costs in every product category and represents a more common consumer purchasing scenario.

ES 5. LED Luminaire Price Projections

Navigant created 5-year LED price projections reflecting the trajectory of DLC and ENERGY STAR qualified LED luminaires. The results showed that in each of the 15 priority product categories, these prices are expected to continue their decline in the 5-year time horizon from 2017 to 2022. Key findings included:

- The price of DLC and ENERGY STAR qualified LED products varies significantly across the 15 priority product categories evaluated in this Study, and in 2017 Q2 ranged from $44 per luminaire for downlights to $249 per luminaire for parking lots.
- Despite changes in DLC or ENERGY STAR technical requirements and other short-term market forces, overall, across all 15 priority product categories, the prices of these LED products are expected to decline 39% on average from 2017 to 2022.
- The overall rate of price decline for LED products will decrease as the market share for LED products grow. Averaging across all 15 priority product categories, the annual rate of decline is 9% per year from 2017 to 2020. This rate of decline decreases to an annual rate of 8% from 2020 to 2022.

ES 6. Limitations and Challenges

As LED technology continues to mature, there are many factors that influence LED product price. As such, Navigant has identified the following limitations and challenges of this Study.

- Sale-weighted LED pricing would be the best predictor of typical consumer purchase price, however, due to limited availability of such data this Study is largely based on online retailer and distributor web-scraped data, allowing Navigant to utilize large samples of LED pricing. However, using methodologies described by Lawrence Berkeley National Laboratory (see Section 2.1.3), this Study aims to use the web-scraped data to estimate typical consumer purchase prices.
- This Study does not assess the potential impact of IOUs' rebate programs on overall LED product prices. Many commercial consumers in the California market outfit their LED lighting systems through IOU incentive programs, which can have a large impact on the actual realized cost to the consumer. However, this Study did not analyze how and to what extent such rebate programs effect the overall LED market price.
- The LED price projections of this Study are provided for 15 priority LED product categories. However, the Study does not analyze price projections in wattage bins or lumen bins within each product category. The prices of LED products are significantly correlated to both lumen output and wattage; therefore, price projections may differ if analyzed by lumen or wattage bins.
- Some luminaire characteristics, such as lumen output or CCT, are modeled as continuous variables in the Study, particularly in the analysis investigating factors that influence LED price. Modeling these characteristics as continuous variables allows for the most intuitive interpretation

of the results. However, manufacturers often provide product lines that have step-wise lumen output and CCT values, which cause some of the variables to behave categorically, rather than as a continuous variable.

- Analyzing lumen output, wattage, and efficacy in the same statistical model presents challenges due to the relationship between these variables. Efficacy is a calculated metric that equates to lumen output divided by wattage. Therefore, these variables are not independent, which could have implications when comparing their influence on LED product price.

ES 7. Recommendations

Navigant has identified the following recommendations for consideration by the IOUs and other stakeholders:

- The results of the statistical tests discussed in Section ES 1 showed that there is no statistically significant price difference between DLC qualified products and non-DLC qualified products that still meet the DLC lumen and efficacy requirements. DLC's Technical Requirements continue to evolve and change over time, with new requirements and specification parameters being implemented periodically. IOUs should monitor and examine if DLC qualification continues to minimally influence LED price as more LED products continue to update to meet the newer DLC Technical Requirements v4.2 and subsequent revisions. This is a particularly important step in maintaining the underlying inputs into the current LED price projections for 2017 to 2022.
- The Study results that are discussed in Section ES 3 demonstrated that there is no correlation between the typical customer purchase price[4] of an LED luminaire and the rated efficacy of the product. Based on these findings, IOUs should carefully consider changes to the current structure of incentive programs. Since the Study results show that price and efficacy are not correlated, this indicates that the price of a low and high efficacy LED product could very well be the same. Therefore, having tiered incentives for LEDs would then make high efficacy products cheaper for the customer than low efficacy products. While this is beneficial from an energy savings perspective, it could also lead to the additional incentive dollars being used towards higher lumen output products (thereby increasing energy use) or more premium manufacturers. The Study shows that both of these factors do lead to higher LED pricing. To control for the possible "up-sell" to a higher lumen output LED product, it may be useful to tier rebate measures by lumen output and efficacy.
- Currently, IOU lighting programs are required to compare fixture-to-fixture price differences when structuring incentives. Based on the results discussed in Section ES 4, IOUs should carefully consider any changes to their incentive program from the traditional fixture-to-fixture method to potentially include more common consumer purchasing scenarios.
- In light of the price projections in Section ES 5, IOUs should continue to monitor LED prices annually. The current projected LED prices from 2017 to 2022 will need to be updated to account for changes to the market, as well as any technological or significant qualification changes from DLC and ENERGY STAR.

[4] The goal of this Study was to evaluate the typical price of LED products purchased through commercial lighting sales channels. Web-scraped data from online retailers and distributors was used to approximate the typical commercial lighting purchase price. Please see section 2.1.3 for a discussion of how web-scraped pricing data has been used to estimate typical customer purchase price.

- As discussed in the DOE Solid-State Lighting (SSL) Program's "2017 Suggested Research Topics Supplement: Technology and Market Context" report,[5] SSL is creating an opportunity for the transition of lighting infrastructure to inherently controllable systems. In particular, connected lighting systems with controls and sensors can provide significant energy savings. As LED technology continues to mature, achieving energy savings from lighting will rely on the integration of connected LED lighting systems. IOU lighting programs should begin monitoring the price and performance of networked and connected LED lighting to help ensure that the energy savings potential of these systems is leveraged effectively now and in the future.

[5] "2017 Suggested Research Topics Supplement: Technology and Market Context", U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, September 2017. https://energy.gov/sites/prod/files/2017/09/f37/ssl_supplement_suggested-topics_sep2017_0.pdf

1. INTRODUCTION

Due to the emergence of light-emitting diode (LED) lighting technology, the lighting industry has experienced dramatic changes over the past decade. In response to the continuing evolution of LED lighting technology, Navigant Consulting, Inc. (Navigant) was contracted by Southern California Edison (SCE), on behalf of California's electric investor owned utilities (IOUs), to revisit the pricing analysis conducted as part of the California LED Workpaper Update Study completed in 2015.[6] LED luminaire prices have been declining rapidly, but this rate of decline is constantly changing and warranted an updated assessment to determine how LED pricing has progressed. Furthermore, a new key focus area for this updated Study was to determine the nature of LED pricing for DesignLights Consortium (DLC) and ENERGY STAR® qualified LED products.

1.1 Study Objectives

The objective of this Study was to assess pricing trends in the LED lighting market and their implications for the IOU's programs. Navigant and IOU stakeholders collaborated to determine the primary Study objectives and priority product categories of LED lighting that were to be included. The Study was designed to address the following five key research objectives:

6. **Current LED Pricing** – Identify the range of current prices for DLC and ENERGY STAR qualified priority LED products.
7. **CA IOU Program Data and Web-based Price Comparison** – Assess the relationship between online and CA IOU pre-rebated prices (provided by SCE and PG&E) for high priority non-residential LED products, and determine how this could be utilized for forecasting purposes.
8. **Factors that Significantly Influence LED Price** – Conduct a multiple variable regression to determine the correlation between various product specifications and price, focusing on metrics including lumen output, efficacy, CCT, CRI, dimmability, DLC qualification status, and manufacturer.
9. **Incremental Cost** – Develop incremental cost estimates for priority LED products relative to their baseline technologies.
10. **Projected LED Pricing** – Determine how, and at what rate, LED price ranges are anticipated to change as the market becomes more mature, looking forward 3 years and 5 years.

Table 1-1 shows the final list of priority product categories agreed upon by IOUs, as well as their dimensions and relative mapping to DLC and ENERGY STAR eligible product categories. This comprehensive list of LED priority products was analyzed to assess LED pricing trends and how LED luminaire characteristics relate to price, and their implications for IOU lighting programs. Because this pricing analysis is focused on DLC and ENERGY STAR qualified LED luminaires, the price analyses are reflective DLC and ENERGY STAR products, and may not be representative of the entire LED luminaire market.

[6] "California LED Workpaper Update Study", Navigant Consulting, Inc., 2015

Table 1-1 LED Priority Product Categories

#	Priority Product Categories	Dimensions (if applicable)	Relevant DLC and ENERGY STAR Categories
1	Area/Roadway and High Wattage Retrofits		Relates to Outdoor Pole/ Arm-mounted Area and Roadway Luminaires (fixtures and retrofit kits) (DLC)
2	Downlight Fixture	Diameters 2" - 10"	Relates to Downlights: Recessed, Surface, Pendant or Retrofits (ENERGY STAR)
3	Recessed Troffer/Panel	1'x4'	Relates to Troffer 1x4, 2x4 and 2x2 Luminaires for Ambient Lighting of Interior Commercial Spaces (DLC)
4	Recessed Troffer/Panel	2'x4'	
5	Recessed Troffer/Panel	2'x2'	
6	Recessed Troffer Retrofit	2'x4'	Relates to Integrated and Linear Style and Retrofit Kits for 2x4 and 2x2 Luminaires for Ambient Lighting of Interior Commercial Spaces (DLC)
7	Recessed Troffer Retrofit	2'x2'	
8	Wall Pack		Relates to Outdoor Wall-mounted Area Luminaires (fixtures and retrofit kits) (DLC)
9	Canopy		Relates to Fuel Pump Canopy Luminaires (fixtures and retrofit kits) and to Parking Garage Luminaires (fixtures and retrofit kits) (DLC)
10	Parking Garage		Relates to Parking Garage Luminaires (fixtures and retrofit kits) (DLC)
11	Parking Lot		Relates to Outdoor Pole/ Arm-mounted Area and Roadway Luminaires (DLC)
12	Strip Light		Relates to Direct and Indirect Linear Ambient Luminaires (DLC)
13	High/Low Bay		Relates to High-Bay Luminaires (fixtures and retrofit kits), Low-Bay Luminaires (fixtures and retrofit kits) and High-Bay Aisle Luminaires (fixtures) (DLC)
14	Indoor Decorative		Includes Pendants, Kitchen Island Light, Ceiling Flush Mount, Decorative Ceiling Light, Flush Mount, Drum Lights (fixtures and retrofit kits) (ENERGY STAR)
15	Outdoor Decorative		Relates to Outdoor Pole/Arm-mounted Decorative Luminaires (fixtures and retrofit kits) (DLC)

1.2 Data Collection

In order to evaluate the objectives of this Study, Navigant relied on the following data sources:

1. **Web-based LED luminaire and baseline lighting price and specification data from online retailers and distributors;**

   The web-based LED luminaire data served as the main data source for the Study, and was collected using Navigant Research's LED Price Tracker, which utilizes web-scraping software to collect data on product pricing and specifications. Two intervals of web-based data were collected, the first interval was collected in December 2016 (hereafter referred to as 2016 Q4), and the second interval was collected in June 2017 (hereafter referred to as 2017 Q2). In addition, one interval of baseline product data was collected in 2016 Q4. Only one interval of baseline data was collected as pricing for these products is more stable and only recent data was needed, rather than trends, to establish incremental costs.

2. **SCE and PG&E pre-incentivized LED light sales data;**

Similar to the previous 2015 California LED Workpaper Update Study, Navigant compared the LED web-based pricing data discussed above, to LED sales and pricing data provided by the SCE and PG&E non-residential lighting programs. Since the SCE and PG&E non-residential lighting program data included information on purchase price and quantity, this enabled the estimation of a sales-weighted price. SCE provided data related to the Low/High Bay category, while PG&E provided data for the Low/High Bay, Downlights, Recessed Troffer/Panel and Recessed Troffer/Panel Retrofit categories.

3. **Phone interviews with manufacturers; and**

   Navigant conducted brief interviews with manufacturers to determine what portion of their product offerings are DLC qualified. Specifically, Navigant completed interviews with 8 large and medium sized manufacturers. These included Hubbell Lighting, Eaton, RAB Lighting, GE Lighting, Philips, Acuity, Sylvania and Cree.

4. **Manufacturer product catalog data.**

   In addition to interviews, Navigant leveraged the data provided in manufacturer product catalogs to investigate the portion of product offerings that are DLC qualified for small California-focused manufacturers. The manufacturers included in this part of the Study consisted of James Industries, NaturaLED, Aurio Lighting, Sun & Stars Lighting, and Shenzhen Syhdee Co. Each of these manufacturers was selected based on the volume of LED program sales in SCE’s territory, as well as the relevance of their product offerings to this Study (i.e. overlap with the determined priority product categories).

Discussion of how each of these data sources was used to evaluate the Study objectives is provided in the following Section 2 of this report.

2. METHODOLOGY

The goal of this Study was to analyze pricing for DLC or ENERGY STAR (where applicable)[7] qualified products. However, to leverage the web-scraped LED price and specification data collected by Navigant Research's LED Price Tracker, it was necessary to organize the data to accurately simulate representative non-residential LED pricing within California. This 3-step process is illustrated below in Figure 2-1.

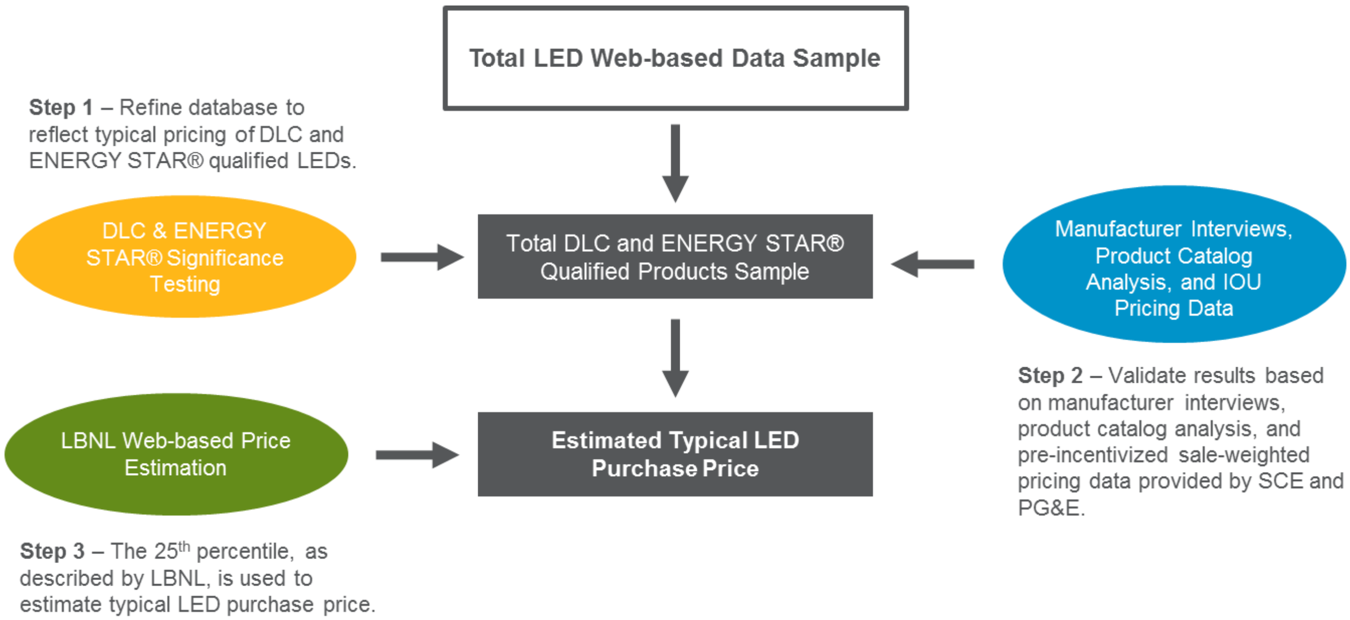

Figure 2-1 Methodology for Estimating Typical LED Purchase Price from Web-based Data

Step 1 – Starting from the total sample of LED web-based data, Navigant refined the data set to only include LED luminaires that are known to be DLC or ENERGY STAR qualified, as well as those that simply meet the technical requirements of DLC, but may or may not be qualified. Based on the significance testing discussed in the following Section 2.1.1, this was determined to be a reasonable assumption for estimating the price of DLC or ENERGY STAR qualified products.

Step 2 – Navigant interviewed large and medium sized manufacturers, and reviewed product catalogs for small manufacturers to determine the portion of product offerings that are DLC qualified. These estimates of DLC qualification rates were compared to the percentage of products in Navigant's database that were refined based on Step 1 and included in the pricing analysis (i.e. LED luminaires that are known to be DLC qualified or ENERGY STAR certified, as well as those that simply meet the technical requirements of DLC, but may or may not be qualified). This methodology is described in Section 2.1.2.

In addition, similar to the previous 2015 California LED Workpaper Update Study, the team also compared the web-based pricing ranges to LED sales and pricing data provided by the SCE and PG&E non-residential lighting programs. Since the SCE and PG&E lighting program data includes information on purchase price and quantity, this enabled the estimation of a sales-weighted price. The sales-weighted

[7] ENERGY STAR qualification is only relevant for LED priority product categories, "Downlight Fixtures" and "Outdoor Decorative"

price was then compared to the web-based ranges, and served as an indicator of the typical purchase price for LED products in California.

Step 3 – Navigant used the same methodology to estimate typical purchase price as we used in the previous 2015 California LED Workpaper Update Study. As described in Section 2.1.3, we continued referencing the 2014 Lawrence Berkeley National Laboratory (LBNL) report which recommends utilizing the 25^{th} percentile of web-based pricing data for characterizing typical purchase price. A discussion of the rationale for using the 25^{th} percentile rather than the mean or median is provided in Section 2.1.3.

After the completion of the 3-step process for refining the LED web-based data, Navigant completed each of the research objectives using the methodology described in Sections 2.2 through 2.5.

2.1 Refinement of the LED Web-based Data

2.1.1 Total DLC and ENERGY STAR Qualified Products Sample

Due to requirements set forth by the California Public Utilities Commission (CPUC), the LED price analysis needed to include products that are DLC or ENERGY STAR qualified. For ENERGY STAR, the only applicable priority product categories were "Downlight Fixture" and "Outdoor Decorative." Furthermore, Navigant's web-scraped database already contains ENERGY STAR qualification data, therefore, this data field was used to filter products in this analysis. However, using only DLC qualified products for the LED pricing analysis was problematic. Retailer and distributor reporting of DLC qualification status is limited and often inconsistent. In addition, while both the DLC qualified product list (QPL) and Navigant's web-scraped database capture data on product model numbers, using a cross referencing strategy based on product model numbers delivered minimal matches between the two data sets. This is due to inconsistencies in model numbers used to identify products in the DLC database.

In order to leverage Navigant's web-scraped pricing data and provide a meaningful analysis, the statewide team agreed to use significance testing (also called hypothesis testing) to determine whether there is a significant difference in pricing between DLC qualified products and those that meet the DLC technical requirements but may not be officially "DLC qualified." Due to time and budgetary constraints of the project, the significance test for DLC qualification was done only using the 2016 Q4 LED web-based data. Navigant conducted significance testing on all priority product categories to determine whether there was a significant difference in pricing between these two groups:

DLC Qualified – These are LED products within the priority product categories that were known to be DLC qualified based on data collected through Navigant's LED Price Tracker, as well as manual verification of manufacturer product specification sheets.

Non-DLC Qualified – These are LED products within the priority product categories that were not tagged as DLC-qualified based on data collected through Navigant's LED Price Tracker, or based on manual verification of manufacturer product specification sheets. However, these "non-DLC qualified products" met the lumen and efficacy requirements detailed in the DLC's Technical Requirements Version 3.1[8] (which was the active DLC specification as of 2016 Q4).

[8] DLC, "Technical Requirements Version 3.1," Released November 20, 2015. https://www.designlights.org/solid-state-lighting/qualification-requirements/past-technical-requirements/version-3-1-released-november-20-2015/

Navigant only included LED products that met the DLC's technical requirements within the non-DLC qualified group to ensure that filtering our database by the DLC lumens and efficacy minimums would be sufficient to simulate the typical pricing for DLC qualified products.

After ensuring an accurate accounting of the DLC qualified and non-DLC qualified definitions provided above, Navigant leveraged Excel's built in t-test functionality to test each priority product category, using an α (level of statistical significance) of 0.05. The details of the statistical methodology can be found in Appendix A.

For the outdoor priority product categories (Area/Roadway, Wall Pack, Canopy, Parking Garage, Parking Lot), Navigant mapped and filtered the products based on lumens and efficacy as specified by the DLC requirements groups called Outdoor Low Output, Outdoor Mid Output, and Outdoor High Output. Each of these three DLC requirement groups within the priority product category was tested separately to ensure that the significance test was not influenced by large variations in lumens. A similar methodology was applied to High/Low Bay products.

For the Outdoor Decorative and Downlights product categories, we conducted significance tests using ENERGY STAR qualification instead of DLC qualification, because DLC does not offer qualifications for these product categories. The same methodology as described above was applied to determine if there was a significant price difference between ENERGY STAR products and non-ENERGY STAR products that meet the same technical requirements. Lastly, we did not conduct hypothesis testing for the Indoor Decorative product categories because this category is not eligible for DLC or ENERGY STAR certification.[9]

The results of the analysis are shown in Table 2-1.

[9] See list of ineligible specialty products: https://www.designlights.org/solid-state-lighting/qualification-requirements/product-eligibility/specialty-products/

Table 2-1 DLC vs non-DLC and ENERGY STAR vs non-ENERGY STAR Price Difference Significance Test Results by Priority Product Category

Priority Product Categories	DLC or ENERGY STAR Technical Requirement Applications	Price Difference
Area/Roadway and High Wattage Retrofits	Outdoor - Low Output	Not Significant
	Outdoor - Mid Output	
	Outdoor - High Output	
Downlight Fixture	Downlights* (ENERGY STAR)	Not Significant
Recessed Troffer/Panel 1x4	Indoor - Troffer	Not Significant
Recessed Troffer/Panel 2x4	Indoor - Troffer	Not Significant
Recessed Troffer/Panel 2x2	Indoor - Troffer	Not Significant
Recessed Troffer Retrofit 2x4	Indoor Retrofit Kit - Troffer	Not Significant
Recessed Troffer Retrofit 2x2	Indoor Retrofit Kit - Troffer	Not Significant
Wall Pack	Outdoor - Low Output	Not Significant
	Outdoor - Mid Output	N/A**
	Outdoor - High Output	Not Significant
Canopy	Outdoor - Low Output	Not Significant
	Outdoor - Mid Output	N/A**
	Outdoor - High Output	Not Significant
Parking Garage	Outdoor - Low Output	Not Significant
	Outdoor - Mid Output	N/A**
	Outdoor - High Output	Not Significant
Parking Lot	Outdoor - Low Output	Not Significant
	Outdoor - Mid Output	
	Outdoor - High Output	
Strip Light	Indoor – Linear Ambient	Not Significant
High/Low Bay	Indoor – High Bay, Lower Range	Not Significant
	Indoor – High Bay, Higher Range	
Outdoor Decorative	Outdoor-, Wall-, Porch-, Post-mounted and Security Luminaires* (ENERGY STAR)	Significant

*Downlights and Outdoor Decorative category used ENERGY STAR qualification and technical requirements instead of DLC.

**These groups did not have enough data to run the significance test. This was primarily due to every product in our database being DLC qualified in these categories.

For DLC qualification, the results show that every product category yielded a statistically insignificant price difference between DLC qualified products and non-DLC qualified products that still meet the DLC lumen and efficacy requirements. Therefore, Navigant used all products in the LED database for the price analysis as long as they met the relevant DLC Technical Requirements as of the date when the data was obtained (i.e. data points on and after April 1, 2017 were subject to Technical Requirements Version 4.2; data points between March 25, 2016 and March 31, 2017 were subject to Technical Requirements Version 3.1, and data points between January 1, 2015 and March 24, 2016 were subject to Technical Requirements Version 2.1). Below Figure 2-2 details the various historical DLC specification versions and their effective dates, as well as Navigant's web-scraping data collection periods going back to March 2011.

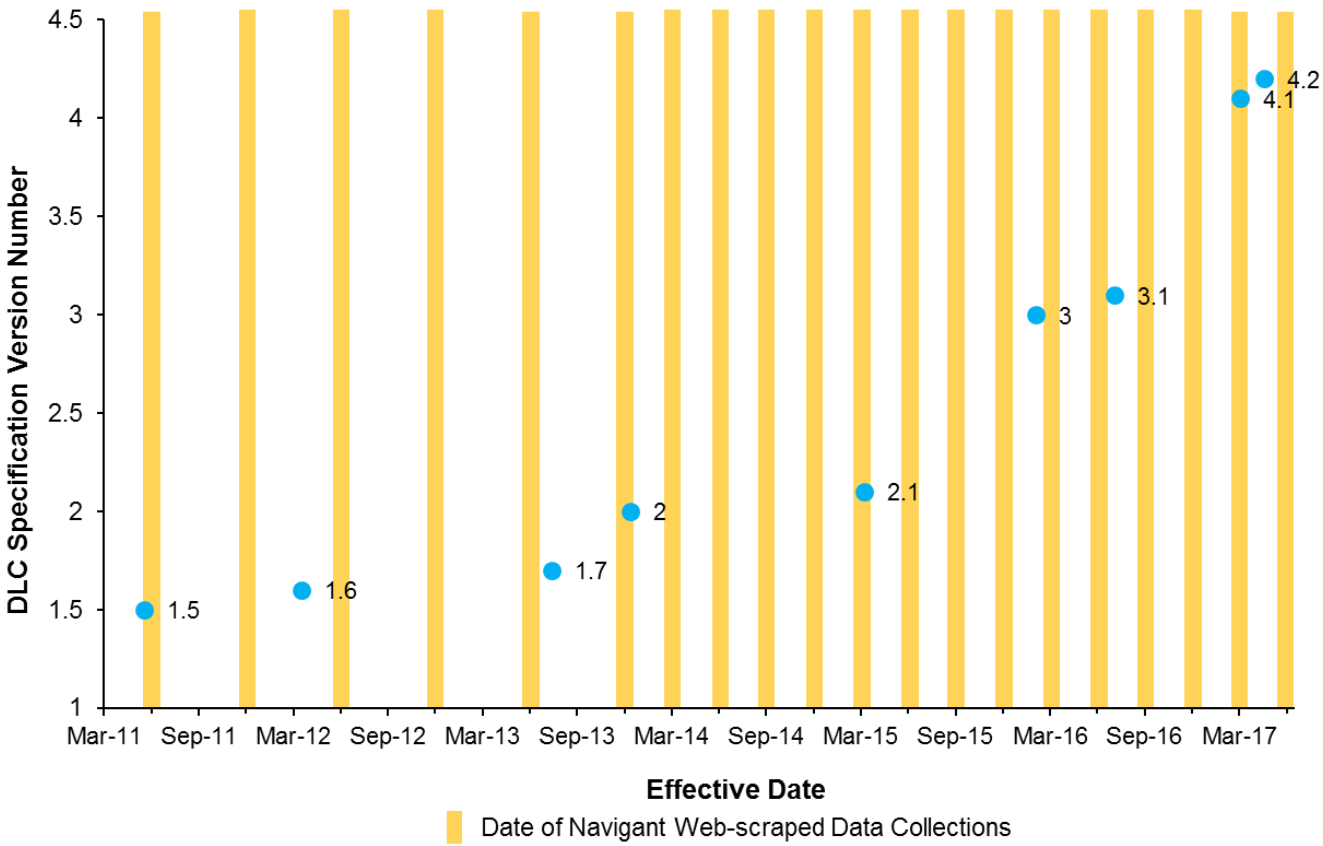

Figure 2-2 Historical DLC Specification Effective Dates and Navigant's Web-scraping Schedule

In the Strip Lights category, the relatively low efficacy allowance for DLC qualification resulted in a significant range in product performance. The efficacy range for all potential qualifying Strip Light products (DLC and non-DLC) that meet the technical requirements ranged from 86 to 206 lumens per watt (lm/W). In this case, the two samples were further refined to produce a comparable dataset. Products in both categories were filtered to within ½ standard deviation from the mean. Removing outliers from the dataset allowed for an accurate price comparison between the two groups. The removal of outliers in the dataset resulted in an insignificant price difference.

For ENERGY STAR certification, Outdoor Decorative products showed a statistically significant price difference between ENERGY STAR certified products and products that meet the ENERGY STAR technical requirements, but whose ENERGY STAR certification status is unknown. In light of the results of the significance test, Navigant filtered and used only ENERGY STAR qualified products for Outdoor Decorative and Downlight products in the price analysis.

The statistical analysis on the LED web-based data showed that among the 2016 Q4 Outdoor Decorative products, non-ENERGY STAR certified products (that still meet the ENERGY STAR technical requirements for efficacy and lumen output) were, on average, more expensive than ENERGY STAR certified products. Further significance testing on the lumens and efficacy showed that there was no significant difference in lumens and efficacy between the non-ENERGY STAR qualified products and ENERGY STAR certified products. This indicated that the statistically significant difference in price between non-ENERGY STAR qualified and ENERGY STAR certified products in the Outdoor Decorative category was most likely caused by variations in aesthetics and design related to the decorative aspect of the products.

This significance testing was essential to this analysis, as the historical web-based pricing data (prior to 2016 Q4) does not include DLC qualification status. This methodology enabled the inclusion of the majority of Navigant's historical data, which allowed for the development of price projections for all priority product categories (the projection methodology is described in the following Section 2.5).

2.1.2 Manufacturer Interviews and Product Catalog Analysis

In addition to the significance testing for DLC qualified and non-DLC qualified products, Navigant conducted brief interviews with manufacturers to determine what portions of their product offerings are DLC qualified. Specifically, Navigant completed interviews with 8 large and medium sized manufacturers and analyzed product catalogs of 5 small manufacturers. The manufacturers included in this part of the Study consisted of Hubbell Lighting, Eaton, RAB Lighting, GE Lighting, Philips, Acuity, OSRAM, Cree, James Industries, NaturaLED, Aurio Lighting, Sun & Stars Lighting, and Shenzhen Syhdee Co.

Figure 2-3 shows the summary of the interview findings and product catalog analysis, as well as alignment relative to Navigant's web-scraped database. The results indicate that rates of DLC qualification are similar between large and medium manufacturers. However, there is a much larger degree of variation in the proportion of product offerings that are DLC qualified among small manufacturers. Among large and medium manufacturers, the median response was that 75% of their products are DLC qualified for indoor LED products, while 63% are DLC qualified for outdoor LED products. For small manufacturers, the median was 63% DLC qualified for indoor LED products and 74% DLC qualified for outdoor LED products. However, some small manufacturers had nearly 100% DLC qualified product offerings, while some had less than 10% of their products listed as DLC qualified. This trend was apparent for both indoor and outdoor LED product categories.

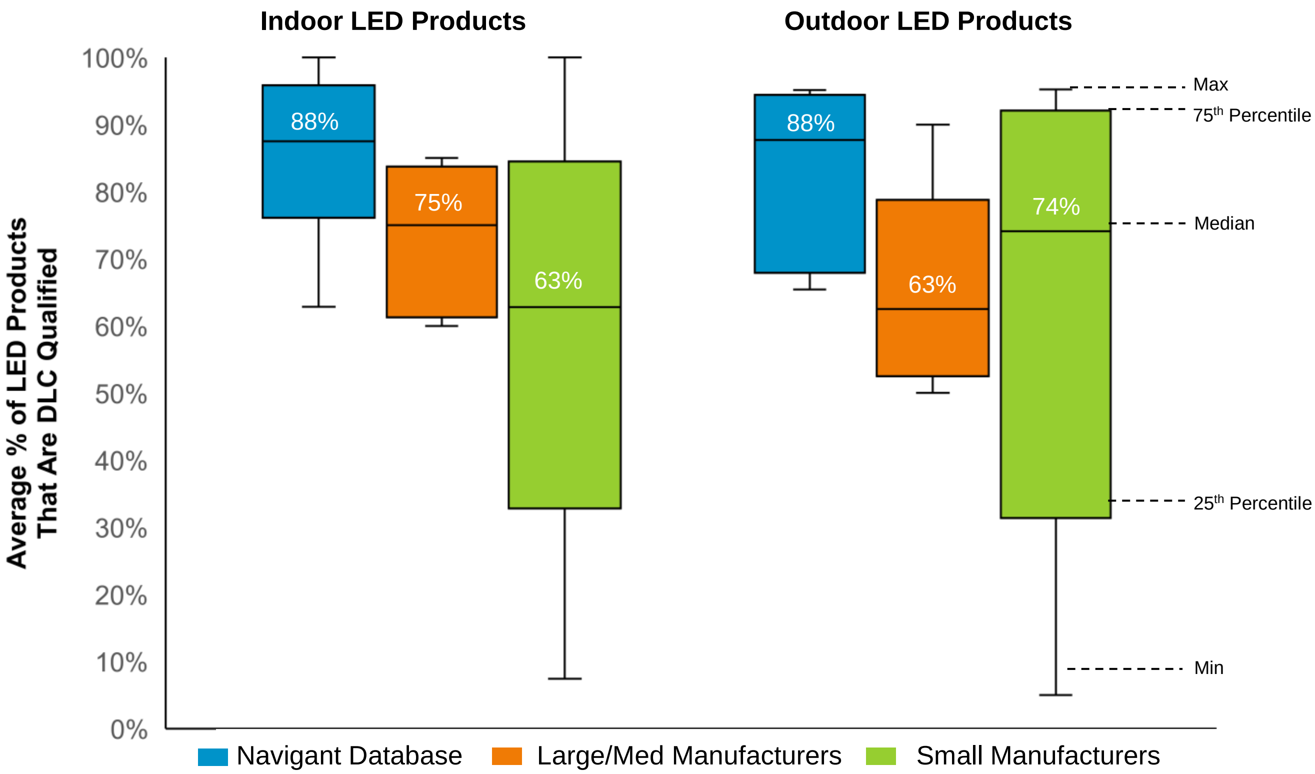

Figure 2-3 DLC Qualification Rates: Manufacturer vs. Navigant's Web-scraped Database

Navigant's database had a median of 88% for products that meet the DLC technical requirements in both indoor and outdoor groups. This reflects the median percentage of estimated DLC qualification in each of Navigant's priority product categories that correspond to indoor and outdoor. Note that this includes Navigant's database of products that are known to be DLC qualified, as well as those where DLC qualification may be uncertain, but would qualify based on the technical requirements. Although the web-scraped database has a slightly higher DLC qualification rate, Figure 2-3 shows that overall the DLC qualification rates of large, medium, and small manufacturers align well with Navigant's LED database and assumptions for inclusion in the analysis.

2.1.3 Typical LED Purchase Price

After refining the web-based data to only those products that are ENERGY STAR certified or meet the DLC technical requirements, Navigant used an analysis methodology based on a 2014 Lawrence Berkeley National Laboratory (LBNL) report. The LBNL team conducted a consumer survey which indicated that more than 80% of respondents purchased an LED lamp at or below the 25th percentile of their collected web-based pricing data.[10] LBNL also concluded that the mean and median are volatile metrics that represent the tail of the purchase distribution, while the 25th percentile of their web-scraped data best represents the characteristic price. While the LBNL analysis was conducted for LED A-type lamps, Navigant concluded that the same principle can be applied for LED luminaires and retrofit kits, based on the web-pricing distributions for LED fixtures. As an example, Figure 2-4 shows the distribution

[10] "The evolving price of household LED lamps: Recent trends and historical comparisons for the US market", LBNL, November 2014.

for LED 2’x4’ LED recessed troffers, which has a significant positive right-tailed skew. Therefore, given the results of the LBNL analysis and the distribution of Navigant’s web-based data, we believe the 25th percentile of web-based price best represents the typical purchase price. Additionally, similar to the previous pricing analysis and as described by LBNL, Navigant suggests the range of LED pricing that encompasses the vast majority of sales has an upper-bound characterized by the median and a lower-bound characterized by the 10th percentile.

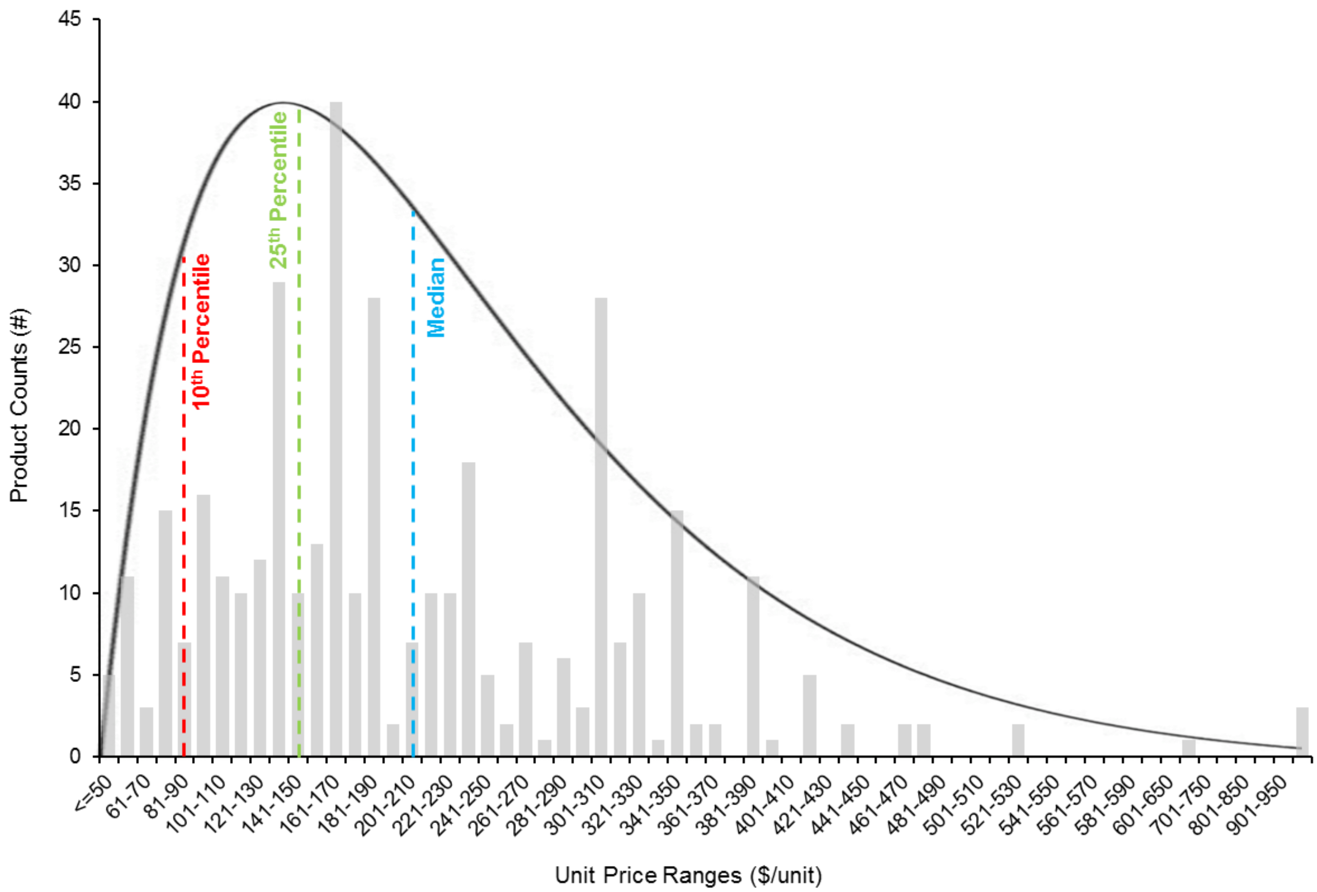

Figure 2-4 Price Distribution of 2’x4’ LED Recessed Troffers 2016 Q1

2.2 Current LED Pricing

In order to determine the current price of the LED priority product categories, Navigant characterized typical purchase price for two time intervals of web-based data. As mentioned prior, the first interval was collected in 2016 Q4, and the second interval was collected in 2017 Q2 (see Section 1.2 for a discussion of the data collection). For both time intervals, Navigant used the methodology described in the previous Section 2.1 to estimate the typical purchase price of DLC or ENERGY STAR[11] qualified LED luminaires and LED luminaires that meet the technical requirements of DLC for each of the 15 priority product categories.

[11] ENERGY STAR certification is only relevant for LED priority product categories, “Downlight Fixtures” and “Outdoor Decorative”

2.3 Factors that Significantly Influence LED Price

In any pricing analysis, it is generally understood that parameters that affect price do not do so in isolation. The large number of parameters that affect LED price made it difficult to understand the precise impact each has on price and how they may interact. To address this challenge, Navigant employed a multiple regression analysis to understand the relationship between these variables and their impact on LED price.

Multiple regression is an extension of linear regression in which more than one independent variable X is used to predict a single dependent variable Y. The predicted Y is a linear transformation of the X's, with the condition that the sum of squared deviations of the observed and predicted Y must be minimized. The complexity of the analysis arises from the interrelationships among all the independent variables. The analysis must account for these relationships by assigning weights to each variable.

With two independent variables, the prediction of Y is expressed by the following equation:

$$Y_i = b_o + b_1 X_{1i} + b_2 X_{2i}$$

The b-coefficients are called regression weights and are calculated in a manner that minimizes the sum of squared deviations mentioned above.

To Study the impacts of various parameters on LED price, the analysis involved setting the price per unit of the LED as the dependent variable, with multiple independent variables that reflect each specification parameter. Navigant assessed the following parameters: lumen output, CCT, CRI, dimmability, DLC qualification (ENERGY STAR in the case of the Downlight and Outdoor Decorative categories), and manufacturer. Of these, the variables were organized into two categories.

1. Continuous variables: lumen output, efficacy, CCT, CRI
2. Categorical variables: dimmability, DLC qualification, manufacturer

Navigant did not include wattage as part of the sensitivity analysis. The reason for this is that lumen output and wattage are two directly related parameters (increasing wattage often causes a proportional increase in lumen output, and vice versa). Their direct relationship causes multicollinearity errors in the multiple regression analysis. Therefore, Navigant assumes lumen output is a proxy for wattage, and only included lumen output in the analysis. However, because of this direct relationship, wattage is also highly correlated to price. This dynamic between lumen output, wattage and price is discussed further in Section 3.3.1.

Navigant classified the categorical variables into binary options: 1 for affirmative instances, 0 for negative instances. For example, a luminaire that has dimmability but is not confirmed to be DLC qualified will have a value of 1 for dimmability and a value of 0 for DLC qualification. By categorizing the variable into two numerical buckets, it was possible to assess the impact magnitude of the variable in the multiple regression analysis. The total multiple regression model is captured into the equation below

$$P_i = b_o + b_L L_i + b_E E_i + b_T T_i + b_C C_i + b_D D_i + b_Q Q_i + b_M M_i + \varepsilon_i$$

where P is LED price, L is lumen output, E is efficacy, T is CCT, C is CRI, D is dimmability (binary), Q is DLC qualification status (binary), M is manufacturer, and ε is the error term. The various b-coefficients are the regression weights indicating the magnitude of impact of the associated variable on price P. b_o is the general constant for the overall regression model.

The various parameters are measured in different units, therefore containing differing ranges of values in each product category. This makes the comparison of regression coefficients meaningless to compare relative to other parameters. In order to calculate a unit-blind regression equation in which regression coefficients can be directly compared for their relative impact on LED price, all dependent and independent variable data was standardized prior to running the regression. This allowed for all regressions to be performed without units.

To solve for multiple coefficients at once, Navigant leveraged Excel's Data Analysis Regression tool. This allowed the team to solve the regression coefficients of each variable while considering the fact that none of the variables impact the price in isolation. This revealed which parameters have greater influence on LED price. It is important to note that the calculated magnitude is relative to the other parameters and does not provide an absolute measure of impact. The regression coefficients are not designed to be used as a "pricing equation" to determine a typical LED purchase price based on specification parameters alone, as there are various market factors that are not captured by the regression analysis.

An important caveat to note is that many of the data fields selected for the multiple regression analysis were reported inconsistently on the retail websites utilized for web-scraping. This was particularly the case with CRI, as many retail websites and specification sheets did not readily provide this information for all products. Therefore, only the products with complete set of parameter values were used in the regression analysis. Furthermore, it was necessary to perform data cleaning regarding brand names recorded in the web-scraped data. For example, some retailers sold products marketed as "Lithonia", while others were sold as "Lithonia Lighting." Navigant modified all brand and manufacturer data for the regression analysis to the ultimate parent company and name.

2.4 Incremental Cost

The incremental cost calculation determined the additional first cost incurred by purchasing an LED luminaire over a baseline system. This Study evaluated the incremental cost of purchasing an LED product by comparing the typical price of LED retrofit kits and luminaires in each priority product category to the price of an equivalent baseline technology lighting system. It is important to note the distinction that the "cost" described by incremental cost is the cost incurred by a purchaser of the LED product (i.e. cost to the customer), not the cost to the distributor or manufacturer in acquiring or manufacturing the product. The incremental cost is important to the IOU incentive programs because it provides a reference as to which products to incentivize and the appropriate incentive level.

To calculate the incremental costs, the baseline and LED prices must be compared for the same quarter of pricing data, since LED product prices change rapidly. Only one interval of baseline product prices was collected, because pricing for these products is more stable than for LED products. Baseline product data was collected from Grainger, Platt, 1000Bulbs.com, Econolight, Home Depot and Lumens.com. Similar to the method used for LED products, Navigant determined that the 25^{th} percentile is appropriate for characterizing the typical purchase price for incandescent, compact fluorescent lamp (CFL), halogen, linear fluorescent, and high-intensity discharge (HID) lighting products when relying on web-based pricing data.

In addition, it is worth noting that the sample size for outdoor baseline housing was small, because LED technology was already dominating these markets. For example, at the time of the analysis, Grainger offered 211 LED area/roadway products, but only offered 13 baseline fixtures (i.e. baseline fixtures typically include both the reflector/diffusors and housing). This will likely impact the following product categories:

a. Area/Roadway and High Wattage Retrofits
b. Wall Pack
c. Canopy
d. Parking Garage
e. Parking Lot

Despite the smaller sample sizes, the baseline pricing data was sufficient to provide a meaningful analysis of incremental cost of LED outdoor products to baseline outdoor products.

Furthermore, including the baseline reflector/diffusors and housing resulted in a low or negative incremental cost for several product categories (e.g. LED luminaires are less costly than the baseline system). To demonstrate this phenomenon, Navigant conducted a simple evaluation, looking at the price of a single 2x4 LED Troffer and LED Area/Roadway luminaire and comparing it to that of a T8 and metal halide system, respectively. While these estimates do not represent the population of all products, the examples shown in Table 2-2 illustrate that LED pricing is sometimes competitive with conventional technology ($125.23 for LED vs. $103.76 for T8 system) or cheaper in the case of the LED Area/Roadway luminaire (highlighted in red, $610.36 for conventional vs. $583.44 for LED), when the fixture is included in baseline pricing. This may affect the viability of IOU incentive programs.

Table 2-2 Example Incremental Cost Comparison[1]

Product Category	Model #	LED Price	Baseline Price			Total Price
			Lamp(s)	Ballast	Fixture (reflector & housing)	
Recessed Troffer/Panel – 2'x4'	E-TFA04A-24R40N	$125.23				***$125.23***
32W T8 2'x4' Recessed Troffer	TCP31032841		*$2.56 x 2 = $5.12*			***$103.76 $30.92 (w/o fixture)***
	ADVIOPA3P32LWN35M			*$25.80*		
	LIT2SP8G232A12MVO				*$72.84*	
LED Area/Roadway	HUBASL16L4	$583.44				***$583.44***
250W Metal Halide Area Light	SATS5886		*$28.16*			***$610.36 $225.7 (w/o fixture)***
	ADV71A5792001D			*$197.54*		
	RABALH250PSQ				*$384.66 (subtract out included lamp)*	

1. All cost data was taken from products listed on Platt.com.

Because the CA IOUs need to include the baseline reflector/diffusors and housing for work paper calculations, Navigant evaluated incremental cost both with and without baseline fixture costs, to represent two distinct scenarios:

1. **Luminaire Market:** For the luminaire market incremental cost, the baseline system included a lamp(s), ballast, reflector/diffusor, and the housing. The incremental cost was calculated relative to a complete LED luminaire or retrofit product. This scenario represented the new construction

market where owners and facility managers are comparing technology options equally. It is important to note that this represents a small proportion of total installations.[12]

2. **Replacement Market:** For the replacement market, the baseline system included just a lamp(s) and ballast. The replacement market baseline system does not include reflector/diffusors or housing. This scenario represented the replacement on lamp or ballast burn-out where owners and facility managers are not comparing technology options equally due to the long lifetime of commercial baseline fixtures (above 100,000 hours). This represents a relatively larger proportion of total installations.[13]

Navigant evaluated incremental costs separately for the Luminaire and Replacement markets to more accurately reflect cost comparisons in each scenario. Furthermore, within each priority product category, separate incremental costs were calculated based on the technology type. For example, the priority product category of Area/Roadway compared LED luminaires with metal halide (MH) baseline systems as well as high pressure sodium (HPS) baseline systems separately, to account for differences in cost of each technology type.

2.5 Projected LED Pricing

Navigant used a similar methodology as described in DOE's "Energy Savings Forecast of Solid-State Lighting in General Illumination Applications" report, to develop LED price projections for each priority product category.[14] This recent report references the mathematical model described in an updated LBNL report.[15] To develop the 3 and 5-year projections, Navigant utilized the typical purchase prices estimated from the historical data collected quarterly since 2013 Q3 to develop an aggregated time series for each priority product category. Figure 2-5 illustrates an example of this trend analysis for LED downlights.

[12] Between 2015 and 2017, new construction of commercial floorspace is estimated to grow at a rate of approximately 1.1% per year according to the Energy Information Administration's Annual Energy Outlook 2017 Table: Commercial Sector Key Indicators and Consumption, https://www.eia.gov/outlooks/aeo/data/browser/#/?id=5-AEO2017&cases=ref2017&sourcekey=0. In addition, the renovation cycle for commercial end-uses varies between 7 and 22 years according to a study conducted by Boston Consulting Group: http://image-src.bcg.com/Images/BCG-How-to-Win-in-a-Transforming-Lighting-Industry-Nov-2015_tcm79-88535.pdf

[13] In contrast to new construction and the renovation of commercial spaces, the lifecycle of baseline lighting products is much shorter. Based on lifetime data collected from product catalogs, the lifetime range in commercial end uses for incandescent and halogen products is 0.6 to 1.2 years, for compact fluorescent is 1.4 to 1.7 years, for linear fluorescent is 2.2 to 5.1 years and for high intensity discharge is 3.7 to 6.1 years. Commercial operating hour assumptions provided in the Department for Energy's 2010 U.S. Lighting Market Characterization (Table 4.6) report were used to develop these lifetime ranges: https://www1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf

[14] "Energy Savings Forecast of Solid-State Lighting in General Illumination Applications", U.S. DOE Solid-State Lighting Program, September 2016

[15] "Recent Price Trends and Learning Curves for Household LED Lamps from a Regression Analysis of Internet Retail Data", LBNL, June 2015.

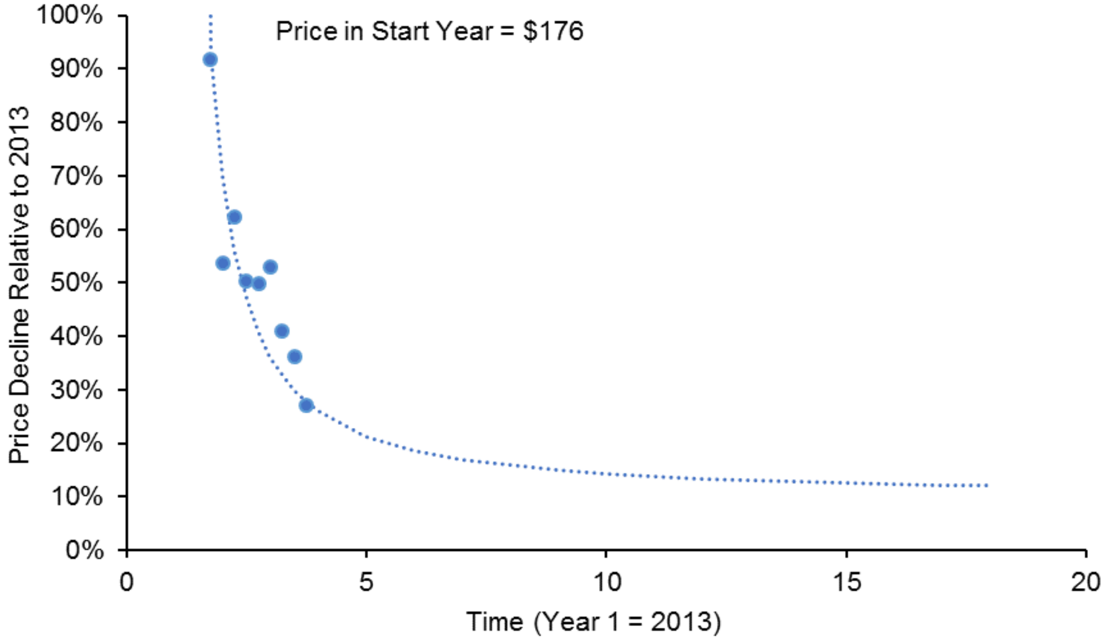

Figure 2-5 Example LED Lamp Price Trends for LED Downlight
Source = U.S. DOE Solid-State Lighting Program, 2016

As discussed in the most recent LBNL report, the phenomenon of new technology price decline is often discussed in the context of experience curves, which characterize the cost of manufacturing for a given technology as a declining power law function of cumulative industry manufacturing experience. An experience curve takes the form:

$$P_i = A * Q_i^{-b} + C,$$

where $\boldsymbol{P_i}$ represents price relative to the initial price, $\boldsymbol{Q_i}$ represents cumulative product shipments relative to market introduction, and ***A***, ***b*** and **C** are constants. ***A*** is a price scaler relative to shipments, ***b*** is the regression coefficient for the experience curve, and ***C*** represents the final relative price at t∞. For this analysis, Navigant used a market introduction year of 2010, since at that time LED lighting represented less than 1% of the lighting market.[16] Future LED prices for each priority product category were then determined by multiplying the projected $\boldsymbol{P_i}$ for years from 2017 to 2022 by the initial 2010 price.

This price projection methodology represents a deviation from the 2015 California LED Workpaper Update Study where the web-data was fit to a simple exponential price decline curve based on Haitz's Law.[17] However, using an experience curve is more accurate when describing price decline because it not only accounts for Haitz's Law, but also for the general observation that cost of production for new technologies tends to fall by a fixed fraction each time their cumulative production doubles. This is a common phenomenon for many electrical products[18] and is used by DOE to estimate future price decline for all regulated products (including LED lighting). The experience curve is an empirical model based on historical fits of price data to cumulative production. Navigant leveraged LED product shipment data

[16] "2010 U.S. Lighting Market Characterization", U.S. DOE Solid-State Lighting Program, January 2012.

[17] Haitz's law is an observation and forecast about the steady improvement, over many years, of LEDs. It states that every decade, the cost per lumen (unit of useful light emitted) falls by a factor of 10, and the amount of light generated increases by a factor of 20.

[18] Using the Expereince Curve Approach for Appliance Forecasting, EERE, February 2011.

collected on behalf of the U.S. DOE SSL Program, as well as known learning curve rates published by the U.S. DOE Appliance and Equipment Standards Program, to develop experience curves. These experience curves then enabled price projections for each LED priority product category looking forward to 3 and 5-years.

2.6 Limitations and Challenges

Navigant has identified several challenges that arise when characterizing the LED lighting market and analyzing LED product price. These limitations and challenges are focused on the following areas:

2.6.1 Pricing

Web-scraping enabled the collection and utilization of large amounts of historical pricing data for LED products, thereby allowing robust estimations and projections. While the ideal analysis would calculate typical purchase price using sales-weighted averages, this was not possible with web-scraped data since there is no available detailed information on relative sales volumes. Instead, the pricing analysis relies on the LBNL method described in Section 2.1.3, which uses the 25th percentile price as the typical consumer purchase price, and the 10th percentile and median as the lower and upper range respectively. While the LBNL method and web-scraped database provide a sound projection of LED pricing, there may be variations between this analysis and actual realized future prices.

2.6.2 Factors that Significantly Influence LED Price

Navigant designed various multiple regression models for each of the 15 priority product categories in order to analyze how LED product characteristics relate to price. Statistical models rely on simplifications of complex technological systems and product design processes, and this Study is no exception. For this Study, LED product characteristics, such as lumen output or CCT, are modeled as continuous variables, which allows for the most intuitive interpretation of the results. However, manufacturers often provide product lines that have step-wise lumen output and CCT values, which cause some of the variables to behave categorically, rather than as continuous variables. Modeling these variables as categorical variables may result in different regression coefficient results from those derived in this Study.

Another important consideration is the relationship between lumen output, wattage, and efficacy. Analyzing each of these variables in the same statistical model presents challenges due to their co-dependence. Efficacy is a calculated metric that equates to lumen output divided by wattage. Therefore, these variables are not independent, which could have implications when comparing their influence on LED product price.

2.6.3 Project Scope

The overarching goal of this Study was to analyze LED product pricing both now and in the future, and while this objective is broad, it was necessary to limit the scope of the project to the research questions presented in Section 1.1. As such, this Study does not assess the potential impact of IOUs' rebate programs on overall LED product prices. Many commercial consumers in the California market outfit their LED lighting systems through IOU incentive programs, which can have a large impact on the actual realized cost to the consumer. However, this Study did not analyze how and to what extent such rebate programs effect the overall LED market price.

In addition, the LED price projections of this Study are provided for 15 priority LED product categories. However, the Study does not analyze price projections in wattage bins or lumen bins within each product category. The prices of LED products are significantly correlated to both lumen output and wattage; therefore, price projections may differ if analyzed by lumen or wattage bins.

3. LED PRICING ANALYSIS RESULTS

Using the methodologies described in Section 2, the results of the analysis are described below for each of the five Study objectives.

3.1 Current LED Price

As determined using the LBNL 25th percentile method, Table 3-1 provides the typical LED purchase price estimates for each of the 15 priority product categories in 2016 Q4 and 2017 Q2. As discussed in Section 2.1 and 2.2, these prices estimates are representative of products that are DLC or ENERGY STAR qualified. The 10th percentile and median prices of each LED priority product category, which represent the lower and upper range of typical LED prices, are also presented.

Table 3-1 Estimated LED DLC and ENERGY STAR Qualified Price Ranges

Priority Product Category	10th Percentile		25th Percentile			Median		Sample Size	
	2016 Q4	2017 Q2	2016 Q4	2017 Q2	% Change	2016 Q4	2017 Q2	2016 Q4	2017 Q2
Area/Roadway	$ 116	$ 164	$ 202	$ 241	19%	$ 339	$ 338	361	544
Downlight	$ 29	$ 28	$ 45	$ 44	-4%	$ 66	$ 75	116	778
Recessed Troffer/Panel 1x4	$ 107	$ 138	$ 125	$ 184	48%	$ 214	$ 203	25	66
Recessed Troffer/Panel 2x4	$ 86	$ 88	$ 121	$ 117	-3%	$ 172	$ 173	180	271
Recessed Troffer/Panel 2x2	$ 77	$ 66	$ 98	$ 90	-8%	$ 136	$ 128	122	211
Recessed Troffer - Retrofit 2x4	$ 74	$ 82	$ 87	$ 93	7%	$ 111	$ 125	27	101
Recessed Troffer - Retrofit 2x2	$ 63	$ 66	$ 66	$ 93	41%	$ 99	$ 108	28	60
Wall Pack	$ 60	$ 59	$ 98	$ 91	-7%	$ 161	$ 149	318	730
Canopy	$ 144	$ 100	$ 204	$ 174	-15%	$ 333	$ 261	74	257
Garage	$ 103	$ 105	$ 183	$ 180	-2%	$ 289	$ 260	60	117
Parking Lot	$ 168	$ 131	$ 265	$ 249	-6%	$ 421	$ 281	103	154
Strip Light	$ 37	$ 37	$ 60	$ 60	0%	$ 109	$ 96	147	291
High/Low Bay	$ 166	$ 158	$ 218	$ 190	-13%	$ 340	$ 298	106	720
Indoor Decorative	$ 181	$ 122	$ 265	$ 174	-34%	$ 399	$ 283	291	379
Outdoor Decorative	$ 55	$ 44	$ 87	$ 78	-11%	$ 131	$ 115	249	1860
Weighted Average	**$ 99**	**$ 80**	**$ 151**	**$ 119**	**-21%**	**$ 238**	**$ 178**		
Total Sample Size								**2,207**	**6,539**

From 2016 Q4 to 2017 Q2, new DLC technical requirements[19] were implemented that changed the minimum efficacy threshold across all DLC product categories. Despite the increase in the minimum efficacy for DLC qualification, the results suggest that this increase did not have a strong influence on the price of DLC qualified products. On average, there was a 21% decrease in price across all product categories from 2016 Q4 to 2017 Q2. However, it is important to note that the micro-trends and quarterly price shifts seen in Table 3-1 can be caused by a large variety of short-term market factors. Price changes of LED products within a short period of time do not necessarily reflect the directionality nor magnitude of the overall price trajectory of the product over a long-term time horizon. Although seasonality has an effect in many markets, and is noticeable for LED lamps, LED luminaires have not shown a seasonal trend. Rather, Navigant believes that these short-term price changes are caused by distributor sales, changes to a manufacturer or brand's product line, promotions, as well as the supply and demand of various lighting products and components.

Taking these factors into account, the 25th percentile DLC and ENERGY STAR qualified LED price estimates should not be used in isolation by quarter when analyzing price trends. Rather, the data should be use collectively over long periods of time to develop a comprehensive understanding of the direction and magnitude of price shifts for any given product (the methodology and results of the price projection analysis are provided in Sections 2.5 and 3.5, respectively). For example, Figure 3-1 shows the short-term quarterly variations and overall long-term price trends for DLC qualified Canopy LED products.

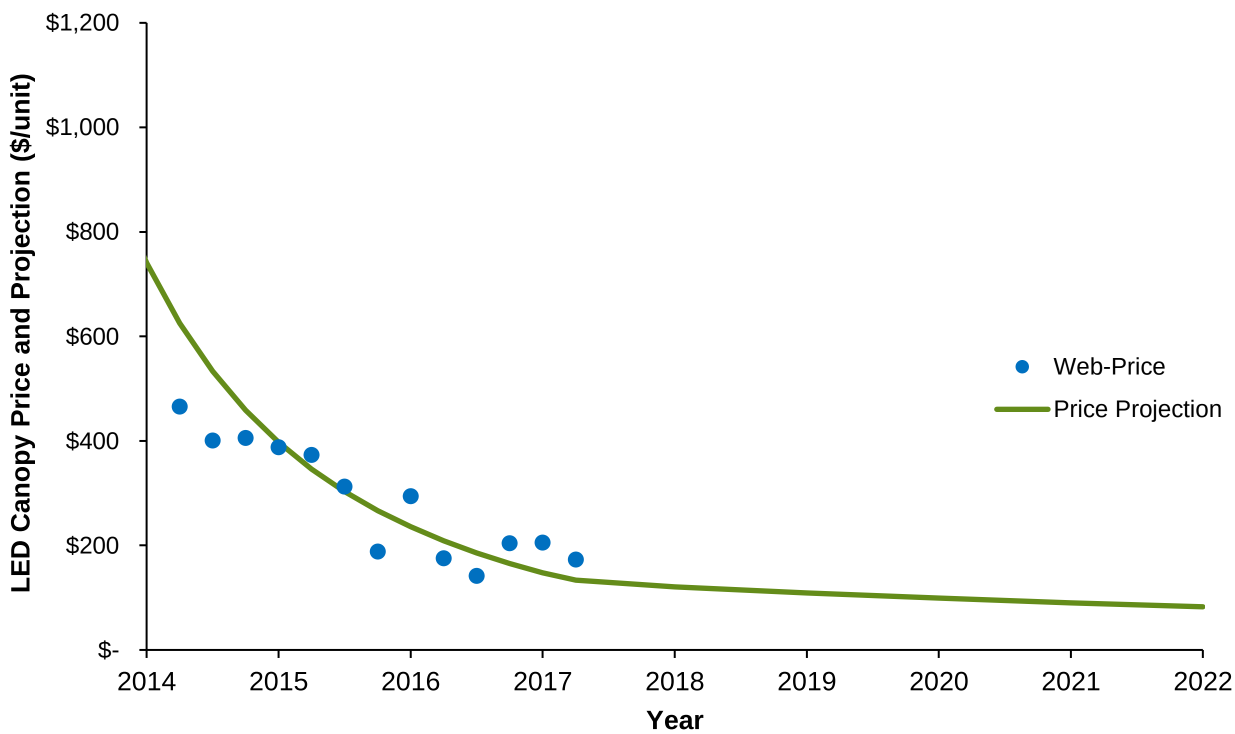

Figure 3-1 Observed Web-Price and Projection of DLC Qualified Canopy LED Products

[19] DLC, "Technical Requirements Version 4.2", Released April 28, 2017. https://www.designlights.org/default/assets/File/SSL/DLC_Technical-Requirements-V4-2.pdf

While there is variation of web-pricing from quarter to quarter, the declining price trend is very apparent, and it is important to note that fluctuations in specific quarterly prices should not affect nor determine the long-term price trends of the product. Navigant emphasizes that continued monitoring and analysis of LED price trends will be important as the market and technology offering continues to mature and develop, thereby affecting the prices of LED products.

3.1.1 DLC Premium Pricing

DLC Technical Requirements provide two tiers of DLC qualification, DLC Standard and DLC Premium. DLC Premium qualification requires higher efficacy thresholds, but maintains the same requirements for lumen output. To examine whether or not DLC Premium products differ significantly in price from DLC Standard products, Navigant employed the same statistical testing methodology as the significance test described in Section 2.1.1. However, instead of testing the prices of DLC qualified products versus the prices of non-DLC products, in this analysis Navigant tested DLC Premium qualifying products versus DLC Standard qualifying products on the basis of lumen output and efficacy.[20] The results of the significance test are shown in Table 3-2 for each product category.

[20] Navigant assessed products that were DLC Premium and DLC Standard qualifying by comparing products that met the efficacy and lumen output requirements for Premium and Standard qualification. Primary data on whether products were DLC Premium or DLC Standard qualified was not available via the web-scraping database, as many retail websites do not list this information consistently.

Table 3-2 Price Difference Significance Test Results by for DLC Standard vs Premium Products

Priority Product Categories	DLC Technical Requirement Applications	DLC Premium Price Difference
Area/Roadway and High Wattage Retrofits	Outdoor - Low Output	Not Significant
	Outdoor - Mid Output	
	Outdoor - High Output	
Downlight Fixture*	Not DLC	Not DLC
Recessed Troffer/Panel 1x4	Indoor - Troffer	N/A**
Recessed Troffer/Panel 2x4	Indoor - Troffer	Significant
Recessed Troffer/Panel 2x2	Indoor - Troffer	Significant
Recessed Troffer Retrofit 2x4	Indoor Retrofit Kit - Troffer	Not Significant
Recessed Troffer Retrofit 2x2	Indoor Retrofit Kit - Troffer	Not Significant
Wall Pack	Outdoor - Low Output	Not Significant
	Outdoor - Mid Output	
	Outdoor - High Output	
Canopy	Outdoor - Low Output	Not Significant
	Outdoor - Mid Output	
	Outdoor - High Output	
Parking Garage	Outdoor - Low Output	Not Significant
	Outdoor - Mid Output	Significant
	Outdoor - High Output	N/A**
Parking Lot	Outdoor - Low Output	Not Significant
	Outdoor - Mid Output	Significant
	Outdoor - High Output	Significant
Strip Light	Indoor – Linear Ambient	Not Significant
High/Low Bay	Indoor – High Bay, Lower Range	Not Significant
	Indoor – High Bay, Higher Range	
Outdoor Decorative*	Not DLC	Not DLC
Indoor Decorative*	Not DLC	Not DLC

* Downlights, Outdoor Decorative, and Indoor Decorative products were not included in the analysis because DLC does not offer product qualifications for these categories.
**These groups did not have enough data to run the significance test.

The results indicate that 4 of 12 DLC priority LED product categories showed a statistically significant price difference between DLC Standard qualifying products and DLC Premium qualifying products. However, the 4 product categories that had a statistically different DLC Premium price showed that DLC Premium qualifying products were, on average, 12% less expensive than DLC Standard qualifying products. Downlights, Outdoor Decorative, and Indoor Decorative products were not included in the analysis because DLC does not offer product qualifications for these categories.

Given the results of this analysis, Navigant concluded that a separate price analysis based on DLC Premium requirements would not differ statistically from the price analysis based on DLC Standard technical requirements and would not produce significant differences in projected price.

3.2 CA IOU Program and Web-based Price Comparison

Similar to the previous 2015 California LED Workpaper Update Study, Navigant also compared the estimated DLC and ENREGY STAR qualified pricing ranges, discussed in detail in Section 2.1.2, to pricing data collected as a part of SCE and PG&E's lighting incentive programs. Navigant compared pre-incentivized sales-weighted pricing data provided by SCE and PG&E to the minimum (10^{th} percentile), typical (25^{th} percentile), and maximum (median) of the web-based LED price estimates for the following product categories: High/Low Bay, Downlight, Recessed Troffer/Panel, and Recessed Troffer/Panel Retrofit. Only these product categories were evaluated since SCE and PG&E currently do not collect pre-incentivized pricing data for all the priority product categories identified for this Study.

As shown in Figure 3-2 and Figure 3-3, the pre-incentivized SCE and PG&E LED pricing data aligns well within the range of web-based LED pricing data for the product categories High/Low Bay, Downlight, Recessed Troffer/Panel, and Recessed Troffer/Panel Retrofits.

Note that Figure 3-2 excludes the High/Low Bay category because of a large range in lumen output. Because High/Low Bay luminaires have a large lumen range (5,000 to 80,000 lumens), the data was split into two groups by lumen ranges, the lower range consisting of products with an output of 0-30,000 lumens and the higher range consisting of products above 30,000 lumens. Figure 3-3 shows the High/Low Bay product category comparison split by these lumen ranges, demonstrating that SCE and PG&E data for High/Low Bay products aligns well within the web-based pricing range when separated into two sub-categories.

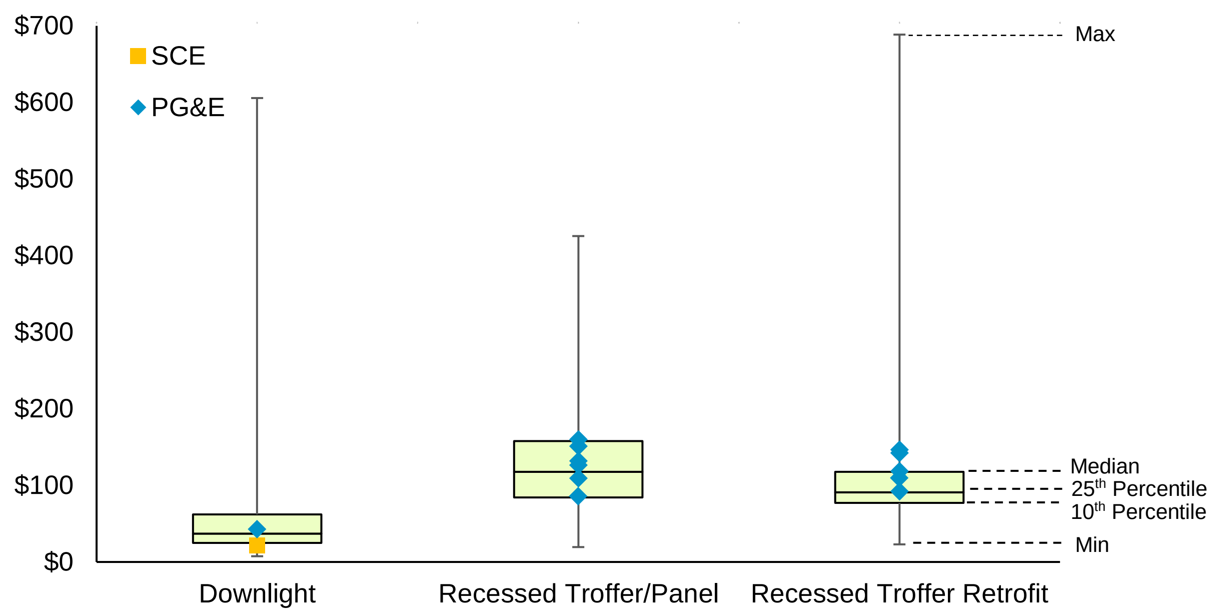

Figure 3-2 SCE and PG&E Pre-incentivized LED Pricing Data & Web-based Price Comparison, Downlight, recessed Troffer/Panel and Recessed Troffer Retrofit 2016 Q4 – 2017 Q2

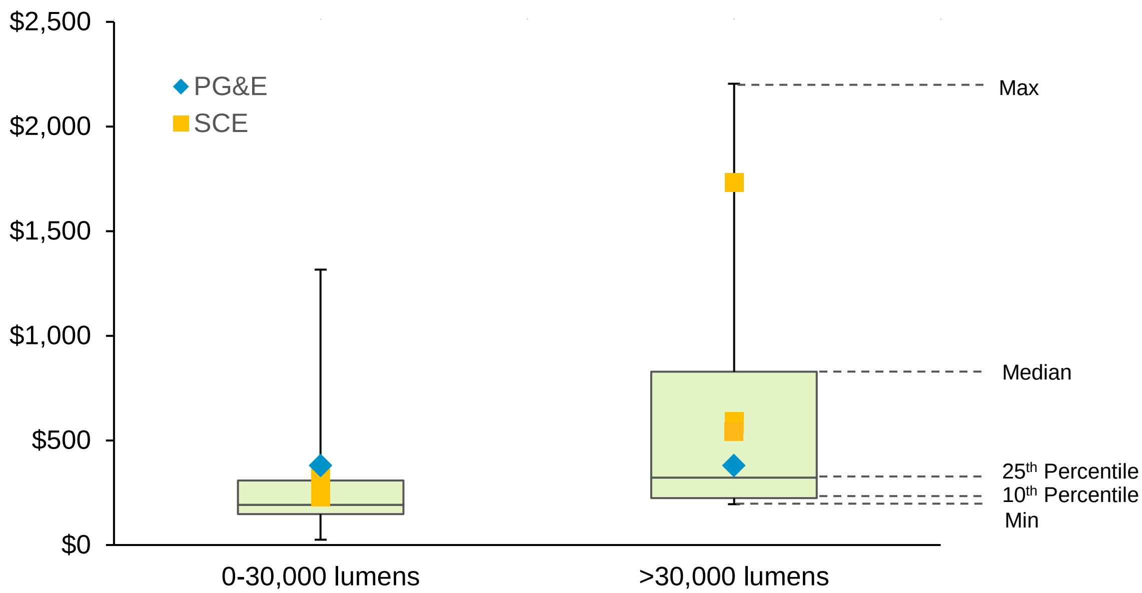

Figure 3-3 SCE and PG&E Pre-incentivized LED Pricing Data & Web-based Price Comparison, High/Low Bay 2016 Q4 – 2017 Q2

From this analysis, Navigant concluded that the 25th percentile is the best representation of DLC and ENERGY STAR qualified purchase price for the evaluated priority product categories, and that the 10th percentile and median represent the most accurate lower and upper range for LED price.

The sample sizes of each source comparing Navigant's web-scraping database to the SCE and PG&E pre-incentivized pricing data is shown in Table 3-3. Navigant believes these data samples are adequate in comparing the alignment of SCE and PG&E pre-incentivized pricing with Navigant's web-based data. Furthermore, although the price comparison was only conducted with the four priority product categories shown below for 2016 Q4 to 2017 Q2, Navigant assumed that the validity of the data alignment can be applied to all priority product categories in enabling an accurate prediction of LED purchase price at the 25th percentile online vendor price.

Table 3-3 Sample Size of Web-scraping and SCE and PG&E Pre-Incentivized Pricing Data-sets by Product Category

Sample Size by Source	High/Low Bay	Downlight	Recessed Troffer/Panel	Recessed Troffer Retrofit
Web-scraping	606	704	1046	321
PG&E	126	73	309	368
SCE	--*	--*	--*	--*

* SCE did not provide total product sample size of sales-weighted price estimates for these categories.

3.3 Factors that Significantly Influence LED Price

The multiple regression analysis was conducted on each of the 15 priority product categories, with each producing a set of regression coefficients. An example of the Area/Roadway product category is shown in Table 3-4, with the standardized data regression coefficients and the p-value[21] of each coefficient. For detailed regression coefficients from each of the product categories, see Appendix B. It is important to note that only the top 6 manufacturers by product count volume for each product category were included in the regression analyses. In addition, only manufacturers with at least 10 products in the sample set were included as a tested parameter in the regression analysis. All other manufacturers were dropped from the model as a default category in order to prevent the statistical model from being over-specified.

Table 3-4 Regression Coefficients for Area/Roadway Products

Parameter	Regression Coefficient*	P-Value
Lumen output	**0.57**	**0.00**
Efficacy	-0.19	0.01
CCT	0.06**	0.31
CRI	-0.03**	0.65
Dimmability	-0.03**	0.57
DLC	0.23	0.00
Cree	-0.10**	0.08
RAB	0.03**	0.58
Acuity	0.06**	0.28
Hubbell	0.13	0.02
Noribachi	0.25	0.00
Neptun Light	0.32	0.00

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the regression coefficient was determined to be statistically insignificant based on the p-value, using a 0.05 alpha level.

The Area/Roadway results in Table 3-4 indicate that lumen output was the most significant characteristic for determining price, within that product category. Furthermore, it was determined that the regression coefficient of CCT, CRI, dimmability, Cree, RAB, and Acuity were statistically insignificant based on their p-value, using an alpha (significance cutoff) of 0.05. We performed this analysis for each of the 15 priority product categories and determined the most significant price determining characteristic. To quantify these results and estimate the overall impact of each parameter, each time a parameter was recorded as the highest magnitude regression coefficient, that parameter was given a score of 1, while all other parameters in that product category were given a score of 0. Figure 3-4 captures how many times a parameter was recorded as the highest magnitude regression coefficient, and illustrates the overall significance score for each parameter within the indoor and outdoor priority product categories. Overall, the results indicate that the biggest driver of LED luminaire price is lumen output, followed by manufacturer, DLC qualification, and CRI.

[21] The p-value is a statistical measure of significance. Using an alpha level of 0.05, it was possible to determine which regression coefficients were not statistically significant. If the p-value of the modeled regression coefficient was above 0.05, the regression coefficient is considered statistically insignificant. Note that all p-values in this report are rounded to two decimal places.

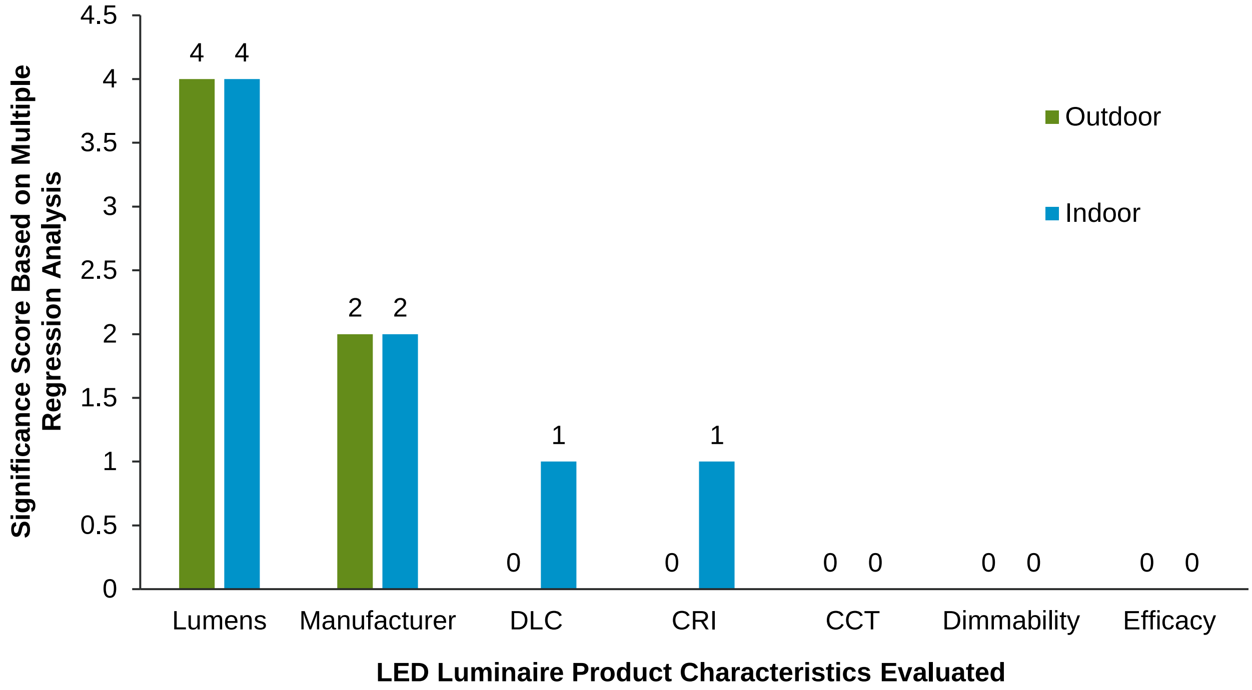

Figure 3-4 Parameters with Largest Influence on LED Luminaire Price

For outdoor products, there was a clear trend with 4 out of 6 categories having lumen output as the most significant price determining characteristic, while 2 had manufacturer as the most significant. There was more variation in the indoor LED product categories, with lumen output showing a significance score of 4 and manufacturer showing a significance score of 2. Both DLC qualification and CRI were the most significant price determining characteristic for 1 indoor category each. There were no product categories, for either indoor and outdoor, that had CCT, dimmability, or efficacy as the most significant price determining characteristic. Therefore, each of these received a score of 0 for all 15 priority product categories. Furthermore, for one indoor product category, no statistically significant regression coefficients could be determined. As mentioned above, while Figure 3-4 includes the summary results, the detailed results of the multiple regression analysis vary by priority product category and are provided in Appendix B.

The results of the multiple regression analysis revealed that efficacy, which often is seen in industry as a price driver, is not correlated to the purchase price of LED luminaire products. To further validate this finding, Navigant examined individual priority product categories to determine whether there is a direct correlation between purchase price of LED luminaires and rated efficacy. Figure 3-5 shows the results of this evaluation for Recessed Troffer/Panel 2' x 4' LED luminaires. The price and efficacy relationship is highly randomized, and the dataset contains a large spread. In addition, regression analyses produce a low R-squared value, indicating that there is no measurable correlation between LED luminaire price and efficacy. Navigant believes that, based on the findings of the multiple regression and correlation analysis, the correlation between LED luminaire price and efficacy is negligible.

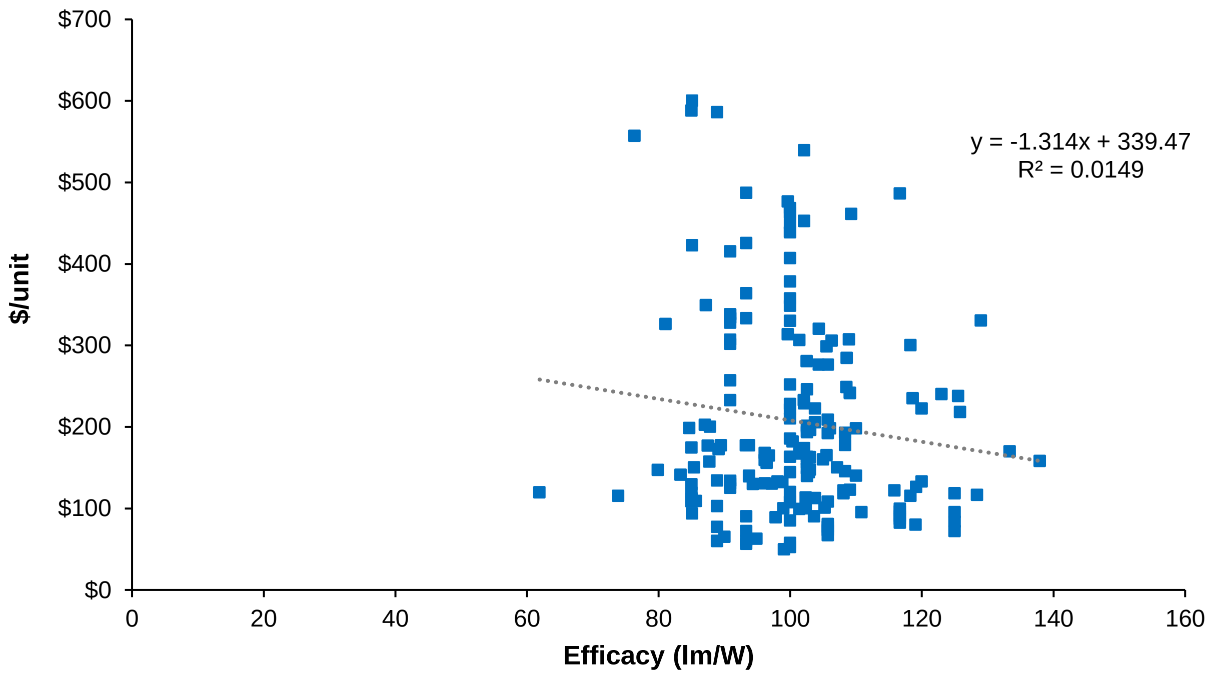

Figure 3-5 Web-based LED Price and Efficacy Data for Recessed Troffer/Panel 2' x 4'

While various factors may play a role in determining the price of an individual product, as a general trend, efficacy is not highly correlated to price. This can also be seen in the IOU lighting program sales data. Figure 3-6 examines the price and efficacy relationship in the PG&E lighting program sales data for the LED Recessed Troffer/Panel 2' by 4' priority product category. Similar to the trend seen above in Figure 3-5Figure 3-4, for both the web-based and PG&E data, LED pricing is highly random in relation to efficacy values, and the spread is very large. In addition, from the low R-squared values it is apparent that the correlation between LED price and efficacy is extremely low, and hence negligible, for both data sets.

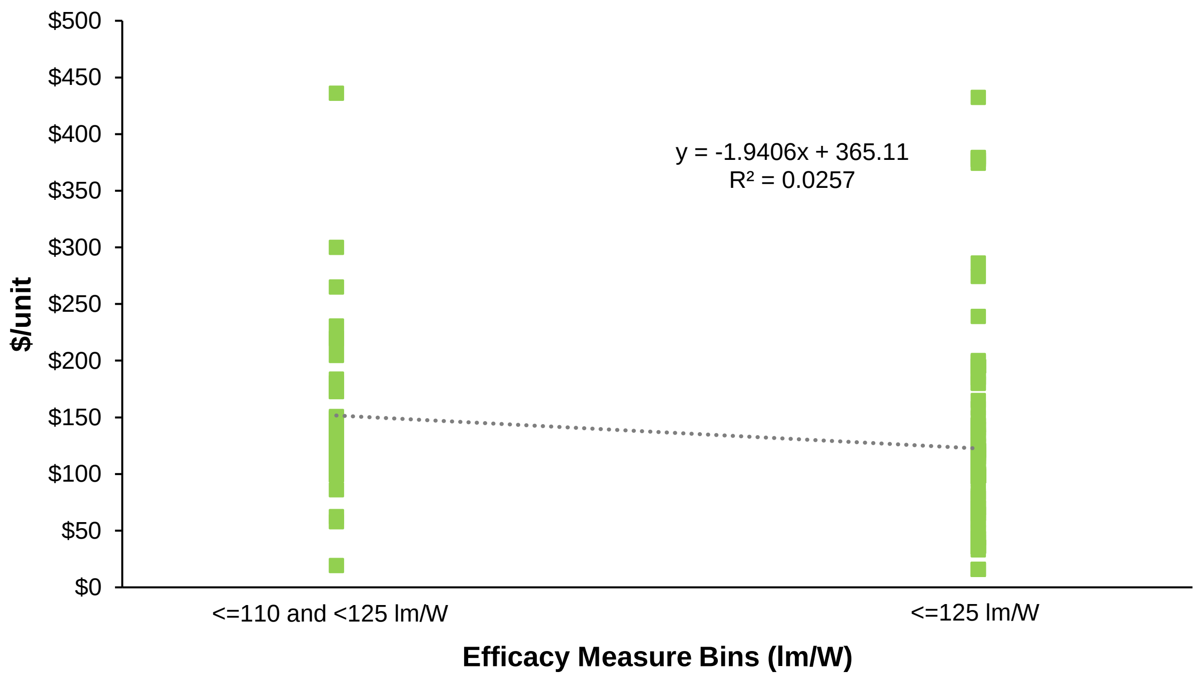

Figure 3-6 PG&E Program Sales LED Pricing and Efficacy Data for Recessed Troffer/Panel 2' x 4'

While it is certainly true that efficacy can potentially play a role in the price of an individual LED luminaire, in the general population of LED products, efficacy is not a price determinant. It is also important to distinguish manufacturing cost from consumer purchase price. Increasing the efficacy of a product undoubtedly requires additional engineering and material costs, which arise from the need for higher quality components. These factors combined may raise the manufacturing *cost* of an LED product. However, the purchase *price* of an LED luminaire product by a customer does not necessarily reflect the additional manufacturing cost associated with increased efficacy. Instead, the results indicate that the customer purchase price is primarily determined by lumen output and the manufacturer of that product. As in many consumer products, certain brands command higher prices.

It has been posited that in some cases, manufacturers may attempt to maintain purchase price as efficacy improves, by reducing some of the other performance parameters. Navigant did not verify this claim in our analysis, by examining whether within a manufacturer, increasing efficacy was accompanied by any decrease or trade-offs in any other performance metric. However, this may be an important factor in explaining why increases in efficacy do not show a corresponding increase in purchase price of an LED product.

A point of concern from a utility perspective is that if LED price does not correlate with efficacy level, it may be challenging to structure effective incentive programs which offer tiered incentive amounts based on efficacy performance. Navigant believes that although the results indicate no correlation between LED luminaire product efficacy and price, incentives could still incentivize customers to purchase higher quality and energy efficient products, particularly if the LED product price is the same despite the higher performance.

Navigant also conducted a second investigation using more controlled datasets to assess whether the analysis results were consistent with the findings noted above. We conducted a refined multiple regression analysis, using the same methodology, but in a dataset controlled for both distributor and manufacturer. The controlled regression evaluated the impacts for Area/Roadway and Recessed Troffer 2' x 4' priority product categories if only products from a single distributor and single manufacturer were included. The results showed that in the multiple regression analysis when the datasets are controlled for distributor and manufacturer, overall lumen output is still the most significant LED price determining characteristic, while efficacy does not correlate significantly to price. However, there are various other factors that may influence the price of an LED product. In a number of these more controlled analyses, the limited sample size led to cases where all regression coefficients in the controlled analysis were statistically insignificant at an alpha level of 0.05. The example in Table 3-5 below shows the comparison of the regression coefficient results from the original analysis versus the analysis that controlled for both distributor and manufacturer. In this case, the distributor and manufacturer were controlled to only include Grainger and Hubbell Lighting products respectively. Even when controlling the data for a specific distributor and manufacturer, lumen output was found to be the most price determining metric. The detailed tabulated results can be found in Appendix C.

Table 3-5 Comparison of Multiple Regression Analysis for Area/Roadway LED Luminaires

Parameter	Un-Controlled Data		Distributor & Manufacturer Controlled Data	
	Regression Coefficient*	P-value	Regression Coefficient*	P-value
Lumen output	**0.57**	**0.00**	**0.81**	**0.00**
Efficacy	-0.19	0.01	0.51**	0.06
CCT	0.06**	0.31	-0.10**	0.62
CRI	-0.03**	0.65	-0.40**	0.13
Dimmability	-0.03**	0.57	0.26**	0.26
DLC	0.23	0.00	N/A***	N/A***
Cree	-0.10**	0.08	-	-
RAB	0.03**	0.58	-	-
Acuity	0.06**	0.28	-	-
Hubbell	0.13	0.02	-	-
Noribachi	0.25	0.00	-	-
Neptun Light	0.32	0.00	-	-

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the regression coefficient was determined to be statistically insignificant based on the p-value, using a 0.05 alpha level.
*** Controlling for distributor and manufacturer eliminated any variability in this parameter.

An important finding regarding LED product manufacturers is that certain manufacturers often offer brands or product lines that all conform to a certain level of performance (i.e. all products of that brand or product line have the same CRI, are all DLC qualified, etc.). This aligns well with the idea that customers may grow to develop a sense of quality around specific manufacturers or brands, thereby creating a brand premium over others. However, this fact also makes it more difficult to deduce how manufacturer and brand or product lines may be interrelated with other LED luminaire characteristics such as CRI.

3.3.1 Comparing the Influence of Lumen Output and Wattage

An essential caveat of the multiple regression is that although the analysis used lumen output as the tested parameter instead of wattage, it could very well be that wattage is the primary price determinant, since lumen output and wattage increase or decrease proportionally. That is, overall high lumen output requires higher wattage. From a technological standpoint, increasing lumen output given a specific LED system is straightforward. However, once the LED chips and drivers are optimized within a luminaire system, the only way to increase output is to increase the power load. The eventual increase in wattage to an LED luminaire requires adding load to the driver, thereby requiring a more sophisticated driver, more total drivers, or both. This process and manufacturing trade-off can dramatically increase the price of the LED product.

Although wattage was excluded in the multiple regression analysis due to multicollinearity[22] errors with lumen output, Navigant conducted the multiple regression for one product category, Area/Roadway, using wattage, instead of lumen output, to determine whether the results would significantly differ from the original analyses. The results of this assessment are shown in Table 3-6.

Table 3-6 Multiple Regression Analysis Results Comparing Lumens and Wattage for Area/Roadway LED Luminaires

Parameter	Regression Coefficient* - Lumens	P-value	Regression Coefficient* - Wattage	P-value
Lumens or Watts	**0.57**	**0.00**	**0.57**	**0.00**
Efficacy	-0.19	0.01	-0.05**	0.53
CCT	0.06**	0.31	0.05**	0.41
CRI	-0.03**	0.65	-0.02**	0.68
Dimmability	-0.03**	0.57	-0.03**	0.57
DLC	0.23	0.00	0.22	0.00
Cree	-0.10**	0.08	-0.11**	0.06
RAB	0.03**	0.58	0.05**	0.40
Acuity	0.06**	0.28	0.06**	0.25
Hubbell	0.13	0.02	0.13	0.02
Noribachi	0.25	0.00	0.26	0.00
Neptun Light	0.32	0.00	0.32	0.00

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the regression coefficient was determined to be statistically insignificant based on the p-value, using a 0.05 alpha level.

In the original analysis for Area/Roadway, lumen output was the largest regression coefficient and the most significant price determining characteristic. When the same regression analysis was conducted with wattage instead of lumen output, wattage was determined to be the largest regression coefficient and the most significant price determining characteristic. This revealed that lumen output and wattage can likely be used interchangeably in the multiple regression analysis. However, because of this, the results must be interpreted to indicate that wattage could be the most significant price determining characteristic of an LED product, rather than lumen output.

[22] Multicollinearity is a statistical phenomenon in which there is a directly linear relationship between two explanatory variables. In the case of this Study, there was significant multicollinearity between lumen output and wattage. The Study excludes using wattage and lumen output in the same regression analysis because these two variables are highly correlated, and it is not possible for the model to analyze these two variables jointly.

3.4 Incremental Cost Analysis

The results in the following section present the incremental cost for DLC and ENERGY STAR qualified products compared to baseline costs averaged across all technology types within a product category. For detailed incremental costs by baseline technology type, see Appendix D.

As described in Section 2.4, because the IOUs need to include the baseline reflector/diffusors and housing for workpaper calculations, Navigant evaluated incremental cost both with and without baseline fixture costs, in order to represent two distinct scenarios:

3. **Luminaire Market:** For the luminaire market incremental cost, the baseline system was comprised of a lamp(s), ballast, reflector/diffusor, and the housing. The incremental cost was calculated relative to a complete LED luminaire. This scenario represented the new construction market where owners and facility managers are comparing technology options equally. It is important to note that this represents a small proportion of total installations.[23]
4. **Replacement Market:** For the replacement market, the baseline system comprised of just a lamp(s) and ballast. The replacement market baseline system does not include reflector/diffusors or housing. This scenario represented the replacement on lamp or ballast burn-out where owners and facility managers are not comparing technology options equally due to the long lifetime of commercial baseline fixtures (above 100,000 hours). This represents a relatively larger proportion of total installations.[24]

For the luminaire market scenario, in the outdoor product categories (excluding Outdoor Decorative), the low and mid-lumen output LED products, defined by DLC as 250-5,000 lumens and 5,000-10,000 lumens respectively, are often cheaper than or competitive with baseline systems. Figure 3-7 shows luminaire market incremental costs of outdoor DLC qualified LED products compared to the 25th percentile baseline costs for each priority product category. This is the comparison of entire LED luminaires to entire baseline systems, including the housing which is often the most expensive component due to its long lifetime. However, for high output products (>10,000 lumens) LED luminaire systems remain significantly more expensive than their baseline luminaires. This aligns with the results of the multiple regression analysis. The likely explanation is that an increase to lumen output for LED luminaire systems often requires scaling of the number of diodes and drivers needed for the system, thereby increasing costs.[25]

[23] Between 2015 and 2017, new construction of commercial floorspace is estimated to grow at a rate of approximately 1.1% per year according to the Energy Information Administration's Annual Energy Outlook 2017 Table: Commercial Sector Key Indicators and Consumption, https://www.eia.gov/outlooks/aeo/data/browser/#/?id=5-AEO2017&cases=ref2017&sourcekey=0. In addition, the renovation cycle for commercial end-uses varies between 7 and 22 years according to a study conducted by Boston Consulting Group: http://image-src.bcg.com/Images/BCG-How-to-Win-in-a-Transforming-Lighting-Industry-Nov-2015_tcm79-88535.pdf

[24] In contrast to new construction and the renovation of commercial spaces, the lifecycle of baseline lighting products is much shorter. Based on lifetime data collected from product catalogs, the lifetime range in commercial end uses for incandescent and halogen products is 0.6 to 1.2 years, for compact fluorescent is 1.4 to 1.7 years, for linear fluorescent is 2.2 to 5.1 years and for high intensity discharge is 3.7 to 6.1 years. Commercial operating hour assumptions provided in the Department for Energy's 2010 U.S. Lighting Market Characterization (Table 4.6) report were used to develop these lifetime ranges: https://www1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf

[25] In contrast to new construction and the renovation of commercial spaces, the lifecycle of baseline lighting products is much shorter. Based on lifetime data collected from product catalogs, the lifetime range in commercial end uses for incandescent and halogen products is 0.6 to 1.2 years, for compact fluorescent is 1.4 to 1.7 years, for linear fluorescent is 2.2 to 5.1 years and for high intensity discharge is 3.7 to 6.1 years. Commercial operating hour assumptions provided in the Department for Energy's 2010 U.S. Lighting Market Characterization (Table 4.6) report were used to develop these lifetime ranges: https://www1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf

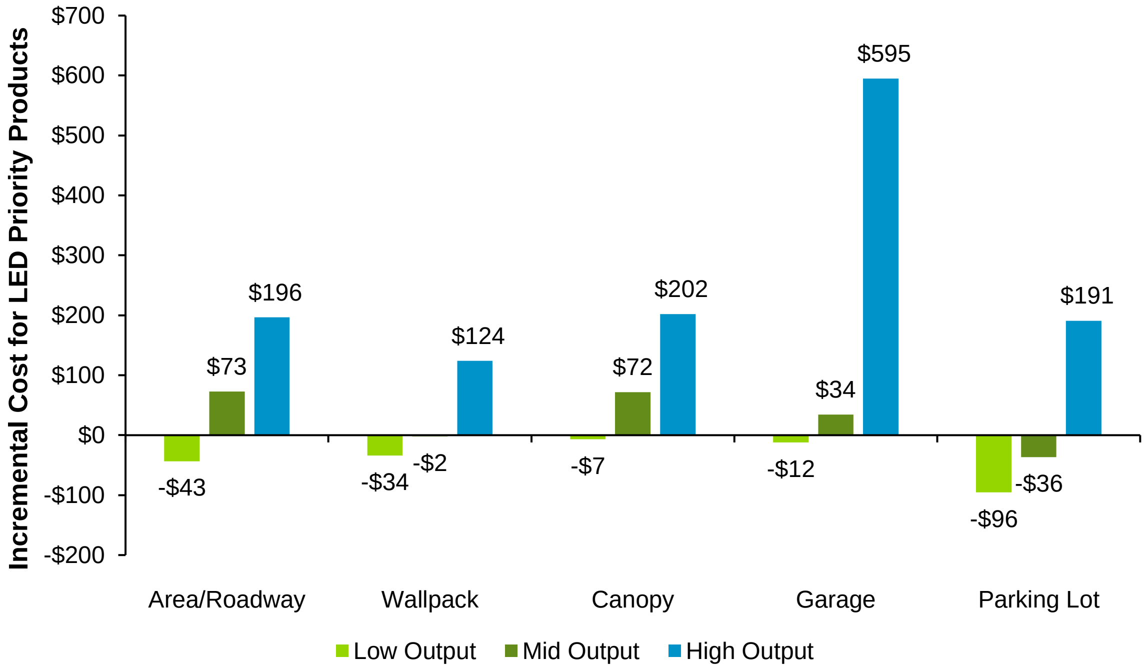

Figure 3-7 Incremental Cost for DLC Qualified Outdoor Product Categories – Luminaire Market

LED products are competitive in the luminaire market, but in the replacement market, DLC qualified LED products have higher incremental costs and remain more expensive across all outdoor product categories and all lumen ranges. Figure 3-8 shows the replacement market incremental costs of LED systems in outdoor priority product categories. It is important to note that the replacement market compares the complete fixture system price of LED luminaires, but only lamp(s) and ballasts of baseline equivalents. When replacing a baseline system with another baseline system on burnout, typically only the lamp and ballast need to be replaced, thereby reducing the cost-competitiveness of LED luminaires which integrate the entire lighting system into one product.

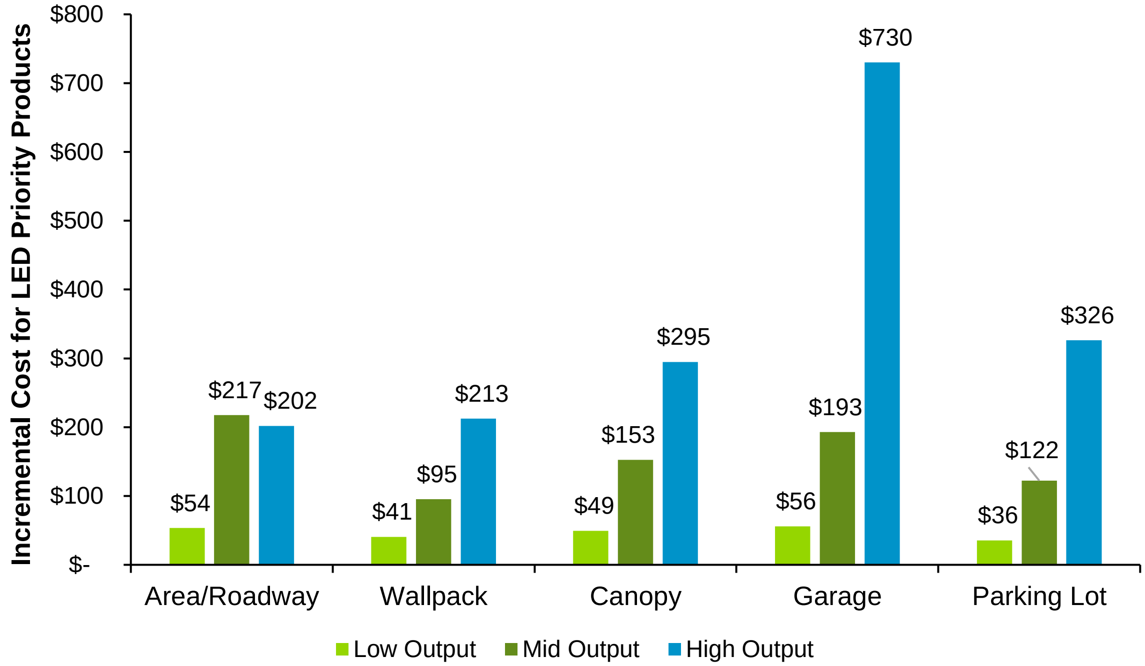

Figure 3-8 Incremental Cost for DLC Qualified Outdoor Product Categories – Replacement Market

Figure 3-9 shows the incremental cost of DLC and ENERGY STAR qualified[26] indoor priority products for the luminaire market. All LED priority product categories still command a price premium relative to their equivalent baseline technology systems when considering an entire luminaire of lamp(s), ballast, reflector/diffuser, and housing.

[26] ENERGY STAR qualification is only relevant for the LED Downlight and Outdoor Decorative priority product category.

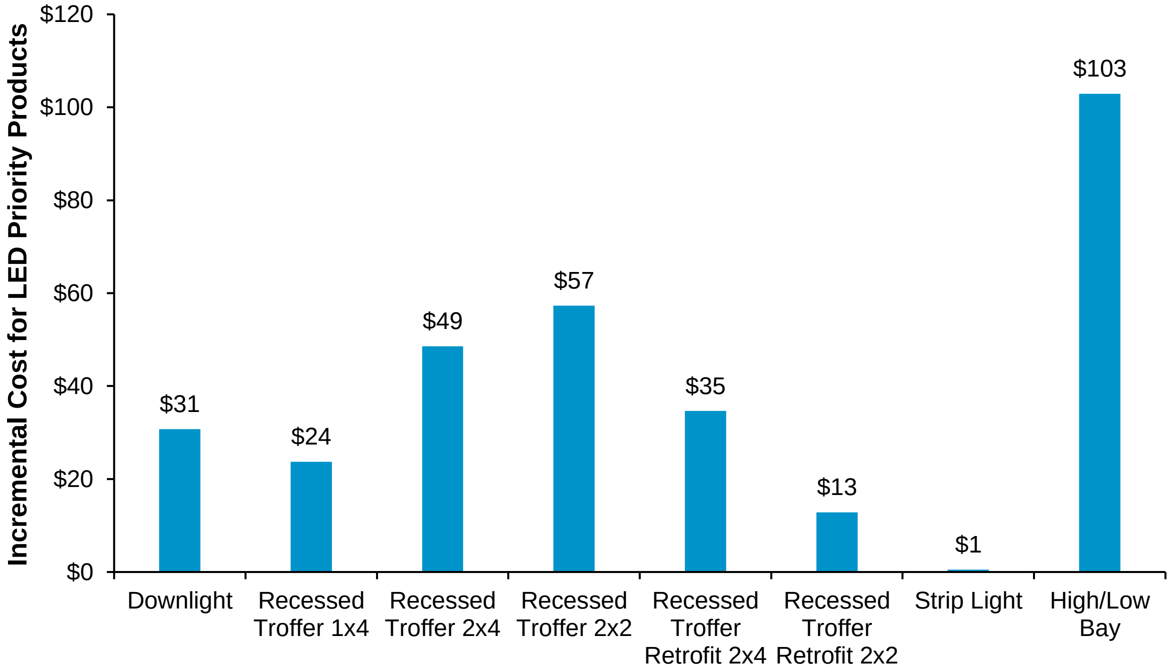

Figure 3-9 Incremental Cost for DLC and ENERGY STAR Qualified Indoor Product Categories – Luminaire Market

Figure 3-10 shows the incremental cost of indoor priority products for the replacement market, which compares complete DLC and ENERGY STAR qualified LED product systems with only the baseline lamp(s) and ballast. In the replacement market, DLC and ENERGY STAR qualified LED products are still more expensive across every indoor priority product category. However, the replacement market incremental cost measures the cost incurred on burn-out of a previous installed lamp and ballast. Therefore, when only comparing the replacement cost, baseline systems are significantly cheaper.

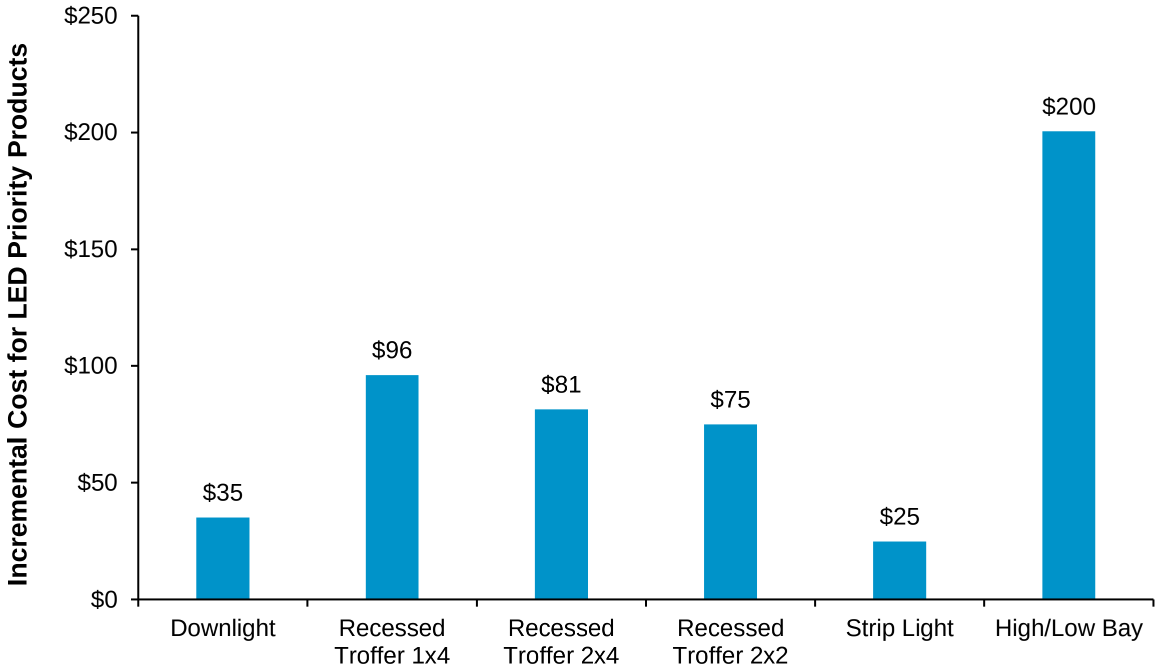

Figure 3-10 Incremental Cost for DLC and ENERGY STAR Qualified Indoor Product Categories – Replacement Market

DLC qualified High/Low Bay LED products showed a relatively high incremental cost in the replacement market, because the high-output fluorescent technology utilized in baseline High/Low Bay products is relatively inexpensive. Furthermore, High/Low Bay products have a very large range of lumen output, with some products providing up to 80,000 lumens.

Navigant also evaluated the incremental cost of Indoor Decorative and ENERGY STAR qualified Outdoor Decorative products. However, decorative products present a unique case from a pricing perspective because pricing for these products is heavily influenced by the architectural and aesthetic qualities of the fixture, rather than any technical characteristics. In the two decorative categories, the price of the fixture housing ranges from prices as low as $20 to well above $5,000. Consequently, calculation of a nominal incremental cost may not be as useful for IOU incentive programs regarding decorative products as it is for other product categories. As shown in Figure 3-11, the price for decorative LED products was shown to be slightly less expensive than baseline decorative lighting systems in the luminaire market.

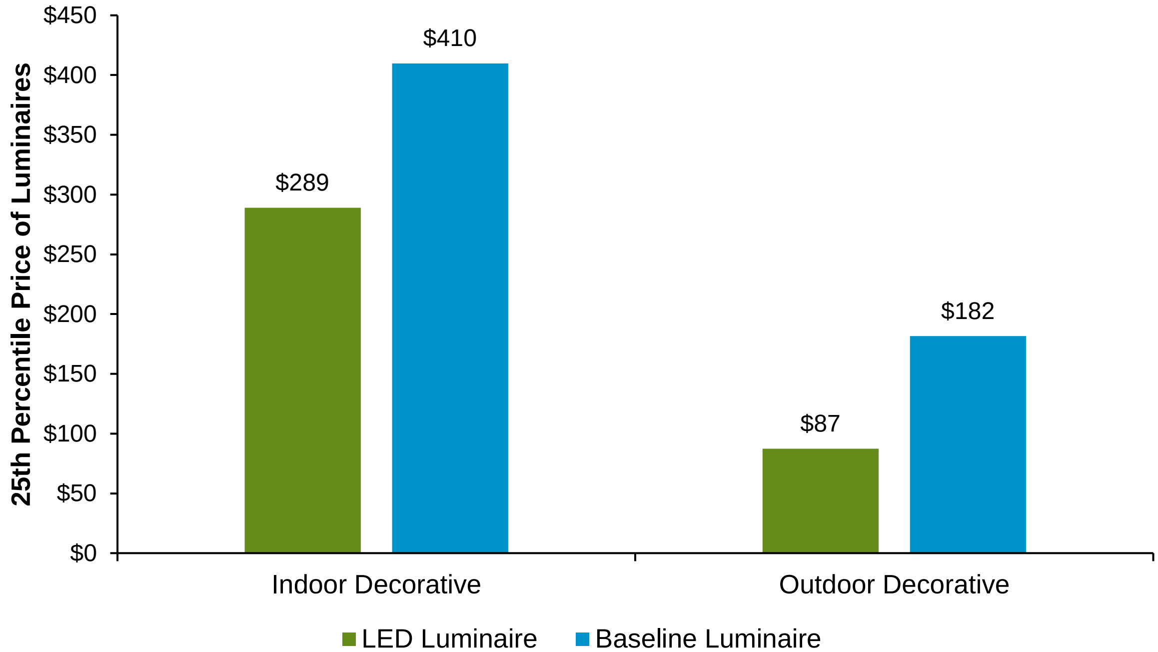

Figure 3-11 Incremental Cost for Indoor Decorative and ENERGY STAR Qualified Outdoor Decorative Product Categories – Luminaire Market

The prices of Indoor Decorative and ENERGY STAR qualified Outdoor Decorative LED luminaires are noticeably lower than their baseline counterparts, thereby leading to a negative incremental cost when comparing LED luminaires to baseline luminaires for decorative products. The likely reason is that high-end LED decorative products are not prioritizing ENERGY STAR certification, so high efficacy performance is less important than the aesthetic design of the product. Therefore, decorative LED products that do meet the ENERGY STAR technical requirements are likely more focused on targeting consumers that value performance over high-end aesthetics. However, as seen in Figure 3-12, when comparing the incremental cost in the replacement market scenario, which removes the cost of the baseline fixture, LED decorative products are substantially more expensive than the baseline products.

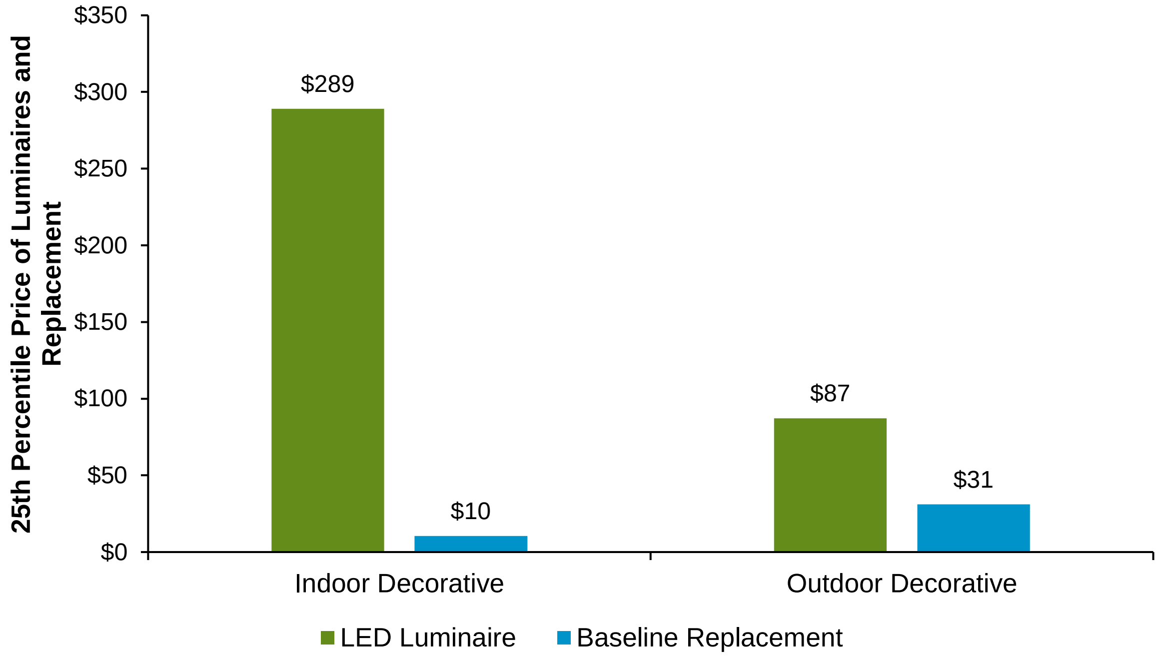

Figure 3-12 Incremental Cost for Indoor Decorative and ENERGY STAR Qualified Outdoor Decorative Product Categories – Replacement Market

As described above, the replacement market price of baseline decorative products is significantly lower than their complete LED luminaire counterparts, because the baseline system in the replacement market does not include the cost of the fixture housing, which is the most expensive component of a lighting system. This is particularly true of decorative products where the fixture housing is priced based on aesthetic value.

Furthermore, halogen and incandescent technology does not use a ballast, as power regulation is not necessary when driving current through filament material to produce light. This causes an even lower replacement market cost in these baseline systems. Consequently, incremental cost calculations, when used in the context of utility incentive programs, may require careful consideration or additional analysis in the case of indoor and outdoor decorative products.

3.5 LED Price Projections

Navigant's 5-year LED price projections for the 15 priority product categories range from years 2017 to 2022. In each of the 15 product categories, the prices of DLC and ENERGY STAR qualified LED luminaires are expected to continue to decline. For detailed, product specific year-by-year price projections, see Appendix E. Figure 3-13 shows the price projection of DLC qualified Troffer/Panel LED products, as well as Retrofit Kits. Between 2017 and 2022, prices for these LED products are expected to decline on average by 40% from current price levels. For DLC qualified Recessed Troffer/Panel LED luminaires, the *rate* of price decline remains flat through this 5-year horizon, and are expected to decline at an annualized rate of 9%.

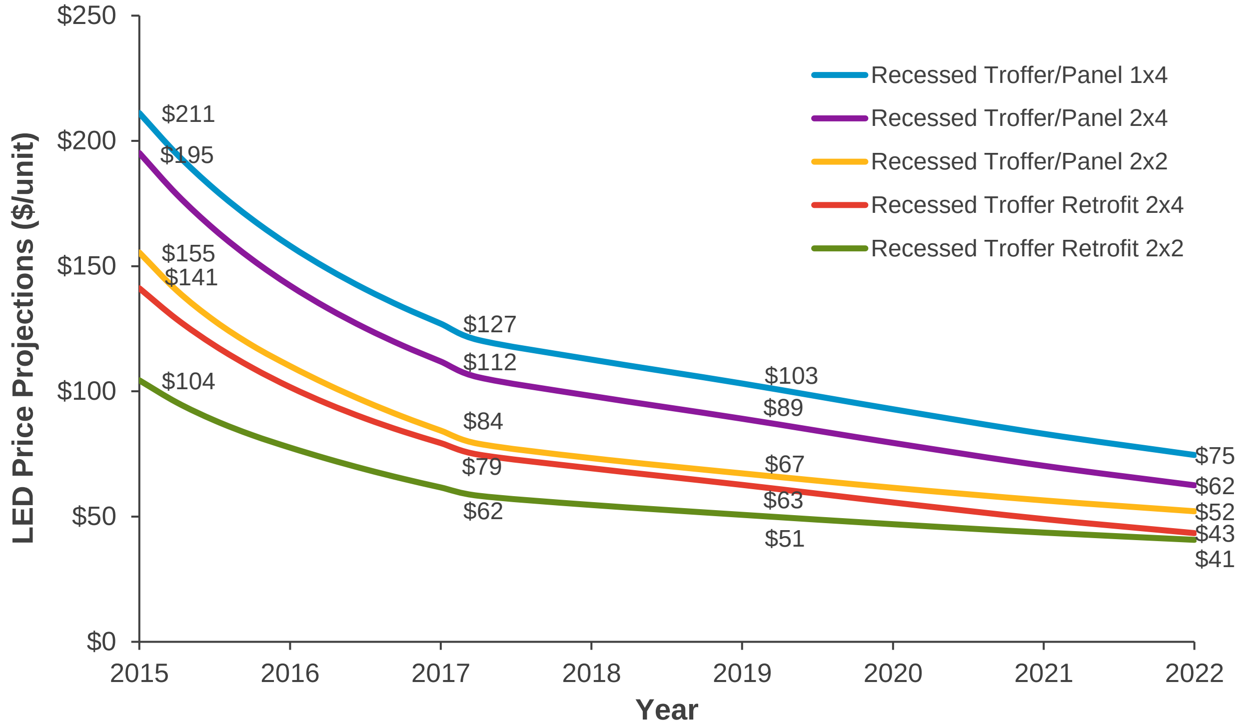

Figure 3-13 Price Projection of DLC qualified Recessed Troffer/Panel LED Products

From 2017 to 2022, the remaining indoor DLC and ENERGY STAR qualified LED products are expected to decline on average by 42% as shown in Figure 3-14. Unlike troffer and panel products, the rate of price decline of the remaining DLC and ENERGY STAR qualified indoor LED product categories is expected to decrease. From 2017 to 2020, these indoor LED luminaires are expected to decline at an annualized rate of 9%, while from 2020 to 2022 they are expected to decline at a lower annualized rate of 7%.

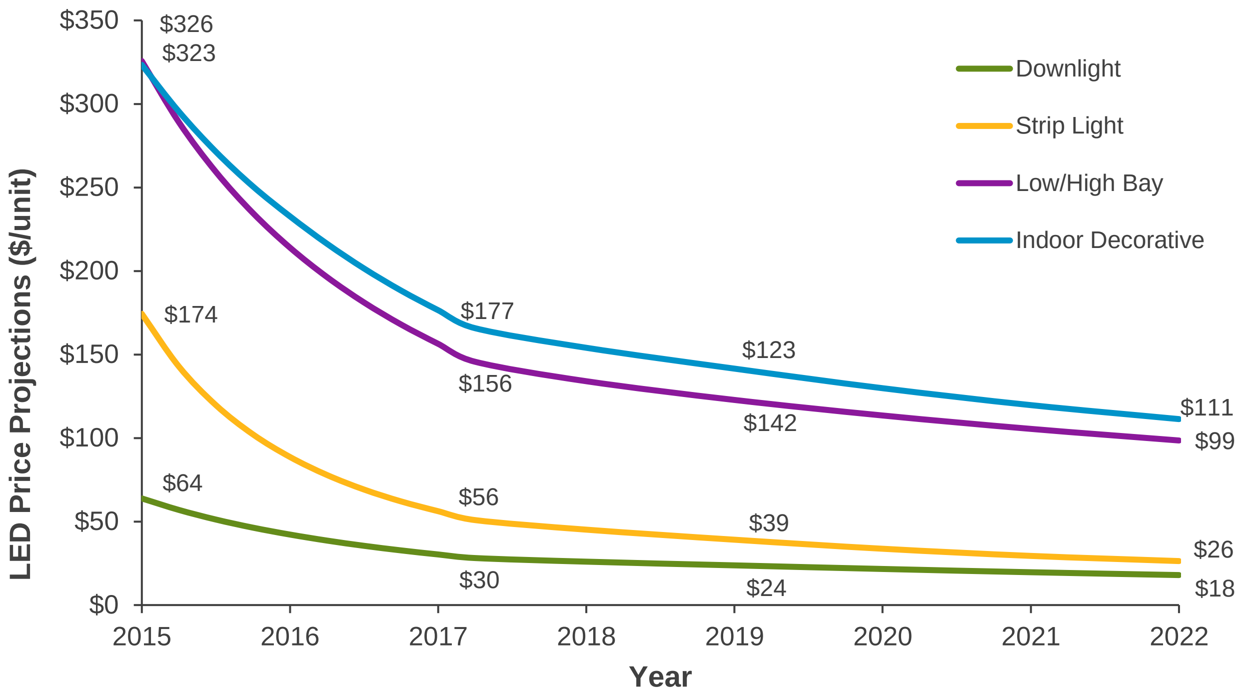

Figure 3-14 Price Projection of Remaining DLC and ENERGY STAR qualified Indoor LED Products

Figure 3-15 shows the projected pricing of DLC qualified and ENERGY STAR qualified outdoor LED priority products. Between 2017 and 2022, outdoor DLC qualified and ENERGY STAR qualified LED product prices are expected to decline 35% on average. The rate of decline for outdoor products varies substantially, because some outdoor LED products, such as Wall Pack products, have a more mature market with relatively stable pricing compared to other outdoor products. According to an LED adoption report by the DOE, wall packs and other building exterior LED products had an installed market penetration of 31% nationally in 2016.[27] The relatively high saturation of LED luminaires in building exterior applications explains the low rate of decline of wall packs LED luminaires. The price decline rate of DLC and ENERGY STAR qualified outdoor LED luminaires is also expected to decrease over the next 5 years. From 2017 to 2020, these outdoor LED luminaire prices are expected to decline at an annualized rate of 10%, while from 2020 to 2022 they are expected to decline at an annualized rate of 9%.

[27] "Adoption of Light-Emitting Diodes in Common Lighting Applications", U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, July, 2017. https://energy.gov/sites/prod/files/2017/08/f35/led-adoption-jul2017_0.pdf

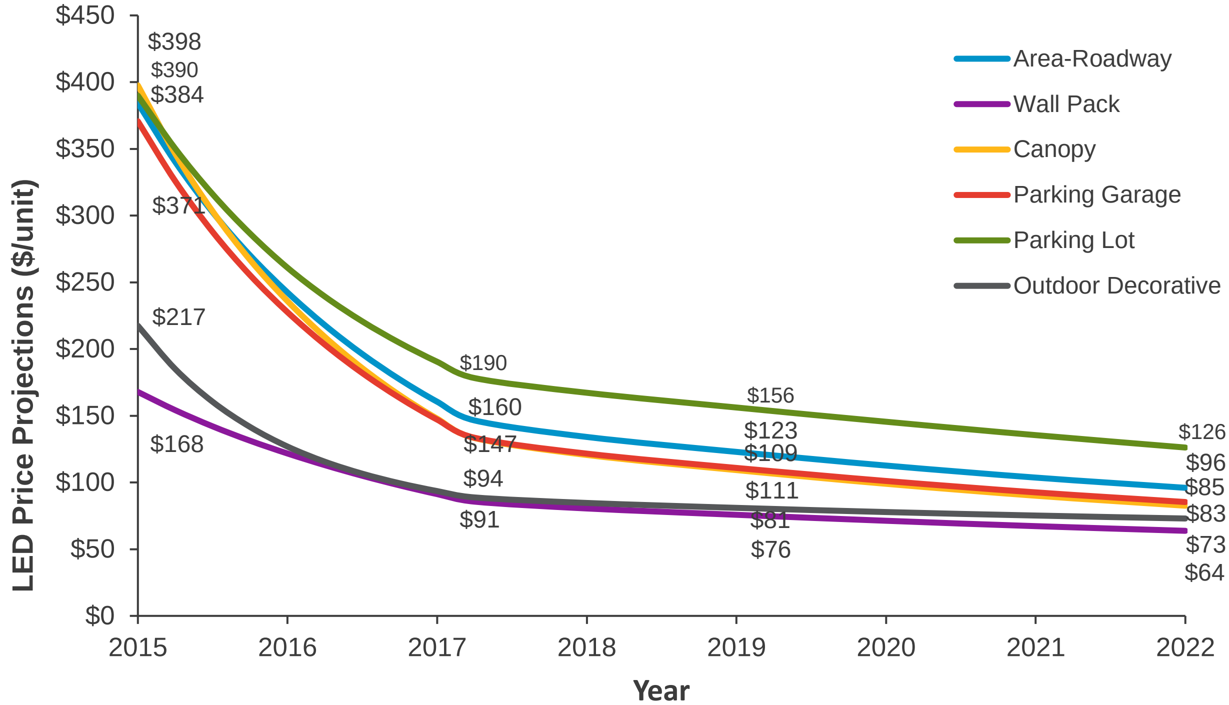

Figure 3-15 Price Projection of DLC Qualified Outdoor LED Products

The price trajectory of all 15 priority product categories assessed in this Study reveal a downward price trend for DLC and ENERGY STAR qualified LED luminaires. These price projections capture the overall, long-term trend of the LED products and do not account for quarterly price shifts due to the variety of market forces described in Section 3.1, such as sales, item promotions, or new product line offerings. The prices of certain product categories, such as Area/Roadway, show a short-term quarterly increase in price from 2016 Q4 to 2017 Q2. However, Navigant's analysis indicates that these types of price shifts are not long-term trends, and the prices of these LED product prices are still expected to continue their overall decline regardless of the recent increases in DLC technical requirements or the resulting manufacturers' product changes.

Overall, across all 15 priority product categories, the price of LED products is expected to decline 39% on average from 2017 to 2022. From an adoption standpoint, LED technology still has room for growth. Improvements to manufacturing, competition, and customer acceptance will continue to exert downward pressure on LED prices. However, the overall rate of decline of LED prices will decrease as the market share for LED products grows. Averaging across all 15 priority product categories, the annual rate of decline is 9% per year from 2017 to 2020. This rate of decline decreases to an annual rate of 8% from 2020 to 2022. This is an important consideration for IOU incentive programs as the rate of decline changes over the next 5 years and potentially will decline further beyond 2022.

3.5.1 Price Projection Comparison

When comparing the price projections from the previous 2015 California LED Workpaper Update Study to the current Study, the 2017 projected values differed from the 2017 actuals between 0% and 33% (in terms of absolute percentages). However, unlike the previous analysis, the current Study used a different calculation method (see Section 2.5) and is representative of DLC and ENERGY STAR LED products, and therefore, the results are not directly comparable. Table 3-7 shows the summary results of this comparison for the priority product categories that overlapped for each analysis.

Table 3-7 Comparison of 2015 Study Projected Values to Current 2017 Actuals

LED Product Categories	2015 Study - Projected 2017	2017 Study - Actual 2017	% Difference
Recessed Troffer 2x4	$96	$117	22%
Recessed Troffer 1x4	$114	$127	11%
Recessed Troffer 2x2	$90	$90	0%
Parking Lot	$291	$236	-19%
Parking Garage	$212	$180	-15%
Downlight Fixture	$66	$44	-33%
Wall Pack	$79	$91	15%
High/Low Bay[1]	$229	$199	-13%

1. Unlike the 2017 Study, the 2015 California LED Workpaper Update Study evaluated high and low bay LED products separately. The value in the table for the projected 2017 represents an average of the two product categories.

4. RECOMMENDATIONS

Navigant has identified the following key findings and recommendations for consideration by the IOUs and other stakeholders.

4.1 DLC Qualification

Finding: The analysis showed that across all product categories, there was no statistically significant difference in prices of LED products that are DLC qualified and those that are not but meet the same technical requirements for lumen output and efficacy.

> **Recommendation**: DLC's Technical Requirements continue to evolve and change over time, with new requirements and specification parameters being implemented periodically. IOUs should monitor and examine if DLC continues to minimally influence LED price as more LED products continue to update to meet the newer DLC Technical Requirements v4.2 and subsequent revisions. This is a particularly important step in maintaining the underlying inputs into the current LED price projections for 2017 to 2022.

4.2 LED Pricing

Finding: The prices of DLC and ENERGY STAR qualified LED products across all the indoor priority product categories are expected to continue to decline from 2017 to 2022, with an overall average of 41% decline in the 5-year period. However, the rate of decline of indoor LED prices is expected to slow from 9% annually from 2017 to 2020, to 8% annually from 2020 to 2022. For outdoor priority LED products, prices are expected to continue to decline from 2017 to 2022, with an overall average of 35% decline in the 5-year period. However, the rate of decline of outdoor LED prices is expected to slow from 10% annually from 2017 to 2020, to 9% annually from 2020 to 2022.

> **Recommendation**: IOUs should continue to monitor both indoor and outdoor LED product prices annually. The current projected LED prices from 2017 to 2022 will need to be updated to account for changes to the market, as well as any technological or significant qualification changes from DLC and ENERGY STAR.

4.3 LED Efficacy and Price Implications

Finding: The analysis results indicate that there is no correlation between the typical customer purchase price of an LED luminaire and the rated efficacy of the product. While efficacy may play a role in the manufacturing cost of the LED system, this is not necessarily translated to the prices paid by the customer. Lumen output and product manufacturer were found to be the most common price determining characteristic of LED luminaires. Furthermore, wattage and lumens are highly correlated, and therefore wattage is also considered to have a significant price determining influence on LED luminaires. As in many industries, a manufacturer's branding image can enable some to command price premiums unrelated to performance characteristics.

> **Recommendation**: Based on these findings, IOUs should carefully consider changes to the current structure of incentive programs. Since the Study results show that price and efficacy are not correlated, this tell us that the price of a low and high efficacy LED product could very well be the same. Therefore, having tiered incentives for LEDs would then make high efficacy products cheaper for the customer than low efficacy products. While this is beneficial from an energy

savings perspective, it could also lead to the additional incentive dollars being used towards higher lumen output products (thereby increasing energy use) or more premium manufacturers. The Study shows that both of these factors do lead to higher LED pricing. To control for the possible "up-sell" to a higher lumen output LED product, it may be useful to tier rebate measures by lumen output and efficacy.

4.4 Incremental Cost – Replacement Vs. Luminaire Market Scenario

Finding: The incremental cost of DLC and ENERGY STAR qualified LED products to complete baseline luminaire systems for certain priority products, particularly in the outdoor groups where DLC separates products by lumen output, were negative. This indicates that LED products were sometimes less expensive than, or comparable to, baseline systems. However, this luminaire market scenario represents a small proportion of the market, accounting primarily for new construction installations. The replacement market incremental cost, in which a complete DLC and ENERGY STAR qualified LED product is compared to a baseline lamp(s) and ballast, yields high incremental costs in every product category.

Recommendation: Currently, IOU lighting program are required to compare fixture-to-fixture price differences when structuring incentives. However, the findings of this incremental cost analysis indicate that DLC and ENERGY STAR qualified LED products have a significant incremental cost relative to baseline systems in the replacement market. IOUs should carefully consider any changes to their incentive program from the traditional fixture-to-fixture method to potentially including the replacement market. Current LED incentive levels may not be sufficient, as they do not factor in baseline lamp and ballast failures which account for the majority of customer lighting replacements.

4.5 Connected LED Lighting

As discussed in the DOE Solid-State Lighting (SSL) Program's "2017 Suggested Research Topics Supplement: Technology and Market Context" report,[28] SSL is creating an opportunity for a whole new lighting system paradigm by the broad transition of lighting infrastructure to inherently controllable SSL systems. The convergences of LED lighting, low-cost sensors, smartphones and apps, and the Internet of Things is expected to enable improved lighting quality and energy performance. In particular, connected lighting systems that can leverage occupancy sensing, daylight harvesting, high-output trim, personal area controls, or any combination of these approaches have been shown to provide energy savings as high as 20% to 60% of SSL power consumption, depending on the application and use-case.

Recommendation: As LED technology continues to mature and becomes more ubiquitous, achieving energy savings from lighting will rely on the integration of connected LED lighting systems into the built environment. IOU lighting programs should begin monitoring the price and performance of networked and connected LED lighting to help ensure that the energy savings potential of these systems is leveraged effectively now and in the future.

[28] "2017 Suggested Research Topics Supplement: Technology and Market Context", U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, September 2017. https://energy.gov/sites/prod/files/2017/09/f37/ssl_supplement_suggested-topics_sep2017_0.pdf

APPENDIX A. HYPOTHESIS TESTING: TWO SAMPLE T-TEST WITH UNEQUAL VARIANCE

The statistical test selected for this analysis was a two sample t-test with unequal variance. This test allowed us to look at two separate data samples, regardless of sample size, and determine if there is a statistically significant difference between the two datasets. The details of the methodology is explained below.

First, the hypothesis needed to be defined for this Study. In the context of the LED price analysis, the hypothesis was as follows: "there is no significant difference in the price between the two samples" (DLC qualified products and non-DLC products[29]). Generally, the null hypothesis aims to set a test value to zero. Navigant defined the null hypothesis as follows: "$\mu_1 - \mu_2 = 0$" which can be interpreted as "the difference of the two sample's averages is equal to zero." *If the t-test failed to reject the null hypothesis, this indicated that we may move forward with the assumption that there is no significant difference in price between products that are DLC qualified and non-DLC qualified for that product category.*[30]

For this analysis, Navigant used a two-tailed test. A two-tailed test is non-directional, meaning that the test does not discriminate whether one dataset is higher or lower than the other. This aligned with our analysis because we were simply testing to see if there is a significant difference between the price of DLC qualified and non-DLC qualified products, not whether one is more expensive than the other.

The next step was to set the α, called the level of statistical significance, which is the probability of rejecting the null hypothesis when it is true. For example, an α of 0.05 indicates a 5% risk of concluding that a difference between two datasets exists when there is no actual difference. **The most common α value is 0.05, and was agreed upon by Navigant and IOUs for this Study.**

In order to process multiple calculations of the large datasets in the priority product categories, Navigant employed Excel's built in t-test functionality, using both the p-value approach and the critical value approach.

The p-value approach involves determining the probability, assuming the null hypothesis were true, of observing a more extreme test statistic than the one actually observed. If the p-value is less than or equal to α, the null hypothesis is rejected, and therefore the difference between the two datasets is statistically significant. Conversely, if the p-value is greater than α, then the null hypothesis cannot be rejected.

The critical value approach involves determining whether or not the *observed* test statistic is more extreme than would be expected if the null hypothesis were true. In essence, it is a comparison of the observed test statistic to a cutoff value called the "critical value." If the observed test statistic is higher in magnitude than the critical value, then the null hypothesis is rejected.

Navigant employed both the p-value approach and the critical value approach in its analysis. Each priority product category was tested and determined separately.

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[29] These "non-DLC products" are LED products within the priority product categories that were not tagged as DLC-qualified based on data collected through Navigant's LED Price Tracker, or based on manual verification of manufacturer product specification sheets. However, these non-DLC qualified products met the lumen and efficacy requirements detailed in the DLC's Technical Requirements Version 3.1 (which was the active DLC specification as of 2016 Q4).

[30] It is important to note that the null hypothesis can only be rejected, or fail to be rejected, but not "accepted." This means the analysis can only verify that the price difference between DLC qualified and unknown products is statistically insignificant, not that there is no price difference.

The hypothesis test for DLC qualification **was done only with the 2016 Q4 LED web-based data** and compared those products that are officially DLC qualified with those that are non-DLC qualified. Additionally, these non-DLC products were filtered using the lumen and efficacy criteria described in the Technical Requirements Version 3.1[31] (which was the active DLC specification as of 2016 Q4) to eliminate products that would not qualify based on performance. By filtering the non-DLC qualified products and DLC qualified data into buckets to match the lumen and efficiency specifications of the DLC technical requirements, we achieved an accurate statistical comparison of their prices.

[31] DLC, "Technical Requirements Version 3.1," Released November 20, 2015. https://www.designlights.org/solid-state-lighting/qualification-requirements/past-technical-requirements/version-3-1-released-november-20-2015/

APPENDIX B. REGRESSION COEFFICIENTS BY PRODUCT CATEGORY

The following tables are the resulting regression coefficients from the multiple regression analysis conducted with each LED priority product category using only 2016 Q4 data. Only products with complete data for the following parameters were included in the regression: lumen output, CCT, CRI, dimmability, DLC qualification (ENERGY STAR in the case of the Downlight and Outdoor Decorative categories), and manufacturer. Furthermore, only the top 6 manufacturers by product count volume for each category were included in the Study. In addition, only manufacturers with at least 10 products in the sample set were included as a tested parameter in the regression analysis. Therefore, certain product categories were tested with fewer than 6 manufacturers. All other manufacturers (other than the top 6 manufacturers and those with above 10 samples) were included as a default category and dropped from the model to prevent the analysis from being over-specified. In each of the following tables, the regression coefficients and associated p-values[32] are given. The highest regression coefficient (that is statistically significant) is noted by bold font.

Table B - 1 shows the results of the multiple regression analysis for Area/Roadway LED products. The manufacturers included were Cree, RAB, Acuity, Hubbell Lighting, Noribachi, and Neptun Light.

Table B - 1 Area/Roadway Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	**0.57**	**0.00**
Efficacy	-0.19	0.01
CCT	0.06**	0.31
CRI	-0.03**	0.65
Dimmability	-0.03**	0.57
DLC	0.23	0.00
Cree	-0.10**	0.08
RAB	0.03**	0.58
Acuity	0.06**	0.28
Hubbell Lighting	0.13	0.02
Noribachi	0.25	0.00
Neptun Light	0.32	0.00
Sample Size		*212*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table B - 2 shows the results of the multiple regression analysis for Wall Pack LED products. The manufacturers included were Light Efficient Design and Acuity.

[32] The p-value is a statistical measure of significance. Using an alpha level of 0.05, it was possible to determine which regression coefficients were not statistically significant. If the p-value of the modeled regression coefficient was above 0.05, the regression coefficient is considered statistically insignificant. Note that all p-values in this report are rounded to two decimal places.

Table B - 2 Wall Pack Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	**0.51**	**0.00**
Efficacy	0.10**	0.30
CCT	-0.02**	0.79
CRI	-0.12**	0.21
Dimmability	0.08**	0.33
DLC	0.01**	0.89
Light Efficient Design	-0.08**	0.33
Acuity	0.33	0.00
Sample Size		*82*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table B - 3 shows the results of the multiple regression analysis for Canopy LED products. The manufacturers included were RAB, Cree, GE Lighting, and LUMAPRO.

Table B - 3 Canopy Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	0.57	0.00
Efficacy	-0.12**	0.39
CCT	0.05**	0.71
CRI	0.08**	0.53
DLC	-0.06**	0.65
RAB	**0.66**	**0.00**
Cree	0.22**	0.15
GE Lighting	0.39	0.00
LUMAPRO	-0.03**	0.77
Sample Size		*47*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table B - 4 shows the results of the multiple regression analysis for Garage LED products. The manufacturers included were Acuity, Cree, Hubbell Lighting, ILP, and LUMAPRO.

Table B - 4 Garage Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	**0.77**	**0.00**
Efficacy	-0.12**	0.26
CCT	-0.12**	0.25
CRI	-0.32	0.01
Dimmability	-0.03**	0.82
DLC	0.09**	0.48
Acuity	0.23**	0.28
Cree	0.11**	0.45
Hubbell Lighting	-0.03**	0.86
ILP	-0.05**	0.69
LUMAPRO	0.22**	0.08
Sample Size		*41*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table B - 5 shows the results of the multiple regression analysis for Parking Lot LED products. The manufacturers included were NaturaLED, LEDone, Jarvis Lights, Neptun Light, and Atlas Lighting Products.

Table B - 5 Parking Lot Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	**0.69**	**0.00**
Efficacy	-0.39	0.00
CCT	0.18**	0.07
CRI	0.12**	0.65
Dimmability	-0.29	0.00
DLC	-0.21	0.01
NaturaLED	0.05**	0.67
LEDone	-0.56	0.00
Jarvis Lights	-0.42	0.00
Neptun Light	-0.26**	0.36
Atlas Lighting Products	0.39	0.00
Sample Size		*23*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table B - 6 shows the results of the multiple regression analysis for Downlight LED products. The manufacturers included were EnviroLite, Lotus, Acuity, and Hubbell Lighting.

Table B - 6 Downlight Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	0.57	0.00
Efficacy	-0.09**	0.35
CCT	-0.07**	0.48
CRI	0.08**	0.48
Dimmability	0.18**	0.14
Energy Star	-0.33	0.00
EnviroLite	0.33	0.01
Lotus	0.50	0.00
Acuity	**0.62**	**0.00**
Hubbell Lighting	0.27**	0.06
Sample Size		*98*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table B - 7 shows the results of the multiple regression analysis for Recessed Troffer/Panel 2x4 LED products. The manufacturers included were Acuity, Cree, EnviroLite, RAB, and GE Lighting.

Table B - 7 Recessed Troffer/Panel 2x4 Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	0.02**	0.81
Efficacy	-0.11**	0.19
CCT	-0.02**	0.78
CRI	0.10**	0.44
Dimmability	0.02**	0.79
DLC	**-0.25**	**0.02**
Acuity	0.10**	0.36
Cree	0.19**	0.16
EnviroLite	0.16**	0.06
RAB	0.01**	0.94
GE Lighting	0.07**	0.40
Sample Size		*171*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table B - 8 shows the results of the multiple regression analysis for Recessed Troffer/Panel 2x2 LED products. The manufacturers included were Cree, GE Lighting, RAB, METALUX, Lithonia Lighting, and EnviroLite.

Table B - 8 Recessed Troffer/Panel 2x2 Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	0.33	0.00
Efficacy	0.03**	0.78
CCT	-0.12**	0.21
CRI	0.23**	0.14
Dimmability	-0.10**	0.38
DLC	0.12**	0.26
Cree	0.13**	0.39
GE Lighting	0.03**	0.74
RAB	0.03**	0.80
METALUX	0.04**	0.67
Lithonia Lighting	0.30	0.00
EnviroLite	**0.42**	**0.00**
Sample Size		*95*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table B - 9 shows the results of the multiple regression analysis for Recessed Troffer/Panel 1x4 LED products. The manufacturers included were Cree, PIXI, RAB, and GE Lighting.

Table B - 9 Recessed Troffer/Panel 1x4 Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	0.13**	0.66
Efficacy	-0.07**	0.71
CCT	-0.11**	0.49
CRI	**0.79**	**0.02**
Dimmability	-0.48**	0.10
DLC	0.52	0.03
Cree	0.05**	0.88
PIXI	0.00	N/A***
RAB	0.09**	0.71
GE Lighting	0.65	0.01
Sample Size		*23*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05
*** There is no p-value (significance level) because the regression coefficient is zero.

Table B - 10 shows the results of the multiple regression analysis for Recessed Troffer 2x4 Retrofit Kit LED products. The manufacturers included were Cree, Keystone, Philips Lighting, and Litetronics.

Table B - 10 Recessed Troffer Retrofit 2x4 Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	**0.60**	**0.04**
Efficacy	-0.31**	0.29
CCT	0.15**	0.54
CRI	0.05**	0.17
Dimmability	0.29**	0.31
DLC	0.91**	0.72
Cree	-0.37**	0.15
Keystone	0.03**	0.99
Philips Lighting	0.60**	0.76
Litetronics	-0.34**	0.15
Sample Size		*23*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table B - 11 shows the results of the multiple regression analysis for Recessed Troffer 2x2 Retrofit Kit LED products. The manufacturers included were Cree, Litetronics, Philips Lighting, and MaxLite.

Table B - 11 Recessed Troffer Retrofit 2x2 Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	-0.24**	0.42
Efficacy	-0.12**	0.85
CCT	0.05**	0.82
CRI	0.20**	0.58
Dimmability	-0.23**	0.49
DLC	0.09**	0.67
Cree	0.60**	0.32
Litetronics	0.01**	0.98
Philips Lighting	0.06**	0.83
MaxLite	-0.14**	0.72
Sample Size		*23*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table B - 12 shows the results of the multiple regression analysis for Strip Light LED products. The manufacturers included were Acuity, Cree, GE Lighting, Feit Electric, and ETI.

Table B - 12 Strip Light Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	**0.34**	**0.00**
Efficacy	0.23**	0.08
CCT	-0.08**	0.31
CRI	0.21**	0.08
Dimmability	0.02**	0.85
DLC	0.17**	0.09
Acuity	0.26	0.00
Cree	0.12**	0.23
GE Lighting	0.30	0.01
Feit Electric	-0.07**	0.40
ETI	-0.05**	0.48
Sample Size		*93*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table B - 13 shows the results of the multiple regression analysis for High/Low Bay LED products. The manufacturers included were Cree, Acuity, Atlas Lighting Products, GE Lighting, and TechBrite.

Table B - 13 High/Low Bay Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	**0.67**	**0.00**
Efficacy	-0.30	0.03
CCT	-0.03**	0.75
CRI	0.19**	0.19
Dimmability	-0.11**	0.38
DLC	0.23	0.04
Cree	0.06**	0.56
Acuity	0.21**	0.08
Atlas Lighting Products	0.01**	0.91
GE Lighting	0.10**	0.42
TechBrite	-0.25**	0.12
Sample Size		*52*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table B - 14Table B - 12 shows the results of the multiple regression analysis for Indoor Decorative LED products. The manufacturers included were ET2 Lighting, Sea Gull Lighting, Robert Sonneman, Tech Lighting, and Modern Forms.

Table B - 14 Indoor Decorative Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	**0.33**	**0.00**
Efficacy	-0.10**	0.28
CCT	-0.15**	0.08
CRI	0.11**	0.25
Dimmability	0.17	0.04
ET2 Lighting	0.04**	0.63
Sea Gull Lighting	-0.16**	0.07
Robert Sonneman	0.06**	0.46
Tech Lighting	-0.11**	0.19
Modern Forms	-0.11**	0.21
Sample Size		*132*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table B - 15 shows the results of the multiple regression analysis for Outdoor Decorative LED products. The manufacturers included were Hubbell Lighting, GE Lighting, Designers Fountain, Hampton Bay, and Neptun Light.

Table B - 15 Outdoor Decorative Multiple Regression Results

Parameter	Regression Coefficient*	P-value
Lumen Output	0.32	0.01
Efficacy	-0.03**	0.71
CCT	-0.05**	0.73
CRI	0.23	0.00
Dimmability	-0.03**	0.64
Hubbell Lighting	-0.12**	0.10
GE Lighting	0.18	0.01
Designers Fountain	0.08**	0.23
Hampton Bay	-0.11**	0.09
Neptun Light	**0.56**	0.00
Sample Size		*111*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

APPENDIX C. CONTROLLED REGRESSION RESULTS

The following tables provide the results of distributor and manufacturer controlled multiple regression analyses for Area/Roadway and Recessed Troffer/Panel 2x4 LED products. In many cases, controlling for distributor and manufacturer caused the product sample to have uniform parameters, such as all having the same CRI or all being DLC qualified, thereby requiring these parameters to be excluded from the regression.

Table C - 16 shows the results of the controlled multiple regression for Area/Roadway LED products. The regression was controlled to only include data for Acuity LED products sold through Grainger.

Table C - 16 Area/Roadway Multiple Regression Results, Controlled for Grainger and Acuity

Parameter	Regression Coefficient*	P-value
Lumen Output	0.78**	0.18
Efficacy	-0.17**	0.71
CCT	-0.08**	0.86
CRI	0.18**	0.71
DLC	0.31**	0.68
Sample size		*9*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table C - 17 shows the results of the controlled multiple regression for Area/Roadway LED products. The regression was controlled to only include data for Hubbell Lighting LED products sold through Grainger.

Table C - 17 Area/Roadway Multiple Regression Results, Controlled for Grainger and Hubbell Lighting

Parameter	Regression Coefficient*	P-value
Lumen Output	**0.81**	**0.00**
Efficacy	0.51**	0.06
CCT	-0.10**	0.62
CRI	-0.40**	0.13
DLC	0.26**	0.26
Sample size		*15*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table C - 18 shows the results of the controlled multiple regression for Area/Roadway LED products. The regression was controlled to only include data for Neptun Light LED products sold through Shine Retrofits.

Table C - 18 Area/Roadway Multiple Regression Results, Controlled for Shine Retrofits and Neptun Light

Parameter	Regression Coefficient*	P-value
Lumen Output	**0.92**	**0.00**
Efficacy	-0.66	0.00
CRI	-0.26	0.00
Sample size		*31*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.

Table C - 19 shows the results of the controlled multiple regression for Area/Roadway LED products. The regression was controlled to only include data for Noribachi LED products sold through Shine Retrofits.

Table C - 19 Area/Roadway Multiple Regression Results, Controlled for Shine Retrofits and Noribachi

Parameter	Regression Coefficient*	P-value
Lumen Output	**0.70**	**0.00**
Efficacy	0.16**	0.39
Sample size		*25*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table C - 20 shows the results of the controlled multiple regression for Recessed Troffer/Panel 2x4 LED products. The regression was controlled to only include data for Acuity LED products sold through Walmart.com.

Table C - 20 Recessed Troffer/Panel 2x4 Multiple Regression Results, Controlled for Walmart.com and Acuity

Parameter	Regression Coefficient*	P-value
Lumen Output	**0.29****	0.12
Efficacy	-0.17**	0.32
CCT	0.16**	0.44
CRI	-0.25**	0.24
Dimmable	0.11**	0.53
Sample size		*35*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table C - 21 shows the results of the controlled multiple regression for Recessed Troffer/Panel 2x4 LED products. The regression was controlled to only include data for GE Lighting LED products sold through Grainger.

Table C - 21 Recessed Troffer/Panel 2x4 Multiple Regression Results, Controlled for Grainger and GE Lighting

Parameter	Regression Coefficient*	P-value
Lumen Output	0.06**	0.63
Efficacy	-0.05**	0.76
CCT	**0.99**	**0.01**
DLC	0.06**	0.76
Sample size		*9*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table C - 22 shows the results of the controlled multiple regression for Recessed Troffer/Panel 2x4 LED products. The regression was controlled to only include data for EnviroLite LED products sold through Home Depot.

Table C - 22 Recessed Troffer/Panel 2x4 Multiple Regression Results, Controlled for Home Depot and EnviroLite

Parameter	Regression Coefficient*	P-value
Lumen Output	0.18**	0.66
Efficacy	0.09**	0.94
CRI	-0.21**	0.87
Sample size		*14*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

Table C - 23 shows the results of the controlled multiple regression for Recessed Troffer/Panel 2x4 LED products. The distributor was controlled to only include data for TCP Lighting LED products sold through 1000Bulbs.com.

Table C - 23 Recessed Troffer/Panel 2x4 Multiple Regression Results, Controlled for 1000Bulbs and TCP Lighting

Parameter	Regression Coefficient*	P-value
Lumen Output	0.66**	0.23
Efficacy	-0.24**	0.68
CRI	-0.06**	0.91
Sample size		*8*

* All data was standardized prior to the regression analysis; therefore, the coefficients are unitless.
** Indicates the coefficient was determined to be statistically insignificant at an alpha level of 0.05

APPENDIX D. INCREMENTAL COST OF PRIORITY LED PRODUCTS BY BASLINE TECHNOLOGY

D.1 Outdoor LED Priority Products

Table D - 24 and Table D - 25 below provide a detailed comparison of outdoor DLC and ENERGY STAR qualified LED products to their relative baseline technologies for the luminaire and replacement market scenarios, respectively. For the luminaire market incremental cost, the baseline system comprised of a lamp(s), ballast, reflector/diffusor, and the housing. The incremental cost was calculated relative to a complete LED luminaire or retrofit product. For the replacement market, the baseline system comprised of just a lamp(s) and ballast. The replacement market baseline system does not include reflector/diffusors or housing. Each product category is broken into Low, Mid, and High lumen output groups as defined by DLC technical requirements.

Table D - 24 Outdoor LED Priority Product Luminaire Market Incremental Cost

LED Priority Product Category	Baseline Technology	DLC Lumen Output Group	LED Luminaire Cost ($)	Baseline Luminaire Cost ($)	Incremental Cost ($)
Area/Roadway	HPS	Low	134	175	-42
		Mid	286	211	75
		High	468	270	198
	MH	Low	134	179	-45
		Mid	286	215	71
		High	468	272	195
Wallpack	HPS	Low	90	130	-40
		Mid	145	126	19
		High	290	154	136
	MH	Low	90	177	-87
		Mid	145	189	-44
		High	290	179	111
	CFL	Low	90	65	25
		Mid	145	124	21
		High	--	--	--
Canopy	HPS	Low	100	149	-49
		Mid	228	96	131
		High	388	131	257
	MH	Low	100	161	-61
		Mid	228	106	122
		High	388	240	147
	CFL	Low	100	97	3
		Mid	228	265	-38

		High	--	--	--
	T8	Low	100	61	39
		Mid	--	--	--
		High	--	--	--
	T5	Low	100	66	34
		Mid	--	--	0
		High	--	--	0
Garage	HPS	Low	113	188	-75
		Mid	270	183	87
		High	823	198	625
	MH	Low	113	235	-122
		Mid	270	289	-19
		High	823	258	565
	T8	Low	113	36	77
		Mid	--	--	--
		High	--	--	--
	T5	Low	113	41	72
		Mid	--	--	--
		High	--	--	--
Parking Lot	HPS	Low	116	188	-73
		Mid	200	183	16
		High	419	198	221
	MH	Low	116	234	-119
		Mid	200	289	-89
		High	419	258	161

Table D - 25 Outdoor LED Priority Product Replacement Market Incremental Cost

LED Priority Product Category	Baseline Technology	DLC Lumen Output Group	LED Luminaire Cost ($)	Baseline Replacement Cost ($)	Incremental Cost ($)
Area/Roadway	HPS	Low	134	66	68
		Mid	286	68	217
		High	468	90	378
	MH	Low	134	95	39
		Mid	286	86	200
		High	468	96	372
Wallpack	HPS	Low	90	55	35
		Mid	145	59	85
		High	290	77	213
	MH	Low	90	73	17
		Mid	145	64	80
		High	290	79	212
	CFL	Low	90	20	70
		Mid	145	24	120
		High	--	--	--
Canopy	HPS	Low	100	66	34
		Mid	228	68	159
		High	388	90	298
	MH	Low	100	95	5
		Mid	228	86	142
		High	388	96	292
	CFL	Low	100	25	75
		Mid	228	70	157
		High	--	--	--
	T8	Low	100	24	76
		Mid	--	--	--
		High	--	--	--
	T5	Low	100	44	56
		Mid	--	--	--
		High	--	--	--
Garage	HPS	Low	113	66	47
		Mid	270	68	202
		High	823	90	733
	MH	Low	113	95	18
		Mid	270	86	184

		High	823	96	727
	T8	Low	113	24	89
		Mid	--	--	--
		High	--	--	--
	T5	Low	113	44	69
		Mid	--	--	--
		High	--	--	--
Parking Lot	HPS	Low	116	66	50
		Mid	200	68	131
		High	419	90	329
	MH	Low	116	95	21
		Mid	200	86	114
		High	419	96	323

Table D – 26 shows the sample size of the baseline and LED product data that was used in the calculation of the outdoor priority product incremental costs shown in Table D – 25 and Table D – 24.

Table D - 26 Outdoor Priority Products – 2016 Q4 Incremental Cost Sample Size

Priority Product Category	Baseline Sample Size				LED Sample Size
	Technology	Lamp	Ballast	Fixture	Luminaire
Area/Roadway	HPS	144	137	13	361
	MH	574	322	13	
Wall pack	HPS	144	137	19	318
	MH	574	322	20	
	CFL	411	30	20	
Canopy	HPS	144	137	2	74
	MH	574	322	4	
	T8	440	262	448	
	T5	242	55	129	
	CFL	411	30	2	
Garage	HPS	144	137	41	60
	MH	574	322	77	
	T8	440	262	448	
	T5	242	55	129	
Parking Lot	HPS	144	137	41	103
	MH	574	322	77	

D.2 Indoor and Decorative LED Priority Products

Table D - 27 and Table D - 28 below provide a detailed comparison of indoor DLC and ENERGY STAR qualified LED products to their relative baseline technologies for the luminaire and replacement market scenarios, respectively. For the luminaire market incremental cost, the baseline system comprised of a lamp(s), ballast, reflector/diffusor, and the housing. The incremental cost was calculated relative to a complete LED luminaire or retrofit product. For the replacement market, the baseline system comprised of just a lamp(s) and ballast. The replacement market baseline system does not include reflector/diffusors or housing. Note that Outdoor Decorative products are listed here to provide side-by-side comparison with Indoor Decorative products.

Table D - 27 Indoor LED Priority Product Luminaire Market Incremental Cost

LED Priority Product Category	Baseline Technology	LED Luminaire Cost ($)	Baseline Luminaire Cost ($)	Incremental Cost ($)
Downlights	CFL	45	19	26
	Halogen	45	15	31
	Incandescent	45	10	35
Recessed Troffer 1x4	T8	127	71	55
	T5	127	134	-8
Recessed Troffer 2x4	T8	116	65	51
	T5	116	71	46
Recessed Troffer 2x2	T8	110	51	59
	T5	110	54	56
Recessed Troffer 2x4 Retrofit	T8	86	39	46
	T5	86	63	23
Recessed Troffer 2x2 Retrofit	T8	64	39	25
	T5	64	63	1
Strip Light	T8	60	75	-15
	T5	60	44	16
High/Low Bay	T8HO	241	121	120
	T5HO	241	156	85
Indoor Decorative	CFL	289	539	-250
	Halogen	289	311	-22
	Incandescent	289	379	-90
Outdoor Decorative	CFL	87	321	-234
	Halogen	87	317	-230
	Incandescent	87	16	72
	MH	87	72	15

Table D - 28 Indoor LED Priority Product Replacement Market Incremental Cost

LED Priority Product Category	Baseline Technology	LED Luminaire Cost ($)	Baseline Replacement Cost ($)	Incremental Cost ($)
Downlights	CFL	45	25	20
	Halogen	45	5	40
	Incandescent	45	1	45
Recessed Troffer 1x4	T8	127	20	107
	T5	127	41	86
Recessed Troffer 2x4	T8	116	23	93
	T5	116	47	70
Recessed Troffer 2x2	T8	110	23	87
	T5	110	47	63
Strip Light	T8	60	23	37
	T5	60	47	13
High/Low Bay	T8HO	241	32	209
	T5HO	241	50	192
Indoor Decorative	CFL	289	25	264
	Halogen	289	5	284
	Incandescent	289	1	288
Outdoor Decorative	CFL	87	25	62
	Halogen	87	5	82
	Incandescent	87	1	87
	MH	87	93	-6

Table D – 29 shows the sample size of the baseline and LED product data that was used in the calculation of the indoor and decorative priority product incremental costs shown in Table D – 27 and Table D – 28.

Table D - 29 Indoor Priority Products – 2016 Q4 Incremental Cost Sample Size

Priority Product Category	Baseline Sample Size				LED Sample Size
	Technology	Lamp	Ballast	Fixture	Luminaire
Downlights	CFL	452	30	266	116
	Halogen	261	-*	113	
	Incandescent	571	-*	113	
Recessed Troffer 1x4	T8	257	262	12	25
	T5	96	55	6	
	T8	257	262	49	180

Recessed Troffer 2x4	T5	96	55	12	
Recessed Troffer 2x2	T8	68	262	13	122
	T5	58	55	12	
Recessed Troffer 2x4 Retrofit	T8	257	262	-**	27
	T5	96	55	-**	
Recessed Troffer 2x2 Retrofit	T8	68	262	-**	28
	T5	58	55	-**	
Strip Light	T8	440	262	241	147
	T5	242	55	29	
High/Low Bay	T8HO	19	11	67	106
	T5HO	100	43	27	
Indoor Decorative	CFL	452	30	184	291
	Halogen	261	-*	385	
	Incandescent	571	-*	447	
Outdoor Decorative	CFL	452	30	8	249
	Halogen	261	-*	2	
	Incandescent	571	-*	5	
	MH	589	322	0***	

* Halogen and incandescent technologies do not utilize ballasts
**The baseline comparisons in retrofit kits were calculated without the cost of the fixture housing
***Outdoor decorative fixture costs for MH technology were unavailable. Incremental costs for MH Outdoor Decorative was calculated using non-technology specific outdoor decorative fixture costs.

APPENDIX E. DLC AND ENERGY STAR QUALIFIED LED LUMINAIRE PRICE PROJECTIONS BY YEAR

Table E - 30 provides the price forecast by LED product category for DLC and ENERGY STAR qualified luminaires. The “2017 Recorded” price indicates the web-scraped 25th percentile price of each priority LED product category at the time of 2017 Q2.

Table E - 30 DLC and ENERGY STAR Qualified LED Luminaire Price Projections

LED Priority Product Category	2017 Recorded	2017	2018	2019	2020	2021	2022	Annualized Decline
Area/Roadway	$241	$160	$134	$123	$113	$104	$96	8%
Downlight	$44	$30	$26	$24	$22	$20	$18	8%
Recessed Troffer/Panel 1x4	$184	$127	$113	$103	$93	$83	$75	8%
Recessed Troffer/Panel 2x4	$117	$112	$98	$89	$79	$70	$62	9%
Recessed Troffer/Panel 2x2	$90	$84	$73	$67	$62	$56	$52	8%
Recessed Troffer - Retrofit 2x4	$93	$79	$69	$63	$56	$49	$43	9%
Recessed Troffer - Retrofit 2x2	$93	$62	$55	$51	$47	$44	$41	7%
Wall Pack	$91	$91	$81	$76	$71	$67	$64	6%
Canopy	$173	$148	$121	$109	$99	$90	$83	9%
Garage	$180	$147	$122	$111	$101	$93	$85	8%
Parking Lot	$236	$190	$167	$156	$145	$135	$126	7%
Strip Light	$60	$56	$45	$39	$34	$29	$26	11%
High/Low Bay	$199	$156	$134	$123	$113	$105	$99	7%
Indoor Decorative	$178	$177	$154	$142	$130	$120	$111	7%
Outdoor Decorative	$78	$94	$85	$81	$78	$75	$73	4%

APPENDIX F. SUMMARY OF FINDINGS AND RECOMMENDATIONS

Study ID	**Study Type**	**Study Title**	**Study Manager**		
		California LED Pricing Analysis	SCE		
Recommendation	**Program**	**Summary of Findings**	**Additional Supporting Information**	**Best Practice / Recommendations**	**Recommendation Recipient**
1		There was no statistically significant difference in prices of LED products that are DLC qualified and those that are not but meet the same technical requirements for lumen output and efficacy.	Detailed significance testing results are presented in Section 2.1.1 and Table 2-1.	IOUs should monitor if DLC continues to minimally influence LED price as both LED products and DLC Technical Requirements are updated. This is a particularly important step in maintaining the underlying inputs into the current LED price projections for 2017 to 2022.	All IOUs
2		The prices of DLC and ENERGY STAR qualified priority LED products are expected to continue to decline. Indoor priority LED products are expected to decline 41% from 2017 to 2022. Outdoor priority LED product prices are expected to decline 35% from 2017 to 2022.	Detailed LED price projections are given in Section 3.5.	IOUs should continue to monitor LED product prices annually. The current projected LED prices from 2017 to 2022 will need to be updated to account for changes to the market, as well as any technological or significant qualification changes from DLC and ENERGY STAR.	All IOUs
3		The analysis results indicate that there is no correlation between the typical customer purchase price of an LED luminaire and the rated efficacy of the product. While efficacy may play a role in the manufacturing cost of the LED system, this is not necessarily translated to the prices paid by the customer. Lumen output and product manufacturer were found to be the most common price determining characteristic of LED luminaires.	Detailed analysis results are presented in Section 3.3.	IOUs should carefully consider changes to the current structure of incentive programs. Since the Study results show that price and efficacy are not correlated, this indicates that the price of a low and high efficacy LED product could very well be the same. To control for the possible "up-sell" to a higher lumen output LED product, it may be useful to tier rebate measures by lumen output and efficacy.	All IOUs
4		The incremental cost of DLC and ENERGY STAR qualified LED products to complete baseline luminaire systems for certain priority products were negative (LED products were sometimes less expensive than, or comparable to, baseline systems). However, this luminaire market scenario represents a	Detailed incremental cost analysis results are presented in Section 3.4.	The findings indicate that DLC and ENERGY STAR qualified LED products have a significant incremental cost relative to baseline systems in the replacement market. IOUs should carefully consider any changes to their incentive program from the traditional fixture-to-fixture method to potentially	All IOUs

		small proportion of the market (new construction installation). The replacement market incremental cost, in which a complete DLC and ENERGY STAR qualified LED product is compared to a baseline lamp(s) and ballast, yields high incremental costs in every product category.		including the replacement market. Current LED incentive levels may not be sufficient, as they do not factor in baseline lamp and ballast failures which account for the majority of customer lighting replacements.	
5		As discussed in the DOE Solid-State Lighting (SSL) Program's "2017 Suggested Research Topics Supplement: Technology and Market Context" report, SSL is creating an opportunity for a whole new lighting system paradigm by the broad transition of lighting infrastructure to inherently controllable SSL systems. Connected lighting systems that can leverage occupancy sensing, daylight harvesting, high-output trim, personal area controls, or any combination of these approaches have been shown to provide energy savings as high as 20% to 60% of SSL power consumption, depending on the application and use-case.	DOE SSL report "2017 Suggested Research Topics Supplement: Technology and Market Context"	IOU lighting programs should begin monitoring the price and performance of networked and connected LED lighting to help ensure that the energy savings potential of these systems is leveraged effectively now and in the future.	All IOUs