NAVIGANT

California LED Workpaper Update Study

Final Report

Prepared for:
Southern California Edison, Pacific Gas & Electric, and San Diego Gas & Electric

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Executive Summary

Southern California Edison (SCE) contracted Navigant Consulting, Inc. (Navigant) on behalf of California's electric Investor Owned Utilities (IOUs) to update key parameters and methodologies used in the statewide light-emitting diode (LED) lighting workpapers.

Between May and August of 2014, Navigant collaborated with IOU stakeholders to identify and prioritize the research objectives and LED product categories to be included in the study. The final set of research objectives selected, focused on three key topics:

- LED **pricing**
- **Non-residential baseline** wattages (which inform the selection of appropriate wattage reduction ratios or wattage ranges)
- The ability of the currently used **savings estimation methods** to predict non-residential baselines (e.g., wattage reduction ratio and wattage ranges)

Prescriptive LED lighting measures in California use one of two savings estimation methodologies: wattage reduction ratios (WRRs) and wattage ranges. Wattage reduction ratios are the ratio of the deemed baseline wattage to the deemed LED wattage. The May 2014 lighting retrofit disposition provides guidance that a designated ratio must be applied to the lowest LED wattage within the range of wattages established for a LED product category (i.e. 6 – 10 W LED for A-19 lamps). The wattage ranges method maps LED wattages to baseline technology wattage ranges within various LED luminaire product categories, and savings are calculated as the difference between the lowest baseline technology wattage in the baseline range and the highest LED technology wattage in the LED range.

Table 1-1 shows the final list of product categories selected, divided into lamps (i.e. screw-in products) and luminaires. This division of product category is important to note, as each group uses a specific savings estimation methodology and carries a unique set of assumptions and findings.

Table ES-1. Priority LED Product Categories

LED Lamps*	
A19	
MR16/PAR16	
PAR20, BR20, R20	
BR30, R30	
R40, BR40	
PAR30	
PAR38	
Downlight Retrofit	

LED Luminaires	
Downlight Fixture	
Recessed Troffer	
High/Low Bay	
Parking Garage	
Parking Lot	
Wall Pack	

Source: Navigant summary of outcomes from discussions with IOU and CPUC staff during June and August

Data Collection

Between June of 2014 and May 2015, Navigant conducted the following primary data collection activities.

- Non-residential market-actor surveys
  - Phone and web surveys
    - Contractors
    - Distributors
    - Commercial End-Users
  - In-depth interviews
    - Manufacturers
    - Retailers
- Web-scraping[1] of LED (and non-LED) pricing and lighting specification data

In addition to primary data, the team used the following secondary data source:

- DOE pricing data - CALiPER, Gateway, SSL Municipal Consortium
- Qualified products list - Design Lights Consortium, LED Lighting Facts
- Pricing data from SCE's midstream pilot.

[1] Web-scraping is a technique used for extracting information from websites, thereby transforming unstructured data on the web into structured data that can be stored and analyzed.

Pricing Analysis Findings

As a key input to cost effectiveness, product price has been a critical yet difficult parameter to characterize and predict for LED products. The primary research objectives of the LED pricing analysis are to:

1. Develop current price estimates for high priority LED products
2. Determine the factors that significantly affect LED price
3. Project LED prices and determine how often assumptions need to be updated
4. Compare LED prices to applicable baseline prices
5. Predict price impacts on forecasted LED penetration

This section describes the findings and results of the LED pricing analysis by research objective. The detailed methodology of this analysis is included in Section 2 and Appendix A.3.

Current Price Estimates

Navigant leveraged its web-scraping database of lighting product pricing, in addition to web-scraped data provided by PG&E, as the key source for determining the current price of LEDs, with the following adjustments.[2]

- **Navigant applied a 30 percent reduction factor to all LED luminaire pricing values to account for the difference between online and typical purchase price.** Input gathered from the manufacturer and retailer in-depth interviews revealed that online and in-store price offerings for LED luminaire systems differ significantly. Unlike LED lamps, which showed a negligible difference in price online versus in-store, LED luminaires are more costly and are typically purchased by commercial end-users direct from manufacturers and distributors. This purchasing channel allows for greater volume discounts, less common to the online environment. Research found luminaire product prices to be between 20 and 40 percent higher online than the prices offered by manufacturers and distributors.
- **Navigant determined that the 25th percentile is appropriate for characterizing the typical purchase price for all LED product categories.** The web-scrape process requires the selection of a statistic that best represents the typical range in price for each LED product category. This ensures that extrapolations adequately characterize the typical purchase price for each point in time. Lawrence Berkeley National Laboratory (LBNL) conducted a consumer survey for a recent LED web-scraping analysis, and found that more than 80 percent of respondents purchased a LED lamp at or below the 25th percentile price, and more than 90 percent purchased

[2] Web-scraping is a technique used for extracting information from websites, thereby transforming unstructured data on the web into structured data that can be stored and analyzed. This database was built using web-scraping software to remotely collect in-store pricing information from Home Depot, Lowes, Walmart, Target, and Ace Hardware locations in San Francisco, Los Angeles and San Diego, as well as from retailers including Best Buy, Grainger, 1000bulbs.com, Amazon, BulbsAmerica.com and ProLighting.com which do not offer locational pricing on their websites. This pricing and specifications data has been collected for all high priority LED products categories annually since 2011 and quarterly starting in Q2 2013.

at or below the median price.[3] 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 for LED lamps.[4]

Navigant found the adjusted web-based pricing data aligns well with data collected across the market actor interviews and surveys, as well as with the data collected through the SCE midstream trial pilot. In contrast, the pricing estimates from the CA Statewide Cost Data Sheet are far outside the upper-bound of the web-based ranges.[5] This is largely due to the fact that the cost sheet data was collected in 2012 and represents a very small sample set of products.

Factors that Significantly Affect LED Price

Navigant analyzed a wide range of LED lamp and luminaire parameters and factors to determine how they affect mean product pricing. For LED lamps, Navigant analyzed the percentage price increase over the mean price for all parameters associated with both ENERGY STAR qualified LED products, and the California LED Quality Standard.[6] Table 2-3 and Table 2-4 in Section 2.2 provide the analysis results. The team found the price increase is particularly substantial for LED A-type and MR16 lamps, where eligible products are estimated to cost nearly 50 percent more than the mean price indicated in Table 2-1.

Navigant also conducted a multi-variable regression to reveal the accuracy with which specific individual parameters predict LED luminaire price. The team considered efficacy, watts, lumens, color temperature (CCT), CRI, and lifetime, and found weak correlations between these parameters and the pricing of the LED luminaire product categories studied. Compared to LED lamps, there is a wider range of acceptable performance specifications for luminaires, which have a more diverse set of application specification considerations. There are also many additional features that characterize luminaire performance that are not tracked in the web-scraped database, such as R9 value, power factor, color tunability, advanced controls, wireless communication, DLC qualification, photometry and beam characterization. Appendix 3.3 provides the detailed results of this multi-variable regression.

Projected LED Prices

Survey responses across all market actors indicated that prices have not stabilized for any high-priority LED product category. Navigant's web-based pricing analysis indicates that in the near term, average LED lamp prices will decrease by 21 percent per year and luminaires by 20 percent per year. Market actor survey results of a 16 percent per year annual decrease support the web-based results. Constant year-over-year price decline, however, will not continue indefinitely. Rather, the rate of decline for several of these LED product categories is expected to slow within the timeframe of this projection

[3] Over 85% of the web-based LED pricing data collected by LBNL was from online-only vendors, therefore, the data source is largely unaffected by rebates.
[4] "The evolving price of household LED lamps: Recent trends and historical comparisons for the US market", LBNL, November 2014.
[5] IMC Analysis CA Statewide Cost Data Sheet, data for LEDs was collected in May 2012. The LED price data sheet is used by the California IOUs for program planning purposes, incentive design, and measure cost estimates.
[6] California Energy Commission, A Voluntary Minimum Specification for "California Quality" LED Lamps, DECEMBER 2012. http://www.energy.ca.gov/2012publications/CEC-400-2012-016/CEC-400-2012-016-SF.pdf

analysis. The team conservatively believes that these price projections will remain reasonable for the next 2 to 3 years only (until about 2017 or 2018).

Baseline Price Comparisons

In addition to collecting web-based data for LED lighting products, Navigant also collected product price and specification data for baseline technologies.[7] Findings were similar to those for LEDs. Based on the analysis of the LBNL study, Navigant determined that the 25th percentile is also appropriate for characterizing the typical purchase price for incandescent, CFL, halogen, linear fluorescent and HID lighting products. The pricing estimates of baseline products included in the CA Statewide Cost Data Sheet are significantly higher than the upper-bound of the web-based ranges. This is largely due to the timing of data collection, completed in 2012, and the very small set of products represented in the sample.

Price Impacts on Forecasted LED Penetration

Navigant updated the existing U.S. DOE lighting market model based on the price projection curves developed for this study to show how national LED adoption would be impacted by these California price projections.[8] The U.S DOE lighting market model predicts LED market share as an aggregate of many individual purchase decisions, based upon two analytic components 1.) an econometric logit model that considers cost factors influencing each decision, and 2.) a technology diffusion curve that considers time dependent market factors influencing each decision.[9] The results indicate that LED price has a significant impact on adoption. If prices continue to fall according to their current trajectory, the team expects LED lamps and luminaires to represent nearly 30 percent of all installations by 2020.

Navigant predicts LEDs to have the greatest adoption in outdoor applications, such as parking and building exterior, largely due to maintenance cost benefits. Improvements to the LED technologies make them the first viable option for these applications. In contrast, saturation is slower for general service and directional lamps since first cost is the major factor driving purchasing decisions and non-energy benefits are not as compelling. LEDs have the lowest adoption in troffer applications due to low cost high efficiency linear fluorescent technology. Additional information and graphics detailing Navigant's analysis methodology and the adoption of LEDs relative to baseline technologies are provided in Section 2.5 and Appendix A.3.5.

[7] Data was collected from Home Depot, Lowes, Ace Hardware, Target, Walmart, and Grainger.
[8] U.S. DOE, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications, Prepared by Navigant, August 2014. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energysavingsforecast14.pdf
[9] The conditional logit model is a widely recognized method of forecasting a product's market penetration based on several quantitative or categorical explanatory variables. The result of the conditional logit is a probability of purchase, which represents an aggregation of a large number of individual consumer purchasing decisions.

Non-Residential Baseline Analysis Findings

The primary research objectives of the LED baseline analysis are to:

1. Define the comparison factors most considered when selecting LED products
2. Outline the type and mix of baseline technologies for early retirement (ER) and replace on burnout (ROB) LED installations
3. Determine whether the decision making for LEDs is unique such that it warrants more rigorous baseline research
4. Understand how assumptions about non-residential baseline technologies should change during the next few years

This section describes the findings and results of the LED baseline analysis by research objective. The detailed methodology of this analysis is included in Section 3.

Comparison Factors

Equivalent light output was the single most important factor for all market actors when choosing an LED product to install. End users also placed importance on light color and wattage equivalency. It is important to note that equivalent light output does not always imply equal lumen output across the baseline and LED cases: some customers wish to increase or decrease light levels for safety or aesthetic reasons and consider light distribution as well as total lumens.

Technology Mix by Baseline Type

Survey responses collectively showed a higher share of CFLs in the market baseline for LED lamps than the 50 percent assumed in the May 2014 lighting retrofit disposition. Of the three groups of surveyed market actors, distributors reported the lowest percent of CFLs in their A-line market mix, at 59 percent. This is important, as the team believes distributors are the least biased primary data source for this question due to their broader market perspective not limited to program activity. Due to program influence, participating contractors and end-users targeted by the surveys, on the other hand may be more likely to choose another incented product when LEDs are unavailable, biasing reported CFL share estimates on the high side. To minimize this bias in the baseline analysis, the team recommends using only the responses from distributors when estimating WRRs.

Beyond the CFL-portion of the baseline, incandescent sales now include halogen incandescent bulbs with higher efficacy, due to EISA legislation. It is unclear to Navigant whether any portion of the current LED lamp baseline was assumed to be halogen.

Linear fluorescent products dominate the market baseline technology mix for both high and low-bay lighting. When asked for market shares by technology for bay lighting, responses for linear fluorescent products ranged from 49 percent for end users to 75 percent for contractors. While the May 2014 lighting retrofit disposition suggests the industry standard practice baseline for bay lighting is pulse-start metal halide (PSMH), market actors generally reported few sales of HID products. End users reported a higher share of HID technology than did distributors and contractors and also estimated that CFLs account for about 16 percent of the market.

Exterior lighting sales also include a significant number of linear fluorescents, though they are not as dominant as in the bay lighting analysis. Other exterior lighting shares vary by sales channel; distributors reported that HID would be the most common alternative to LEDs, contractors reported higher shares of induction lighting, and end-users reported a higher share of CFLs. These results suggest that as other products take market share from HID luminaires in new installations, PSMH technology may no longer be an accurate representation of standard practice in bay and exterior lighting.

Incidence of Early Replacement

The majority of contractors and end users indicated that they are more likely to replace equipment before the end of useful life when installing LEDs than when installing new non-LED equipment (Figure 3-7). This suggests that LED decision making is unique and warrants additional research on early retirement and replace-on-burnout baselines, especially given the variation in technology mixes this study found to exist across these two baselines. This finding is corroborated by the SCE LED Midstream Pilot Evaluation, which found that 92 percent of pre-existing equipment replaced in the pilot was in working order.[10] PG&E's Midstream Trial found similar results, where eighty-two percent of Trial LED replacement lamps were installed in sockets with functioning existing lamps, and 18 percent were installed in places where lamps had failed.[11]

Savings Estimation Methods Analysis Findings

Non-residential prescriptive LED lighting measures in California use one of two savings estimation methodologies: wattage reduction ratios (WRRs) and wattage ranges. These methodologies were selected, in part, due to the fact that many IOU programs offer measures in wattage ranges, rather than requesting individual lamp wattages or other technical specifications, in an attempt to reduce administrative burden on participants.

- **Wattage reduction ratios** are the ratio of the deemed baseline wattage to the deemed LED wattage. The CPUC's original integral LED disposition[12] sought to establish WRRs that drew upon the available data provided in IOU workpapers where possible. At the time, the CPUC was concerned about the use of LED wattage ranges for a single baseline wattage, as they believed there was no assurance that lower wattage LED lamps provided the same level of service as higher wattage products. CPUC also noted lack of evidence for customer preference for equivalent light output products, which this study has since researched. These concerns weighed in to the guidance delivered in May 2014 lighting retrofit disposition, which states that a designated ratio must be applied to the lowest LED wattage within the range of wattages established for a LED product category (i.e. 6 – 10 W LED for A-19 lamps), creating a disincentive for programs to focus on more efficient products. May 2014 lighting retrofit disposition.

[10] "Evaluation of the Southern California Edison Commercial Midstream LED Lighting Distributor Pilot Program." Evergreen Economics, May 2015. CALMAC ID: SCE0376.01
[11] "PG&E Lighting Innovation Midstream Trial Evaluation." Evergreen Economics, 2015. Final report not yet posted.
[12] Integral LED Lamp Disposition, 2012

- The **wattage ranges method** maps LED wattages to baseline technology wattage ranges within various LED luminaire product categories. Savings are calculated as the difference between the lowest baseline technology wattage in the baseline range and the highest LED technology wattage in the LED range, again creating a disincentive for programs to focus on more efficient products.

While CPUC and IOU staff have recognized the weaknesses of both approaches, the timing between disposition releases and revised filing deadlines have historically limited IOUs' ability to propose substantial changes to the current methodologies to date.

This study sought to provide direction for future improvements to LED workpapers, and Navigant's research aimed to address three main questions for both of these methods. Figure ES-1 summarizes these questions.

Figure ES- 1 Core Savings Estimation Research Questions

Source: Navigant

This section describes the findings and results of the LED savings estimation method analysis by method. The detailed methodology of this analysis is included in Section 4 and Appendix A.4 and A.5. Baseline findings apply to non-residential applications only; the team did not collect data on residential baseline.

Wattage Reduction Ratio Findings

Navigant's analysis resulted in three key findings:

- **The WRR approach provides a disincentive for programs to focus on more efficient products**. The current WRR method assumes that the baseline always shifts linearly with LED wattage within a product group. For LEDs, a product family where the efficacy is changing at rates of 20 percent per year[13] and is highly variable at any point in time across and within manufacturers, this is not an accurate assumption. Moreover, this use of a multiplier results in lower savings for more efficient (lower wattage) LED products and higher savings for less efficient (higher wattages) LEDs products. For example, in the case where both a 13 W and 11 W A-lamp LEDs have the same lumen output, using a WRR of 2.96 would yield a savings of 26 W and 22W

[13] Year over year change in average efficacy of A-line products in the 25th price percentile from 2013 to 2014: 14% for 40W equivalents, 23% for 60W equivalents, 15% for 75W equivalents, and 24% for 100W equivalents.

respectively.[14] Despite the 11W product being more efficient by 2 W (or 15%), the savings determined using the current WRR method is reduced by 3.9 W (-15%). This disparity creates an incentive for *less efficient* technology and underestimates savings for more efficient LEDs. Additionally, the current method forces program staff to apply the WRR to the most efficient product regardless of what is installed. For a measure covering a range of LED wattages, for example 15-21W LED A-lamps, current guidance states that the WRR must be applied to the lowest LED wattage within the range, providing no incentive to promote the most efficient products in the market.[15]

- **Some existing WRRs may be too broad.** In the case of A-line lamps, the existing WRRs are too broad to accurately capture the range of efficacies within a product category: LED efficacy varies across the different lumen bins defined by EISA. In addition, the baseline varies across these bins due to bin-jumping.
- **Most existing WRRs are too high.** Increases in the shares of efficient baseline screw-in lamp technologies have lowered the baseline wattage for most screw-in technologies in the non-residential sector. For A-lamps and most reflectors, CFLs are becoming an increasingly large portion of sales. In addition, A-lamp incandescent sales are giving way to more efficient halogen lamps as the EISA legislation takes effect.

Navigant collected survey responses regarding the current market mix of baseline technologies to create revised WRRs for LED lamps. These values, as well as recommendations to further improve the methodology are provided in Section 4-2 and 4.4 respectively.

Wattage Ranges

Navigant's analysis suggests that the typical installed LED wattage for bay and exterior lighting applications falls nearer to the mean of the existing LED wattage ranges. The existing methodology of deriving delta watt savings using the upper bound of the LED wattage range is therefore underestimating savings and not reflecting typical installation. It also dis-incentivizes the promotion of more efficacious products.

Navigant collected survey responses regarding the current market mix of baseline technologies to create revised wattage ranges for LED bay lighting. These ranges, as well as recommendations to further improve the methodology are provided in Section 4.3 and Section 4.5 respectively.

Key Findings and Recommendations

Navigant has identified the following key findings and recommendations by research topic, as well as providing the stakeholder for whom each recommendation is most relevant.

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[14] The baseline for the 13W LED would be: 13W x 2.96 = 38.5W, and the delta Watts would be: 38.5W – 13W = 25.5W. For the 11W LED, the baseline would be 11W x 2.96 = 32.6W, and the Delta Watts would be: 32.6W – 11W = 21.6W.
[15] In response to this guidance, Program Staff have created individual measure codes to very finely bin wattage ranges, which has complicated both the programs and evaluation efforts.

Pricing

Program Staff

- Finding: Current prices for both LED and baseline (non-LED) products included on the CA Statewide Cost Data Sheet are no longer accurate.[16]
  - Recommendation: Update cost sheet to use web-based pricing analysis results for LED and baseline (non-LED) products provided in Table 2-1. Also consider using updated incremental cost results.
- Finding: There is no statistical difference for any high-priority LED product category between the San Francisco and San Diego mean price at the 95 percent level of confidence.
  - Recommendation: All IOUs can use the same updated cost data.
- Finding: Prices have not stabilized for any high-priority LED product category. The web-based pricing analysis indicates that in the near term, average LED lamp prices will decrease annually by 21 percent per year and luminaires by 20 percent per year.
  - Recommendation: Use updated costs data for the next 2 to 3 years only (until about 2017 or 2018).

Non-Residential Baseline

CPUC – Energy Division & IOU Program Staff

- Finding: Although there was variation among market actors, survey responses collectively showed a higher share of CFL lamps in the non-residential market baseline than the 50 percent assumed in the disposition. Additionally, due to EISA legislation, incandescent sales now include halogen incandescent lamps with higher efficacy. For bay lighting applications, most market actors reported high shares of linear fluorescent lamps and relatively low shares of PSMH lighting. This indicates that a baseline of 100 percent PSMH may no longer be standard practice. Standard practice baselines are especially important where no code requirements exist or code requirements are unclear.
  - Recommendation: Consider updating the non-residential baseline for LED lamps to reflect the current market mix of baseline technologies.
  - Recommendation: Consider updating the non-residential baseline for bay lighting to reflect the current market mix of baseline technologies. This may require additional research since not all fixtures are one-to-one replacements and the survey did not collect data on number of lamps per linear fluorescent fixture.

Savings Estimation Methods

Wattage Reduction Ratios
CPUC – Energy Division & IOU Program Staff

[16] IMC Analysis CA Statewide Cost Data Sheet, data for LEDs was collected in May 2012.

- Finding: The WRR method underestimates savings for more efficient lamps and overestimates savings for less efficient lamps, which provides a disincentive for programs to focus on more efficient products. Additionally, existing WRR values also do not accurately reflect the current baseline and LED efficacies in the non-residential market.
    - Recommendation: Navigant presents the following "good, better, best" options for the DEER team to consider as they continue research focused on improving the methodology for screw-in lamps, recognizing that some changes may not be possible.
        - **Ideal "Best" Method**. The most accurate option is to determine a single baseline for each product category—i.e. EISA lumen bin—and determine which bin LEDs fall into by collecting actual lumen output for incented products. This is the recommended approach for A-line lamps in the residential lighting uniform methods protocol.[17] Average program LED wattage per bin would determine the savings. In lieu of program LED wattage averages, average LED wattage for each bin could be updated annually with web-scraping data.
            - This approach would require programs to collect detailed records of incented LED products including wattage and efficacy or lumen output.
        - **Alternative "Better" Method**. If collecting lumen output is not possible, simply assigning a single baseline wattage for each product category and assigning product categories by LED wattage could be an improvement. In this case, savings should be the category baseline watts minus the actual LED watts. Programs would need to review the LED wattage bin mapping annually to account for increases in efficacy that will change the LED bounds of each EISA category.
            - This approach would require programs to collect the rated wattage of incented LED products.
        - **Possible Improvements to WRR Method**. If the WRR method cannot be changed, the following improvements to its application will improve accuracy:
            - Update average LED efficacy and wattage annually using web-scraped data
            - Apply different WRRs to each EISA bin as determined by LED lumens (ideal) or wattage (possible)
            - Update baseline technology mix and wattage regularly, starting with mix reported in distributor surveys

Wattage Ranges
CPUC – Energy Division & IOU Program Staff

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[17] Dimetrosky, Scott. "Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures. Chapter 6, Residential Lighting Evaluation Protocol." p. 6-7. http://energy.gov/sites/prod/files/2013/11/f5/53827-6.pdf

- Finding: Navigant's analysis suggests that the typical installed LED wattage for bay and exterior lighting applications falls nearer to the mean of the existing LED wattage ranges. The existing methodology of deriving delta watt savings using the upper bound of the LED wattage range, therefore, is underestimating savings and not reflecting typical installation. Moreover, it provides a disincentive to promote the most efficacious products.
    - Recommendation: Update guidance in next lighting disposition to specify using the mean of LED wattage ranges for delta watts calculations instead of upper end.
    - Recommendation (for bay lighting):[18] Consider adding the narrower ranges suggested in Figure 4-7 within the current lowest wattage range to improve accuracy in the delta watts savings calculation.

IOU Program Staff

- Finding: Due to the large variability in LED product efficacy and quality, using broad wattage ranges may lead to inaccurate savings estimates.
    - Recommendation: Collect more detailed product information on pre-and post-retrofit fixtures, namely quantity and rated input wattage and lumen output. This will allow programs to verify whether high quality, efficacious products are in fact the majority of program participation. An alternative method based on lumen output and fixture quantity is presented in the recent disposition on LED troffers, which could be used here but would also require programs to collect data on rated lumen output.[19]

Suggestions for Future Work

As the price, specifications and market share of LED products are rapidly changing, Navigant suggests the following areas for future work, aimed at keeping LED workpaper assumptions current and accurately predicting achieved savings.

Pricing

Program Staff

- Goal: Update price forecasting assumptions for LEDs annually until prices stabilize.
    - Suggested method: Use web-scraping to continually collect LED and baseline pricing. Specifically consider conducing web-scraping:
        - Quarterly for LEDs
        - Annually for baseline technologies
- Goal: Product price is a key determinant of LED cost-effectiveness, and is often cited as the most powerful influencer of adoption. The insights gained from a customized California lighting

[18] Bay lighting was the only wattage range application for which Navigant collected sufficient survey data to compare to the existing wattage ranges.
[19] Workpaper Disposition for PGECOLTG179 LED Ambient Commercial Fixtures and Retrofit Kits, California Public Utilities Commission, Energy Division, June 26, 2015

market model could be used to identify future attainable savings potential and help shape long term lighting measure goals and strategies.

- Suggested method: Further customize DOE's lighting market model to better reflect the unique trends in the California region. (e.g. Initial installed stock and distribution of lighting technologies, building stock and space types, floor space growth, lighting product characteristics and performance, operating hours, etc.)

Non-Residential Baseline

CPUC – Energy Division & IOU Program Staff

- Goal: Better understand the distribution of early retirement versus replace on burnout LED installation. The majority of surveyed contractors and end users indicated that they are more likely to replace equipment before the end of useful life when installing LEDs than when installing new non-LED equipment.
  - Suggested method: Conduct additional research, including on-site evaluations, to establish prevalence of various baselines and customer motivations for early retirement LED projects.[20]

Savings Estimation Methods

Wattage Reduction Ratios
Program Staff

- Goal: Keep WRRs accurate.
  - Suggested method: Conduct annual web-scraping to update LED efficacies and wattages.
  - Suggested method: Continue research on baseline technology mix and consider alternative research methods such as field work or collecting non-residential sales data. Field work can support research on early replacement baselines, but understanding ROB baselines requires data on the mix of products newly installed outside of programs. While difficult to collect, sales data from distributors can be a valuable tool for assessing market baselines and has been used successfully in the Northwest.[21]
  - Suggested method: Collect lumen output data of incented lamps to improve understanding of which baseline products they are replacing by using lumens to map an incented product to its EISA lumen range

Wattage Ranges

[20] Note that IOUs cannot claim early retirement projects unless they are program-induced early retirements. CPUC has provided guidance on establishing the "preponderance of evidence" that a program influenced early retirement.
[21] Bonneville Power Administration, "Northwest Nonresidential Lighting Market Characterization: 2010-2012." Prepared by Navigant Consulting and Cadeo Group, May 2014. http://www.bpa.gov/EE/Utility/research-archive/Documents/Northwest_NonRes_Lighting_Market_Characterization.pdf

Program Staff

- Goal: Keep Wattage ranges accurate:
    - Suggested method: Conduct additional research focused on mapping LED lumen output and wattages to baseline technology lumen output and wattages. This could include the following activities:
        - Reviewing a random sample of manufacturer literature for suggested equivalency
        - Reviewing custom program tracking data or tracking data from other jurisdictions where pre-and-post case fixture wattage, efficacy and quantity are known
        - Collecting more detailed data on program LED products and equipment they are replacing, including wattage, efficacy and quantity
        - Repeating original workpaper analysis with current Design Lights Consortium (DLC) data[22]
        - Conducting field research to confirm reported preference for equivalent light output

[22] Using the current Design Lights Consortium qualified product list available at https://www.designlights.org/QPL

1. Introduction

1.1 Research Objectives

Navigant Consulting, Inc. (Navigant) has been contracted by Southern California Edison (SCE), on behalf of California's electric Investor Owned Utilities (IOUs), to help update key parameters and methodologies used in light-emitting diode (LED) lighting workpapers across the state.

Between May and August of 2014, Navigant collaborated with IOU stakeholders to identify and prioritize the research objectives and LED product categories to be included in the study. The final set of research objectives selected focused on three key topics:

- LED **pricing**
- **Non-residential baseline** wattages (which inform the selection of appropriate wattage reduction ratios or wattage ranges)[23], and
- The ability of the currently used **savings estimation methods** to predict non-residential baselines (e.g., wattage reduction ratio and wattage ranges).

Prescriptive LED lighting measures in California use one of two savings estimation methodologies: wattage reduction ratios (WRRs) and wattage ranges. Wattage reduction ratios are the ratio of the deemed baseline wattage to the deemed LED wattage. The May 2014 lighting retrofit disposition provides guidance that a designated ratio must be applied to the lowest LED wattage within the range of wattages established for a LED product category (i.e. 6 – 10 W LED for A-19 lamps). The wattage ranges method maps LED wattages to baseline technology wattage ranges within various LED luminaire product categories, and savings are calculated as the difference between the lowest baseline technology wattage in the baseline range and the highest LED technology wattage in the LED range.

Table 1-1 shows the final list of product categories selected, divided into lamps (i.e. screw-in products) and luminaires. This division of product category is important to note, as each group carries a unique set of findings. Appendix A.1 includes additional details into the development of these research objectives and product categories, including the full list of research questions

[23] The team excluded LEDs from the baseline due to their low current market penetration and long lifetime, which together suggest that the majority of currently installed LEDs are still functioning.

Table 1-1. Priority LED Product Categories

LED Lamps*	
A19	
MR16/PAR16	
PAR20, BR20, R20	
BR30, R30	
R40, BR40	
PAR30	
PAR38	
Downlight Retrofit	

LED Luminaires	
Downlight Fixture	
Recessed Troffer	
High/Low Bay	
Parking Garage	
Parking Lot	
Wall Pack	

Source: Navigant summary of outcomes from discussions with IOU and California Public Utilities Commission (CPUC) staff during June and August 2014. *PAR20 was combined with BR20/R20 and PAR16 with MR16 since no discernable price differences were found. PAR36 was removed from the analysis due to minimal product availability.

1.2 Data Collection

Between June of 2014 and May 2015, Navigant conducted the following primary data collection activities.

- Non-Residential market-actor surveys
  - Phone and web surveys
    - Contractors
    - Distributors
    - Commercial end-Users
  - In-depth interviews
    - Manufacturers
    - Retailers
- Web-scraping of LED (and non-LED) pricing and lighting specification data

Web-scraping is a technique used for extracting information from websites, thereby transforming unstructured data on the web into structured data that can be stored and analyzed. Appendix A.2 provides the detailed list of market actors web-scraped and/or contacted as a part of this study. Table 1-2 below shows the final dispositions for the phone and web surveys for each market actor.

Table 1-2 Final Dispositions for Phone and Web Surveys

	Contractors	Distributors	End Users
Total # of Contacts	490		1,492
Not Attempted or Quota Filled	41*		765
Bad Numbers	33		59
Not Eligible	47		7
Transferred to Contractor/Distributor	n/a		6
Total # of Eligible Contacts	369		655
Not Reached (vm, etc.)	163		438
Refusals	76		113
# of Phone Completes	65	65	104
Refused Web Survey on Phone	0	0	6
Phone Response Rates	18%	18%	16%
# of Web Completes	34	40	49
Web Survey Response Rates	52%	62%	47%

Source: E&W & Navigant analysis

*The Navigant team fully exhausted the contractor sample.

The Navigant team calculated the resulting confidence and precision assuming a coefficient of variation of 0.5 and a total LED contractor/distributor program participating population of 800. Survey questions with fewer responses than the total number of completes shown above may have a lower question-level precision. However, double ratio estimation can be used where web questions were nested within phone questions.

Table 1-3 Confidence and Precision by Market Actor

Market Actor	Phone	Web
Contractors/Distributors	90/7	90/9
End Users	90/8	90/12

Source: Navigant analysis

Question-level statistics can be calculated where needed.

2. Pricing

As a key input to cost effectiveness, product price has been a critical yet difficult parameter to characterize and predict for LED products. The primary research objectives of the LED pricing analysis are to:

1. Develop current price estimates for high priority LED products.
2. Determine the factors that significantly affect LED price.
3. Project LED prices and determine how often assumptions need to be updated.
4. Compare LED prices to that of baseline products.
5. Predict price impacts on forecasted LED penetration.

This section describes the findings and results of the LED pricing analysis by research objective. The detailed methodology of this analysis is included in Appendix A.4.

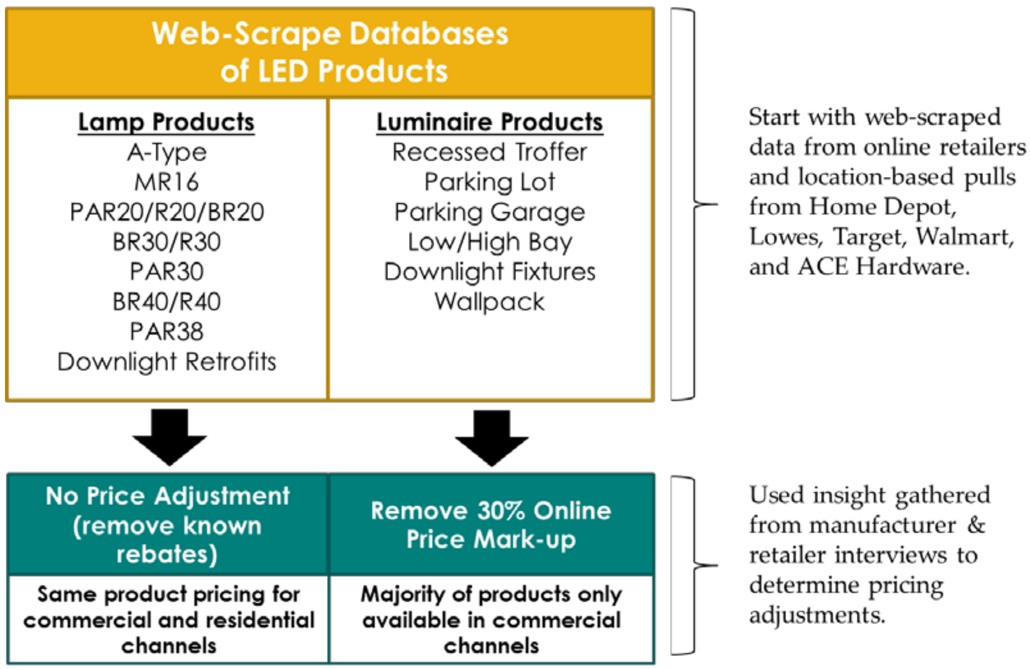
2.1 Current Price Estimates

In order to determine the price of LEDs, Navigant leveraged both its and PG&E's web-scrape databases[24] of lighting product pricing and specifications combined with responses gathered across the market actor surveys and interviews. Input gathered from the manufacturer and retailer in-depth interviews revealed that online and in-store pricing offerings are comparable for LED lamp products and that differences between residential and commercial channel pricing for LED lamps are negligible. Manufacturers and retailers indicated that for LED lamp products, volume discounts are insignificant and the pricing offered at big box retailers, such as Home Depot and Lowes, is comparable to pricing offered by distributors and other commercial channel outlets.

For LED luminaire products, however, differences are significant. Manufacturers and retailers indicated that LED luminaires are more costly and typical purchased by commercial end-users. Volume discounts are more significant, and online prices for luminaire products are between 20% and 40% higher than the high-volume pricing typically offered by manufacturers and distributors. As shown in Figure 2-1, a 30% reduction factor is applied to all LED luminaire pricing values in the web-scrape database to account for this difference between online and typical purchase price.

[24] The Navigant web-scrape database was built using web-scraping software to remotely collect in-store pricing information from Home Depot, Lowes, Walmart, Target, and Ace Hardware locations in San Francisco, Los Angeles and San Diego, as well as from retailers including Best Buy, Grainger, 1000bulbs.com, Amazon, BulbsAmerica.com and ProLighting.com which do not offer locational pricing on their websites. This pricing and specifications data has been collected for all high priority LED products categories annually since 2011 and quarterly starting in Q2 2013.

Figure 2-1 Price Adjustments Made to Navigant Web-scrape Database



Source: Web-scraped data & Navigant analysis

After these adjustments were made to the web-based pricing data, it was necessary to select a statistic that best represents the typical range in price for each LED product category. This is critical to ensure that extrapolations adequately characterize the typical purchase price for each point in time. As illustrated in Figure 2-2, the distribution of LED A19 web-based pricing data, for example, has a significant positive right-tailed skew, meaning that the product offerings are concentrated at lower prices, but a few are available at significantly higher price. Since LEDs have a wide range of performance and pricing and are a rapidly changing technology, using an unweighted average for calculating typical price would lead to inaccurate estimates. The ideal statistic would be a sales-weighted average, but since the web-scrape data does not provide insights on relative sales, this is not possible.

Lawrence Berkeley National Laboratory (LBNL) conducted a consumer survey for a recent LED web-scraping analysis, and found that more than 80% of respondents purchased a LED lamp at or below the 25^{th} percentile price, and more than 90% purchased at or below the median price. LBNL also concluded that the mean and median are volatile metrics that represent the tail of the purchase distribution, while the 25^{th} percentile of their web-scraped data best represents the characteristic price for LED lamps. Based on this assessment, Navigant determined that the 25^{th} percentile is appropriate for characterizing the typical purchase price for all LED product categories. Additionally, the team 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 10^{th} percentile.[25]

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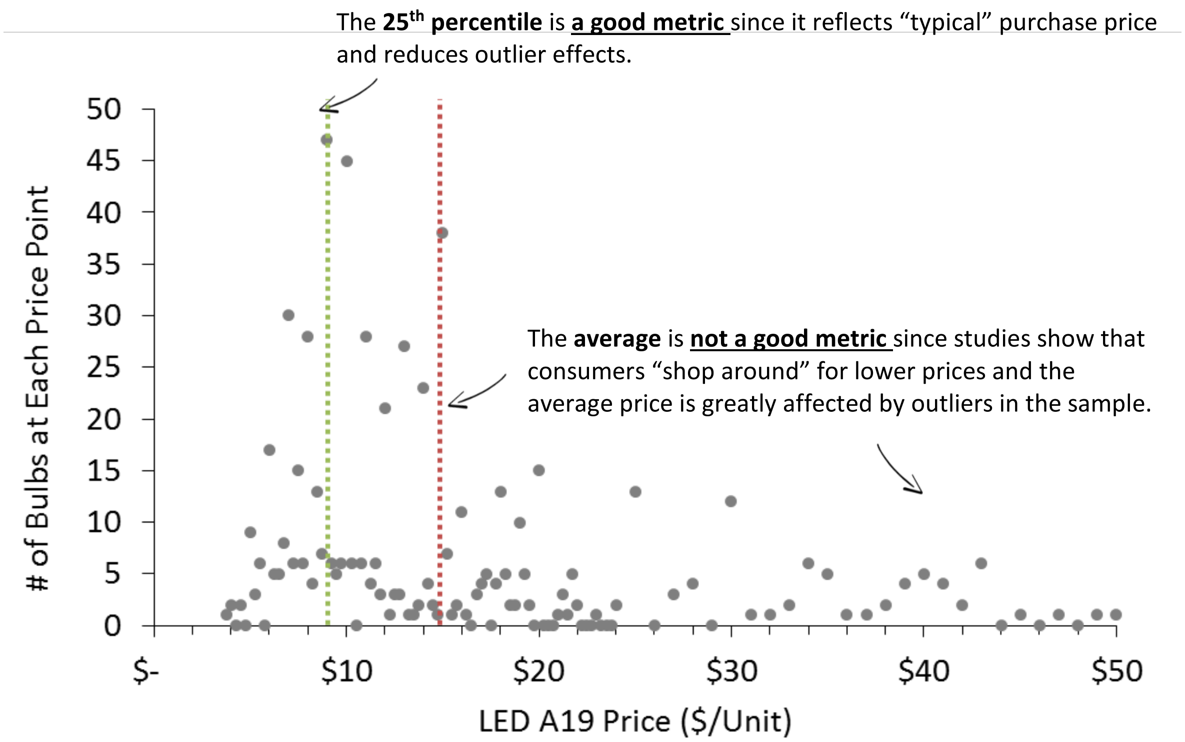
[25] "The evolving price of household LED lamps: Recent trends and historical comparisons for the US market", LBNL, November 2014.

Figure 2-2 Frequency Plot of Web-based LED A19 Pricing for Q1 2015



Source: Web-scraped data & Navigant analysis

When evaluating LED product price, product categories were broken down into wattage equivalents (lumen bins) or dimensions, where applicable and feasible. For several reflector lamp categories (MR16, PAR20/BR20/R20, PAR30, etc.) Navigant found that lumen bins for wattage equivalents are poorly defined and therefore price differences are not statistically significant. The calculated range of prices for each LED product category based on the web-based analysis is shown in Table 2-1.

Table 2-1. Range of LED Price by Product Category

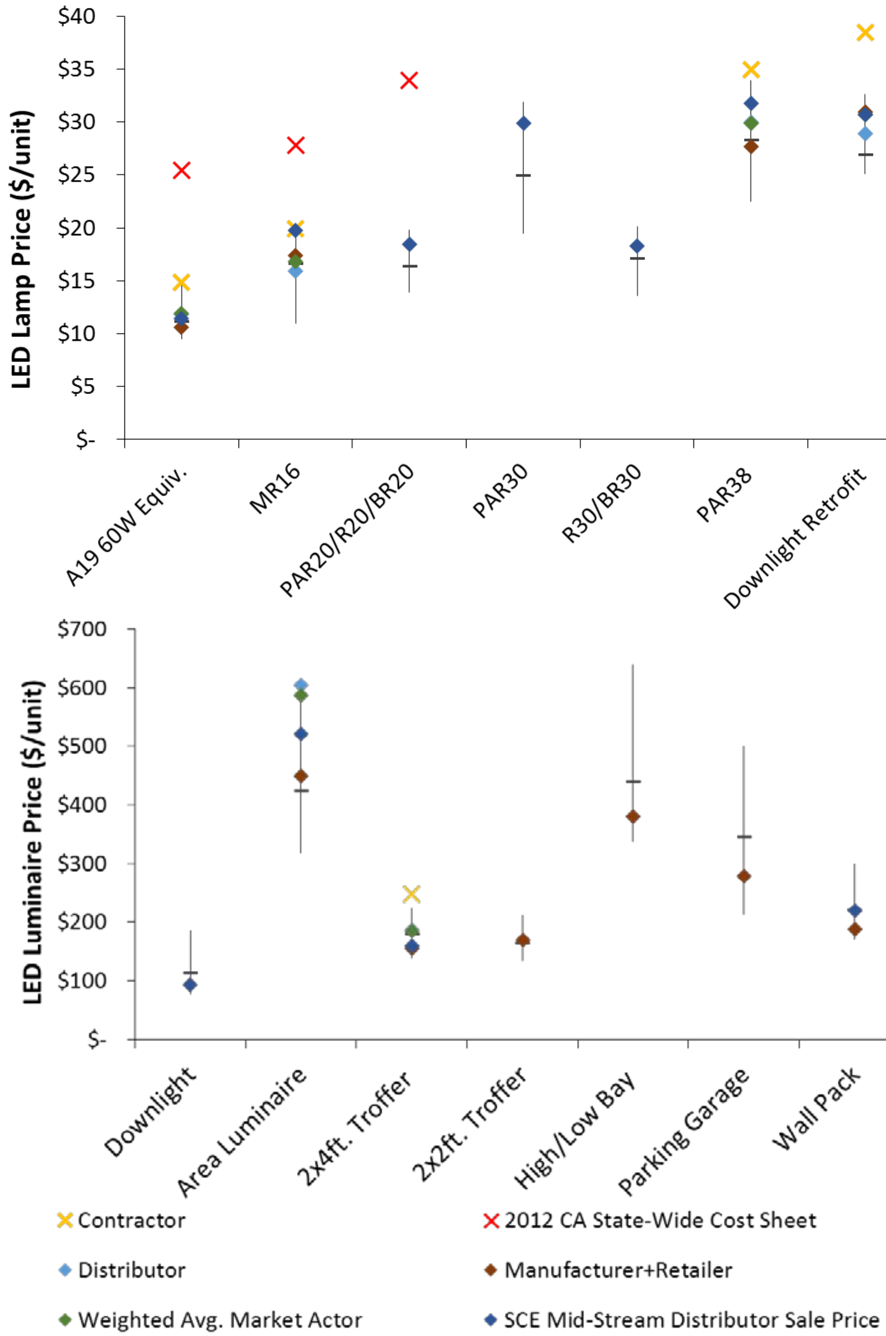
LED Product Type	Upper (Median)	Mean (25th Percentile)	Lower (10th Percentile)
A15	$ 10	$ 9	$ 7
A19 40W equivalent	$ 12	$ 9	$ 7
A19 60W equivalent	$ 15	$ 11	$ 10
A19 75W equivalent	$ 24	$ 20	$ 17
A19 100W equivalent	$ 26	$ 23	$ 22
MR16	$ 20	$ 17	$ 11
PAR20/BR20/R20	$ 20	$ 16	$ 14
BR30/R30	$ 20	$ 17	$ 14
PAR30	$ 32	$ 25	$ 19
R40/BR40	$ 24	$ 20	$ 18
PAR38	$ 34	$ 28	$ 23
Downlight Retrofit	$ 33	$ 27	$ 25
Downlight Fixture	$ 196	$ 118	$ 83
Recessed Troffers 2x4	$ 223	$ 179	$ 139
Recessed Troffers 1x4	$ 261	$ 222	$ 192
Recessed Troffers 2x2	$ 212	$ 165	$ 135
Parking Lot	$ 607	$ 423	$ 318
Parking Garage	$ 501	$ 344	$ 213
Low Bay	$ 582	$ 332	$ 223
High Bay	$ 697	$ 548	$ 454
Wall Pack	$ 299	$ 220	$ 170

Source: Web-scraped data & Navigant analysis

To verify this methodology, the team compared the web-based pricing ranges to the CA Statewide Cost Data Sheet[26], market actor responses, as well as pricing data collected from distributors as a part of the SCE mid-stream program. [27] The results of this comparison are shown in Figure 2-3. In this figure, the lines represent the web-based pricing ranges and the points indicate the additional pricing data sources.

[26] IMC Analysis CA Statewide Cost Data Sheet, data for LEDs was collected in May 2012.
[27] Evergreen Economics 2015: Evaluation of the Southern California Edison Commercial Midstream LED Lighting Distributor Pilot Program. http://calmac.org/publications/SCE_LED_Midstream_Trial_EM%26V_Final_Report2.pdf

Figure 2-3 Comparison of 2014 Web-based LED Price Ranges to Additional Pricing Data Sources[28]



Source: Web-scraped data & Navigant analysis

[28] Prices estimates from each additional source were not provided for all LED product categories of interest. For example, while all sources provided price estimates for the LED A19 60 Watt equivalent, only manufacturers and retailers commented on the price of LED 2x2 ft. troffers.

This comparison indicates that the web-based ranges generally have good agreement with the results of the market actor interviews and surveys, as well as the data collected through the SCE mid-stream program. In contrast, the pricing estimates from the CA Statewide Cost Data Sheet are far outside the upper-bound of the web-based ranges. This is largely due to the fact that the cost sheet data was collected in 2012 and represents a very small sample set of products.

The contractor data is also outside the upper-bound of the web-based price ranges. However the team does not believe that contractor pricing is an accurate representation of typical LED pricing. Our commercial end-user survey respondents indicated that contractors account for approximately 14% of LED lighting purchases, while 86% of purchases come from distributors, manufacturers and retailers. If the price data collected via the market actor surveys are weighted using this breakdown, (represented by the green plot point in Figure 2-3,) the resulting weighted-average price points are all within the web-based price ranges. Given the good agreement with these additional price data sources, Navigant believes that the 25th percentile is appropriate for characterizing the typical purchase price for all LED product categories.

2.1.1 Regional Specific Prices

As evidenced by the responses shown in Table 2-2 distributors and contractors believe that regional pricing differences within California are not significant.

Table 2-2 Regional Pricing Differences – Results from Distributor and Contractor Web-Survey

Q26. Do LED lamps and fixtures cost more in Northern California than in Southern California, more in Southern California than in Northern California, or roughly the same across the state?

1. More in Northern California	2	5%
2. More in Southern California	2	5%
3. Roughly the same	33	89%
98. Don't know	0	0%
99. Refused	0	0%
Total	37	100%

Source: Navigant survey data analysis

To verify this finding, Navigant used web-scraping software to automatically and remotely collect in-store pricing information from several big box retailers in San Francisco and San Diego. The team compared the pricing data collected for each of these cities through hypothesis testing[29] of the web-based pricing data. This analysis was conducted for each of the LED lamp categories.

The results of this test also indicate that it is reasonable to assume that all IOUs can use the same cost data provided in Table 2-1, since there are no LED product categories for which the difference between the San Francisco and San Diego mean price is significant at the 95% level of confidence (alpha = 0.05). The detailed results of the hypothesis testing are provided in Appendix A.3.2.

[29] A two-sided heteroscedastic t-Test ("t-Test: Two-Sample Assuming Unequal Variances") was selected as the best method to test for equality of population means.

2.2 Factors that Significantly Affect LED Price

In addition to LED pricing data, the Navigant web-scraped database also includes additional product-level data including, but not limited to wattage, lumen output, efficacy, correlated color temperature (CCT), color rendering index (CRI), voltage, dimensions, dimmability, Energy Star qualification status, number of product reviews, and number in stock. To determine how the mean LED price changes with each of these parameters, known and commonly used inflection points were selected for comparison. For example, the latest draft Energy Star lamp specification proposes that lamps have a minimum efficacy of 65 lm/W[30] in order to qualify. Table 2-3 shows the percentage price increase of an Energy Star-qualified lamp over the mean price (25th percentile), as well as the percentage price change associated with other performance specifications.

Table 2-3. Change in 2014 Price (%) Associated with LED Lamp Performance Specifications

LED Lamp Type	CRI >= 90	CCT > 3000K	Efficacy >=65 lm/W*	Dimmable	Energy Star Qualified	Lifetime >= 25,000 hours
A15	NA	14%	-7%	2%	7%	9%
A19 40W equiv.	40%	5%	6%	24%	1%	27%
A19 60W equiv.	36%	9%	-7%	27%	13%	31%
A19 75W equiv.	NA	6%	-13%	0%	17%	0%
A19 100W equiv.	NA	2%	-21%	8%	23%	0%
MR16	36%	NA	-13%	6%	30%	47%
PAR20/BR20/R20	32%	1%	-5%	11%	1%	0%
BR30/R30	15%	6%	-3%	16%	9%	35%
PAR30	20%	3%	1%	19%	4%	31%
R40/BR40	19%	6%	2%	23%	0%	3%
PAR38	11%	4%	-12%	7%	19%	14%
Downlight Retrofit	17%	10%	-18%	NA	NA	NA
Average	25%	6%	-8%	13%	11%	18%

Source: Web-scraped data & Navigant analysis

*A negative percent implies that price decreases as efficacy increases.

Navigant also analyzed the percentage price increase over the mean price associated with California LED Quality Standard[31] eligible products, as seen in Table 2-4. This quality standard only applies to lamps sold through residential channels, and requires that LED bulbs meet the following criteria in order to be eligible for rebates:

[30] ENERGY STAR® Program Requirements Product Specification for Lamps (Light Bulbs), Eligibility Criteria Version 2.0 DRAFT 2. https://www.energystar.gov/sites/default/files/ENERGY%20STAR%20Lamps%20V2.0%20Draft%202%20Specification.pdf

[31] California Energy Commission, A Voluntary Minimum Specification for "California Quality" LED Lamps, DECEMBER 2012. http://www.energy.ca.gov/2012publications/CEC-400-2012-016/CEC-400-2012-016-SF.pdf

- Energy Star qualified
- Minimum CRI of 90
- CCT equal to 2700K or 3000K
- Dimmable
- Minimum 5 year warranty

Table 2-4. Change in 2014 Price (%) Associated with CA LED Quality Standard Eligible Products

LED Lamp Type	Percentage Increase of CA LED Quality Standard-eligible Products vs. Non- Qualified Products
A15	NA
A19 40W equiv.	50%
A19 60W equiv.	48%
A19 75W equiv.	NA
A19 100W equiv.	NA
MR16	46%
PAR20/BR20/R20	38%
BR30/R30	26%
PAR30	23%
R40/BR40	26%
PAR38	33%
Downlight Retrofit	22%

Source: Web-scraped data & Navigant analysis
*NA – No products available that meet the CA LED Quality Standard.

The price increase is particularly substantial for LED A-type and MR16 lamps, where eligible products are estimated to cost nearly 50% more than the mean price indicated in Table 2-1. Based on inputs from manufacturers, the significant increase in price associated with California LED Quality Standard eligibility is largely due to the high CRI requirement. As show above in Table 2-3, CRI was determined to have the greatest impact on price. Across all LED lamp categories, products that offer CRI equal to or greater than 90 on average cost 25% more compared to the mean price.

Navigant conducted a multi-variable regression to reveal how accurate specific parameters are at predicting LED luminaire price. Specifically, Navigant considered the impact that efficacy, watts, lumens, color temperature (CCT), CRI, and lifetime have on price. Ultimately, the team found that none of these specifications are highly correlated with price for any of the LED luminaire product categories studied. Compared to LED lamps, there is a wider range of acceptable performance specifications for luminaires, which have a more diverse set of application specification considerations. There are also many additional features that characterize luminaire performance that were not tracked in the web-scraped database, such as R9 value, power factor, color tunability, advanced controls, wireless communication, DLC qualification, photometry and beam characterization. The detailed results of this multi-variable regression are provided in Appendix A.3.3.

2.3 Projected LED Prices

Looking beyond 2014 and 2015, survey and interview responses shown below in Table 2-5 revealed that the majority of market actors believe that prices for LEDs have not yet stabilized.

Table 2-5 LED Price Stabilization – Results from Market Actor Surveys and Interviews

Q6. Have prices for any LED products stabilized yet? Which products? (Select all that apply)

Product Type	Contractors	Distributor	Manufacturer and Retailer
Screw-ins / integral lamp	22%	17%	11%
High bay / low bay	2%	7%	
Exterior LEDs	15%	7%	
Panel / troffer	7%	11%	
Accent / track / downlight	5%	7%	11%
Prices have not stabilized for any products	29%	39%	56%
Don't know	15%	11%	
Other (please specify):	5%	2%	22%
Total:	100%	100%	100%

Source: Market Actor Survey Results & Navigant analysis

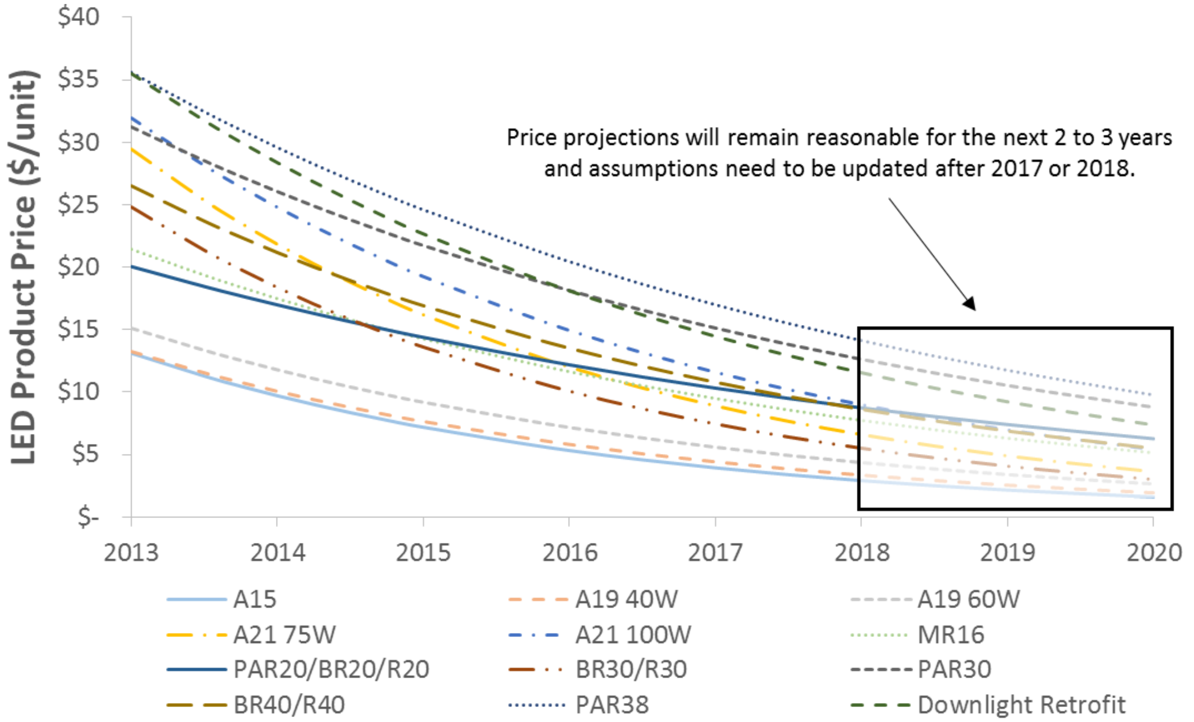
These findings align well with Haitz's law[32], as well as price trends found in several other lighting technology studies[25], therefore Navigant believe it is logical to predict an exponential price decline in the near term. Using the mean 25th percentile price points for each LED product type, Navigant fit price data to an exponential model in order to describe the overall time trends. A simple exponential model was used in the LBNL analysis of LED web-based pricing and also proved effective for our dataset, producing the greatest R-squared values for all LED types when performing least-squares minimization. While these exponential models can used to forecast future LED price, each is based on a limited dataset with only about 6-15 price observations. These small samples of data present significant challenges when attempting to use regression analysis to project future pricing, and as a result, impact the accuracy of the model. These limitations are discussed in Section 5.2.3, and plots of the calculated 25th percentile versus the predicted price for each LED product categories are provided in Appendix A.3.4.

Figure 2-4 and Figure 2-5 present the price forecast modeling results for LED lamps and luminaires respectively.[33]

[32] 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.

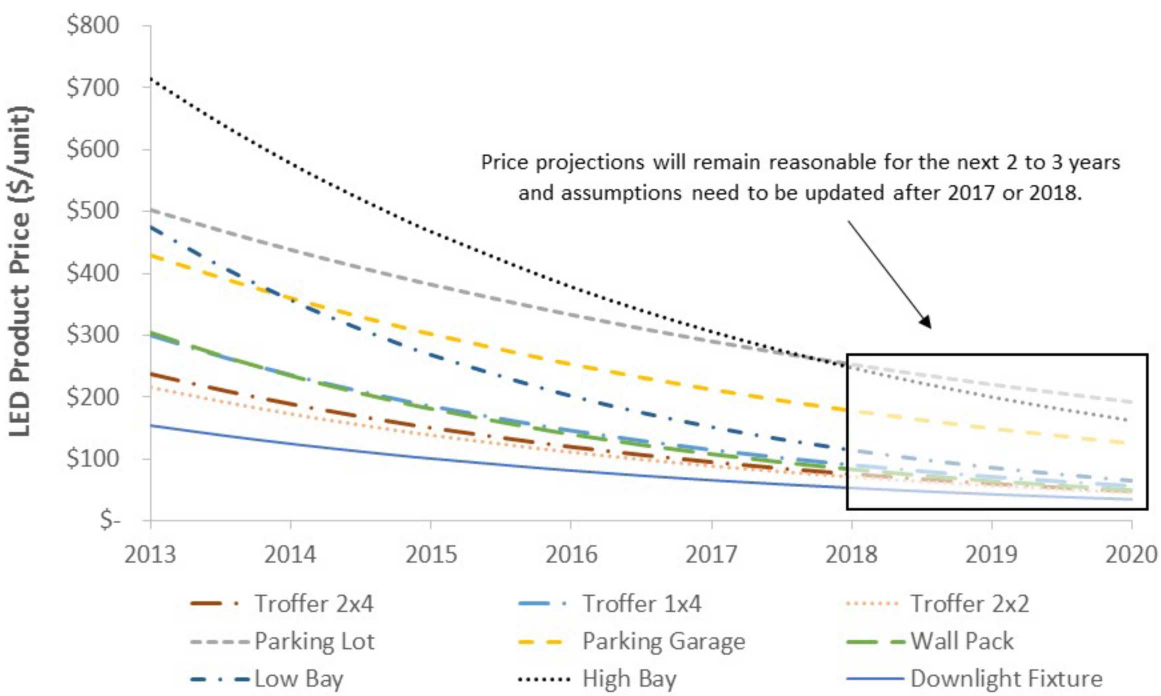
[33] A table of all price projections is provided in Appendix A.3.5.

Figure 2-4 Mean (25th Percentile) Forecasted Prices LED Lamps



Source: Web-scraped data & Navigant analysis

Figure 2-5 Mean (25th Percentile) Forecasted Prices LED Luminaires



Source: Web-scraped data & Navigant analysis

The web-based pricing analysis indicates that in the near term, average LED lamp prices will decrease annually by 21% per year and luminaires by 20% per year. This is supported by the 16% per year annual decrease the surveyed market actors reported Constant year-over-year price decline, however, will not continue indefinitely. Rather, the rate of decline for several of these LED product categories is expected to slow within the timeframe of this projection analysis.

The estimated 2 to 3 year forecast reliability is based on an empirical validation test of the model accuracy. For A19 LED lamps, Navigant analysts set aside the last few years of data to determine how accurately the forecasting methods would have predicted actual pricing trends within that period. This exercise showed that the team could eliminate roughly 3 years of data and still have the forecast fall within the median to 10th percentile range. Therefore, to be conservative, the team believes that these price projections will remain reasonable for the next 2 to 3 years only (until about 2017 or 2018). However, the ability of the exponential model to accurately forecast LED product price is limited since there are only 6-15 price observations for any one of these models.[34] To ensure accurate characterization of LED product price, Navigant suggests quarterly web-scraping of LED pricing and an annual analysis of pricing-related assumptions based on the quarterly web-scraping results. This will help ensure projections of LED price remain useful to the IOUs.

2.4 Baseline Price Comparisons

In addition to collecting web-based data for LED lighting products, product price and specification data were also collected for baseline technologies.[35] Similar to the method used for LEDs, Navigant determined that the 25th percentile is also appropriate for characterizing the typical purchase price for incandescent, CFL, halogen, linear fluorescent and HID lighting products. Figure 2-6 compares the mean 2014 LED lamp and luminaire cost to that of the lamp replacement cost[36] for baseline technologies.

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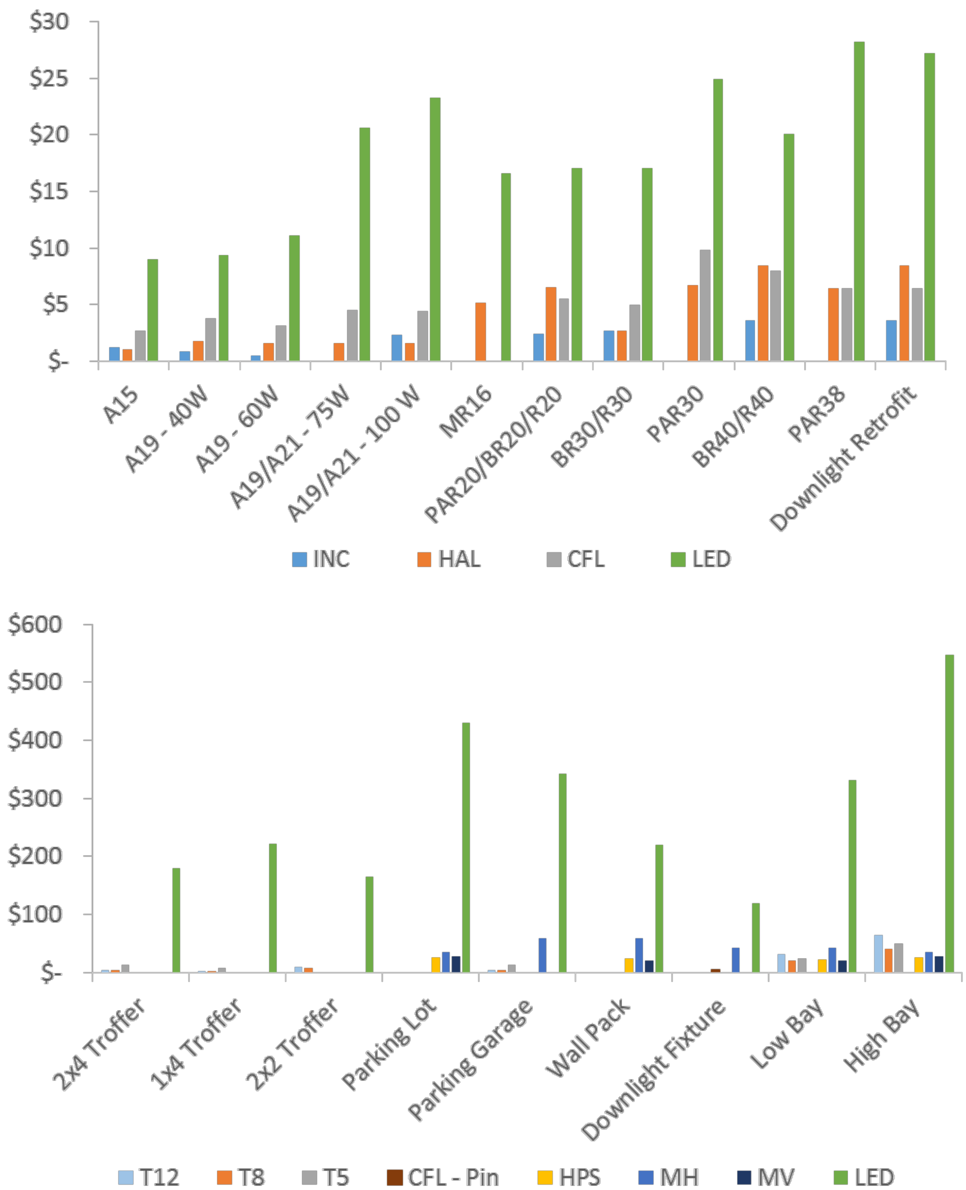
[34] The limitations of the exponential model for LED price forecasting are discussed in detail in Section 5.2.1.

[35] Data was collected from Home Depot, Lowes, Ace Hardware, Target, Walmart, and Grainger.

[36] Only lamp replacement costs for baseline technologies are considered. All ballast and fixture costs are excluded from the baseline cost estimates.

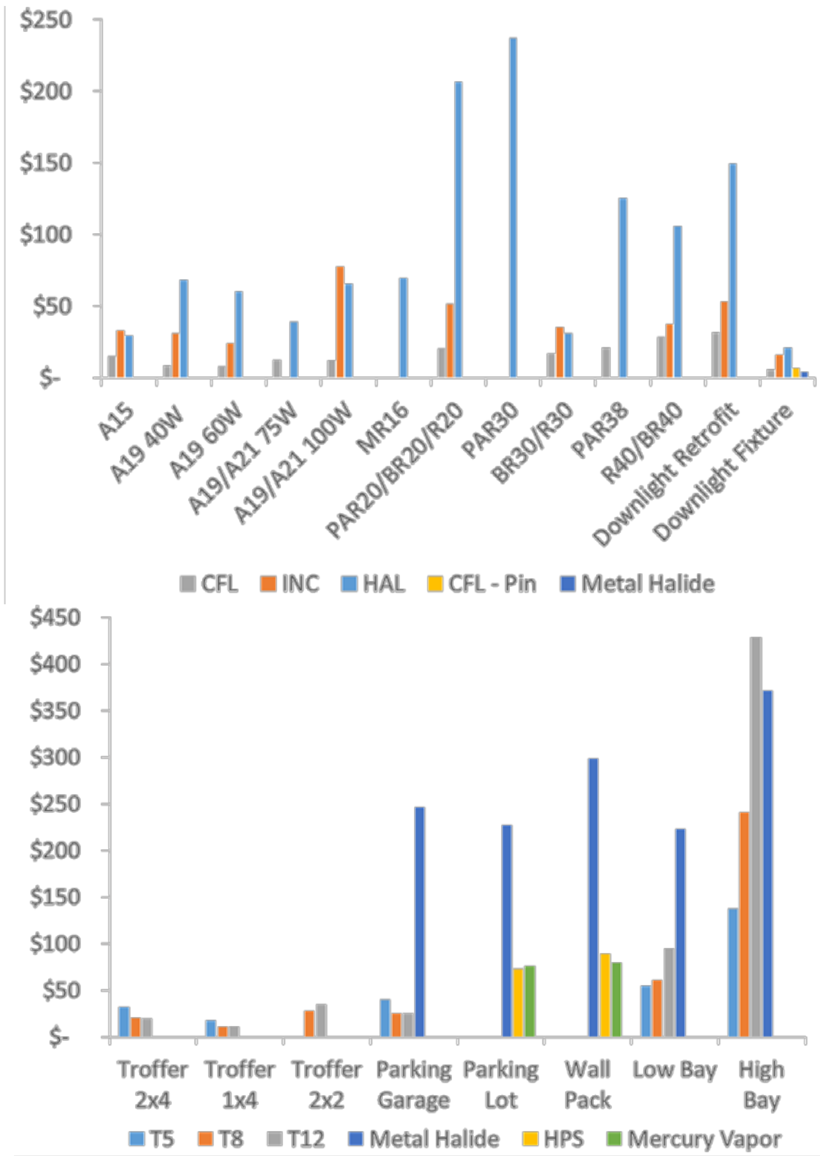
Figure 2-6 Comparison of 2014 LED and Baseline Technology Pricing



Source: Web-scraped data & Navigant analysis

When comparing the lamp product categories, LEDs cost anywhere from two to five times that of CFL, incandescent and halogen equivalent lumen output alternatives. For luminaires, this cost difference is even more significant ranging from two to over one hundred time that of conventional linear fluorescent and HID options. In some cases, however, the higher incremental cost of LEDs becomes more acceptable when considering the avoided maintenance costs of multiple baseline technology lamp replacements over the lifetime of an LED lamp or luminaire product. According to web-scraped product data, lifetimes for LED lamps range between 20,000 and about 35,000 hours. This is three to over 30 times that of conventional lighting options. LED luminaires have even longer lifetimes that range from about 45,000 to over 70,000 hours, which are anywhere from two to seven times that of linear fluorescent or HID lamp life. When relamping and installation labor costs of baseline technologies are considered over the lifetime of the LED products that replace them, LEDs often offer attractive financial returns. As seen in Figure 2-7, replacing halogen reflector lamps with LEDs can save as much as $250 over the life of an LED, and replacing metal halide high bay lighting with LEDs can save nearly $450.

Figure 2-7 Avoided Maintenance Costs Over LED Lifetime[37]



Source: Web-scraped data & Navigant analysis

[37] Assumptions for labor costs are based on those utilized for the U.S. DOE lighting market model. Navigant calculated both relamping and labor costs over the lifetime of an LED, to determine the avoided maintenance costs.

Tables detailing the prices illustrated in Figure 2-6 and Figure 2-7 as well as details of the avoided maintenance cost assumptions are provided in Appendix A.3.5.

2.5 Price Impacts on Forecasted LED Penetration

The U.S DOE lighting market model[38] predicts LED market share as an aggregate of many individual purchase decisions, based upon two analytic components: an econometric logit model[39] that considers cost factors influencing each decision, and a technology diffusion curve that considers time dependent market factors influencing each decision. Table 2-6 provides the U.S. DOE lighting market model outputs of forecasted installed stock penetration of LED lamps, based on the price projection curves developed for this study.

Table 2-6. Forecasted Installed Stock Penetration of LEDs into Select Lighting Applications

Lighting Applications	2015	2016	2017	2018	2019	2020
General Service	7.7%	12%	18%	24%	30%	36%
Directional	11%	16%	22%	29%	35%	42%
Troffer	0.9%	1.9%	3.4%	5.4%	8.3%	12%
Low/High Bay	3.4%	6.4%	11%	17%	25%	34%
Parking Lot	19%	29%	41%	54%	67%	78%
Parking Garage	12%	21%	32%	45%	59%	72%
Building Exterior	11%	19%	30%	42%	54%	66%
All – Weighted Average	4.4%	7.4%	12%	17%	23%	29%

Source: U.S. DOE Lighting Market Model & Navigant analysis

These results indicate that LED price has a significant impact on adoption. If prices continue to fall according to their current trajectory, LED lamps and luminaires are expected to represent nearly 30% of all installations by 2020. LEDs are predicted to have the greatest adoption in outdoor applications, such as parking and building exterior largely due to maintenance cost benefits and LEDs for these applications were some of the first viable products for the technology. In contrast, saturation is slower for general service and directional lamps since first cost is the major factor driving purchasing decisions. LEDs have the lowest adoption in troffer applications due to low cost high efficiency linear fluorescent technology. Additional information and graphics detailing Navigant's analysis methodology and the adoption of LEDs relative to baseline technologies are provided in Appendix A.3.6.

[38] U.S. DOE, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications, Prepared by Navigant, August 2014. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energysavingsforecast14.pdf

[39] The conditional logit model is a widely recognized method of forecasting a product's market penetration based on several quantitative or categorical explanatory variables. The result of the conditional logit is a probability of purchase, which represents an aggregation of a large number of individual consumer purchasing decisions.

3. Non-Residential Baseline

The primary research objectives of the LED baseline analysis are to:

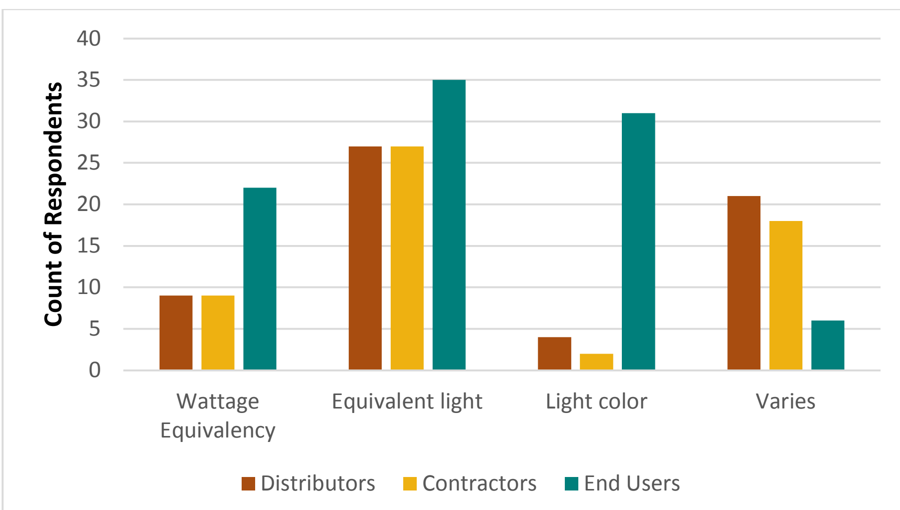
1. Define the comparison factors most considered when selecting LED products.
2. Outline the type and mix of baseline technologies for early retirement (ER) and replace on burnout (ROB) LED installations.
3. Determine whether the decision making for LEDs is unique such that it warrants more rigorous baseline research.
4. Understand how assumptions about non-residential baseline technologies should change during the next few years.

This section describes the findings and results of the LED baseline analysis by research objective. The detailed methodology of this analysis is included in Appendix A.4.

3.1 Comparison Factors

As shown in Figure 3-1, equivalent light output was the single most important factor for all market actors when choosing an LED product to install. End users, more so than contractors and distributors, also reported placing importance on light color and wattage equivalency, and many respondents indicated that relative importance of comparison factors varies by project, depending on customer needs. It is important to note that equivalent light output does not always imply equal lumen output across the baseline and LED cases: some customers wish to increase or decrease light levels for safety or aesthetic reasons and consider light distribution as well as total lumens.

Figure 3-1. First Comparison Factor When Selecting an LED



Source: Navigant survey data analysis. n = 61 distributors, 56 contractors, 94 end users

3.2 Non-Residential Technology Mix by Baseline Type

The team sought to characterize the mix of baseline (i.e. non-LED) technologies both in current market sales and in the products LEDs are replacing.[40] These technology mixes can provide context for updating replace-on-burnout (ROB) and early replacement (ER) baselines, respectively. Navigant understands the current baseline choices in California as follows:

- **Lamps:** All lamps use a ROB baseline for ex ante savings, implemented through a Wattage Reduction Ratio (WRR). The 2012 Integral LED disposition baseline references previous studies on socket saturation, which could imply an ER baseline, but since these measures are classified in DEER as ROB the team believes that in this case ED used socket saturation to approximate technology shares in an ROB baseline.
- **Luminaires:** ED has set a "code" baseline of pulse-start metal halide (PSMH) technology for bay and exterior lighting ex ante savings. However, programs may use a dual-baseline approach if implementation can demonstrate that a project is early replacement. In this case, the ER baseline is used for the remaining useful life of the previous equipment and the ROB baseline is used for the remainder of the efficient product lifetime.

Best practice baseline determination methods for ROB and ER are as follows:

- **ER**: Baseline is the actual technology replaced by the efficient product, determined by actual pre-conditions or estimated average pre-retrofit conditions.
- **ROB**: There are two common approaches to determining ROB baselines:
    - **Minimally efficient option**. In this case, the baseline is defined as the lowest efficiency level that is available on the market per standards or code. If this efficiency level is lower than the average efficiency of installed stock, using this baseline may overestimate savings.
    - **Market baseline/standard practice**. If the minimally efficient option is not representative of industry standard practice, a baseline estimated from the actual mix of products in the market will provide more realistic savings estimates.

3.2.1 Market Technology Mixes for Integral Lamps

For each LED lamp product category, Navigant asked market actors two questions in succession:[41]

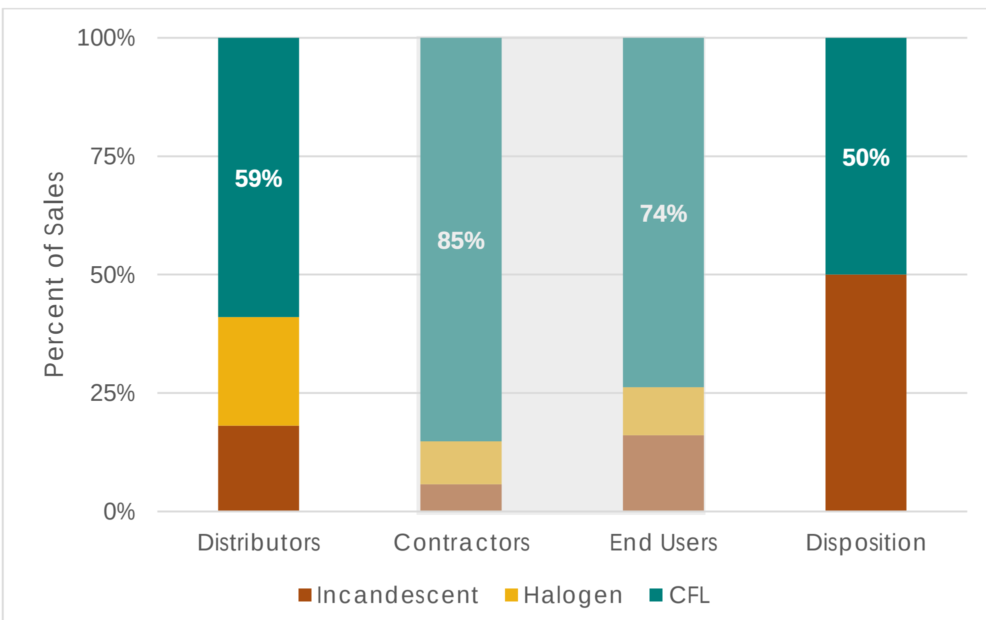
1. What is your current sales mix by lighting technology, including LEDs?
2. What would your sales mix look like if LEDs were not available?

[40] The team excluded LEDs from the baseline due to their low current market penetration and long lifetime, which together suggest that the majority of currently installed LEDs are still functional.
[41] Exact phrasing of second question varied by product group; see Appendix A.6 for complete interview guides.

Navigant used responses to the second question to determine the non-LED technology mix in the market.[42] While most respondents reported that they would sell/install more CFLs without LED lamps available, distributors reported a lower percent of CFLs in their A-line and reflector lamp market mix compared to contractors and end-users. Due to program influence, the team believes that participating contractors and end-users targeted by the surveys may be more likely to choose another incented product when LEDs are unavailable and, therefore, may report bias CFL share estimates on the high side.[43] To minimize this bias in the baseline analysis, the team recommends only using the responses from distributors, as the team believes distributors have a broader market perspective not limited to program activity. Although distributor respondents also reported participating in programs, program sales are typically a smaller portion of distributors' total business than contractors', as many program contractors likely work in the program retrofit market niche. Distributors, in contrast, serve a broader portion of the market.

Figure 3-2 shows the reported hypothetical sales mix for A-line lamps in the absence of LEDs. For comparison, national market data shows CFLs as 40 percent of A-line shipments in the first quarter of 2015.

Figure 3-2. Reported A-Line Market Technology Mix



Source: Navigant survey data analysis; n = 26 distributors, 21 contractors, 11 end users

[42] For A-type and bay lights, this question was asked directly, soliciting an answer in the form of a percentage: respondents provided estimated shares of incandescent, halogen, and CFL. For other lighting types, the survey asked how the given technology mix from question one would change in the absence of LEDs (i.e., which technologies would increase/decrease). The team used these responses to estimate the hypothetical shares by technology in the absence of LEDs.

[43] 100 percent of contractors, 98 percent of end users and 100 percent of distributors reported participating in an IOU program.

For reflectors, market actors also reported significant shares of CFL sales. As with A-line lamps, distributors reported a lower percent of CFLs in their reflector market mix than did contractors and end-users. Just as with A-line lamps, discussed above, the team believes these responses may be biased by the level of program influence any market actor group may have. As such, to minimize this bias in the baseline analysis, the team recommends only using the responses from distributors.

Table 3-1. Percent CFL in Reflector Market Technology Mix

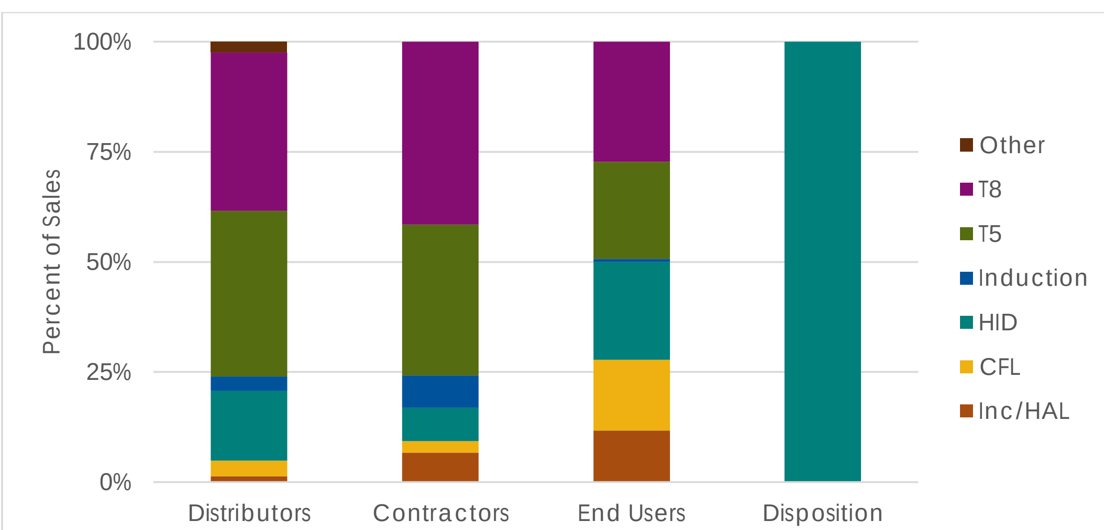
Technology	*Contractors (n = 20)*	*Distributors (n=23)*	*End Users (n=14)*	LED Disposition
MR16*	*0%*	*0%*	*0%*	0%
PAR/BR/R20	*74%*	*45%*	*75%*	0%
PAR30, PAR38				25%
R/BR40**	*73%*	*49%*	*74%*	n/a

Source: Navigant survey data analysis, Integral LED disposition
*Note: Due to the low number of MR16 CFL products available, Navigant overrode MR16 CFL responses.
**Percent CFL not listed in Integral LED disposition.

3.2.2 Market Technology Mix for Luminaire Applications

Linear fluorescent products dominate the non-LED market technology mix for both high and low-bay lighting. When asked for market shares by technology for this market, responses for linear fluorescent products ranged from 49 percent for end users to 75 percent for contractors. While the May 2014 disposition suggests the industry standard practice baseline for bay lighting is pulse-start metal halide, market actors generally reported few sales of HID products in this application. End users reported a higher share of HID technology than did distributors and contractors and also estimated that CFLs account for about 16 percent of the market, as seen in Figure 3-3.

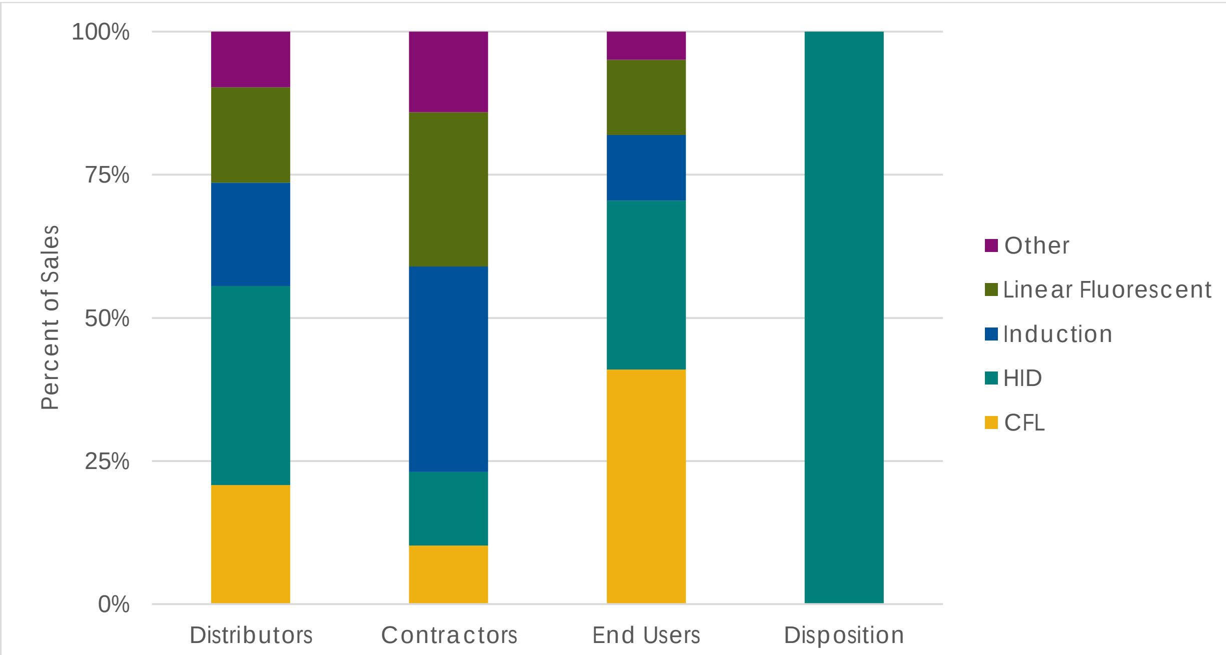
Figure 3-3. Bay Lighting Market Technology Mix



Source: Navigant survey data analysis; n = 23 distributors, 23 contractors, 9 end users

Figure 3-4 groups responses for parking garages, parking lots, and wall packs. Linear fluorescents are a significant share of reported sales as well, though they are not as dominant as in the bay lighting analysis. Distributors reported that HID would be the most common alternative to LEDs in exterior lighting while contractors reported higher shares of induction lighting, and end-users reported a higher share of CFLs.

Figure 3-4. Exterior Lighting Market Technology Mix



Source: Navigant survey data analysis; n = 27 distributors, 30 contractors, 25 end users

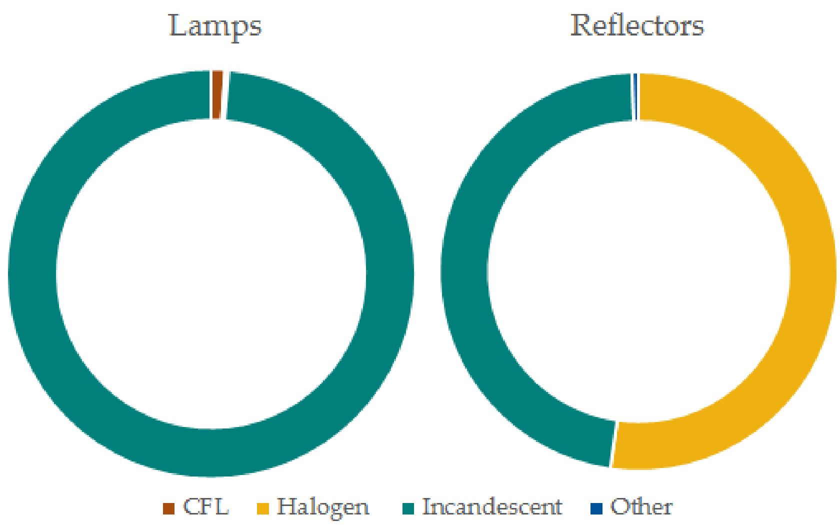
These results suggest that as other products take market share from HID luminaires in new installations, PSMH technology may not be an accurate representation of standard practice in bay and exterior lighting, even when customers' existing fixtures are HID.

3.2.3 In-situ Baseline Technology Mixes

Recent on-site data collected in California showed that nearly 100 percent of LED lamps (A-line and reflector) replace halogen or incandescent lamps.[44] This is different from the market technology mix, which is dominated by CFLs.

[44] 2010-2012 LED Impact Evaluation Report Appendices (Add-on work to WO-29). Navigant received raw data from this study from Itron.

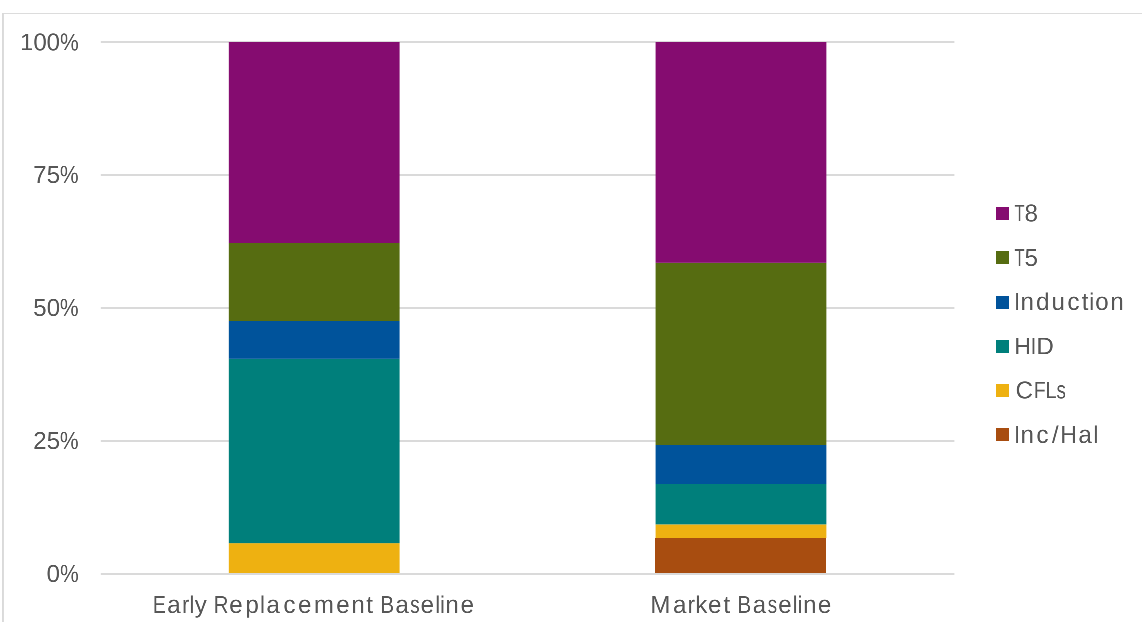
Figure 3-5. In-situ baseline technology mix for A-line and reflector lamps



Source: WO 0029 Data

Navigant asked contractors and end-users about replaced (in-situ) luminaire technologies in the web surveys, but received very few responses. Figure 3-6 provides an illustrative comparison of contractors' responses for in-situ technology shares versus their reported sales mix for bay lighting. While the response rate for this application is low (n = 9), the results indicate that the share of HID is likely greater in the in-situ blend compared to the market mix, but still less than the 100% share suggested in the disposition.

Figure 3-6. Comparison of contractor responses for bay lighting market and in-situ technology mixes

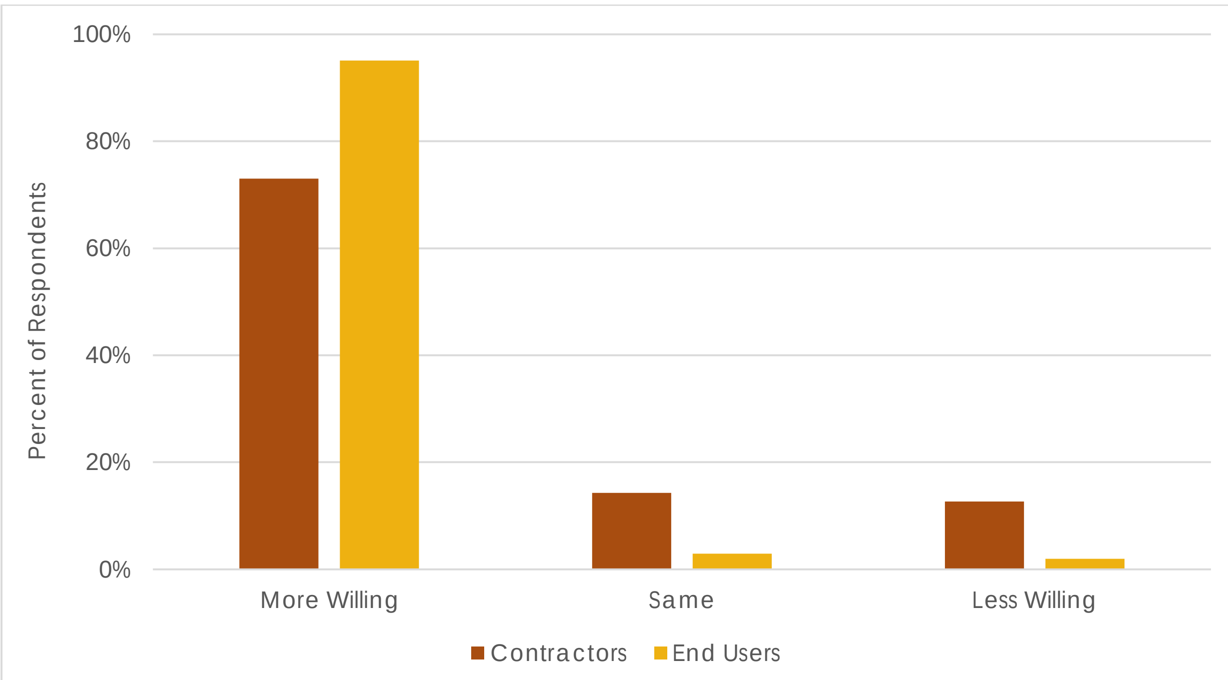


Source: Navigant survey data analysis; n = 9 early retirement baseline, 26 market baseline

3.3 Incidence of Early Replacement

The majority of contractors and end users indicated that they are more likely to replace equipment before the end of useful life when installing LEDs than when installing new non-LED equipment (Figure 3-7). This suggests that LED decision making is unique and warrants additional research on early retirement and replace-on-burnout baselines, especially given the variation in technology mixes this study found to exist across these two baselines.

Figure 3-7. Willingness to replace equipment with LEDs before end of useful life, relative to other replacements



Source: Navigant survey data analysis; n = 63 contractors, 102 end users

4. Savings Estimation Methods

Non-residential prescriptive LED lighting measures in California use one of two savings estimation methodologies: wattage reduction ratios (WRRs) and wattage ranges. These methodologies were selected, in part, due to the fact that many IOU programs offer measures in wattage ranges, rather than requesting individual lamp wattages or other technical specifications, in an attempt to reduce administrative burden on participants.

- **Wattage reduction ratios** are the ratio of the deemed baseline wattage to the deemed LED wattage. The CPUC's original integral LED disposition[45] sought to establish WRRs that drew upon the available data provided in IOU workpapers where possible. At the time, the CPUC was concerned about the use of LED wattage ranges for a single baseline wattage, as they believed there was no assurance that lower wattage LED lamps provided the same level of service as higher wattage products. CPUC also noted lack of evidence for customer preference for equivalent light output products, which this study has since researched. These concerns weighed in to the guidance delivered in May 2014 lighting retrofit disposition, which states that a designated ratio must be applied to the lowest LED wattage within the range of wattages established for a LED product category (i.e. 6 – 10 W LED for A-19 lamps), creating a disincentive for programs to focus on more efficient products. May 2014 lighting retrofit disposition.t

- The **wattage ranges method** maps LED wattages to baseline technology wattage ranges within various LED luminaire product categories. Savings are calculated as the difference between the lowest baseline technology wattage in the baseline range and the highest LED technology wattage in the LED range, again creating a disincentive for programs to focus on more efficient products.

While CPUC and IOU staff have recognized the weaknesses of both approaches, the timing between disposition releases and revised filing deadlines have historically limited IOUs' ability to propose substantial changes to the current methodologies to date.

This study sought to provide direction for future improvements to LED workpapers, and Navigant's research aimed to address three main questions for both of these methods. Figure ES-1 summarizes these questions.

[45] Integral LED Lamp Disposition, 2012

Figure 4-1 Core Savings Estimation Research Questions

Source: Navigant

The team analyzed survey data and technical specifications from the Navigant web-scraped database to estimate the actual delta watts (difference between baseline and efficient lamp wattage) typically achieved by non-residential customers. Navigant relied on internal expertise and secondary research to compare these methodologies to other approaches across the country.

This section describes the findings and results of this analysis by savings estimation method. The detailed methodology is included in Appendix A.4.

4.1 Methodology

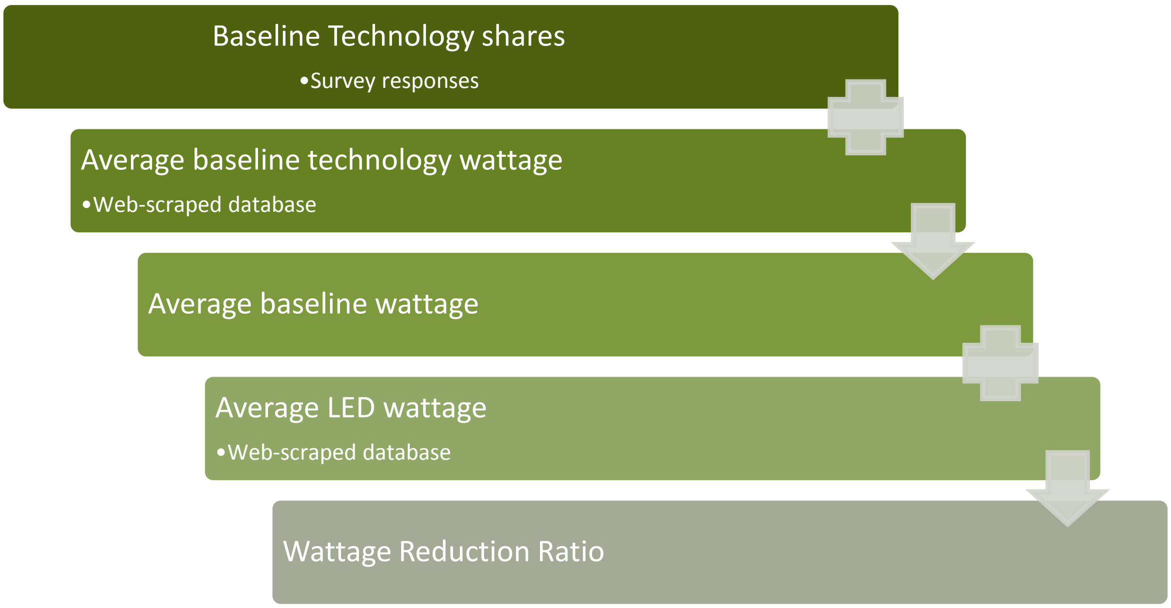
The Navigant team used the market actor surveys to elicit the actual market and hypothetical baseline technology mixes for non-residential applications as described in Section 3.2. In order to evaluate LED savings over this baseline technology mix, the lighting evaluation team compiled lighting characteristics such as average wattages, luminous efficacies and lumen output for each of the lighting technology categories and sizes. Navigant used data from the web-scraped database for wattages, efficacies, and lumens for all lamp types. The team also used lighting characteristics from the LED Lighting Facts, the Design Lights Consortium qualified product lists to verify that the web-scraped data were within the expected ranges.

4.2 Wattage Reduction Ratio Findings

Navigant's analysis suggests that existing WRRs used for the non-residential application of LEDs are currently too high, given the changes to the mix of baseline screw-in lamp technologies and, in the case of A-line lamps, too broad to accurately capture the range of efficacies within a product category. Additionally, the guidance to apply the WRR to the lowest LED wattage in the relevant range further disincentivizes the promotion of more efficacious products.

Figure 4-2 illustrates the process and data sources Navigant used to recalculate wattage reduction ratios for A-line lamps, reflectors and downlights.

Figure 4-2. Wattage Reduction Ratio Estimation Process



Source: Navigant

4.2.1 A-Line Lamps

Navigant's analysis revealed that revised wattage reduction ratios for A-Line lamps in non-residential applications varied across different wattage equivalency bins.[46] Navigant's set of revised WRRs are provided in Figure 4-3.

There are four main factors which the team believes drive differences between the revised and disposition WRRs:

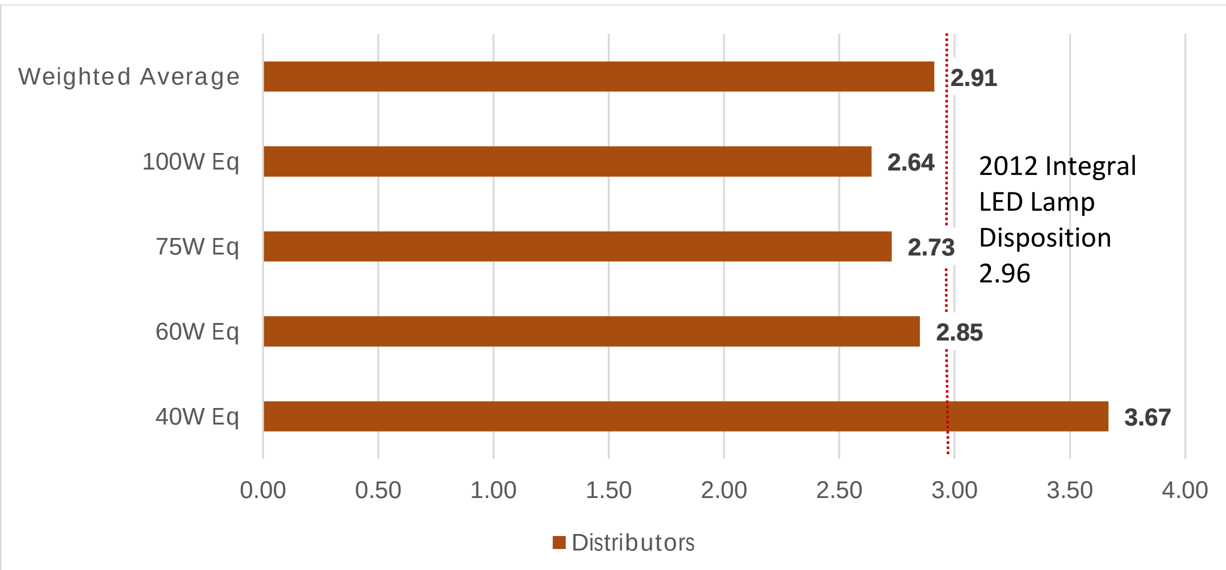
- **Percentage CFL in baseline**. Although there was variation among market actors, the responses collectively showed a higher share of CFL in the market baseline than the 50 percent assumed in the disposition. Using the share reported by distributors (59 percent) decreases the WRR.
- **Bin-jumping.**[47] Accounting for bin-jumping generally increased the WRR for lower wattage equivalent lamps and decreased slightly for higher wattage equivalent lamps.
- **Percentage halogen in baseline**. Distributors reported that incandescent lamps account for 44 percent of combined halogen and incandescent A-line lamp sales. The team used this percentage

[46] The Energy Independence and Security Act (EISA) legislation established four A-line lamp lumen output bins as equivalence bins for the four dominant wattages of traditional incandescent lamps: 40W, 60W, 75W, and 100W. The current CA lighting disposition uses a single WRR of 2.96 for all A-line bulbs regardless of lumen bin.
[47] Bin jumping refers to market actors choosing an LED that does not align with its rated lumen or wattage equivalent. For example, using an LED 40W equivalent lamp in place of a 60W equivalent halogen or incandescent, is bin jumping "down," whereas using an LED 75W equivalent lamp in in place of a 60W equivalent halogen or incandescent is bin jumping "up."

in the revised A-line WRR. The 2012 LED Integral Lamp Disposition likely used a traditional incandescent efficacy, making this change a driver for decreasing the WRR.

- **LED efficacy**. Due to the year over year increase in LED efficacy and decrease in wattage for a given lamp category, using current LED efficacy should increase the WRR. LED efficacy also varies across the different lumen bins defined by EISA, increasing the need for individual WRRs for each bin.

Figure 4-3. A-Line Wattage Reduction Ratios



Source: Navigant survey data analysis, Navigant web-scraped database, Integral LED lamp disposition (2012); n = 26 distributors

Table 4-1 and Table 4-2 summarize the average wattage and efficacy assumptions the team used to revise the WRRs for A-line lamps. Tables for reflectors and downlights can be found in Appendix A.4.4.

Table 4-1. Summary of A-Line Lamp Wattage Assumptions by Technology (Watts)

Technology	40W Equivalent	60W Equivalent	75W Equivalent	100W Equivalent
LED	5.9	10.6	14.0	17.8
CFL	9.0	13.7	18.5	23.3
Halogen	29	43	53	72
Incandescent	40	60	75	100

Source: Navigant data analysis, Navigant web-scraped database

Table 4-2. Summary of A-Line Lamp Efficacy Assumptions by Technology (Lumens per Watt)

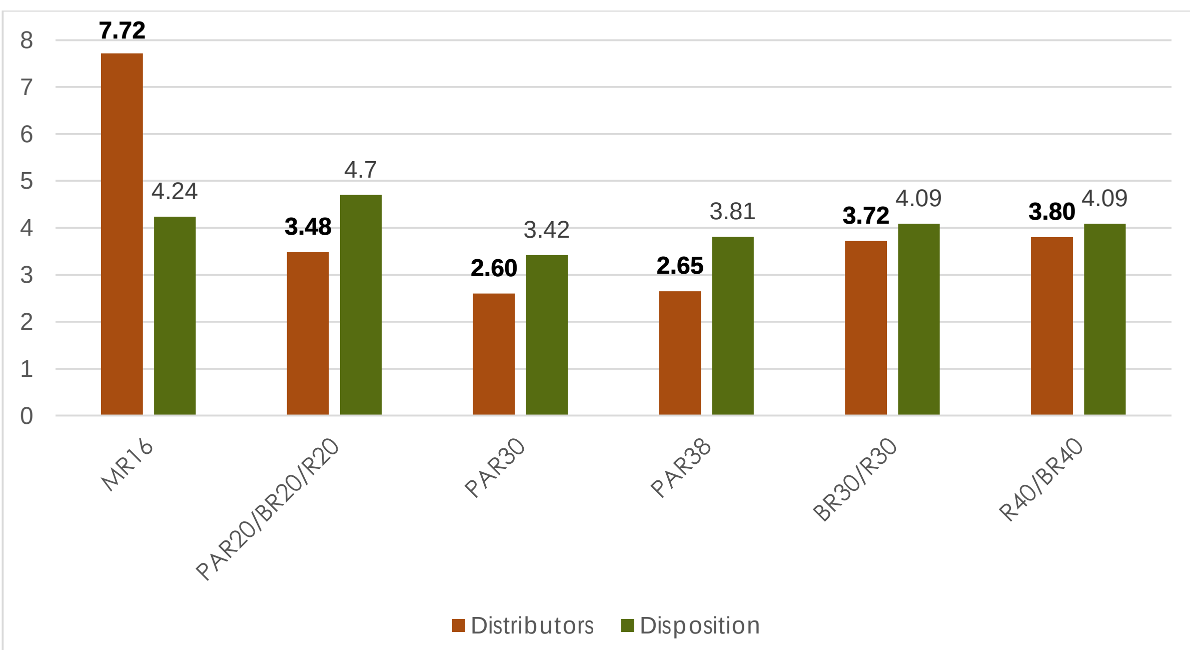
Technology	40W Equivalent	60W Equivalent	75W Equivalent	100W Equivalent
LED	69	77	73	85
CFL	57	63	67	69
Halogen	16	15	17	20
Incandescent	10	14	15	14

Source: Navigant data analysis, Navigant web-scraped database

4.2.2 Reflectors and Downlights

Figure 4-4 and Figure 4-5 display the revised WRRs for reflector lamps and downlight retrofits, respectively. As with A-line lamps, the higher reported share of CFLs reduced the WRR for most lamp types. The exception is MR16 lamps, where Navigant overrode the few market actor responses indicating high shares of CFLs in the baseline. Due to the low number of CFL MR16 products available on the market, the team does not believe that CFLs have a large share of shipments for this technology. In this application, the WRR is much higher than the disposition value. Navigant believes this reflects the improvement in MR16 LED efficacy and average wattage since 2012. Navigant assumed an MR16 LED efficacy of 56 lumens per watt and an average wattage of 4.8 watts.[48]

Figure 4-4. Reflector Wattage Reduction Ratios

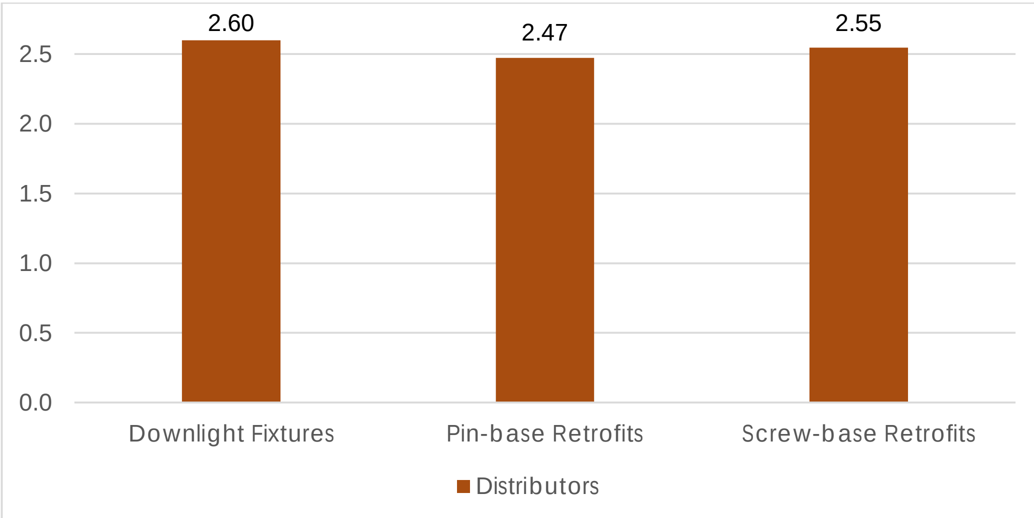


Source: Navigant survey data analysis, Navigant web-scraped database, Integral LED lamp disposition (2012); n = 23 distributors

[48] Based on average of web-scraped products in the 25th price percentile (n = 182)

For downlights, there is not a current disposition WRR value for comparison.

Figure 4-5. Downlight Wattage Reduction Ratios



Source: Navigant survey data analysis; n = 30 distributors, 22 contractors, 14 end users

4.3 Wattage Range Findings

Navigant's analysis suggests that the typical installed LED wattage for bay and exterior lighting applications falls near the mean of the existing LED wattage ranges. The existing methodology of deriving delta watt savings using the upper bound of the LED wattage range, therefore, is underestimating savings and not reflecting typical installation. Moreover, it disincentivizes the promotion of more efficacious products.

Navigant used the market actor surveys to gather data on typical LED and non-LED fixtures in the market today. For each bay lighting and exterior application, web respondents provided detailed information on their "go-to" LED and non-LED fixtures. Navigant verified the fixture specifications through online manufacturer literature for as many responses as possible. Navigant grouped LED responses from all market actors in order to achieve significant sample sizes.

4.3.1 Bay Lighting

Navigant found that the average wattage of market actors' "go-to" LED fixtures were closer to the mean of the DEER measure LED ranges than the upper bounds. Since the current savings methodology requires programs to use the upper bound of the wattage range for LED product to derive delta watt savings, this suggests that the current application of the ranges for these LED measures does not accurately reflect typical savings occurring in the market. Table 4-3 shows the average LED watts derived from market actor responses and resulting delta watts for the two measures with sufficient response sizes.

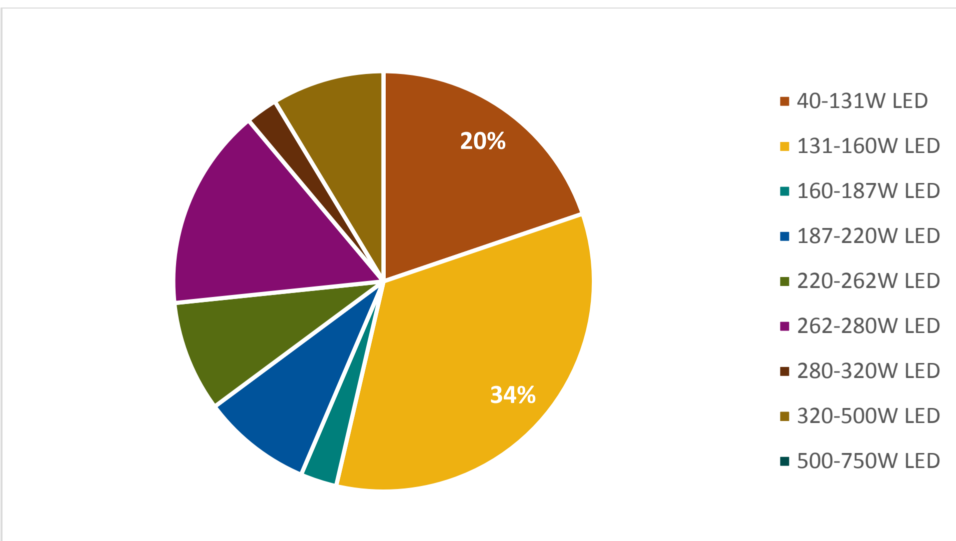
Table 4-3. Delta Watts for Bay LED Luminaires by Measure

Measure	Source of LED Watts	LED Watts	Base Watts	Delta Watts
40 – 131W LED Replacing 175W PS-MH	DEER - Upper Bound	131	208	77
	DEER - Range Average	86		122
	Survey - Average (*n = 33*)	93		115
131 – 160W LED Replacing 200W PS-MH	DEER - Upper Bound	160	232	72
	DEER - Range Average	146		86
	Survey - Average (*n = 10*)	149		83

Source: Navigant survey data analysis, May 2014 lighting disposition

While Navigant was only able to obtain sufficient survey responses for two of the nine distinct LED wattage ranges included in the prescription bay lighting measure category, Figure 4-6 shows that these two ranges represent over 50% of program savings.

Figure 4-6. 2014 SCE and PG&E Program Savings by LED Wattage Range within Bay Lighting

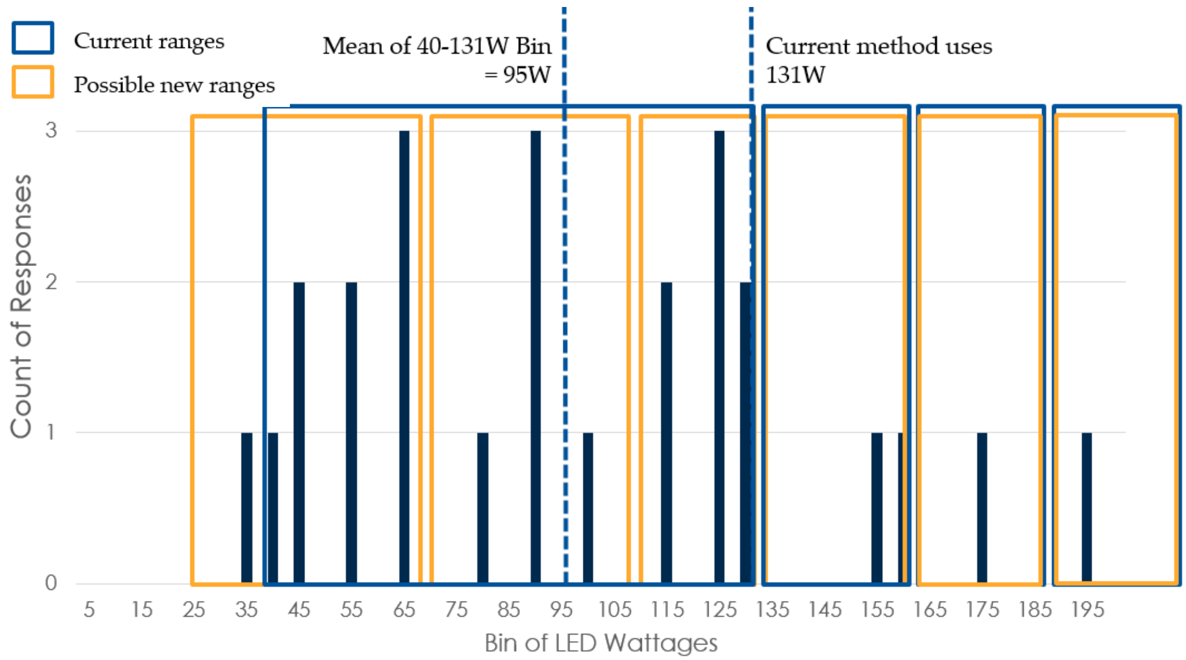


Source: Navigant analysis of SCE and PG&E program tracking data, downloaded May 2015. Measures dates include Q3 and Q4 of 2014.

Navigant also reviewed the distribution of these go-to luminaire responses.[49] Figure 4-7 shows the distribution layered within the current LED wattage ranges (blue).

[49] The team also compared the go-to responses to the bay lighting products in the Design Lights Consortium (DLC) qualified product list, which also has numerous products well below 131 watts.

Figure 4-7. Distribution of LED Go-to Luminaire Wattages



Source: Navigant survey data analysis, May 2014 lighting disposition

The application of the wattage range methodology for the lowest bay lighting range (40-131W) is problematic because it is so large. It appears that there are multiple groups of LED products within this range. Given these peaks in distribution, it is likely that some of these product groups may even be replacing a different baseline technology wattage range. For this reason, even using the average of the LED wattage range will likely misrepresent savings for LEDs at the lower end of the LED wattage range.

The yellow boxes in Figure 4-7 show Navigant's suggestions for possible new, narrower ranges, designed to reduce the problems described above.

4.3.2 Exterior Lighting

Using the same methodology as for bay lighting, Navigant found that average LED luminaire wattages for exterior products are also closer to the mean of the DEER LED wattage ranges for exterior area lighting. This suggests that the current application of the ranges for these measures does not accurately reflect actual savings occurring in the market. Table 4-4 summarizes the findings for the exterior area lighting ranges with sufficient survey responses.

Table 4-4. Delta Watts for Exterior Area Lighting Measures

Measure	Source of LED Watts	LED Watts	Base Watts	Delta Watts
Replace 71-100W Lamp (50-70W LED)	DEER	70	120	50
	LED Range Average	60		60
	Survey Average *(n = 5)*	59		61
Replace 101-150W Lamp (70-110W LED)	DEER	110	176	66
	LED Range Average	90		86
	Survey Average *(n = 8)*	95		82
Replace 151-200W Lamp (110-150W LED)	DEER	150	234	84
	LED Range Average	130		104
	Survey Average *(n = 6)*	137		97
Replace 201-250W Lamp (150-192W LED)	DEER	192	293	101
	LED Range Average	171		122
	Survey Average *(n = 6)*	158		135

Source: Navigant survey data analysis, May 2014 lighting disposition

There were not enough responses for wall pack measures to conduct this analysis, but given the trend for both bay and exterior area lighting, the team believes that average LED range wattage is more representative than the upper bound of the range for these measures as well.

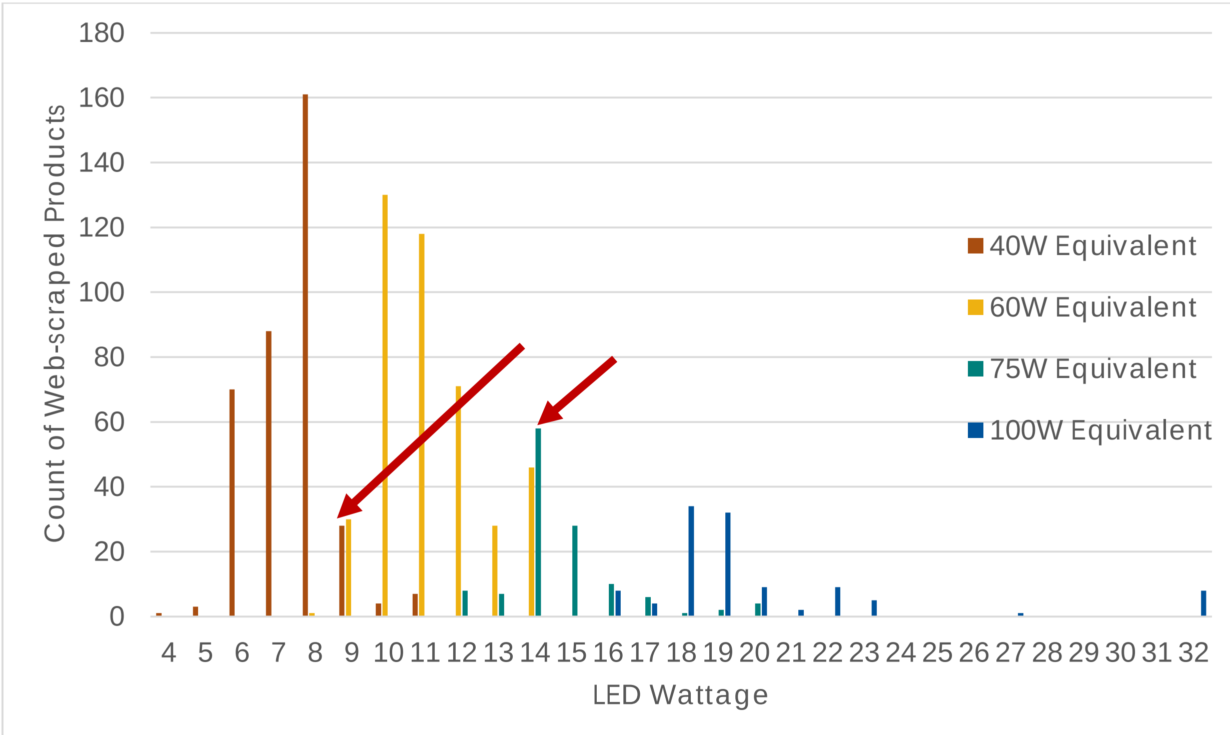
4.4 Methodology Review: Wattage Reduction Ratios

Balancing ex ante and impact evaluation needs with ease of program implementation is always challenging. The current wattage reduction ratio offers a simple calculation method which requires minimal data collection. Programs only need to record LED lamp wattage, which is generally simple to identify. But for LEDs, a product family where the efficacy is changing at rates of 20 percent per year[50], wattage is rarely the best metric for determining what application it is serving and what baseline it is replacing. This is especially clear in the case of A-line lamps.

For most other lighting products, the efficacy of a given lamp type, for example, a halogen incandescent 40W equivalent, does not vary significantly between manufacturers. In contrast, LED efficacy is highly variable across and within manufacturers. This results in some overlap between product groups if LEDs are assigned to groups by wattage, as shown in Figure 4-8. A 9W LED could be a low efficacy 40W equivalent, or it could be a high efficacy 60W equivalent. Product packaging tells the consumer which type of lamp this is, but wattage alone cannot.

[50] Year over year change in average efficacy of A-line products in the 25th price percentile from 2013 to 2014: 14% for 40W equivalents, 23% for 60W equivalents, 15% for 75W equivalents, and 24% for 100W equivalents.

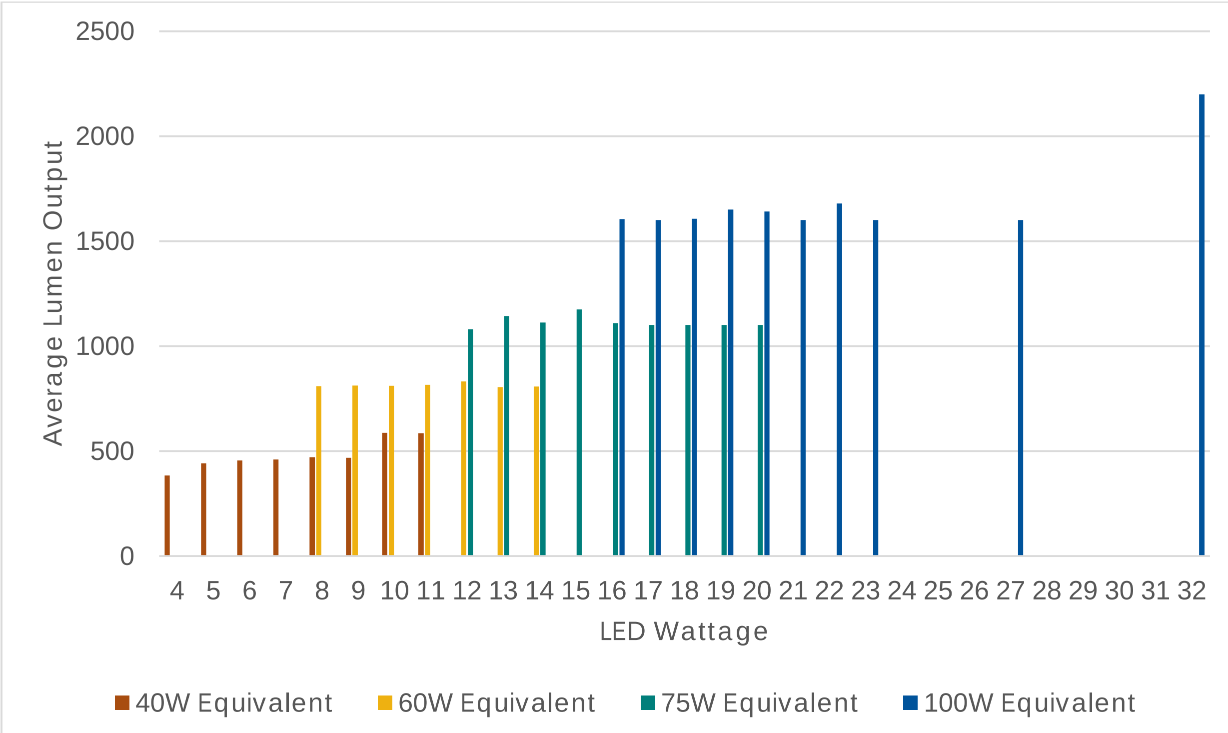
Figure 4-8. Histogram of LED A-Line Wattages by EISA Lumen Bin



Source: Navigant web-scraping database, 2014 products

Lumen output is a much more accurate way to classify LED lamps. By definition, there is no lumen bin overlap between EISA categories. Figure 4-9 shows the average lumen output for each wattage and EISA equivalence bin: average lumen output is very consistent within the bins, and there are clear steps between each.

Figure 4-9. Average A-Line Lumen Output by Wattage and EISA Bin

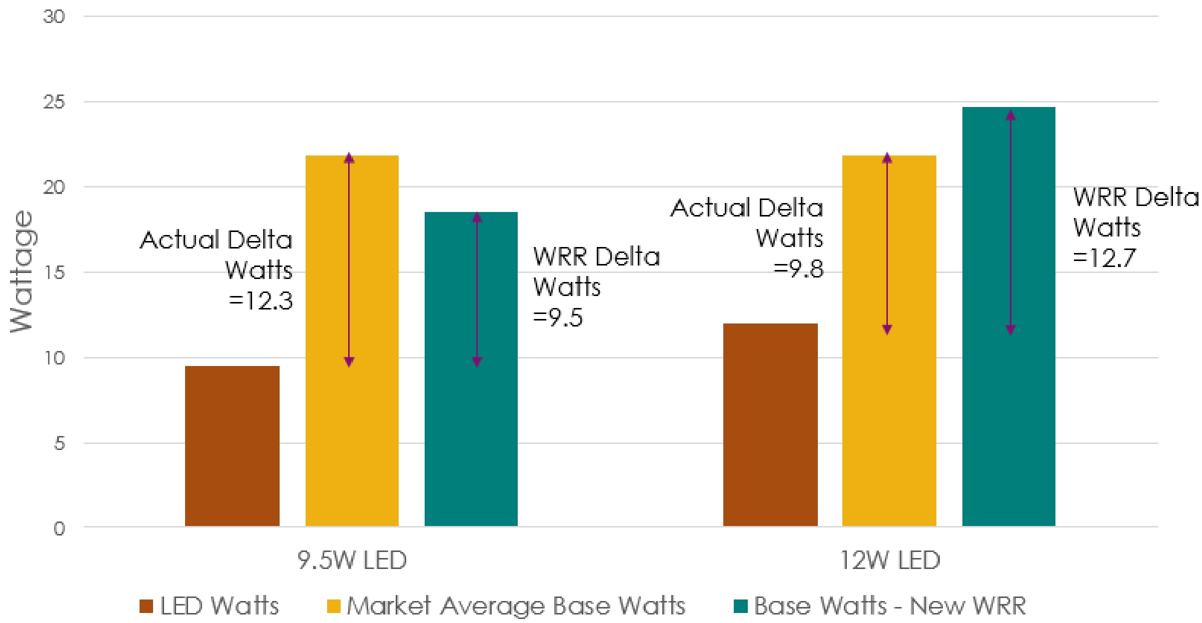


Source: Navigant web-scraping database, 2014 products

The main disadvantage of the WRR method is that it assumes that the baseline shifts linearly with LED wattage. At a high level this is true for A-line products because the baseline does vary by EISA bin. However, there are actually ranges of LED equivalent product wattages replacing a single baseline product. As a result, the method underestimates savings for more efficient lamps and overestimates savings for less efficient lamps. This is illustrated in Figure 4-10 using the calculated WRR for the 60W equivalent bin from this study.

While the average may be appropriate in narrow ranges and across large samples, the more important impact of this methodology is that it provides a disincentive for programs to focus on more efficient products. If programs promote the most efficient lamps on the market, savings derived from the WRR method will be systematically underestimated. With an accurate WRR applied to individual LED wattages, the difference between the market baseline and WRR calculated baseline is not large in absolute terms at the individual lamp level. However, it can be large as a percent of claimed delta watts, and can add up at the program level for this common measure.

Figure 4-10. Delta Watts Comparison: Actual Baseline Product and WRR Baseline for Two 60W Equivalent LEDs



Source: Navigant survey data analysis, Navigant web-scraped database

For measures where LED wattage ranges are broader than for A-lamps, the WRR approach is less accurate because the average WRR must be applied to the lowest wattage in the range.

Navigant presents the following options for improving the methodology for screw-in lamps in a "good, better, best" format, recognizing that some changes may not be possible.

- **Ideal "Best" Method**. The most accurate option is to determine a single baseline for each product category—i.e. EISA lumen bin—and determine which bin LEDs fall into by collecting actual lumen output for incented products. This is the recommended approach for A-line lamps in the residential lighting uniform methods protocol.[51] Average program LED wattage per bin would determine the savings. In lieu of program LED wattage averages, average LED wattage for each bin could be updated annually with web-scraping data.
    - This approach would require programs to collect detailed records of incented LED products including wattage and efficacy or lumen output.
    - .
- **Alternative "Better" Method**. If collecting lumen output is not possible, simply assigning a single baseline wattage for each product category and assigning product categories by LED wattage could be an improvement. In this case, savings should be the category baseline watts

[51] Dimetrosky, Scott. "Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures. Chapter 6, Residential Lighting Evaluation Protocol." p. 6-7. http://energy.gov/sites/prod/files/2013/11/f5/53827-6.pdf

minus the actual LED watts. Programs would need to review the LED wattage bin mapping annually to account for increases in efficacy that will change the LED bounds of each EISA category.

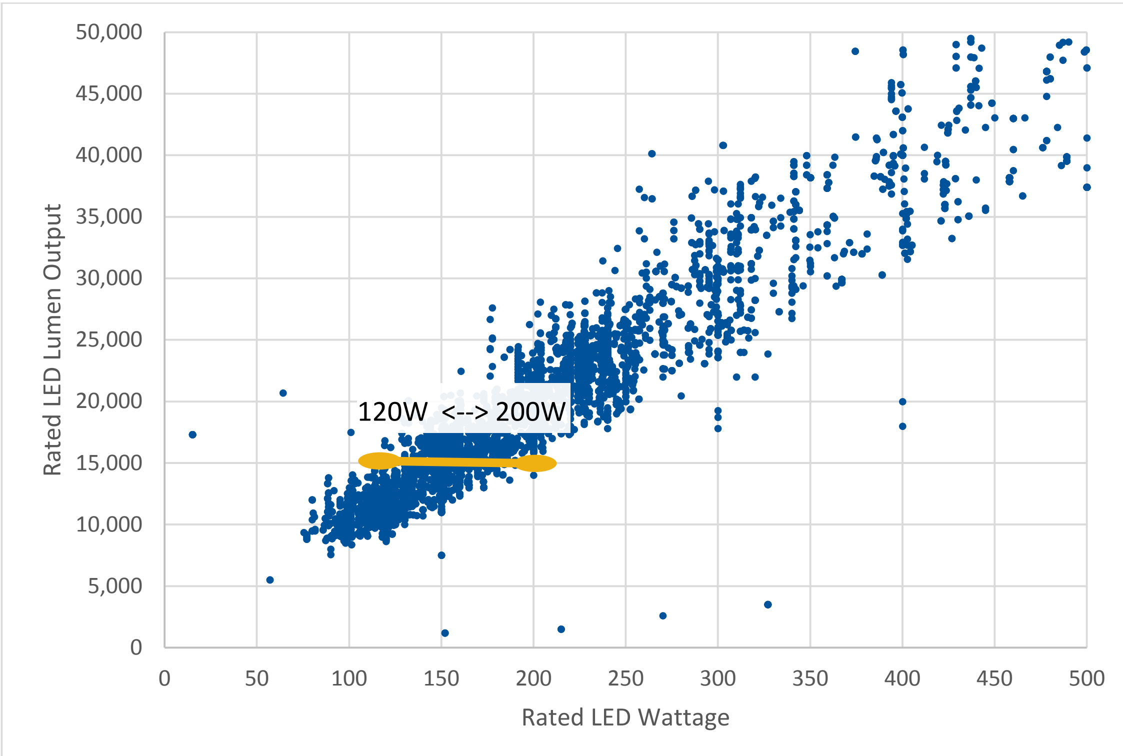
- This approach would require programs to collect the rated wattage of incented LED products.

- **Possible Improvements to WRR Method**. If the WRR method cannot be changed, the following improvements to its application will improve accuracy:
  - Update average LED efficacy and wattage annually using web-scraped data
  - Apply different WRRs to each EISA bin as determined by LED lumens (ideal) or wattage (possible)
  - Update baseline technology mix and wattage regularly

4.5 Methodology Review: Wattage Ranges

Much like WRRs, wattage ranges represent a relatively simple savings estimation method that relies on LED wattage as a predictor of baseline within a given application. While some contractors and distributors reported off-hand rules of thumb for estimating LED wattage equivalents, LED efficacy is actually highly variable in luminaires: market actors reported go-to luminaire efficacies for high-bay products ranging from below 80 lumens per watt to over 110 lumens per watt. For a typical high-bay lumen output of 15,000 lumens, that represents a difference of over 50 watts for two products that could be replacing the same baseline fixture. This is illustrated in Figure 4-11 for high bay products currently qualified for the DLC product list, where products with lumen output within 100 lumens of 15,000 lumens range from 120W to 200W.

Figure 4-11. Range of LED Wattages by Lumen Output from DLC Qualified Product List



Source: Navigant analysis of DLC qualified product list, downloaded May 2015

For this reason, lumen output is inherently a more accurate way to determine LED baselines. However, this is not as straightforward for luminaires as it is for A-line lamps, where EISA has defined clear lumen bins. While this study collected some data on both LED and baseline "go-to" fixtures, the team observed that these responses were not necessarily paired, and respondents did not indicate whether the LED and baseline luminaires they chose were one-to-one equivalent products. Because LED luminaires typically have better light distribution than baseline luminaires, it is generally accepted that total LED rated lumens may be lower than rated baseline lumen output.

5. Recommendations & Suggestions for Future Research

This section provides Navigant's recommendation and suggestions of areas for future research.

5.1 Recommendations

Navigant has identified the following key findings and recommendations by research topic, as well as provided the stakeholder for which each recommendation is relevant.

5.1.1 Pricing

Program Staff

- Finding: Current prices for both LED and baseline (non-LED) products included on the CA Statewide Cost Data Sheet[52] are no longer accurate.
    - Recommendation: Update cost sheet to use web-based pricing analysis results for LED and baseline (non-LED) products provided in Table 2-1. Additionally, consider using updated incremental cost results.
- Finding: There is no statistical difference for any high-priority LED product category between the San Francisco and San Diego mean price at the 95% level of confidence.
    - Recommendation: All IOUs can use the same updated cost data.
- Finding: Prices have not stabilized for any high-priority LED product category. The web-based pricing analysis indicates that in the near term, average LED lamp prices will decrease annually by 21% per year and luminaires by 20% per year.
    - Recommendation: Use updated costs data for the next 2 to 3 years only (until about 2017 or 2018).

5.1.2 Non-Residential Baseline

CPUC – Energy Division & IOU Program Staff

- Finding: Although there was variation among market actors, survey responses collectively showed a higher share of CFL lamps in the non-residential market baseline than the 50 percent assumed in the disposition. Additionally, due to EISA legislation, incandescent sales now include halogen incandescent lamps with higher efficacy. For bay lighting applications, most market actors reported high shares of linear fluorescent lamps and relatively low shares of PSMH lighting. This indicates that a baseline of 100 percent PSMH may no longer be standard practice. Standard practice baselines are especially important where no code requirements exist or code requirements are unclear.
    - Recommendation: Consider updating the non-residential baseline for LED lamps to reflect the current market mix of baseline technologies.

[52] IMC Analysis CA Statewide Cost Data Sheet, data for LEDs was collected in May 2012.

- Recommendation: Consider updating the non-residential baseline for bay lighting to reflect the current market mix of baseline technologies. This may require additional research since not all fixtures are one-to-one replacements and the survey did not collect data on number of lamps per linear fluorescent fixture.

5.1.3 Savings Estimation Methods

5.1.3.1 Wattage Reduction Ratios used for Non-Residential Applications

CPUC – Energy Division & IOU Program Staff

- Finding: The WRR method underestimates savings for more efficient lamps and overestimates savings for less efficient lamps, which provides a disincentive for programs to focus on more efficient products. Additionally, existing WRR values also do not accurately reflect the current baseline and LED efficacies in the non-residential market.
  - Recommendation: Navigant presents the following "good, better, best" options for the DEER team to consider as they continue research focused on improving the methodology for screw-in lamps, recognizing that some changes may not be possible.
    - **Ideal "Best" Method**. The most accurate option is to determine a single baseline for each product category—i.e. EISA lumen bin—and determine which bin LEDs fall into by collecting actual lumen output for incented products. This is the recommended approach for A-line lamps in the residential lighting uniform methods protocol.[53] Average program LED wattage per bin would determine the savings. In lieu of program LED wattage averages, average LED wattage for each bin could be updated annually with web-scraping data.
      - This approach would require programs to collect detailed records of incented LED products including wattage and efficacy or lumen output.
    - **Alternative "Better" Method**. If collecting lumen output is not possible, simply assigning a single baseline wattage for each product category and assigning product categories by LED wattage could be an improvement. In this case, savings should be the category baseline watts minus the actual LED watts. Programs would need to review the LED wattage bin mapping annually to account for increases in efficacy that will change the LED bounds of each EISA category.
      - This approach would require programs to collect the rated wattage of incented LED products.
    - **Possible Improvements to WRR Method**. If the WRR method cannot be changed, the following improvements to its application will improve accuracy:

[53] Dimetrosky, Scott. "Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures. Chapter 6, Residential Lighting Evaluation Protocol." p. 6-7. http://energy.gov/sites/prod/files/2013/11/f5/53827-6.pdf

- Update average LED efficacy and wattage annually using web-scraped data
- Apply different WRRs to each EISA bin as determined by LED lumens (ideal) or wattage (possible)
- Update baseline technology mix and wattage regularly, starting with mix reported in distributor surveys

5.1.3.2 Wattage Ranges used for Non-Residential Applications

CPUC – Energy Division & IOU Program Staff

- Finding: Navigant's analysis suggests that the typical installed LED wattage for bay and exterior lighting applications falls nearer to the mean of the existing LED wattage ranges. The existing methodology of deriving delta watt savings using the upper bound of the LED wattage range, therefore, is underestimating savings and not reflecting typical installation. Moreover, it provides a disincentive to promote the most efficacious products.
  - Recommendation: Update guidance to specify using the mean of LED wattage ranges for delta watts calculations instead of upper end.
  - Recommendation (for bay lighting): Consider adding the narrower ranges suggested in Figure 4-7 within the current lowest wattage range to improve accuracy in the delta watts savings calculation.

IOU Program Staff

- Finding: Due to the large variability in LED product efficacy and quality, using broad wattage ranges may lead to inaccurate savings estimates.
  - Recommendation: Collect more detailed product information on pre-and post-retrofit fixtures, namely quantity and rated input wattage and lumen output. This will allow programs to verify whether high quality, efficacious products are in fact the majority of program participation. An alternative method based on lumen output and fixture quantity is presented in the recent disposition on LED troffers, which could be sued here but would also require programs to collect data on rated lumen output.[54]

5.2 Limitations & Mitigation Strategies

Navigant has identified the following limitations and mitigation strategies by research topic as a means to better inform the appropriate application of this study's findings, as well as too identify additional opportunities for future research.

[54] Workpaper Disposition for PGECOLTG179 LED Ambient Commercial Fixtures and Retrofit Kits, California Public Utilities Commission, Energy Division, June 26, 2015

5.2.1 Non-Residential Baseline

The main limitation of the non-residential baseline analysis is that the primary data source is self-report phone and web surveys. As stated in Section 3.2, nearly all market actors had participated in California efficiency programs which may bias results, in particular for contractors and end users. The team recommends using distributor responses only to mitigate this bias.

In addition, not all respondents provided data for every question. In particular, very few respondents provided data on equipment that LEDs replace (i.e. early retirement baseline technology mix). As noted throughout the findings and recommendations, additional research may be needed to confirm individual findings.

5.2.2 Savings Estimation Methods

The recommendations in this section rely on analysis of survey data, web-scraping data, program tracking data, and secondary data sources such as the DLC and Lighting Facts qualified product lists. As the team leveraged broader market data to estimate average program LED characteristics, the main uncertainty is whether LED products installed through the program differ in any way from market averages. Program tracking data did provide some information on the most common wattage ranges and measure applications, however, as noted in the recommendations and suggestions for future work, collection of additional LED product details such as wattage and lumen output would help better characterize measure savings in the future. For LED luminaire applications such as bay and exterior lighting, survey data did not provide sufficient information to validate or change the current mapping of LED wattage ranges and baseline wattage ranges. Section 5.3 provides additional detail on addressing this limitation.

5.2.3 Pricing

While web-scraping enables the collection of a large amount of pricing data for several key LED product categories, there is significant uncertainty introduced when using this data to estimate both current and future pricing. While the ideal statistic for calculating typical purchase price is a sales-weighted average, this is not possible with web-scrape data since this process yields no information on relative sales. Instead, the pricing analysis uses the LBNL method for analyzing web-scraped LED pricing data to best approximate typical pricing for LED products. This is characterized by a range with the median as the upper bound, 25^{th} percentile as the mean, and 10^{th} percentile as the lower bound. This method helps to address the entry of these high-priced products into the market, as well as, the effects of temporarily low-priced products in sale events.

Furthermore, this method condenses hundreds of price points, collected via the web-scraping tool, into single point estimates over discrete time values which then enables a simple exponential model to be fit to the data for all LED product categories. These exponential models can then be used to forecast future LED price. However, since the web-scraped price data is aggregated into a single estimate at each point in time, each of these exponential price models is based on a limited dataset with only about 6-15 price observations. These small samples of data present significant challenges when attempting to use regression analysis to project future pricing, and as a result, impact the accuracy of the model. For example, several of the LED price models exhibit some tendency toward serial correlation, which compromises the usefulness of the predicted values. This is not surprising since the datasets are small and do not represent an immutable process, as manufacturers and retailers of LED products engage in strategic pricing behavior and respond to market events.

Given the limited statistical validity of the exponential models for LED product price, Navigant highly recommends the CA IOUs continue regular web-scraping activities, as this process is sufficiently reliable and efficient, eliminating the need to rely on price forecasts. These recommendations are discussed further in section 5.3.1.

5.3 Suggestions for Future Work

As the price, specifications and market share of LED products are rapidly changing, Navigant suggests the following areas for future work, aimed at keeping LED workpaper assumptions current and accurately predicting achieved savings.

5.3.1 Pricing

Program Staff

- Goal: Update price forecasting assumptions for LEDs annually until prices stabilize.
    - Suggested method: Use web-scraping to continually collect LED and baseline pricing. Specifically consider conducing web-scraping:
        - Quarterly for LEDs
        - Annually for baseline technologies
- Goal: As price is a key determiner of the cost effectiveness of LED measures, it is often cited as the most powerful influencer of adoption. The insights gained from a customized California lighting market model could be used to identify future attainable savings potential and help shape long term lighting measure goals and strategies.
    - Suggested method: Further customize DOE's lighting market model to better reflect the unique trends in the California region. (e.g. Initial installed stock and distribution of lighting technologies, building stock and space types, floorspace growth, lighting product characteristics and performance, operating hours, etc.)

5.3.2 Non-Residential Baseline

CPUC – Energy Division & IOU Program Staff

- Goal: Better understand the distribution of early retirement versus replace on burnout LED installation. The majority of surveyed contractors and end users indicated that they are more likely to replace equipment before the end of useful life when installing LEDs than when installing new non-LED equipment (Figure 3-7).

- Suggested method: Conduct additional research, including on-site evaluations, to establish prevalence of various baselines and customer motivations for early retirement LED projects.[55] .

5.3.3 Savings Estimation Methods

5.3.3.1 Wattage Reduction Ratios used for Non-Residential Applications

Program Staff

- Goal. Keep WRRs accurate.
    - Suggested method: Conduct annual web-scraping to update LED efficacies and wattages.
    - Suggested method: Continue research on baseline technology mix and consider alternative research methods such as field work or collecting non-residential sales data. Field work can support research on early replacement baselines, but understanding ROB baselines requires data on the mix of products newly installed outside of programs. While difficult to collect, sales data from distributors can be a valuable tool for assessing market baselines and has been used successfully in the Northwest.[56]
    - Suggested method: Collect lumen output and input wattage data of incented lamps to improve understanding of which baseline products they are replacing by using lumens to map an incented product to its EISA lumen range

5.3.3.2 Wattage Ranges used for Non-Residential Applications

Program Staff

- Goal: Keep Wattage ranges accurate:
    - Suggested method: Conduct additional research focused on mapping LED lumen output and wattages to baseline technology lumen output and wattages. This could include the following activities:
        - Reviewing a random sample of manufacturer literature for suggested equivalency
        - Reviewing custom program tracking data or tracking data from other jurisdictions where pre-and-post case fixture wattage, efficacy and quantity are known
        - Collecting more detailed data on program LED products and equipment they are replacing, including wattage, efficacy and quantity

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[55] Note that IOUs cannot claim early retirement projects unless they are program-induced early retirements. CPUC has provided guidance on establishing the "preponderance of evidence" that a program influenced early retirement.
[56] Bonneville Power Administration, "Northwest Nonresidential Lighting Market Characterization: 2010-2012." Prepared by Navigant Consulting and Cadeo Group, May 2014. http://www.bpa.gov/EE/Utility/research-archive/Documents/Northwest_NonRes_Lighting_Market_Characterization.pdf

- Repeating original workpaper analysis with current Design Lights Consortium (DLC) data[57]
- Conducting field research to confirm reported preference for equivalent light output

[57] Using the current Design Lights Consortium qualified product list available at https://www.designlights.org/QPL

Appendix A. Methodology

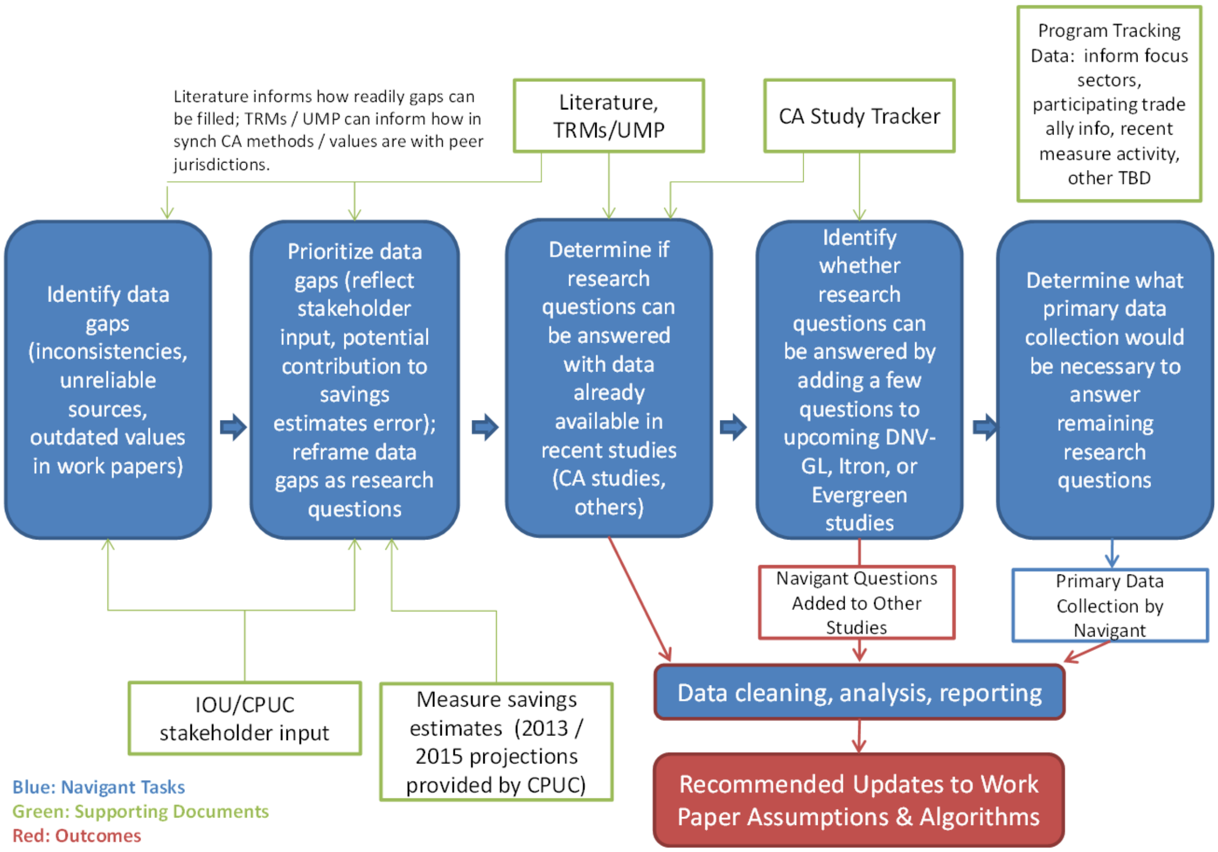
A.1 Research Plan

This report summarizes the finding and recommendation from the LED Market Characterization and Workpaper Update Study: Research Plan, presented to stakeholders in September of 2014. This research plan was the result of several months of preliminary research and stakeholder input. One of the initial tasks in the study was to review relevant workpapers to find and prioritize data gaps and inconsistencies in and across LED workpapers to inform the identification of near- and long-term data collection needs. A separate memo, presented in July 2014, shared findings from the workpaper review, as well as proposed research questions associated with the high priority data gaps identified through the review. Navigant's development and refinement of research questions for the study was also based on research questions included in the RFP, as well as discussion during the kickoff meeting and additional research prioritization discussions with IOU stakeholders in early May, 2014. Navigant leveraged stakeholder feedback, a literature review, current and projected measure-level saving estimations, and a review of ongoing LED research to assign a research priority to all identified gaps.

Not all data gaps identified through the workpaper review were ultimately selected by Navigant to address as part of this workpaper update study, as not all issues of importance can be adequately addressed with the resources available. As part of this prioritization process, Navigant reframed each data gap into one or more tangible research questions that, if answered, would provide the data necessary to fill the data gap. Navigant considered whether secondary sources, existing evaluation data, or upcoming evaluation efforts could provide the necessary data, then prioritized the primary data collection activities that would best address the remaining research questions within the available budget. Navigant collected stakeholder feedback through group discussions, one-on-one conversations, and written comments to obtain consensus on the list of research questions to be addressed through this study as well as the data collection methods that will be used to answer those research questions. The IOU stakeholders provided valuable guidance on where to focus, in terms of sector (non-residential), product categories, and topics (wattage reduction ratio/baseline wattages, pricing). The sources and uses (S&U) table is the documentation of the outcomes of that prioritization and planning process.

Figure A-1 presents a general overview of the study workflow from identifying data gaps in the workpapers through to recommending updates to the workpaper assumptions.

Figure A-1 Overview of Study Workflow



Source: Navigant

The final prioritized research topics are (a) savings estimation methods, (b) the non-residential baseline, and (c) price. Table A-1 presents the research questions that were addressed by this study. Question numbers refer to the numbering in the sources and uses table. The specific approach to addressing these questions is presented in more detail in the following sections.

Table A-1. Selected Research Questions

A. Savings Estimation Methods
A1. Do the multipliers used in current wattage reduction ratios reflect the average delta watts achieved by non-residential customers? Specifically in regards to high efficiency products?
A2. Are other methods more accurate? If so, what makes them so and can that be used to improve the ratio?
A3. If wattage reduction ratios continue to be used, how should those ratios be determined?
A4. How should non-residential LED lamps and fixtures be mapped to baseline wattages?
A5. Do current wattage ranges, and guidance describing how to use these ranges, reflect the average delta watts achieved by non-residential customers? Specifically in regards to high- and low-wattage fixture categories?
A6. Are other methods more accurate? If so, what makes them so and can that be used to improve the ranges?
A7. Are workpapers currently mapping to the correct wattage range based on actual in situ or market baseline technologies?
B. Non-Residential Baseline
B1. Are non-residential decision-makers more inclined to replace lighting equipment before the end of its useful life in the case of LEDs vs. other replacement technologies? Is the decision making for LEDs unique such that it warrants more rigorous research on ER vs ROB baselines?
B2. For a given LED product, what are the market baseline technologies: what the customer would have chosen if not an LED (types, wattages, performance specs)?
B3. In practice, when replacing existing equipment with LEDs, what comparison factors are considered most when selecting the LED products: lumen equivalency, wattage equivalency, or other factors? (for both contractors and customers making purchase decisions)
B4. For early replacement scenarios, what are the incumbent (in situ) baseline technologies: types, wattages, and performance specs of lamps/fixtures replaced by LEDs?
B5. Where multiple baselines exist, what is the approximate break-down (estimated percentage) of each baseline technology?
B6. How should assumptions about non-residential baseline technologies change during the next few years (e.g., due to Title-24, and forecasted growth in specific LED application types)?
C. Pricing
C1. What is the range of prices for LED products of focus (addressing both residential and non-residential measures, but limiting to the LED Quality Standard List for residential measures)?
C2. How are LED price ranges anticipated to change as the market becomes more mature, looking forward 3 years and 5 years?
C3. At what rate are prices changing, and how often should price assumptions be updated?
C4. What factors significantly influence product price? (non-residential focus)
C5. What is the relationship between online prices and shelf survey prices, and how could that be used for forecasting purposes?
C6. Are CA LED Quality Standard-eligible products priced higher than other LED products?
C7. What is the incremental cost of LED products relative to their baseline technologies?
C8. How is product adoption expected to change in response to changes in price based on diffusion modeling?
C9. What are the avoided maintenance costs of multiple baseline technology replacements over the lifetime of an LED lamp/fixture?
C10. Can all IOUs use the same standard cost data?

A.2 Data Collection

Between June of 2014 and May 2015, Navigant conducted the following primary data collection activities.

- **Market-actor phone and web surveys with contractors, distributors and commercial end-users.** Navigant worked with each of the electric IOUs to get comprehensive lists of participating contractors, distributors and end-users. Phone and web surveys were designed to get input from these market actors regarding the three key research topic areas, and participants who completed both surveys received a $100 incentive.
- **In-depth interviews with manufacturers and retailers.** Interviewees included Acuity Brands, Cooper Lighting, TCP, CREE, Philips, Osram Sylvania, GE, Home Depot and two others who chose to remain anonymous.
- **Web-scraping of LED (and non-LED) pricing and lighting specification data.** Since 2012, Navigant has been utilizing the web-scraping software WebHarvy to automatically collect LED pricing and performance specification data from online retailers. The WebHarvy tool enables Navigant to remotely collect in-store pricing information from Home Depot, Lowes, Walmart, and Ace Hardware locations, as well as from retailers including Best Buy, Target, Grainger, 1000bulbs.com, Amazon, BulbsAmerica.com and ProLighting.com which do not offer locational pricing on their websites.

In addition to primary data, the team used the following secondary data source:

- DOE pricings data - CALiPER, Gateway, SSL Municipal Consortium
- Qualified products list - Design Lights Consortium, LED Lighting Facts

A.3 Pricing Analysis

This section provides additional detail into the methodology and data cleaning used in the pricing analysis.

A.3.1 Web-based Data Cleaning

Navigant utilized its web-scrape database of lighting product pricing and specifications as the primary data source for the pricing analysis. The web-scraping tool automatically collects pricing and specification data and organizes it into spreadsheet form. However, in order to maintain high data quality, the web-scraped data must be thoroughly checked and cleaned, as this is essential to producing robust extrapolations of product price.

In order to correct for any organizational issues and errors in the pricing information, several queries are run to ensure that products are classified in the correct technology (LED, CFL, T8, high pressure sodium, etc.) and product category bins (A19, MR16, Recessed Troffer, etc.). In addition, Navigant makes an effort to remove utility rebates offered at big box retailers. To do this, the model numbers of lighting products are cross-checked at each location and are also compared to prices offered via online retailer websites such as 1000bulbs.com, Amazon, BulbsAmerica.com and ProLighting.com.

A.3.2 Comparison Factors

To verify the pricing methodology, the team compared the web-based pricing ranges to the CA Statewide Cost Data Sheet[58], market actor responses, as well as pricing data collected from distributors as a part of the SCE mid-stream program. The results of this comparison are shown in Table A-2.

Table A-2 Cost Comparison by LED Product Type

LED Product Type	2012	2014		2014/2015			
	CA State-Wide Cost Sheet*	Web-based Pricing Analysis Results	Weighted-Avg. SCE Distributor Sale Price	Weighted Avg. Market-Actor	Pricing Broken-out by Market Actor		
					Contractor	Distributor	Manufacturer+ Retailer
A19 60W equivalent	$ 25.47	$ 11.10	$ 11.55	$ 12.07	$ 15.00	$ 12.00	$ 10.75
MR16	$ 27.90	$ 16.61	$ 19.81	$ 16.99	$ 20.00	$ 16.00	$ 17.50
PAR20/R20/BR20	$ 33.97	$ 16.29	$ 18.55	--	--	--	--
PAR30	$ 45.23	$ 24.90	$ 29.95	--	--	--	--
R30/BR30	--	$ 17.03	$ 18.39	--	--	--	--
PAR38	$ 44.97	$ 28.22	$ 31.82	$ 30.07	$ 35.00	$ 30.00	$ 27.75
6" Downlight Retrofit	--	$ 26.85	$ 30.72	$ 30.91	$ 38.50	$ 29.00	$ 31.00
Downlight Fixture	--	$ 112.16	$ 96.59	--	--	--	--
Area Luminaire	--	$ 423.06	$ 522.23	$ 592.70	$ 828.00	$ 605.00	$ 450.00
2ft. by 4ft. Troffer	--	$ 179.00	$ 161.58	$ 188.52	$ 250.00	$ 188.50	$ 157.81
2ft. By 2ft. Troffer	--	$ 164.52	--	--	--	--	$ 172.16
High/Low Bay	--	$ 439.86	--	--	--	--	$ 381.37
Parking Garage	--	$ 344.43	--	--	--	--	$ 280.46
Wall Pack	--	$ 219.84	$ 221.52	--	--	--	$ 190.50

*IMC Analysis CA Statewide Cost Data Sheet, data for LEDs was collected in May 2012.

Source: Various cited sources including survey data, web-scraped data and Navigant analysis.

Green = **Value is** within the web-pricing range

Red = **Value is not** within the web-pricing range

[58] IMC Analysis CA Statewide Cost Data Sheet, data for LEDs was collected in May 2012.

This comparison indicates that the web-based ranges generally have good agreement with the results of the market actor interviews and surveys, as well as the data collected through the SCE mid-stream program. In contrast, the pricing estimates from the CA Statewide Cost Data Sheet are far outside the upper-bound of the web-based ranges. This is largely due to the fact that the cost sheet data was collected in 2012 and represents a very small sample set of products.

When considering the contractor data on its own, it is also outside the upper-bound of the web-based price ranges. However our commercial end-user survey respondents indicated that contractors account for only 14% of LED lighting purchases, while the remaining purchases come from distributors (58% of purchases) and manufacturers and retailers (28% of purchases). If the price data collected via the market actor surveys are weighted using this breakdown, (represented by the green plot point in Figure 2-3,) the resulting weighted-average price points are all within the web-based price ranges. Given the good agreement with these additional price data sources, Navigant believes that the 25th percentile is appropriate for characterizing the typical purchase price for all LED product categories.

San Francisco and San Diego California Price Comparison

To verify the finding that contractors and distributors reported no significant difference in LED product price between regions in California, Navigant compared the pricing data collected for San Francisco and San Diego through hypothesis testing[59] of the web-based pricing data. Specifically, a two-sided heteroscedastic t-Test ("t-Test: Two-Sample Assuming Unequal Variances") was selected as the best method to test for equality of population means. This hypothesis test is a conservative method used frequently when the population variances are unknown. [60,61,62]

For each product category, the calculated test statistic (t-Stat) and the Student's T critical value (t-critical) are reported in Table A-3 below. If the t-Stat is greater than the t-critical value, the null hypothesis that San Francisco and San Diego populations have the same mean is rejected (i.e. there is a statistically significant difference between population means). The results shown below indicate that there are no product categories for which the difference between San Francisco and San Diego population means is significant at the 95% level of confidence (alpha = 0.05). The results of this test also indicate that it is reasonable to assume that all IOUs can use the same cost data provided in Table 2-1.

[59] A two-sided heteroscedastic t-Test ("t-Test: Two-Sample Assuming Unequal Variances") was selected as the best method to test for equality of population means.

[60] Where "population" refers to all LED products prices in the region, or within a given product category and region.

[61] The t-Test is used instead of the Z-test because the true standard deviations of the Washington D.C. metropolitan area and Massachusetts LED prices are unknown.

[62] A two-sided test is appropriate when there is no specific claim that one mean is smaller or larger than the other—all that is desired is to find out if the population means are different.

Table A-3. Summary of t-Test Results for the Cities San Francisco and San Diego

LED Lamp Type	|t-Stat|	t-critical (2-sided, alpha = 0.05)	Significance
A15	0.06	2.11	t-stat < t-critical, not significant
A19	0.26	1.97	t-stat < t-critical, not significant
MR16	0.00	2.02	t-stat < t-critical, not significant
PAR20/BR20/R20	0.07	2.10	t-stat < t-critical, not significant
BR30/R30	0.01	1.99	t-stat < t-critical, not significant
PAR30	0.03	2.08	t-stat < t-critical, not significant
R40/BR40	0.13	2.09	t-stat < t-critical, not significant
PAR38	0.07	2.02	t-stat < t-critical, not significant
Downlight Retrofit	0.26	2.05	t-stat < t-critical, not significant

Source: Web-scraped data & Navigant analysis

A.3.3 Factors That Significantly Affect Product Price

To determine how the mean LED price changes with various parameters, Navigant selected known and commonly used inflection points for comparison. As multiple variable regression on LED lamp product attributes has been analyzed in other web-scraping analyses[63], Navigant believed it would be more valuable to compare mean prices for bulbs with and without specific product features. Specifically, Navigant analyzed the percentage price increase over the mean price associated with the required set of parameters for California LED Quality Standard[64] eligible products, as seen in Table 2-4. The team found the price increase is particularly substantial for LED A-type and MR16 lamps, where eligible products are estimated to cost nearly 50% more than the mean price indicated in Table 2-1.

This quality standard applies to only lamps sold through residential channels and requires that LED bulbs meet the following criteria in order to be eligible for rebates:

- Energy Star qualified
- Minimum CRI of 90
- CCT equal to 2700K or 3000K
- Dimmable
- Minimum 5 year warranty

This analysis suggests that all of these parameters do influence product price, however, some more than others. CRI was determined to have the greatest impact. Across all LED lamp categories, products that offer CRI >= 90 on average cost 25% more compared to the mean price. Interestingly, there is a negative

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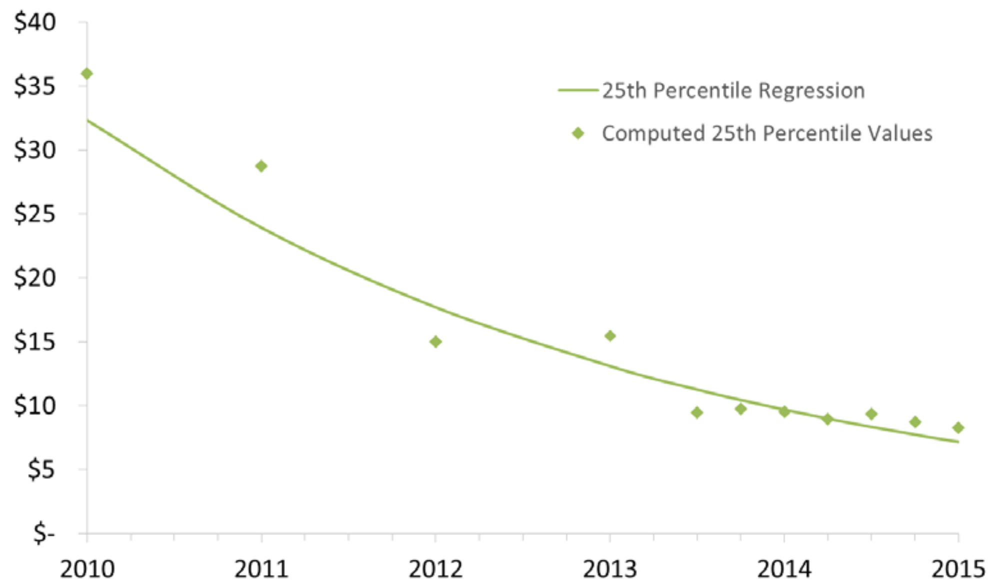
[63] Energy Solutions, "Leveraging Big Data to Develop Next Generation Demand Side Management Programs and Energy Regulations". ACEEE 2014. http://energy-solution.com/wp-content/uploads/2015/01/Leveraging-Big-Data-to-Develop-Next-Generation-Demand-Side-Management-Programs-and-Energy-Regulations_EnergySolutions_ACEEE-2014.pdf

[64] California Energy Commission, A Voluntary Minimum Specification for "California Quality" LED Lamps, DECEMBER 2012. http://www.energy.ca.gov/2012publications/CEC-400-2012-016/CEC-400-2012-016-SF.pdf

correlated with high efficacy products – meaning that more efficient LED lamp products tend to be slightly cheaper. This is likely due to the impacts of brand quality. Major manufacturers, such as Philip, GE Lighting, Osram Sylvania and Cree continue to develop increasingly efficient products at lower and lower cost and have found that increasing efficiency of LED lamps causes a reduction in the costs needed for thermal management design. There are also a vast number of new entrants to the LED lighting market that offer products on online-exclusive retailers that still struggle to develop efficient products at economies of scale.

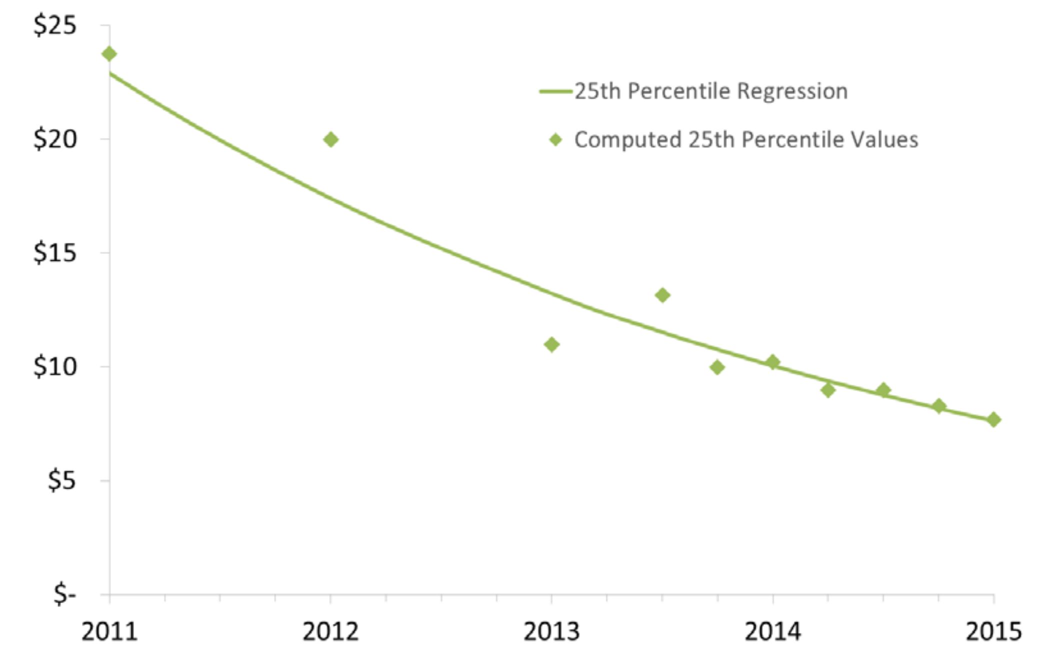
A.3.4 Web-scraping Exponential Model-Fit: Actual Versus Predicted Values

Figure A-2. LED A15 Historical Pricing Trend ($/unit)



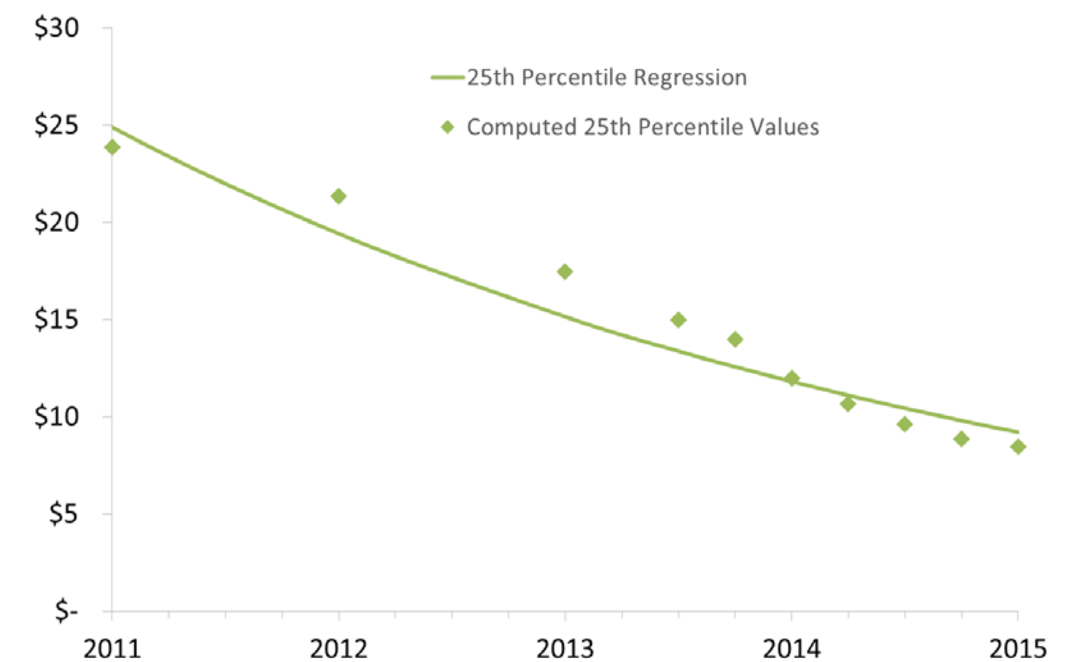
Source: Web-scraped data & Navigant analysis

Figure A-3. LED A19 40W Equivalent Historical Pricing Trend ($/unit)



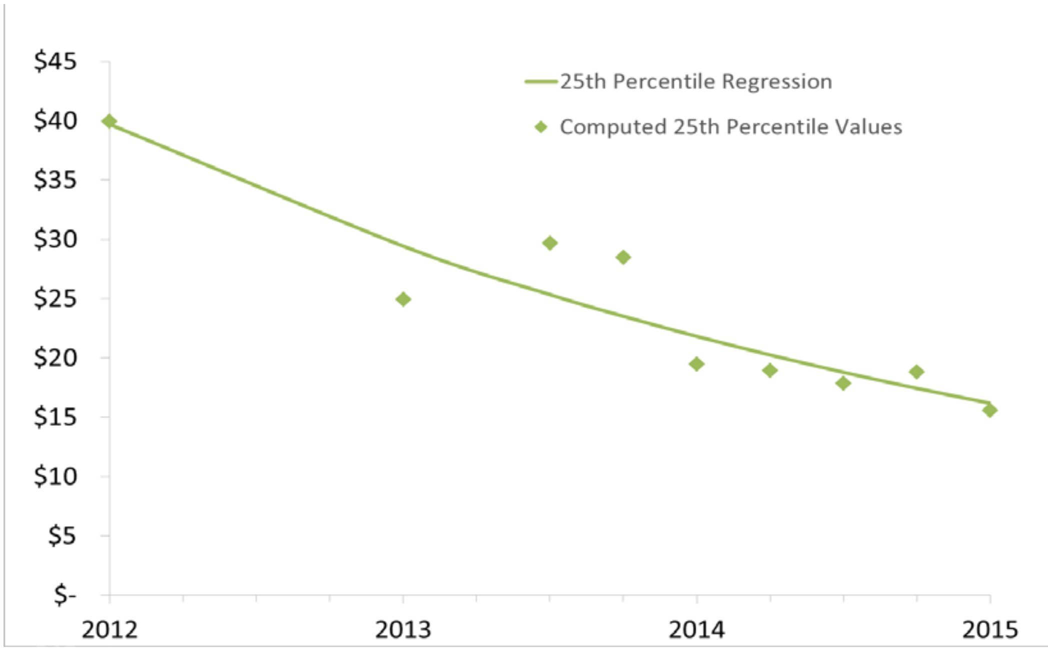
Source: Web-scraped data & Navigant analysis

Figure A-4. LED A19 60W Equivalent Historical Pricing Trend ($/unit)



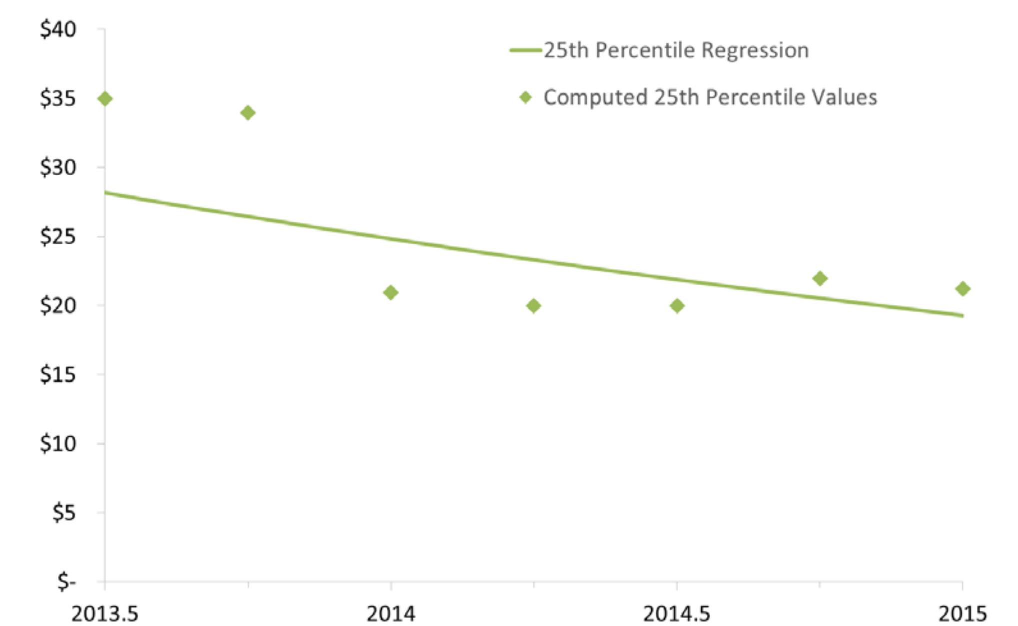
Source: Web-scraped data & Navigant analysis

Figure A-5. LED A19 75W Equivalent Historical Pricing Trend ($/unit)



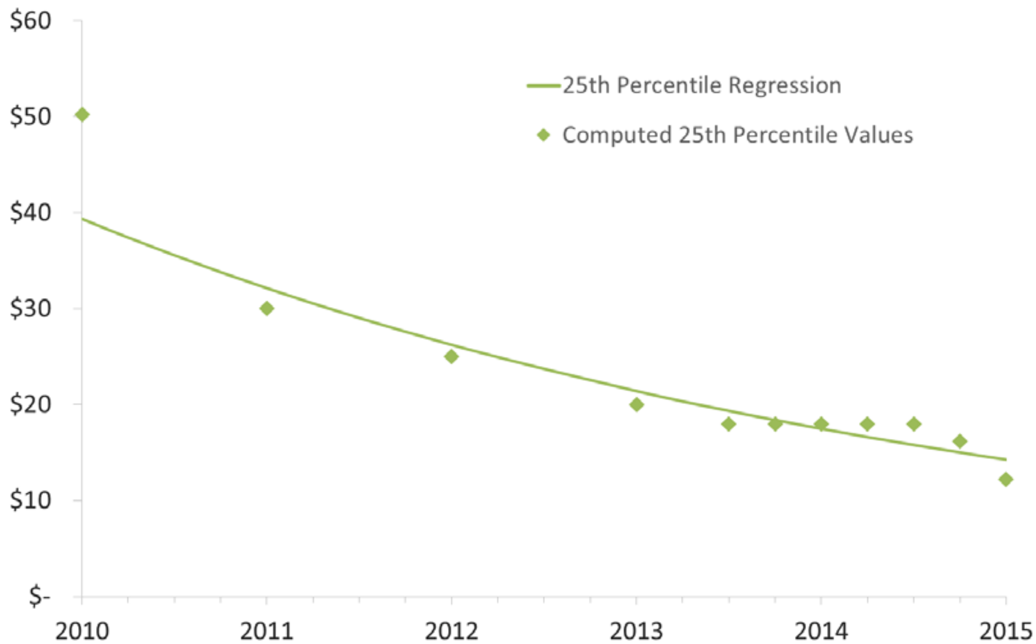
Source: Web-scraped data & Navigant analysis

Figure A-6. LED A19 100W Equivalent Historical Pricing Trend ($/unit)



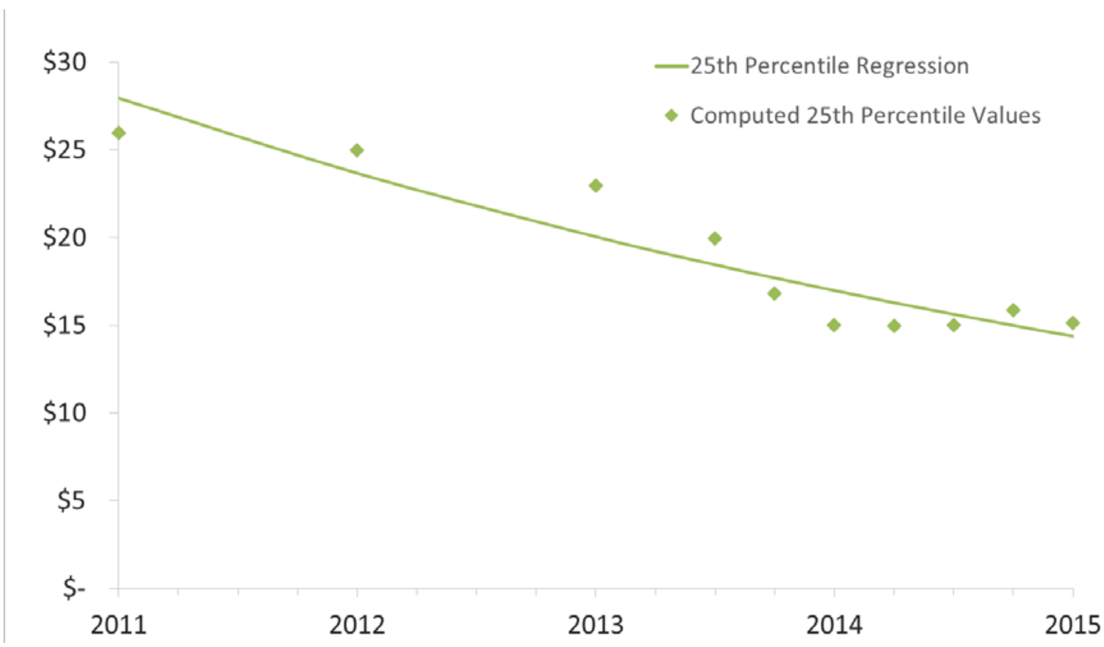
Source: Web-scraped data & Navigant analysis

Figure A-7. LED MR16 Historical Pricing Trend ($/unit)



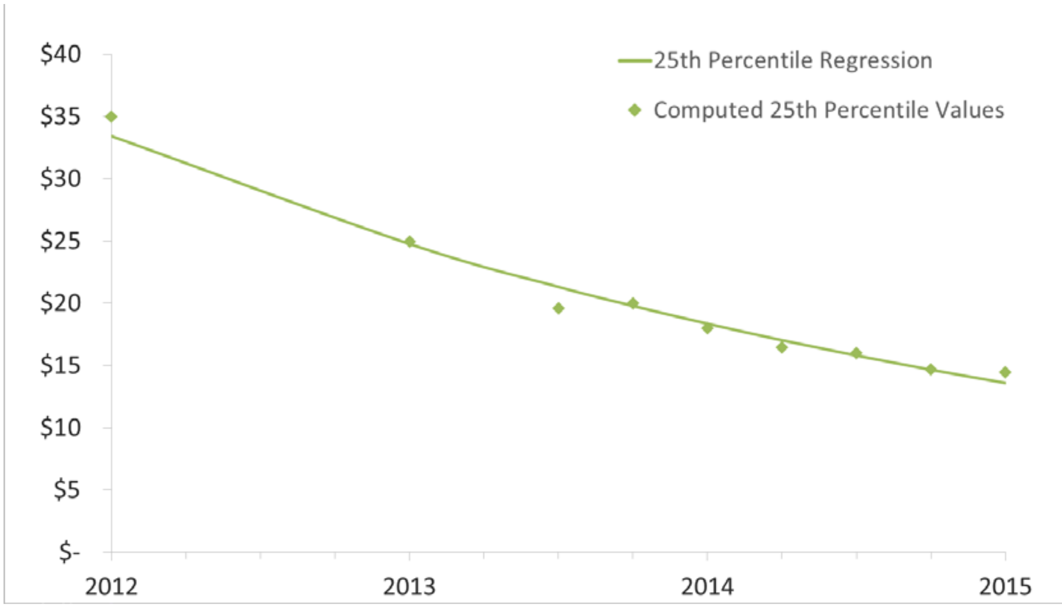
Source: Web-scraped data & Navigant analysis

Figure A-8. LED PAR20/R20/BR20 Historical Pricing Trend ($/unit)



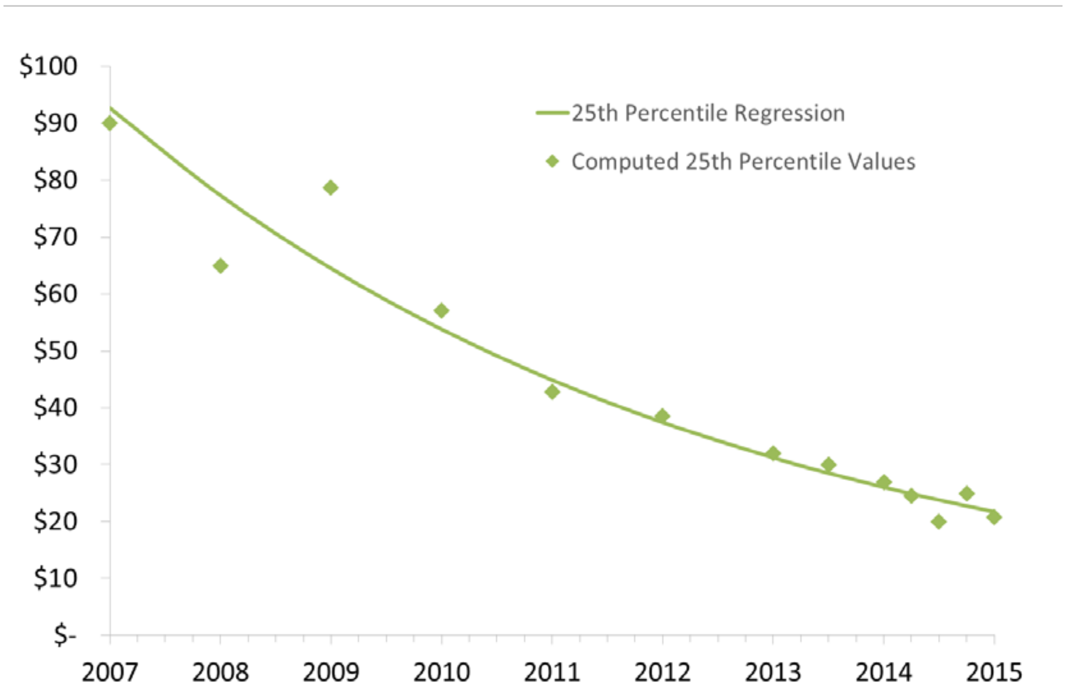
Source: Web-scraped data & Navigant analysis

Figure A-9. LED R30/BR30 Historical Pricing Trend ($/unit)



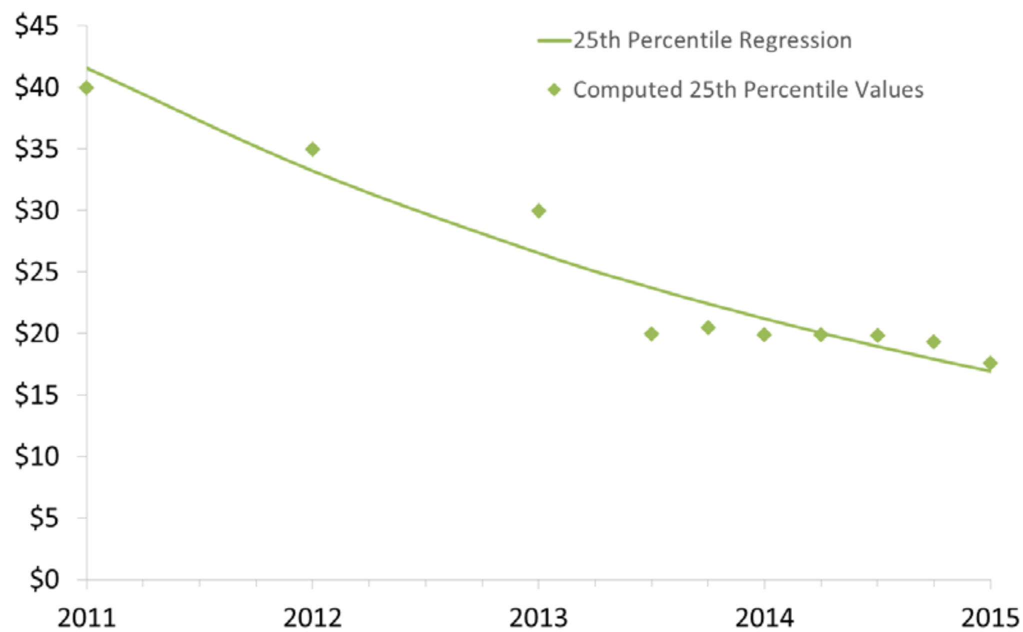
Source: Web-scraped data & Navigant analysis

Figure A-10. LED PAR30 Historical Pricing Trend ($/unit)



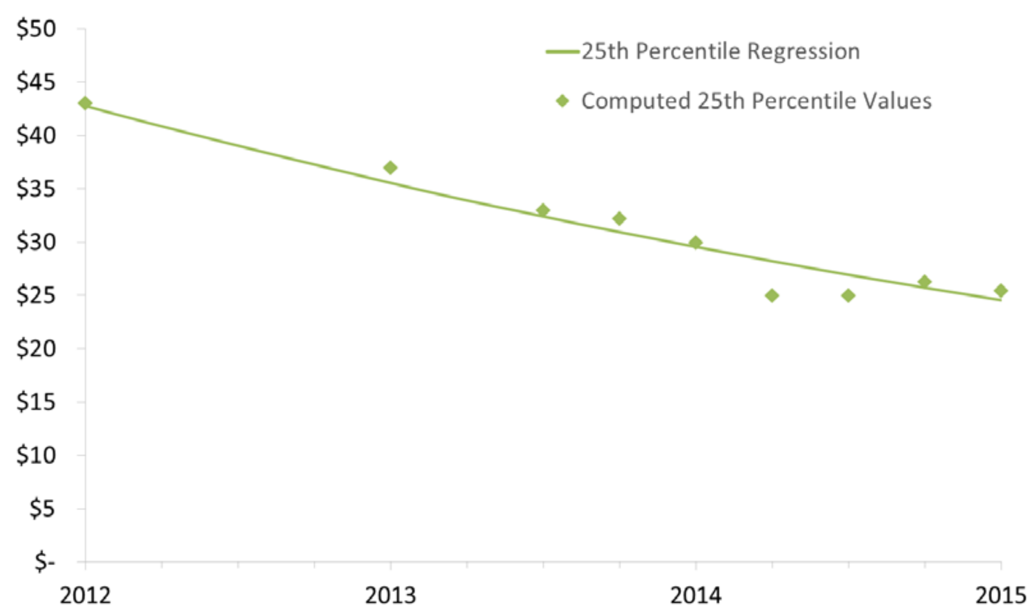
Source: Web-scraped data & Navigant analysis

Figure A-11. LED R40/BR40 Historical Pricing Trend ($/unit)



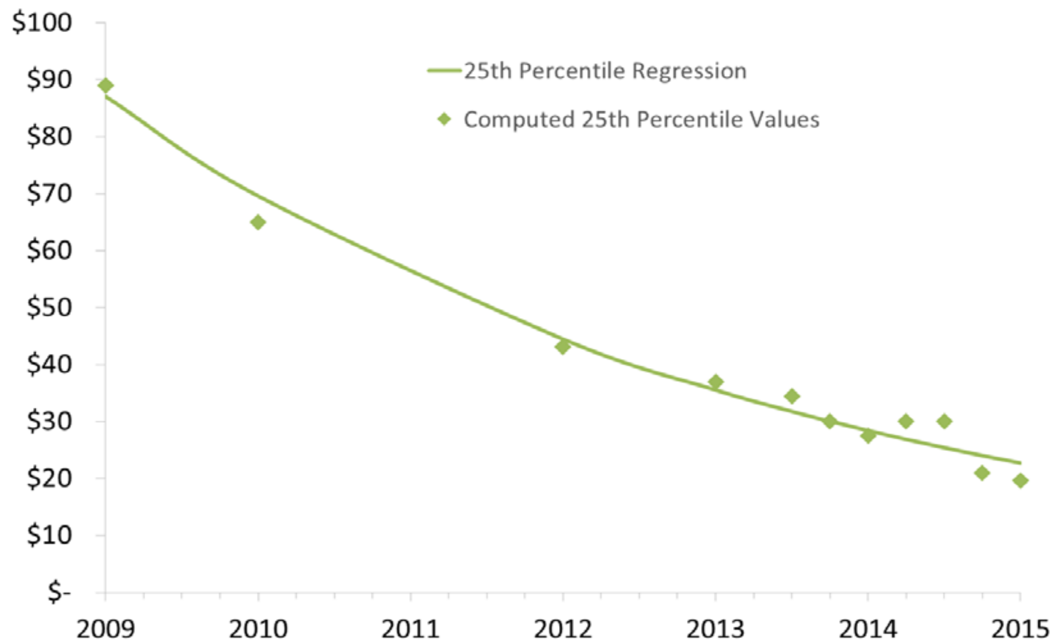
Source: Web-scraped data & Navigant analysis

Figure A-12. LED PAR38 Historical Pricing Trend ($/unit)



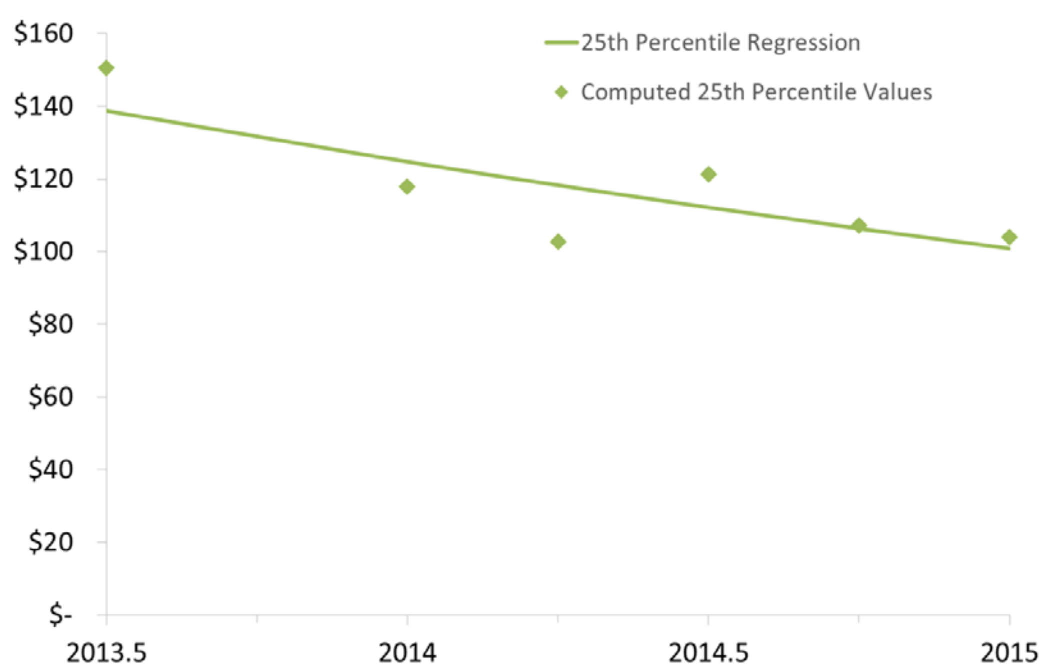
Source: Web-scraped data & Navigant analysis

Figure A-13. LED Downlight Retrofits Historical Pricing Trend ($/unit)



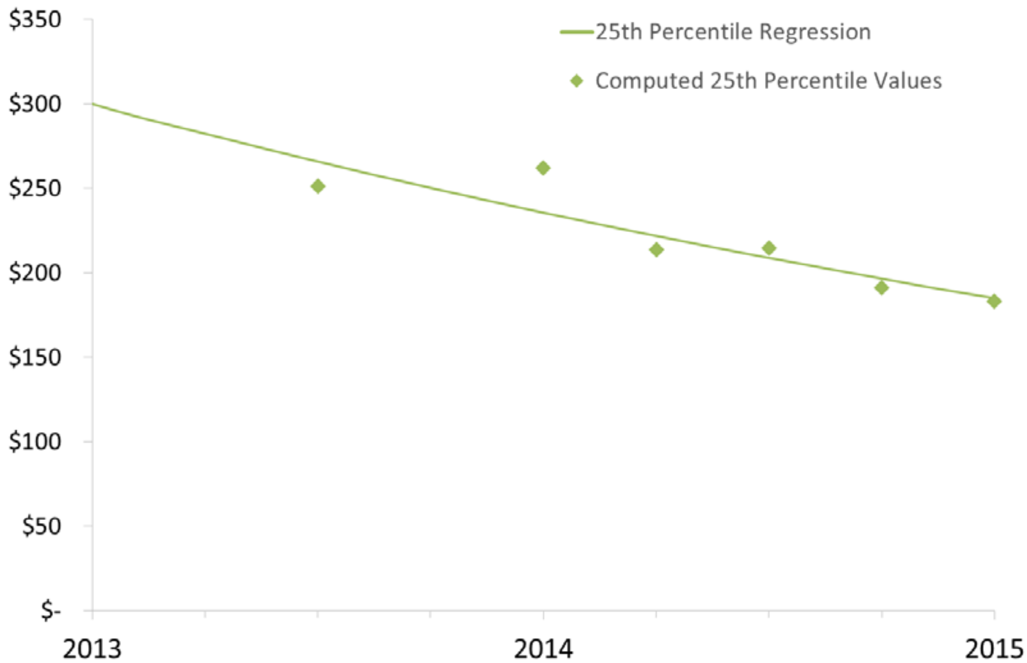
Source: Web-scraped data & Navigant analysis

Figure A-14. LED Downlight Fixtures Historical Pricing Trend ($/unit)



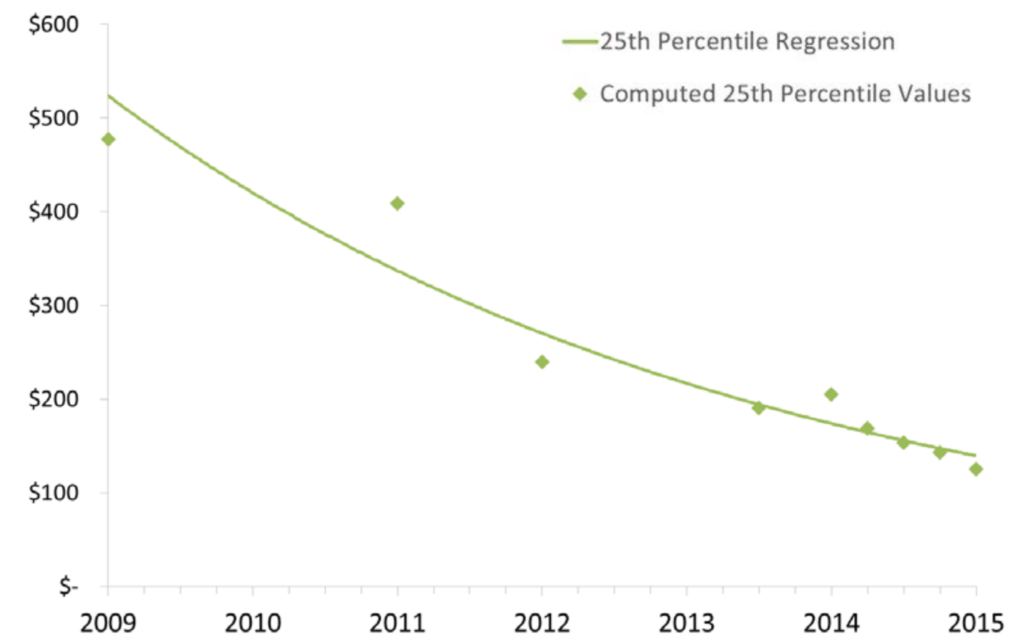
Source: Web-scraped data & Navigant analysis

Figure A-15. LED Troffer 1x4 Historical Pricing Trend ($/unit)



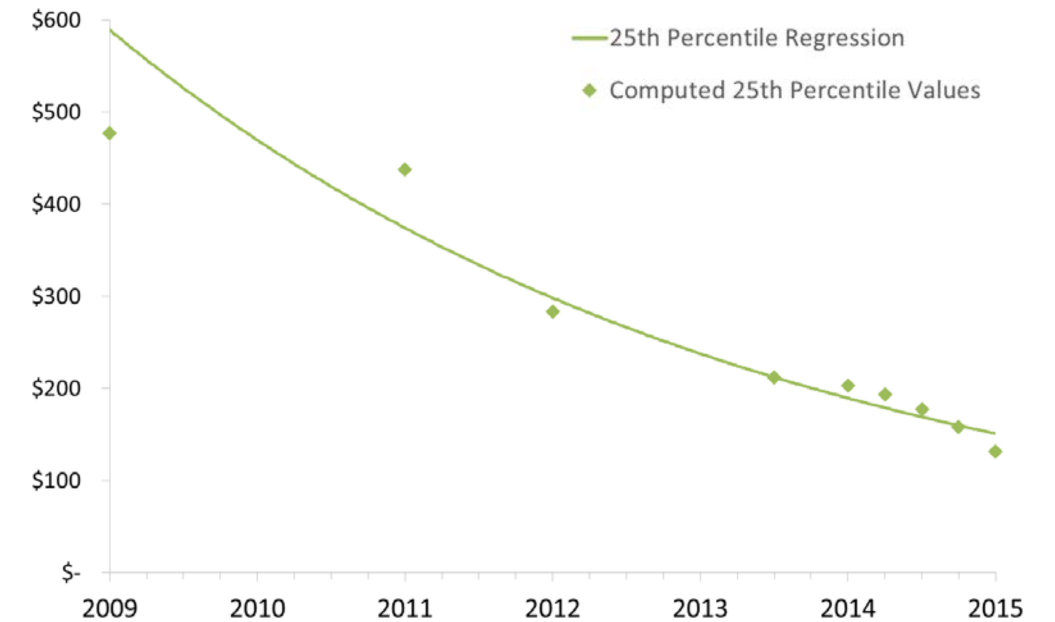
Source: Web-scraped data & Navigant analysis

Figure A-16. LED Troffer 2x2 Historical Pricing Trend ($/unit)



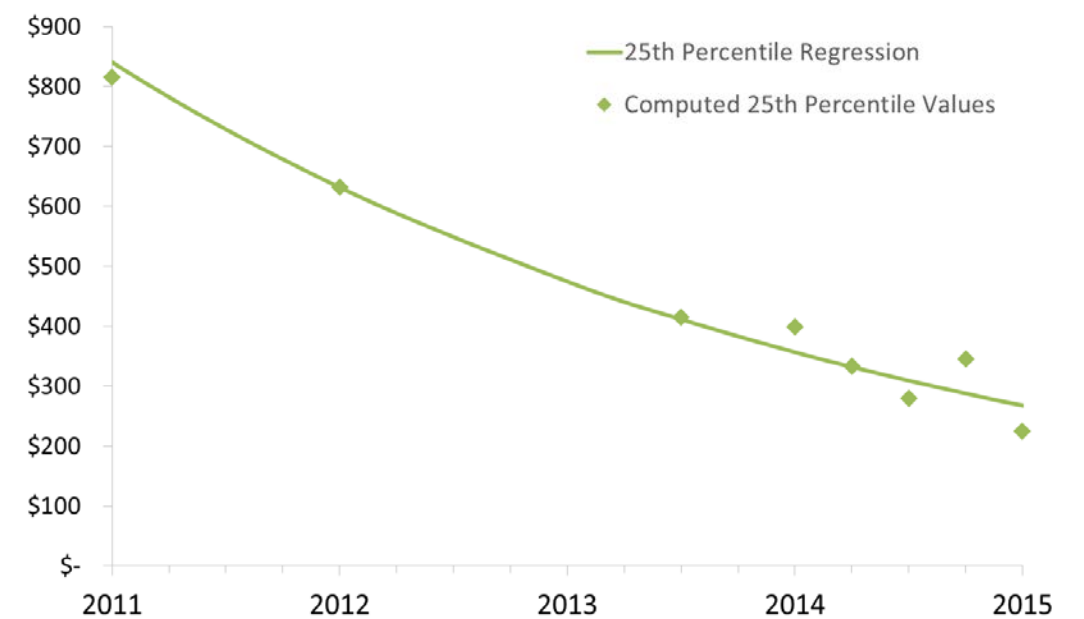
Source: Web-scraped data & Navigant analysis

Figure A-17. LED Troffer 2x4 Historical Pricing Trend ($/unit)



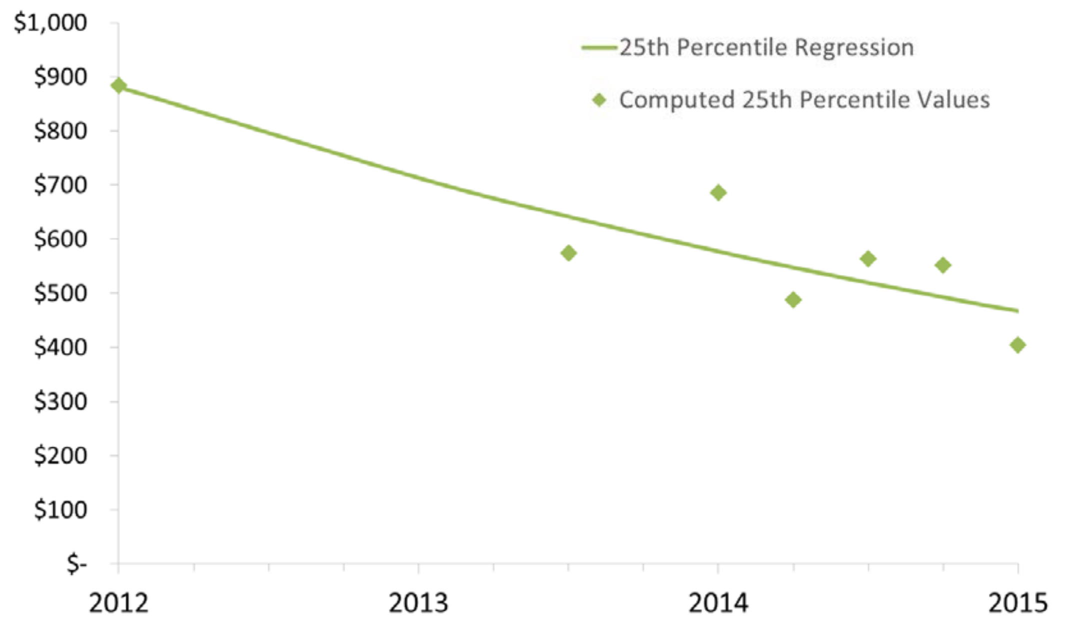
Source: Web-scraped data & Navigant analysis

Figure A-18. LED Low Bay Historical Pricing Trend ($/unit)



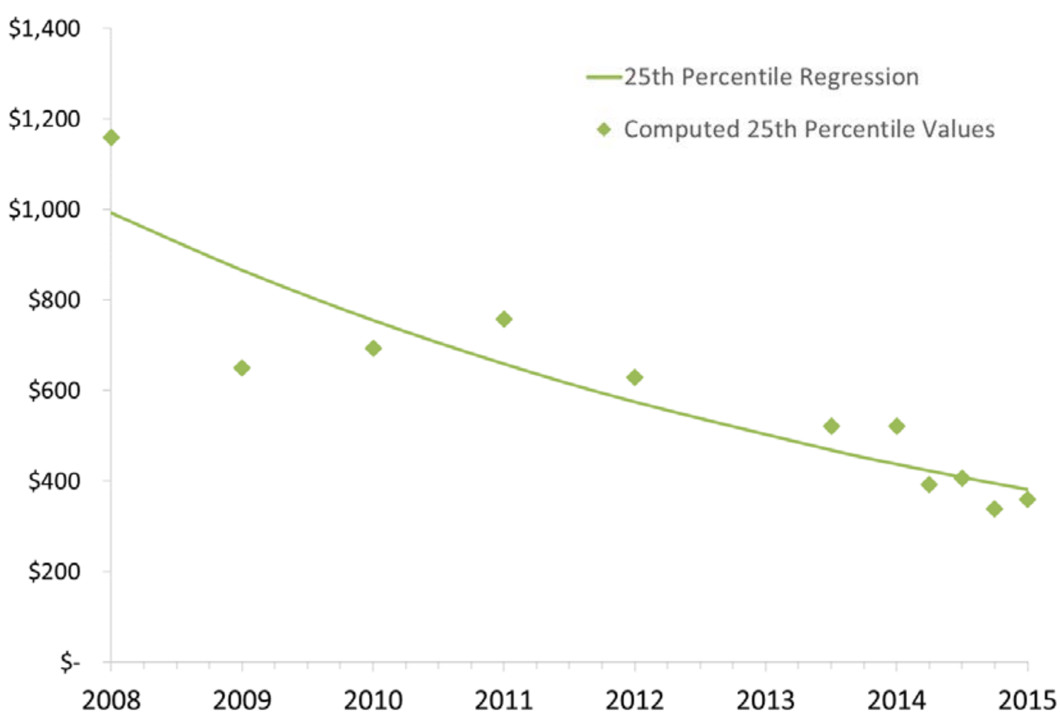
Source: Web-scraped data & Navigant analysis

Figure A-19. LED High Bay Historical Pricing Trend ($/unit)



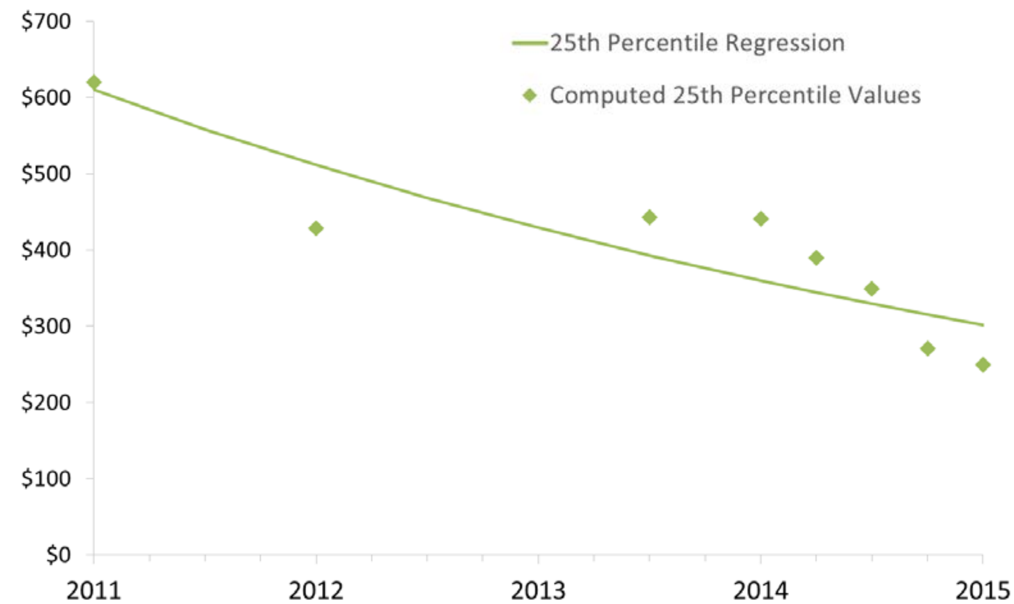
Source: Web-scraped data & Navigant analysis

Figure A-20. LED Parking Lot Historical Pricing Trend ($/unit)



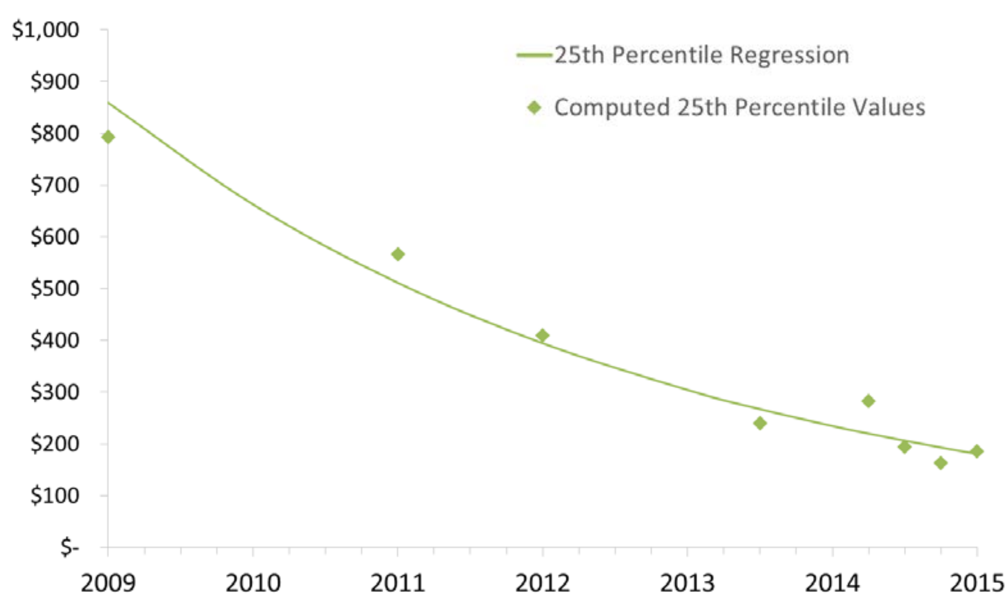
Source: Web-scraped data & Navigant analysis

Figure A-21. LED Parking Garage Historical Pricing Trend ($/unit)



Source: Web-scraped data & Navigant analysis

Figure A-22. LED Parking Garage Historical Pricing Trend ($/unit)



Source: Web-scraped data & Navigant analysis

A.3.5 Projected LED Prices

Table A-4 provides the price forecast by LED product category.

Table A-4. LED Price Forecast Results by Product Category

LED Product Categories	2014	2015	2016	2017	2018	2019	2020	Annual Price Decline (%)[65]
A15	$9.0	$7.2	$5.3	$3.9	$2.9	$2.2	$1.6	26%
A19 40W equivalent	$9.4	$7.6	$5.8	$4.4	$3.3	$2.5	$1.9	24%
A19 60W equivalent	$11	$9.2	$7.2	$5.6	$4.4	$3.4	$2.7	22%
A19 75W equivalent	$20	$16	$12	$8.9	$6.6	$4.9	$3.6	26%
A19 100W equivalent	$23	$19	$15	$12	$9.0	$7.0	$5.4	22%
MR16	$11	$8.9	$6.7	$5.0	$3.8	$2.8	$2.1	18%
PAR20/BR20/R20	$14	$12	$10	$7.8	$6.3	$5.1	$4.2	15%
BR30/R30	$14	$11	$7.7	$5.6	$4.0	$2.9	$2.1	26%
PAR30	$25	$22	$18	$15	$13	$11	$8.8	17%
R40/BR40	$20	$17	$14	$11	$8.6	$6.9	$5.5	20%
PAR38	$28	$25	$20	$17	$14	$12	$10	17%
Downlight Retrofit	$27	$23	$18	$14	$12	$9.3	$7.4	20%
Recessed Troffer 2x4	$179	$151	$120	$96	$76	$61	$49	20%
Recessed Troffer 1x4	$222	$185	$145	$114	$90	$70	$55	21%
Recessed Troffer 2x2	$165	$139	$112	$90	$72	$58	$46	20%
Parking Lot	$423	$382	$333	$291	$254	$221	$193	13%
Parking Garage	$344	$302	$253	$212	$178	$149	$125	16%
Downlight Fixture	$118	$101	$82	$66	$53	$43	$35	19%
Wall Pack	$170	$138	$104	$79	$60	$45	$34	23%
Low Bay	$332	$268	$201	$151	$114	$86	$64	25%
High Bay	$548	$467	$378	$306	$248	$201	$162	19%

Source: Web-scraped data & Navigant analysis

A.3.5 Baseline Price Comparisons

The following tables provide a detailed price comparison of LED lamp and luminaire baseline technologies.

[65] The exponential model produces a constant rate of change, therefore the annual price decline percentage is constant throughout time.

Table A-5. Price of Conventional Lamp Baseline Technologies

Lamp Product Category		INC		HAL		CFL	
		Web-based Data	CA Cost Sheet(1)	Web-based Data	CA Cost Sheet(1)	Web-based Data	CA Cost Sheet(1)
A15		$1.30	$0.80	$1.00	--	$4.40	$5.90
A19/A21	40W Equiv.	$0.90	$0.80	$1.80	--	$2.50	$7.30
	60W Equiv.	$0.50	$0.80	$1.60	--	$2.70	$8.40
	75W Equiv.	--	--	$1.60	--	$4.00	--
	100W Equiv.	$2.30	$0.80	$1.60	--	$3.20	$12.00
MR16		--	--	$5.20	$6.80	--	--
PAR20/BR20/R20		$2.70	--	$6.50	$9.50	--	--
BR30/R30		$2.50	--	$2.70	--	$5.00	--
PAR30		--	--	$6.80	$9.50	--	$11.00
BR40/R40		$3.40	--	$8.50	--	$8.00	--
PAR38		--	--	$6.50	$8.70	$6.40	$12.00

Source: Web-scraped data and IMC Analysis CA Statewide Cost Data Sheet, data was collected in May 2012.

Table A-6. Price of Conventional Luminaire Baseline Technologies

Luminaire Product Categories		T12	T8	T5	CFL - Pin	HPS	MH	MV
Recessed Troffers	2x4	$3.9	$4.4	$13	--	--	--	--
	1x4	$2.0	$2.2	$6.6	--	--	--	--
	2x2	$10	$7.2		--	--	--	--
Parking Lot		--	--	--	--	$25	$35	$27
Parking Garage		$3.9	$4.4	$13	--	--	$58	--
Wall Pack		--	--	--	--	$23	$58	$21
Downlight Fixture		--	--	--	$6.0	--	$42	--
Low Bay		$32	$20	$24	--	$22	$42	$21
High Bay		$64	$40	$49	--	$25	$35	$27

Source: Web-scraped data and Navigant analysis

Table A-7and Table A-8 provide the detailed avoided costs data for LED lamps and luminaires respectively.

Table A-7. Avoided Maintenance Costs over the Lifetime of an LED Lamp

Lamp Product Categories		LED Lifetime (hours)	Incandescent # of Relamps	Incandescent Avoided Relamp + Labor ($)	Halogen # of Relamps	Halogen Avoided Relamp + Labor ($)	CFL # of Relamps	CFL Avoided Relamp + Labor ($)	CFL - pin # of Relamps	CFL - pin Avoided Relamp + Labor ($)	Metal Halide # of Relamps	Metal Halide Avoided Relamp + Labor ($)
A15		21,630	14	$33	14	$29	3	$15	--	--	--	--
A19/ A21	40W Equiv.	23,907	16	$31	24	$68	2	$8.2	--	--	--	--
	60W Equiv.	22,520	16	$24	23	$60	2	$7.8	--	--	--	--
	75W Equiv.	24,696			15	$39	3	$13	--	--	--	--
	100W Equiv.	24,588	23	$78	25	$65	3	$12	--	--	--	--
MR16		25,256	--	--	11	$70	--	--	--	--	--	--
PAR20/BR20/R20		27,381	14	$51	27	$206	3	$20	--	--	--	--
PAR30		30,455	--	--	30	$237	--	--	--	--	--	--
BR30/R30		24,919	10	$35	8	$31	3	$17	--	--	--	--
PAR38		27,500	--	--	17	$125	3	$21	--	--	--	--
R40/BR40		25,000	8	$37	11	$106	3	$28	--	--	--	--
Downlight Retrofit		35,357	12	$53	16	$149	4	$31	--	--	--	--
Downlight Fixture		45,441	15	$16	20	$21	5	$5.5	6	$6.6	4	$4.1

Source: Web-scraped data and Navigant analysis

Table A-8. Avoided Maintenance Costs over the Lifetime of an LED Luminaire

Luminaire Product Categories		LED Lifetime (hours)	T12 # of Relamps	T12 Avoided Relamp + Labor ($)	T8 # of Relamps	T8 Avoided Relamp + Labor ($)	T5 # of Relamps	T5 Avoided Relamp + Labor ($)	HPS # of Relamps	HPS Avoided Relamp + Labor ($)	Metal Halide # of Relamps	Metal Halide Avoided Relamp + Labor ($)	Mercury Vapor # of Relamps	Mercury Vapor Avoided Relamp + Labor ($)
Recessed Troffers	2x4	53,796	2	$20	2	$20	2	$32						
	1x4	58,600	3	$11	2	$11	2	$17						
	2x2	55,164	3	$35	3	$28								
Parking Lot		57,143							2	$72	6	$227	2	$76
Parking Garage		67,500	3	$25	3	$25	2	$40			4	$246		
Wall Pack		85,286							4	$89	5	$299	4	$79
Low Bay		56,983	2	$95	2	$61	2	$54			5	$223		
High Bay		71,618	5	$428	4	$240	2	$137			7	$371		

Source: Web-scraped data and Navigant analysis

A.3.6 Price Impacts on Forecasted LED Penetration

The U.S DOE lighting market model[66] predicts market share as an aggregate of many individual purchasing decisions by way of three components: an econometric logit model that considers economic factors, a technology diffusion curve that considers existing marketplace presence, and an acceptance factor that calibrates market share projections to historical data. This approach of using a logit model and a technology diffusion model in concert is well tested and has been previously used in many forecast models (Cao, 2004; Paidipati, Frantzis, Sawyer, & Kurrasch, 2008). The DOE lighting market model uses a conditional logit model to award available market to multiple competing lighting technologies, similar to the model used in the National Residential Sector Demand Module of NEMS 2010 for the lighting technology choice component.

The conditional logit model is a widely recognized method of forecasting a product's market penetration based on several quantitative or categorical explanatory variables. The result of the conditional logit is a probability of purchase, which represents an aggregation of a large number of individual consumer purchasing decisions. The logit model is predicated on the assumption that these individual decisions are governed by consumer utility (i.e., the relative value) that consumers place on the various technology attributes of an alternative. For example, consumers may be strongly influenced by a product's first cost, but may also place some lesser value on a product's efficiency. In the lighting market model, it is assumed that lighting purchasing decisions are primarily governed by two economic parameters, both of which are expressed in dollars per kilolumen for comparison between technologies:

- *First Cost* includes the lamp price; ballast price, if applicable; and, in the case of the new and retrofit market segments, the fixture price. For LEDs in certain submarkets, first cost indicates the price of the luminaire. This also includes a labor charge, where applicable.
- *Annual Operation and Maintenance (O&M) Cost* includes annual energy cost and annual replacement cost. It is a function of the mean lamp or ballast life; annual operating hours; lamp price; ballast price, if applicable; and a labor charge, if applicable.

These parameters, which collectively constitute the life-cycle cost of a lighting product, were chosen to help characterize two types of lighting consumers:

- Those that prefer low retail price. These consumers place less importance on annual cost savings, which is derived from the efficacy and lifetime performance of a lighting product.
- Those that make purchasing decisions based primarily on the life-cycle or annual cost of a lighting product. These consumers place less importance on the upfront product cost.

The market penetration model bases market share calculations in each lighting market sector (residential, commercial, industrial, and outdoor stationary) on one of these two characteristic consumers. In order to estimate how each sector makes purchasing decisions (i.e., to determine the characteristic relationship between the two cost variables), logistic regressions of historical price and

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[66] U.S. DOE, Energy Savings Forecast of Solid-State Lighting in General Illumination Applications, Prepared by Navigant, August 2014. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energysavingsforecast14.pdf

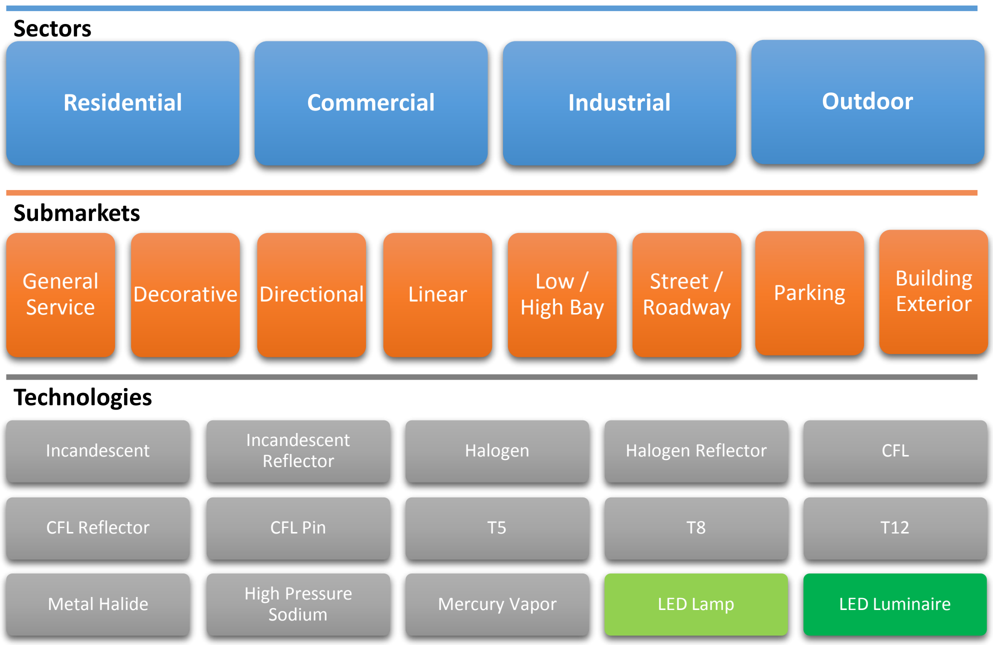
performance data were performed for several lighting technologies within each sector. Historical data for one specific submarket for each sector was chosen to represent consumer decisions. GSL–MSB data, linear fluorescent data, and HID data were considered representative of the residential sector, commercial and industrial sectors, and outdoor stationary sector, respectively.

The econometric model used to forecast market share relies entirely on economic metrics and is therefore a simplification of consumer rationale. In reality, consumers consider other factors, such as color quality, dimmability, or aesthetics in their lighting decisions, in addition to economic factors. To account for these qualities, the lighting market model applies acceptance factors to particular technologies to derate that technology's value to a consumer. For example, the model assumes acceptance factors less than one for CFL and HPS technologies in indoor applications which, despite competitive price and performance with other technologies, have low market share largely due to their color quality and dimmability (for CFLs only).

In its original state, the U.S. DOE lighting market model primarily uses price projection curves for LED lighting based on data published in the *2013 SSL Pricing and Efficacy Trend Analysis for Utility Program Planning*[67]. Navigant has customized the lighting market model by utilizing the LED pricing projections developed for this study to analyze the price impacts on LED penetration in the California region. However, while Navigant has provided LED price projections for all 'high' priority product categories Navigant cannot provide LED penetration projections for each 'high' priority product category. Due to the limitations of the existing lighting market model structure, the LED product categories selected for this analysis have been combined in to one of the submarkets shown in Figure A-23.

[67] U.S. DOE, SSL Pricing and Efficacy Trend Analysis for Utility Program Planning, Prepared by PNNL, October 2013. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_trend-analysis_2013.pdf

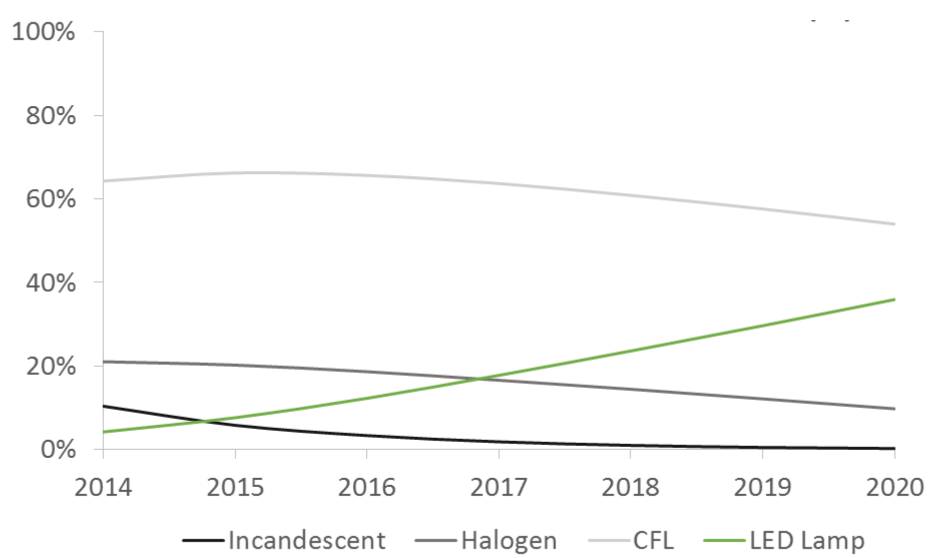
Figure A-23. Lighting Market Model Technology and Submarket Mapping Arenas



Source: U.S. DOE Lighting Market Model

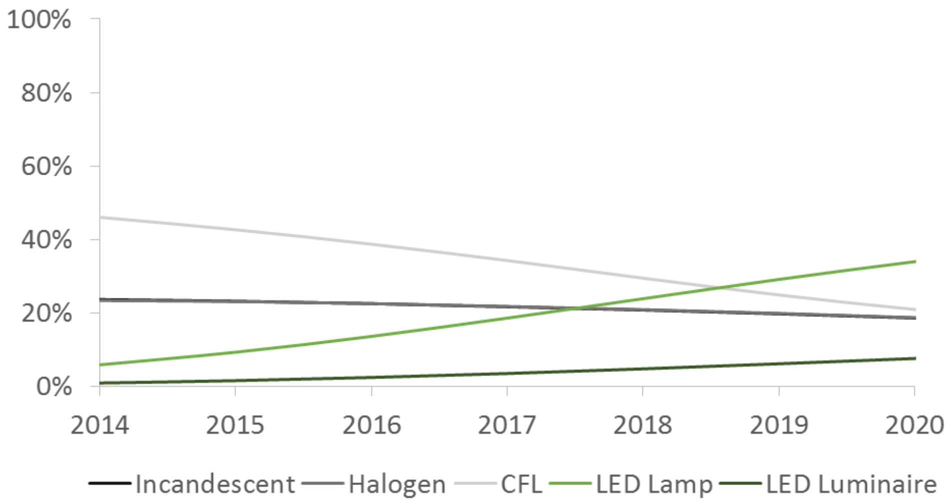
The following figures provide the diffusion curves by LED product category.

Figure A-24. General Service Forecasted Installed Stock (%)



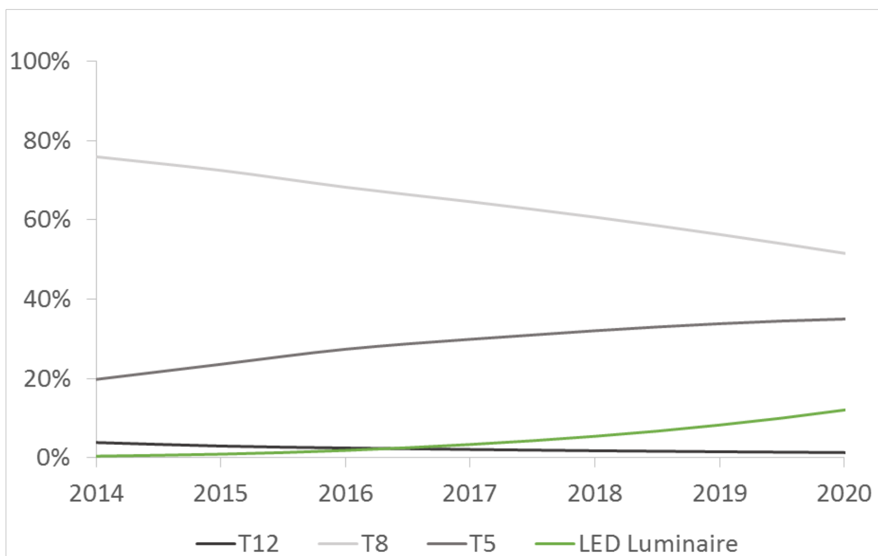
Source: U.S. DOE Lighting Market Model & Navigant analysis

Figure A-25. Directional Forecasted Installed Stock (%)



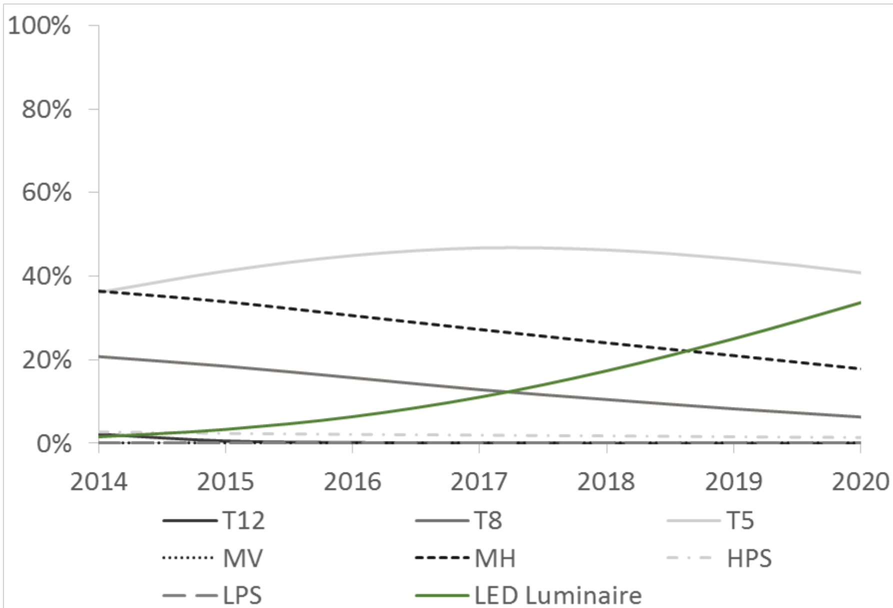
Source: U.S. DOE Lighting Market Model & Navigant analysis

Figure A-26. Troffer Forecasted Installed Stock (%)



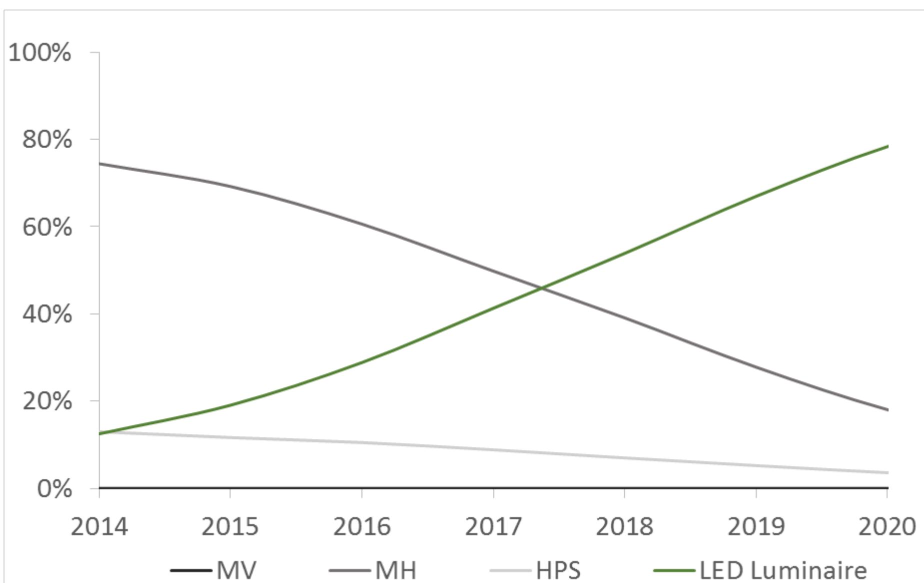
Source: U.S. DOE Lighting Market Model & Navigant analysis

Figure A-27. Low/High Bay Forecasted Installed Stock (%)



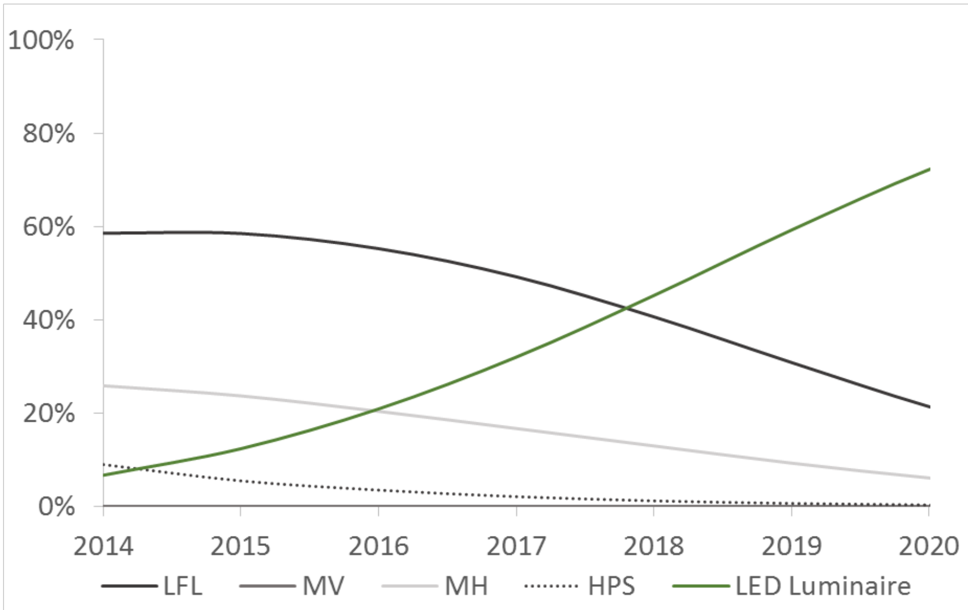
Source: U.S. DOE Lighting Market Model & Navigant analysis

Figure A-28. Parking Lot Forecasted Installed Stock (%)



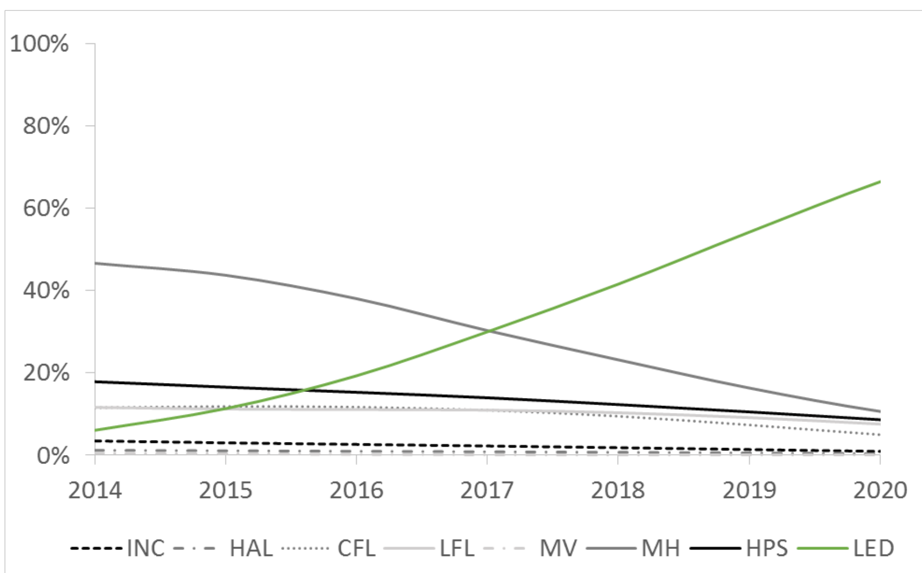
Source: U.S. DOE Lighting Market Model & Navigant analysis

Figure A-29. Parking Garage Forecasted Installed Stock (%)



Source: U.S. DOE Lighting Market Model & Navigant analysis

Figure A-30. Building Exterior Forecasted Installed Stock (%)



Source: U.S. DOE Lighting Market Model & Navigant analysis

A.4 Wattage Reduction Ratio Analysis

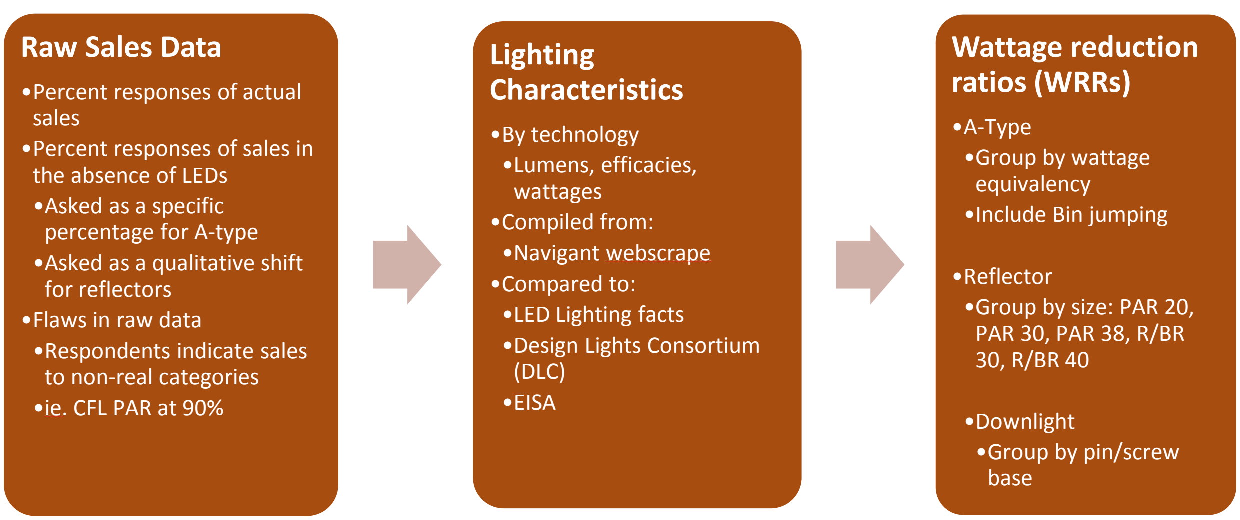
The first method for characterizing energy savings discussed in the main text is the wattage reduction ratio (WRR). The WRR functions as a ratio of the given baseline watts of a lighting technology divided by the watts of the LED lighting replacement. The result is that a larger wattage reduction is associated with a higher wattage reduction ratio.

$$Wattage\ Reduction\ Ratio\ (WRR) = \frac{Baseline\ Wattage}{LED\ Wattage}$$

In creating such a distinct representation of the savings, it is essential that this measurement technique make a fair comparison between baseline wattage and LED wattage. It would be misleading to compare a brighter baseline to a more dim replacement. As such, the WRR is used to characterize lighting categories that can be delineated into specific sub-categories, indirectly based on light output. This methodology applies to three main categories of commercial lights: A-type, reflector, and downlights. For example, A-type lights can be broken into wattage equivalent bins, and the lighting units within these bins can be compared across lighting technologies. Similarly, reflectors can be binned by common sizes.

Navigant conducted a similar analysis for each of these three categories of lights. Raw sales data collected through market actor surveys were expanded with the use of database-compiled lighting characteristics, and finally compared to an LED baseline which served as the hypothetical most efficient case. The analysis of these categories is shown in the following flow chart below:

Figure A-31. Wattage Reduction Ratio Data Analysis Flow Chart



Source: Navigant analysis

The Navigant analysis team created wattage reduction ratios within the pre-determined sub-categories of each lighting category. Navigant used a division of categories that matched the bins used in the existing lighting disposition. A-type bulbs were broken out into wattage equivalencies, reflectors were broken out by size, and downlights were broken out by pin base or screw base. By using the same bins that had been employed previously, it was possible to compare the existing WRRs with the calculated values.

The general method for calculating WRRs is broadly consistent across each of the technology types but varied in subtle ways as discussed in the following sub-sections on individual product categories.

A.4.1 A-type

The calculations that the Navigant team used for A-type lighting units were the most unique of any of the categories to which the WRR methodology was applied. As discussed above, the A-type analysis had the most complete baseline survey questions, including a specific question for the actual sales baseline as well as a specific question for what the hypothetical baseline would be in the absence of LEDs.

In addition to the A-type market baseline and the hypothetical baseline, the survey asked respondents a specific question to gauge the prevalence of bin jumping, the idea that a baseline unit is replaced with a unit from another category.

> **Bin jumping:** "When you are installing A-line LEDs, how often do you choose a LED wattage that is not labeled as the "equivalent wattage" of the lamp that's being replaced? For example, if you're replacing a 60W equivalent CFL, how often do you install an LED labeled as a 40W equivalent or 75W equivalent rather than a 60W equivalent? (Move the slider between 0 and 100%)"

This question answered the question of whether the initial baseline could be compared to the LED replacement. If customers reported replacing dim lights with brighter lights or vice versa, an unfair comparison would be made between the initial and final case, and the WRR would not be an effective measure of energy savings.

The Navigant team used the data obtained from this bin jumping line of questioning to adjust the WRR calculation accordingly. If a respondent indicated that a typical 40Weq LED would be replaced with a 60Weq incandescent bulb, and adjustment was made to account for a higher lumen output as well as a higher wattage. This was done as follows:

First, data from the bin jumping question was compiled into a table, shown below for contractors, as the percent of respondents who moved up or down in wattage equivalency.

Table A-9. Prevalence of distributor bin jumping

Replacement	40W LED	60W LED	75W LED	100W LED
40W eq. Inc	28%	0%	0%	0%
60W eq. Inc	13%	28%	0%	0%
75W eq. Inc	0%	9%	28%	3%
100W eq. Inc	0%	0%	6%	25%
40W eq. CFL	53%	0%	0%	0%
60W eq. CFL	6%	59%	6%	3%
75W eq. CFL	0%	3%	56%	0%
100W eq. CFL	0%	0%	3%	69%

Source: Navigant survey data analysis

The analysis team then expanded these percentages by weighting the bin jumping responses, the non-darkened boxes of Table A-9 by the hypothetical baseline technology breakdown, the percent of different types of technologies in the absence of LEDs. Now, instead of a simple breakdown by technology, each lamp replacement could be identified by technology and wattage equivalency, shown in Table A-10.

For example, as shown in Table A-10, it could be expected that all 40W bulbs would be replaced with a 40Weq, but based on the prevalence of bin jumping, only 68 percent of 40W bulbs were replaced with a 40Weq replacement. Replacements also included some percentage of 60Weq bulbs and 75Weq bulbs.

Table A-10. Distributor A-line baseline weights, accounting for bin jumping

		Power (W)	Lumens/Watt	Lumens	40 eq LED	60 eq LED	75 eq LED	100 eq LED
40W eq	Inc	40	10	390	11%	0%	0%	0%
	Hal	29	16	443	13%	0%	0%	0%
	CFL	9	57	513	45%	0%	0%	0%
	LED	6	69	390				
60W eq	Inc	60	14	822	5%	12%	0%	0%
	Hal	43	15	747	6%	15%	0%	0%
	CFL	14	63	853	5%	48%	5%	2%
	LED	11	77	806				
75W eq	Inc	75	15	1,100	0%	4%	13%	2%
	Hal	53	17	918	0%	5%	16%	2%
	CFL	19	67	1,232	0%	3%	43%	0%
	LED	14	73	1,116				
100W eq	Inc	100	14	1,406	0%	0%	3%	14%
	Hal	72	20	1,409	0%	0%	4%	17%
	CFL	23	69	1,600	0%	0%	2%	48%
	LED	18	85	1,617				

Source: Navigant survey data analysis & Navigant web-scraped data

The Navigant team then used the values in Table A-10 to create an average wattage and average efficacy (lumens per watt) for each of the wattage equivalencies. These values are shown below in Table A-11.

Table A-11. Efficacies and wattages for actual baseline and LEDs (shown for distributors)

	Baseline		LED		
	l/W	Watts	l/W	Watts	WRR
40 eq	39.4	21.5	69	5.9	3.67
60 eq	43.1	30.2	77	10.6	2.85
75 eq	45.8	38.1	73	14.0	2.73
100 eq	47.4	47.1	85	17.8	2.64

Navigant survey data analysis & Navigant web-scraped data

The values calculated in Table A-11 are more descriptive than the WRR indicated in the existing lighting disposition, which only includes one WRR of 2.96 for all A-type lights. Navigant broke out A-type WRR values by wattage equivalency. This analysis makes clear the difference between replacements of 40Weq bulbs and 100Weq bulbs.

A.4.2 Reflectors

Analysis of the reflector technology followed the same basic procedure as the A-type lights, but instead of using a specific alternative baseline question, the hypothetical baseline was obtained through analysis of a single qualitative question:

> **Hypothetical Baseline:** "Hypothetically, if LED reflectors did not exist, how do you think your current sales mix as described in the previous table would look different? Would it be more likely that…" (select one of the following)

Large increase in incandescents & halogens	Smaller increases in both incandescents/halogens and CFLs	Large increase in CFLs

The simplistic qualitative nature of the responses within the reflector category prevented the detailed analysis that was undertaken for the A-type lights, but these questions were still used to create the hypothetical baseline of the reflector category. Responses of small increases in both categories were thrown out and weights were assigned based on the percent of respondents indicating a switch to incandescent/halogen technology or to CFL technology.

In the same manner that A-type WRR values were created, the wattages and efficacies of the hypothetical baseline were calculated for each of the reflector categories and compared to a fully LED baseline. Once the theoretical baseline was created, these technology percentages were multiplied by their respective technology efficacies to determine the overall efficacy of each reflector category. This analysis was performed for MR16, PAR20/BR20/R20, PAR30, PAR38, BR30/R30, and R40/BR40. Shown in Table A-12 for distributor responses, this allowed for creation of a table to compare the survey WRR with the WRR of the lighting disposition.

Table A-12. Distributor WRRs Compared to 2012 Disposition WRRs

	Hypo w/o LEDs		LED only			
	l/W	Watts	l/W	Watts	Navigant WRR	Lighting disposition WRR
MR16	12.8	40.9	56	5	7.72	4.24
PAR20/BR20/R20	21.6	28.0	59	8	3.48	4.70
PAR30	29.9	33.5	62	13	2.60	3.42
PAR38	33.8	45.3	64	17	2.65	3.81
BR30/R30	27.7	39.8	65	11	3.72	4.09
R40/BR40	30.3	50.5	68	13	3.80	4.09

Source; Navigant survey data analysis & Navigant web-scraped data

An additional aspect of reflector based lighting units, largely unique to the reflector category, was the survey respondents' proclivity to assert unrealistic market share. For example, the Navigant web-scrape returned no instances of CFL or incandescent MR16 lamps; however, as high as 80% of respondents indicated that they would switch to a CFL MR16 in the absence of an LED.

A similar artifact of the survey was that respondents indicated incandescent PAR units and halogen R/BR lighting units, neither of which were shown from the web-scrape to exist. The Navigant research team discussed these unique instances and addressed them by forcing their values to a 0% market prevalence, representative of the actual market.

A.4.3. Downlights

The lighting category of downlights was the simplest of the WRR categories. Similar to reflectors, Navigant collected data based on the physical difference between available reflector units: pin base and screw base reflectors.

Here, the Navigant survey created the actual baseline from a survey specific baseline question, and created the hypothetical baseline from a qualitative response question similar to the one asked to determine the reflector hypothetical baseline. Following the same WRR procedure, the hypothetical non-LED baseline was compared to the LED target to obtain the WRR for screw base and pin base downlights.

A.4.4 Efficacy and Wattage Assumptions for Reflector and Downlight Products

Table A-13. Summary of Reflector and Downlight Lamp Wattage Assumptions (Watts)

Technology	Downlights	MR16	PAR	R/BR
LED	64	-	-	65
CFL	50	41	49	46
Halogen	20	-	18	18
Incandescent	11	5	13	12

Source: Navigant data analysis, Navigant web-scraped database

Table A-14. Summary of Reflector and Downlight Efficacy Assumptions (Lumens per Watt)

Technology	Downlights	MR16	PAR	R/BR
LED	8	-	-	8
CFL	16	13	16	14
Halogen	46	-	45	44
Incandescent	57	56	60	67

Source: Navigant data analysis, Navigant web-scraped database

A.5 Range Based Wattage Reduction Analysis

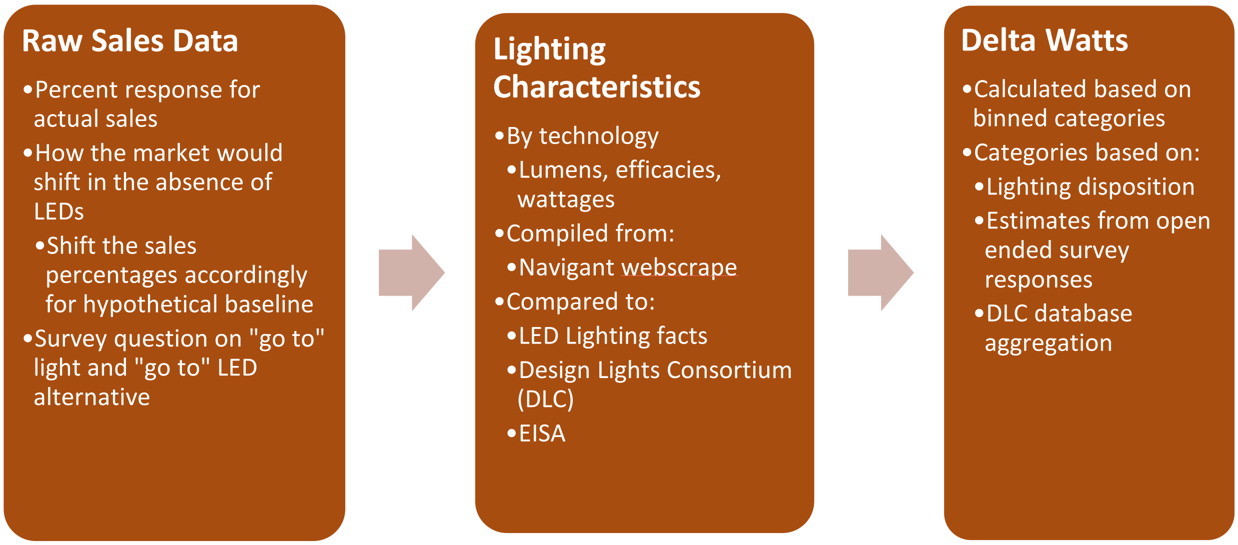
The second method for analyzing the energy savings discussed in the main text is through range based wattage reduction. These lighting categories include bay lighting, exterior lighting, and potentially troffers, which are available over a range of wattages and lumens. As a result, the binning of these lighting groups is accomplished by a wattage reduction range or a delta watts term, a measure of the difference between the lower wattage limit of the baseline lighting unit and the upper wattage limit of the LED replacement.

$$\Delta Watts = Lower\ wattage\ limit\ of\ baseline\ - upper\ wattage\ limit\ of\ LED\ replacement$$

The fundamental difficulty with range based lighting units is creating the categories in which to bin groups of lights. Unlike WRR categories which can be easily delineated by product sub-categories, range based lighting fixtures exhibit a breadth of products available over a spectrum of wattages and lumens that are not easily delineated by size or wattage equivalents. This leaves an open ended range where binning must be artificially imparted on a continuous product distribution.

Apart from this step of defining the wattage bins, Navigant performed much of the analysis in the range based technologies in a similar fashion to the WRR calculations. The general flow of data analysis is shown below.

Figure A-32. Wattage Range Data Analysis Flow Chart



Source: Navigant analysis

Navigant used the same distributor, contractor, and end user raw survey data as was used in the WRR calculations in this analysis. Again, each survey asked specific questions about the market baseline and each category contained explicit responses for the actual baseline. Similar to A-type, bay lighting also contained a specific hypothetical baseline question while exterior and troffer fixtures used a qualitative response question to infer how the actual baseline would change in the absence of LEDs.

Navigant again prepared the lighting efficacies, wattages and lumens by category and technology from the Navigant web-scrape data and compared these to efficacies and wattages compiled from lighting databases.

Using these data, Navigant calculated the wattage range, the difference between the lower wattage limit of the baseline lighting unit and the upper wattage limit of the LED replacement. Navigant conducted this analysis for binned categories within bay lighting and exterior fixtures.

The existing lighting disposition measures included target replacement ranges for each of these measures, but Navigant analysis revealed that these ranges failed to capture the focus of the market replacement on similar wattage, similar lumen LEDs.

A.5.1 Bay Lighting

Bay lighting survey questions directly asked for the actual baseline as well as the hypothetical baseline for both high bay and low bay lighting fixtures. This is a similar method to the line of questioning used for A-type lamps:

> **Bay Lighting Actual Baseline:** "Thinking about all of your **high bay** fixtures (typical lumen output: >10,000) sales in the past year, approximately what percentage of total sales are LEDs vs. other technologies? (Total must equal 100%)"

> **Bay Lighting Hypothetical Baseline:** "Hypothetically, if **high bay LED fixtures** did not exist, how do you think your current sales mix as described in your response to the previous question would look different?"

The responses to these questions showed the breakdown of lighting technology in the market, but in determining the difference between the actual baseline and hypothetical baseline, the bay lighting fixture category needed to be broken into lighting ranges. This had been done previously for the CA lighting disposition, creating seven artificial bins based on wattages.

Navigant's research survey explored the market and hypothetical baseline through the open ended questions shown below:

> **Market baseline:** "Please describe one of your "go-to" **high bay LED fixtures** and the application in which you typically use it. Please be specific with brand, wattage, lumens, number of lamps, etc., as applicable."

> **Hypothetical baseline:** "Think about the scenarios in which you would normally install that LED high bay fixture. If you could not purchase an LED and had to install an alternative immediately, what would be your preferred non-LED alternative? Again, please be as descriptive as possible in terms of brand, wattage, lumens, number of lamps, etc."

Navigant received these responses as general comments that varied from detailed quantitative responses to softer more general responses. Navigant analysis parsed out survey respondents that sufficiently answered both of these questions in order to create a market baseline and a hypothetical baseline. Qualitative open ended responses were then transcribed into quantitative initial and final cases in order to gain a better understanding of lumen bins in the market baseline and in the hypothetical baseline. Additionally, non-LED responses in the market baseline were removed in order to account solely for the shift between LED and non-LED fixtures.

Analysis of the responses showed that LED fixture wattages were contained in a much more narrow range than the non-LED baseline. That is, the wide range of bay lighting fixtures were being replaced with a narrow range of LED replacements.

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

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

A.5.2 Exterior Lighting

Survey questions for exterior lighting fixtures covered similar ground as the bay lighting analysis. Navigant's research survey explored the market and hypothetical baseline through the open ended questions shown below:

> **Market baseline:** "What is your 'go-to' LED parking lot luminaire? Please be specific with brand, wattage, lumens, number of lamps, etc."
>
> **Hypothetical baseline:** "Think about the scenarios in which you would normally install that LED parking lot luminaire. If you could not purchase an LED and had to install an alternative immediately, what would be your preferred non-LED alternative? Again, please be as descriptive as possible in terms of brand, wattage, lumens, number of lamps, etc."

Navigant analysis calculated delta watts for exterior lighting using a similar analysis method as was used for bay lighting. The survey asked specific market questions about the technology breakdown in the actual and hypothetical baseline, but more useful to the analysis were the open ended response questions.

Navigant's survey analysis showed higher wattage reductions than the DEER proposed wattage range. As discussed in the main body of the report, more efficient products are thus disadvantaged. Analysis concluded that it would be beneficial to use a mean or median but also to update the ranges regularly to account for fast changing LED efficacies.

A.6 Market Actor-Specific Web Surveys

California LED Study – Contractor Survey.p

California LED Study – End User Survey.pd

California LED Study – Distributor Survey.p