BONNEVILLE POWER ADMINISTRATION

2016 Non-Residential Lighting Market Characterization

JULY 2017

EXECUTIVE SUMMARY

Introduction
This report contains the detailed findings from the Bonneville Power Administration's (BPA) characterization of the Pacific Northwest non-residential lighting market. BPA's market characterization effort gathered and analyzed data to model non-residential lighting energy consumption and estimate Momentum Savings for BPA and the Pacific Northwest region for 2010-2015. The study included:

Sales Data Collection and Analysis
In collaboration with the Northwest Energy Efficiency Alliance (NEEA), the team collected lighting product sales data from 34 regional electrical distributors. Data submissions were organized by technology and product type to allow detailed analysis of sales trends.

Market Actor Interviews
The team completed in-depth interviews with 85 regional market actors including contractors, manufacturers, manufacturer representatives, national accounts specialists, and outdoor and industrial lighting professionals. Interview results informed the team's analysis and interpretation of sales data.

Program Data Analysis
Analysis of regional lighting program data identified trends in installed technologies, baselines, and the relative size of the three major non-residential sectors within programs (commercial, industrial and agriculture, and outdoor).

Literature Review
The team supplemented its primary data collection with a review of secondary data sources to develop inputs to the model.

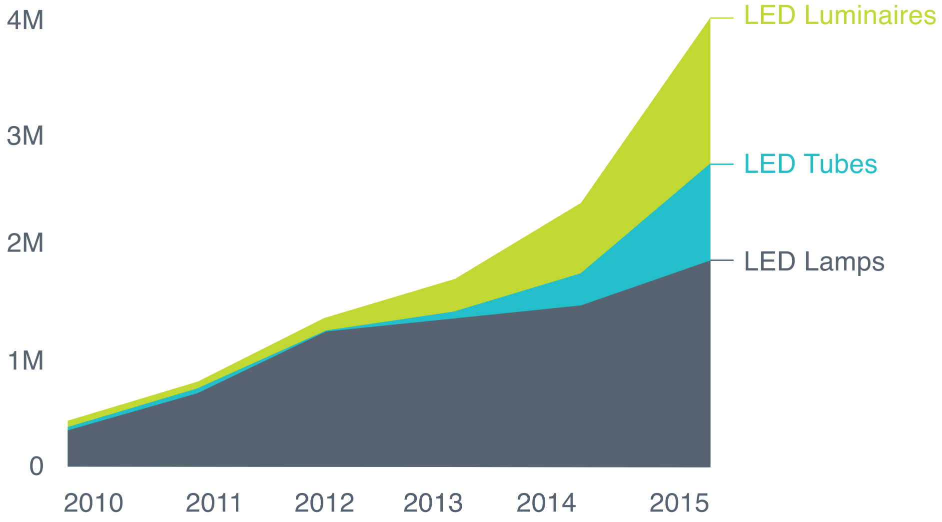
Regional Model Development
The team combined the information from these research tasks, as well as from NEEA's Commercial Building Stock Assessment, to model changes in regional lighting energy consumption over time.

Market Insights
BPA's 2016 market research revealed several insights. Specifically, LEDs grew to almost 15% of non-residential unit sales in 2015. Combined with improving efficiency in linear fluorescents and the decline of high intensity discharge (HID) lighting, LEDs helped reduce non-residential lighting consumption by 7% - even as the total number of fixtures installed in the region grew by nearly 10%.

LED Technology Sales See Continued Growth

LEDs reached 15% of all non-residential sales in 2015

LED sales continue to increase rapidly, and they are the only technology with growing sales. LED lamps and tubes represent the majority of this growth at 10% of total 2015 sales: these technologies are the easiest way for customers to convert to LED. Fixture sales have also increased - especially in more recent years - representing 5% of total 2015 sales.



Significant Potential Remains for Converting Stock to LED

The non-residential market will take time to convert to LED because, in many applications, existing technologies are relatively efficient and long-lived.

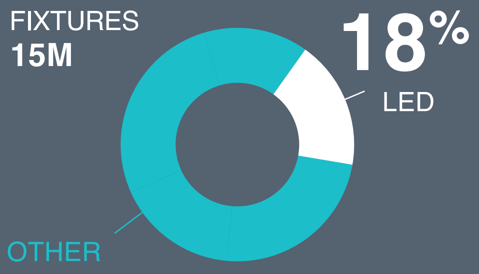
Linear fluorescent and LED technologies have changed the non-residential lighting stock over the past few years, but the market is poised for an even greater shift. Increasing LED sales put more LEDs into the region's building stock and outdoor fixtures, but converting all 54 million non-residential lighting fixtures in the Pacific Northwest will take sustained increases in LED sales.

LEDs have penetrated different parts of the non-residential stock at different rates: small lamp applications such as general purpose lamps and downlights are already 18% LED, and exterior and outdoor fixtures are 11% LED; however, ambient and high and low bay fixtures are just 2% LED. Ambient and high and low bay lighting represent 65% of non-residential lighting consumption, indicating there is significant potential remaining for LED growth.

Installed Lamp Stock

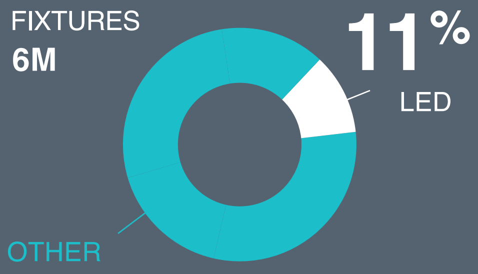
Small Lamps

FIXTURES
15M



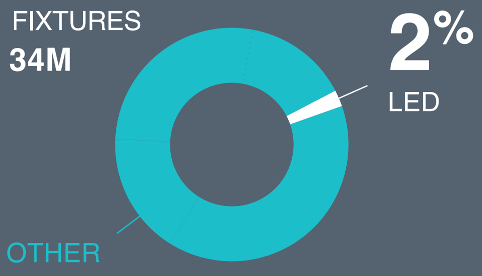
Exterior and Outdoor

FIXTURES
6M

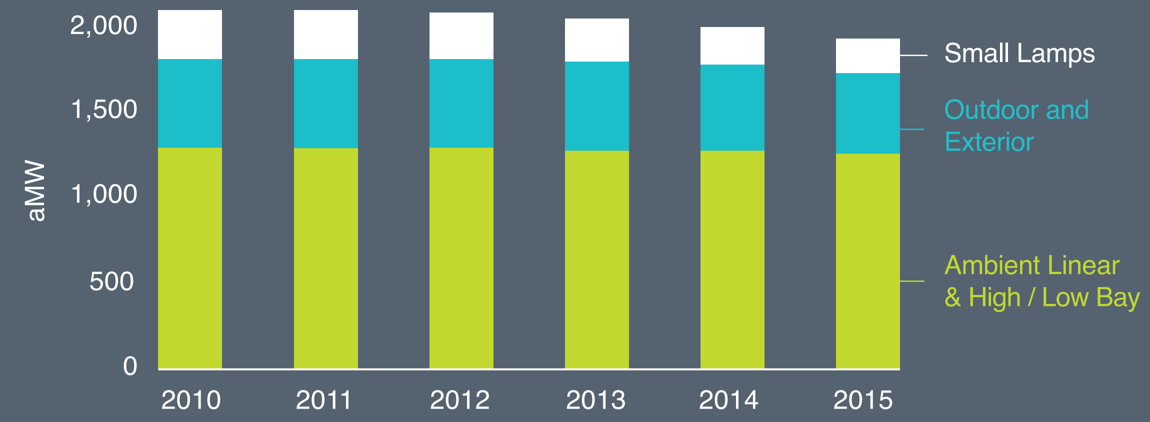


Ambient Linear and High / Low Bay

FIXTURES
34M



Regional Energy Consumption



Energy consumption from non-residential lighting declined in all applications despite a 9% increase in the number of installed fixtures in the region. Small lamp applications saw the largest percent decline at 28% of 2010 consumption, followed by exterior and outdoor lighting (10% decline) and ambient and high and low bay lighting (2% decline).

Relative to the frozen baseline, the ambient linear and high and low bay applications generated 39% of total market savings between 2010 and 2015. Despite consuming the least energy annually, small lamp applications produced 33% of market savings and exterior and outdoor comprised the remaining 28%.

Key Drivers

150 aMW

Momentum Savings from non-residential lighting

3.7 MILLION

T12 fixtures retired since 2010

10.5 MILLION

LED products sold in the Pacific Northwest between 2010 and 2015

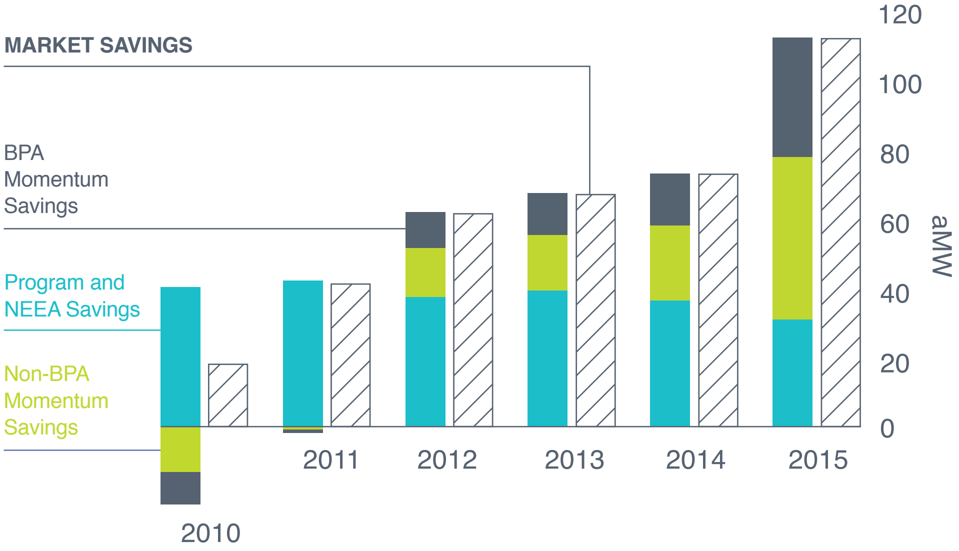
47%

Of 2015 utility and NEEA savings were from exterior and outdoor lighting

+28%

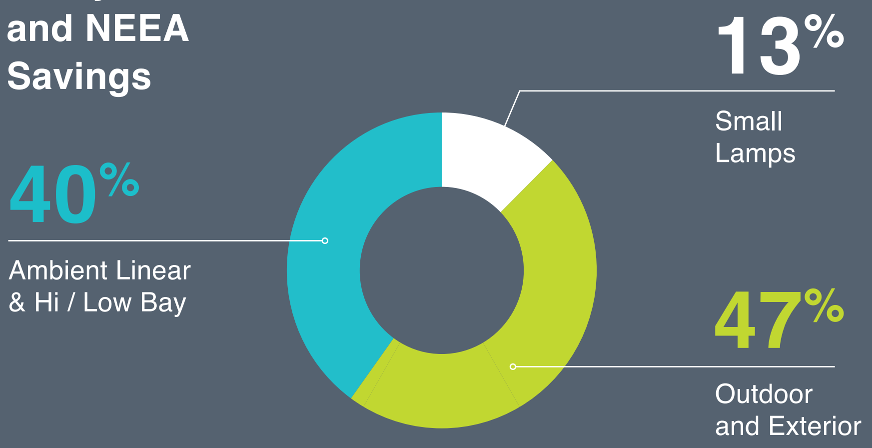
Increase in the share of high and low bay fixtures that are T5, T8, or LED

Momentum Savings Results



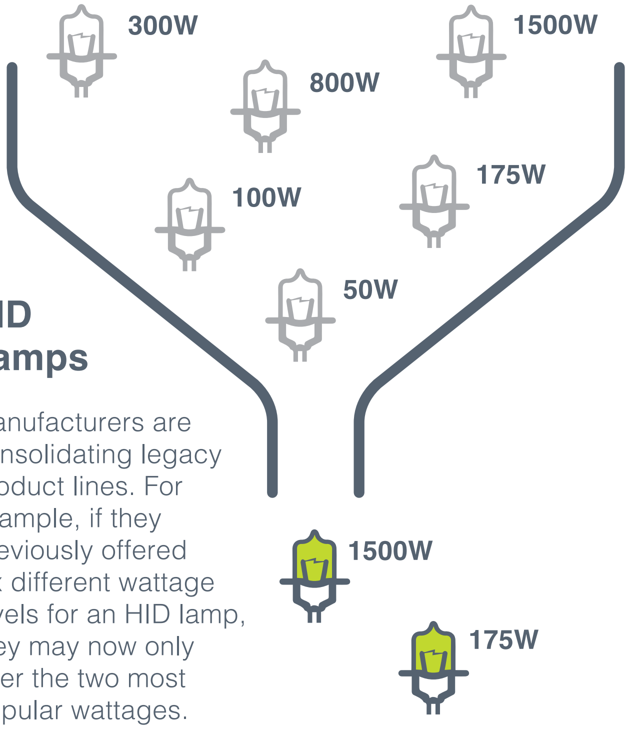
While utility and NEEA savings outpaced total market savings in 2010 and roughly equaled market savings in 2011, Momentum Savings accumulated as market efficiency increased in 2012 through 2015, resulting in 377 aMW of market savings and 150 aMW of regional Momentum Savings. The negative savings in the early years reflect the frozen baseline efficiency assumption that the market will be at least as efficient as the baseline year (2009). Thus, only incremental gains in market share for efficient technologies contributed to market savings. For example, even though overall 2010 sales were 35% 32W T8, the 32W T8 sales share only increased by 1.5% between 2009 and 2010. As efficient fluorescent and LED sales shares grew relative to the frozen baseline and these technologies penetrated the stock, savings increased throughout the Northwest Power and Conservation Council's Sixth Power Plan (Sixth Plan) period.

Utility and NEEA Savings



Non-Residential Lighting Market Insights

Out With the Old



HID Lamps

Manufacturers are consolidating legacy product lines. For example, if they previously offered six different wattage levels for an HID lamp, they may now only offer the two most popular wattages.

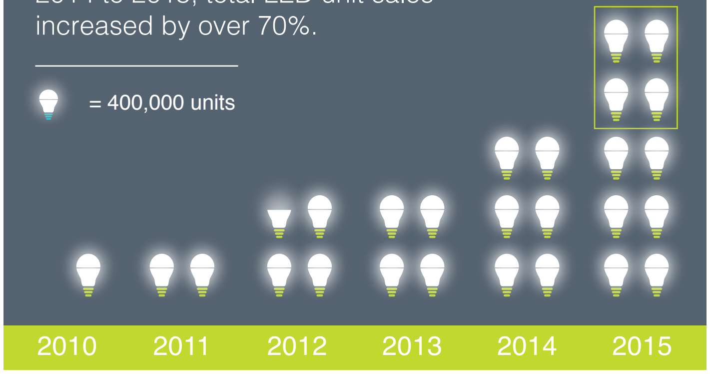
In With the New

LED sales grew rapidly from 2010 through 2015, with the rate of growth increasing in recent years. From 2014 to 2015, total LED unit sales increased by over 70%.

+70%

From 2014 to 2015

💡 = 400,000 units



High Growth Categories

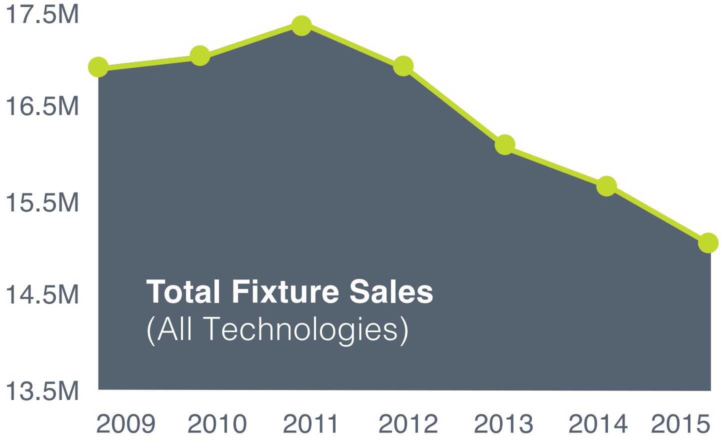
TLED	LED Downlights
x3 Nearly tripled from 2014 to 2015	**x2** Doubled from 2014 to 2015

Market Responding to Change

Total lighting unit sales are declining as a consequence of longer-lived products such as LEDs becoming more prevalent. This poses a threat to some traditional lighting businesses that have relied on a steady stream of maintenance sales and puts pressure on all market actors to differentiate themselves in a competitive market. This competition is driving more sophisticated, consultative sales strategies and product innovation.

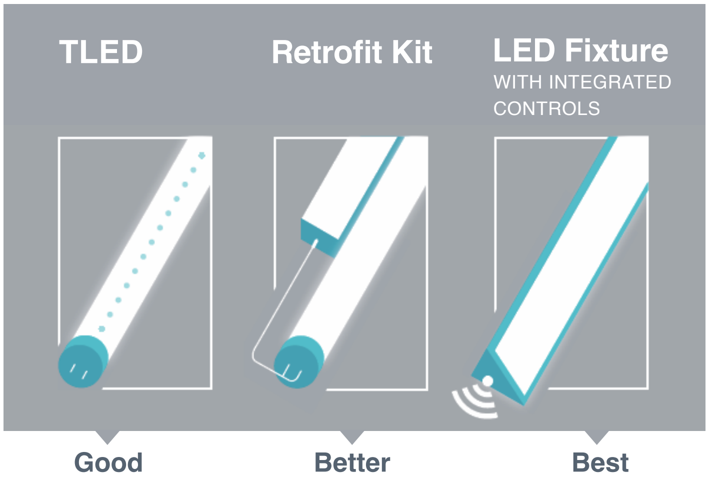
Total Fixture Sales Declining

As longer-lived products (including LEDs) are gaining market share, the turnover rate is slowing down. This trend is evident in a slow decline in total fixture sales starting in 2011, corresponding to the rapid growth in LED sales.



Good, Better, and Best

A maturing LED market now includes good > better > best options, as manufacturers refine their product offerings to meet a range of customer needs.



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Introduction

Bonneville Power Administration (BPA) contracted with Navigant Consulting, Inc. and Cadeo (the research team) to characterize the non-residential lighting market in the Pacific Northwest. To this end, the research team interviewed a wide-range of lighting industry market actors, analyzed lighting sales data from regional distributors, and developed a regional model to estimate changes in lighting-related energy consumption over time. This report summarizes the results of these efforts.

How to Use This Document

Before reviewing the research findings, it is important to understand the structure of this document as well as the activities completed to investigate the non-residential lighting market. This document consists of two parts: a **Research Summary** and a **Research Portfolio**.

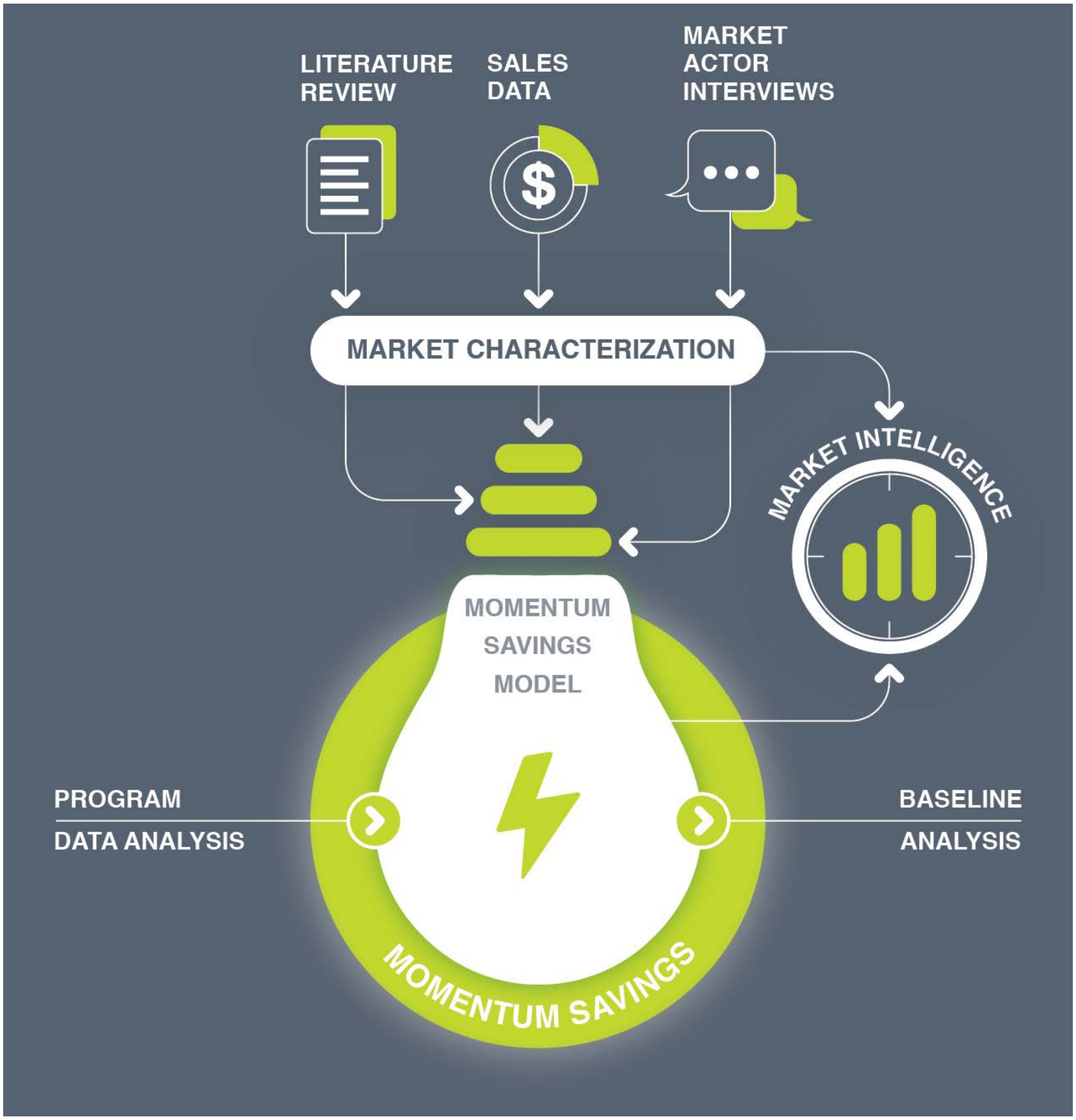
The **Research Summary** distills the findings from the wide-ranging activities the research team completed as part of the non-residential lighting market characterization. In this section, the team highlights key findings, identifies important connections across research activities, and discusses the implications of this market intelligence for the region. It also includes the research team's estimation of Momentum Savings generated between 2010 and 2015.

The second part of this report is the **Research Portfolio**. It contains the seven deliverables that the research team submitted to BPA between January 2016 and June 2017 following the completion of each research activity. These memos and presentations detail each activity's methodology and findings. Readers should refer to the Research Portfolio for an in-depth discussion of each activity.

Description of Research Activities

The research team combined several research activities to understand the evolving lighting market, characterize market baselines, model changes in regional lighting energy consumption, and estimate Momentum Savings in the non-residential lighting market. This third market study builds on research conducted by the team in 2013 and 2014, incorporating previous findings and increasing the depth and quantity of qualitative and quantitative data collected. Figure 1 illustrates how the research team leveraged each activity to quantify Momentum Savings, conduct baseline analysis, and provide market intelligence.

Figure 1: 2016 Research Activities and Outputs



Sales Data Collection and Analysis. The research team collected 2015 sales data from 29 unique distributors and combined it with data from previous research to build a database of regional non-residential lighting sales. The team's collaborative process coordinated regional outreach, leveraged existing relationships and enlisted trusted messengers including Northwest Energy Efficiency Alliance (NEEA) staff, Evergreen Consulting, and lighting program managers to engage distributors. The final database contains data from 34 distributors spanning 2010 to 2015. The team cleaned and analyzed raw distributor data to assess sales trends across and within the six major lighting technologies in the non-residential market: linear fluorescent, high-intensity discharge (HID), incandescent, halogen, LED, and compact fluorescent (CFL). This data served as a critical input for the regional lighting model.

Market Actor Interviews. The research team developed and executed a market actor interview strategy based on gaps in previous research and data input needs for regional modeling. This strategy targeted five research areas: market evolution, purchase decisions, regional variation, industrial lighting and outdoor lighting. The research team conducted interviews with 85 regional market actors including contractors, manufacturers, manufacturer representatives, national accounts specialists, and outdoor and industrial lighting professionals. These interviews provided the perspectives of market actors on the current state of the lighting market, as well as new insights into the non-residential lighting supply chain and customer decisions.

Literature Review. The research team completed a review of secondary data sources to inform the regional model development where primary data was not available. This review included over 40 regional and national data sources. The literature review documents key findings that informed inputs to the model and provided general market intelligence.

Program Data and Baseline Analyses. The research team reviewed recent BPA program data to assess trends in installed technologies, baselines, and the relative size of the three major non-residential sectors within programs (commercial, industrial and agriculture, and outdoor). This analysis informed two additional components of the project: the research team's approach to incorporating regional program savings into the regional model to estimate Momentum Savings, and comparing model outputs to Regional Technical Forum (RTF) current practice baselines.

Regional Model Development. The team built a new, more robust non-residential lighting Momentum Savings model. The new model uses a stock turnover approach with additional granularity and forecasting capability. First, the model calculates the failure of existing lights based on their age, technology, and expected useful life. Next, the model replaces all failed lamps with a mixture of technologies on an annual basis. The replacement technologies mirror the mix of technologies sold by regional distributors in each year. The model's stock turnover approach allowed the research team to estimate a number of regional lighting metrics, including total non-residential lighting energy consumption, total market savings (relative to a specified baseline), and regional Momentum Savings—the market savings that remain after accounting for previously claimed local utility program and NEEA lighting savings. This model calculates momentum savings for BPA and the Pacific Northwest region for 2010-2015.

Throughout the study, the research team also leveraged the concurrent BPA Residential Lighting Study.[1]

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[1] Bonneville Power Administration, "Residential Lighting Market Characterization Study." April 2017. https://www.bpa.gov/EE/Utility/research-archive/Documents/Momentum-Savings-Resources/2017_Residential_Lighting_Final_Report.pdf

Uncertainties

The research team leveraged the most robust and recent data available from both regional and national data sources including RTF assumptions, the Northwest Power and Conservation Council's (the Council's) Sixth Power Plan (Sixth Plan) and Seventh Power Plan (Seventh Plan), the 2014 Commercial Building Stock Assessment (CBSA), Department of Energy (DOE) data on technology characteristics and stock saturations, and the sales data collected during this study. Each data source has uncertainty: for example, the CBSA study documents sampling error and the distributor sales data the research team collected does not represent the entire market. The research team used the most representative information available regarding which data sources to prioritize and how to best fill data gaps. The team relied on and leveraged both internal and external lighting market experts to ensure proper use and interpretation of the data. The Model Reliability section provides an overview of how varying data quality affected the Momentum Savings model; Section B. Memo Describing Gaps in Sales Data of the Research Portfolio discusses the research team's approach to addressing sales data gaps; and Section D. Report on Data Collection Activities to Improve the Model of the Research Portfolio details how BPA can resolve some of these data gaps in the future. The research team did not conduct quantitative uncertainty analysis due to the numerous inputs and complexity of assessing the uncertainty of each input. However, the team did conduct a sensitivity analysis to better understand which inputs affect Momentum Savings results the most and used this analysis to help BPA prioritize future data collection activities.

Research Summary

Momentum Savings

The research team modeled the Pacific Northwest non-residential lighting-related energy consumption between 2009 (the model's base year) and 2015 (the last year of the Council's Sixth Plan period). The model simulates the effect of all non-residential lamp sales on the installed stock of lamps, ballasts, and fixtures in the Pacific Northwest and calculates both the market (i.e., actual) and baseline regional lighting energy use based on these trends. This allows the research team to compare market and baseline energy use and—after accounting for programmatic and NEEA-claimed savings—calculate Momentum Savings.

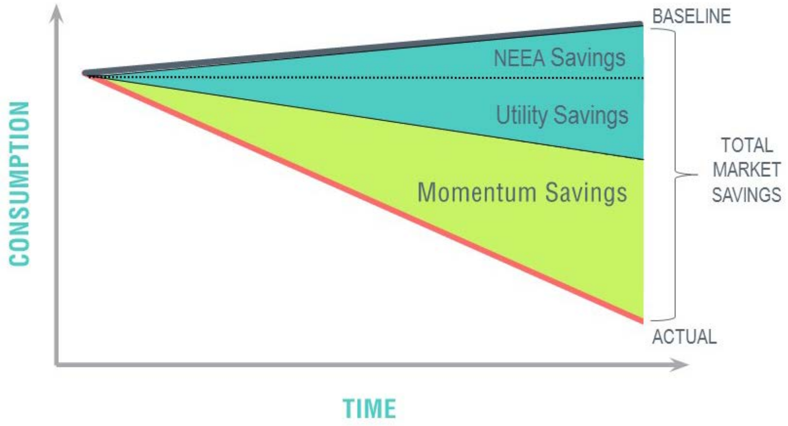
Before discussing the model or its results in more detail, it is important to first define several key Momentum Savings terms:

- **Baseline consumption:** The anticipated annual energy consumption for a given market—in this case, non-residential lighting
- **Market consumption:** The actual annual energy consumption for that market, determined retrospectively using market data
- **Total market savings:** The difference between baseline energy consumption and actual energy consumption
- **Utility savings:** All programmatic savings within the market claimed by regional utilities
- **NEEA savings:** Any net market effects claimed by NEEA for initiatives within the market

- **Momentum Savings:** Any savings that occur above the baseline and that are not directly incented by programs or claimed as part of NEEA's net market effects

Figure 2 highlights the interdependent relationships between these terms.

Figure 2: Elements of Momentum Savings



The remainder of this section details the scope and structure of the regional non-residential lighting model and the research team's estimates of total market and Momentum Savings. The team also offers some critiques of the model and recommends improvements for the data collection process. For more information about each of the topics covered below, please see research portfolio Section C. Methodology Memo.

Analysis Scope and Model Details

The purpose of a stock turnover model is to identify how consumers adopt technologies and how these adoptions affect the size and efficiency mix of the stock—in this case total lamp installations—over time. For the non-residential lighting market, this model determines the size and efficiency mix of the applications and sectors within this market as defined in Section C. Methodology Memo. The results are the total installed lamp counts by technology required for properly calculating the baseline energy consumption and actual energy consumption, which drive the Momentum Savings analysis.

The research team defined the region's non-residential lighting market as described in Table 1.

Table 1: Market Definitions

Dimension	Scope of Model	Notes
Unit of Account	All installed lamps in the geographic, sector, application, and technology scopes listed below	The model tracks sales of lamps, ballasts, and fixtures. Lamp characteristics and the assumed average number of lamps per ballast and fixture dictate ballast and fixture consumption. Thus, the primary unit of account is lamps.
Geographic Scope	Oregon, Washington, Idaho, and Western Montana[2]	Consistent with the regional power plan; the research team did not vary stock or sales mixes by this dimension.
Sector	Interior and exterior lighting in commercial, industrial, and agricultural buildings; outdoor lighting	Agriculture uses the same sales and stock mix as industrial.
Building Type	All commercial building types	Applies to the commercial sector only; the research team did not vary sales mixes by this dimension. Stock inputs began at the building type level, but the team aggregated all data to the sector level for the analysis.
Application	Dominant lighting applications in each sector; specific exclusions include exit signs, refrigerated case lighting, and railway and airfield lighting	Defined as a common lighting need in the market that can be met by several competing technologies; may be further divided by lumen bins. The methodology memo provides a summary of all applications and technologies included in the model.
Technology	Dominant technologies within each application	Defined as an individual technology modeled as a distinct product choice within appropriate applications.
Purchase Triggers	New construction, maintenance (lamp and ballast), and natural replacement	Lamp and ballast burnout drive maintenance; retrofit, renovation, and system turnover drive natural replacement. LED technologies can only leave the stock due to maintenance (lamp or driver burnout).

These market definitions resulted in a total installed lighting stock of 54.6 million commercial, industrial and outdoor fixtures in 2015. These fixtures contained 106 million lamps in 2015.

Building this model required many sources and assumptions to develop the three primary areas of input:

1. A characterization of the installed stock (size, mix, and age of the lamps in the stock) for at least one year of the analysis period
2. An estimate of how fast the existing stock turns over each year due to the four purchase triggers
3. An efficiency mix of sales in each year of the analysis period

With these inputs, the model estimates how the mix of installed technologies in the stock changes over time in both the baseline and market scenarios. In the baseline scenario, the sales mix is frozen at 2009 levels, reflecting the concept that sales into the market will not get more efficient. Yet, even in the baseline, lamps and ballasts burn out, customers replace fixtures in renovations, and new buildings require lighting. The model uses 2009 sales mixes for each application to fill sockets in each of these

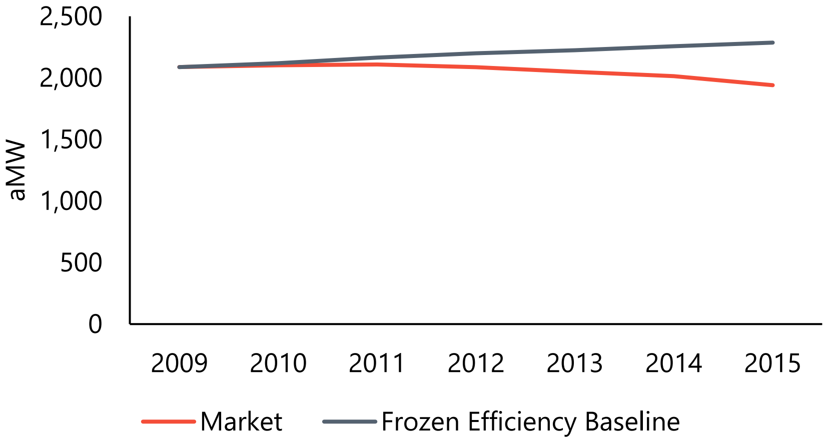
[2] The sales mix reflects sales from all of Montana, but the stock and sales market size only represents Western Montana.

situations. Thus, if the frozen 2009 sales mix is more efficient than the existing stock, the stock in the baseline scenario will get more efficient over time—though likely at a slower rate than the actual stock. The research team multiplied the stock data in this baseline scenario and the market scenario by the unit energy consumption of each technology to calculate consumption in each case and the resulting market savings.

Regional Lighting Consumption

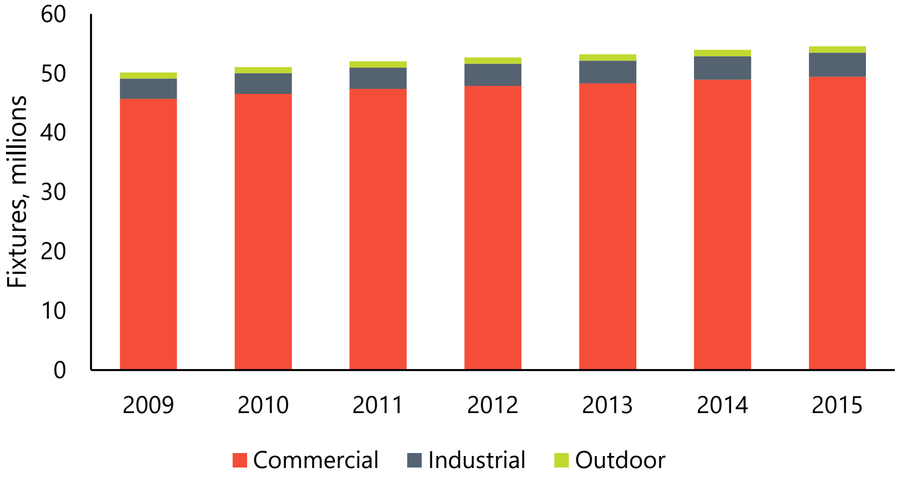
Figure 3 compares the research team's estimate of the changes in total non-residential lighting energy consumption between 2009 and 2015. Specifically, the figure compares the two modeled scenarios: the actual (market) scenario and the frozen efficiency baseline scenario. The market consumption decreased by 7% between 2009 and 2015 despite 9% growth in the total number of installed fixtures (shown in Figure 4). In contrast, growth in fixtures and continued sales of less efficient products increased frozen baseline consumption by nearly 10% during the same years.

Figure 3: Model Estimates of Total Lighting Energy Consumption: 2009-2015



Source: Non-Residential Momentum Savings Model

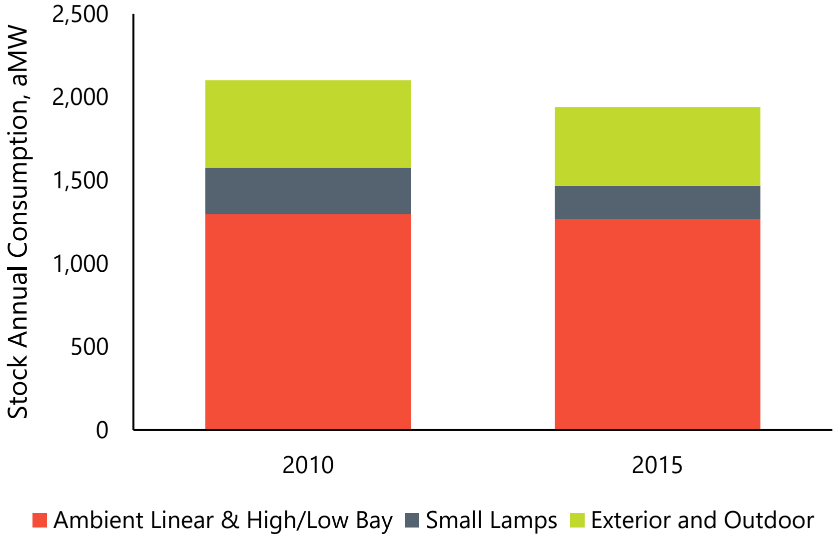
Figure 4. Model Estimates of Total Installed Fixtures: 2010-2015



Source: Non-Residential Momentum Savings Model

Most non-residential lighting consumption comes from ambient linear, high bay and low bay lighting, but these applications' consumption fell the least, with 2015 consumption only 2% lower than 2010 consumption. Ambient linear and high and low bay constituted 62% of consumption in 2010 and grew to 65% of consumption by 2015. Exterior and outdoor lighting represent approximately one-quarter of consumption in each year. Small lamps—general purpose, downlights, decorative, and track lighting—shrank from 13% of consumption in 2010 to 10% of consumption in 2015, representing a 28% drop in consumption in the small lamp applications. Exterior and outdoor lighting consumption fell by 10% between 2010 and 2015.

Figure 5: Consumption by Application over Time

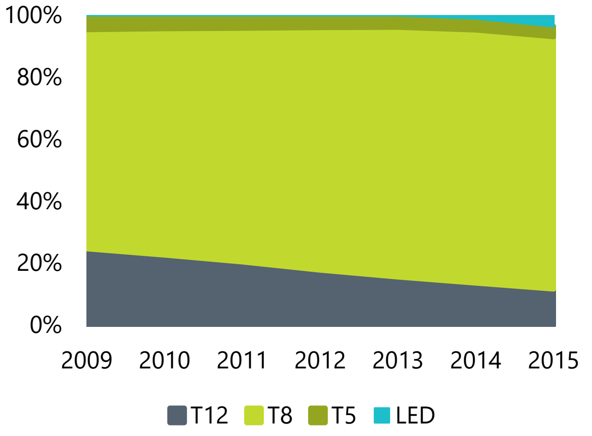


Source: Non-Residential Momentum Savings Model

Three trends drove the decline in non-residential consumption:

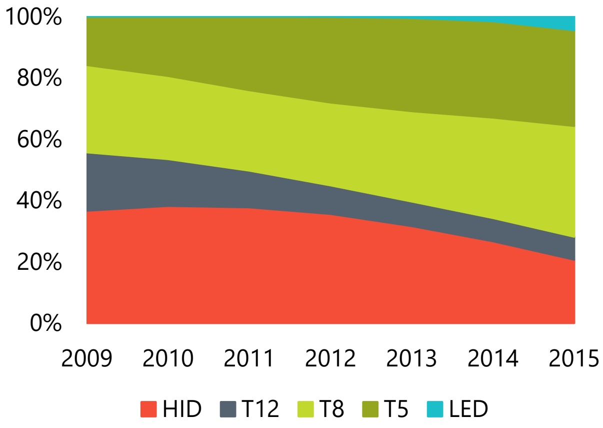
First, linear fluorescent lamps became more efficacious as installed stock shifted from T12 fluorescent systems to T8 and T5 fluorescent systems in ambient linear and high and low bay applications (Figure 6). Linear fluorescent technologies represented 57% of all non-residential fixtures in 2015.

Figure 6: Ambient Linear Installed Fixture Mix



Second, linear fluorescent lamps, particularly T8 and high output T5 systems, also displaced HID systems in high and low bay lighting (Figure 7). This increased linear fluorescent fixtures from 62% of high and low bay fixtures in 2010 to 75% in 2015 while HID systems fell from 38% to 21% of these fixtures in the same period.

Figure 7: High/Low Bay Installed Fixture Mix



Third, LED lamps and fixtures began eroding installed market share of all technologies, including: incandescent, halogen, and CFL in small lamp applications; linear fluorescent and HID systems in ambient linear and high and low bay applications; and primarily HID systems in exterior and outdoor lighting (Figure 8 and Figure 9). Small lamp applications comprised over 30 million installed lamps in 2015, and outdoor and exterior applications included over 11 million installed lamps in the same year.

Figure 8: Building Exterior (Low Output) Installed Fixture Mix

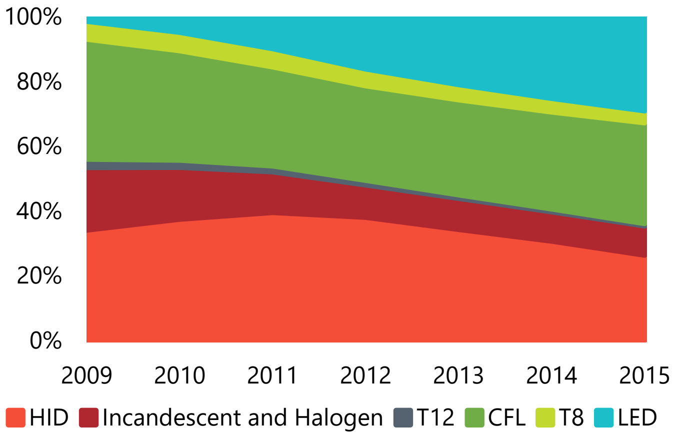


Figure 9: General Purpose Application Installed Fixture Mix

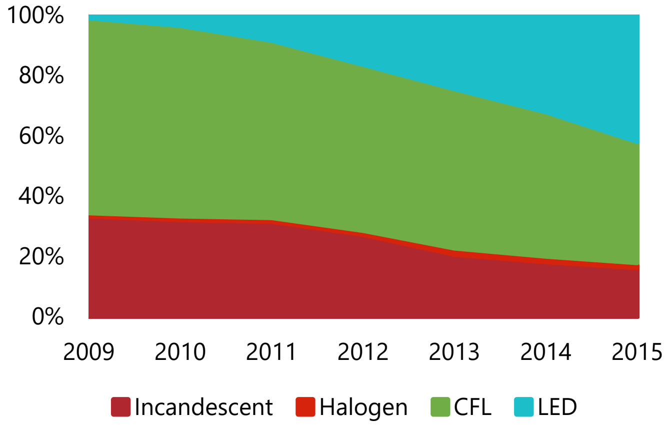
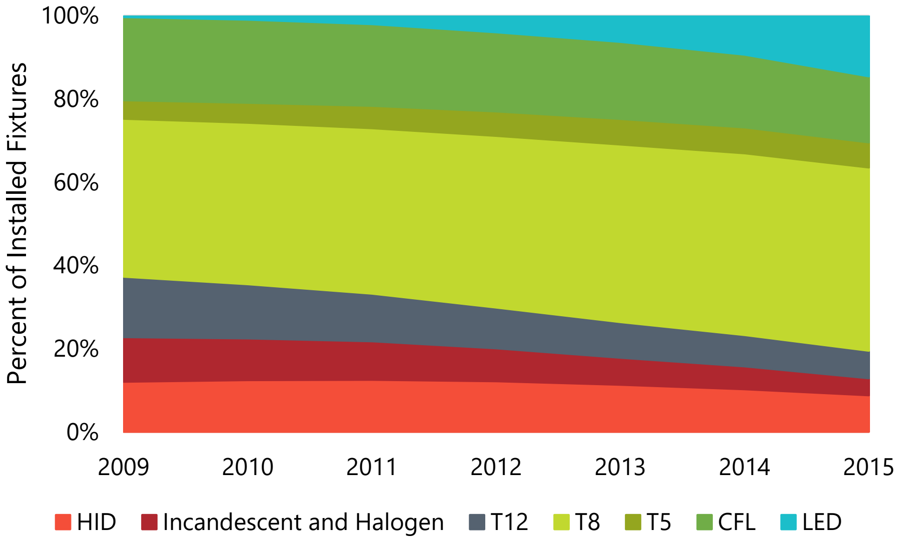


Figure 10 summarizes the effect these trends have on the mix of installed fixtures in the entire non-residential lighting stock. The least efficient technologies—HID, incandescent and halogen, and T12s—shrank from 37% of stock fixtures in 2009 to just 19% in 2015.

Figure 10: Installed Fixture Mix, All Applications



While small lamp applications saw the sharpest decline in consumption from 2010 to 2015, the rest of the non-residential market is poised for larger reductions in the coming years as LEDs become more competitive relative to linear fluorescent and HID technologies. In small lamp applications, as in the residential sector, non-LED technologies have short lifetimes, LED product cost is low, and customers can replace lamps as they burn out. These factors have led to faster growth in LED stock saturation—and larger decreases in consumption—compared to most non-residential applications. The research team expects that a combination of plug-and-play solutions like LED tubes, falling LED luminaire costs, and manufacturers' focus on LED products will drive accelerated LED adoption.

Accounting for Utility and NEEA Savings

The difference between the modeled market and the two baseline scenario consumption estimates shown in Figure 3 reflect the total market savings for each year relative to the baseline scenario. To avoid double counting any previously claimed program savings, the research team subtracted all lighting-related utility and NEEA savings from the total market savings. The remaining market savings, as illustrated by Figure 2, are Momentum Savings.

The analysis required the total savings for BPA programs, non-BPA programs (investor-owned utilities, or IOUs), and NEEA programs. BPA provided savings for its programs and the research team used Regional Conservation Progress (RCP) data to calculate non-BPA savings. [3] NEEA provided data for its Reduced Wattage Lamp Replacement initiative.

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[3] The RCP data comes from https://rtf.nwcouncil.org/about-rtf/conservation-achievements/previous-years, Summary Workbook from 2014, Tab: Achieved by Sector EndUse Chart. This data includes BPA and non-BPA utility savings data at the busbar level. The research team subtracted the BPA savings from the RCP data based on the data provided by BPA via email on September 9, 2016.

The research team subtracted savings for lighting controls; split savings into retrofit and new construction projects for each of the commercial, industrial, and outdoor sectors; and leveraged the detailed program data extracted from individual lighting calculator project files that BPA provided to estimate the following:

- The fraction of savings attributable to each application
- The mix of efficient technologies installed by programs within each application
- The mix of baseline technologies programs used to calculate savings within each application

For applications and years where programs did not use a current practice baseline, the research team calculated a baseline adjustment factor to ensure the model only subtracts program savings above the frozen baseline from the total market savings relative to that baseline.

Table 2 summarizes the team's estimate of total utility and NEEA savings by year and application. These savings accounted for 60% of the total market savings achieved in the region between 2010 and 2015 relative to the frozen baseline.

Table 2: Adjusted Utility Program and NEEA Savings by Year and Application (aMW)

Application	2010	2011	2012	2013	2014	2015
Ambient Linear	4.9	5.7	5.2	5.1	5.6	6.2
Building Exterior HIGH	3.1	3.2	2.7	3.0	2.5	1.8
Building Exterior LOW	11.4	11.6	9.9	10.5	9.3	6.6
Decorative	0.1	0.1	0.1	0.1	0.1	0.1
Downlight Large	0.5	0.5	0.4	0.5	0.5	0.5
General Purpose	2.9	3.0	2.6	2.8	2.6	1.5
High/Low Bay HIGH	3.8	3.9	3.5	4.1	3.7	3.4
High/Low Bay LOW	2.6	2.7	2.3	2.6	2.6	2.6
Other	0.2	0.2	0.2	0.2	0.2	0.3
Parking Garage	2.0	2.1	1.7	1.5	1.3	1.1
Parking Lot	1.6	1.6	1.4	1.5	1.5	1.7
Street and Roadway HIGH	0.0	0.3	0.9	0.9	0.8	0.5
Street and Roadway LOW	4.7	4.8	4.0	3.8	3.6	2.3
Track Large	1.9	1.9	1.6	1.8	1.7	1.4
Track Small	0.9	0.9	0.8	0.8	0.7	0.4
Total	**41**	**43**	**37**	**39**	**37**	**30**

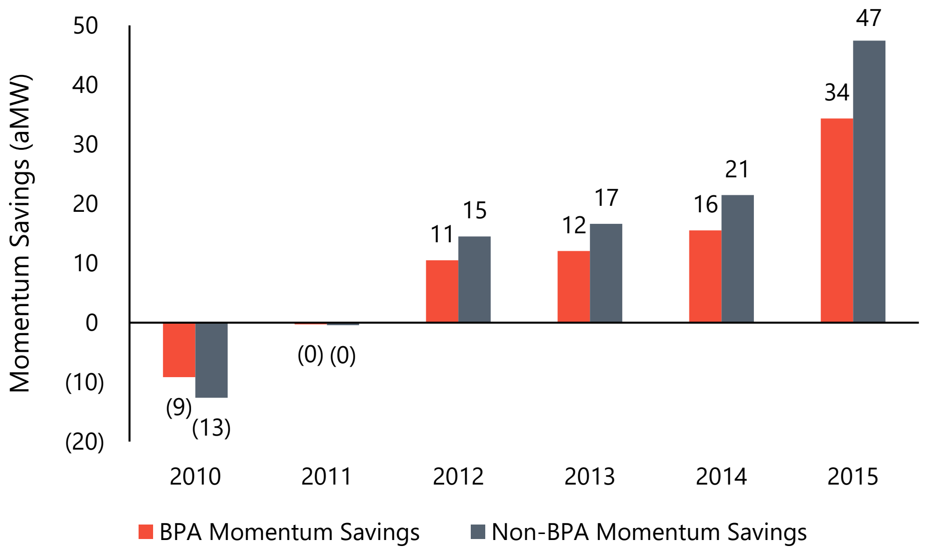
Source: Non-Residential Momentum Savings Model

Momentum Savings Results

The team subtracted utility and NEEA savings from the frozen efficiency baseline to reveal any remaining regional Momentum Savings (as shown in Figure 11). BPA Momentum Savings are 42% of total regional Momentum Savings; the balance is non-BPA Momentum Savings.[4]

The research team found that utility and NEEA savings outpaced total market savings in 2010 and were roughly equal to market savings in 2011 relative to the frozen baseline. As the efficiency of market sales increased in 2012 through 2015, Momentum Savings accumulated, resulting in 150 average megawatts (aMW) of regional Momentum Savings during that period. The negative savings in the early years reflects that the frozen efficiency scenario effectively assumes that the market will be at least as efficient as the baseline year (2009). Thus, only incremental gains in market share for efficient technologies contributed to market savings. For example, even though overall 2010 sales were 35% 32W T8, the 32W T8 sales share only increased by 1.5% between 2009 and 2010. However, as efficient fluorescent and LED sales shares grew relative to the frozen baseline and these technologies grew in the stock, savings increased throughout the Sixth Plan period.

Figure 11: Non-Residential Lighting Momentum Savings: 2010-2015



Market savings were highest for the ambient linear and high and low bay applications because of their size and the combined effects of linear fluorescent efficacy improvement, declining HID sales, and increasing LED sales. However, program savings were highest in the exterior and outdoor applications. Figure 12 illustrates this comparison, showing that programs have driven significant change in these applications, while market savings have outpaced programs the most in small lamp applications.

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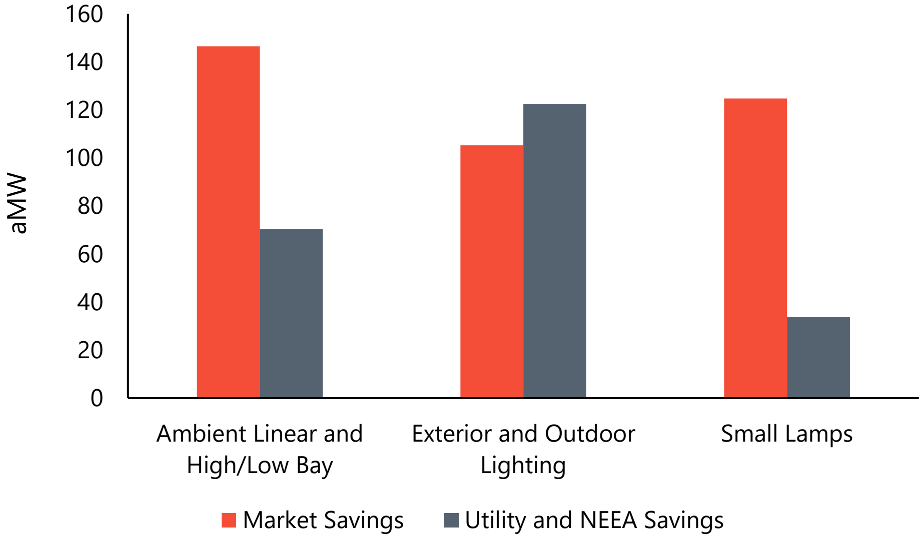
[4] BPA established the 42% allocation of regional Momentum Savings in its Energy Efficiency Action Plan: https://www.bpa.gov/EE/Policy/EEPlan/Documents/BPA_Action_Plan_FINAL_20120301.pdf. The plan states: "BPA has taken responsibility for achieving the public power share of approximately 42% of savings."

Figure 12: Comparison of Market and Program Savings: 2010-2015



Leveraging the Model to Examine Current Practice Baselines

In addition to estimating Momentum Savings, the research team utilized the regional non-residential lighting model to calculate current practice baselines for non-residential lighting measures. The team aligned its baseline methodology with the Regional Technical Forum's (RTF's) provisional Standard Protocol for Non-Residential Lighting Retrofits,[5] using this protocol as a basis to examine how the regional lighting model could inform baseline calculations. This analysis took two perspectives: 1) comparing the RTF's application-level current practice baseline efficacies to those calculated in the model, and 2) applying the RTF methodology, combined with data from the model and other sources, to calculate baseline wattages for measures currently incented through midstream programs.[6]

The RTF's current practice baseline efficacies are expressed at the application level, using similar applications to those used in BPA's regional lighting model. This allowed the research team to compare the 2015 current practice efficacies calculated by the regional lighting model with those utilized in the RTF standard protocol.[7]

The regional lighting model calculates current practice efficacies by estimating the sales mix of technologies within each application and applying a representative efficacy for each technology. The correct baseline for a given measure depends on whether a lamp or a fixture is being replaced, the application or building type, and how the measure is incented (i.e., is it a midstream measure or a custom measure?). These scenarios are presented in Section E. Slide-Doc Describing Non-Residential Lighting

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[5] RTF Non-Residential Lighting Retrofits Standard Protocol, Version 2.4, and Calculator version 2.4. https://rtf.nwcouncil.org/standard-protocol/non-residential-lighting-retrofits

[6] Lighting To Go is a midstream commercial lighting incentive program that offers instant discounts on efficient lighting products through participating distributors. Multiple Pacific Northwest utilities, including Snohomish PUD, implement this program. As an information resource for its customer utilities, BPA and the research team applied the baseline analysis to the measures currently offered through Lighting To Go.

[7] The comparison used 2015 data because this is the baseline year for the Northwest Power and Conservation Council's Seventh Power Plan.

Baseline Categories and Values of the Research Portfolio, which provides detailed results of the team's baseline analysis. Table 3 illustrates the inputs to this calculation for one application.

Table 3: Ambient Linear Application Market Shares and Efficacies (Fixture Basis)

	25W T8	28W T8	32W T8	LED Luminaire	T12	T5SO	TLED	Total
Market Share	3%	13%	62%	5%	9%	2%	6%	**100%**
Efficacy (lumens/W)	87	91	92	92	58	91	112	**88**

Note: The research team calculated weighted average efficacy as total lumens divided by total watts.

The research team's analysis revealed minor differences between the outputs of the BPA regional lighting model and the RTF's assumptions—in most cases, the regional lighting model produced slightly lower current practice efficacies. The RTF's standard protocol applies a dual baseline corresponding to the remaining useful life (RUL) of the existing lighting equipment, with current practice baselines applied only for the second savings period, or the post-RUL period. If the RTF adopted the regional lighting model's efficacies (or one of its drivers, such as technology market shares), the result would likely be:

- Increased first-year and lifetime savings for measures with zero RUL (e.g., general service lamps and reflector lamps)
- Increased lifetime savings for measures where savings for the RUL period are based on the pre-condition baseline

Model Reliability

The regional lighting model was developed with the best available data, and thus has both strengths and weaknesses, which the research team highlights in Table 4. Section D. Report on Data Collection Activities to Improve the Model in the Research Portfolio provides additional detail on future data collection efforts that could strengthen model validity.

The model leverages the available data for both stock and sales despite some disconnects between these data sources. The uncertainty around each input source makes divergence of results from raw inputs inevitable. For example, the relatively high sales shares of LED lamps in the regional sales data and turnover dynamics of the screw-in lamp applications lead to higher end-of-year 2013 LED lamp stock saturation than found in the 2014 Commercial Building Stock Assessment (CBSA), while outdoor LED fixture sales estimates lead to lower stock penetration of LED street lights than other sources indicate. Future data—such as the next CBSA study and more extensive sales data collection—will provide a valuable check for these results and will inform whether the next iteration of this model will need to adjust turnover, stock, or sales inputs.

Table 4: Regional Lighting Model Strengths and Weaknesses

Strengths	Weaknesses
Built bottom-up with Pacific Northwest-specific data. The commercial and outdoor stock forecasts come from the Council's Seventh Power Plan (Seventh Plan); the commercial lighting stock information comes from the CBSA; and the market data is all from regional distributors and retailers. The research team also leveraged the CBSA hours of use assumptions.	**Backcast base year.** The lack of reliable market data before 2010 required the research team to backcast technology trends to determine the technology mix for 2009. This means that the stock and sales technology mixes in this year are more uncertain than in 2010-2015. If this model is used to estimate Momentum Savings in the Seventh Plan period, this weakness will be resolved as the data leading up to 2015 is robust for both stock and sales.
Broad scope. Combining detailed data from the commercial, industrial, and outdoor sectors was a significant undertaking and allows the region to better understand the relative size of these sectors as well as how trends may differ across and within them.	**Result validity declines for some granular results.** The research team focused on calibrating the model sales and stock estimates for the largest applications that drive overall results. The results for smaller applications, at the submarket level and within the industrial sector, are more uncertain.
Versatility. The richness of the available regional data allowed the research team to segment the model by year, application, technology, and sector. As a result, the model can provide guidance for a wide variety of research and program planning objectives.	**Lack of exterior and outdoor data may underestimate size of these applications.** The research team believes that the CBSA sampling methodology for some exterior lighting types likely underrepresents the size of these applications. Thus, the model savings for these applications may be conservative.
Easily updatable, with many options for improvements. The research team designed the model as a long-term regional resource. The incremental effort to update the model with more recent data and further explore the lighting market is relatively low. As noted below, the Analytica modeling platform also leaves the door open for additional uncertainty analysis.	**Program savings are highly uncertain.** The research team had little detailed data on the mix of technologies and applications in programs. This lack of data led to numerous assumptions about technology and application mixes over time, inputs that directly affect the magnitude of program savings in each application.
Forecasting capability. The model can estimate sales and stock dynamics into the future, giving researchers the opportunity to explore the effects of changing sales and stock mixes on market size and remaining efficiency potential.	**Statistical uncertainty.** The research team did not conduct statistical uncertainty analysis due to the large number of inputs and the complexity of the modeling process. However, the team did develop a sensitivity analysis in the model to allow users to assess how sensitive the model results are to variations in a specific input. Additionally, the model platform, Analytica, is capable of statistical uncertainty analysis should BPA choose to pursue this in future research.

Market Intelligence

In developing the regional lighting model, the research team collected both quantitative and qualitative market data that informed the model's structure, assumptions, and inputs. This foundational information also revealed insights into the evolution of the non-residential lighting market in the Pacific Northwest region. This section summarizes the team's market intelligence learnings. Greater detail can be found in Section A. Aggregated Report of Market Results and Section F. Market Actor Interview Findings Memo of the Research Portfolio.

The non-residential lighting market continues to change. Lighting supply chains are evolving to meet customer demands—from new manufacturers to downstream distributors, everyone is striving to find innovative ways to serve customers now as well as into the future.

LED Market Maturing

LEDs have joined the non-residential lighting mainstream—at least from a manufacturing perspective. While LED products remain a minority in the total pool of per-unit lighting sales, market actors reported through interviews that the industry has shifted its focus away from legacy technologies (incandescent, fluorescent, and HID bulbs) to longer-lasting LED solutions. This shift in focus means manufacturers are consolidating their legacy product lines (i.e., inefficient technologies) and expanding their LED offerings.

Major lighting manufacturers are consolidating legacy lighting product lines by reducing the variety of offerings. They continue to manufacture legacy products to meet the maintenance needs of their customers, but they see the market shifting toward LEDs as the preferred technology and want to be on the forefront of that trend. Over time, this will hasten the market's transition to LEDs, as even reluctant consumers will have fewer legacy direct-replacement options.

Coinciding with the reduction in legacy lighting options, manufacturers are also expanding their LED offerings. Interviewed manufacturers said that their research and development (R&D) funds are now almost exclusively focused on LED lighting solutions. Previously, manufacturers aimed their LED R&D investments at increasing efficacy and reliability; now, however, emphasis has shifted to include entire lighting applications and systems solutions. Market actors described three specific LED product evolutions resulting from these market shifts: niche applications; good, better, best product lineups; and in-field application performance.

LEDs for niche applications: Five or so years ago, manufacturers were racing to enter specialized LED spaces to offer name brand options for products serving niche applications, such as explosion-proof fixtures for hazardous environments. Today, manufacturers are focusing on offering more diverse options for specialized bulb applications, including enhanced dimmability and integrated controls.

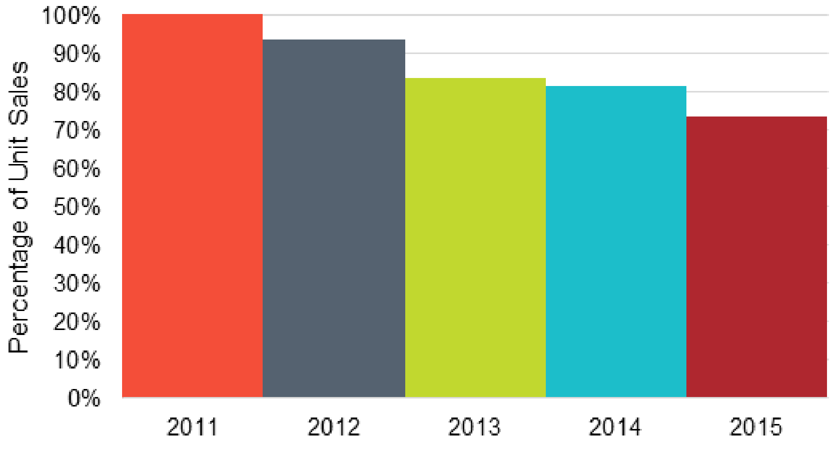
Good, better, best product lineups: In addition to new LED product types, the range of quality and complexity of LEDs is also expanding. Manufacturers now offer good, better, best options at a variety of price points to overcome the first cost barriers of LEDs. This is evident when upgrading linear fluorescent lamps and fixtures, for example. The low-cost good option involves simply switching out a fluorescent lamp for a tubular LED (TLED) lamp. A better option is an LED linear fixture retrofit kit, which utilizes the existing fixture housing and replaces the innards with a hardwired, LED light source. Finally, the best option is an entirely new LED fixture designed to optimize the LED light source and that could include an integrated controls feature.

In-field application performance: The lighting industry has also raised the bar on LED quality over the past several years, especially for application performance (i.e., proper lighting performance for a given application). Building on lessons learned from early LED street lighting technologies, the industry improved the quality of features such as directionality and efficacy; it also improved communication to consumers as to why these features are important. Several early adopters of LED street lighting, for example, were unaware of these features and chose poor quality options—such as improper optics—that led to lamps only lighting the area directly beneath the fixture. The lack of warmer color temperature options also led to unhappy residents complaining about bright blue LED light that caused glare and looked unattractive. Manufacturers learned from these negative experiences and are now producing much better LED lamps by keeping the application performance concept in mind.

Non-Residential Lighting Sales Trends

Efficient lighting is on the rise in the non-residential sector, from LEDs to high performance linear fluorescents. These efficient lamps save significant amounts of energy per bulb and have much longer lifetimes than their inefficient counterparts. For example, many LEDs now have a rated life of 50,000 hours, while the norm for a replaced HID product is only 20,000 hours. This is a major bonus for consumers from a cost standpoint because the high efficiency options reduce maintenance costs (the need to replace lamps every couple of years) and reduce the need to purchase replacement lamps as often. To emphasize this decline in unit sales over the past five years, Figure 13 shows reported sales in 2015 were 74% of those reported in 2011.

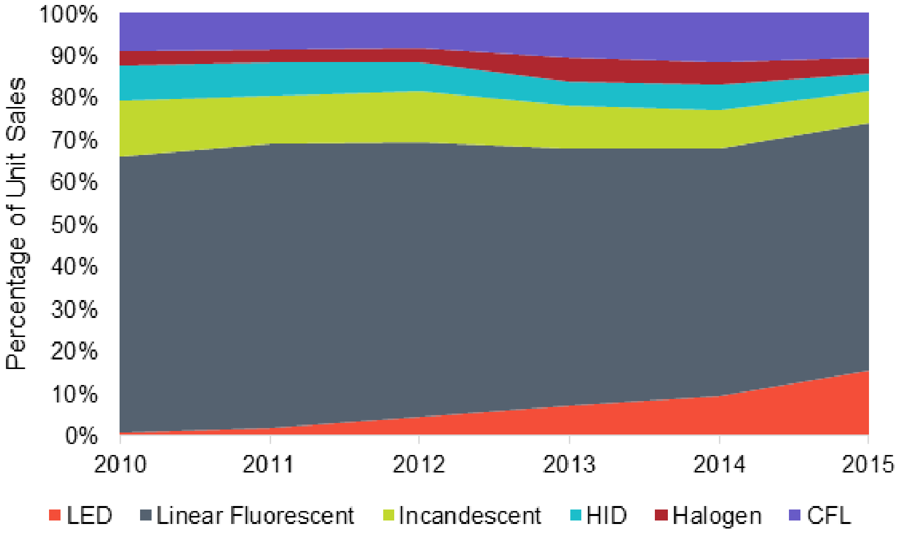
Figure 13: Non-Residential Lighting Sales as a Percentage of 2011 Sales: 2011-2015



Source: Analysis of distributor sales data based on a constant number of distributors reporting data over the study period.

The research team identified this shift toward efficient products in the collected sales data for all major product categories. The most notable and widely known change was the increase in LED sales, both in terms of unit sales and LED sales as a share of total unit sales. Figure 14 shows the growth of the LED share of total unit sales over the six years of the study period from nearly zero in 2010 to approximately 15% of unit sales in 2015.

Figure 14: Unit Sales by Technology Type: 2010-2015



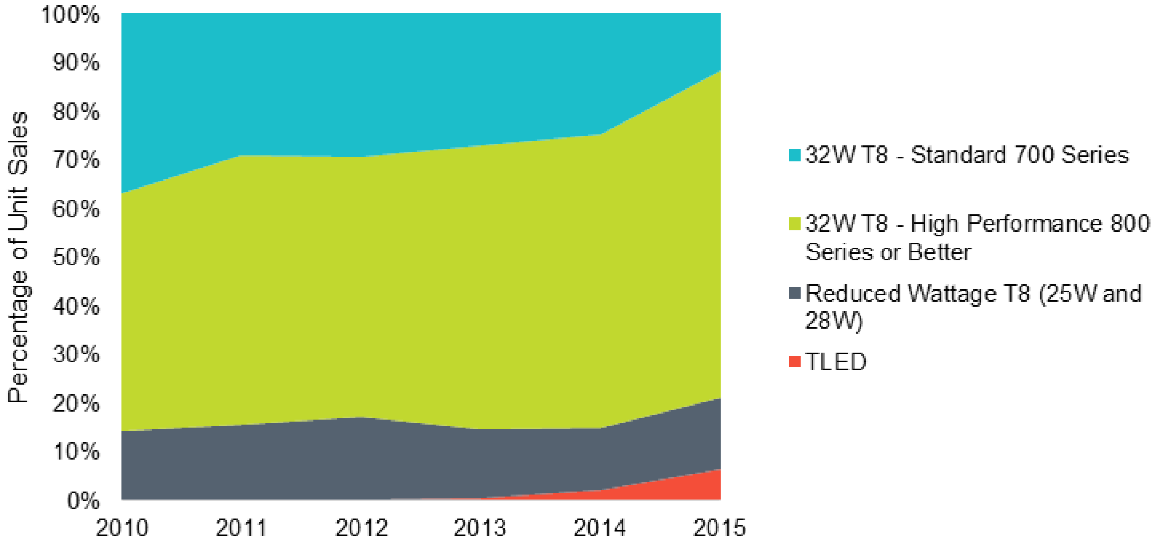
Source: Analysis of distributor sales data

LED sales grew in several product categories during the study period, including reflectors, downlights, and fixtures. From 2014 to 2015, reported LED fixture sales more than doubled, indicating fast growth in a category displacing multiple legacy products.

Figure 14 also shows that linear fluorescent lamps are still the leading technology in terms of unit sales—nearly 59% of unit sales in 2015 were linear fluorescent products. However, the linear fluorescent category has also seen substantial changes over the study period, most notably shifting markedly toward higher efficiency product options.

Figure 15 shows the trends for the most common lamp type in the linear category, the 4-foot T8 lamp.

Figure 15: 4-Foot T8 and Equivalent Linear Lamp Sales by Type: 2010-2015



Source: Analysis of distributor sales data

Two key changes occurred over the study period: a decreasing share of the less efficient 700-series T8 and the advent of the TLED as a T8 replacement. The 32W high performance 800 series linear fluorescent was the leading product type in this category in 2015, accounting for 67% of 4-foot linear lamp sales. TLEDs only accounted for a small portion of sales in 2015, but the pace of their growth increased rapidly with reported unit sales nearly tripling from 2014 to 2015.

As lighting sales shift toward higher efficiency products, less efficient product sales are declining. A key example of this trend involves HID products. HID lighting has traditionally been the norm in many outdoor and high bay applications; however, over the study period, sales showed a steady decline in this product type. This indicates that customers are retrofitting their HID lighting and choosing other technologies—namely high efficiency fluorescents (T8 or high output T5 lamps) and LEDs.

Lighting Market Actors Adapt

The decline in overall non-residential sector lighting sales (as shown in Figure 13) may be beneficial for the end-use customer, but it is not great news for lighting manufacturers and other market actors. The research team's market actor interviews found that some market actors see this decline as an existential threat— distributors sometimes use the term "illumageddon" to describe the bleak sales picture they see for the future. What this really means, however, is that these trends are forcing contractors and distributors to change their business models to keep up with the new opportunities in the market.

The shrinking market for maintenance, repair, and operations—i.e., the sales of replacement bulbs—has opened the door for innovations in total lighting solutions that many opportunistic actors are capitalizing on. The research team identified four such opportunities, including:

- **Consultative sales approaches.** In response to competition and lighting technology's increasing complexity, distributors, manufacturer representatives, and contractors are moving toward consultative, sophisticated sales strategies. They are getting involved in aspects of the sale they may not have participated in traditionally, including conducting payback analysis and offering design consultation. Those taking this approach reported that these additional roles have increased their ability to make a sale in a competitive marketplace.

- **Online sales.** Many established distributors and retailers, as well as new market entrants, are expanding their online sales capabilities. These distributors can now offer their customers—typically electrical contractors—direct shipping of products ordered online. This development challenges the notion that the distributor's role is solely geographical. Indeed, with online ordering and shipping options, geographic proximity is less important than ever. Manufacturers are also beginning to offer direct online shipping. However, many distributors see the online trend as a negative outcome because they traditionally vetted products for quality.
- **Lighting loaded with features.** Manufacturers are hoping to counteract the slowing sales trends by offering new innovations and total lighting solutions. One area many market actors are particularly excited about is controls. Some companies see advanced lighting controls as a gateway to the Internet of Things, where sensors in fixtures are able capture non-lighting-specific data such as customer behavior in retail stores, monitor the location of equipment in schools and hospitals, or control building systems like HVAC and security.
- **Lighting as a service.** Distributors and contractors are adding service packages wherever they can. These contracts allow the market actor to maintain a relationship with customers, even if their lighting equipment lasts much longer than legacy technologies would have.

These four trends demonstrate the creativity that lighting businesses are bringing to a tumultuous market. Staying nimble and responding to market changes will be the key to traditional lighting businesses staying relevant.

Meeting End-Use Customer Needs

End-use customers are also reacting to changes in the lighting market. Interviews with market actors revealed three key areas where end-users are shifting their behavior: manufacturer direct sales, outdoor lighting, and industrial facilities.

Manufacturer Direct Sales

Businesses are beginning to work directly with manufacturers to implement lighting solutions at their facilities. Market actors described two ways in which this is happening:

1. Small manufacturers targeting business owners directly, circumventing distributors and looking to make direct sales
2. Large national accounts or multisite businesses making deals with manufacturers for direct sales

In the second case, the large end-user has substantial purchasing power, and the manufacturer agrees to a direct sale to keep their business. Distributors and contractors are concerned about this type of manufacturer direct marketing for a few reasons. Most importantly, it is undercutting their role in the lighting market. Distributors also say it removes their influence in recommending high quality products.

Developments in Outdoor Lighting

The outdoor lighting market—for LED lighting in particular—has evolved over the past several years to resolve many of the early problems with product and project design and continues to be important to the promotion of energy efficiency, mainly due to the size of this market. According to the Council's Seventh Plan, outdoor lighting accounts for roughly 370 aMW of energy use, or about 23% of the Seventh Plan's 2015 load forecast for commercial lighting. The Seventh Plan further characterizes the outdoor market into three segments: building exterior (accounting for 63% of outdoor lighting load), street and roadway (30%), and covered parking garages (6%). HID is still the leading technology in installed stock in all three outdoor segments, but this is changing as LED products continue to improve.

Current LED sales in the street and roadway segment show a major shift, with market actors estimating that LEDs make up 80% of lighting products sold today. This means that when street lighting owners decide to retrofit their lights, they no longer face a technology decision: they are almost certainly going to choose LED. They do, however, still face a timing decision, and in some cases, utility program incentives push owners to retrofit their lights sooner than they otherwise would have.

BPA's Option 1 lighting program activity in fiscal year 2015 (FY15), which the research team analyzed,[8] reflects the influence of these incentives on all types of outdoor lighting. The team's analysis showed that 46% of FY15 savings occurred in outdoor measures, most of which (83% of kilowatt-hour savings) involved upgrading existing HID lighting to LEDs.

Energy Efficient Lighting for Industrial Facilities

Developing new and improved LED products for niche applications means industrial facilities have more energy efficient lighting options than ever before. While industrial facilities have the potential to be a fertile ground for adopting high efficiency lighting products, market actors described two different approaches industrial end-users take when it comes to lighting:

- Some facilities see investment in lighting upgrades as detracting from their main focus: production. Dedicating capital or maintenance budget to lighting means that funding cannot go toward production line investments. Furthermore, lighting upgrades often require shutting down production during installation, forcing facility managers and owners to avoid these projects until absolutely necessary.
- Conversely, some industrial end-users see lighting upgrades as an opportunity to boost production. In some cases, they invest in lighting upgrades because they want to reduce the need for lighting maintenance, preventing future interruptions to production and eliminating maintenance costs. Some facility owners want to increase the light levels on the production floor, which allows for improvements in safety and quality of production.

These differing approaches highlight the need for continued customer engagement and education about the benefits of high efficiency lighting.

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[8] BPA's program calculator does not identify outdoor lighting as a sector, so the research team mapped the individual measures associated with exterior or outdoor fixtures from other sectors to identify outdoor measures.

Research Portfolio

The following sections include all major deliverables submitted to BPA over the course of this project. In some cases, these deliverables may include interim analysis findings.

Table of Contents

A. Aggregated Report of Market Results

BPA published the following report in September 2016. It presents the results of the third annual BPA and NEEA Northwest Electrical Distributor Lighting Survey.

ANNUAL LIGHTING SURVEY OF

NORTHWEST ELECTRICAL DISTRIBUTORS

2015

SEPTEMBER 2016

Bonneville Power Administration
Northwest Energy Efficiency Alliance

PREPARED BY:

Navigant and Cadeo Group

REPORT HIGHLIGHTS

- LED unit sales grew by 52% from 2014 to 2015
- Linear fluorescent lamps remain the most common lamp technology, but show steady decline in unit sales
- LED growth was strongest in TLED, downlights, and fixtures
- 2015 TLED unit sales more than doubled 2014 sales
- HID unit sales continue to decline rapidly

TABLE OF CONTENTS

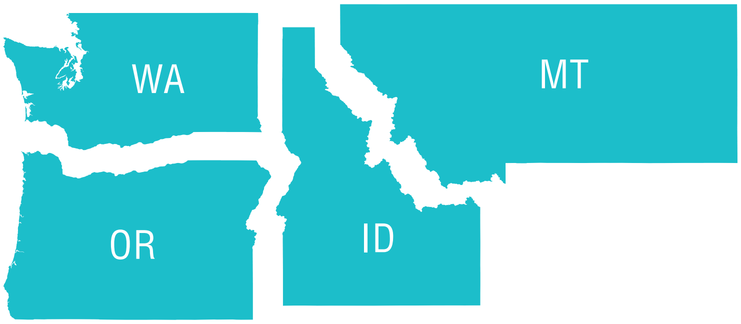
REPORT OVERVIEW

This report presents the results of the third annual BPA and NEEA Northwest Electrical Distributor Lighting Survey. The first two surveys, conducted in 2013 and 2014, analyzed lighting sales data from 2010-2014. This year's survey presents sales data for 2015, representing 29 Northwest distributors, including 14 new participants, as well as more detailed sales categories for controls and LEDs.[1] The research team estimates the total sales of these distributors represented 35 percent to 70 percent of the total Northwest non-residential distributor market, depending on the product.[2]

COMPOSITION OF PARTICIPANTS

DATA COLLECTED FROM
29 DISTRIBUTORS THIS ROUND

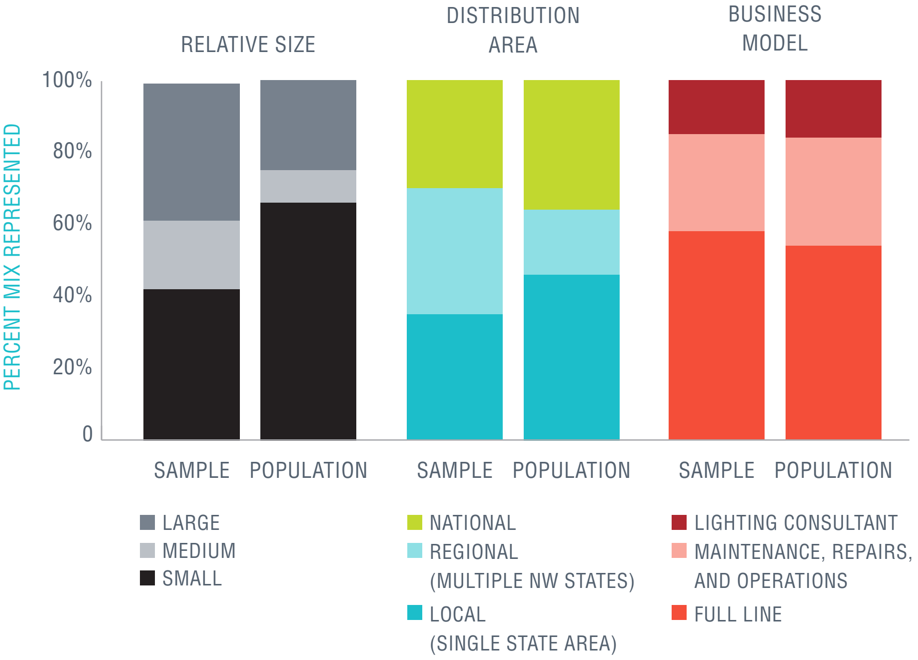
15 WEB QUESTIONNAIRE RESPONSES FROM
DISTRIBUTORS NOT PARTICIPATING IN NEEA'S
REDUCED WATTAGE PROGRAM



35-70%

ESTIMATED PERCENT OF THE TOTAL MARKET REPRESENTED BY
COLLECTED SALES DATA (VARIES BY PRODUCT)

MIX OF DISTRIBUTORS IN THE SAMPLE COMPARED TO THE POPULATION



Source: Analysis of distributor sales data

Applying lessons learned from the first two rounds of research, the team again worked with NEEA program staff, as well as BPA's Energy Efficiency Market Liaison, Evergreen Consulting Group, and lighting program managers from regional utilities. Through this coordinated effort, the team reached 29 distributors for the 2015 sales data collection, an increase from the 18 distributors included in last year's effort. The chart to the left shows the mix of participating distributors by relative size, distribution area, and business model, compared to the mix of the population of distributors in the Northwest.

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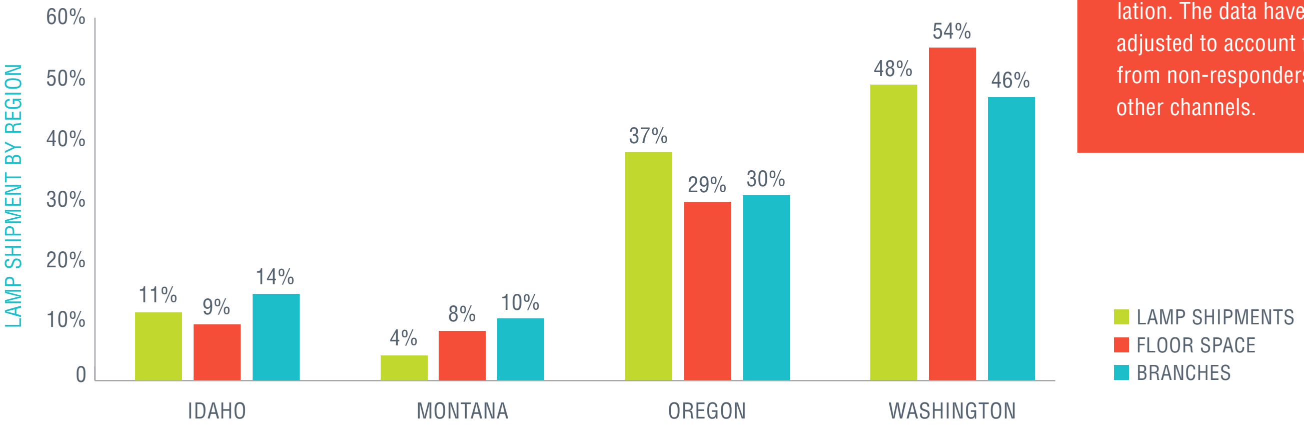
[1] A combined 18 unique distributors provided data in the previous two surveys, representing sales from 2010 through 2014. In this year's study 14 new distributors provided data, in most cases submitting sales data dating back to 2013, and 12 of last year's participants provided updated sales data through 2015. This report reflects data from a combined 34 unique distributors that have provided data in the three surveys.

[2] Total non-residential lighting sales in the Northwest were calculated by scaling national sales data estimates to the Northwest region based on commercial floor space.

The chart below shows lamp shipments by state, along with shares of total commercial floor space and known distributor branch locations by state for context. Relative to commercial floor space, sales quantity appears to be largely representative of the region with the majority of sales going to Washington (48%) and Oregon (37%).

This report characterizes the sales data as estimated totals and market averages. These "estimated" values are based on actual sales data from distributors, and include a limited amount of extrapolation adjustments to account for missing data. The 2015 data is the most complete, while past years required more extrapolation. The data have not been adjusted to account for sales from non-responders and other channels.

DISTRIBUTOR LAMP SHIPMENTS, FLOOR SPACE, AND BRANCHES BY STATE, 2015

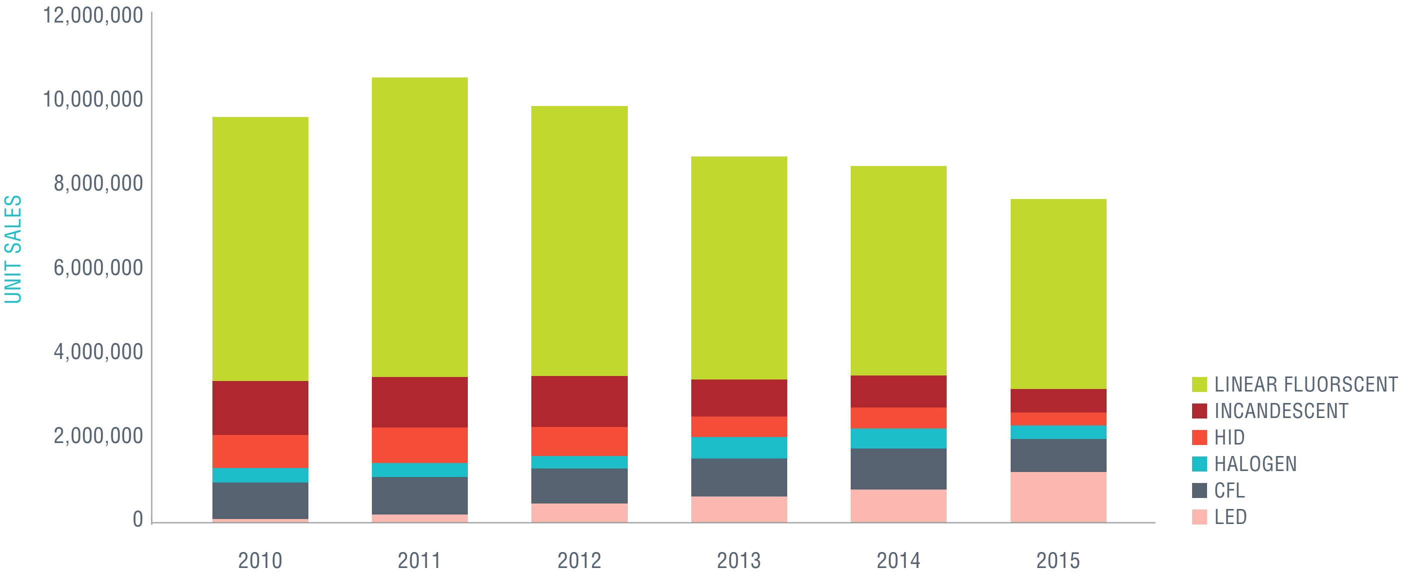


Source: Analysis of distributor sales data, total Northwest branches and square footage for all distributors

SURVEY RESULTS

Linear fluorescent lamps (LFLs), again, accounted for the majority of the sales across the Northwest non-residential lighting market in 2015. Compared to other lamp types on a per unit basis, LFLs made up 59 percent of the 2015 sales. LED sales increased rapidly from 2014 to 2015, with LEDs accounting for 15 percent of sales in 2015, up from nine percent in 2014. The chart below shows estimated total sales for reporting distributors, reflecting reported sales only, not the entire Northwest market.

ESTIMATED UNIT SALES FOR REPORTING DISTRIBUTORS BY TECHNOLOGY TYPE, 2010-2015

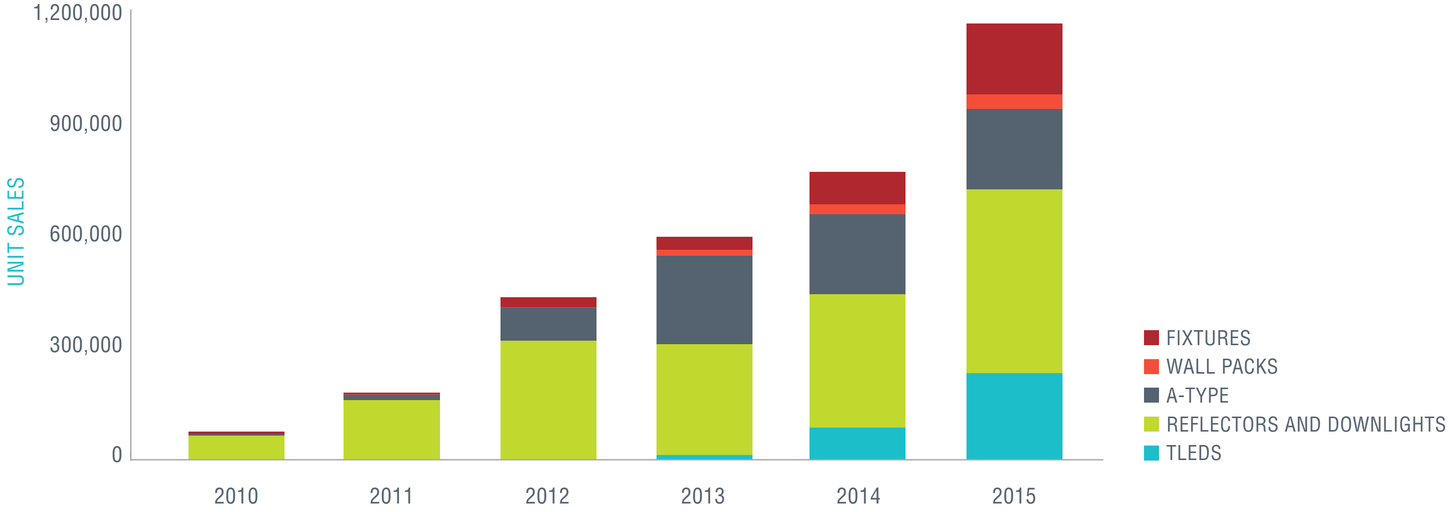


Source: Analysis of distributor sales data

LED LAMPS AND FIXTURES

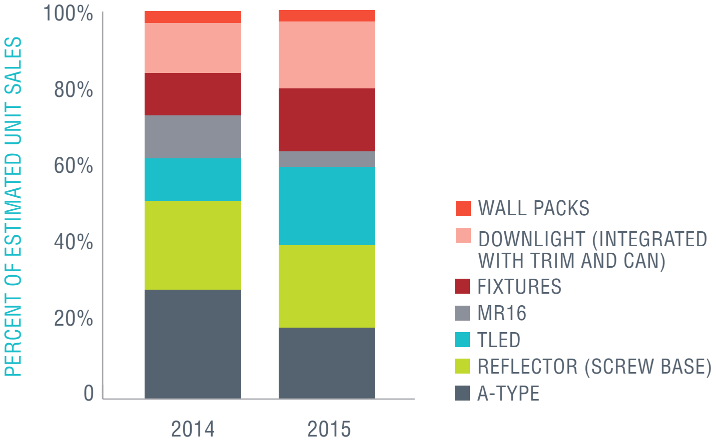
Sales of LED lamps and fixtures in the Northwest continued to boom in 2015. Estimated unit sales grew from approximately 767,000 in 2014 to 1.2 million in 2015, surpassing all other technologies except linear fluorescent. In terms of year-over-year growth in LED sales, 2015 showed the biggest gain yet. The unit sales shown below and throughout the report are estimated values based on actual sales data from distributors, including a limited amount of extrapolation adjustments to account for missing data. These values have not been adjusted for nonrespondents or other sales channels.

ESTIMATED LED UNIT SALES, 2010-2015



Source: Analysis of distributor sales data

PERCENT OF LED UNIT SALES BY PRODUCT TYPE, 2014 AND 2015



Source: Analysis of distributor sales data

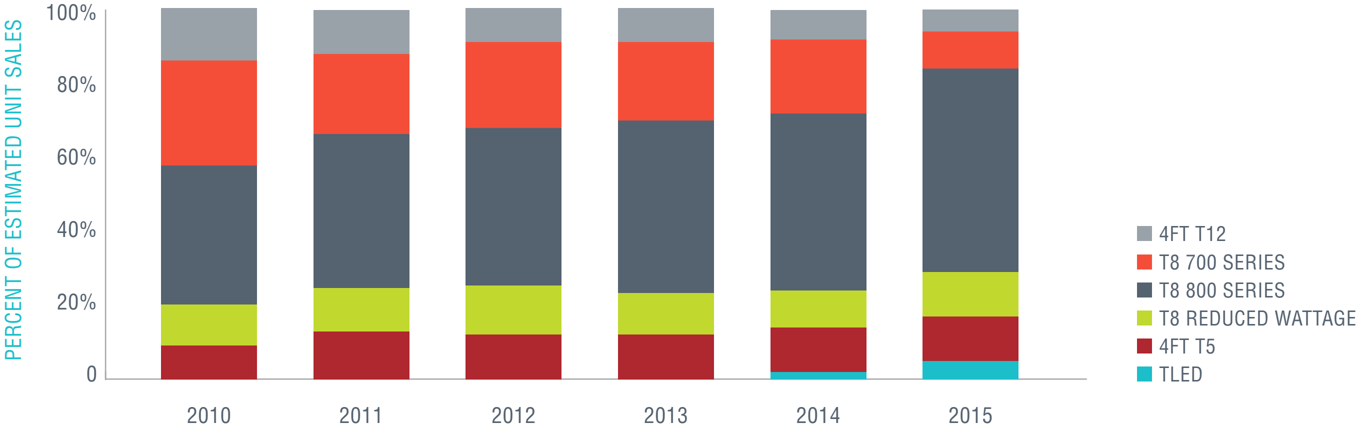
The LED market is changing quickly, and so are the LED products that comprise its sales. From 2010-2014, reflectors, downlights, and A-type lamps constituted the majority of LED sales, and these categories still accounted for 61 percent of sales in 2015. Downlights showed major growth last year, with unit sales doubling from 98,000 in 2014 to 199,000 in 2015. Another notable change was the boom in TLEDs. Distributors' 2015 sales included more TLEDs than any other single LED product category, more than doubling 2014 sales. While accounting for only a small percentage of LED sales, LED fixtures also saw continued growth with sales doubling from 2014 to 2015.

LINEAR FLUORESCENT LAMPS AND TLEDS

LFLs remain the dominant commercial lighting technology, but 2015 continued a steady decline in LFL sales. LFL categories with low efficacies, such as 700 series T8s and four-foot T12s, showed the sharpest decline, reflecting changes in the federal standards for General Service Fluorescent Lamps. A combination of 800 series 32 watt T8s and reduced wattage T8 lamps, and a smaller but growing number of TLEDs absorbed this changing market share. These changes continue a trend toward higher-efficiency lighting across the Northwest. However, the dominance of the 32-Watt T8 remains a significant opportunity to shift toward energy-saving options such as reduced wattage lamps, TLEDs, and LED fixtures.

While TLED sales boomed in 2015, TLEDs still account for only a small portion of linear lamp sales, making up 5 percent of total linear lamp sales (including LFL and TLED). Simultaneously, reduced wattage (25W and 28W) T8 lamps showed a sales boost in 2015, with a 12 percent increase in unit sales over 2014.

ESTIMATED LINEAR LAMP UNIT SALES BY TYPE, 2010-2015

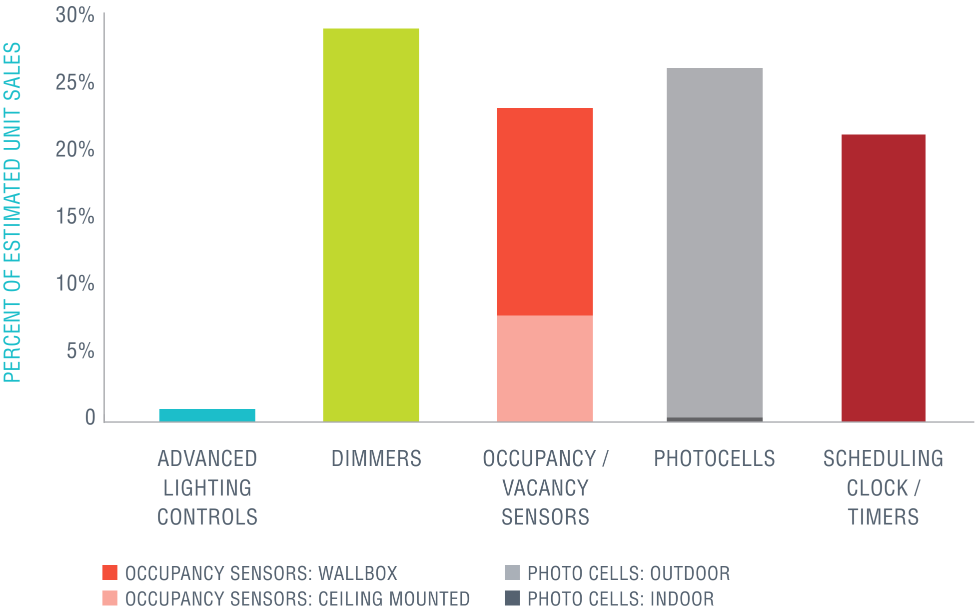


Source: Analysis of distributor sales data

LIGHTING CONTROLS

The survey data on lighting controls showed that dimmers and outdoor photocells were the most common types of control product sold. The adjacent graph combines sales from 2013-2015, because only some distributors reported controls sales. During this time period, dimmers, photocells, occupancy sensors, and timers made up the vast majority of lighting controls sales. A smaller number of advanced controls products were sold, and market actors expect these products to see increased sales in coming years.

LIGHTING CONTROLS UNIT SALES, 2013-2015



Source: Analysis of distributor sales data

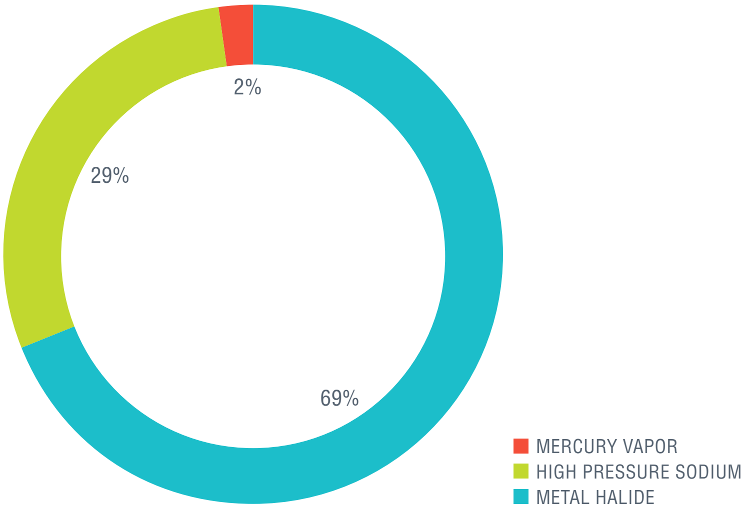
HIGH INTENSITY DISCHARGE LAMPS

The decline in HID lamp sales continued in 2015. Distributors reported HID lamp sales in the Northwest region dropped from over 800,000 unit sales in 2011 to 300,000 units in 2015. This also represents a decline in HID share relative to other technologies. Some of the decrease likely reflects the strong adoption of LED lamps in outdoor lighting in recent years.

Metal halide sales remain the top choice in the HID market with an estimated average market share of 69 percent of all HID sales in 2015.

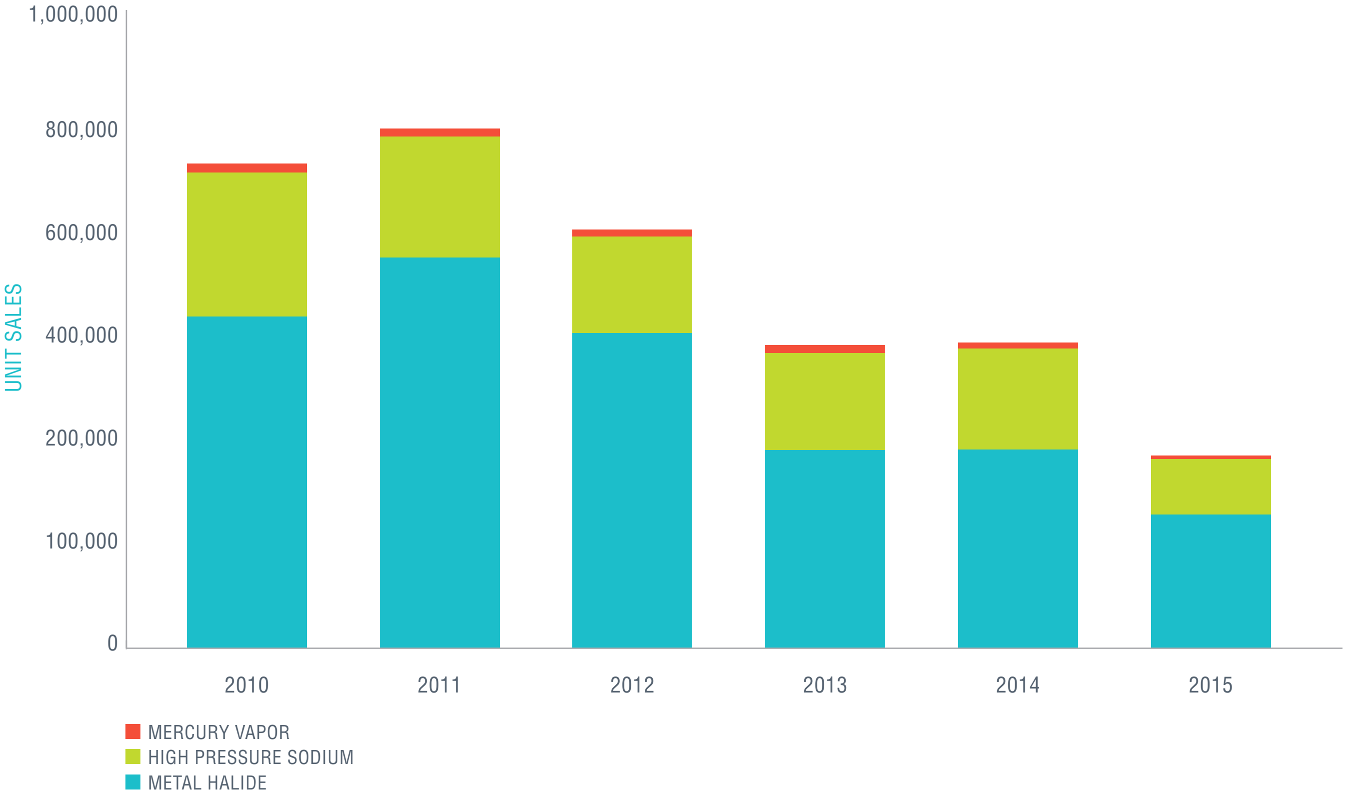
Mercury vapor lamps, banned by the federal government in 2009, continue to have an estimated average market share of less than two percent of HID sales.

ESTIMATED HID UNIT SALES BY TYPE, 2015



Source: Analysis of distributor sales data

ESTIMATED HID UNIT SALES BY TYPE, 2010-2015



Source: Analysis of distributor sales data

CONTACT

This survey is intended to help utilities with their understanding of the non-residential lighting marketplace and to provide electrical distributors with data useful for business planning. The team welcomes feedback on the data presented in this report. Please direct questions and comments to:

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B. Memo Describing Gaps in Sales Data

This memorandum, submitted to BPA on September 16, 2016, summarizes the distributor sales data collection and analysis process and what gaps remain in the sales data.

Memorandum

To: Jessica Aiona and Carrie Cobb, Bonneville Power Administration (BPA)

From: Laura Tabor, Ariel Esposito, Navigant Consulting, Inc.; Kate Bushman, Katie Arquiette, Cadeo

Date: September 16, 2016

Subject: Non-Residential Lighting Distributor Sales Data Gaps

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This memorandum describes the process the Navigant and Cadeo team (the research team) used to collect and analyze distributor sales data for the non-residential lighting market in the Northwest. The content is organized in the following sections:

- Data Summary
- Outreach and Data Collection Process
- Data Cleaning and Aggregation Process
- Assessing and Addressing Data Gaps
- Representativeness and Weighting Analysis

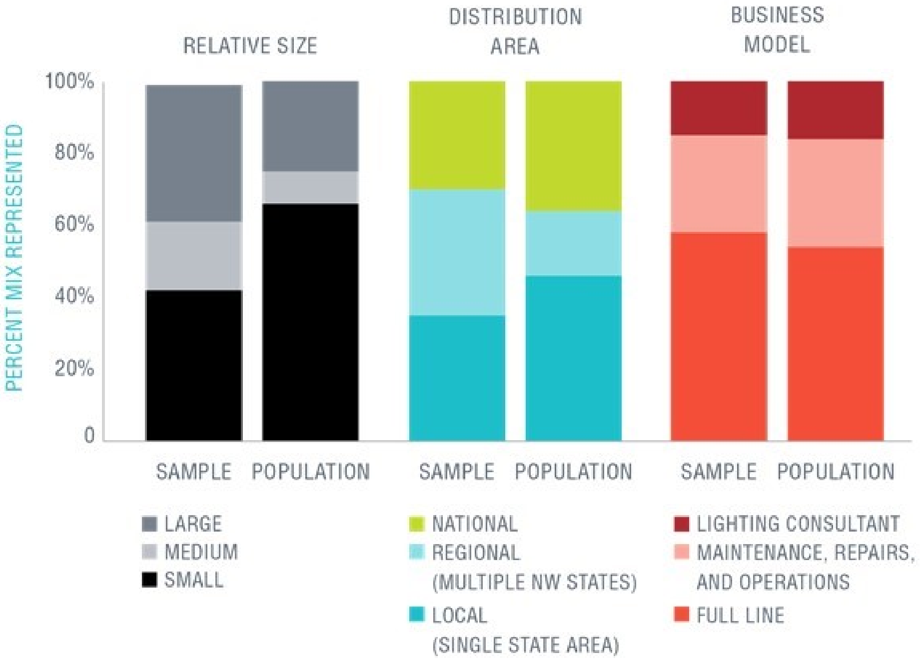
This document also includes two appendices that provide a summary of database organization, historic mapping tables, and detailed descriptions of the raw data cleaning.

Data Summary

A total of 29 distributors submitted data to the research team in 2016. Figure 1 shows the mix of participating distributors by relative size, distribution area, and business model compared to the distributor population mix in the Northwest. These distributors represented the following:

- A larger portion of large and medium distributors than small distributors relative to the population
- A slightly larger portion of regional distributors than national and local distributors relative to the population
- A representative mix of business models

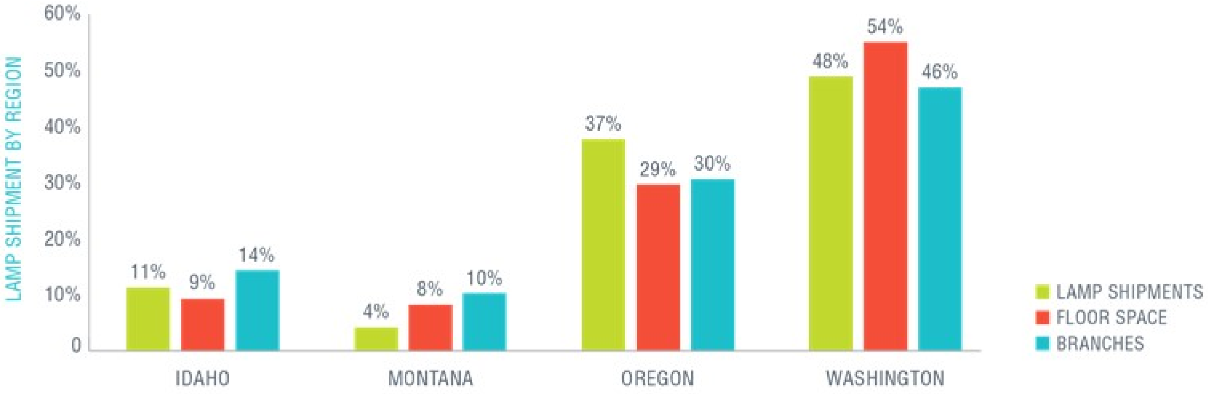
Figure 1: Mix of Distributors Submitting Data Compared to the Northwest Distributor Population



Source: Team analysis of distributor interviews and online research as compiled in 2016 distributor database

Figure 2 shows lamp shipments by state along with state shares of total commercial floor space and known distributor branch locations by state for context. Relative to commercial floor space, sales quantity appears to be largely representative of the region, with the majority of sales going to Washington (48%) and Oregon (37%).

Figure 2: Distributor Lamp Shipments, Floor Space, and Branches by State: 2015



Source: Distributor sales data analysis, Commercial Building Stock Assessment (CBSA) floor space by state, and 2016 distributor database

The research team observed the following strengths and weaknesses of this year's dataset.

- **Data strengths:**
  - **Record participation**. The 2015-2016 data collection effort yielded a new high of 29 distributors submitting sales data, up from 18 last year. A total of 34 unique distributors have now provided data for at least one of the three surveys conducted since 2012.
  - **Improved data quality.** More distributors than ever before submitted sales in all technology categories, improving the data's accuracy with respect to the mix of technologies in total non-residential sales.
  - **Enhanced data analysis.** The team improved the process for extrapolating and interpolating sales data for distributors that did not submit data for all years or categories. This makes year-over-year comparisons more accurate.
- **Data weaknesses:**
  - **Missing data and inconsistent granularity.** The research team needed to aggregate certain technology categories due to data gaps and varying levels of granularity provided by distributors. Specifically, data gaps and lack of granularity in the 2010-2012 data limited full use of 2013-2015 data for 2010-2015 comparisons. For example, while the team collected new categories such as CFL A-type in the most recent survey, this data exists for three years for new participants and one year for prior participants. This weakness—which mostly affects results around CFL, incandescent, and halogen products—will subside once Bonneville Power Administration (BPA) transitions to analyzing the Seventh Power Plan period, as all data for that period will use the new full categories. Table 1 shows the percentage of data in each technology group and year for which the team extrapolated the data from reported sales. The number of distributors reporting full sales has increased over time, leading to less extrapolation in recent years.

Table 1: Percentage of Data Extrapolated by Year and Technology

Technology	2010	2011	2012	2013	2014	2015	All Years
CFL	70%	61%	61%	27%	8%	3%	38%
Halogen	63%	62%	62%	36%	17%	1%	39%
HID	8%	8%	8%	28%	28%	6%	13%
Incandescent	69%	68%	70%	20%	8%	2%	47%
LED	43%	37%	34%	18%	9%	16%	19%
Linear Fluorescent	21%	21%	20%	14%	6%	5%	15%
Total	**33%**	**30%**	**31%**	**18%**	**9%**	**6%**	**22%**

Source: Distributor sales data analysis

  - **Relative magnitude of non-traditional channels remains unclear.** While the survey includes a new online retailer participant, limited quantitative information exists regarding the relative size of online and direct-to-customer sales. Investigating sales to the market outside of regional distirbtors would improve our understanding of the total market.
  - **Uncertainty in self-reported data.** The research team observed several instances of distributors reporting different totals between the BPA survey and the Northwest Energy Efficiency Alliance's (NEEA's) Reduced Wattage Lamp Replacement (RWLR) initiative for

overlapping products. Some other distributors who submitted data in multiple formats over their years of participation have also shown inconsistency in sales that could be due to reporting errors.

  - **Extrapolation assumes constant market share.** To estimate the total unit sales across technology types, the research team extrapolated sales to fill gaps in distributors' reporting for individual years and technologies. The team assumed that distributors' market share remains relatively constant over the years for a given technology group—a necessary simplifying assumption for this analysis to remain feasible. However, businesses change over time and this approach may under- or over-state sales for individual companies whose market share is growing or declining relative to their competition.

Outreach and Data Collection Process

Applying lessons learned from the first two rounds of non-residential lighting sales data collection, the research team developed a more coordinated approach to distributor outreach for the 2015 data collection process. BPA's addition of an Energy Efficiency Market Research Liaison (BPA Liaison) was a significant driver in enabling the research team to increase the level of regional coordination in distributor outreach. This regional coordination included contributions from several partners:

- NEEA's RWLR Initiative
- Evergreen Consulting Group
- Lighting program managers from the following regional utilities:
  - Puget Sound Energy
  - Snohomish County Public Utility District (PUD)
  - Tacoma Power
  - Idaho Power
- BPA Energy Efficiency Program Staff

These partners, led by the BPA Liaison and with assistance from the research team, made up the Outreach team. The Outreach team's goals included coordinating regional outreach, leveraging existing relationships, and enlisting trusted messengers to engage distributors in contributing to Momentum Savings research. The research team sought involvement from additional utility program managers, but not all were able to commit to the Outreach team's weekly meetings and outreach plan.

The Outreach team's goal was to build trust with distributors by keeping all members aware of ongoing data collection efforts and avoiding multiple touchpoints on distributors. A summary of the Outreach team's outreach strategy follows:

1. A Outreach team member contacted each assigned distributor and asked them to participate, giving them an FAQ/information packet.
2. If the distributor agreed to participate, the Outreach team member handed over communication to the research team. In instances where distributors had questions or concerns regarding participation, the BPA Liaison reached out directly. In total, the research team received:

    a. 31 handoffs from Evergreen
    b. 12 handoffs from NEEA
    c. One handoff from BPA program staff
    d. Two handoffs from utility program managers
3. The research team followed up with the distributor to provide the sales data collection form and instructions for submitting data via the Secure File Transfer Protocol (SFTP). The research team followed up with distributors, as needed via email and/or phone.
4. The research team logged all communication with distributors in a dashboard and noted updates to distributor information to change in the Microsoft Access distributor database.

NEEA's partnership was instrumental to the Outreach team's success. First, NEEA's RWLR program manager provided guidance on how to approach distributors, specifically recommending that the research team wait until after the end of the calendar year since many distributors are busy in November and December. Additionally, NEEA's RWLR participant distributors make up a large portion of the regional market and are critical to accurately estimating sales trends. Thus, NEEA's support and coordination with these distributors was critically important.

In addition, NEEA provided the funding which made it possible to add the expertise of Evergreen Consulting Group to the project team. Evergreen was an extremely effective partner and provided more than 10 new participants through their contacts across the region.

Final Outreach Disposition and Results

Table 2 provides details on the final disposition for the distributors included in the team's outreach.

Table 2: Summary of Distributor Outreach: Final Disposition

Category	Number of Distributors
Total distributors included in outreach*	**84**
Distributors submitting data	27**
• Repeat participants	12
• New participants	15
Distributors declining to participate	14
• Lack of time and/or interest	8
• Data reporting limitations	4
• Prohibited by company policy	2
Distributors unresponsive to outreach	43
• Initial interest but unresponsive to follow up	9
• No response to Outreach team	34

*Includes individual distributor branches that operate independently

**In addition to these 27 distributors, the team analyzed partial data from two NEEA RWLR participants that did not submit additional data through the survey.

Source: Distributor outreach tracking

As shown in Table 2, many distributors were unresponsive: 34 out of the 84 did not respond to communications from the Outreach team and an additional nine stopped responding after an initial expression of interest. Among the 14 distributors who declined to participate, the most common reason for declining was a lack of time and/or interest. These figures indicate that making initial contact with distributors is a challenge, affirming the need for continued coordinated outreach in future years.

Outreach Lessons Learned/Recommendations

- **Employ the Outreach team in future outreach efforts.** Specifically, enlist the assistance of NEEA's RWLR program manager and Evergreen's lighting specialists. These outreach partners were instrumental in increasing the number of distributors participating in this year's study.
- **Ensure that the Outreach team fully documents outreach attempts and results.** This will allow future outreach to pick up where the prior year left off. For example, in instances where Evergreen cannot reach a distributor but attempts contact, the research team should collect the contact information and the reason for not participating.
- **Begin outreach in January to increase effectiveness.** Distributors tend to be busy at the end of the calendar year (November-December).
- **Plan for a minimum of four months for the outreach and data collection process.** While the majority of distributors respond within one month, initiating contact may take weeks and many distributors required multiple follow-up communications before they submitted data.

Data Cleaning and Aggregation Process

The research team performed two levels of quality control (QC) review on incoming data submissions. First, the research team reviewed submissions within 48 hours of receipt to identify any notable data gaps that required follow-up requests to the distributor. Second, the research team reviewed the final submitted data relative to previous submissions (where applicable) and to other distributors' sales trends. In order to perform this second review, the research team aggregated all sales data into a common format in a SQL server database. This database format was new for 2016; in previous years, the research team stored data in Microsoft Excel. The following sections describe these processes.

Initial Data QC Review

The research team used a standard QC checklist to review all data submissions. The checklist covers the major areas where errors in data input are likely to occur. It also ensures the appropriate information for aggregating the data for analysis is present. A summary of the initial data QC follows.

1. **Scope of review:** The research team ensured distributors did not report sales outside of the Northwest region (Idaho, Montana,[1] Oregon, and Washington), branch information was included for datasets spanning multiple locations, and sales totals were given for both units and dollars. The team also checked that the data did not violate any data validation rules.
2. **Data gaps:** The research team reviewed all datasets, flagged any sales field that was missing data (either a "0.00" or blank cell), and, if missing data, followed up with the distributor to confirm the gap. If the distributor confirmed zero products were sold, the research team filled in zeros. However, if a product was sold but the distributor could not report it, the research team left it blank. For example, some distributors could not extract sales for controls or fixtures due to reporting system limitations.
3. **Data magnitude:** The research team also reviewed each tab to ensure the magnitude of sales for each application was reasonable and flagged any cell that could have been an error (e.g., "0.25" or "250,000,000" sales for a particular application, or an unusual increase or decrease in sales year-over-year).
4. **Data reporting:** Lastly, the research team confirmed that distributors reported all sales data in terms of individual lamps and not packages of multiple lamps.

Merging Data from Multiple Sources

Distributors submitted data in three different formats in 2015:

- Using the standardized survey form provided
- Through NEEA's RWLR initiative database (for linear fluorescent only)

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[1] The research team accepted data from all of Montana; however, the Northwest region only includes western Montana. Thus, using data from the entire state for regional analysis assumes that the sales mixes of the eastern and western portions of the data are similar.

- In raw data extracts of all sales by model number and/or product description

In order to create a comprehensive database to serve BPA’s long-term research objectives, the research team merged this data with historic data submissions from 2013 and 2014. These data span sales from 2010-2014. The following sections describe the process for creating this database and the nuances of each data source.

Creating Standardized Description Fields

The research team created five fields to organize the sales data by lamp and luminaire characteristics as shown in Table 3.

Table 3: Sales Data Fields

Field Name	Description
Lighting_Technology_Type	The technology category includes either the lighting technology type (i.e., LED, linear fluorescent, etc.) or controls.
General_Category	This field lists the lamp shape (T8, T5, A-Type, Reflector, etc.), fixture type, or type of high intensity discharge (HID) lamp (high pressure sodium, metal halide, or mercury vapor).
Subcategory	This field provides additional detail on lamp and fixture characteristics. Detail may be a specific wattage, wattage range, lumen output, or more specific lamp shape (e.g., MR16 within the “Reflectors” general category).
Dimension	Where applicable, this field provides the length or dimensions of the lamp or fixture. This field is primarily used for linear lamps and fixtures (e.g. 4-foot and 8-foot lamps).
Base_Type	This field specifies whether the product is a fixture, for lamps it indicates whether the base type is screw-in, mogul-base screw-in, or pin.

Appendix 1 provides a complete list of possible entries for these fields. Organizing the data in this structure allows users to filter and compare sales data across many dimensions. For example, users can easily view all lamps of the same shape and base type—e.g., A-type, medium screw-base lamps—across technologies to see the mix of CFL, LED, halogen, and incandescent lamps.

The SQL database also includes fields with data from distributors on the percentage of sales by state and projections of future increases and decreases in sales for each category.

Mapping Sales Survey Forms to Standardized Fields

The research team created a data import process to bring data from the Excel survey forms into SQL. Using a data extraction template worksheet created by the team, Navigant extracted all key data fields from the survey forms into a comma separated values (CSV) file. The research team then imported these CSV files directly into the SQL database. The team repeated this process for each of the returned distributor surveys.

Mapping Historic Data (2010-2014) to Standardized Fields

Each year the research team revisits the Excel-based sales survey form sent to distributors to capture any new product categories and to look for opportunities to collapse categories to ease the reporting burden. Thus, the team had to ensure that data from previous collection efforts (originally stored in Excel) mapped to the proper lamp and luminaire characteristics in the new database. (See Appendix 2 for tables summarizing this mapping and for specific cases when the category names changed in the 2015 version of the sales survey.) For the 2010-2015 analysis, the research team collapsed categories that were more detailed in the recent survey years (2013-2015) to maintain consistency with the historic data. Moving into the Seventh Power Plan period, the research team will continue to request the new level of detail for these categories and will not need to collapse them in future analyses. Thus, the team will maintain a dataset with this detail for the later survey years.

Mapping NEEA RWLR Data to Standardized Fields

NEEA's RWLR initiative collects sales data on linear fluorescent and tubular LED (TLED) lamps for all of its participating distributors. NEEA cleans this data to identify the share of 4-foot T8 lamps that are reduced wattage (25W and 28W) and standard wattage (32W). Participating distributors must submit sales data for all 4-foot T8 lamps, including T12 and T5 lamps, on a monthly basis. As NEEA's goals and data structure differ from this project's goals and data structure, the research team needed to map NEEA's data to the standardized fields in the database and, in some cases, add granularity to the data provided. The research team took the following steps in this process:

1. **Identify and eliminate products that are not linear fluorescent or TLED.** For example, some distributors also submitted sales of CFLs and metal halide lamps. The research team also removed black light lamps, gold tubes, and germicidal lamps. The team used the following fields to identify products to exclude, in the order listed:
    a. Technology type
    b. Bulb description
    c. Bulb type
2. **Standardize the naming conventions for incorporation in the SQL database.** In some cases, multiple product descriptions mapped to the same category in the SQL database. Table 3 provides an example of 15 unique combinations of the NEEA fields "Shape" and "Category" that map to U-shape lamps.

Table 4: Inconsistent Naming Convention Example: U-Shape Lamps

Shape	Category
T8-6U	T8LEDU
T8-6U	Other
U-Bent	Other
T8-1-5/8 (U-Bend)	Other
T8-1-5/8 (U-Bend)	U-Bend-T8
T8-6U	U-Bend-T8
T8-6U	32W
U-Bend	Other
T8-U	T8
T8-U	32W
T8 U-Bend	Other
T8-6U	T8-6U
T8-6U	T8
T8-U	T8LEDU
T8 U-Bend	U-Bend-T8

Source: NEEA RWLR database

3. **Review categorized lamps.** Table 4 provides examples of the classifications given to four model numbers that correspond with a single LED lamp type (with two different correlated color temperatures). In two cases, these lamps were incorrectly identified as 4-foot fluorescent lamps, and in two cases, they were correctly classified as LED U-shape lamps. The research team reviewed online manufacturer catalogs to verify correct product classification.

Table 5: Incorrect Product Categorization Example

Model Number	Description	Shape	Technology	Watts	Lumen	Length
PHIL 16.5T8/244000 IF6U		T8-6U	Fluorescent	16.5	1900	48
PHIL 16.5T8/24-4000 IF-6U		T8-6U	Fluorescent	16.5	1900	48
PHIL 16.5T8/245000 IF6U	Fluorescent - Tube - T8	T8	LED	16.5	1950/2150/290*	24
PHIL 16.5T8/24-5000 IF-6U	Fluorescent - Tube - T8	T8	LED	16.5	1950	24

*Lumen output with different ballast options

Source: NEEA RWLR database

4. **Map data to SQL data categories.** The research team used the following data to map to the SQL database linear fluorescent and TLED data categories:
    a. Lighting technology type (LED or linear fluorescent)

b. Lamp shape (T8, T5, T12, or LED tubes)

c. Lamp wattage

d. Lamp length

e. T8 series (for 4-foot or 2-foot U-shape T8 lamps between 29W and 32W: 700 series or 800 series based on color rendering index)

For any lamp where one of these fields was missing, the research team used text strings from other product fields or an online web search to fill in the missing data. Table 5 summarizes the linear fluorescent and LED categories in the SQL database.

Table 6: Standardized Data Fields for Linear Lamps

Lighting Technology Type	General Category	Dimension	Subcategory
Linear Fluorescent	T12	4 ft.	34W
Linear Fluorescent	T12	4 ft.	40W
Linear Fluorescent	T12	4 ft.	Other
Linear Fluorescent	T12	4 ft.	U-Shape
Linear Fluorescent	T8 - High Performance 800 Series or Better	4 ft.	25W
Linear Fluorescent	T8 - High Performance 800 Series or Better	4 ft.	28W
Linear Fluorescent	T8 - High Performance 800 Series or Better	4 ft.	32W
Linear Fluorescent	T8 - Standard 700 Series	4 ft.	32W
Linear Fluorescent	T8	4 ft.	Other
Linear Fluorescent	T5	4 ft.	28W
Linear Fluorescent	T5	4 ft.	54W
Linear Fluorescent	T5	4 ft.	Other
Linear Fluorescent	T12	8 ft.	Slimline
Linear Fluorescent	T12	8 ft.	High Output
Linear Fluorescent	T12	8 ft.	U-Shape
Linear Fluorescent	T8	8 ft.	Slimline
Linear Fluorescent	T8	8 ft.	High Output
Linear Fluorescent	T8	8 ft.	U-Shape
Linear Fluorescent	T12	2 ft., 3 ft.	Other
Linear Fluorescent	T8	2 ft., 3 ft.	Other
Linear Fluorescent	T5	2 ft., 3 ft.	Other
LED	LED Tubes	4 ft.	
LED	LED Tubes	3 ft.	
LED	LED Tubes	2 ft.	
LED	LED Tubes		Other

Source: Distributor sales data structure

Processing Raw Sales Data (Data Dumps) and Mapping to Standardized Fields

Three distributors did not use the Excel-based form to provide sales. The research team used a combination of SQL logic, webscraping, and manual classification to map these raw data to the SQL database categories. Lighting product descriptions and model numbers do not follow consistent formatting and often vary by manufacturer, making automated classification of products often just as time-intensive as a strictly manual approach.

The research team used SQL for the following:

1. Used existing SQL code from previous years to classify as many products as possible
2. Used SQL code to extract specific product characteristics from model number and product description fields
3. Used completed mapping from earlier data submissions to classify products included in subsequent submissions

For products that the SQL code could not easily map, the research team manually mapped products using a combination of available data fields and online model number searches.

Data Cleaning and Aggregation Lessons Learned and Recommendations

- **Maintain data quality by using a quick-turnaround QC process that ensures prompt follow-up questions to distributors on unusual data.** The research team recommends continuing this year's process. Future efforts will also have the advantage of having all historic data loaded into the database, enabling more efficient review of each data submission relative to prior years and other distributors.
- **Consider use of an online data submission form instead of Excel for future research**. This would reduce the chance of error from maintaining multiple versions of Excel survey forms and manually mapping these forms to the SQL database.
- **Avoid making raw sales data extracts the default data submission option.** Every raw data extract is unique, and it is difficult to reach economies of scale in data cleaning. Each distributor has different terminology and descriptors for each product type. While parsing code can identify some products automatically, every raw data submission ultimately requires several hours of manual QC review and product verification. While this data format can be the easiest way for some distributors to submit data, the research team does not recommend making this the default data submission option. Submission through a standardized form reduces potential for analytical errors.[2]

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[2] There is still some risk to standardized form data collection as distributors may or may not interpret category names correctly and could commit errors in their own internal queries; the standardized form option limits quality review of underlying data.

Assessing and Addressing Data Gaps

Over the past three years, BPA collected sales data from a total of 32 distributors, but not every distributor provided data for every year or technology category. Specifically, recent years of data collection are the most complete as BPA has become more successful in collecting data, and has expanded data to include sales categories which were not as prevalent in the market several years ago (for instance, some types of LEDs). The following sections describe how the research team addressed two common data gaps: limited granularity and missing years/technologies.

Limited Granularity

The limited granularity data gap occurs when a distributor provides total sales for a category but does not split that total by bulb shape or wattage. For example, a distributor could provide the total number of Incandescent A-Type lamps sold in a given year but not provide specifics on the number that were 100W, 75W, 60W, or 40W. The research team addressed this common data gap in a similar manner across all years and distributors with some slight variation due to data availability (discussed below).

The data collection process from prior years presented three cases of the limited granularity data gap. First, one distributor only reported the total lamp sales by technology type for a subset of the categories for 2013 and 2014 but had reported the split for prior years. Table 6 shows an example of reduced granularity in 2013 and 2014 where the number of sales at each relevant wattage level (e.g., 25W, 28W, 32W, other) is not specified as requested.

Table 7: Example of Incomplete Data: Reduced Granularity

	Wattage	2010	2011	2012	2013	2014
Linear Fluorescent T8- 4 ft. lamp	25W	7,000	5,000	3,000		
	28W	160,000	170,000	150,000		
	32W	50,000	55,000	60,000		
	Other	1,000	1,000	1,000		
	Total	**218,000**	**231,000**	**214,000**	**220,600**	**204,000**

Note: Example data only

Second, one distributor only reported the total lamp sales by technology type for a subset of the categories for 2010-2014. Finally, the research team could not segregate the lamps into specific bulb shapes for some of the technologies for one distributor that provided data in a data dump.

The research team calculated the split by bulb shape or wattage using the average split of the data provided by other distributors for all three cases. Where distributors provided limited data for 2010- 2014, such as within A-Type and Reflectors, the team calculated the average split for all years available. For categories where many distributors reported sales splits, the research team calculated an average split for each year of the data gap. The first approach assumes that individual distributors' sales mixes are relatively stable over time, while the second approach assumes that these detailed mixes are, on average, similar across distributors.

Missing Years and Technologies

Distributor sales data was also inconsistent in both the years provided and the technologies covered. For example, two lighting distributors submitted 2010-2012 sales data for the previous study conducted in 2014 but did not provide data for 2013-2015. The research team also did not request data from 2010-2012 for new participants in 2016 to limit the distributors' reporting burden, leaving gaps in those years for the 16 new participants. Other distributors failed to report data for all lighting categories reflected in the data request.

To assess the completeness of the data as received, the research team organized all sales data by distributor, technology, and year. The six technology groups requested were linear fluorescent (LFL), HID, LED, incandescent and halogen (INC/HAL), CFL, and controls. Table 7 shows the total number of distributors that provided sales data by category for each year.

Table 8: Number of Distributor Datasets Received by Year and Technology

Category	2010	2011	2012	2013	2014	2015
LFL	13	15	16	22	25	25
HID	13	15	16	23	26	25
LED	13	15	16	23	29	27
INC/CFL	7	7	8	22	23	25
Controls	6	6	7	21	23	22

Note: New 2016 participants submitted data as far back as 2013

Source: Distributor sales data

The research team used two approaches to enhance the robustness of the data sets.

1. **Data gaps within historic data of up to one year:** For data gaps of one year or less within previously submitted data—distributors who missed one year for one or more technologies during the 2010-2014 period—the research team kept previously calculated extrapolated data. This calculation process took place during the 2015 analysis and included two steps:

    a. The research team first computed the market shares of total reported sales for each technology category that was missing data using the distributor's market share from adjacent years. For example, if a distributor reported HID sales from 2010-2012 with an average market share of 3% but failed to report sales in 2013, the research team assumed a market share of 3% in 2013 and filled in the appropriate number of lamps accordingly.

    b. Then, the research team used the subcategory breakdown of the two most recent adjacent years for the same distributor to develop subcategory sales shares after the overall technology sales were calcualted. For example, if a distributor did not provide HID sales for 2010 but had reported HID sales from 2011-2014, the team filled the percentage breakdown of lighting subcategories in 2010 using the observed percentages from 2011 and 2012. If the distributor did not provide sales for HID for 2013 but reported sales for 2012 and 2014, the team estimated the breakdown of lighting subcategories in 2013 using the observed percentages in 2012 and 2014.

2. **Data gaps for new distributors and historic data gaps of greater than one year**: For these

data gaps, the research team used a similar process with two key differences:

a. The manual approach used to estimate market shares for missing data in the 2015 analysis was not feasible due to the larger number of distributors missing data in various years. The team developed optimization code in Analytica to calculate consistent market shares for each distributor. This optimization ensured that market shares for each year/ general technology data gap were filled with the average market share for that general technology across all years for each distributor.

b. Instead of using the distributor's mix of subcategory sales within each general category, the optimization code used the average percentage breakdown for the rest of the submitted sales within each distributor type in that year. This approach is a departure from the 2015 analysis and reduces the opportunity for bias because filling in gaps based on the overall average ensures a consistent market size without changing the market mix of the distributors who did provide data. The research team believes that this is more accurate than projecting distributor-specific trends in product mixes in a quickly changing market.

Representativeness and Weighting Analysis

The research team used three distributor business types to classify all distributors in the region in the 2015 analysis: maintenance, repair, and operations (MRO); full line; and lighting only. These different business models can lead to different sales mixes. In 2016, the team reviewed the sales data in these categories to assess whether various sales trends (e.g., the portion of sales that are LED and the portion of sales that are lamps versus fixtures) are correlated with these business models. This review led the research team to refine these three categories, splitting the lighting only category into those more like MRO distributors and a smaller category of distributor consultants, as defined below:

- **Full line (unchanged from 2015 study):**
    - Traditional electric distributors selling all general electric products, including (but not limited to) scheduled regular maintenance orders
    - Larger businesses that typically have in-house lighting and/or electrical staff
    - Lighting is usually a small portion of the overall business
- **MRO and online:**
    - Primarily serve scheduled regular maintenance orders
    - Often receive orders online or via email
    - May sell a variety of products or just lighting only
    - Tend to have higher proportion of lamps to fixtures in sales
- **Distributor consultants:**
    - Small companies with focus on energy efficiency projects
    - May only sell LED products and lighting controls

  - May sell lighting only or a variety of products

As shown earlier in Figure 1, the mix of distributor types in the population differed from the mix of distributor types that submitted data. The research team used the sales data, branch counts, and publicly available financial reports for those distributors that submitted data to estimate market shares for distributors that did not submit data. This analysis revealed that while the sample proportion of full line and MRO/online distributors was fairly representative, the size of the distributor consultant and non-distribution channels is uncertain. The research team investigated the effect of adjusting the distributor type weights to better align with the overall market share analysis, but determined that weighting the 2016 data submissions to reflect the relative presence of these three business models in the market would not improve the accuracy of the sales data, as there is too much uncertainty around non-participating distributors' market shares. All sales data represent an unweighted mix of sales reported by all participating distributors. The following sections outline possible data collection and analysis improvements that could lead to greater certainty around representativeness in future years.

Sources of Uncertainty and Research Suggestions to Improve Future Analyses

The following sections expand on uncertainties in three areas the research team identified in this year's research, in order of priority for future research:

- **Manufacturer direct sales:** The research team has heard anecdotally that as much as 10%-15% of sales could be bypassing distributors through various direct-from-manufacturer channels. The team does not yet have a reliable estimate for the size of this channel nor any data on the sales mix within it.
- **Distributor consultants:** This is likely a small segment, and the team has data from a handful of small distributors to inform the sales mix. However, the small size and number of distributors providing data to date make the size and mix of this segment uncertain relative to the MRO and full line segments.
- **MRO and full line sales:** The team believes that the distributors reporting in the full line and MRO/online distributor types are likely representative of the total sales for those distributors and represent a large share of those distributor types. Future research efforts should continue to recruit additional distributors to improve estimates of total volume and mix for these channels.

Distributor Consultants

The team believes the distributor consultant segment is much smaller than the other two based on the number of distributor consultants identified in the market and the low level of sales from those who have submitted sales data. Therefore, the research team believes this segment has a lesser impact on the overall reliability of the sales data as compared to the first two segments. Future research to confirm the relative size of this group could include interviews with known distributor consultants asking them about their competitors in order to identify any additional distributor consultants operating in the Northwest market.

Manufacturer Direct Sales

While the research team has gathered anecdotal evidence through interviews that manufacturer direct sales do occur, market actor interviews to date have provided little information about the magnitude of this channel. The team recommends prioritizing manufacturer direct sales as a research effort, focusing first on estimating the size of this channel.

From previous market actor interviews, the team learned manufacturer direct sales typically come from two sources:

- Small manufacturers, often new to the lighting industry that either have no access to traditional wholesale distribution or elect to skip the distributor to keep costs low.
- In some large projects, the customer may have the buying power to demand product straight from the manufacturer to reduce its project costs. BPA's upcoming research on national and regional accounts will be a starting point for improving understanding of this channel and may include opportunities to gather additional qualitative information about how prevalent direct sales are among large end-users.[3]

Research into the prevalence of this direct channel is difficult because manufacturers, wary of upsetting their distributor customers, sometimes do not acknowledge circumventing distributors. To get around this reticence and to investigate how often customers were demanding product straight from the manufacturer, the research team could take a sample of large projects and interview the customers to see how they procured their lamps. Three ideas for building the sample of projects include the following:

- Asking efficiency programs for a list of their 10 largest projects completed this year
- Asking manufacturer reps for a list of the largest projects they sold this year
- Asking lighting designers for a list of the largest projects they designed this year

Another option would be reviewing responses to RFPs for lighting projects at public utilities or government agencies. If the bidders are manufacturers, that is evidence of direct sales.

Lastly, the research team could interview the largest contractors and property maintenance companies in the Northwest to determine the extent to which they are purchasing directly from manufacturers.

Pending the findings of this research, the team could investigate data collection opportunities to better understand the sales mix in this market segment.

Full Line and MRO/Online Distributors

The research team identified all major distributors in each of these two segments and estimated market shares for each of these segments based on the sum of the market shares of the constituent distributors in each segment. The best way to improve the segment market share estimate is to improve the market share estimate of each individual distributor in the segment's population.

While the team collected sales data from several distributors in each segment, many distributors have not submitted sales data. However, the research team estimates there are only a handful of missing distributors that could have significant enough market share to shift the results of the current dataset. This understanding is based on several factors, including program staff or program implementer assessment, distributor assessment (in interviews) of their largest competitors, and branch counts in the

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[3] BPA completed its preliminary National Accounts research in March 2017. A presentation of the findings can be be found here: https://www.bpa.gov/EE/Utility/research-archive/Documents/Momentum-Savings-Resources/National_Accounts.pdf

region. The team sees three alternative approaches for improving its knowledge of these missing distributors through future research: successfully obtaining their sales data, interviewing the missing distributors, or gathering information from other market actors.

Successfully targeting these large missing distributors for data collection would be the most effective means to reduce the uncertainty regarding representativeness of the sales data, and this should be a priority for researchers in the next round of data collection. Obtaining sales data from all distributors in both segments would eliminate uncertainty, as no weighting would be required.

If these large missing distributors will not participate in the data collection, the research team could request interviews with questions specifically aimed at assessing their size and sales mix relative to others for whom the team does have sales data. Example questions could include the following:

- Who is your closest competitor in terms of business model and size?
- Against whom do you find yourself competing most frequently?
- What portion of your revenue comes from lighting products?

Finally, either in place of or in addition to the first two tactics, future research could include gathering information from other market actors about the missing distributors. For a direct approach, the research team could interview or survey large contractors who have relationships with the distributors of interest. More creatively, future research could survey people in the field (contractors, Evergreen staff, etc.) on the relative sizes of these distributors, perhaps even asking them to rank each distributor according to their best estimate of market size. While having no inside information on the distributors’ actual size, those surveyed may have developed an intuitive sense for how the major distributors compare in size in the Northwest.

Appendix 1: Summary of Unique Database Category Entries

The following tables summarize the possible entries for the General_Category, Dimension, Subcategory, and Base_Type fields for each lighting technology type.

Table 9: Lighting Technology Type: Linear Fluorescent

General Category	Dimension	Subcategory	Base Type
T12	4 ft.	34W	Lamp
	4 ft.	40W	Lamp
	4 ft.	U-Shape	Lamp
	4 ft.	Other	Lamp
T8 - High Performance 800 Series or Better	4 ft.	25W	Lamp
	4 ft.	28W	Lamp
	4 ft.	32W	Lamp
T8 - Standard 700 Series	4 ft.	32W	Lamp
T8	4 ft.	Other	Lamp
T5	4 ft.	28W	Lamp
	4 ft.	54W	Lamp
	4 ft.	Other	Lamp
T12	8 ft.	Slimline	Lamp
	8 ft.	High Output	Lamp
	8 ft.	U-Shape	Lamp
	8 ft.	Other	Lamp
T8	8 ft.	Slimline	Lamp
	8 ft.	High Output	Lamp
	8 ft.	U-Shape	Lamp
	8 ft.	Other	Lamp

Table 10: Lighting Technology Type: HID

General Category	Dimension	Subcategory	Base Type
Mercury Vapor		<150W	Mogul-Base Lamp
		151-249W	Mogul-Base Lamp
		250W	Mogul-Base Lamp
		400W	Mogul-Base Lamp
		>400W	Mogul-Base Lamp
		Other Wattages	Mogul-Base Lamp
High Pressure Sodium		70W	Mogul-Base Lamp
		100W-150W	Mogul-Base Lamp
		250W	Mogul-Base Lamp
		400W	Mogul-Base Lamp
		>400W	Mogul-Base Lamp
		Other Wattages	Mogul-Base Lamp
Metal Halide		<150W	Mogul-Base Lamp
		151W-249W	Mogul-Base Lamp
		250W	Mogul-Base Lamp
		400W	Mogul-Base Lamp
		>400W	Mogul-Base Lamp

Table 11: Lighting Technology Type: LED

General Category	Dimension	Subcategory	Base Type
A-Type		100W Incandescent Equivalent	Screw-Base Lamp
		75W Incandescent Equivalent	Screw-Base Lamp
		60W Incandescent Equivalent	Screw-Base Lamp
		40W Incandescent Equivalent	Screw-Base Lamp
		<40W Incandescent Equivalent*	Screw-Base Lamp
		Three-Way	Screw-Base Lamp
Reflectors		MR16	Pin-Base Lamp
		Other MR Lamps*	Pin-Base Lamp
		PAR	Screw-Base Lamp
		R/BR	Screw-Base Lamp
		Other LED Reflectors	Screw-Base Lamp
LED Downlights		PL13 Replacement	Pin-Base Lamp
		PL26 Replacement	Pin-Base Lamp
		<4-inch	Fixture
		>6-inch	Fixture
		<4-inch	Retrofit Kit
		>6-inch	Retrofit Kit

General Category	Dimension	Subcategory	Base Type
LED Tubes	4 ft.	4' Tube with Internal Driver that Wires to Existing LFL Ballast (UL Type A)	Lamp
	4 ft.	4' Tube with Internal Driver Powered Directly from Main Voltage (UL Type B)	Lamp
	4 ft.	4' Tube with Remote Driver (UL Type C)	Lamp
	4 ft.	Other (U-Bend, Plug and Play/Ballast Bypass combo, etc.)	Lamp
	4 ft.		Lamp
	3 ft.		Lamp
	2 ft.		Lamp
Other LED Linear Fixtures	2 ft. x 2 ft.	Panels	Fixture
	2 ft. x 4 ft.	Panels	Fixture
	2 ft. x 8 ft.*	Panels	Fixture
	2 ft. x 2 ft.	Troffers	Fixture
	2 ft. x 4 ft.	Troffers	Fixture
		Linear Strip Fixture (Lightbar)	Fixture
Decorative*		<5W	Screw-Base Lamp
		>5W	Screw-Base Lamp
Globe*		<5W	Screw-Base Lamp
		>5W	Screw-Base Lamp
Flood Light*		<20W	Fixture
		>20W	Fixture
LED Post-top & Bollard			Fixture
LED Area and Parking Lot Fixtures			Fixture
LED Track Head			Fixture
LED Garage Fixtures			Fixture
LED Canopy Fixtures (e.g., Gas Stations)			Fixture
LED Roadway (e.g., Cobra type)			Fixture
LED Other Form Factors			Fixture
Industrial Applications		High-bay > 15,000	Fixture
		Low-bay 5000-15,000	Fixture
		High-bay > 15,000	Mogul-Base Lamp
		Low-bay 5000-15,000	Mogul-Base Lamp

*Only received through raw data extract submissions (category not in sales survey form)

Table 12: Lighting Technology Type: Incandescent

General Category	Dimension	Subcategory	Base Type
A-Type		>100W Incandescent Equivalent*	Screw-Base Lamp
		100W Incandescent Equivalent	Screw-Base Lamp
		75W Incandescent Equivalent	Screw-Base Lamp
		60W Incandescent Equivalent	Screw-Base Lamp
		40W Incandescent Equivalent	Screw-Base Lamp
		<40W Incandescent Equivalent*	Screw-Base Lamp
		Three-Way*	Screw-Base Lamp
Reflectors		R/BR	Screw-Base Lamp
		PAR	Screw-Base Lamp
		Other Incandescent Reflectors	Screw-Base Lamp
Globe*		<60W	Screw-Base Lamp
		>60W	Screw-Base Lamp
Decorative*		<60W	Screw-Base Lamp
		>60W	Screw-Base Lamp
Flood Light*			Fixture

*Only received through raw data extract submissions (category not in sales survey form)

Table 13: Lighting Technology Type: Halogen

General Category	Dimension	Subcategory	Base Type
A-Type		>100W Incandescent Equivalent*	Screw-Base Lamp
		100W Incandescent Equivalent	Screw-Base Lamp
		75W Incandescent Equivalent	Screw-Base Lamp
		60W Incandescent Equivalent	Screw-Base Lamp
		40W Incandescent Equivalent	Screw-Base Lamp
		<40W Incandescent Equivalent*	Screw-Base Lamp
		Three-Way*	Screw-Base Lamp
Flood Light*			Fixture
Reflectors		R/BR	Screw-Base Lamp
		PAR	Screw-Base Lamp
		MR16*	Pin-Base Lamp
		Other MR Lamps*	Pin-Base Lamp
		Other Halogen Reflectors	Screw-Base Lamp
Globe*		<60W*	Screw-Base Lamp
		>60W*	Screw-Base Lamp
Decorative*		<60W*	Screw-Base Lamp
		>60W*	Screw-Base Lamp

*Only received through raw data extract submissions (category not in sales survey form)

Table 14: Lighting Technology Type: CFL

General Category	Dimension	Subcategory	Base Type
A-Type		>100W Incandescent Equivalent*	Screw-Base Lamp
		100W Incandescent Equivalent	Screw-Base Lamp
		75W Incandescent Equivalent	Screw-Base Lamp
		60W Incandescent Equivalent	Screw-Base Lamp
		40W Incandescent Equivalent	Screw-Base Lamp
		<40W Incandescent Equivalent*	Screw-Base Lamp
		Three-Way*	Screw-Base Lamp
Flood Light*		>20W	Fixture
CFL Wall Packs*		<20W	Fixture
		>20W	Fixture
Single Tube		<20W	Pin-Base Lamp
		>20W	Pin-Base Lamp
Double Tube		<20W	Pin-Base Lamp
		>20W	Pin-Base Lamp
Triple Tube		<20W	Pin-Base Lamp
		>20W	Pin-Base Lamp
Quad Tube*		<20W	Pin-Base Lamp
		>20W	Pin-Base Lamp
Square*		>20W	Pin-Base Lamp
Reflectors		R/BR	Screw-Base Lamp
		PAR	Screw-Base Lamp
		MR16*	Pin-Base Lamp
		Other CFL Reflectors	Screw-Base Lamp
Globe*		<60W	Screw-Base Lamp
		>60W	Screw-Base Lamp
Decorative*		<60W	Screw-Base Lamp
		>60W	Screw-Base Lamp

*Only received through raw data extract submissions (category not in sales survey form)

Appendix 2: Historic Mapping Tables

This table summarizes where the team standardized naming and merged categories between the historic and current datasets.

Table 15: Mapping Historic to New Data Categories

Historic Category	Historic Lamp Type	Mapped Lighting Technology Type	Mapped General Category	Mapped Dimension	Merged Base Type
4 ft. LFL	T5	Linear Fluorescent	T5	4 ft.	Lamp
	T8		T8		Lamp
	T12		T12		Lamp
8 ft. LFL	T8		T8	8 ft.	Lamp
	T12		T12		Lamp
HID	High Pressure Sodium	HID	High Pressure Sodium		Mogul-Base Lamp
	Mercury Vapor		Mercury Vapor		Mogul-Base Lamp
	Metal Halide		Metal Halide		Mogul-Base Lamp
LED	LED A-Type	LED	A-Type		Screw-Base Lamp
	LED Reflectors		Reflectors		Screw-Base Lamp
	LED Downlight		LED Downlights		Fixture
	LED 4-foot Linear Tube Replacement		LED Tubes	4 ft.	Lamp
	Other LED Linear Fixtures		Other LED Linear Fixtures		Fixture
	LED Post-Top & Bollard		LED Post-Top & Bollard		Fixture
	LED Area and Parking Lot Fixtures		LED Area and Parking Lot Fixtures		Fixture
	LED Track Head		LED Track Head		Fixture
	LED Garage Fixtures		LED Garage Fixtures		Fixture
	LED Gas Station Fixtures		LED Canopy Fixtures (e.g., Gas Stations)		Fixture
	LED Roadway (e.g., Cobra		LED Roadway (e.g., Cobra type)		Fixture

Historic Category	Historic Lamp Type	Mapped Lighting Technology Type	Mapped General Category	Mapped Dimension	Merged Base Type
	type)				
	LED High-Bay/Low-Bay Fixtures		Industrial Applications		Fixture
	LED MR16 Replacement		Reflectors		Pin-Base Lamp
	LED Wall Packs		LED Wall Packs		
Other	Incandescent A-Type	Incandescent	A-Type		Screw-Base Lamp
	Incandescent Reflectors		Reflectors		Screw-Base Lamp
	Pin-Base CFL	CFL			Pin-Base Lamp
	CFL Reflectors		Reflectors		Screw-Base Lamp
	Halogen A-Type	Halogen	A-Type		Screw-Base Lamp
	Halogen Reflectors		Reflectors		Screw-Base Lamp

C. Methodology Memo

This memorandum, submitted to BPA on June 9, 2017, summarizes the methodology developed to estimate Momentum Savings for the non-residential lighting market in the Northwest.

Memorandum

To: Jessica Aiona and Carrie Cobb, Bonneville Power Administration (BPA)

From: Laura Tabor, Ariel Esposito, and James Milford, Navigant Consulting, Inc.

Date: June 9, 2017

Subject: Non-Residential Lighting Momentum Savings Methodology

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This memo documents the Navigant Consulting, Inc. and Cadeo team's (the research team's) methodology for estimating non-residential lighting Momentum Savings. The team presents the methodology per the Four Question Framework, which is Bonneville Power Administration's (BPA's) standard analytical framework for estimating Momentum Savings.

Momentum Savings Analysis Framework

The research team answered four key questions to calculate non-residential lighting Momentum Savings over the Northwest Power and Conservation Council's (the Council's) Sixth Plan period (2010-2015). These questions are as follows:

1. What is the market?
2. How big is the market?
3. What are the total market savings?
4. What are the program savings?

Answers to these questions provide the data necessary to estimate Momentum Savings—the energy savings that occur above the Council's Sixth Plan frozen baseline and that are not directly incented by programs or claimed as part of the Northwest Energy Efficiency Alliance's (NEEA's) net market effects.

Most Momentum Savings analyses define the market in terms of sales, which is accurate when measure lifetime is relatively comparable between the baseline and efficient replacements. For the non-residential lighting market, however, there are substantial differences in measure lifetimes between baseline and efficient bulbs. For example, the average lifetime of a T12 linear fluorescent lamp is shorter than the average lifetime of an efficient LED luminaire replacement by about 30,000 hours. If the analysis considered only total bulb sales, the results would show a much greater count of inefficient T12 lamps in the market as compared to LED luminaires, but only because consumers using T12s must purchase multiple lamps to every one LED. For this reason, the team defined the non-residential lighting market as the total number of lamps installed in the region (stock), rather than the total volume of lamps sold in any given year (flow).

Using this definition of the total number of installed lamps, the research team followed the Four Question Framework to define the non-residential lighting market. **Question 1** describes what elements the non-residential lighting market includes such as geographic scope, sectors impacted, and technology types installed throughout the region.

Question 2 uses several regional sources to estimate exactly how big the non-residential lighting market is as well as the number of installed fixtures[1] included in the commercial, industrial, agricultural, and outdoor lighting sectors. This data informs the stock turnover model that the team built to estimate the changes in the efficiency mix of sales and installed lamps and fixtures over time, addressing **Question 3.** The model incorporates the total number of installed fixtures across the many sectors, application types, and technology types that make up the diverse non-residential lighting market. **Question 3** also describes how the team used detailed sales data from regional distributors to calibrate this model.

Question 4 defines the programmatic savings across the region during the study period that the team removes from the total market savings to arrive at Momentum Savings. Figure 1 summarizes how the four questions fit together to estimate Momentum Savings.

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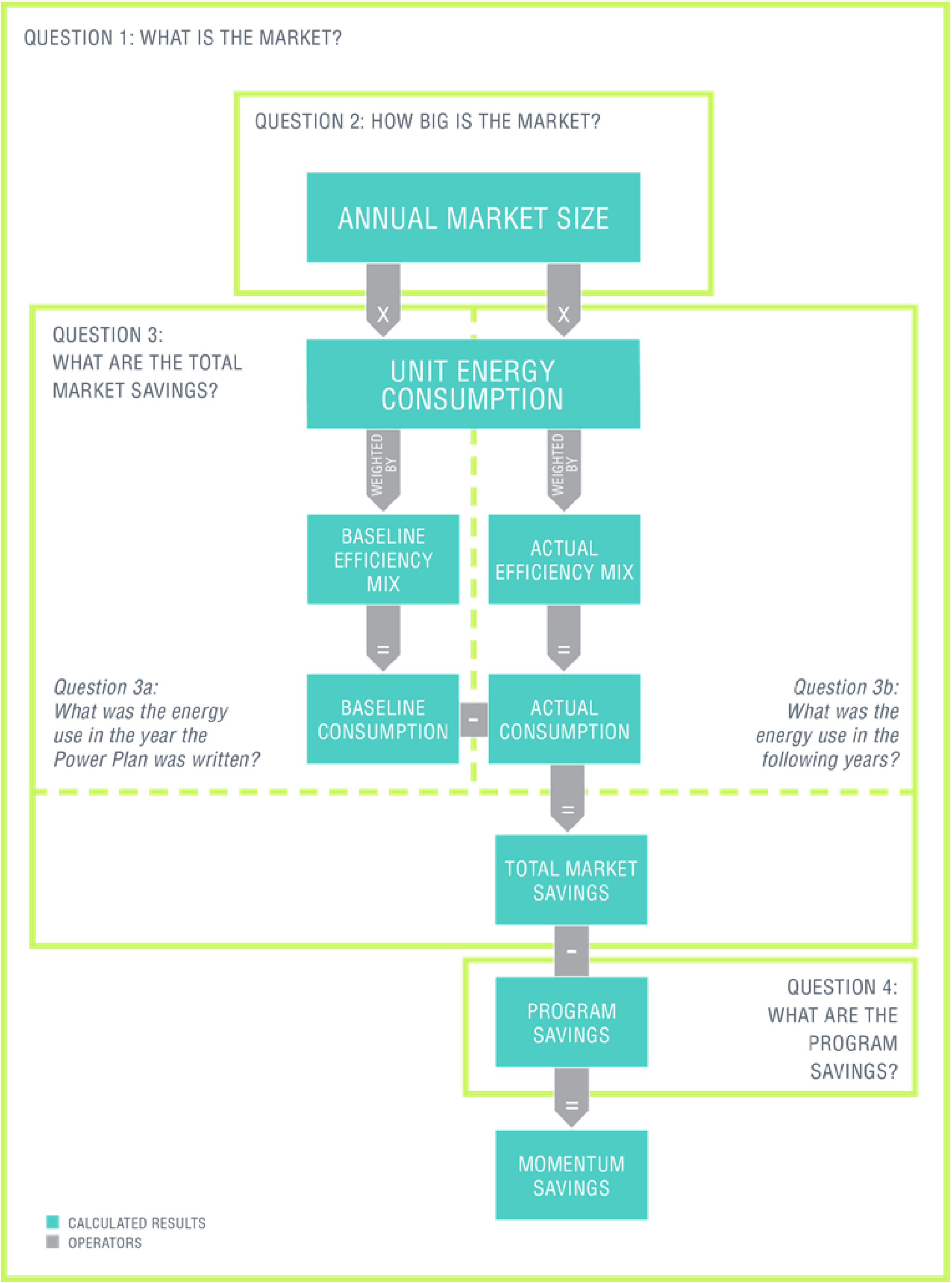
[1] The research team had to first identify the total number of installed fixtures throughout the region; thus, Question 2 defines the market in terms of fixtures. The team then used a stock turnover model (defined in Question 3) to share the total fixtures across the various technology types for the study. Since the number of lamps per fixture depends on the technology type, only then could the team estimate the market size in terms of lamps.

Figure 1: Overview of the General Momentum Savings Analysis Framework



Question 1: What is the market?

Question 1 of the Four Question Framework defines the various elements and dimensions of the non-residential lighting market, including technologies, sectors, applications, and geographic boundaries. The current analysis does not include lighting controls. Table 1 defines the unit of account, dimensions, and scope of the overall market used in this study.

Table 1: Market Definitions

Dimension	Scope of Model	Notes
Unit of Account	All installed **lamps** in the geographic, sector, application, and technology scopes listed below	The model tracks sales of lamps, ballasts, and fixtures. Lamp characteristics and assumed average number of lamps per ballast and fixture dictate ballast and fixture consumption. Thus, the primary unit of account is lamps.
Geographic Scope	Oregon, Washington, Idaho, and Western Montana[2]	Consistent with the regional power plan; the research team did not vary stock or sales mixes by this dimension.
Sector	Interior and exterior lighting in commercial, industrial, and agricultural buildings; outdoor lighting	Agriculture uses the same sales and stock mix as industrial.
Building Type	All commercial building types	Applies to commercial sector only; the research team did not vary sales mixes by this dimension. Stock inputs began at the building type level, but the team aggregated all data to the sector level for the analysis.
Application	Dominant lighting applications in each sector; specific exclusions include exit signs, refrigerated case lighting, and railway and airfield lighting	Defined as a common lighting need in the market that can be met by several competing technologies; may be further divided by lumen bins.
Technology	Dominant technologies within each application	Defined as an individual technology that is modeled as a distinct product choice within appropriate applications.
Purchase Triggers	New construction, maintenance, and natural replacement	Lamp and ballast burnout drive maintenance; retrofit, renovation, and system turnover drive natural replacement. LED technologies can only leave the stock due to maintenance (lamp or driver burnout).

Unit of Account

The unit of account is the metric the research team uses to quantify the non-residential lighting market. In this analysis, the unit of account is the installed **lamps** in each year of the analysis. That is, the research team defines the market as the total number of lamps in service each year of the analysis period. The model also tracks total installed fixtures and ballasts since the number of lamp installations depends on the characteristics of the installed fixtures (e.g., linear fixtures can have anywhere from one to eight lamps

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[2] The sales mix reflects sales from all of Montana, but the stock and sales market size only represents Western Montana.

depending on the application). The number of lamps per fixture also affects the number of ballasts per fixture, which in turn affects the total wattage and lumen output of the fixture, lamp, and ballast system.

Sector and Building Type Definitions

The team sought to define comprehensive and mutually exclusive sectors that represented all non-residential lighting applications in the Pacific Northwest. The results include three distinct sectors: commercial, industrial, and outdoor lighting. Agriculture is included in the industrial sector.

Commercial

The commercial sector covers lighting applications in building types as defined in the Council's Seventh Power Plan (Seventh Plan) and includes any exterior lighting associated with these buildings. Table 2 provides the list of commercial building types.

Table 2: Building Types Included in the Commercial Sector

Commercial Building Types
Office*
Retail*
School K-12
University
Warehouse
Grocery*
Restaurant
Lodging
Hospital
Residential Care
Assembly
Other

**The research team collapsed granular categories in the Office, Retail, and Grocery sectors from the Seventh Plan for conciseness.*

Industrial

The industrial sector covers lighting applications in building types as defined by the Industrial Facilities Stock Assessment (IFSA) data (e.g., manufacturing, food processing, and warehouses) and includes any exterior lighting associated with these buildings. This category also includes agricultural building stock because the research team did not have enough data to effectively distinguish between the two.

Outdoor Lighting

The team included outdoor lighting applications not associated with buildings, such as street and roadway lights.

Application and Technology Definitions

Applications provide a useful framework for non-residential lighting because they define the various technologies that are eligible for installation. For example, only a small set of technology types work as large downlights, as defined in Table 3. The team defined the major applications and eligible technologies that can be installed within them to understand the correlation between incumbent and emerging technologies. The team considers LED lamps, LED luminaires, and tubular LEDs (TLEDs) as emerging technologies; all others are incumbent technologies.

The research team reviewed the following sources to determine which applications to include:

- The US Department of Energy's (DOE's) national lighting model—used to support the Solid State Lighting (SSL) Adoption Report—which is also organized by application
- The Seventh Plan, which focused on a subset of lighting applications
- Program measure offering descriptions
- Manufacturer product categories
- Lamp and fixture type categories in NEEA's 2014 Commercial Building Stock Assessment (CBSA)

Table 3 provides a complete list of the applications covered in this study, the eligible technologies within each application, and which applications are included in each sector.[3]

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[3] Commercial and industrial have both interior and exterior applications in the model. The outdoor sector consists of only outdoor lighting applications not associated with buildings (e.g., street lighting) and is mutually exclusive of the exterior lighting in the other sectors.

Table 3: Summary of Application Definitions and Eligible Technologies

Application	Description	Eligible Technologies	Sectors
Ambient Linear	Low bay linear lighting lamps and luminaires	Linear Fluorescent LED Tubes LED Luminaires	Interior Commercial Interior Industrial
General Purpose/ Omnidirectional	Omnidirectional lamps used for general purpose lighting	Incandescent LED Halogen CFL	Interior Commercial Interior Industrial
Downlight Large	Directional lamps (pin and screw base) and downlight luminaires **Large:** PAR and R/BR lamps	Incandescent LED Lamps Halogen CFL LED Luminaires	Interior Commercial Interior Industrial
Track Large	Display and track lighting **Large:** PAR and R/BR lamps (diameter >2.5”) **Small:** MR16 lamps	Incandescent LED Lamps Halogen CFL LED Luminaires	Interior Commercial Interior Industrial
Track Small			
Decorative	Decorative mini-base lamps	Incandescent LED Lamps Halogen CFL	Interior Commercial
High/Low Bay	Bay lighting with ceiling height of at least 15 feet and/or lumen output of at least 5,000 lumens per fixture	Linear Fluorescent Metal Halide High Pressure Sodium Mercury Vapor LED Luminaires LED Lamps	Interior Commercial Interior Industrial
Parking Garage	Ceiling and wall lighting in parking garages	Incandescent Linear Fluorescent LED Tubes Metal Halide High Pressure Sodium LED Luminaires LED Lamps	Commercial Exterior

Application	Description	Eligible Technologies	Sectors
Building Exterior	Exterior lighting associated with buildings: wall packs, walkway lighting, exterior sales, and flood lights	CFL High Pressure Sodium Metal Halide LED Luminaires Halogen Incandescent Linear Fluorescent	Commercial Exterior Industrial Exterior
Parking Lot	Exterior lighting in parking lots, including area lighting	High Pressure Sodium Metal Halide LED Lamps LED Luminaires Linear Fluorescent Mercury Vapor Halogen Incandescent	Commercial Exterior Industrial Exterior
Street and Roadway	Street and roadway lighting	High Pressure Sodium Metal Halide LED Luminaires	Outdoor
Other	Other outdoor lighting, including signage and stadium lighting	Linear Fluorescent LED Tubes LED Luminaires Metal Halide High Pressure Sodium Incandescent Halogen	Outdoor

Purchase Triggers

A purchase trigger occurs any time there is an opportunity to purchase a lighting technology. When a fixture is replaced, a lamp or ballast burns out, or a new building is constructed, the consumer must make a choice as to what lighting option to install. The research team identified four main purchase triggers for lighting technologies:

- **Lamp maintenance** involves the replacement of a lamp or bulb that has burned out at the end of its average lifetime; also referred to as naturally occurring lamp failure.
- **Ballast and lamp maintenance** involves naturally occurring ballast failure where the entire lighting ballast fails. In this case, the consumer replaces both the ballast and the lamps associated with the ballast.
- **Natural replacement** involves early retirement fixture purchases, or replacements of ballasts and/or lamps before the end of their average lifetime. The lamp or ballast has not yet failed, but a consumer still decides to upgrade to a more efficient alternative. Projects of this type include retrofits, major renovations, and tenant improvement upgrades.
- **New construction** includes all fixtures installed through the addition of new floor space (new construction and additions) to the market.

Question 2: How big is the market?

This analysis defines the size of the market as the estimated total number of lamps installed in each sector of the non-residential market across Oregon, Idaho, Washington, and Western Montana.[4] The research team relied on several sources to estimate the total lamps installed in the region, including square footage estimates from the Council's Seventh Plan and lamp and fixture density data from the 2014 CBSA. There are three factors that influence the number of lamps installed: the total space that requires lighting (usually in square feet), the density of fixtures within that space (i.e., fixtures per square foot), and the number of lamps in each fixture.[5] The number of lamps per fixture depends on the technology, making the total lamps dependent on the technology mix, which is addressed in Question 3. Question 2, therefore, defines the size of the market as the total number of fixtures installed in each sector and later applies lamps per fixture within the stock turnover model, which is discussed at length in Question 3.

At a high level, the research team used three different types of density:

- For **interior** lighting, fixture density is expressed as interior fixtures per interior square foot of building space
- For **exterior** lighting (associated with buildings), fixture density is expressed as exterior fixtures per interior square foot of building space

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[4] While the market size is Western Montana only, the research team used sales data and stock saturation data for the entire state of Montana, assuming that the efficiency mix does not vary across the state.

[5] Lamp density depends on the technology and application type shares defined within the stock turnover model. The research team calculated a lamp per fixture density based on these shares to get to the total count of installed lamps. See Question 3 for more details.

- For **outdoor** lighting (not associated with buildings), fixture density is expressed as fixtures per population, such that the total installed stock is the product of the total Pacific Northwest population and the average number of street and roadway lamps per person [6]

The research team used the data from the Council's Seventh Plan to estimate the total floor space for each commercial building type included in the study. The team also accounted for changes to these totals—through new construction and demolitions—to ensure they accurately represent the floor space for each sector across the region for each year of the study. For industrial floor space, the team used the national Manufacturing Energy Consumption Survey (MECS) data scaled down to the region and then scaled up to include agricultural areas.[7]

The research team calculated a fixture density for each building type in 2014 and assumed the values do not change over time.[8] Table 4 summarizes the data sources for market size (square footage or population) and fixture density for each portion of the non-residential market.

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[6] Outdoor lighting density is the average number of street and roadway lamps per person from the Council's Seventh Plan. The plan assumed 81 streetlights per 1,000 people based on a regression analysis using data from the Pacific Northwest National Laboratory (PNNL) and other sources. For more information, see: Seventh Power Plan, "com-streetlight-7P_V9.xlsx," "7PSourceSummary" tab.

[7] The research team estimated regional industrial square footage using manufacturing employment data from the US census. Then, the team estimated the relative size of the agricultural lighting market by comparing the volume of agricultural and industrial sector lighting program participation and scaled up regional square footage accordingly.

[8] Overall fixture density at the application or sector level may change over time due to different building type growth and demolition rates, but the team assumes fixture density at the building type level remains constant. 2014 CBSA data is represented in the model as end-of-year 2013.

Table 4: Fixture Density Metrics and Data Sources

Sector	Density Metric	Market Size Data Source	Fixture Density Data Source	Notes/Exceptions
Commercial Interior	Fixtures per square foot	Seventh Plan (square feet)	2014 CBSA	Based on mapping detailed CBSA lighting data to model application and building types. Hospital and University used additional data sources due to the lack of detailed lighting data in the CBSA.[9]
Industrial Interior	Fixtures per square foot	MECS, scaled to Pacific Northwest with census data (square feet)	2014 CBSA (Warehouse)	The 2014 IFSA data did not have sufficient square footage or fixture count data to provide an industrial-specific estimate; the team used CBSA data for the Warehouse building type as a proxy.
Commercial Exterior	Exterior fixtures per interior square foot	Sum of Seventh Plan commercial and MECS industrial square footage (square feet)	2014 CBSA	The 2014 CBSA provides exterior fixture and wattage density relative to interior square footage. While this metric has some uncertainty around it, the team believes this is the best data source available to estimate total exterior fixture counts at this time.
Industrial Exterior	Exterior fixtures per interior square foot		2014 CBSA (Warehouse)	The 2014 IFSA study contained little outdoor lighting data; the team again used CBSA data for the Warehouse building type as a proxy.
Street and Roadway	Fixtures per population	Seventh Plan (population)	Seventh Plan	The Council analyzed several data sources to estimate fixtures per Pacific Northwest population; the team used these estimates directly.

Question 3: What are the total market savings?

Total market savings are the difference between baseline consumption beginning in the year the Council's Sixth Plan was written—calculated in Question 3a—and actual consumption in the years after the Plan was written, calculated in Question 3b. For example, if the analysis finds actual market energy consumption to be lower than the baseline energy consumption in any given year, the difference is the total market savings.

The research team arrived at the baseline consumption and the actual consumption estimates by mapping all the installed fixtures defined in Question 2 into the many building types, application types, and technology types that make up the diverse non-residential lighting stock and modeling how the

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[9] The 2014 CBSA used a separate data collection approach for Hospitals and Universities and did not use the same detailed lighting form as other building types. This resulted in non-standard, and in many cases, qualitative or approximate, data on fixture technology type and quantity. Thus, the research team was unable to include these data in the CBSA lighting analyses.

installed technology shares change over time. The team then multiplied these shares by the unit energy consumption (UEC) of each technology to estimate the total energy use of the market in each year.

This process required the use of a stock turnover model to accurately identify how the mix of technologies within the installed lamps in the various dimensions of the market changes over time. This section defines this process and how the stock turnover model calculates energy consumption in the non-residential lighting market,[10] leading to answers to Questions 3a and 3b.

The Stock Turnover Model

The purpose of a stock turnover model is to identify how consumers adopt technologies and how these adoptions impact the size and efficiency mix of the stock—in this case total lamp installations—over time. For the non-residential lighting market, this model determines the size and efficiency mix of each application defined in Question 1. The results are the total installed lamp counts by technology required to properly calculate the baseline energy consumption and actual energy consumption that drive the Momentum Savings analysis.

Building the Model

The research team first had to build the stock turnover model using a number of sources and assumptions, which led to three primary input areas:

1. A characterization of the installed stock (size, mix, and age of the lamps in the stock) for at least one year in the analysis period—explained in the Stock Characterization: Application and Technology Shares section
2. An estimate of how fast the existing stock turns over each year due to the four purchase triggers in each year—described in the Turnover section
3. An efficiency mix of sales in each year of the analysis period—provided in the Using the Model to Refine the Sales Efficiency Mix section

With these inputs, the model estimates how the mix of installed technologies in the stock changes over time in both the baseline and actual scenarios. In the baseline scenario, the sales mix is frozen, reflecting the concept that sales into the market will not get more efficient. Yet, even in the baseline, lamps and ballasts burn out, renovations occur, and new buildings require lighting. Thus, if the frozen sales mix is more efficient than the existing stock, the stock in the baseline scenario will get more efficient over time—just at a slower rate than the actual stock.

These changes in the installed technology mix affect total lighting energy consumption. This stock data multiplied by the UEC of each technology yields the consumption in each case (described in the Question 3a: What was the energy use in the year the plan was written? and Question 3b: What was the energy use in the following years? sections below).

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[10] Appendix 1. Technical Data offers additional detail around the technology-specific data supporting consumption calculations.

Stock Characterization: Application and Technology Shares

After defining the market size in fixtures as described in Question 2, the research team then defined the portion of total lamps and fixtures in the stock belonging to each application and then applied the share of technologies—or technology mix—to each defined application (as seen in Table 3). The team used the most up-to-date data available to apply the technology mix to the stock turnover model: the 2014 CBSA, 2014 IFSA, and the Seventh Plan.[11] The application shares remained constant within a building type over time, whereas the mix of technologies within each application varied as the stock turned over.

The research team used the following steps to estimate the commercial technology mix for interior lighting applications, assuming that the 2014 CBSA and IFSA data were representative of regional stock at the end of 2013:

1. Mapped each entry from the detailed CBSA lighting data to the corresponding model application and technology (example shown in Table 5)

Table 5: Example of CBSA Data Mapped to Model Application and Technology

CBSA Database Fields					**Mapped Fields**	
Fixture Category	**Fixture Type**	**Lamp Type**	**Lamp Details**	**Watts Per Lamp**	**Application**	**Technology**
Linear Fluorescent	LF Ceiling Mount	Fluorescent T8	HP	25	Ambient Linear	25W T8

2. Calculated the share of fixtures (application share) in the stock that belong in each application by building type using the detailed CBSA fixture data (example shown in Table 6)

Table 6: Example Fixture Application Shares for Assembly and Food Service Building Types

Application	**Percentage of Assembly Fixtures**	**Percentage of Food Service Fixtures**
Ambient Linear	45%	30%
Decorative	0%	4%
Downlight Large	29%	31%
General Purpose	11%	22%
High/Low Bay HIGH	2%	0%
High/Low Bay LOW	6%	2%
Track Large	4%	8%
Track Small	2%	4%
Total	**100%**	**100%**

Source: Analysis of 2014 CBSA data

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[11] The CBSA/IFSA took place during 2013-2014. For purposes of this study, the research team defines this data as the technology mix at the beginning of 2014.

3. Calculated the share of fixtures represented by each technology for each application in 2014 using the following equation and the CBSA detailed fixture data. Table 7 shows the technology shares for two applications in the commercial sector.

Equation 1: Technology Fixture Share

$$\text{Technology Fixture Share}_{a,b,t,y} = \text{Application Share}_{s,b} \times \text{Technology Share}_{a,s,y}$$

Where:

a = application

b = building type

s = sector

t = technology

y = year in study period

Table 7. Example Technology Shares for Ambient Linear and High/Low Bay Low Applications (Commercial Sector)

Technology	Percent of Ambient Linear Fixtures	Percent of High/Low Bay Low Fixtures
25W T8	4%	0%
28W T8	5%	0%
32W T8	78%	67%
CFL	0%	0%
Halogen	0%	0%
High Pressure Sodium	0%	0%
Incandescent	0%	0%
LED Lamp	0%	1%
LED Luminaire	0%	0%
Mercury Vapor	0%	0%
Metal Halide	0%	5%
Pin CFL	0%	0%
T12	10%	12%
T5 High Output	0%	14%
T5 Standard Output	3%	1%
LED Tubes	0%	0%

Source: Analysis of 2014 CBSA data

For the industrial sector, the research team used the IFSA lighting data to estimate the mix of applications and technologies. The team leveraged the Council's analysis of the IFSA data for the Seventh Plan, which provided some standardization of the fixture descriptions in the raw IFSA data. The team repeated the commercial analysis process of mapping individual site fixture data to applications and technologies to calculate the share of installed watts and fixtures by application and technology for the industrial sector.

For the exterior lighting applications for both commercial and industrial (parking garages, parking lots, and building exterior), the research team relied on 2014 CBSA data. The team categorized CBSA outdoor lighting entries to the building exterior model applications. Table 8 documents these assumptions.

Table 8: Exterior Lighting Classification

CBSA Outdoor Lighting Use Type	Model Application
Walkway	Building Exterior
Parking Lot	Parking Lot
Signage	Other
Façade	Building Exterior
Other	Other
Sporting Field	Other
Unknown	Other
Exterior Sales	Building Exterior

Source: Analysis of 2014 CBSA

The Seventh Plan contains estimates of the mix of incumbent technologies in street and roadway lighting and draws on several sources to estimate the LED installed stock penetration in 2015. The analysis cites the 2013 DOE SSL Market Adoption report estimate of a 7.1% penetration of LEDs in the 2013 installed stock. The team combined this data point with the mix of incumbent technologies to estimate the overall mix of technologies in the street and roadway application in 2013 (Table 9).

Table 9: Street and Roadway Installed Stock Technology Mix: 2013

Fixture	Distribution
LED < 400W	7.0%
LED ≥ 400W	0.1%
High Pressure Sodium 100W	50.2%
Metal Halide 200W	13.0%
High Pressure Sodium 250W	12.2%
Metal Halide 400W	16.3%
Metal Halide 1000W	1.3%

Source: Analysis of Seventh Plan and the 2013 DOE SSL Market Adoption report

After characterizing the stock into application and technology shares, the research team applied a lamps-per-fixture equation using data from the CBSA on the average number of lamps per fixture for each technology type. For some technologies, this varies by application—for example, the average 32W T8 fixture in the ambient linear application has fewer lamps (one or two) than the average 32W T8 fixture in high bay lighting (four to eight). The research team made some adjustments to the lamps per fixture data from the CBSA to ensure that all technologies had similar lumen output. The team applied these lamps per fixture estimates at the application level, assuming that applications would be similar across building types and sectors. The team used CBSA data for the industrial sector and assumed a single lamp per outdoor street and roadway fixture.

Equation 2: Calculating Technology Share of Lamp Stock

$$\text{Technology Lamp Share}_y = \text{Application Share}_{s,b} \times \text{Technology Share}_{a,s,y} \times \text{Lamps per Fixture}_{a,t}$$

Turnover

As discussed in the definition of purchase triggers in Question 1, lamps enter the market through lamp failure, ballast failure, natural replacement of fixtures, and new construction. Each of these purchase triggers creates a submarket, which is the subset of total market sales that result from that trigger. The research team considers the sales due to the new construction and natural replacement purchase triggers a single submarket with the same mix of technologies in sales. The model applies these purchase triggers as follows:

- All fixtures except LED technologies—regardless of year installed—are subject to the natural replacement turnover. That is, if the natural replacement turnover rate is 5%, the model removes 5% of all installed fixtures and fills the stock with new sales using the sales mix for the natural replacement and new construction submarket. The team exempted LED technologies from this turnover because they are emerging technologies installed recently and therefore unlikely to be replaced during the modeling period of 2009 to 2015.
- A subset of the remaining ballasts not removed through natural replacement of fixtures fail according to their vintage, rated lifetime and operating hours. When a ballast fails, the model replaces both the ballast and associated lamps with the sales mix for the ballast maintenance submarket.
- A subset of the remaining lamps not removed through natural replacement of fixtures or ballast replacement fail according to their installation year, rated lifetime and operating hours. The model replaces these burned out lamps with the sales mix for the lamp maintenance submarket.

The remainder of this section describes the inputs driving turnover in more detail.

Lamp Failure. For lamp failure, the lifetime and operating hours of each unique lamp type (e.g., incandescent general purpose lamp, LED reflector lamp, etc.) in the stock determine the frequency with which it fails, on average. For example, if an incandescent general purpose lamp has a lifetime of 1,000 hours and the research team assumes lamps of this type operate (are turned on) for 500 hours per year, then the team can expect these bulbs to fail, on average, after they have been in the stock for two years. Using the count and age of each lamp type in the stock, the stock turnover model determines the number of failures by lamp type and the corresponding number of replacement lamps in any given year.

Equipment does not always fail exactly at its rated lifetime. To account for this, the model employs failure distributions for each technology that assign the percentage of lamps of a certain age that will fail in any given year. The research team estimated failure rates using a Weibull distribution having a mean value equal to each lamp's expected lifetime, along with a shaping factor of five.[12] The Weibull distribution assumes that a greater portion of lamps fail after the expected lifetime as opposed to a normal distribution, which would assume equal numbers of lamps failing before and after the mean (expected) lifetime.

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[12] The value of the shaping factor is consistent with the US DOE lighting market model.

Lamp replacement sales are calculated as shown in Equation 3 through Equation 7.

Equation 3: Failure Distribution

$$\text{Failure Distribution}_{a,g,t,y} = \text{Weibull Distribution}\ (\text{Mean Lifetime}_{a,t,y=i}\ ,\ \text{Shaping Factor})$$

Where:

a = application

g = age

i = installation year

s = sector

t = technology

y = year in study period

The model tracks the age of every installed lamp, which enables it to apply the appropriate failure percentage to each age cohort.[13] For every year of the study period, the model predicts the quantity of lamps that fail from each age cohort.

Equation 4: Lamp Failures by Vintage

$$\text{Lamp Failures}_{a,i,s,t,y} = \text{Lamp Stock}_{a,i,s,t,y} \times \text{Failure Distribution}_{a,g,t,y=i}$$

Ballast Failure. For ballast failures, the model uses a simplified approach that assumes a constant fraction of ballasts fail in each year. This fraction is one divided by the rated ballast lifetime for each technology. The research team assumes that with each ballast replacement, the associated lamps are replaced as well.

Equation 5: Ballast Failures

$$\text{Ballast Failures}_{a,i,s,t,y} = \text{Ballast Stock}_{a,i,s,t,y} \times \frac{1}{\text{Ballast Lifetime}_{a,t,s,y=i}}$$

Natural Replacement of Fixtures. For all technologies except LED, the model calculates the number of fixtures replaced each year using Equation 6. The research team investigated varying the application of this turnover rate by technology or vintage (e.g. so that older fixtures or certain technologies would have a higher chance of turning over). Given the lack of detailed primary data on turnover rates with this level of granularity—and, in the case of varying by vintage, the additional computational burden required—the

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[13] An age cohort is all the lamps installed in a given year. The failure rate is a function of lamp age as shown in Equation 3.

team chose to use a single turnover rate for all technologies and vintages (the model does not track fixture vintage) to avoid false precision and keep the model a more reasonable size.[14]

Equation 6. Natural Replacement Turnover

$$\text{Natural Replacement Turnover}_{a,s,y} = \text{Fixture Stock}_{a,s,y} \times \text{Natural Replacement Turnover Rate}_{a,s}$$

Total Replacement Sales from All Purchase Triggers. All lamp and ballast failures and natural turnover fixtures are then subject to replacement. Upon replacement, a fixture or lamp and ballast system can switch from one technology to another based on the assumed sales mix across technologies within each submarket.

Equation 7: Replacements

$$\text{Replacements}_{a,s,t,y} = \left(\textstyle\sum_{i,t} \text{Lamp Failures}_{a,i,s,t,y}\right) \times \text{Sales Mix}_{a,t,y,m} + \left(\textstyle\sum_{i,t} \text{Ballast Failures}_{a,i,s,t,y} \times \text{Lamps per Ballast}_{a,i,s,t}\right) \times \text{Sales Mix}_{a,t,y,m} + \left(\textstyle\sum_{i,t} \text{Fixtures Replacements}_{a,i,s,t,y} \times \text{Ballasts per Fixture}_{a,i,s,t} \times \text{Lamps per Ballast}_{a,i,s,t}\right) \times \text{Sales Mix}_{a,t,y,m}$$

Where:

m = submarket

Table 10 summarizes the key data inputs and sources for the turnover portion of the model.

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[14] Turnover rates for each application are based on a weighted average of building type-level turnover rates. Tracking fixture vintage is possible, but adding this complexity would dramatically increase the size of the model. This would make the model less accessible (some computers may not have enough memory to run larger models) and increases run time.

Table 10: Turnover Inputs and Sources

Input	Description	Source
Lifetime	Rated lifetime of lamps and ballasts in hours; varies by technology and application	DOE input assumptions for SSL Market Model
Hours of Use	Annual operating hours of lighting equipment; varies by sector and application	Commercial buildings: Seventh Plan hours of use by building type weighted to application level Industrial buildings: IFSA Exterior Lighting: Sixth Plan
Natural Replacement Turnover Rate	Percentage of fixtures replaced each year due to retrofits, renovations or other upgrades	Commercial: Sixth Plan building type rates weighted to application level Industrial: Sixth Plan value for warehouse building type Outdoor: Sixth Plan
New Construction and Demolition Rates	Number of fixtures added to or removed from the stock due to new construction or demolition of building stock	Seventh Plan floor space estimates by building type multiplied by fixture density

Together these inputs drive how much the stock grows or shrinks each year and what fraction of lamps, ballasts, and fixtures will fail and require replacement. From this data, the model calculates the total sales of lamps, ballasts, and fixtures in each year as follows:

- The **natural replacement turnover rate** determines the number of fixtures replaced in each year, making up one part of the fixture submarket.
- The **lifetime in hours** of the lamp or ballast divided by the **annual hours of use** by sector and application equals the **expected lifetime in years** for each technology in each application and sector. This is the lifetime used to calculate the failure distributions described above and dictates the number of lamps and ballasts that fail each year. This drives the size of the lamp and ballast submarkets.
- The **new construction rate** determines how many fixtures will be added to the stock in each year through new buildings, which makes up the remainder of the fixture submarket.
- The **demolition rate** determines how many fixtures will be removed from the stock in each year due to the demolition of existing buildings.

Figure 2 provides a snapshot of how in each year, failures in the existing stock drive the next year’s sales, which in turn determine the mix of technologies installed in the next year. New construction and demolitions also affect the stock and sales in each year. This process applies for the entire modeling period.

Figure 2. Illustration of How Stock and Sales Interact in Model

Source: BPA Non-Residential Lighting Model development

Using the Model to Refine the Sales Efficiency Mix

The efficiency mix of sales flowing into the market in each year is the percentage of lamps that each technology makes up in the sales. This mix varies by application and submarket. There are three possible methods for determining efficiency mix: using technology shares from available sales data, manually estimating technology shares based on available data and professional judgment, and building economic logic within the model to estimate technology shares. Actual sales data is the most direct, and through this and prior projects BPA has collected sales data from 34 unique distributors over the 2010-2015 period.[15]

This sales data is a resource unavailable to many market modelers, and it provides a clear, high-level target for the non-residential share of market sales. There are two main limitations to using this data directly for each individual purchase trigger and application: technology representativeness and allocation granularity. The implications of these sales data limitations are as follows:

- **Technology representativeness.** The sales data is not equally complete for every technology. For example, in the first year of non-residential data collection, very few distributors submitted significant data beyond linear fluorescent and high-intensity discharge (HID). Therefore, the data for these years does not provide a full picture of the relative magnitude of these product sales relative to other technologies (e.g., LED, incandescent, CFL).
- **Allocation granularity.** To understand the large-scale changes happening across the market, it is important to understand what is happening at a more granular level than the current sales data can provide. For example, lamps may be going to industrial, outdoor, or commercial applications, which have a variety of operating hours and conditions, at varying rates. To be more accurate in estimating energy consumption and savings, the research team needed to assess not just the high-level sales but also which lamps are going where—something that sales data cannot inform directly.

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[15] For additional information on this data collection and data cleaning analysis, see: Non-Residential Lighting Distributor Sales Data Gaps memorandum.

To address these limitations, the research team developed a sales allocation process to estimate the share of each technology's sales going to each sector and application. This process also weights the overall sales mix by the known size of each application in the stock, alleviating the issue of technology representativeness in early years. The research team implemented this process in two steps:

- **Step 1: Determine relative size of applications and submarkets for each technology.** Using the 2013 stock application and technology saturation data and the turnover assumptions described above, the team turned over the 2013 stock to calculate the relative size of each application and submarket's lamp sales in 2014 (each year's sales are driven by stock changes in the prior year). Turning over the stock applied the lifetime and turnover assumptions to calculate the volume of each submarket's lamp sales as follows:
    - The lamp submarket size is equal to the number of lamps that failed in 2013
    - The ballast submarket size is equal to the number of ballasts that failed in 2013 multiplied by the number of lamps per ballast
    - The fixture submarket size is equal to the number of fixtures removed in 2013 due to natural turnover multiplied by the number of lamps per fixture

  The team calculated initial application-level sales by assuming like-for-like sales (T12s replace T12s). The research team also needed a way to understand how these application shares could be changing over the modeling period: for example, anecdotal evidence from program activity suggests that the share of T8s going into the High/Low Bay applications increased over the modeling period as HID technology sales declined. The team needed a second point estimate of application shares from a different year to inform these trends rather than assuming the 2014 shares were representative for all years. The team repeated the process described above using estimates of 2010 stock application and saturation from the DOE national lighting model.[16] Then, the team interpolated and extrapolated to estimate sales allocations for each technology and application from 2009 to 2015.

- **Step 2: Scale application and submarket-level mixes to align with distributor sales data.** Once these trends in allocations were established, the research team needed to align the technology mixes with the sales mix found in the distributor sales data for the entire non-residential market. The 2010-2015 market sales mixes come directly from distributor data. The team estimated the 2009 market sales mix through the following process:
    - Trending each technology's share backwards based on 2010-2015 shares
    - Adjusting any negative values to zero
    - Capping CFL, 28W T8, and 25W T8 shares to not exceed 2010 values given these technologies were in a growth stage at this time
    - Re-normalizing so that all technology shares summed to 100%.

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[16] The research team chose to use this national data because it is already broken into applications. The team reviewed the overall technology saturation trends between the 2003, 2009, and 2014 CBSA studies and made some adjustments to individual technology saturations in the national model where the national data did not align with regional trends. For example, national T12 saturation was higher in 2010 than the trend the CBSA studies implies.

To align the application-level sales estimates with the distributor data, the team multiplied the application-level results by the overall sales mix in 2014 using Equation 8. Finally, the team renormalized each application and submarket so that the technology shares summed to 100%.

Equation 8. Scaling Sales Mixes to Align with Sales Data

$$\text{Sales Mix}_{a,m,t,y} = \text{Like-for-Like Sales Mix}_{a,m,t,y} \times \text{Overall Sales Mix}_{t,y}$$

Where:

a = application

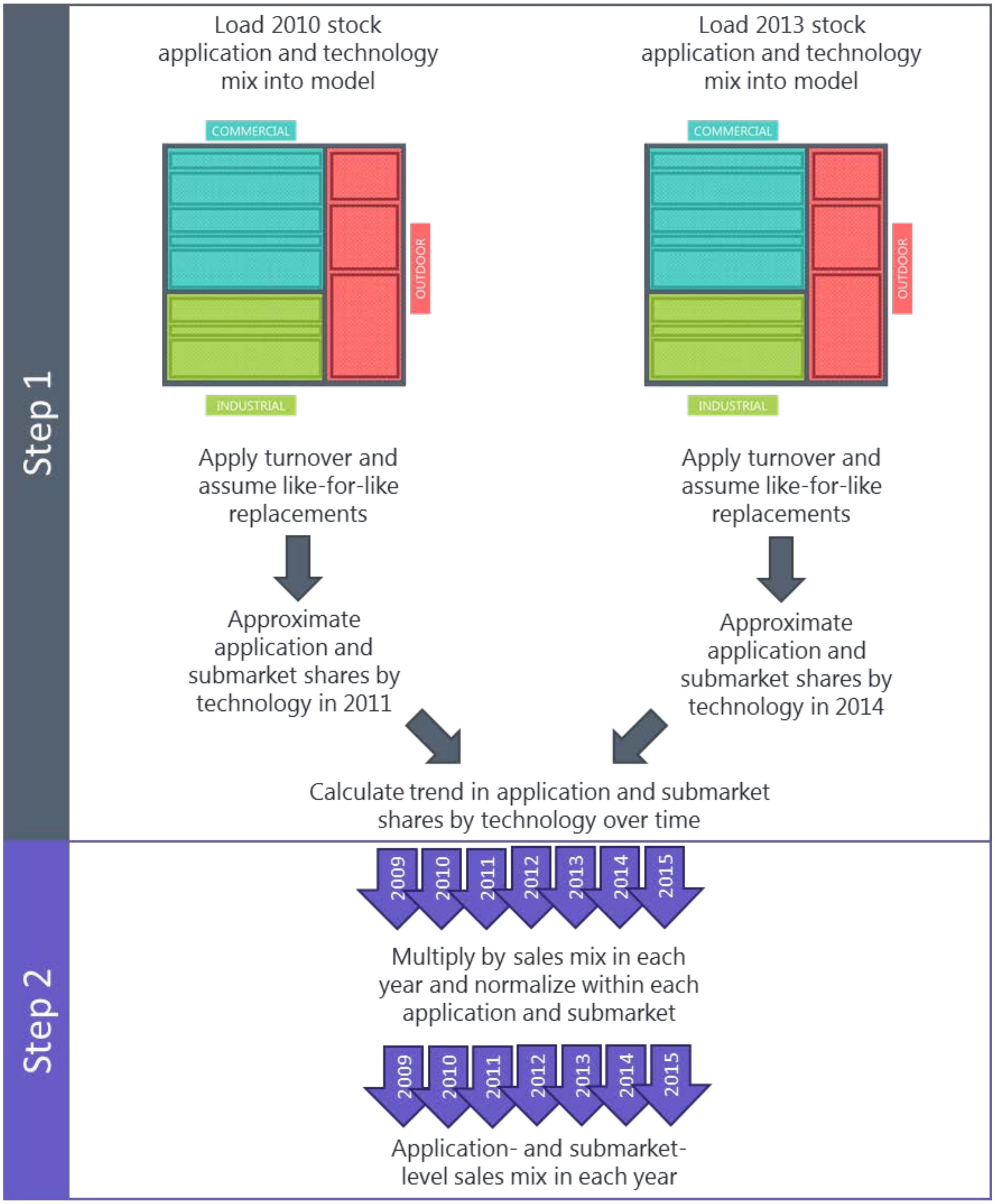
m = submarket

t = technology

y = year

Figure 3 summarizes this process.

Figure 3: Sales Allocation Methodology



The output from the sales allocation process is the sales mix for each application and submarket over time. Each year, the model summed all the lamp failures from all sectors within each application and submarket and applied the application- and submarket-specific sales mix to determine the number of new lamps of each technology type in that year.

Applying Sales Mixes to Model Stock Over Time

The research team used the 2010 stock technology saturations as an estimate for end of year 2008 stock saturation. The model turned over the stock in each year and applied the sales mixes for each submarket and application to the corresponding incoming sales. Due to the complexity of the stock turnover which has so many products of varying lifetime, the stock in 2013 as calculated in the model does not exactly match the input data described previously and used in the sales allocation process. The research team compared the modeled 2013 stock with the 2013 input data. As shown in Table 11, the model is within 1% to 5% of the input technology shares. Given the uncertainty around the technology mixes and the error bounds of the input data, the team chose not to further manipulate sales data or other inputs to improve alignment with the input 2013 stock mix.

Table 11. 2013 Stock Mix Comparison

Technologies	2013 Model Stock Mix	2013 Input Stock Mix
T8	54%	59%
T5	7%	6%
T12	11%	10%
CFL	13%	12%
Halogen	2%	2%
HID	6%	4%
Incandescent	3%	5%
LED	4%	2%

Source: BPA Non-Residential Lighting Model, research team analysis of CBSA, IFSA and 7th Plan data

The team considered iteratively back-calculating the 2008 stock saturations based on the sales data and 2013 stock data, but this approach did not improve the alignment with 2013 data or the trends in stock over time.[17]

Refining Model Sales Mixes to Improve Sales Data Alignment

After running the model using the sales mixes estimated through the sales allocation process, the research team found that this methodology underestimated LED sales relative to the calculated sales allocations based on distributor sales data (for additional detail on why this occurs, see Appendix 3). This was especially pronounced in applications where the incumbent technologies have much shorter lifetimes and the initial "like-for-like" assumption did not allocate enough LED sales to the lamp failure submarket, where most sales occur. The team modified the model to automatically adjust submarket-level sales mixes in applications where the modeled sales for individual technologies were higher or lower than the sales allocations at the application level. This greatly improved the modeled sales mixes with respect to the sales allocation targets and overall distributor sales data.

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[17] The model cannot simply back-cast from the 2013 stock and prior years' sales shares alone, because the number of lamps and fixtures failing in each year depends on the mix of technologies in the stock in the prior year.

Applying the Model's Results

The results of the stock turnover model are twofold: 1) an actual market scenario, and 2) a frozen baseline scenario. The resulting differences in stock energy consumption between these two scenarios directly equate to savings in the non-residential lighting market as described in Questions 3a and 3b, which are discussed below.

Question 3a: What was the energy use in the year the plan was written?

The research team used the stock turnover model to estimate the total stock and sales technology mixes of the non-residential lighting market in 2009, prior to the Council's Sixth Plan. The team then held the 2009 sales estimates as frozen for each subsequent year of the study to compare each year to the actual market scenario. That is, while the sales mix in the actual scenario changes each year, the sales mix in the frozen scenario stays the same. The technology mix in the *stock* did change in both scenarios but less so in the frozen scenario, which drives savings.

Table 12 shows an example of the efficiency mix for the ambient linear application in 2009, the year immediately preceding the Sixth Plan, and the following years.

Table 12: Sales Mix over Time, Ambient Linear

	2009 Sales (Frozen Baseline)	2010 Sales	2011 Sales	2012 Sales	2013 Sales	2014 Sales	2015 Sales
25W T8	5%	5%	4%	4%	4%	4%	3%
28W T8	7%	8%	11%	13%	11%	10%	13%
32W T8	64%	66%	66%	67%	70%	69%	64%
LED Luminaire	0%	0%	0%	0%	0%	1%	2%
T12	21%	19%	16%	13%	12%	11%	9%
T5SO	3%	3%	3%	3%	3%	3%	2%
TLED	0%	0%	0%	0%	0%	2%	6%

Source: Non-Residential Momentum Savings Model

As shown in Equation 9, the research team calculated market energy consumption based on the resulting installed lamp stock technology mix and the UEC of each lamp type and age cohort. The model determined the number of installed lamps by simulating stock turnover, whereas the UEC came directly from input assumptions.

Equation 9: Energy Consumption

$$\text{Annual Energy Consumption}_{s,y} = \sum_{a,b,i,t} \left(\text{Installed Lamps}_{a,b,i,s,t,y} \times \text{Unit Energy Consumption}_{a,b,s,t,y=i}\right)$$

Where:

a = application

b = building type

i = installation year

s = sector

t = technology

y = year in study period

Unit Energy Consumption

Understanding how much energy one unit (lamp) consumes is a key input for calculating how much the entire lighting market consumes and must be calculated for each lamp type included in the study. The team used the following equation (Equation 10) to calculate the UEC for each lamp type in the application table in Question 1.

Equation 10: Unit Energy Consumption

$$\text{UEC} = \text{Average Wattage}_{a,b,s,t,y=i} \times \text{Annual Operating Hours}_{b}$$

Where:

a = application

b = building type

s = sector

t = technology

y = year in study period

i = installation year

See Appendix 1. Technical Data for a more detailed account of the technology specifications used in the UEC calculation.

Question 3b: What was the energy use in the following years?

In the actual market scenario for the non-residential lighting market, the team ran the model using the actual allocated sales shares over time to come up with the total stock and technology mixes for each year of the study. This allowed the model to estimate the efficiency mix in each application and submarket, effectively determining the market shares of incoming products in each purchase trigger and application.

The research team then calculated total energy consumption in the stock in the actual scenario using the UEC for each technology in each year and the modeled technology mixes.

Calculating Total Market Savings

The research team subtracted the actual stock energy consumption from the frozen baseline to arrive at the cumulative savings in each year. It is important to note that direct comparisons of stock energy consumption in any given year yield **cumulative** energy savings—savings that includes efficiency improvements in prior years. In contrast, Momentum Savings and program savings are **first-year** savings, so an adjustment was necessary. To arrive at the first-year savings, the team deducted the prior year's cumulative savings. This approach, shown in Equation 11 and Equation 12, isolates first-year savings in each year of the analysis.[18]

Equation 11: Cumulative Savings

$$\text{Cumulative Savings} = (\text{Baseline Stock Consumption} - \text{Actual Stock Consumption}) \times \text{Busbar Factor}$$

The busbar factor in Equation 11 converts energy savings at the customer meter to the generation source. The research team used a busbar factor of 1.09056 per BPA's guidance.

In 2010, the cumulative savings are equal to the first-year savings. For all other years, the team calculated first-year savings as the difference between the cumulative savings in that year minus the cumulative savings of the prior year (Equation 12).

Equation 12: First-Year Savings

$$\text{First-Year Savings}_y = \text{Cumulative Savings}_y - \text{Cumulative Savings}_{y-1}$$

Where:

y = year in study period

Question 4: What are the program savings?

The research team followed the process shown in Figure 4 to estimate program savings. This process is detailed below, including caveats by program year. Since the model frozen baseline is based on the current practice in 2009, the research team adjusted program savings that were not claimed relative to a current practice baseline to align with the model baseline.

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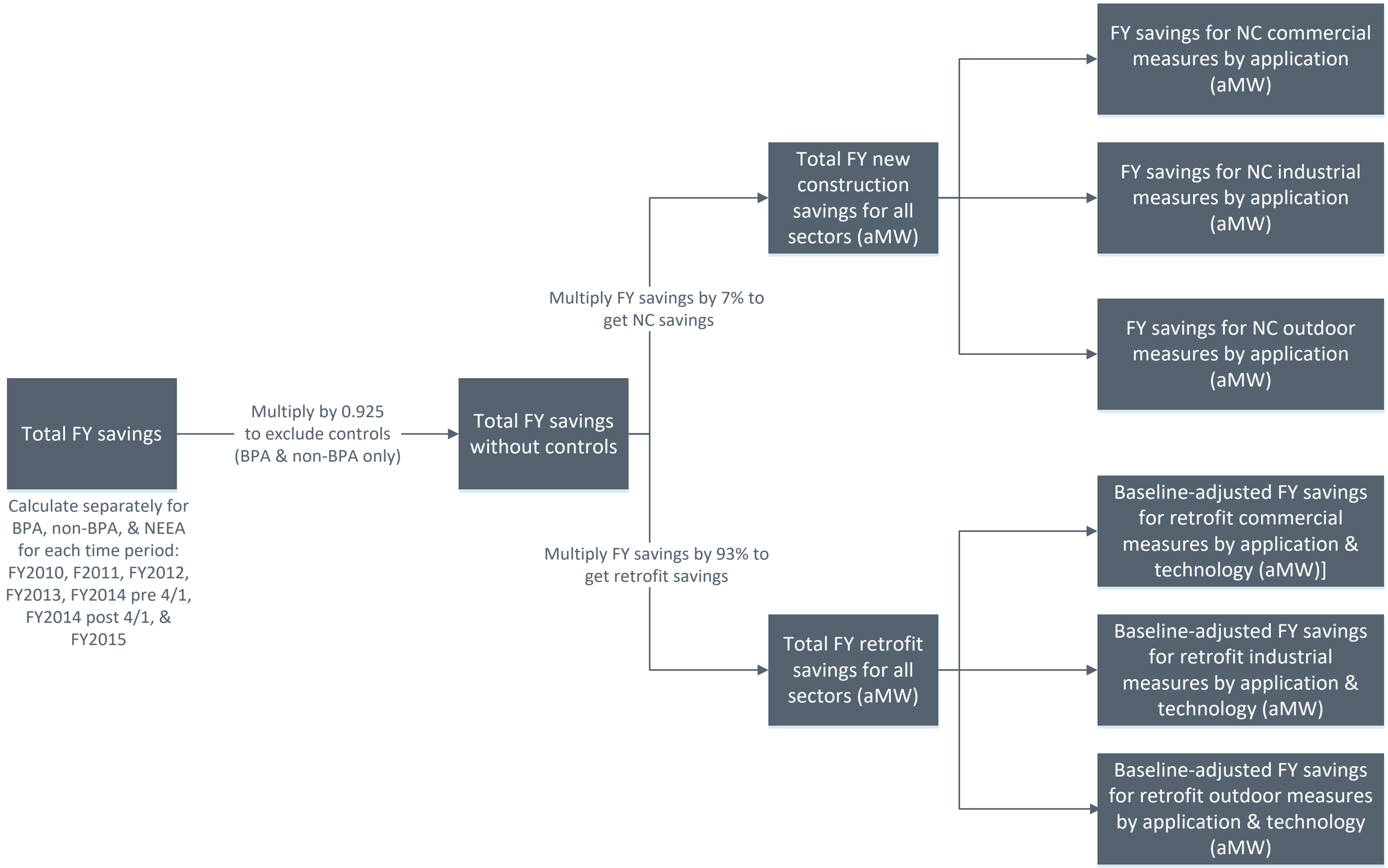
[18] In contrast to past Momentum Savings analyses, the research team had to calculate savings by monitoring changes in the stock because the conventional methodology—direct comparison of first-year consumption from lighting sales between the baseline and actual cases—overstates savings. This overstatement stems from a difference in sales volume between the baseline and actual cases. In this analysis, the actual case has fewer sales in each year because the market mix is longer lived than in the baseline mix (e.g., more LEDs and CFLs, etc.). The prevalence of longer lived products in the actual case slows the stock turnover, which results in fewer annual sales than in the baseline. However, this decrease in annual sales does not contribute to real savings as the same number of existing sockets need lamps in both scenarios.

Figure 4: Program Savings Analysis Process



Baseline adjustment notes
--No baseline adjustment for NEEA
--No baseline adjustment for new construction

Source: Research team and BPA analysis

Key Assumptions

- The team did not apply a baseline adjustment to new construction savings because new construction savings are claimed against energy code lighting power density levels, and the team assumed that energy code requirements are at least as efficient as the frozen baseline (sales in 2009).[19]
- The team did not apply a baseline adjustment to the NEEA program savings because NEEA used a current practice baseline or one that is more efficient.
- The team did not apply a baseline adjustment to linear fluorescent savings claimed relative to a current practice baseline because this baseline is at least as efficient as the model frozen baseline (sales in 2009).
- All savings are reported in average megawatts (aMW).
- All savings data inputted into the model are at the meter (site) level. The model converts them to busbar savings as needed to compare to the total market savings.
- Due to limitations in data from investor-owned utilities (IOUs) and earlier BPA projects, the research team needed to use the program savings adjustments from BPA's FY2014 and FY2015 data to estimate both the application mix and application-specific adjustment factors for all other lighting program savings. As lighting program baselines and project types have changed over this period due to federal standards regulating T12s and the emergence of LEDs, this is a significant assumption with great uncertainty that directly affects Momentum Savings estimates.

Total Fiscal Year Savings

The team's first step to estimate program savings was to obtain the total savings for each program year included in the analysis (2010-2015). The analysis required the total savings for BPA programs, non-BPA programs (investor-owned utilities, or IOUs), and NEEA programs. Table 13 provides a summary of the data sources for the program savings.

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[19] This is based on the research team's professional judgement. New construction program baselines are driven by code, which is expressed as lighting power density rather than a technology mix. This difference in metrics makes it difficult to make a direct comparison to confirm that code is more efficient than the frozen baseline; however, because new construction is the most efficient part of the market, the team believes this is a reasonable simplifying assumption.

Table 13: Data Sources for Program Savings

Entity	Data Year	Data Type	Data Source
BPA	Fiscal year (October 1 to September 30); the team converted it to calendar year (January 1 to December 31) for the model.	Busbar level; the team converted the savings to the site level (at the meter level).	BPA[20]
Non-BPA	Fiscal year (October 1 to September 30); the team converted it to calendar year (January to December 31) for the model.[21]	Busbar level; the team converted the savings to the site level (at the meter level).	Regional Conservation Progress (RCP) data, which includes both BPA and non-BPA utility savings data; the team subtracted out the BPA savings to determine the non-BPA savings[22]
NEEA	Calendar year (January 1 to December 31); the team did not have to convert the savings for the model.	Site energy savings (at the meter level); the team did not have to convert the savings for the model.	NEEA[23]

Source: Research team and BPA analysis

Accounting for Controls and New Construction Savings

The team's next step to estimate program savings was to adjust the total fiscal year (FY) savings for controls. To adjust for savings from controls, the team assumed that 7.5% of the total FY savings were savings from controls rather than changing out lamp technology.[24] This assumption applies only to the BPA program savings and non-BPA program savings.

After adjusting for controls, the team adjusted for new construction savings. The team assumed that 7% of the total FY savings without controls were from new construction and 93% of the total FY savings without controls were from existing buildings.[25] It was important to divide the total FY savings into savings from new construction and existing buildings because the team did not apply a baseline adjustment to new construction savings.

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[20] Provided by BPA via email on September 9, 2016.

[21] The Council noted to the team on October 13, 2016 that some utilities report savings in a fiscal year (October-September) while other utilities report savings in a calendar year (January-December). For the purposes of this analysis, the research team assumed that all of the RCP data corresponds to the fiscal year.

[22] The RCP data comes from https://rtf.nwcouncil.org/about-rtf/conservation-achievements/previous-years, Summary Workbook from 2014, Tab: Achieved by Sector End Use Chart. This data includes BPA and non-BPA utility savings data at the busbar level. The research team subtracted the BPA savings from the RCP data based on the data provided by BPA via email on September 9, 2016.

[23] Data provided by NEEA via email on September 8, 2016.

[24] This assumption was used in the previous non-residential lighting model and was provided by the Energy Trust of Oregon through an email correspondence.

[25] The research team used the file provided by BPA via email on September 16, 2016 titled "LCData_Latest." The team filtered completion date by 4/1/14 – 9/30/15. The team calculated percentage split using the following columns in the database: CompletionDate, CalculatorType, NC_TotalkWhSavedAdjustedForHVACAndBusbar (new construction savings), and EquipSav_HVAC_MAB_Busbar (existing building savings).

Accounting for Savings at the Sector Level

After accounting for controls and new constructions savings, the research team accounted for the split of savings by sector. The team split the data into savings from commercial, industrial/agricultural, and outdoor lighting. The team used the data sources below for all entities (BPA, non-BPA, and NEEA). The team used BPA data as a proxy for non-BPA program savings and NEEA program savings due to the lack of granularity in those datasets.

- **FY2010-FY2012:** The research team used the BPA lighting calculator data from project files between April 12, 2010 and November 16, 2013; additional details on the source of the data were provided in the Lighting Calculator Data Summary memo submitted by the research team in August 2013[26]
- **FY2013, FY2014 Pre 4/1/14:** The team used a savings midpoint from the FY2010-FY2012 dataset and the FY2015 dataset[27]
- **FY2014 Post 4/1/14:** The team used lighting calculator data[28] from April 1, 2014-September 30, 2014[29]
- **FY2015:** The team used lighting calculator data from October 1, 2014-September 30, 2015[30]

Application Mix

Once the team split savings by sector, it applied an application mix to the total FY new construction savings and total FY existing building savings. The application mix shows the percentage of savings that comes from each application. The team used a variety of sources to calculate the application mix, which are detailed below for each FY. All the data sources below are from BPA program data, which the team used as a proxy for the non-BPA program data and NEEA program data due to the lack of granularity in those data sources.

- **FY2010-FY2013 and FY2014 Pre 4/1/14:** The team used the program data from April 1, 2014-September 30, 2015. The team had to map the program data to convert it into the applications used in the model.[31]

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[26] The file behind the 2013 lighting calculator memo is called “Option1LightingData.” This file contains BPA program data for FY2010-FY2012, but it is mostly FY2012 data. The team filtered tab "tblLightingSpace," Column F (MeasureCategory) by "Deemed."

[27] The FY2010-FY2012 data comes from the Lighting Calculator Data Summary memo on August 9, 2013, which is supported by the spreadsheet “Option1LightingData.” The FY2015 data is based on measures completed between October 1, 2014 and September 30, 2015 in the spreadsheet provided by BPA via email on September 16, 2016 titled “LCData_Latest.”

[28] Extract of the lighting projects completed using the BPA Lighting Calculator; template available for download: https://www.bpa.gov/EE/Sectors/Commercial/Documents/BPA%20LC%203.3%20Final.xls

[29] The team used the file provided by BPA via email on September 16, 2015 titled “LCData_Latest.” Filtered completion date by 4/1/14 – 9/30/14.

[30] The team used the file provided by BPA via email on September 16, 2016 titled “LCData_Latest.” Filtered completion date by 10/1/14 – 9/30/15.

[31] The team used the file provided by BPA via email on September 16, 2016 titled “LCData_Latest.” Filtered completion date by 4/1/14 – 9/30/15. The lighting calculator data supporting the August 9,2013 Lighting Calculator Data Summary memo did not have reliable measure-level details to assign application mixes, therefore, the team used the BPA lighting calculator data from April 1, 2014-September 30, 2015 as a proxy.

- **FY2014 Post 4/1/14:** The team used lighting calculator data from April 1, 2014-September 30, 2014 to calculate the application mix. The team had to map the program data to convert it into the applications used in the model.[32]
- **FY2015:** The team used lighting calculator data from October 1, 2014-September 30, 2015 to calculate the application mix. The team had to map the program data to convert it into the applications used in the model.[33]

Key Assumptions

- Due to the lack of granularity in the non-BPA program data, the team used the BPA program data as a proxy to determine the application mix for non-BPA program data.
- The team assumed 100% of NEEA savings came from the ambient linear application.[34]
- The BPA lighting calculator data for new construction measures only shows the savings—not the measure-level details (e.g., baseline fixture details, efficient fixture details). Thus, the team used the retrofit data as a proxy for the new construction data to determine the application mixes.
- There are six applications that depend on wattage: High/Low Bay LOW, High/Low Bay HIGH, Building Exterior LOW, Building Exterior HIGH, Street and Roadway LOW, and Street and Roadway HIGH. The team used stock data to determine the split between high and low wattage fixtures in these applications.

Baseline Adjustment

The team's final step to estimate program savings was to adjust the baseline assumed in the program data to the model frozen baseline, thus adjusting the savings estimate. This adjustment is needed so that all savings are being compared against the same baseline and can be compared to each other (e.g., savings from the total market and the program).

This method allows for an apples-to-apples comparison of the existing equipment in the program data (the actual baseline) to the frozen baseline. Due to the limited granularity in the non-BPA program savings data, the team used the BPA baseline adjustment as a proxy for the non-BPA program savings. The team did not adjust the baseline for the NEEA program savings because NEEA uses either a current practice baseline or one that is more efficient. The team used the same data sources for the BPA program data as noted in the Application Mix section.

Baseline Adjustment Process

The research team followed these steps to complete the baseline adjustment:

1. **Created a table to indicate when to adjust and when not to adjust the baseline.** "No adjustment" means the baseline for that FY and application is current practice; therefore, no

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[32] The team used the file provided by BPA via email on September 16, 2016 titled "LCData_Latest." Filtered completion date by 4/1/14 – 9/30/14.

[33] The team used the file provided by BPA via email on September 16, 2016 titled "LCData_Latest." Filtered completion date by 10/1/14 – 9/30/15.

[34] NEEA savings are reported for linear fluorescent lamps (28W and 25W lamps) only.

adjustment is needed to make it comparable to the 2009 frozen baseline. "Adjust" means the baseline for that FY and application is not current practice; therefore, an adjustment is needed to make it comparable to the 2009 frozen baseline.

Table 14: Baseline Adjustment

Fiscal Year	Ambient Linear		General Purpose/ Omnidirectional		All Other Applications
	BPA	Non-BPA (IOUs)	BPA	Non-BPA (IOUs)	BPA and Non-BPA (IOUs)
FY2010	Adjust	Adjust	Adjust	Adjust	Adjust
FY2011	Adjust	Adjust	Adjust	Adjust	Adjust
FY2012	Adjust	Adjust	Adjust	Adjust	Adjust
FY2013	Adjust	Adjust	Adjust	Adjust	Adjust
FY2014 Pre 4/1/14	Adjust	Adjust	Adjust	Adjust	Adjust
FY2014 Post 4/1/14	No Adjustment	Adjust	No Adjustment	Adjust	Adjust
FY2015	No Adjustment	No Adjustment	No Adjustment	No Adjustment	Adjust

Source: Research team analysis of programs' adoption of current practice baselines

2. **Mapped the baseline and efficient technology names in the BPA program data to one of the 16 technologies in the model.** The naming conventions of the technologies in the program data differ from the naming conventions used in the model, which required the team to map the program data baseline and efficient technologies to one of the 16 technologies in the model (e.g., metal halide, incandescent). The non-BPA program data does not have technology-level data; therefore, the team used the BPA technology mix as a proxy. The BPA program data also does not list the baseline wattage; therefore, the team was not able to split out the T5 and T8 technologies any further (e.g., 32W T8, 28W T8) using the available information in the program data. The team instead used stock data to split out the T8s into 32W, 28W, and 25W lamps and T5s into high output T5s and standard output T5s.
3. **Calculated the percentage of savings from each baseline technology and from each efficient technology within a specific FY, sector, and application**. The purpose of this exercise was to use the percent savings to come up with a weighted average baseline and efficient wattages within a given FY, sector, and application as detailed in Step 4.
4. **Used the wattage assumptions for the technologies in the model to determine a weighted average wattage for both the baseline technology and the efficient technology in each FY, sector, and application.** The team determined a weighted average baseline wattage and weighted average efficient wattage for every unique combination of FY, sector, and application by multiplying the percent savings of each technology by the wattage of the technology in the model and summing them together for all 16 technologies. The team did this calculation for both the baseline wattage and the efficient wattage.
5. **Calculated a baseline adjustment factor for each FY, sector, and application combination.** The team calculated the adjustment factor using the following equation:

Equation 13: Baseline Adjustment Factor Calculation

$$\text{Baseline adjustment factor} = \frac{\text{Wattage}_{\text{Baseline, Frozen}} - \text{Wattage}_{\text{Efficient, Program Data}}}{\text{Wattage}_{\text{Baseline, Program Data}} - \text{Wattage}_{\text{Efficient, Program Data}}}$$

Where:

- $\text{Wattage}_{\text{Baseline, Frozen}}$ = Weighted average baseline wattage from the 2009 frozen baseline for a given FY, sector, and application (calculated from the frozen baseline scenario within the model)
- $\text{Wattage}_{\text{Efficient, Program Data}}$ = Weighted average efficient wattage from BPA program data for a given FY, sector, and application (see Step 4 above)
- $\text{Wattage}_{\text{Baseline, Program Data}}$ = Weighted average baseline wattage from BPA program data for a given FY, sector, and application (see Step 4 above)

6. **Applied the adjustment factor to the program savings for a given FY, sector, and application, when applicable (see Table 14).** The team applied the adjustment factor to the program savings when applicable to adjust the program savings baseline to the 2009 frozen baseline.

Key Assumptions

- The research team did not have detailed program data for years prior to 2014 and thus used the program baseline and efficient technology mixes for 2014 for 2010 through 2013. This makes the baseline adjustment for prior years highly uncertain.
- When this application of 2014 mixes resulted in LEDs in program mixes before LED sales began in an application, the research team removed LEDs from the program mix and renormalized the remaining technologies to 100%.
- The team allowed baseline adjustment factors to be greater than 1.0 (e.g. programs used a baseline more efficient than the frozen baseline), with two exceptions:
    - **Building Exterior LOW**: This application has many different lighting types (wall packs, post-top/low output area lighting, bollards, flood lights etc.) and the research team believes that the difference between the frozen and program baselines is likely because programs focus on a certain subset of building exterior: metal halide is the most common baseline technology in programs, whereas incandescent are a large portion of the frozen baseline. The goal of the baseline adjustment is to make sure the program and frozen baselines are aligned—and in this case the difference does not indicate that program baselines were incongruent, rather programs focused on a subset of the application. The research team applied an adjustment factor of 1.0 for this application.
    - **Building Exterior HIGH**: The adjustment for most years is almost exactly 1.0, but when the LED percentage drops in earlier years (2010 and 2011), the efficient wattage gets much closer to both baselines. This makes the difference in baselines (approximately one watt) more significant. The research team believes this is an issue with lack of data on the program efficient mix in earlier years which should not affect the adjustment factor—not an issue of incongruent program baselines—and used an adjustment factor of 1.0 for these early years.

Calculating Momentum Savings

The research team removed the savings associated with programs calculated in Question 4 from the team's estimates of total market savings calculated in Question 3 to arrive at an estimate of non-residential lighting Momentum Savings.

Appendix 1. Technical Data

The majority of the technical data used in this study relates to the technical specifications of all the different lamps, ballasts, and fixtures competing in the stock turnover model. The technical specifications (tech specs) include lifetime, labor cost, equipment cost, efficacy, lumen output, and wattage. Additional technical data includes HVAC interaction factors and the sales categories that compete in each technology category within an application.

Lifetime drives how often lamps and ballasts burn out, and wattage dictates the energy consumption of each technology. The team used lumen output and efficacy data to derive wattage estimates for each technology and to ensure all technologies in each application had similar lumen outputs. Since the forecasting part of the model uses economic logic to determine what portion of sales go to each technology when equipment fails or is replaced, the team also needed data on first cost and operating cost. Wattage drives operating cost, while equipment and installation costs drive first cost; equipment and installation costs are not insignificant for some applications such as streetlights.

For each of the three submarkets—lamp, ballast, and fixture—the team developed tech specs at the year, sector, application, and technology levels. The tech specs can be defined as the value that represents that general category but not any given lamp on the shelf or available online. This is because within a subcategory of lamps there can be some variation in the actual specifications. There are six tech specs necessary for the model. Table 15 lists the value and unit for the individual tech specs for each of the three submarkets.

Table 15: Tech Specs by Submarket

	Lamp (y, s, a, t)	Ballast (y, s, a, t)	Fixture (y, s, a, t)
Efficacy	lm/W (lamp)	Ballast efficiency (%)	1.0
Lifetime	1,000 hours (lamp)	1,000 hours (ballast)	N/A (retrofit rate)
Lumen Output	lm/lamp	lm/lamp * lamps/ballast	lm/lamp * lamps/ballast * ballasts/fixture
Watts	W/lamp=lumen output/efficacy	Watts/lamp * lamps/ballast	Watts/lamp * lamps/ballast * ballasts/fixture
Equipment Cost	$/lamp	$/ballast + $/lamp*lamps/ballast	$/fixture+ $/ballast*ballasts/fixture+ $/lamp*lamps/ballast
Labor Cost	$/lamp	$/ballast	$/fixture

Lamp Specifications

The research team first calculated all lamp specifications except for labor cost at the level of granularity of the sales data. The granular level of the sales data, in many cases, maps more closely to a given lamp on a shelf or online (i.e. 400W metal halide lamp). For LED luminaires, the sales data is at a luminaire category level such as LED track lighting luminaires. Developing the technical specifications at the sales level allows flexibility to roll up those categories into the model separate from an input value at the general category level. For example, both a 40W and 100W A-type incandescent fit within the category "General Purpose" and technology type "Incandescent." However, the 40W A-type has different technical specifications than a 100W A-type. The sales level granular lamp tech specs are agnostic of the purchaser and thus do not vary by application or sector: that is, a 250W metal halide lamp has the same wattage, efficacy, lumen output, and equipment cost whether it is installed in a low bay commercial warehouse, high bay industrial facility, or parking lot. Differences by application and sector do arise from differences in mapping subcategories of lamps to each application, which is discussed in the next section. Table 16 lists the inputs for the lamp specifications.

Table 16: Inputs for Lamp Specifications

Inputs for Lamp Specifications	Sales Level				Application Level
Input	Lamp lumen output	Lamp efficacy	Equipment cost	Lifetime	Labor cost
Unit	lm/lamp	lm/W	$/lamp to purchase	1,000 hours	$/lamp to install

Lamp Lumen Output

Lumen output is a unique characteristic of a lamp or luminaire. For some technologies where the sales data was for a specific wattage, the lumen output correlates with that wattage. For example, a 100W incandescent has a different lumen output than a 40W incandescent. For other more general categories, such as a halogen R/BR reflector, the team used a representative lumen output to approximate the mix of lamps in that category (e.g., R60, BR40, and BR60).

There are two main data sources for lumen output. The team used the lumen output data for 2010-2014 from previous Momentum Savings research the team developed over the past three years. This analysis relied on data from DOE rulemakings for incumbent technologies and a combination of qualified product list databases and webscraping for LED technologies. The 2014 and 2015 BPA Lighting Market Characterization reports summarize these methods in more detail.[35] Second, the team filled in 2015 lumen output with the latest national data (for changing technologies such as LED) or held the data constant (for incumbents). For 2009, the team either backcast or held the lumen output constant depending on whether the 2010-2015 data showed a consistent trend. For some lamp types in the model where BPA did not collect sales data, the team did not estimate tech specs as part of the previous analysis. Figure 5 summarizes these special cases and the source of the tech specs for each product. In this figure, ES Database stands for the ENERGY STAR database of qualified lamps.

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[35] Bonneville Power Administration, "Northwest Nonresidential Lighting Market Characterization," 2014. https://www.bpa.gov/EE/Utility/research-archive/Documents/Northwest_NonRes_Lighting_Market_Characterization.pdf

Bonneville Power Administration, "2015 Non-residential Lighting Market Characterization," 2015. https://www.bpa.gov/EE/Utility/research-archive/Documents/Momentum-Savings-Resources/2015_Non-Res_Lighting_Mkt_Characterization.pdf

Figure 5: Lumen Output Source Data for Select Lamp Types

Lamp Type	Lamp Lumens						
	Sales Year						
	2009	2010	2011	2012	2013	2014	2015
Other LED Lamps							
Decorative (40W equivalent)	Extrapolated				ES Database		
High Output Lamp		2016 DOE National Model					
Incandescent A-type							
100W Incandescent Equivalent	Assumed conservative lumen output based on looking at EISA minimums and published values of lumen output						
75W Incandescent Equivalent							
60W Incandescent Equivalent							
40W Incandescent Equivalent							
Other Incandescent							
Decorative (40W)	Based on National Model efficacy and assumption of 40W incandescent decorative						
Outdoor High Output	Based on online listed output of 500W incandescent lamps						
CFL							
A-Type	Extrapolated				Based on a weighted average of lumen output from sales data collected on CFL A-Type by wattage from 2013-2015		
Decorative (40W equivalent)	Extrapolated			ES Database			
CFL Reflectors							
PAR	Extrapolated	2016 DOE National Model					
R/BR	Extrapolated	ES Database	Extrapolated		ES Database		
Halogen A-type							
100W Incandescent Equivalent	Assumed conservative lumen output based on looking at EISA minimums and published values of lumen output						
75W Incandescent Equivalent							
60W Incandescent Equivalent							
40W Incandescent Equivalent							
Halogen Reflectors							
PAR	Extrapolated	2016 DOE National Model					
R/BR							
MR16							
Other Halogen							
Decorative (40W equivalent)	Set to be the same lumen output as the 40W incandescent decorative lamp						
Outdoor High Output	Extrapolated	2016 DOE National Model					

Lamp Efficacy and Wattage

The research team used the same data sources for efficacy as for lumen output and calculated wattage by dividing lumen output by efficacy for each lamp type. Additional nuances for the lamp efficacy data are as follows:

- Manufacturers may report LED lamp efficacy based on the mean lumen output or the initial lumen output. For incumbent technologies, the team used mean lumen output. For LED lamps and luminaires, the team used the listed lumen output provided by manufacturers and assumed that this represented the mean lumen output.
- Ballast efficiency is included in the lamp efficacy estimates—thus, the average lamp wattage represents the power draw of that lamp type given the average mix of ballasts with which it could be paired. This is relevant for linear fluorescent and HID systems, where technology progress and

standards have led to changes in ballast efficiency over time. The team derived ballast mixes for these technologies using ballast sales data from 2010 to 2012. However, while the CBSA has some data on ballast efficiency mixes in the stock, there is not sufficient data to justify an adjustment to differentiate ballast efficiency in new versus existing fixtures. Thus, the team made the simplifying assumption that a lamp replaced due to maintenance is installed into a fixture with a ballast that has the same efficiency and lifetime of the average new ballast sold for that technology.

- For CFL and LED decorative lamps, lamp efficacy was determined by dividing the lumen output by lamp wattage in the ENERGY STAR database.

Equipment Cost

For equipment cost data, the research team relied upon inputs from the national lighting model that Navigant built for the US DOE. These inputs leverage the rich datasets used in DOE rulemaking analysis. When the team adapted these costs to the individual sales categories for incumbent technologies, the team assumed that cost scales linearly with lumen output. The national lighting model determined LED lamp and LED luminaire costs at the dollar/kilolumen level. The equipment cost was determined by multiplying the dollar/kilolumen by the lumen output of each lamp or luminaire. LED luminaire costs are identical in each submarket because the team assumed that LED luminaires compete for every purchase trigger. The national model's first year is 2010, so for 2009 the team backcasted this data. The model annualizes the equipment cost over the lifetime of the lamp.

Labor Cost

The research team also leveraged data from the DOE lighting model for labor cost estimates. In most cases, the team held labor cost constant across applications and sectors. However, labor cost varies by application and sector, as shown in Table 17, for HID and the LED luminaire equivalent. In this case, lamps are cheaper to install in interior applications than exterior applications in the outdoor sector. As with the equipment costs, the model annualizes labor cost based on the lamp lifetime to account for the fact that labor costs over a given period will decrease if CFLs or LEDs with longer lifetimes replace incumbents with shorter lifetimes.

Table 17: Examples of Labor Cost

Technology	High/Low Bay (LOW and HIGH)	Building Exterior (LOW and HIGH)	Parking Lot	Parking Garage	Street and Roadway (LOW and HIGH)
Metal Halide	$18	$54	$54	$54	$54
High Pressure Sodium	$18	$54	$54	$54	$54
Mercury Vapor	$18		$54		
LED Luminaire	$18	$54	$54	$54	$54

Source: Research team analysis of DOE data

Lamp Lifetime

One of the most important technical specifications is lamp lifetime. This determines the turnover in the lamp submarket or maintenance submarket. The research team used the lamp lifetime data from the DOE model. For the incumbent technology, the DOE model determined a 2010 value and annual rates of increase that vary by technology category. A lifetime value for all years was determined for the LED lamps and luminaires with some increasing over time and others held constant.

Lamp Operating Costs

Wattage and the electricity costs determine the lamp operating costs. In the forecast period, the model competes the technologies against one another based on the sum of the annualized labor cost, annualized equipment cost, and yearly operating costs.

Ballast Specifications

Ballast specifications drive the costs and turnover in the ballast submarket. While some of the technologies do not have ballasts (such as screw in lamps), HID, linear fluorescent, and pin CFLs do have ballasts. As LED lamps and TLEDs may have various ballast or driver configurations, the team made the following assumptions:

- TLEDs installed in the lamp submarket are those that can integrate with the existing ballast (may be known as instant fit or plug and play).
- TLEDs installed in the ballast submarket do not have a ballast and an electrician wires them directly to the power source (also known as ballast bypass). This leads to an associated labor cost and a lifetime associated with that wiring set, which is the same as a linear fluorescent ballast replacement.
- Higher output LED lamps can have external drivers similar to a ballast. In the ballast submarket, the team assumed that these lamps would have a driver installed that is similar to the ballast of the technology that they are replacing and that labor costs and lifetime are the same. The team did not find significant price differences between lamps with integrated and external drivers and thus assumed that equipment cost for this external driver is part of the lamp cost. The result is that the ballast cost for LED lamp replacements is zero.

Table 18 list the inputs for the ballast specifications.

Table 18: Inputs for Ballast Specifications

Inputs for Ballast Specifications	**Sector and Application Level**			**Technology Level**
Input	Lamps per ballast	Equipment cost	Labor cost	Lifetime
Unit	Lamps/ballast	$/ballast to purchase	$/ballast to install	1,000 hours

Lamps per Ballast

Based on the stock mapping and lamps per fixture data in the CBSA, the research team assumed that all applications and technologies have only one ballast per fixture, except for linear fluorescent fixtures with more than four lamps in the High/Low Bay HIGH application. The team assumes these fixtures have two ballasts per fixture in both the commercial and industrial sectors. The team calculated the lamps per ballast by dividing the lamps per fixture by the number of ballasts per fixture. Since the model does not force lumens to remain constant in lamp, ballast, or fixture replacements, it is important that the lamps competing in a single application have roughly equivalent lumen output at either the ballast or fixture level. For example, if a consumer decides to replace a failed T12 ballast and the corresponding two T12 lamps with a T8 ballast and two lamps, the lumen output of that combination needs to be a reasonable substitute for that of the T12 fixture.

Equipment Cost

The equipment cost for the ballast comes from the DOE model. The DOE model determined a 2010 equipment cost by technology and sector and assigns a cost decline rate for each technology. The rate of decline is either 0% or 0.5% per year.

Labor Cost

The team set up the model logic such that when a ballast fails, the lamps associated with the ballast are replaced in addition to the ballast. The equipment costs for the lamps associated with the ballast are included in the overall cost of a ballast replacement, and there is not a separate labor cost to account for the lamp replacement.

Ballast Lifetime

The ballast lifetime drives the ballast submarket and is from the DOE model. The DOE model provides a 2010 ballast lifetime and an improvement rate in the ballast lifetime. The 2010 ballast lifetime is either 50,000 hours for all linear fluorescent and pin base CFLs or 75,000 hours for all HID lamps such as metal halide, high pressure sodium, and mercury vapor. The improvement rate for both groups is 0.5% per year.

Fixture Specifications

The research team assumed that all lamp types except for LED luminaires require a fixture. The team did not analyze fixture specifications as part of previous Momentum Savings research except for LED luminaires. Thus, the team relied on the fixture specifications in the DOE lighting model. For LED lamps including TLEDs, the fixture cost is the same as the incumbent technology. All the fixture specifications vary at the sector and application level (Table 19).

Table 19. Inputs for Fixture Specifications

Inputs for Fixture Specifications	Sector and Application Level			
Input	Ballasts/fixture	Equipment cost	Labor cost	Lifetime for annualizing costs
Unit	Ballast/fixture	$/fixture to purchase	$/fixture to install	150,000 hours

Ballasts per Fixture

The ballast per fixture is set to one in all cases except for High/Low Bay HIGH fixtures in commercial and industrial where it is set to two ballasts per fixture because the lamps per fixture is close to six lamps.

Equipment Cost

The fixture equipment cost for all incumbent technologies is from the DOE model and varies at the sector and application levels. The DOE analysis estimated 2010 fixture costs by technology and sector and assigned a cost decline rate for each technology. The rate of decline is either 0% or 0.5% per year. The team calculated the cost of LED luminaires at the granular sales data level using the same process as for lamp cost and rolled it up based on mapping, as discussed in the next section.

Labor Cost

The fixture labor cost is from the DOE model and varies at the sector and application levels. It ranges from $2 to $225 depending on the sector and application, with the two drivers being lamp type and lamp location—either interior or exterior. It does not change over time.

Lifetime

Turnover in the fixture submarket only occurs due to retrofit rates. The model does not incorporate fixture failure in the model in a similar way to lamp or ballast failure. However, the model needed to annualize fixture labor costs and equipment costs in a similar manner to lamp and ballast equipment and labor costs. For this reason, the model uses a fixture lifetime of 150,000 hours for all technologies to annualize the upfront costs.

HVAC Interaction Factor

The research team used the most recent HVAC interaction factors available through the RTF for commercial buildings. The RTF derived these interaction factors from building simulations for the entire region. The team used the regional weighted average values for each building type and used the warehouse building type for the industrial sector. There is no HVAC interaction for exterior and outdoor lighting.

Mapping Sales Data to Model Technologies and Applications

Between 2010 and 2015, BPA has collected sales data for more than 70 lamp and fixture types and technology combinations. To keep the model size more manageable, the research team collapsed many of these subcategories to align with the technologies and applications in the model. The team varied how each lamp and fixture type in the sales data maps to the model technologies by application and sector so that the rolled up tech specs would vary by application and sector, as applicable. For example, the team mapped different wattages of HID lamps to the Building Exterior High and Building Exterior Low categories to ensure that the high output application wattage and lumen output were higher than those in the low output application. The following sections describe the model technologies in more detail and how the team weighted the detailed sales data to create tech specs for each technology in each application and sector.

Model Technology Definitions

The research team defined model technologies after reviewing several sources, such as policy initiatives that could change the overall technology deployment over time, and regional stock data. The model's technologies include HID, linear fluorescent, halogen, incandescent, CFL, and LED lamps and luminaires. Table 20 provides more detail. To limit the model's size, the team only split two of the linear fluorescent technologies into different wattage groups. The team split T5 into T5SO (28W) and T5HO (54W) and T8 into 32W, 28W, and 25W.

Next, the team defined which technologies compete in each application and sector. The 2013 CBSA provided information on technologies available in that year. Due to significant improvements in LEDs since that time, the team added at least one LED technology such as an LED lamp, LED luminaire, or TLED to each application independent of whether it was present or not in the 2013 CBSA stock analysis. Table 20 shows the technology map for all the interior commercial applications. The 16 model technologies are listed in the first row. The number of model technologies that compete in an application ranges from two (Track Small) to 12 (Commercial Building Exterior Low).

Table 20: Commercial Interior Technology Map

Application	32W T8	28W T8	25W T8	T12	T5SO	T5HO	CFL	Pin CFL	Hal	Inc	HPS	MH	MV	LED Lamp	LED Luminaire	TLED
Ambient Linear	▨	▨	▨	▨	▨										▨	▨
General Purpose							▨		▨	▨				▨		
Downlight Large							▨	▨	▨	▨		▨		▨	▨	
Track Large							▨		▨	▨				▨	▨	
Track Small									▨					▨		
Decorative							▨		▨	▨				▨		
High/Low Bay LOW	▨			▨	▨	▨					▨	▨	▨	▨	▨	▨
High/Low Bay HIGH	▨			▨	▨	▨					▨	▨	▨		▨	▨

Since the model technology categories are fewer than the sales data categories, the team needed to roll up the lamp tech specs at the sales level to determine the lamp tech spec at the higher level category. To do this, the team weighted the lamp tech specs of each subcategory mapped to that application by the sales quantities for each subcategory. This way the model-level category matches closely with the sales data. The team weighted to roll up lamps split by lumen output and wattage, efficacy level, length, bulb type, and application type in the sales data as necessary for each mapping.

For categories where lamp characteristics were not generally improving such as HID technologies, A-type incandescent, and halogen, the average weight of each lower level category for 2010-2015 was used to provide one higher level tech spec for the entire period of 2009-2015. For categories that were changing over time (linear fluorescents, reflectors, and LEDs), the team calculated a tech spec for each year with sales data from 2010 to 2015 and for 2009 by using the 2010 sales splits.

The general equation for the tech spec if two lamp types (x and y) are mapped to one model-level category is shown in Equation 14:

Equation 14: Tech Spec Aggregation

$$\text{tech spec}_{\text{group, application, sector}} = \frac{\left(\text{sales quantity}_x \times \text{tech spec}_x\right) + \left(\text{sales quantity}_y \times \text{tech spec}_y\right)}{\text{sales quantity}_x + \text{sales quantity}_y}$$

Lumen Output and Wattage Rollup

Many of the general lamp categories in the sales data have subcategories of lamps grouped by wattage. These categories include all HID lamps, A-type incandescent, halogen, LED lamps, and linear fluorescent lamps. For example, the research team calculated weighted average specifications based on all wattages of A-type incandescent lamps (40W, 60W, 75W, and 100W) for the incandescent technology in the general purpose application.

In some cases, the team needed to map different wattage levels to the model-level categories using lumen bins. The team determined the lumen bin cutoff for the three applications with HIGH and LOW lumen bins. The lumen bin cutoffs are as follows:

- High/Low Bay is 15,000 lumens and above in HIGH
- Building Exterior is 7,000 lumens and above in HIGH
- Street and Roadway is 25,000 lumens and above in HIGH

The team mapped the individual lamp wattage subcategory using the mean lumen output determined in the lamp tech specs. The team split LED luminaires by specific application if no lumen output information was available from the sales categories. Table 21 lists the sales category split for the three applications with lumen bins.

Table 21: Mapping Technologies and Applications

Technology	High/Low Bay LOW *<15,000 lm*	High/Low Bay HIGH *≥15,000 lm*	Building Exterior LOW *<7,000 lm*	Building Exterior HIGH *≥7,000 lm*	Street and Roadway LOW *<25,000 lm*	Street and Roadway HIGH *≥25,000 lm*
High Pressure Sodium	<250W	-	70W	-	100-250W	-
	-	≥ 250W	-	>70W	-	-
Metal Halide	<250W	-	≤ 150W	-	150-250W	-
	-	≥ 250W	-	>150W	-	≥ 400W
Mercury Vapor	<250W	-	-	-	-	-
	-	≥ 250W	-	-	-	-
LED Luminaire	Low Bay 5,000-15,000	-	LED Wall Packs, LED Post-Top, and Bollard	-	LED Post-Top and Bollard	-
	-	High Bay >15,000	-	LED Canopy Fixtures, LED Area, and Parking Lot	-	LED Roadway

Lamp Shape Rollup

For the reflector category for incandescent, halogen, CFL, and LEDs, the sales data is at the lamp shape level (i.e., R/BR, PAR). For the Downlight Large and Track Large applications, the research team rolled up all reflector lamp shapes into the model-level technology. The MR16 lamps are the only shape included in the Track Small application.

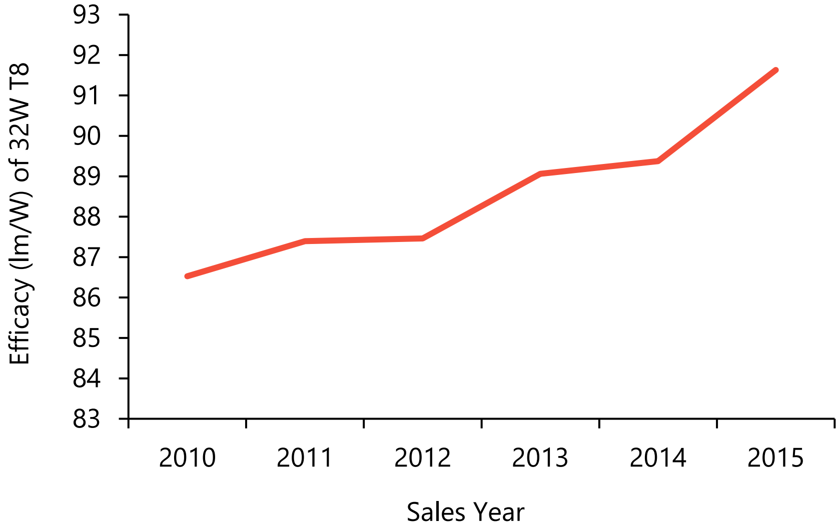
Length Rollup

For the T12 and T8 categories with sales data for both 4-foot and 8-foot lamps, the research team determined the sales amount by which to weight the tech specs by doubling the sales quantities of the 8-foot lamps and keeping the sales quantities of the 4-foot lamps the same. The team halved the wattage and lumen output tech specs of the 8-foot lamps for the roll up. The two applications with 8-foot lamps are High/Low Bay HIGH and High/Low Bay LOW. The model considers all linear fluorescents as 4-foot lamps.

Efficacy Rollup

In one case, the research team collected sales data for the same lamp at two efficacy levels: the 700 and 800 series 32W T8. Since the model only has one 32W T8 category, the sales of both the 700 and 800 series are mapped to that one model technology. This mapping has an important impact on the efficacy of the 32W T8 since the efficacy varies between the 700 and 800 series. For the case of the 32W T8, the team weighted the tech specs for the 700 and 800 series by the split of 32W T8 between 700 and 800 series for each year. The impact of this roll up on the efficacy of the model-level category is evident in Figure 6.

Figure 6: 32W T8 Rollup of 700 and 800 Series 4-Foot Lamps



The reason the efficacy increases over time is that in the sales data collected for 2010-2015 the percentage of 800 series 32W T8 lamps increased over time, and the 800 series lamps have a higher efficacy than the 700 series. The rolled up 32W T8 tech specs are used for all 32W T8 lamps in all applications unless there are 8-foot T8s mapped to that application. In those cases, the team weighted in the 8-foot T8 tech specs as well.

Lamp Types Not in the Sales Data

In some cases, the research team did not collect sales data for a lamp or technology type that was present in an application. For example, the team did not collect any sales data on decorative lamps, but there is a decorative lamp application. Thus, the team did not weight the tech specs by sales and generated the specs at the model application and sector levels. Other missing gaps are high output TLEDs; high output outdoor halogen, incandescent, and LED lamps; CFL A-type lamps; and halogen MR16s.

Modifications to Individual Technologies

The research team reviewed lumen output data for each application at the fixture level to ensure that all technologies were reasonable replacements. This review led to the following adjustments:

- Revising the number of lamps per fixture for linear fluorescent technologies in the high/low bay applications to better align with metal halide lumen output
- Reducing LED Luminaire lumen output in many applications to account for higher fixture efficiency of LED products relative to incumbents
- Making wattage for high pressure sodium and metal halide lamps equal within applications where both technologies compete; this assumes customers purchase based on wattage, not lumen output, due to the poor light quality of high pressure sodium lamps
- Revising both the halogen and LED lumen output levels within Track Small to reduce the difference between the technologies' lumen output

Appendix 2. Historic Stock Model to Determine Initial Age Distribution

To estimate the age of lamps installed in the baseline year (2009), the research team used a stock tracking model to simulate the growth in lamp stocks prior to the baseline year. The model accounts for the lifetimes and survival distributions of various technologies, the historic rate of sales growth,[36] building stock demolition rates, and lamp replacements associated with ballast failure and fixture retrofits. With information about the rate of growth in sales, the model accumulates sales for each technology beginning in 1989 (20 years prior to 2009) and simulates like-for-like replacement for lamp turnover. By tracking these dynamics for 20 years, the model can determine a reasonable approximation of the age distribution of the stock at the beginning of 2009. In addition, the historic stock tracking routine applies the same turnover dynamics as the logic used for the 2009-2020 horizon, ensuring internal consistency.

The pre-2009 stock tracking routine does not make any assumptions about the relative mix of technologies because that adjustment takes place after computing the age distribution. Additionally, the routine does not need to know the absolute quantity of sales for a given technology to determine an age distribution. As such, the pre-2009 stock tracking relies upon a normalized representation of stocks—meaning that the quantity of lamps is not tied to historic quantities but is tied to historic growth rates.

As shown in Figure 7, the historic stock tracking model provides an estimate of how the stock has grown up to 2009 (in a normalized representation) and what percentage of the stock comes from different installation years. This information inherently captures the age of lamps included in the commercial model's baseline year initial lamp stock.

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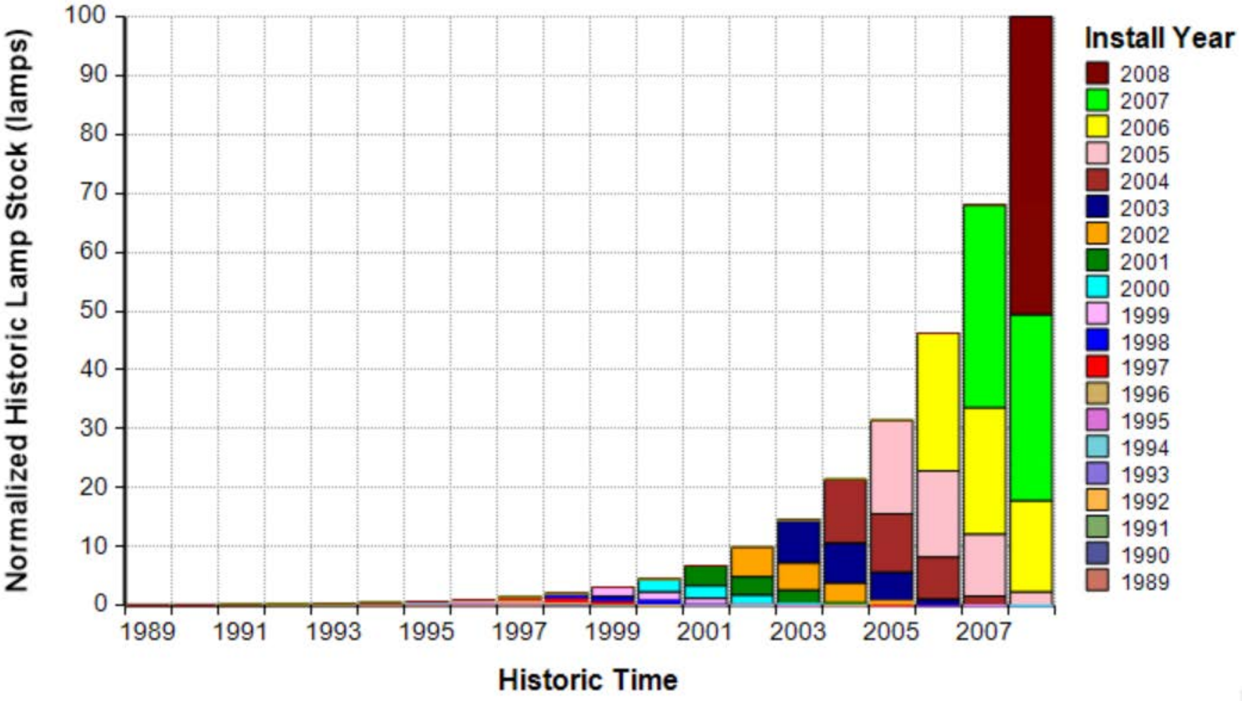
[36] Where data was available, the model used historic growth rates in sales. When data was not available, the model used historic building stock growth rates as a proxy for the growth rate in sales.

Figure 7: Illustrative Normalized CFL Lamp Stock for Historic Years (Lamps)



Source: Non-Residential Momentum Savings Model

By examining the end-of-year 2008 lamp stock (i.e., the beginning of year 2009 lamp stock), the model determines the percentage of that stock coming from various installation years. As shown in Table 22, this information regarding how much of the stock was installed in each year provides an age distribution for the baseline year. The age distributions reflect the different operating hours for each application, the different rated lifetimes for each technology, and the different demolition rates by building type.

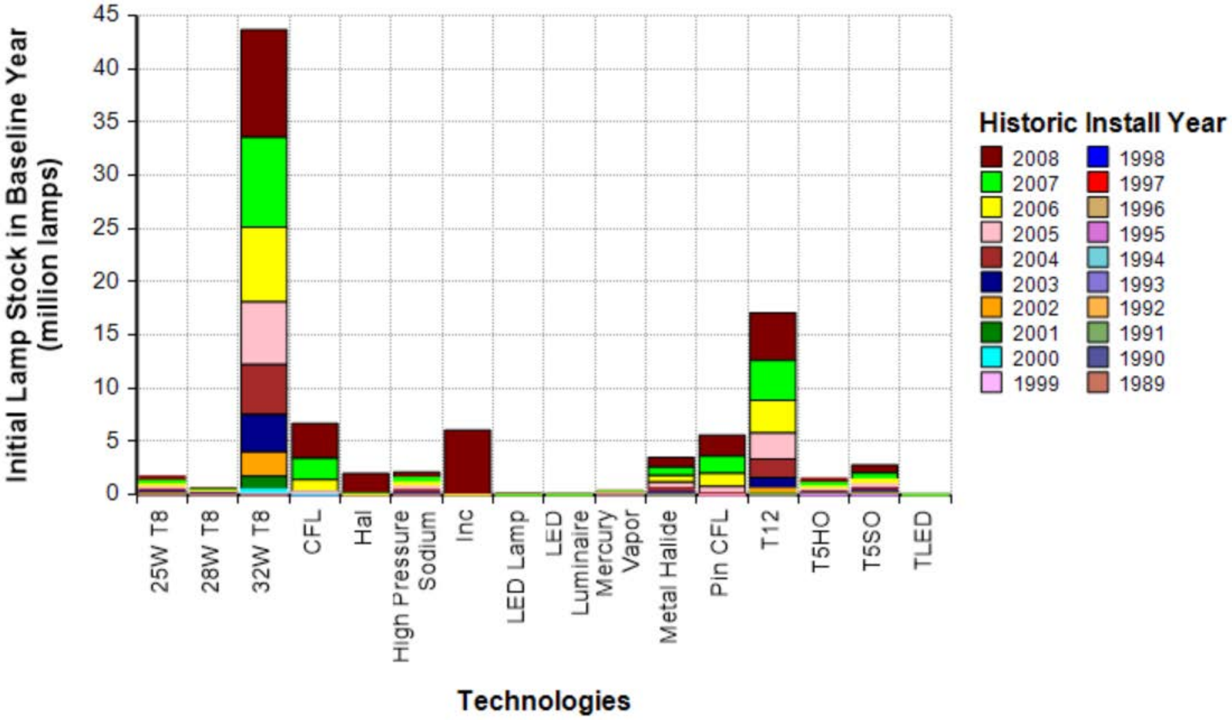
Table 22: Illustrative Base Year Age Distribution of CFLs by Commercial Application

Installation Year (Proxy for Age)	Building Exterior LOW	Decorative	Downlight Large	General Purpose	Track Large
1995	0.0%	0.0%	0.0%	0.0%	0.0%
1996	0.0%	0.0%	0.1%	0.2%	0.0%
1997	0.9%	2.5%	4.5%	5.0%	1.8%
1998	14.4%	15.7%	16.7%	16.8%	14.9%
1999	32.4%	31.1%	30.2%	30.0%	31.2%
2000	52.4%	50.8%	48.5%	48.0%	52.1%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Source: Non-Residential Momentum Savings Model

After determining the age distribution of the baseline year's lamp stock, the model distributes the 2009 lamps stocks across the appropriate installation years. The result is a baseline lamp stock with the correct number of lamps for 2009 and a robust estimation of the age distribution. Figure 8 provides an illustrative example.

Figure 8: Illustrative Lamp Stock in Baseline Year (2009) by Technology (Million Lamps)



Source: Non-Residential Momentum Savings Model

Appendix 3. Difference Between Calculated and Applied Sales Mixes

As noted in Question 3, applying the sales mixes estimated in the sales allocation process does not result in modeled sales that align exactly with the sales allocations estimates without adjustment. There are two reasons the actual modeled sales do not exactly match the sales allocation targets before the final adjustment.

Accounting for Stock Turnover Dynamics

The sales allocations process identifies what percent of total sales for each technology go to an application. However, once these mixes are renormalized within each application and submarket, the actual volume of sales over time can result in different total mixes at the application or market level. The following example illustrates this effect.

The product of summed sales allocations (indexed by applications, submarkets and technologies) and the observed sales mix (indexed by technologies) establishes relative share of sales going to each application and submarkets, summing to 100% over all applications, submarkets and technologies in each year. Table 23 provides a simplified summary of this using example data (submarket-level detail omitted for clarity).

Table 23. Simplified Example of Sales Allocation Outputs before Normalization

Technology	Ambient Linear	High/Low Bay High	High/Low Bay Low	Total
T8	55%	5%	10%	**70%**
T5	1%	7%	2%	**10%**
HID	0%	10%	10%	**20%**
Total	56%	22%	22%	**100%**

To apply these data in the model, the research team normalized the mix such that it would sum to 100% over all technologies in each application and submarket. Table 24 illustrates how the example data from Table 23 would be normalized to the application level.

Table 24. Example Normalized Application Sales Mixes

Technology	Ambient Linear	High/Low Bay High	High/Low Bay Low
T8	98%	23%	45%
T5	2%	32%	9%
HID	0%	45%	45%
Total	100%	100%	100%

The model turnover dynamics then dictate the quantity of sales occurring in each application. Table 25 provides example data for the share of lamp sales going to each application.

Table 25. Example Share of Modeled Lamp Sales by Application

Ambient Linear	High/Low Bay High	High/Low Bay Low	Total
52%	24%	24%	100%

When the model aggregates over applications to calculate a total sales mix by technology, the quantity of sales used to weight each application's contribution to the total can differ from the original sales targets. These differences in weighting lead to a simulated technology sales mix that is different from the original sales data mix: note that multiplying the sales mixes in Table 24 and Table 25 yields a different total mix in Table 26 than the starting mix in Table 23.

Table 26. Example Simulated Sales Mix

Technology	Ambient Linear	High/Low Bay High	High/Low Bay Low	Total
T8	51%	5%	11%	**67%**
T5	1%	8%	2%	**11%**
HID	0%	11%	11%	**22%**
Total	52%	24%	24%	**100%**

These variations can also occur at the submarket level.

Variances in Lamps per Fixture

The second complication is that to align with the sales data (which is in lamps) and sum across submarkets, the sales allocations process occurs at the *lamp* level. Different technologies have different numbers of lamps per fixture—and some technologies cannot replace each other without replacing the ballast and/or fixture—so attempting to force a certain lamp sales mix can result in differences in lamp counts. For example, perhaps T5 lamps should be 60% of lamps in the High/Low Bay High lamp submarket. Some of the lamp outflows will be metal halide, and the model must replace the whole fixture and install multiple T5 lamps to replace a single metal halide lamp. The model will do this, and could in doing so inflate the number of T5 lamps relative to the sales allocation target.

D. Report on Data Collection Activities to Improve the Model

This memorandum, submitted to BPA on May 10, 2017, summarizes ways that BPA can collect additional data to improve the non-residential Momentum Savings model.

Memorandum

To:	Jessica Aiona and Carrie Cobb, Bonneville Power Administration (BPA)
From:	Laura Tabor, Ariel Esposito, James Milford and Julie Penning, Navigant Consulting, Inc. (Navigant); Kate Bushman and Rob Carmichael, Cadeo Group
Date:	May 10, 2017
Subject:	Data Collection Activities to Improve Non-Residential Lighting Model

This memo summarizes the data gaps that the Navigant and Cadeo team (the research team) identified in developing the non-residential lighting Momentum Savings model and possible data collection activities to improve the inputs to the model. The research team presents this information in the following sections:

- **Discussion of Data Gaps:** Describes the data gaps and uncertainties in five key model areas: sales data, stock data, program data, technical data, and modeling assumptions.
- **Prioritization of Data Gaps:** Provides context for the relative effect of each data gap or area of uncertainty on the model's results and summarizes where BPA should prioritize future research to improve the non-residential lighting model.
- **Recommended Data Collection Activities:** Elaborates on the specific data needs of each prioritized input area and suggested data collection and analysis to improve the model's inputs.

Discussion of Data Gaps

This section summarizes the strengths, weaknesses and areas of uncertainty of each major input data source.

Sales Data

BPA has collected sales data annually since 2013 to understand the new products being sold into the Pacific Northwest market from lighting distributors across all major technology types and form factors in the non-residential sector; data submissions spanned 2010 to 2015. For the purpose of modeling the non-residential lighting market between 2010 and 2015—with estimated 2009 sales mixes establishing the baseline—this data had the following shortcomings:

- **Temporal.** The team estimated 2009 sales using a backcast based on 2010 to 2015 trends. In addition to not having data for 2009, the data collected increases in both the number of participants and quality of submissions over time. BPA and the research team have refined the art of requesting extensive sensitive data from distributors and built relationships with participants over time, yielding an increase in participation from 12 distributors in 2013 to 29 distributors in 2016.

- **Technology.** The 2013 data collection, which requested data from 2010 to 2012, emphasized linear fluorescent and high intensity discharge (HID) sales. BPA requested lamp and ballast sales for these technologies; thus, few distributors provided sales estimates for incandescent, compact fluorescent lamp (CFL), or light-emitting diode (LED) products. Later data requests focused on lamps, and more distributors provided sales estimates for these product types. However, data quality generally increases significantly in 2013, as the team requested that participants in the 2016 survey provide only data for 2013 through 2015 to minimize reporting burden. The research team has also modified the 2016 data collection tool to include model categories not previously requested such as decorative lighting.
- **Sales channel.** Through the annual sales data collection survey, BPA and the research team have collected comprehensive data from distributors—currently the largest sales channel within the non-residential lighting market. Sales also flow to the non-residential lighting market through online and brick and mortar retailers, directly from manufacturers, and through national account distributors. The research team has included some sales from online retailers and leveraged retail sales mixes to refine estimates of incandescent, halogen, CFL, and LED lamp sales. However, the relative size of and typical sales mix within the national account channel remain uncertain. Using sales mixes primarily from distributor submissions assumes that this data is representative of the market as a whole.
- **Representativeness.** The primary weakness in ongoing sales data collection is lack of information on how representative the sales data via the regional distributor channel is of the non-residential lighting market and how representative the participating distributors are of this channel. The research team believes that the participating distributors are generally representative of the distributor sales channel, though continued recruitment can improve this. However, this project revealed the following broader representativeness concerns specific to additional channels:
    - Large direct shipping orders (such as shipments to new construction sites) do not provide detailed technology information to distributors; the distributors handle the financial transaction, but the manufacturer and its representative ship and track the order. Based on distributor feedback, it appears that the current data submissions might not consistently include those lamps sales, which tend to have a higher prevalence of LEDs.
    - There might be direct or national distribution networks that have higher LED sales than what the research team currently captures. For example, modeled uptake of LED street and roadway luminaires is slower than other research suggests (i.e., national data, qualitative research, and local research from specific areas of the Pacific Northwest). This could indicate that these luminaires are primarily sold through other channels and the sales data underrepresents them.

Stock Data

The research team used several data sources to estimate the total number of installed lamps and fixtures in the non-residential sector. Regional data sources include the Seventh Power Plan (Seventh Plan) developed by the Northwest Power and Conservation Council (the Council) and the Northwest Energy Efficiency Alliance (NEEA)’s 2014 Commercial Building Stock Assessment (CBSA) and Industrial Facilities

Stock Assessment (IFSA). The team also used national data from the Manufacturing Energy Consumption Surveys (MECS) of 2006 and 2010.

Table 1: Fixture Density Metrics and Data Sources

Sector	Density Metric	Market Size Data Source	Fixture Density Data Source	Notes and Data Limitations
Commercial Interior	Fixtures per square foot	Seventh Plan (square feet)	2014 CBSA	Based on mapping detailed CBSA lighting data to model application and building types. Hospital and University used additional data sources due to the lack of detailed lighting data in the CBSA.
Industrial Interior	Fixtures per square foot	MECS, scaled to Pacific Northwest with census data (square feet)	2014 CBSA (Warehouse)	The 2014 IFSA data did not have sufficient square footage or fixture count data to provide an industrial-specific estimate. The team used CBSA data for the Warehouse building type as a proxy.
Commercial Exterior	Exterior fixtures per interior square foot	Sum of commercial and industrial square footage (square feet)	2014 CBSA	The 2014 CBSA provides exterior fixture and wattage density relative to interior square footage. While this metric has some uncertainty around it, the research team believes this is the best data source available to estimate total exterior fixture counts at this time.
Industrial Exterior	Exterior fixtures per interior square foot		2014 CBSA (Warehouse)	The 2014 IFSA study contained little outdoor lighting data. The team used CBSA data for the Warehouse building type as a proxy.
Street and Roadway	Fixtures per population	Seventh Plan (population)	Seventh Plan	The Council analyzed several data sources to estimate fixtures per Pacific Northwest population; the team used these estimates directly. The Council analysis triangulated multiple national estimates of street lighting luminaire quantities with an estimate of luminaire density per population and regional population. As the sources the Council reviewed varied substantially, uncertainty remains around this input.

Source: Non-Residential Lighting Momentum Savings Methodology Memo

Across all sectors, the research team made the following assumptions:

- Fixture density does not vary between existing and new construction for a given building type
- Application mix—e.g., the percentage of fixtures in each building type that fall into each application—does not vary between existing and new construction for a given building type

Commercial Interior

The 2014 CBSA study collected detailed lighting data for most building types, which enabled the research team to estimate the following:

- Fixture density by building type
- Application mix by building type
- Technology mix by application

- Lamps per fixture by technology

The primary weakness for interior lighting in the 2014 CBSA data is lack of detailed lighting data for the University and Hospital building types. The lighting data for the University and Hospital building types was not collected in a standardized, quantitative format and would have required extensive assumptions to analyze. The research team conducted additional analysis based on other data sources to estimate fixture density and application mix for these building types. A secondary weakness for the modeling effort is that the 2014 CBSA did not classify the detailed lighting data by application; the research team used a combination of fixture details, space type, building type and ceiling height to assign applications to each entry in the database.

Industrial

The following sections describe the data sources used to determine the size of the industrial lighting market and the application and technology mix within it.

Market Size

The research team estimated total industrial square footage by scaling down national estimates from the MECS surveys of 2006 and 2010 and used the CBSA fixture density data from the Warehouse building type to estimate total industrial fixtures. This analysis incorporated the national upward trend in manufacturing square footage and regional trends based on census data on regional manufacturing employment. This approach maximizes the value of these regional and national data sources but is less directly applicable than a region-specific survey of total square footage.

The Seventh Plan does not rely on square footage to inform total industrial power consumption. The team did analyze the electric consumption of lighting in the industrial sector in the Seventh Plan to calculate a second estimate of the total number of fixtures using operating hours and average fixture wattage estimates. The indirect nature of this calculation adds uncertainty to this estimate, but the team’s analysis of the Seventh Plan did corroborate the estimated number of fixtures in the industrial sector currently used in the model.

Application and Technology Mix

The 2014 IFSA study collected detailed lighting data, though it was not as complete or standardized as the CBSA lighting data. The research team used the IFSA data to inform the application mix and technology mix for interior industrial lighting as well as the application mix within exterior industrial lighting.

The lighting data in the IFSA is less consistent and standardized than the CBSA lighting data. The Council analyzed the IFSA data prior to this project and standardized the lighting entries to identify key linear fluorescent and HID categories. The team leveraged this analysis to map each entry in the IFSA lighting database to the model technology and application definitions. While most site data included counts of lighting fixtures and major technology types, the technology descriptions were less detailed and did not always include wattage, lamps per fixture, or detailed space descriptions. Many sites did not have square footage estimates corresponding to lighting fixture counts, and there were few entries for exterior lighting. Due to these data gaps, the research team used the CBSA data as a proxy for industrial data for the following inputs:

- Interior and exterior fixture density (using the CBSA Warehouse building type)

- Lamps per fixture by technology and application
- Technology mix within exterior lighting applications

While the CBSA provides a reasonable proxy for these inputs, industrial facility lighting needs can vary significantly from commercial building needs, even within applications; thus, industrial-specific inputs would strengthen the model's industrial sector estimates.

Agriculture

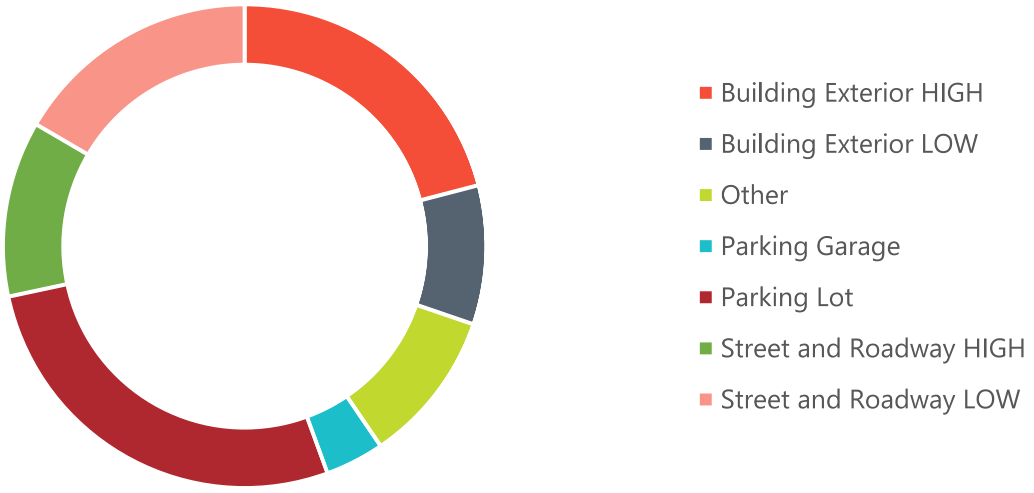
The research team did not identify any agriculture-specific lighting data sources to inform the size or mix of technologies within agricultural lighting. The research team used the following analysis and assumptions to address this data gap in the model:

- Performed a simple analysis of the relative size of industrial and agricultural lighting projects within BPA's lighting program to estimate the size of the agricultural lighting market
- Assumed that the mix of applications and technologies within agricultural lighting is the same as in the industrial sector

Outdoor and Exterior Lighting

There are five main applications within outdoor and exterior lighting: Building Exterior, Parking Garage, Parking Lot, Street and Roadway, and Other. Figure 1 summarizes the relative size of each outdoor and exterior application in the draft non-residential Momentum Savings model. For modeling purposes, the research team divided Building Exterior and Street and Roadway into high and low lumen output applications.

Figure 1: Estimated 2010 Consumption from Outdoor and Exterior Applications, aMW



Source: Non-Residential Momentum Savings Model

The CBSA only captures lighting associated with buildings—Building Exterior, Parking Lots, Parking Garages, and Other outdoor lighting (e.g., stadiums). As noted above, the IFSA contains little data on exterior lighting, and the research team used CBSA data to estimate the size of and mix within industrial exterior applications. The research team observed the following weaknesses in the CBSA exterior lighting data:

- **The CBSA sampling methodology for parking lots and parking garages likely underrepresents the total size of these applications and therefore the data on technology mix may not be representative of the region.** The 2014 study only collected data on parking lots and parking garages affiliated with sampled buildings and did not sample standalone parking garages or parking lots. This likely underrepresents the size of these applications in the non-residential lighting market and increases uncertainty around the technology mix within them as reflected in Table 2 below.
- **The building exterior application size is uncertain because it is not clear whether the metric of outdoor watts per interior square foot is a meaningful way to estimate total outdoor lighting wattage.** The drivers for differences in exterior lighting density are not well understood, which creates uncertainty around the size of and technology mix within exterior applications as highlighted in Table 2. While the CBSA does report exterior lighting density by building type as a function of interior square footage, other factors likely affect the amount and type of exterior lighting for a given building. Proximity to street lighting, proximity to other buildings, and building type likely all contribute to how much exterior lighting buildings have. For example, urban buildings near street lighting or other facilities may need less lighting, whereas rural buildings might have more lighting; additionally, car dealerships may always have more lighting than other retail buildings. Given these uncertainties, the research team did not believe that the differences in CBSA exterior lighting fixture density by building type were meaningful and chose to use a single exterior lighting fixture density—expressed as fixtures per interior square foot—for all building types and did not vary technology mix by building type.

For this version of the model, the research team included street and roadway lighting based on estimates using the Seventh Power Plan. The Seventh Plan leverages several national and local data sources to estimate the average density of street and roadway lighting per population and the mix of technologies within this application for both low and high output luminaires. However, there is no comprehensive regional study available that estimates either metric based on a broad survey of existing equipment, and the estimates of market size that the Council reviewed for the Seventh Plan varied significantly from 1 million to 1.8 million luminaires.[1]

Table 2 summarizes the effect of the gaps and weaknesses described above on the quality of the model inputs for the size of and technology mix within each application. Green shading indicates robust data sources with few, if any, weaknesses or data gaps; yellow shading indicates data sources with some known weaknesses or gaps; pink shading indicates data sources with significant gaps; and red shading indicates areas where no usable data exists.

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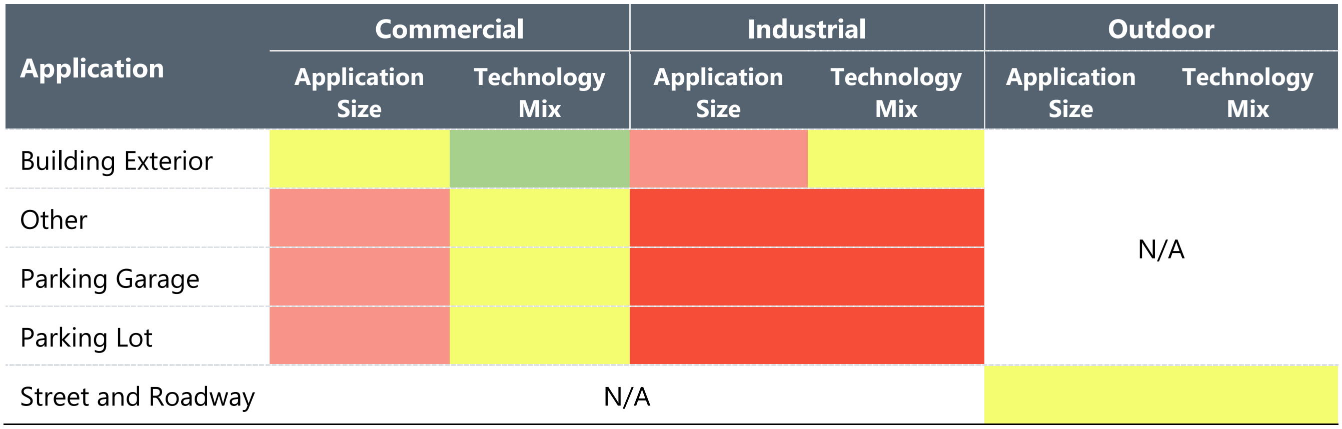
[1] Seventh Plan Final Conservation Files, "Com-Streetlight-7P_v9.xlsx" workbook, Outdoor Stock tab. Downloaded from https://nwcouncil.app.box.com/v/7thplanconservationdatafiles.

Table 2: Summary of Exterior and Outdoor Data Quality



Application	Commercial		Industrial		Outdoor	
	Application Size	Technology Mix	Application Size	Technology Mix	Application Size	Technology Mix
Building Exterior	🟨	🟩	🟧	🟨	N/A	
Other	🟧	🟨	🟥	🟥		
Parking Garage	🟧	🟨	🟥	🟥		
Parking Lot	🟧	🟨	🟥	🟥		
Street and Roadway	N/A				🟨	🟨

Note: Green shading indicates robust data sources with few, if any, weaknesses or data gaps; yellow shading indicates data sources with some known weaknesses or gaps; pink shading indicates data sources with significant gaps; and red shading indicates areas where no usable data exists.

In addition to the data weaknesses for the applications described above, the existing data likely excludes or at minimum underrepresents outdoor lighting for the following types of lighting:

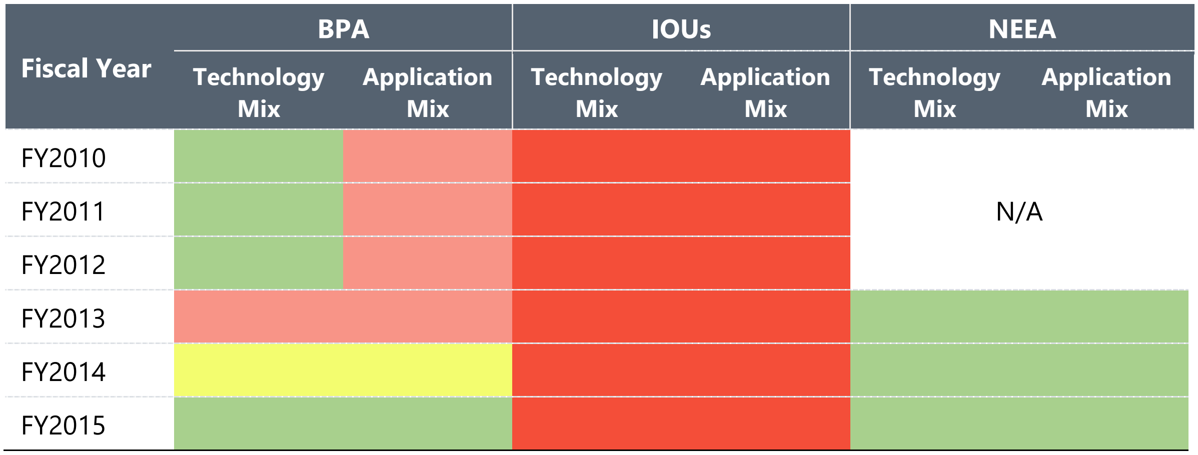
- Parks and other public spaces
- Airfield and railway lighting
- Other utility lighting

Program Data

Program data represents one of the largest areas of uncertainty in the model. However, it should be noted that this is an attribution issue, as it does not affect the total market savings number. The data availability limitations result in less certainty of what savings above the Council baseline utility programs incentivized. The methodology that the research team and BPA developed requires estimating program savings adjustments for each application in each year based on the actual mix of efficient and baseline technologies in program projects. This analysis requires detailed program data that includes technology types for baseline and efficient equipment as well as data on the sector, building, and space types where lighting was installed. While total program savings in kilowatt-hours (kWh) is available for all utilities in the region through the Regional Conservation Progress (RCP) survey, the majority of the data utilities provide for the RCP is not at this level of detail. BPA’s current lighting calculator does collect this detailed data for every lighting project, and BPA has the capability to extract this data into a summary for all projects using lighting calculator version 3.2 (available April 2014) and later.

Due to limitations in data from investor-owned utilities (IOUs) and earlier BPA projects, the research team needed to use the program savings adjustments from BPA’s FY2014 and FY2015 data to estimate both the application mix and application-specific adjustment factors for all other lighting program savings. As lighting program baselines and project types have changed over this period due to federal standards regulating T12s and the emergence of LEDs, this is a significant assumption with great uncertainty that directly affects Momentum Savings estimates. Table 3 summarizes the availability of detailed program data by year and source. Green shading indicates full data availability; yellow indicates partial availability; pink indicates limited availability; and red indicates no availability.

Table 3: Summary of Detailed Lighting Program Data Availability



Fiscal Year	BPA		IOUs		NEEA	
	Technology Mix	Application Mix	Technology Mix	Application Mix	Technology Mix	Application Mix
FY2010	🟩	🟧	🟥	🟥	N/A	
FY2011	🟩	🟧	🟥	🟥		
FY2012	🟩	🟧	🟥	🟥		
FY2013	🟧	🟧	🟥	🟥	🟩	🟩
FY2014	🟨	🟨	🟥	🟥	🟩	🟩
FY2015	🟩	🟩	🟥	🟥	🟩	🟩

Note: Green shading indicates full data availability; yellow indicates partial availability; pink indicates limited availability; and red indicates no availability.

The research team also made the following assumptions:

- BPA lighting calculator data for new construction measures only shows the savings—not the measure-level details (e.g., baseline fixture details, efficient fixture details). As a result, the team used the retrofit data as a proxy for the new construction data to determine the application mixes.
- To adjust for savings from controls, the team assumed that 7.5% of the total fiscal year savings were savings from controls rather than changing out lamp technology.[2] This assumption applies only to the BPA and IOU program savings.
- The team assumed that 7% of the total fiscal year savings without controls were from new construction, and 93% of the total fiscal year savings without controls were from existing buildings.[3] It was important to divide the total fiscal year savings into savings from new construction and existing buildings because the team did not apply a baseline adjustment to new construction savings.

Technical Data

The research team leveraged many robust data sources to estimate typical lumen output, wattages, and lifetimes for individual technologies and, where applicable, weighted these estimates with sales data to aggregate individual technologies to the model technology level. The team believes the main areas of weakness in this data are as follows:

- **The level of detail in the distributor sales data is not sufficient to calculate sales-weighted average technical data for LED products.** There is a wide variety of LED products available. As an emerging technology, different products within the same application have different wattages,

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[2] The previous non-residential lighting model used this assumption, which was provided by the Energy Trust of Oregon (ETO) through an email correspondence.

[3] The research team used the file provided by BPA via email on September 16, 2016 titled "LCData_Latest." The team filtered completion date by 4/1/14 – 9/30/15. The team calculated percentage split using the following columns in the database: CompletionDate, CalculatorType, NC_TotalkWhSavedAdjustedForHVACAndBusbar (new construction savings), and EquipSav_HVAC_MAB_Busbar (existing building savings).

efficacies, and costs. The research team used average product data based on qualified product lists and webscraped data on products available online. For many lamp technologies, the research team used the average specifications from Navigant's online web scraping database. A recent Lawrence Berkeley National Laboratory study showed that most lamps purchased are in 25th percentile by price (i.e., the cheapest lamps); thus, the team used the average efficacy and wattage of products in this percentile. For other technologies, the team used the average specifications from the DesignLights Consortium (DLC) and LED lighting facts product lists from each year.

- **The model does not account for differences in ballast efficiency between submarkets.** For example, T8 and T12 ballast efficiency has improved over the past few years due to federal standards phasing out magnetic ballasts and the development of high efficiency electronic ballasts. The wattages for these lamp sales account for average ballast efficiencies but do not vary by lamp, system, or fixture submarket. In reality, lamp submarket sales could be installed in fixtures with lower ballast efficiency. However, there is minimal data on ballast efficiency in the stock and how it has changed over time. This would require additional model complexity.
- **Estimates of LED lifetime do not account for the recent changes in ENERGY STAR requirements, which reduce the minimum lifetime requirements** for some lamp types. This and the increasing prevalence of value LEDs could increase the importance of revisiting LED lifetime estimates in the future.
- **The model does not explicitly account for fixture efficiency**, though by assuming some LED replacement fixtures have lower rated lumen output than incumbent products the research team believes the model does capture the effect of higher LED fixture efficiency in comparing LED and incumbent fixture wattages. However, there is certainly uncertainty in how end-users make these product comparisons and what purchasers consider equivalent products.
- **Cost estimates include some simplifying assumptions.** The research team assumed that cost scales linearly with lumen output when adjusting the data to align with the wattages and lumen output levels for each technology. The team also leveraged national cost data and did not make any adjustments for regional price differences. Cost data only affects model outputs for the forecast period or if economic logic is used.

Modeling Assumptions

Consumers make decisions about replacing equipment for a variety of reasons. The research needed to approximate this by assuming a natural fixture replacement rate: the percentage of fixtures replaced each year for reasons other than lamp or ballast failure. The research team currently uses estimates of natural turnover rates from the Sixth Power Plan by building type. The Seventh Plan uses estimates based on CBSA surveys that asked building owners how recently they had replaced fixtures and ballasts; these estimates are generally lower than the Sixth Plan estimates. There is little quantitative research on turnover rates, but these assumptions are a significant driver for how quickly the market changes. What data there is does not vary by application, yielding additional uncertainty.

The research team made the following simplifying assumptions in the stock turnover:

- Lamps alone are not replaced before burnout except through a fixture or ballast replacement event.

- When ballasts are replaced, all associated lamps are replaced.
- There is no minimum age for retrofitted fixtures. Tracking fixture age would add significant computational burden to the model.
- LED technologies are exempt from natural turnover and only leave the stock due to lamp or driver failure.
- The model uses a time step of one calendar year. Some technologies with short lifetimes burn out in less than one year, and the model does not capture this additional sales volume. A shorter time step would significantly increase the size of the model.

Prioritization of Data Gaps

The research team reviewed these data gaps and used a sensitivity analysis and professional judgment to assess their effects on the model's results. For each data gap, the team considered two factors:

- **Data quality:** How significant are the weaknesses or gaps in the available data source?
  - Robust data sources with **few, if any, weaknesses or data gaps** are shown in green.
  - Data sources with **some known weaknesses or gaps** are shown in yellow.
  - Data sources with **significant gaps that may undermine the validity** of the results are shown in pink.
  - Areas where **no usable data exists** are shown in red.
- **Effect on model:** What is the sensitivity of the model to changes in this input?
  - **Low** sensitivity indicates overall results are unlikely to change significantly due to varying inputs.
  - **Medium** sensitivity indicates model results could change moderately due to varying inputs.
  - **High** sensitivity indicates model results could change significantly due to varying inputs.

Table 4 summarizes how the research team categorized each input area described in this memo. These assignments are based on the team's review of the quantitative sensitivity analysis conducted within the model and professional judgment of which data sources are the most robust.

Table 4: Summary of Data Quality and Importance

Model Area	Data Gap	Commercial	Outdoor	Industrial	Agriculture
Stock Characterization	Size of Installed Stock	High	High	Medium	Low
	Mix of Applications in Stock	Medium*	Medium	Medium	Low
	Mix of Technologies within Each Application in the Stock	High*	High	Medium	Low
Sales Input Data	Baseline Year (2009) Technology Mix	High*	High*	High*	Low*
	Distributor Sales Channel Representativeness	High	High	Medium	Low
	Small Lamp Technology Mix	Medium*	Low*	Low*	Low*
Modeling Assumptions and Technical Data	Retrofit Turnover Rate	Medium	Medium	Medium	Low
	LED Wattage and Lumen Output	Medium	Medium	Medium	Low
	Ballast Efficiency	Low	Low	Low	Low
	LED Lifetime after 2015	Medium	Low	Low	Low
	Fixture Efficiency	Medium	Medium	Low	Low
	Detailed LED Cost Data	Low‡	Low‡	Low‡	Low‡
Program Savings	Mix of Applications	High	Medium	Medium	Low
	Portion of Savings from Controls	Medium	Medium	Low	Low
	Portion of Savings from New Construction	Medium	Low	Low	Low
	Baseline and Efficient Technology Mix	High	High	Medium	Low

*For Sixth Plan Period; low impact or greater certainty for Seventh Plan Period

‡For model results not using economic logic

Based on this analysis, the research team recommends prioritizing future research on the inputs and assumptions listed in Table 5.

Table 5: High Priority Data Gaps

Input Data Gap	Effect on Model	Current Data Quality
Outdoor and Exterior Installed Stock Size	High	🟥
Program Savings Application Mix	High	🟥
Program Savings Baseline and Efficient Technology Mix	High	🟥
Outdoor and Exterior Mix of Technologies in the Stock	High	🟨
Outdoor and Exterior Sales Technology Mix	High	🟨
Retrofit Rate Assumptions	Medium	🟥
Fixture Efficiency and Lumen Equivalence	Medium	🟨
Industrial Stock Application and Technology Mix	Medium	🟨
LED Lifetime after 2015	Medium	🟨

Platform and Computational Limitations

As noted in the Modeling Assumptions section, addressing some model weaknesses would introduce computational burden to the model—i.e., the model size and runtime would increase. The Analytica platform allows users to include many dimensions that can enhance understanding of market dynamics, but running such models on a typical modern computer can become a lengthy or impossible process when model structure becomes too complex. Thus, the research team has not implemented fixture vintage tracking or a shorter time step. As data availability changes over time, BPA may wish to revisit these decisions and consider collapsing some model dimensions to add complexity elsewhere.

Recommended Data Collection Activities

The following sections outline recommended data collection activities to fill the prioritized data gaps identified in the previous section.

Outdoor and Exterior Lighting Inputs

Outdoor and exterior lighting include many high output applications; thus, understanding the size and technology shifts within these applications is important for generating accurate Momentum Savings for the non-residential sector.

The highest priority for future outdoor lighting data collection is better characterizing outdoor lighting not associated with buildings—that is, all applications other than Building Exterior—with a focus on the largest applications, Parking Lot and Street and Roadway. Additionally, the research team recommends gaining a better understanding of the amount of lighting not captured in current model applications, such as area lighting not on streets or roads. The CBSA (and to a lesser extent the IFSA) collected lighting data characterizing the stock of the Building Exterior application. However, a better understanding of the drivers behind the types of building exterior lighting density (building type, location, proximity to other buildings, etc.) could improve the representativeness of this data, and a larger sample size for the IFSA would improve the technology mix and market size estimates for the industrial sector.

For each application, BPA's goal for future outdoor and exterior stock research should be to refine estimates of three key inputs:

- **Application size:** The number of fixtures in the region in the application, dependent on a base metric (e.g., total Pacific Northwest population, road miles, or parking lot square footage) and fixture density (e.g., fixtures per population, per mile, per square foot).
- **Application technology mix:** The percentage of fixtures each technology comprises within the application.
- **Technology characteristics:** The average wattage, lumen output, and number of lamps per fixture for each technology.

Table 6 summarizes which studies—the CBSA, the IFSA, and a future outdoor lighting stock assessment (OLSA)—are best suited to research each input area. The research team also notes:

- If the next CBSA cannot collect data on parking garages and/or parking lots not associated with sampled buildings, it may be more efficient to study these applications through a separate outdoor lighting study.
- The CBSA is the most efficient study for collecting detailed data on exterior lighting but BPA needs to determine through secondary research the appropriate metrics that drive exterior lighting density, and therefore can be used to estimate exterior lighting application size. Metrics might include illuminated wall façade area (square feet), distance from neighboring buildings (feet, miles), height or spacing of pole lighting (feet), or illuminated walkway length (feet) depending on the exterior lighting application. Additional research will allow the CBSA to efficiently collect the necessary data to improve certainty around this application's size.
- The 2014 IFSA collected limited outdoor lighting data. The research team used commercial data to inform the industrial exterior lighting inputs, and improved commercial data may reduce uncertainty for industrial exterior lighting, but the drivers of exterior lighting density may differ for the industrial sector.

Table 6. Recommended Research for Exterior and Outdoor Lighting Applications

Application	Commercial		Industrial		Outdoor	
	Application Size	Technology Mix*	Application Size	Technology Mix*	Application Size	Technology Mix*
Building Exterior	CBSA**	CBSA	IFSA	IFSA	N/A	
Other	OLSA or CBSA	OLSA or CBSA	OLSA or IFSA			
Parking Garage						
Parking Lot						
Street and Roadway	N/A				OLSA	OLSA

*Includes technology characteristics

**Additional research on what measure of fixture density is appropriate for building exterior lighting may be necessary to improve CBSA estimates of application size.

In addition to verifying these stock elements, BPA should enhance the sales data collection process to ensure representative outdoor sales data collection. First, BPA should ask distributors targeted questions during the sales data collection process on what percentage of HID products in each lumen bin go to outdoor and exterior applications and whether they see competition from other sales channels for these products. This data could serve as a reference when reviewing how the model allocates sales to interior versus exterior applications. If this research identifies other sales channels, BPA should investigate collecting sales data from market actors in these channels.

The remainder of this section provides additional detail on data needs for the three stock characteristic areas described above.

Application Size

For interior applications, the research team calculated the market size in a base metric of square footage and then used fixture density (fixtures per square foot) to calculate the number of fixtures. The following steps outline the data needs for refining exterior and outdoor application size estimates.

1. **Determine relevant base metrics for each application.** This requires improving the understanding of drivers behind outdoor lighting density: Does population truly drive the density of street and roadway lighting? Is interior building square footage a good predictor of exterior lighting density? What patterns can BPA leverage in sampling parking lot sites to fully understand regional stock with a feasible number of site visits?
2. **Identify data sources for estimating the size of the Pacific Northwest market in terms of the base metric.** For example, if population is the base metric for street and roadway lighting, census data for the Pacific Northwest region would be an appropriate source.
3. **Develop a sampling plan to estimate fixture density relative to the base metric.** Continuing the population base metric example, a sampling plan could stratify cities and towns by population and verify total street light counts and current population through a combination of onsite and phone verification.

Application Technology Mix

To calculate the percentage of fixtures and lamps of each technology type within an application, each study must collect data on the number of fixtures of each technology type within a site or sampled area. The sampling plan described above should target desired confidence and precision for both the fixture density and technology mix for each application.[4] BPA should design the data collection strategy to collect information on the number of fixtures of each technology type within each sampled area.

Technology Characteristics

The final input area is the technical detail of each technology. This data drives the savings calculations in the model, and better data on average fixture and lamp characteristics in the field will help BPA refine the technical specifications for each application's technologies.

Onsite or phone data collection should seek to verify the following:

- **Lamps per fixture.** This data is necessary because the model tracks both lamps and fixtures—and in some applications, different building types have different numbers of lamps per fixture.
- **Watts per lamp.** Together with lamps per fixture, this dictates the total wattage consumed by each lamp and fixture.
- **Lumens per lamp.** Together with lamps per fixture, this helps compare lumen output across technologies to assess equivalence.

Program Savings

The weaknesses in program savings estimates in the current model stem from three issues: lack of granularity in program data for non-BPA utilities, lack of granularity in BPA program data prior to 2014, and program data fields not aligning with model structure. Data gaps for 2010-2013 will not contribute to uncertainty in savings estimates beyond the Sixth Plan period of 2010-2015; thus, this section focuses on suggested improvements to BPA lighting data collection and possible analyses to better understand the composition of non-BPA utility program data. The research team recommends three strategies for improving program data, outlined below.

Including a field in program data for application. For the 2014 and 2015 BPA lighting calculator data, the research team used a combination of the Building Type, Sector, and Space Use Type fields—plus data on existing and new technology types—to map program data line items to model applications. While the research team used look-up tables to facilitate this process, the large number of permutations of these fields in the program data required the team to conduct extensive manual quality control to ensure line items were mapped correctly. Having a field in program data for application would simplify this analysis. However, this would require users to understand the application concept.

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[4] The CBSA targets 90% confidence and 10% precision at the building type level and 80% confidence and 20% precision for each intersection of more granular stratification (building size, vintage, and urban/rural classification). A similar approach could be to target 90% confidence and 10% precision at the application level (if feasible within budgetary constraints), with lower targets for more granular stratification such as building type or urban/rural classification.

Aligning regional lighting program data collection with data organization of other regional efforts, namely the CBSA and Council power planning. For non-BPA utilities, the research team assumed that the application and technology mix was the same as that of BPA utilities due to the lack of granular lighting data available. Ideally, all regional programs would use standardized data collection with common building type, technology, space type, and sector definitions that would enable consistent tracking of applications and technology types region-wide. The research team recognizes that this is unlikely to occur in the near future but recommends that any effort to standardize lighting program data collection align with other regional data collection—namely the CBSA and Council power planning. For example, a standard regional lighting calculator would have the same building, space, and technology type definitions and options as the CBSA data collection tool to facilitate comparison between stock and program data.

In the meantime, BPA could consider requesting a sample of project files from these programs to analyze. This analysis would attempt to map the sampled project data to model applications and technology types to assess whether the mix of applications and technology types (baseline and efficient) in non-BPA lighting programs is statistically different from the mix within BPA member utilities' programs.

Collecting additional detail on program projects. Table 6 summarizes the program data details required for the model analysis that the most recent BPA and non-BPA program data does and does not provide.

Table 7: Summary of Current Program Data Status

Program Data Need	BPA Data*	Non-BPA Data
Efficient product technology	✓	X
Efficient product quantity	✓	X
Baseline product technology	✓	X
Baseline product quantity	X	X
Sector and space type	✓	X
Application**	X	X

*Based on 2015 BPA lighting calculator data format

**Can be inferred based on baseline and efficient technology, sector, and space type

In addition to the data in Table 6, detail on the wattage and lumen output of both baseline and efficient equipment in program projects could provide BPA insight into whether non-residential customers are maintaining, increasing, or decreasing lumen levels in different applications and whether this depends on the baseline technology. This would be a valuable resource for refining technical data assumptions.

Turnover Rates and Technical Data

The research team recommends leveraging existing and future CBSA data to inform natural replacement turnover rates, as described below, as well as considering new research in this area that could be combined with surveys to assess technology equivalence and replacement patterns. The primary goal of these efforts is to estimate fixture turnover rates—defined as the fraction of fixtures replaced each year for any reason other than individual lamp or ballast failure—at the application level. Secondary goals would be to understand whether typical natural replacements—in particular new LED installations—maintain or change lumen levels in spaces, whether longer lifetime lamps (e.g., CFLs) are also replaced before burnout and if so, to what extent, and providing corroboration for sales-based estimates of which applications are seeing the most LED growth.

The model currently relies on natural replacement turnover rates from the Sixth Plan, which are at the building type level. The model applies the turnover rate at the application level across building types. The research team calculated a weighted average turnover rate for each application based on the share of fixtures from each building type, as shown in Table 8.

Table 8: Turnover Rates by Building Type and Application

Building Type	Turnover Rate
Assembly	6.7%
Commercial Exterior	7.7%
Food Service	12.5%
Grocery	10.8%
Hospital	6.7%
Industrial	5.0%
Industrial Exterior	5.0%
Lodging	6.7%
Office	6.7%
Other	6.7%
Residential Care	6.7%
Retail	12.5%
School	5.0%
Street and Roadway	8.3%
University	6.7%
Warehouse	5.0%

→

Application	Turnover Rate
Ambient Linear	8.0%
Building Exterior HIGH	7.7%
Building Exterior LOW	7.7%
Decorative	9.1%
Downlight Large	7.6%
General Purpose	7.6%
High/Low Bay HIGH	8.5%
High/Low Bay LOW	8.8%
Other	7.7%
Parking Garage	7.7%
Parking Lot	7.7%
Street and Roadway HIGH	8.3%
Street and Roadway LOW	8.3%
Track Large	10.8%
Track Small	9.2%
Industrial: All	5.0%

Sources: Sixth Plan, research team analysis

CBSA Opportunities for Turnover Rate Research

The 2014 CBSA survey included questions on how recently building owners had renovated lighting fixtures and ballasts. The research team recommends including the same questions in the next CBSA to understand changes in retrofit rates over time. Collecting the same data five years later could indicate whether building owners are replacing lighting systems more frequently due to the attractiveness of new LED technologies.

In addition, BPA should consider adding a simpler question to the CBSA survey: how frequently do building owners replace a significant portion of lighting fixtures, and how does this vary by application? Data from this question could help corroborate analysis based on the more detailed questions and provide insight as to whether certain applications have higher turnover.

New Research

The CBSA provides a customer perspective on lighting fixture and ballast turnover, but other market actor insights may be beneficial. BPA should consider using online surveys to gather data on recent projects from contractors and maintenance firms. This survey could also collect data to improve BPA's understanding of equivalent technologies and the allocation of sales for a given technology across applications. These surveys would ask respondents for detail on their current or most recently completed project, including:

- Size of project, in square feet and number of fixtures
- Building type and sector
- Applications present in the project and their relative size (also in square feet and number of fixtures)
- Approximate percentage of building fixtures replaced in the project
- For each application:
    - Age and condition of replaced fixtures
    - Number, type, wattage, and lumen output of fixtures replaced using standard technology descriptions that align with model definitions
    - Number, type, wattage, and lumen output of fixtures installed using standard technology descriptions that align with model definitions

For both existing and new equipment, providing standardized product options (e.g., 4-lamp 32W T8) and/or predefined wattage and lumen output ranges will improve consistency and usability of responses; additionally, asking contractors to specify model numbers could help verify the information they provide.

This research should include a pilot phase to test the data collection tool; a detailed sampling plan to ensure appropriate representation of building types, sectors, and applications; and a task to develop a compelling value proposition to maximize participation.

Industrial Stock Application and Technology Mix

The 2014 IFSA collected detailed lighting data as part of its site visits, including the number and technology type of fixtures and, in some cases, square footage and space type. However, this data was not standardized and was often incomplete for individual sites. This is understandable given lighting can be a relatively small portion of an industrial facility's energy consumption. The research team leveraged the Council's industrial lighting analysis for the Seventh Plan—which standardized the technology descriptions and provided useful aggregations such as average operating hours—but missing data for many sites made certain analyses impossible or unreliable. Future industrial lighting stock assessments would be more useful to BPA's modeling work with the following changes:

- **Larger sample sizes.** All applications other than High/Low Bay and Ambient Linear have fewer than ten records in the IFSA database. Ideally, future industrial stock assessments could establish specific confidence and precision targets for technology mix and fixture density at the application level based on application importance and budgetary constraints.[5]
- **Square footage data for spaces with lighting, as collected in the 2014 CBSA.** This would enable BPA to calculate fixture density specific to the industrial sector rather than using commercial Warehouse data as a proxy.
- **Standardized lighting data collection that aligns with the CBSA.** In the current data, many entries are vague or even contradictory. Having standardized technology and space type (or even application) definitions that mirror commercial sector data collection would greatly simplify future analyses.

LED Lifetimes

To assess the change in typical LED product lifetime, the research team recommends the following data collection and analysis activities:

- **Review qualified product lists (QPLs) and calculate average lifetime by year added** by application. This analysis should include the LED Lighting Facts and DLC database. Analyzing the change in average lifetime for new products each year will help BPA understand the prevalence of shorter lifetime products and how quickly the typical lifetime may be changing.
- **Use webscraping to collect lifetime and cost data on LED products** regardless of QPL status. Using webscraping tools can enable researchers to collect detailed product data from multiple online retailers with relative ease. By collecting both cost and lifetime data, BPA could understand whether cheaper LEDs do have shorter lifetimes and use this relationship to estimate what portion of LED sales may have shorter lifetimes. For example, assuming the mean price of all products reflects the price paid for most sales, the research team could calculate the average lifetime of all products at or below that price point in lieu of an actual sales-weighted average.
- **Leverage lifetime data from NEEA's shelf stocking survey** for retail products.
- **Ask distributors about demand for value LED products.** This topic alone does not warrant market actor interviews, but if BPA interviews distributors or contractors, the survey guide should include a question about consumers' knowledge of and demand for shorter lifetime LED products.

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[5] The CBSA targeted 90% confidence and 10% precision at the building type level and the detailed lighting table includes over 20,000 records; the average application technology mix in the model input analysis is based on over 1,000 records. The IFSA detailed lighting database includes just over 200 records, 170 of which are for the three dominant applications (High/Low Bay high and low and Ambient Linear). As the industrial sector is much smaller, BPA may not need the same level of confidence and precision, but even reaching a lower target such as 80% confidence and 20% precision would likely require additional records for most applications.

Considerations for Future CBSA Studies

The research team recommends the following changes to lighting data collection in the upcoming CBSA study:

- Collect detailed lighting data for the Hospital and University building types using the same data collection protocol and format as the other building types. The sampling method for these should ensure statistically relevant results for the following lighting inputs, ideally at the application level (at minimum for major applications):[6]
    - Fixture density (fixtures per square foot)
    - Mix of lighting technologies in the stock, as a percentage of lamps and/or fixtures
    - Average number of lamps per fixture by technology
    - Average lamp wattage by technology
- Add a field for application to the lighting data collection form, restricting entries to the list of applications in the model.
- Consider collecting data on possible metrics for building exterior lighting density if secondary research indicates these or other data could be a better predictor of total building exterior fixtures than interior square feet:
    - Illuminated façade area
    - Illuminated walkway length
    - Fixture height and spacing
    - Distance from neighboring buildings and/or roadways
- Improve consistency and data quality for the following exterior lighting characteristics:
    - Lamps per fixture
    - Watts per lamp
    - Lumens per lamp
- Continue surveying building owners on recent lighting equipment replacements using the same questions as the previous CBSA to understand changes in turnover rates over time and add a question on how frequently building owners replace a significant portion of lighting fixtures, and how this varies by application.
- Develop a methodology for sampling additional parking lots and parking garages or shift study of these applications to an outdoor lighting study.

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[6] Major applications are Ambient Linear, High/Low Bay HIGH and LOW, General Purpose, and Downlight Large.

E. Slide-doc Describing Non-Residential Lighting Baseline Categories and Values

This slide document, submitted to BPA on June 13, 2017, summarizes the implications of the model results on current practice baselines, providing comparisons to current RTF protocols.

Non-Residential Lighting Current Practice Baselines

June 2017

Bonneville
POWER ADMINISTRATION

Overview

BPA's regional non-residential lighting model uses market and stock data to estimate momentum savings. Estimated market-average mix of efficiencies within various lighting applications are a critical element in the model, offering insight on current practice in the non-residential lighting market. Leveraging this aspect of the model, the Navigant and Cadeo research team examined current practice baselines for non-residential lighting measures.

This document and its accompanying spreadsheet describe the approach for, and results of, calculating current practice baselines for:

1. All applications delineated in the regional non-residential lighting model.
2. All measures in the Lighting To Go program.

Contents

This document contains four main sections:

1. What is a current practice baseline?
2. BPA regional lighting model methodology summary
3. Application-level current practice baseline estimates and comparison to RTF current practice estimates
4. Current practice baselines for Lighting To Go measures

What is a
Current Practice Baseline?

Defining our terms.

Defining Current Practice Baseline

Current practice baselines are used to calculate energy savings by comparing the energy consumption of the new equipment (i.e., the equipment incented by the program) to the energy consumption of the average equipment that a customer would likely choose to fill that particular need (application).

Therefore, the current practice baseline is the average efficiency of all products sold in a given application during the previous calendar year.

This is distinct from the other approach commonly used in the Northwest to calculate savings, which is to compare the new equipment to existing equipment (called pre-existing condition baseline).

For this analysis, the team estimated current practice baselines at the application level (including all purchase triggers) and at the measure level for Lighting To Go measures.

Why Current Practice Baselines?

Current practice baselines are important to examine in the Northwest because:

- They are the foundation of most measures (including non-residential lighting) included in Council’s Power Plans.
- They are used in many RTF measures, including the most recent non-residential lighting protocol, released in December 2016.
- They provide market intelligence on the current sales mix of technologies, which can inform decision-making both within and outside programs.

What Data are Used to Calculate Current Practice Baselines?

Ideally, current practice baselines are calculated based on **sales data** to characterize technology mix.

As described in the next section, the team's non-residential lighting current practice baselines use modeled estimates of the product mix.

BPA Regional Lighting Model
Methodology Summary

A brief recap for context.

Using the Regional Lighting Model

The BPA regional lighting model is the foundation of the baseline analysis. This section summarizes the model's methodology as it pertains to baselines, including the following elements:

1. Defining applications
2. Describing technology options
3. Allocating market sales data to estimate sales and stock trends at the application level

This analysis calculates current practice efficacies for 2015, the baseline year for the 7th Plan.

Greater detail on the modeling methodology is documented in the Non-Residential Lighting Momentum Savings Methodology Memo.

Defining Lighting Applications

Because current practice baselines reflect the average efficiency of products, the team must answer the question, “average of which products?”

To that end, the team divided the lighting market into a series of applications.

An application is a common lighting need that a group of technology options compete to fill.

Within each application, the appropriate products fill available “sockets” (or lighting needs) in different proportions, driven by various market forces. The market average efficiency of all sales within a given application informs the current practice baseline.

Regional Lighting Model Applications and Sectors

This table shows the 15 applications used in the regional non-residential lighting model, and for which sectors they each apply.

Application	Commercial	Industrial	Outdoor
Ambient Linear	🟥	🟩	
General Purpose	🟥	🟩	
Downlight	🟥	🟩	
Track Large	🟥		
Track Small	🟥		
Decorative	🟥		
High/Low Bay LOW	🟥	🟩	
High/Low Bay HIGH	🟥	🟩	
Parking Garage	🟥	🟩	
Building Exterior LOW	🟥	🟩	
Building Exterior HIGH	🟥	🟩	
Parking Lot	🟥	🟩	
Street and Roadway LOW			🟦
Street and Roadway HIGH			🟦
Other	🟥	🟩	

Defining Technology Options within Each Application

After defining the applications that make up the lighting market, the team had to identify which technologies could be used within each application. This reflects the real-world product selection process, limiting the options within each application to product types (technologies) that an end-user would actually consider for that application. These options are constrained by physical factors (e.g., socket type), performance characteristics (e.g., required lumen levels), and regulations.

The team determined which technology types were eligible to be installed within each application by reviewing sources including: the US Department of Energy's national lighting model, the Seventh Plan, NEEA's CBSA, and manufacturer product catalogues.

Example of Technologies

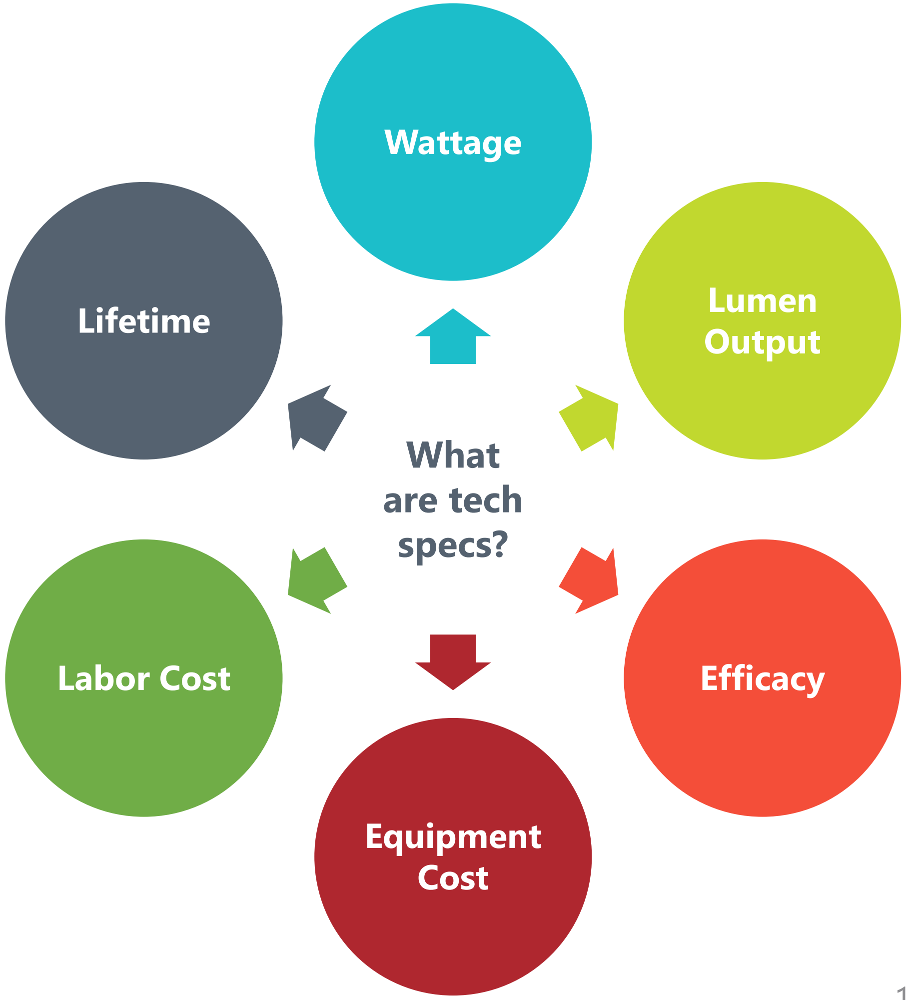
For example, within the Parking Garage application, the technology options are:

- 32W T8
- T12
- T5HO
- Incandescent
- High Pressure Sodium
- Metal Halide
- LED Lamp
- LED Luminaire
- TLED

Defining Technology Specifications

For each product, the modeling team developed technology specifications, or “tech specs.” The tech specs are an input into the BPA regional lighting model, and they define the representative characteristics of each technology. These are based on sales data collected for the momentum savings research, and on inputs to the DOE’s national-level non-residential lighting model.

Competing technologies’ suitability for an application is dictated by market use (not necessarily lumen equivalence). For example, a TLED competes with a T8 despite having a lower lumen output.



Estimating Total Market Sales

The BPA regional lighting model is a stock-turnover model that uses actual regional sales data. The model's sales allocation methodology uses trends in stock saturations over time and turnover dynamics to estimate sales within each application and purchase trigger. The model's purchase triggers are: maintenance (lamp or ballast replacement), natural replacement of fixtures (system replacement), and new construction.

The model calculates a sales-weighted average efficacy or wattage of estimated technologies sold in each application. These model outputs are the basis of the current practice baseline results presented in the next section. Additional detail on the model methodology is documented in the Non-Residential Lighting Momentum Savings Methodology Memo.

Application-Level
Current Practice Baselines

And comparison to RTF current practice estimates.

Application-Level Baselines: BPA regional lighting model Outputs

As described in the previous section, the BPA regional lighting model estimates market average sales within each of 15 lighting applications. These model outputs can be interpreted as current practice baselines.

The team first determined the appropriate model outputs to examine as current practice baselines: i.e., should the baselines be expressed in terms of efficacy or wattage? For the purpose of comparing the regional non-residential lighting model outputs to the RTF current practice baseline, the team focused on average efficacy. (Note: for context, the accompanying spreadsheet also includes average wattage, by lamp and by fixture.)

Mapping Applications Across Analyses

Next the team reviewed how the BPA regional lighting model applications mapped to the RTF's applications. Two areas of inconsistency complicate the comparison between the momentum savings outputs and the RTF's current practice baselines.

First, The RTF uses separate current practice efficacy estimates for two product types: "lamp only" and "fixture/retrofit kit." The model, conversely, includes both lamps and fixtures in each application (where appropriate). In the subsequent slides, the model outputs are compared with both the RTF product categories.

Second, both the BPA regional lighting model and the RTF's analysis use lumen bins to break up applications with wide ranges of lumen output, but lumen bins differ between the RTF and the BPA model for the Parking Lot & Area and Street & Roadway applications. Thus these two applications are not directly comparable.

Despite these differences, most applications are structured to allow a one-to-one comparison between the RTF's current practice baselines and the BPA regional lighting model outputs.

Comparing Apples to Apples

In order to improve comparability to the momentum savings efficacies, the RTF efficacies shown on the next slide are not adjusted for fixture efficiency. Although the RTF’s calculator expresses efficacies in *delivered* lumens per watt (i.e., adjusted for fixture efficiency), the BPA regional lighting model uses *rated* lumens per watt. Therefore for this comparison, the team removed the fixture efficiency adjustment from the RTF efficacies.

Application-Level Baselines: RTF Efficacy Comparison

Momentum Savings Model Application	RTF Application	Momentum Savings Model, 2015 Current Practice Efficacy (rated Lumens per Watt)	RTF Current Practice Efficacy for Lamps (rated Lumens per Watt)	RTF Current Practice Efficacy for Fixtures (rated Lumens per Watt)
Ambient Linear	Linear Fixture	88	84	84
General Purpose	General Purpose/Omnidirectional	23	41	N/A
Downlight Large	Directional - Large (PAR/MR)	33	37	40
Track Large	Directional - Large (PAR/MR)	25	37	40
Track Small	Directional - Small (MR16)	23	27	31
Decorative	Decorative	17	21	22
High/Low Bay LOW	Low and High Bay - < 15,000 Lumens	84	79	81
High/Low Bay HIGH	Low and High Bay - ≥ 15,000 Lumens	76	82	85
Parking Garage	Parking Garage	75	87	83
Building Exterior LOW	Building Exterior - < 7,000 Lumens	35	55	62
Building Exterior HIGH	Building Exterior - ≥ 7,000 Lumens	61	60	68
Parking Lot	Parking Lot & Area - ≥ 25,000 Lumens + Parking Lot & Area - < 25,000 Lumens	68	70	76
Street and Roadway LOW	Street and Roadway - < 25,000 Lumens	72	75	80
Street and Roadway HIGH	Street and Roadway - ≥ 25,000 Lumens	65	86	91
Other	N/A	62	N/A	N/A

Application-Level Baselines: RTF Efficacy Comparison

As shown on the previous slide, there are few large differences between the BPA regional lighting model efficacies and the RTF's efficacies. The differences that do appear are driven by two factors:

- The efficacy assumptions for each technology/application (i.e. the tech specs) differ slightly
- Market shares for each technology within each application differ slightly

These differences are mostly minor and result from the different data sources that inform each analysis.

The RTF's market shares and tech specs are based on a review of many regional and national data sources, (including BPA's previous non-residential lighting market analysis).

Application-Level Baselines:
RTF Efficacy Comparison Implications

In most cases, the non-residential regional lighting model produced slightly lower current practice efficacies. The RTF's Standard Protocol applies a dual baseline corresponding to the remaining useful life (RUL) of the existing lighting equipment, with current practice baselines applied only for the second savings period, or the post-RUL period.

If the RTF adopted the regional lighting model's efficacies (or a driver thereof, such as technology market shares), the result would likely be:

- Increased first-year and lifetime savings for measures with zero RUL (e.g., general service lamps and reflector lamps)
- Increased lifetime savings for measures where savings for the RUL period are based on pre-condition baseline.

Current Practice Baselines for Lighting To Go Measures

Applying the RTF standard protocol.

Lighting To Go Baseline Analysis: Context

Lighting To Go is a midstream commercial lighting incentive program, which offers instant discounts on efficient lighting products through participating distributors. Multiple northwest utilities, including Snohomish PUD, implement this program. As an information resource for its customer utilities, BPA and the research team applied the baseline analysis to the measures currently offered through Lighting To Go.

The team aligned its methodology with the RTF’s standard protocol, calculating an average wattage baseline for each Lighting To Go measure. The team followed three key steps to apply the RTF methodology to the Lighting To Go measures:

1. Map measures to RTF applications.
2. Identify sources for inputs into the RTF method: efficacies for baseline and efficient lamps, and wattages for efficient lamps. The team used the RTF’s assumptions where possible.
3. Calculate baseline wattage.

RTF Methodology and Inputs

The RTF’s standard protocol uses this equation to calculate current practice baseline wattage: **Base_Watts = (LPW_EE/LPW_BASE)*WATT_EE**

- **Base_Watts:** Estimated current practice baseline wattage.
- **LPW_EE:** Efficacy of the efficient product in delivered lumens per watt.
- **LPW_Base:** Baseline efficacy in delivered lumens per watt. The team used the RTF's assumptions in all cases where direct mapping to the RTF applications was appropriate. The only exception is the LED pin replacement measure.
- **Watt_EE:** Wattage of the efficient product. The team used multiple sources for these assumptions. Where possible, the team used the BPA regional lighting model tech specs. However, for many products the BPA regional lighting model technologies included too broad a range of wattages to use for this analysis.

The next slides provide more detail on data sources.

RTF Method Inputs: LPW_Base

Wherever possible, the team used the RTF’s assumptions to calculate the measure baseline wattages. In some cases the RTF’s analysis did not include the necessary level of granularity, so the team identified alternative sources for the following inputs:

LPW_Base for LED Pin Replacement

There is no direct match in the RTF applications for this technology, since pin-based CFLs and their LED equivalents are rolled into the other directional lamp applications.

Deriving inputs from the RTF's directional applications was not appropriate for this measure because those applications include halogen and incandescent technologies in their market average mix. However, pin-base LEDs (PL LEDs) are specifically a replacement product for pin-base CFLs. They are also a relatively new LED product, so it is most appropriate to use the average efficacy of a pin-based CFL as the LPW_Base value in the RTF's calculation.

This assumes no LEDs in the baseline, which is reasonable for this year, but should be revisited in the future when more sales data on PL LEDs is available.

RTF Method Inputs: Watt_EE

Watt_EE: Multiple Sources

The team drew from multiple sources for Watt_EE, the wattage of the efficient product, because the RTF application assumptions were not granular enough to apply for this input. The key sources the team used were:

- BPA regional lighting model tech specs (where direct mapping was possible)
- ENERGY STAR Certified Product List
- Review and analysis of manufacturer, distributor, and retailer product catalogues.

Detailed sources and analysis are documented in the accompanying spreadsheet.

The following slides present the inputs and results of the team's Lighting To Go baseline analysis.

Lighting To Go Current Practice Baselines

		RTF NR Lighting Retrofit Standard Protocol Methodology>>>>>>>>>			
Lighting To Go Measure	**Most similar RTF application**	**LPW_Base (RTF, unless noted)**	**LPW_EE (RTF, unless noted)**	**Watt_EE**	**Base_Watts = (LPW_EE/LPW_BASE)* WATT_EE**
LED Exterior Power Flood: 1-74W	Building Exterior - < 7,000 Lumens (Fixture)	49	93	41	78
LED Exterior Power Flood: 75-174W	Building Exterior - < 7,000 Lumens (Fixture)	49	93	89	170
LED Exterior Power Flood: ≥175W	Building Exterior - ≥ 7,000 Lumens (Fixture)	52	93	315	563
LED Pin Replacement, 2 and 4 pin	NA: Use Model Tech Specs for Pin CFLs (Lamp)	44*	63*	11	16
LED Decorative lamps	Decorative (Lamp)	21	66	5	15
LED Omni-directional (A-lamp)	General Purpose/Omnidirectional (Lamp)	41	73	10	19
LED MR16	Directional - Small (MR16) (Lamp)	27	54	7	14
LED Directional PAR20	Directional - Large (PAR/MR) (Lamp)	37	61	7	11
LED Directional PAR30	Directional - Large (PAR/MR) (Lamp)	37	61	14	23
LED Directional PAR38, PAR40	Directional - Large (PAR/MR) (Lamp)	37	61	17	27
LED T8	Linear Fixture - Lamp Over Ballast (Lamp)	57	78	20	27
LED Recessed can retrofit kit	Directional - Large (PAR/MR) (Fixture)	40	81	16	33
LED Exterior Wall Pack: 1-34W	Building Exterior - < 7,000 Lumens (Fixture)	49	93	25	47
LED Exterior Wall Pack: 35-99W	Building Exterior - < 7,000 Lumens (Fixture)	49	93	52	100
LED Exterior Wall Pack: ≥100W	Building Exterior - ≥ 7,000 Lumens (Fixture)	52	93	139	248

*For the LED Pin Replacement measure, which does not have a corresponding RTF application, the team used the model's tech specs for pin-based CFL lamps and their LED equivalents for LPW_Base and LPW_EE

Applying Average Wattage Baselines for Midstream Programs

Average wattage baselines like those presented on the preceding slides work well for standardized products with narrow lumen output or wattage ranges (e.g., 4-ft linear fluorescent lamps). However, this approach can introduce evaluation risk for measures with wider ranges. Among the Lighting To Go measures, Power Flood lamps and Wall Packs are grouped into large wattage ranges. This can introduce evaluation risk: the mix of wattages and efficacies among efficient incented products may differ greatly from the assumptions the team used in the analysis, resulting in the potential for evaluated savings to differ from *ex ante* savings calculated off the wattage baselines presented here.

A potential strategy for mitigating this risk would be to add more lumen bins. The RTF has developed a proposed unit energy savings (UES) methodology for non-residential lighting mid-stream measures that employs lumen bins. This analysis was introduced in the June 8, 2017 non-residential lighting subcommittee meeting.

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Please refer to questions to:

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F. Market Actor Interview Findings Memo

The following memo, submitted to BPA on July 8, 2016, summarizes the research team's findings from its interviews with non-residential lighting market actors.

Memorandum

To: Jessica Aiona, Carrie Cobb, Bonneville Power Administration

From: Kate Bushman, Katie Arquiette, Rob Carmichael, Cadeo; Laura Tabor, Navigant

Date: July 8, 2016

Subject: Non-Residential Lighting Market Actor Interview Findings

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This memo summarizes the Navigant and Cadeo team's (the research team's) findings from its interviews with non-residential lighting market actors conducted on behalf of Bonneville Power Administration (BPA). The research team conducted 50 long and 35 short interviews to investigate the five research areas described in Table 1.

Table 1: Areas of Inquiry

Market Aspect	Key Research Question
Market Evolution	How has the structure of the market and the flow of products changed recently?
Purchase Decisions	How, when and why do customers decide to purchase new lighting equipment?
Regional Variation	What differences exist within the Pacific Northwest lighting market?
Industrial Lighting	What are the key characteristics of the industrial lighting market?
Outdoor Lighting	What are the key characteristics of the outdoor lighting market?

Source: Non-Residential Lighting Market Actor Interview Strategy, 2016.

Key Findings

These findings reflect the perspectives of market actors on the current state of the lighting market, as well as new insights into the non-residential lighting supply chain and customer decisions.

Manufacturers are consolidating legacy lighting products and focusing on development of LED products. All manufacturer interviewees noted that research and development (R&D) now focuses almost exclusively on LED products and controls. Although they continue to produce products in legacy technologies in order to meet the maintenance needs of their customers, manufacturers are reducing the number of products offered in those lines. Over time, this will hasten the market's transition to LED, as fewer legacy lines will be available for direct-replacement maintenance.

Implications/opportunities: The reduced availability of legacy products may create an opportunity for program intervention in the maintenance market, as it will force decision makers to do something new—that is, replace legacy products with new alternatives. Secondarily, the narrowing of legacy product lines has implications for future Department of Energy (DOE) standards. It lowers the cost of complying with higher efficiency standards for manufacturers because they have fewer products to redesign, which in turn increases the likelihood of more stringent standards passing in the future.

Turnover of LED products may occur more often than expected given innovative products and business needs for improved lighting and controllability. Market actors see the long lives of LEDs as a potential threat, particularly to their maintenance, repair, and operations (MRO) business. However, customers may retire systems earlier than expected if new products, that better suit their needs, become available. Customer-facing segments such as retail are particularly prone to faster turnover cycles, and will likely be among the first business segments to begin making LED-to-LED upgrades.

Implications/opportunities: Monitoring LED system turnover by customer segment will improve regional understanding of turnover rates and where efficiency opportunities remain.

LED product offerings are expanding to good/better/best options. For linear fixtures, for example, these options are TLED lamp replacement (good), LED retrofit kit (better), and new LED luminaire with embedded controls (best). Even within the TLED option, manufacturers have launched 'value' models to offer customers a shorter life alternative to the more expensive Design Lights Consortium-listed (DLC) TLEDs. This represents a change from earlier years in the development of LEDs, when customers considered any LED solution a premium option that came at a much higher price point. Now, with the development of good/better/best options, customers have access to an LED upgrade at multiple price points.

Implications/opportunities: In the LED world, the difference in energy use between the good and best options may be minimal. As such, qualifying product lists (QPLs) and incentives targeting only premium options may in fact increasingly incentivize non-energy related bells and whistles. Energy efficiency programs should consider periodically reevaluating the goals of their QPLs and incentives with respect to the products they promote.

Competition is driving increasingly sophisticated sales strategies. The threat of new entrants and declining MRO sales have driven both new and established market actors toward increasingly nuanced sales strategies. Chief among these is a consulting-style sales approach, which involves more sophisticated analytical services, nurturing long-term customer relationships, and an increase in customized outreach to customers.

Implications/opportunities: There may be a need to reassess the education and training needs of end-users and trade allies as both the technology and sales tactics are changing. Similarly, this market change merits a reevaluation of which market actors require such support.

Large customers and small manufacturers drive "manufacturer direct" sales. While the vast majority of the non-residential lighting market goes through wholesale electrical distribution channel, some market actors reported increased activity in the manufacturer-direct channel driven by two sources. First, new small manufacturers (typically new entrants hoping to benefit from the LED craze) often sell directly to end-users because they either lack access to distribution or purposely cut distributors out in order to reduce cost. Second, large customers often seek to negotiate directly with manufacturers to eliminate the middleman (the distributor) from their lighting transactions. Both types of direct sales can bring potential problems: large manufacturers can encounter logistical issues without distributor involvement, and small manufacturers can have quality problems when they cut corners to reduce costs. These issues can drive customers back to traditional channels, according to market actors.

Implications/opportunities: Additional research, particularly on national accounts that may have manufacturer-direct arrangements, will clarify the scope and scale of this phenomenon in the Northwest, and whether there is a place for program intervention in this direct channel.

Industrial customers face competing priorities when considering lighting retrofits. Many energy intensive manufacturing and processing facilities view lighting as ancillary to production-related energy uses that directly affect their core business, and this can lead decision makers to deprioritize lighting retrofits. Furthermore, lighting upgrades often require production to halt, which results in revenue loss. These barriers can make industrial customers reluctant to upgrade lighting systems, despite the energy and maintenance savings and the potential for improved safety and production quality. On the other hand, many large industrial facilities are highly sophisticated, with in-house maintenance and engineering staff capable of installing, operating, and maintaining lighting systems.

Implications/opportunities: Industrial facilities with in-house engineering and maintenance staff may be an optimal market segment for implementing advanced lighting controls, because of their existing knowledge of controls systems for other equipment. Energy efficiency programs should consider timing marketing overtures during seasonal downtimes for each industry to reduce the burden of halting production.

LED street lighting is becoming the norm for retrofits. LED street lighting projects previously required two decisions. The first was whether to do a retrofit project at all; the second was to choose LED technology for that project over other cheaper options. Now, the only decision is whether to do a retrofit. Virtually all new street lighting projects are LEDs. End-user and public perceptions of LED street lights have improved with LED street lights becoming mainstream in recent years, even in non-major urban areas. The majority of these projects have involved grant funding and/or utility incentive funding, and market actors say outside funding is an important driver for achieving cost-effective LED street light retrofit projects.

Implications/opportunities: Incentive funding may primarily affect the timing of retrofits (and savings), rather than the choice of LED over incumbent technologies. With LED streetlights dominating the retrofit market, outside funding may become less critical in the future.

The following sections of this memo outline the research team's methodology for conducting this research and detailed findings organized by area of inquiry.

Methodology

The research team followed a five-step approach to develop the interview strategy it used for this market research. First, the team conducted eight interviews with BPA program, planning, and engineering staff, Northwest Energy Efficiency Alliance (NEEA) program staff, and NEEA and BPA program implementers to solicit input on data and knowledge gaps and key areas of interest. Based on this input and the research gaps identified in previous lighting research, the team selected the five key research areas shown in Table 1.

Next, the team identified the types of market actors (distributors, manufacturers, etc.) who could illuminate these specific avenues of inquiry and developed a master interview guide with questions tailored for each of the identified market actor types. Finally, the research team allocated 50 long and 35 short interviews to the market actor types based on the level of uncertainty associated with a given research question and the expected variability in responses within a market actor group.

Based on this approach, the research team interviewed and surveyed the market actors shown in Table 2.

Table 2: Summary of Research Activities

Market Actor	Short Interviews or Online Surveys	Long Interviews
Manufacturer representatives		10
Manufacturers		2*
National account specialists		22
Outdoor and roadway lighting specialists	5	8
Industrial lighting specialists	5	8
Lighting installation and maintenance contractors	10	
Electrical Distributors (Online Survey)	15	
Total	35	50

Source: Interview tracking data, 2016

**The team interviewed two manufacturers for their general perspective on the market; however, other market actor categories also included manufacturers with specialized perspectives.*

These interviews amounted to more than 55 hours of conversation about the current state of the non-residential lighting market. The research team used NVivo, a qualitative analysis software tool, to map the detailed interview notes to the relevant research questions and uncover themes and findings. Appendix 1 includes additional details about the research strategy, areas of investigation, interview methodology, and the interview guide.

Detailed Findings

The following sections provide detailed results of the team's market actor interviews. These sections include input from various respondent groups. Where relevant, the text provides the number of respondents or responses supporting a finding. However, in all cases, the reader should recall that these findings are qualitative and not designed to be representative of any population.

Market Evolution

LED lighting has revolutionized the lighting market in all sectors. According to recent forecasts from the DOE, LED lighting will account for over 80% of lighting sales by lumen-hours in the commercial and industrial sectors in the United States by 2030.[1] The rapid growth in the LED market has led to great opportunities for energy savings, but has also led to some changes in how lighting products get from the manufacturer to the end-use customer. This section describes how the market is evolving on five fronts: new entrants, LED product offerings, how market actors are adapting, manufacturer direct sales, and online sales of lighting products.

New Players in a Maturing LED Market

Nearly all interviewees commented on the continued influx of new LED products, manufacturers, and purveyors. However, market actors reported varying assessments of what was coming next. Several market actors stated that the LED market is becoming less hospitable to new entrants trying to compete on cost, and predicted that the influx of small new players will abate. Established players (e.g., large manufacturers) are increasingly innovative in the LED space, so new entrants do not have as much of an advantage as they did three to five years ago. On the other hand, many market actors predicted that there is no end in sight for the wave of new entrants into the lighting market. One market actor noted, for example, that for every company that goes out of business, another one starts up. These companies include:

- Manufacturers in Asia looking to market their products in the United States
- Small and medium-scale manufacturers in the United States developing new products
- So-called "re-labelers" who purchase (typically low-cost) products from Asian manufacturers and sell them in the United States
- Lighting consultants who develop lighting projects for end-use customers (market actors mentioned that these consultants range from highly experienced lighting experts to opportunistic start-ups with little expertise)

Market actors mentioned that there is a high rate of turnover among these new companies. This can cause problems for end-use customers, particularly when they have purchased a warranty-protected product from a company that then goes out of business. However, some of the new companies that have succeeded in the LED market have become a long-term part of the lighting market landscape. Companies like Digital Lumens, Lunera, and Start Lighting have grown into established competitors in the

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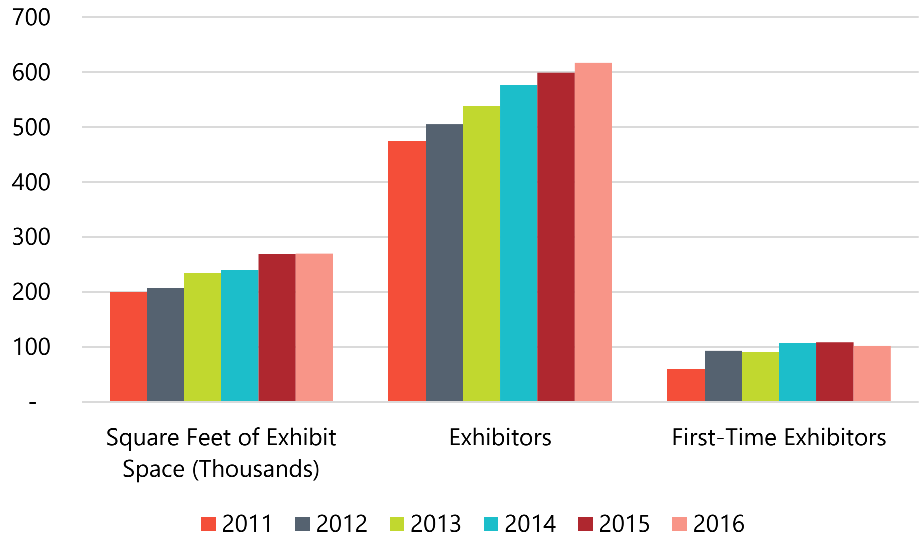
[1] DOE SSL Program, "Energy Savings Forecast of Solid-State Lighting in General Illumination Applications," 2014. [Online]. Available: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/energysavingsforecast14.pdf

market.[2] In some cases, larger established market actors have acquired successful new entrants, leading to consolidation among successful market actors. Many recent acquisitions by large lighting manufacturers have focused on adding controls and software capabilities. For example, Acuity Brands recently acquired software company DGLogick, Inc., and Current, Powered by GE, acquired lighting controls manufacturer Daintree.[3,4] Three interviewees mentioned that major technology companies entering the lighting business are a new competitive force. A notable example is Cisco, which has recently partnered with Philips, Cree, and Eaton (among others) to develop their Digital Ceiling offering, a networked power-over-Ethernet lighting system with extensive controls and data collection capabilities.[5]

The growth of LightFair, the leading trade show for lighting companies, reflects this proliferation of new actors in the lighting market in the last five years. As shown in Figure 1, there has been steady growth in the number of exhibitors at LightFair, with a growing number of first-time exhibitors attending each year until 2016.

Figure 1: Growth of Participation in LightFair from 2011 to 2016



Source: Analysis of LightFair International Press Releases. http://www.lightfair.com/lightfair/V40/press.cvn

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[2] Electrical Trends. "Could the Future of the Big 3 Lamp Lines Be On a Dimmer?" 2014. Available online: http://www.electricaltrends.com/2014/03/could-the-future-of-the-big-3-lamp-lines-be-on-a-dimmer.html

[3] Acuity Brands. "Acuity Brands, Inc., announces acquisition of DGLogick." 2016. Available online: http://www.acuitybrands.com/investors/news-releases

[4] LEDs Magazine. "GE's Current acquires Daintree Networks and SSL ControlScape Platform." 2016. Available online: http://www.ledsmagazine.com/articles/2016/04/ge-s-current-acquires-daintree-networks-and-ssl-controlscape-platform.html

5 Cisco. "Cisco Digital Ceiling Partners." 2016. Available online: http://www.cisco.com/c/en/us/solutions/digital-ceiling/partner-ecosystem.html

With the proliferation of LED technology, many market actors mentioned that there are almost too many options – trade allies and end-users are getting overwhelmed at times. This has contributed to an increasing focus on customer and trade ally training and education. Manufacturers have invested in education initiatives like Cree's Lighting Experience Centers, and the GE Institute. Beyond lighting showrooms, these provide in-depth training to end-users and trade allies.

Differentiation of LED Offerings

Many market actors described a developing consensus in the linear fluorescent to LED retrofit market, with product offerings and contractor recommendations settling on a common set of "good/better/best" options.

- Good: TLEDs – a low-cost, easily installed way to save energy by switching from fluorescent tubes to TLEDs in existing fixtures.
- Better: LED Retrofit kits – manufacturers have developed retrofit kits with the aim of minimizing the labor required to install a new LED light fixture into the existing housing of the legacy linear fluorescent fixture.
- Best: New LED fixture with embedded controls – the most labor intensive and costly option is to redesign the lighting system fully, with new LED fixtures. Controls offer additional savings.

Market actor comments revealed that manufacturers have resolved many of the early problems regarding the quality and design of TLEDs. Most market actors recognized having seen issues in the past, but the vast majority of those who commented on TLED quality noted that they had not seen any problems with the products themselves in the past two years. Contractors and customers are happy with TLED products available now.

Three main types of TLEDs are available, as defined by Underwriters Laboratories (UL):

- Type A: "Plug and Play" – these have an internal driver and wire directly to the existing LFL ballast.
- Type B: "Direct Wire" or "Ballast Bypass" – these wire directly to the main voltage after removing the existing ballast.
- Type C: "Remote Driver" – these require the installation of an external driver.

Market actors have some concern about Type B TLEDs, because of the potential safety risk if an end-user unknowingly replaces the TLED with a linear fluorescent tube. Market actors said there is a possibility that attempting to install a linear fluorescent tube in a fixture wired for a Type B TLED could result in electric shock and/or the tube exploding. Due to this potential safety risk, most market actors require extensive labeling of the fixture to warn users not to attempt installing a fluorescent tube after the fixture has been re-wired. However, some market actors find this risk unacceptable and avoid manufacturing and installing this type of TLED. While Type A "Plug and Play" TLEDs appear to be the preferred configuration in the market, a few market actors also have concerns about ballast compatibility with this design. One manufacturer interviewed noted that in order to mitigate compatibility issues, their company publishes and periodically updates a comprehensive list of ballasts that are compatible with their Type A TLEDs.

With the widespread availability of TLEDs, many customers are beginning to adopt them as a relatively easy way to take advantage of the benefits of LEDs. Roughly one-third (6 out of 15) of distributors responding to the web survey agreed that customers that used to buy low-wattage (25 Watt and 28 Watt) T8s are now buying TLEDs. Another six were neutral on the topic, whereas two disagreed with the statement.

Market Actors Are Evolving to Meet New Challenges

Electrical distributors, one of the key market actors in delivering lighting products to end users, have faced increasing pressures in recent years. With the advent of LEDs, many distributors, especially those who rely on MRO sales as their primary business, have expressed concern about the foreseen drop-off in lamp sales as long-life LEDs take over from legacy technologies with shorter lives. Market actors (including three interviewees) have called this phenomenon "illumageddon," referring to the threat of declining business. In response to this threat, distributors are developing sophisticated sales strategies in order to differentiate themselves within an increasingly complex market. One market actor noted that the way for distributors to stay in the market is to improve expertise and preserve relationships with their customers: "as long as they have that they'll be an important element in the lighting market." A manufacturer noted, "Larger distributors have a vehicle to drive customers to higher-efficiency and LED. They provide ROI[6] analysis and consultation to their customers. Some have an energy efficiency group or specialist."

Many market actors noted that distributors will continue to play a large role in the non-residential market because they finance purchases for end-use customers (usually on a short-term basis), which facilitates large transactions. Furthermore, they play a logistics role by warehousing many products locally – not just lighting products, but many staples that electrical contractors rely on to do business.

The research team observed this evolution in their sales data collection and research on regional distributors as well, seeing a growth in "distributor consultants," which tend to be smaller businesses focused on selling LED projects. However, in addition to these stand-alone consulting businesses, full line and MRO distributors have also incorporated consulting approaches into their broader offerings.

End-Use Customers Buying Direct from Manufacturers

Manufacturers are also responding to the changing market, and 15 of the 27 market actors commenting on this topic believe that there is an increasing trend of manufacturers selling products directly to end-use customers, circumventing the traditional distribution channel. The remaining 12 interviewees were unsure whether these practices were increasing, but recognized that direct sales do occur sometimes. Interviewees mentioned two ways in which this is happening:

1. A re-labeler or small manufacturer tries to compete on price by cutting out the middleman. One market actor's guess is that approximately 10% of the retrofit market goes through that channel, possibly less. That market actor noted, "Those smaller companies can come in with a 10% or 15% lower price because they don't have the additional mark-up layer. That discount can be compelling for customers. They don't have economies of scale, but they still can sell on price alone."

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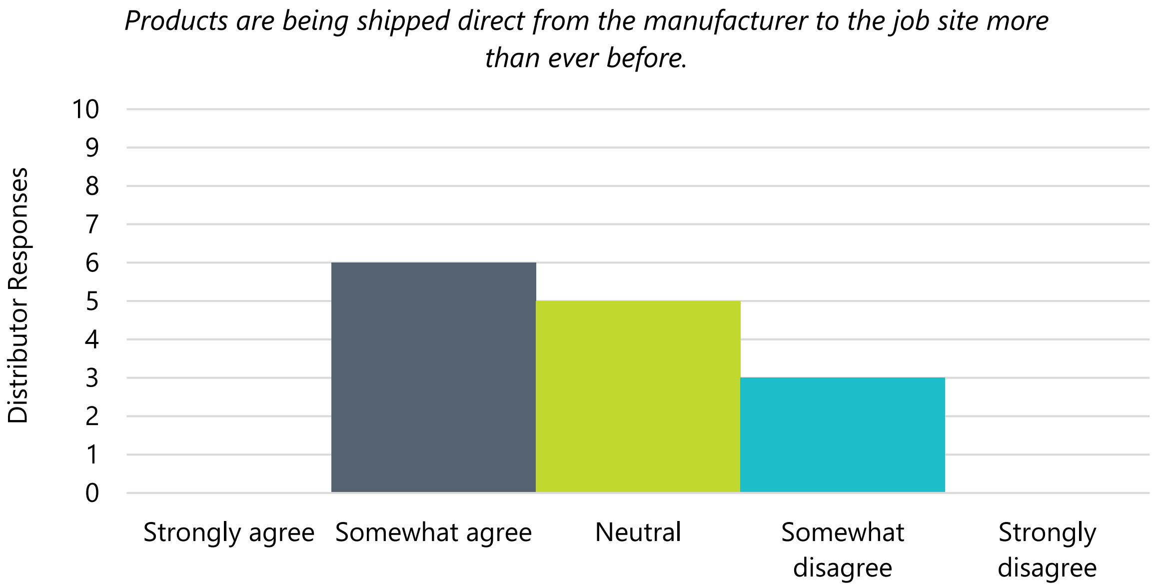
[6] Return on Investment

2. Large end-use customers or national accounts (e.g., fast food chains, retail chains) typically use national account distributors to supply lighting products. A few market actors think there is a trend toward these large accounts purchasing lighting products directly from the manufacturer and circumventing the distributor. Others say this is not a growing trend, but rather simply an option that companies try out, while the distributor remains a strong and necessary actor in the market. One mid-sized manufacturer stated, “Today’s market requires an omni-channel approach. I work with national accounts who want to buy direct. As clients get larger they want to cut out the middleman, and they have huge purchasing power. So we call directly on them.”

Distributor opinions differed about whether manufacturer-direct shipments are increasing. Figure 2 shows the range of distributor responses.

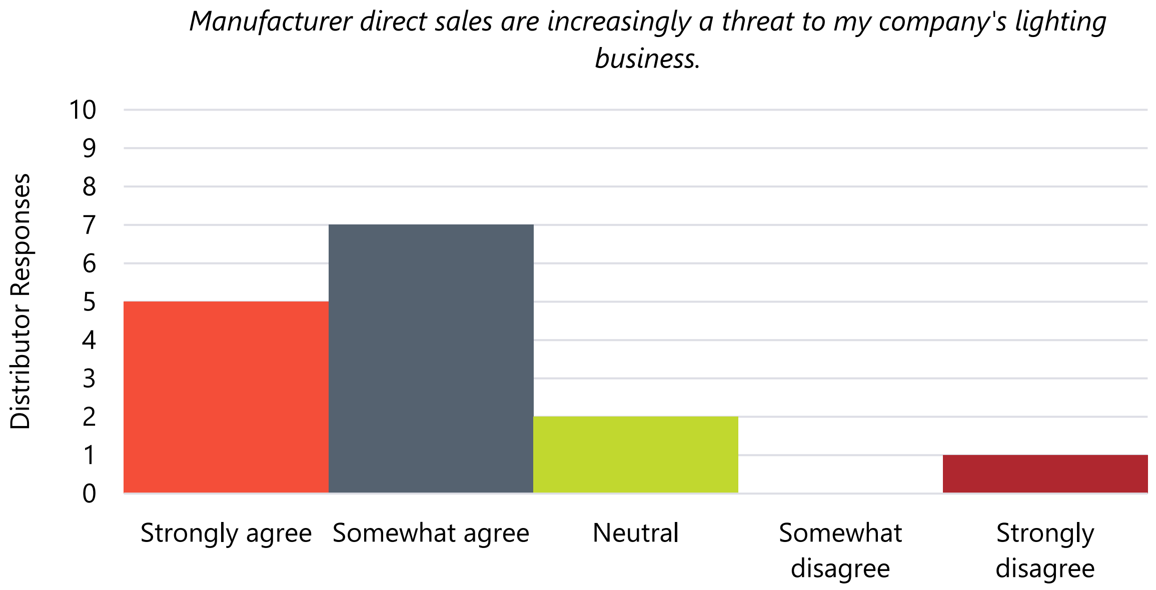
Figure 2: Distributor Views on Manufacturer Direct Shipment Trends (n=14)



Source: Online survey of Northwest distributors, 2016

Despite the lack of strong indication of an increase in direct shipments, 12 out of 15 distributors agreed that manufacturer direct sales are increasingly a threat to their lighting business, shown in Figure 3.

Figure 3: Distributor Views on Threat of Manufacturer Direct Sales (n=15)



Source: Online survey of Northwest distributors, 2016

Increasing Competition from Online Sales

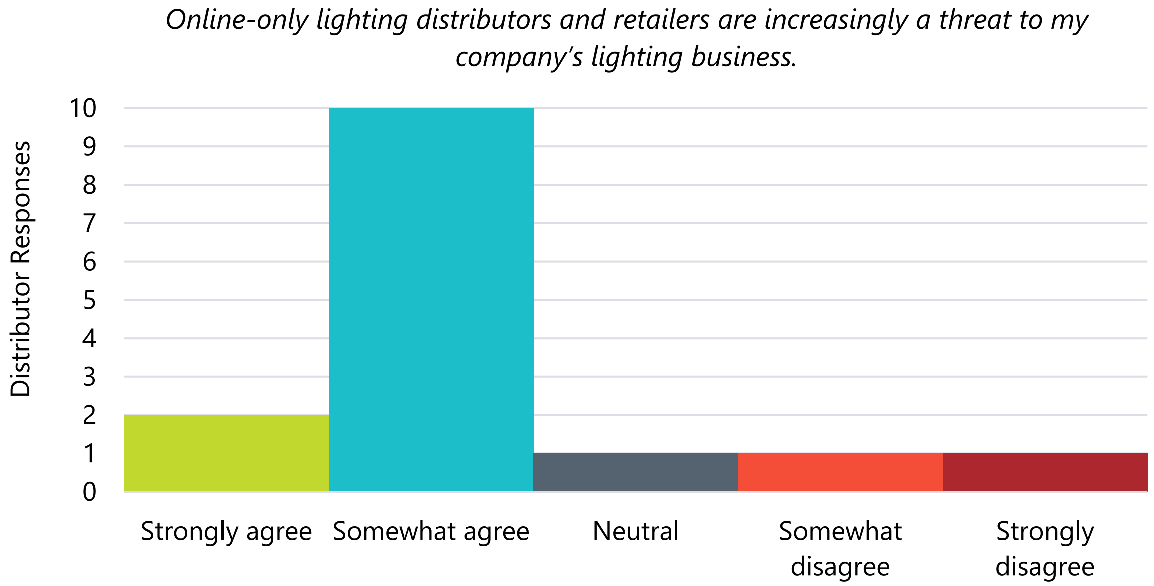
Twelve market actors reported that they have observed increased online sales of lighting products to non-residential customers, coming from at least three different types of online sources:

- Online-only purveyors of lighting products, such as bulbs.com and 1000bulbs.com
- Brick & mortar distributors with an online presence
- Manufacturers selling direct to end users online

Some end-users see an opportunity to change their purchasing strategy by buying products online while others maintain relationships with distributors. Some manufacturers and distributors expressed concern that customers unknowingly buy low quality products online. According to these market actors, customers purchasing lighting products online may find low quality options that distributors do not offer, since distributors vet the products they sell to ensure quality. Furthermore, customers may not have enough information to select the appropriate product for the application. One distributor stated, “With competition from online sales, we have to coach people to do good projects. When you go with us, we know the utilities, we also know the products and the market out there.”

Figure 4 highlights the threat felt by distributors regarding online-only lighting distributors and retailers. The vast majority, (12 out of 15) agreed that these new market players were an increasing threat to their business. One distributor remained neutral, and two disagreed, not feeling threatened.

Figure 4: Distributor Views on Online-only Lighting Sales (n=15)



Source: Online survey of Northwest distributors, 2016

Purchase Decisions

Customers' decisions about lighting projects have become increasingly complex with the rapid increase in the number of products available. Retrofitting or installing a new lighting system requires a great deal of specialized knowledge, and the amount of knowledge required has increased with the advent of LED and the increasing prevalence of lighting controls. The team asked market actors about how customers are making lighting decisions today, who is involved in the decision chain, and what factors drive customers to retrofit their lighting systems.

Turnover and Motivators for Lighting Retrofits

Most interviewees believe that technology innovation/advancement drives lighting system turnover. One market actor described this technology-driven pattern, saying, "It can be embarrassing, because 10 years ago we might have recommended something to a customer, and today we go back to that same customer and say, 'get that out of here!'"

Market actors noted that the more customer facing the business, the quicker they are to upgrade their lighting. Retail businesses are most likely to re-do their lighting on a frequent cycle, because lighting affects their bottom line in terms of sales, not just energy costs. Retailers are concerned with maintaining an aesthetically appealing store, and lighting upgrades are commonly included in aesthetic updates. Retailers also want to optimize color rendering to improve the appearance of their merchandise. Market actors say both these factors can drive retailers to install LED lighting. With these drivers, market actors estimate that retail businesses follow an approximately five- to seven-year system turnover cycle.

By contrast, the industrial segment reportedly follows a slower turnover cycle, estimated by market actors to be about 10 years on average. One market actor summed this up by saying, "Industrial will run them till they die."

Across the board, market actors believe that the most powerful motivator for a lighting retrofit is cost savings; the shorter the payback, the easier the sale. Financing can make a difference, especially for capital constrained businesses and institutions. For example, school districts often work with energy service companies (ESCOs) who finance their lighting purchases, and medium-sized commercial businesses with access to private financing sometimes utilize financing to implement lighting upgrades. Productivity and safety can motivate some commercial and industrial customers to retrofit.

The appeal of new technology, while not a primary motivator, can be a factor for some customers. For example, color-tunable LEDs, an emerging technology, can motivate some customers to conduct a retrofit. Availability of new technologies influences turnover rate. With the speed of the LED product cycle, new functionality is becoming available before the end of the last generation product's life. Market actors expect new functions and features to drive the "second generation" of LED retrofits. For example, if a customer installs LED luminaires with no controls, that product might have a 20-year useful life, but the same customer might decide to upgrade to a product with advanced controls after five years. In this way, the lighting turnover cycle is becoming more like the consumer electronics product cycle. One extreme example is smart phones, which consumers often replace long before the end of the phone's useful life. While lighting may not match the smart phone turnover cycle, market actors believe that features will increasingly drive turnover before burnout.

How do National Accounts Make Decisions about Lighting?

The research team conducted 22 interviews with a variety of market actors that work with national accounts, defined in this context as large national or regional scale businesses with multiple commercial locations. These businesses include chain stores, restaurants, hotels, banks, and many other types of corporations. Most national accounts fall into one of two ownership models: chains or franchises. A chain business entails one parent company, which owns and manages all of the business locations. A franchise business consists of independent owners (franchisees) who operate individual stores, with overarching management occurring at the corporate (franchiser) level. They are large customers, and market actors tend to tailor their businesses to attend to their need. Many market actors mentioned every company has its own personality, approach, values, and priorities. They emphasized that it is necessary to customize services for these large entities.

National Account Lighting Project Process

The research team compiled information about the typical decision makers and steps involved in a national account lighting project. However, this information reflects only a basic idea of the process, and further research will help to understand variations by project type, as well as across different segments and types of national accounts.

Corporate offices typically drive national account lighting projects. The top of the decision chain varies from company to company, but the key decision maker may be the Chief Financial Officer (CFO), Vice President of Finance, Head of Operations, Head of Engineering, or the owner or Chief Executive Officer (CEO).

Several national account-specific market actors specialize in serving these multi-site customers. These entities can be influential partners in large lighting projects executed by national accounts.[7]

- National Account Distributors – these companies operate as lighting distributors but serve national accounts primarily or exclusively. Examples of these companies include Regency Lighting, Capitol Light, and Weidenbach Brown.
- ESCOs – some national accounts work with ESCOs on their lighting retrofit projects, and they can be key decision makers in lighting maintenance. Amaresco and Facility Solutions Group are examples of ESCOs. Some market actors think that ESCOs are not a major player for national accounts, but others do consider ESCOs as competitors in this space. There is some crossover between ESCOs and national account distributors. Facility Solutions Group, for example, operates as both an ESCO and a distributor.
- Rebate Administrators – these companies help national chains make decisions about where to invest in energy efficiency projects by identifying the most cost-effective utility incentives. Examples include RealWinWin and Green Generation Solutions. Rebate administrators partner with national account distributors and ESCOs to assist their clients in prioritizing investments.

Many of the same market actors are involved in both new construction projects and retrofit projects. Both tend to involve a third-party architect and engineering firm in the design phase of the project, though there are cases where the end-use customer uses in-house specialists to perform design functions.

The general phases of the project process, as described by market actors, include the following.

1. **Initiation**. Some companies initiate lighting projects internally, addressing a need to upgrade or install new lighting equipment. Motivators can include energy savings, aesthetic refresh of space, rebranding of space, or expansion and addition of new locations. Alternatively, a third party may influence the initiation of a project, such as a manufacturer, distributor, or ESCO presenting a proposal.
2. **Design and Specification**. In developing project specifications, national account end-use customers rely on expertise from their design team (internal or external), as well as sometimes involving lighting manufacturers and distributors in selecting the appropriate solutions. According to market actors, manufacturer representatives are not typically involved in specification for national account projects, since they tend to have specific geographical territories. Specifications include a bill of material, which can give varying levels of detail about the specified products. Sometimes the bill of material identifies the exact product number from a particular manufacturer, while in other cases the bill of material gives general parameters that allow bidders to offer various suitable solutions. Notably, market actors mentioned that energy efficiency upgrades for national accounts are often bundled together: a project typically includes not only lighting but also other energy upgrades like HVAC, and potentially other non-energy-related work.
3. **Contracting**. Often, but not always, projects go out for competitive bid, with a national account soliciting proposals from contractors via a request for proposals. In other cases, national accounts have established dedicated relationships with contractors to whom they assign projects.

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[7] The companies listed here are examples only. The research team did not interview all of these companies.

Some national accounts have relationships with several local or regional contractors, while others have one national-level contractor that manages lighting retrofit work nationwide.

4. **Implementation.** National accounts investing in lighting upgrades (and other energy efficiency upgrades) typically prioritize the projects in geographical areas with the highest cost of power. National accounts typically implement projects in these areas first, and phase in projects in other areas if and when it is financially feasible. National accounts also prioritize areas with largest utility rebates, as those rebates contribute to projects with a more favorable ROI. Ease of participation in utility programs is sometimes a deciding factor as complying with utility requirements from hundreds of utilities requires significant work. The regional prioritization of energy efficiency projects often involves input from national market actors who advise national accounts on costs and benefits, such as national rebate administrators.

Processes Specific to Franchises

The general process described above applies to both chains and franchises, but franchises have additional unique considerations. In most cases, the franchise operator (or franchisee – the owner of the individual business location) is responsible for the cost of upgrades to the property. However, the corporate management (the franchiser) often mandates specific requirements for the appearance of individual store locations. Franchisees typically agree to maintain these brand standards as part of their franchise agreement. Franchisers can require periodic updates to branded space, which franchisees are responsible for implementing. For example, if a franchise business updates their aesthetic look and feel of their stores, they may require their franchisees to update their lighting systems as part of this "brand refresh."

Some market actors that serve national accounts do not work with franchises. A national account distributor, for example, said their company does not work with franchises, because doing so would involve working with many individual franchise operators, rather than one centralized decision maker. Instead, this interviewee said that local contractors tend to serve franchises, and therefore they likely use local and regional distributors for purchasing lighting equipment.

California's Title 24 Energy Code

While not directly applicable to Northwest business locations, many market actors mentioned California's 2013 Building Energy Efficiency Standards as a Northwest-adjacent issue, commonly referred to as Title 24.[8] Title 24 has been a major driver of change in the non-residential lighting market in California, particularly in new construction, as well as in large retrofits that require code compliance. The research team asked market actors whether the strict energy efficiency requirements of Title 24 would affect national account business locations in the Northwest, and the consensus was that in some cases it would. Some national accounts develop a California-only specification to meet Title 24 requirements, and a different specification for the rest of the country. Others, however, will apply their California-ready, Title-24-compliant specification nationwide in order to maintain consistency across all locations.

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[8] The California Energy Code, or Building Energy Efficiency Standards, are part of the California Building Standards Code, which is title 24 of the California Code of Regulations. Market actors commonly used the term Title 24 to refer to the energy efficiency standards that affect lighting.

Role of Utility Programs in Today's Lighting Market

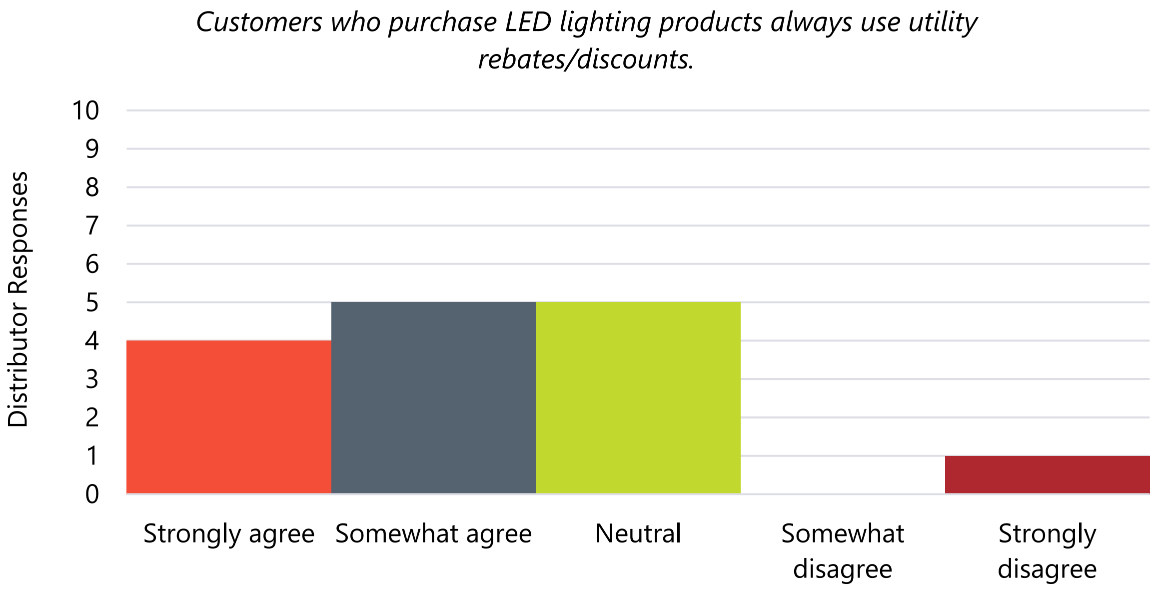
Of the 75 market actors interviewed, 44 of them mentioned utilities and utility programs as an important player in the non-residential lighting market. These market actors emphasized that utility incentives have driven lighting retrofits forward, and help make their job selling lighting products and services easier. They also emphasized that although LED prices are falling, utility rebates still play a very important role in non-residential customer decisions about lighting. The utility rebate sometimes pushes the decision to the "tipping point," making a project's ROI attractive enough for a building owner to move forward with it.

In addition to the general importance of utility incentives in lighting projects, interviewees pointed to three specific areas utility programs influence most strongly:

- Controls – three market actors mentioned that utility incentives are often the deciding factor that leads a customer to include controls in a retrofit project, because in some cases the additional incentive is enough to make the project highly cost-effective.
- Gas station lighting – one market actor pointed to the BPA program as the driving factor that caused many gas stations in the Northwest to convert their lighting to LED.
- Street lighting – all five utilities interviewed about street lighting projects noted that outside funding (from utility incentives or from other grant programs) are an important factor in driving street light owners (including the utilities themselves) to upgrade to LED.

As shown in Figure 5, a majority of the distributors responding to the web survey (9 out of 15) agreed that customers who purchase LED lighting products always used utility rebates or discounts. Only one distributor strongly disagreed, and the remaining five were neutral on the topic.

Figure 5: Distributor Views on Utility Rebates for LEDs (n=15)



Source: Online survey of Northwest distributors, 2016

Lighting Maintenance Evolving with LED Penetration

Two general approaches to lighting maintenance are possible: either replace lamps and ballasts as they burn out (spot re-lamping), or replace all lamps and ballasts in a building or an area at a scheduled time (group re-lamping). Market actors reported that spot-lamping is the norm, with most customers performing maintenance on an as-needed basis. This corroborates the findings of the Building Owner and Operator Survey conducted under BPA's residential lighting study, which found that 18% of businesses perform group re-lamping.

The businesses that do conduct group re-lamping are motivated to maintain the highest quality lighting possible. Customer-facing and luxury businesses such as high-end retail stores tend to be among those that prefer scheduled group re-lamping. These companies do not want to have even a single lamp out in their stores, so they schedule group re-lamping at 75% of the life of the lamp.

Some companies hire maintenance contractors to maintain their lighting systems, while others perform lighting maintenance with in-house labor. Maintenance contracts take different forms, but often involve a monthly/bimonthly/quarterly visit to check for lamps that have burnt out and replace them. Two market actors mentioned that the market for lighting maintenance slowed down significantly during the recession, with companies extending their maintenance cycle to annual visits. Despite the improved economy, these market actors have found that companies have not switched back to more frequent maintenance.

Another factor affecting maintenance behavior is the advent of long-life LEDs. One manufacturer's representative stated, "Up until 3-4 years ago, large customers like grocery stores, they'd have scheduled re-lamps. They'd go through a store every three years and change out all the lamps. Nobody's doing that anymore – now they just go through and upgrade to LED fixtures. It's a no-brainer for those big customers. Group re-lamping customers are becoming fewer and further between – if I'm a big grocery chain, I'm not scheduling a group re-lamp three years from now anywhere. I'm changing all my locations to LED fixtures so I don't have to do that anymore." These factors point to a decline in group re-lamping as a lighting maintenance strategy, which will likely persist as LEDs continue to penetrate the market.

Regional Variation

The research team asked market actors about variation in customer behavior or market characteristics within the Northwest region. Specifically, the research team wanted to find out whether there were notable differences between urban and rural customers or market actors.

The web survey asked distributors to compare purchasing behaviors between urban and rural customers. The majority (9 out of 14) distributors answered that their urban customers tend to purchase lighting equipment that is more efficient. The remaining five distributors answered that urban and rural customers purchase equipment of the same level of efficiency.

Business Size is a Driver of Differences

Four market actors (out of 23 commenting on the difference between urban and rural customers) noted that larger businesses are concentrated in urban areas. These market actors believe there is no difference in customer purchasing behavior between urban and rural areas, but noted that large businesses are more likely to purchase new technologies (due to cost and sophistication of operation). One market actor noted the example of LED canopy conversions at gas stations, stating that the larger, busier gas stations along the I-5 corridor were the first to convert, and the remaining "hold outs" are small businesses that do not have the capital to invest in lighting upgrades. These smaller gas stations tend to be in rural areas.

Urban/Rural Divide in Exposure to High-Efficiency Lighting

A few market actors mentioned that there is a difference in end-use customers' access to information about LED products between rural and urban areas. For example, manufacturer representatives are less likely to visit businesses in outlying areas. One contractor specializing in calling on rural customers noted, "In small towns you can walk in and say what you're here to do because they're not inundated with sales people. In a metro area you wouldn't be allowed in because they've had twenty people come in already, it's already been done, or you can't get in the door because it's handled out of a corporate engineering department." Seven market actors (out of 23 commenting on the topic) specifically noted that rural customers lag behind urban customers due to lack of exposure to information about new products and technologies. Three market actors also mentioned that distributors and retailers in rural areas might carry fewer high-efficiency products, which would further limit access and exposure.

Industrial Lighting

The research team interviewed market actors directly involved in serving industrial lighting customers. These included manufacturers of industrial lighting products, an industrial facility energy audit specialist, and an industrial specialist working for a distributor. They offered industrial-focused perspectives on the key market segments in the Northwest, the special lighting needs of their customers, adoption of high-efficiency lighting and controls, customers' motivations, and how facilities handle lighting maintenance.

Industrial Lighting Segments

The market actor interviews identified the key segments of the industrial sector in the Northwest. Table 3 summarizes the characteristics of these key segments, as described by market actors.

Table 3: Key Industrial Lighting Segments

Key Segment	Characteristics
Manufacturing/Processing	Dominant types of manufacturing plants include food processing, lumber mills, and pulp, paper, and glass processing. Each plant tends to have unique lighting needs due to the variety in products.
Indoor Agriculture	This is a growing market segment, but not all facilities are optimal utility program candidates.
Warehousing/Storage	Includes manufacturing storage facilities and cold storage. High square footage and hours of operation represent a strong opportunity for controls. Some market actors do not include warehousing in their definition of industrial customers.

Source: Research team analysis of market actor interview results.

The main lighting application across all three key industrial segments is high bay. High Intensity Discharge (HID) was the traditional technology of choice for all of these segments, and market actors estimated that HID still dominates installed lighting. Some HID systems have been replaced by multilamp fluorescent fixtures, however many interviewees noted that HID is still a prominent technology in the industrial sector. LED is currently the preferred technology for retrofits, although adoption is slower than in the commercial sector. Facilities that have already upgraded to high-output T5 fluorescent fixtures are less likely to consider LED upgrades because the incremental efficiency gain is lower.

It is important to note that industrial facilities include attached office spaces and outdoor areas, such as parking lots and production yards, which are often included in a retrofit project. One market actor noted, “When you say ‘paper mill’ that also encompasses offices, warehouse, exterior warehousing, areas over paper machines, under paper machines. Each site encompasses so much.” Market actors noted that lighting retrofits often include all areas of the facility, not just the processing areas, and that all areas (offices, outdoor areas, etc.) are moving toward LED.

Lighting Needs and Considerations for Industrial Facilities

The needs and motivators of industrial facilities differ from their commercial counterparts. Across all three segments, employee safety is a primary concern. One interviewee explained, “We’re talking about safety of human beings, and in commercial it’s more about pleasantness and emotional impact. [We] have to make sure people are safe regardless of how pretty it is. Safety, security, improvement of process.” The section below expands on these and other industrial-specific considerations.

- **Safety is paramount.** Safety can be a big motivator to upgrade to LEDs. Compared to existing lighting, especially older lights that have degraded over time, new LEDs are typically much brighter and often more controllable. The instant-on capability of LEDs is also attractive to industrial facilities. Many interviewees shared the sentiment that “a lot of facilities don’t even realize they’re working in in dangerous conditions (…) a lot of customers have installed 1000-Watt metal halides that have depreciated 15% over 10 years so they are severely under-lit.”
- **Long operating hours (usually).** Compared to commercial facilities with shorter operating house, ROIs for lighting upgrades at industrial facilities tend to be quite short because of the high hours of use. However, in energy-intensive manufacturing, processing, or cold storage facilities, lighting comprises a small portion of the overall operating budget. Therefore, lighting tends to be a low priority for upgrades or maintenance.
- **Mobile equipment.** Industrial facilities often have mobile equipment and sometimes reconfigure their facility space depending on changing needs. For example, storage and warehouse spaces are often reconfigured with wider or narrower aisles based on changing inventory. Manufacturing plants with mobile equipment need temporary mobile lighting, as well as task lighting for parts of their production process that require focused lighting. Mobile lighting typically needs to meet the same safety requirements as wall- and ceiling-mounted lighting (see below).
- **Food processing safety requirements.** Food processing facilities can require niche products. These are becoming more and more available in LED versions, according to interviewees.
  - Waterproof fixtures are often required for cleaning, as food processors must regularly spray down the whole production facility to comply with health standards. This can make TLEDs an attractive option: food processors often decide to use TLEDs in existing waterproof fixtures instead of upgrading to LED fixtures. The higher cost of waterproof fixtures decreases the potential ROI of a project that involves replacement of fixtures.

    - Glass is dangerous. Glass bulbs in the production area can shatter because of exposure to high heat or vibration. If this occurs, facilities must shut down production and dispose of all product potentially exposed to shattered glass. Therefore, food processors require glass-free or protected lamps and fixtures.

- **Hazardous conditions.** Especially in manufacturing and production facilities, heat, moisture, dust, and debris associated with industrial activities challenge standard commercial products. The most common needs follow.
    - Some facilities (e.g., bakeries, paper mills) require fixtures/lamps that can withstand extreme heat.
    - Some facilities require explosion-proof fixtures designed to avoid causing explosions due to flammable gasses or combustible dust. This poses a similar issue as with waterproof fixtures – if a facility has already invested in explosion-proof fixtures, the cost of an LED fixture upgrade may be prohibitive or unattractive.[9]

Along with their specialized conditions and requirements for lighting, industrial facilities have specialized staff and contractors. Most industrial facilities have technical and engineering staff on-site at all times, including in-house electricians who regularly perform lighting maintenance. These employees may conduct lighting projects without the assistance of electrical contractors. In addition to their in-house staff, market actors said that larger industrial facilities tend to have relationships with electrical contractors. One market actor noted, “One interesting thing about the larger [industrial] plants is that they almost always have a relationship with a large electrical contractor. They have a sales rep or account manager who already has a sense of what’s going on because they are out there all the time. They trust that rep to only bring them good projects. That electrical contractor will be weeding out projects before they get to the end-use customer.”

Some Industrial Facilities Slow to Upgrade Lighting, but LEDs are Gaining Ground

Lighting upgrades can be a low priority for industrial facilities: they want to invest in their production process equipment first, because that is most important to their business. One interviewee explained that for industrial customers, “the best lighting system is the one you can forget about.” Market actors identified two main drivers for industrial customers’ reluctance to upgrade lighting.

- Production is top priority, as stopping production to upgrade lighting can result in a huge loss in revenue. All eight industrial market actors mentioned this. Some industrial facilities will delay upgrading or maintaining lighting until it is truly necessary for this reason, and many market actors gave anecdotes of very old HID lighting installed in industrial facilities. One recounted visiting a facility “so dark it looks like you’re walking into a house of horrors dungeon.”
- Two interviewees noted that LED adoption is moving slowly because no facility wants to be the first to have a lighting upgrade fail or have a negative impact on production for an extended period. Industrial facilities need to see successful retrofits at other facilities before investing, because so much more than lighting is at stake for their facilities.

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[9] The National Fire Protection Association defines three classes of explosion-proof fixtures to meet the needs of facilities with various risks of combustion. For example, a Class I fixture is rated for safe use around flammable gasses, vapors, or liquids, while Class III fixtures are safe for use around easily ignitable fibers such as cotton.

On the other hand, all eight industrial market actors mentioned that LEDs are gaining popularity with industrial customers. One noted, "LED is there in industrial now. It wasn't there 2-3 years ago. But now customers see it as a good option."

Controls Compete with Safety Concerns

Industrial market actors reported that interest in lighting controls is just getting started in the industrial market. Interviews uncovered two main themes regarding controls: that there is great opportunity for controls in industrial facilities and that legitimate safety concerns exist about controls in industrial facilities. Six market actors focused primarily on the opportunity, three saw both opportunity and safety risks, and two interviewees focused their comments on the safety risks.

Interviewees who see good industrial opportunities for controls cited the large square footage of industrial facilities as the driving factor for utilizing them. Many agreed that placing occupancy sensors in less trafficked areas, particularly in large warehouses or storage facilities, was an obvious choice. One interviewee explained, "You can put in an incredibly efficient driver and lamp, but if you don't include controls you're missing the trifecta." Others noted that controls provide additional savings for industrial customers, ranging anywhere from 20%-90%.

Interviewees cited safety as a major barrier to controls for some facilities, due to concerns that lights could turn off while someone is working with dangerous equipment or in an area not picked up by occupancy sensors. Liability concerns drive many industrial facilities to keep all lights on at all times, regardless of whether workers are in the area or not. One market actor noted that the only type of controls his industrial customers ask for is high-low dimming, because they want the lights to remain on for safety. The same market actor noted that some customers are not interested in controls at all, because in addition to safety issues, "they just view it as one more failure point in the fixture."

The types of controls utilized vary by facility. Occupancy sensing is the most common, with many facilities employing the technology in some portion of the space. Dimming is also a popular option, paired either with occupancy sensors or timeclocks. Daylighting is less common, and market actors reported this is due to safety concerns surrounding appropriate light levels. One market actor highlighted that integrated controls systems that are programmable and controllable via a back-end software system can help mitigate safety risks when properly implemented.

Return on Investment is Key

Industrial customers are looking for payback periods of 1-3 years, according to all seven respondents commenting on this topic. They tend to be sophisticated about their capital investments, since many industrial facilities invest frequently in equipment repairs and upgrades to support their core business. One market actor explained, "Regarding financials, they always want an 18-month or less payback. Very quick payback requirements. It's interesting because they have such large investments in their facility already, you'd think they would have higher tolerance for payback. Lighting projects are so cost-effective especially with high hours of operation. But they really focus on the fast payback."

One market actor (a lighting manufacturer specializing in hazardous location lighting) stated that their customers do not care about energy savings, and instead are looking for a long-lasting, low-maintenance, durable product to meet their lighting needs. Non-energy benefits of an LED upgrade can be more difficult to quantify than energy savings, but are often influential in decision making, especially if market actors are able to monetize these benefits and include them in ROI calculations:

- Maintenance savings can be huge due to the reduced labor costs for less frequent re-lamping, and avoided shutdown time. As noted, not having to stop production is a high priority for industrial facilities, and this means reduced maintenance is an attractive benefit of upgrading to LEDs.
- Higher quality in production due to better light levels. For example, a lumber mill having a lower reject percentage on boards because workers can see problem pieces before sending them to a customer.
- Facilities can save on insurance premiums if they have higher light levels.
- Some facilities view LEDs as glamorous additions and are simply interested in doing the "cool, new thing".
- Utility incentives are a huge selling point, sealing the deal by driving down cost and shortening the ROI.

Diverse Approaches to Lighting Maintenance

There is no consistent lighting maintenance strategy across industrial facilities. Some facilities simply allow lamps to burn out until the facility is too dark for them to work in. Others conduct batch re-lamping and hire companies to replace all lamps at once. Facilities with in-house engineering staff or maintenance staff are more likely to do their own electrical work.

Industrial facilities that already have lifts typically do not hire outside firms to work on lighting equipment. One interviewee also explained that "most of them have O&M[10] work on millions of dollars of equipment every day, when they look at a fixture it's almost like they see it as something a kid could do. They have nothing but bodies to do work, all they need is a sweet deal from their supplier and they're off and running." Often, maintenance or upgrades occur during scheduled production shut downs (holidays or mid-year). Some industrial facilities have energy efficiency managers who utilize supply networks to purchase equipment, but use in-house staff for maintenance labor. On the other hand, one market actor mentioned that large industrial facilities sometimes contract with ESCOs to perform major retrofits, and that those projects sometimes include an ongoing maintenance contract.

Market actors agreed reduced maintenance costs are a primary benefit of LEDs installations and can be a selling point. However, one market actor noted that he sometimes has difficulty convincing his customers of the magnitude of the maintenance savings because they are so accustomed to maintaining their legacy systems, which require frequent lamp and ballast replacements.

Outdoor Lighting

The research team interviewed 13 market actors specializing in outdoor lighting. They included five manufacturers producing outdoor lighting products, three large contractors specializing in outdoor lighting, and five representatives of utilities who have performed outdoor lighting retrofit projects. These

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[10] Operations and maintenance.

market actors offered insight on the key applications in outdoor lighting, how street lighting projects work, the state of LEDs in outdoor lighting, and outdoor lighting maintenance.

Outdoor Lighting Applications

Among the wide range of applications in outdoor lighting, the research team's interviews covered the categories described in Table 4. The outdoor lighting applications discussed here do not align with the lighting applications defined in the research team's momentum savings modeling and analysis. Rather, the applications shown here illustrate the areas of expertise of the market actors interviewed. The sections that follow give more detail about these findings.

Table 4: Outdoor Lighting Applications

Application	Market Insights
Building exterior	Many interviewees agreed that LED wall packs were one of the first applications embraced by early adopters in the outdoor market.
Signage	One market actor mentioned that many convenience stores and other chain stores are retrofitting signage to LED.
Street and Roadway	LED is becoming the norm. Retrofit projects vary with ownership of the lamps. End-users may be required to conform to a particular look and feel, with some steering away from "space age type fixtures."
Site and Area Lighting	This application includes parking lots, parks, yards, and open areas at commercial facilities. Utilities see opportunity in parking lot lighting after the success of LED street lighting projects. Maintenance benefits are important to commercial customers.
Car Dealerships	Car dealerships were an early adopter of LED outdoor lighting, because of the benefit of increased visibility and improved color rendering. Controllability is a draw too, as a way to save on power costs without losing nighttime visibility.
Petroleum Stations (Gas Stations)	A wave of gas station retrofits, driven in part by BPA's incentive program, has converted many of the region's stations to LED canopy and area lights.
Sports Venues	Sports venues have low hours of operation and stringent lighting requirements. However, they are also a highly public venue for demonstrating the effectiveness and savings of LEDs, making them attractive opportunities for market actors.
Marine Lighting	Customers more interested in durability than energy savings. Boat lights are generator-powered, but most marinas are utility customers.

Source: Research team analysis of market actor interview results.

Street and Area Lighting Retrofits Are Predominantly LED

Many cities and towns still operate and maintain legacy HID systems, and some have installed induction streetlights over the past several years. However, according to interviewees, nearly all street lighting and area lighting retrofits in the past two years have installed LED systems. Of the eight outdoor lighting interviewees who sell lighting products, two stated that they exclusively sell LEDs, focusing their business on what they see as the future of outdoor lighting. Part of this shift stems from price, with LED prices dropping significantly in the past two years. In earlier years, LED projects had higher costs and the payback periods were longer than many customers required. Interviewees said most street lighting projects sought a 3- to 4-year simple payback, and now, most projects are falling under a 3-year simple payback due to the reductions in LED prices.

One utility interviewee described two street lighting projects in eastern Washington to demonstrate this change. A medium-sized city installed induction lights in 2014 and everyone involved considered them a great replacement for high-pressure sodium (HPS). Just two years later, in early 2016, a nearby town went through the process of upgrading their HPS street lights, and only considered LEDs. LEDs are now the norm in street lighting projects in that area, and induction no longer appears to be a viable option. The interviewee reported that cities have observed that LEDs look better aesthetically; the incremental cost is lower than it used to be; and market actors and end users now see LED as a proven technology.

The majority of interviewees noted that utility programs are an influential factor in most street lighting projects. One Washington utility reported the street lighting retrofit projects coming through the utility's incentive program have grown in numbers over the past two years, more than doubling between 2014 and 2016. All these projects have included LED lights, and the interviewee stated that these projects have now become sufficiently cost effective with the drop in LED prices and the support of utility incentives.

Another interviewee (a contractor), stated, "LED street lighting retrofits are becoming a commodity at this point… it's like what replacing T12s used to be." However, reasons for upgrading to LED differ depending on who leads the project. In some cases, the key decision factor is reduction in energy and maintenance costs with a favorable ROI, but for others it is a different aesthetic look, dark sky friendly fixtures, or a desire to increase sustainability or promote green practices. Regardless of the motives, projects all tend to focus on achieving a highly cost-effective solution, and outside grant funding (such as funds from the Washington State Transportation Improvement Board's Relight Washington program) and utility incentives are of utmost importance.

Dark Sky ordinances[11] can also be a driver for LED replacements because the directionality of LEDs makes compliance easier. Most market actors noted that while dark sky compliance was a consideration, it was not a primary driver of retrofit projects.

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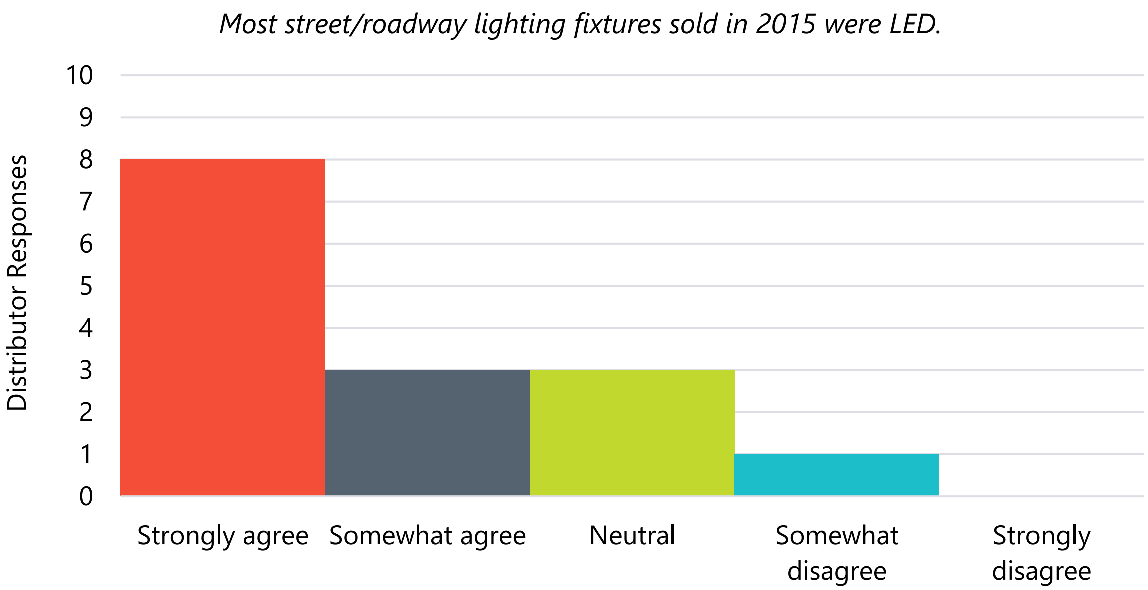
[11] Dark Sky ordinances aim to limit light pollution by setting standards for outdoor lighting. See more information at the International Dark-Sky Association's website, http://www.darksky.org.

Distributors also see a trend toward LED street lighting in the Northwest. The majority of distributors responding to the web survey (11 out of 15) agreed that LED products comprised the majority of street/roadway fixtures sold in 2015, as shown in Figure 6.

Figure 6: Distributor Views on LED Street and Roadway Fixtures (n=15)



Source: Online survey of Northwest distributors, 2016

Similarly, commercial area lighting, such as retail parking lots and car dealerships have moved toward a norm of LEDs for lighting retrofits. Market actors mentioned that better color rendering (compared to HPS, for example) can be a major driver of LED upgrades in parking lots because of improved security. According to one market actor serving retail customers such as shopping mall tenants said of parking lot lighting, "it would be very hard for a smart landlord or tenant to look at anything other than LED, since it's adaptable to connectivity and network controls."

Understanding the Street Lighting Retrofit Process

The research team collected information from utilities, contractors, and manufacturers involved in street lighting retrofit projects to understand how street lighting retrofits work and who is involved.

Ownership and Operation

Street light ownership can be quite complex, with multiple public and private entities owning streetlights even within the same geographical area. Ownership falls into four general categories:

- Municipality or county: In many cities and towns, the municipality owns streetlights. Most municipalities have a 'streetscape standard' with requirements for streetlight appearance.
- Utility: Both public utilities and IOUs own streetlights, particularly those affixed to power poles.
- State department of transportation or highway district: A state department of transportation typically owns roadway lighting along state highways and interstates, while highway districts may own lighting along rural roadways.

- Private entities: Businesses and private individuals own some roads and roadway lighting.

There are some cases where the entity responsible for street lighting leases a lighting system, rather than owning it. However, leasing is much more expensive than owning, and it is not as common as the other ownership and maintenance arrangements. One interviewee stated, "Some commercial customers might be interested in private leasing options but government customers don't go down that path."

Operation and maintenance of roadway lighting adds another layer of complexity, since it is quite common for one entity to own a streetlight but a different entity to be responsible for its operations and maintenance. This split between ownership and operation can be a barrier to upgrading streetlights in some cases, since the operator may be more motivated to upgrade than the owner is. However, in other cases, maintenance savings are great enough that the operator is willing to fund upgrades on streetlights they do not own.

A common arrangement, according to interviewees, is for the municipality to own a town or city's streetlights and the utility to carry responsibility for operating and maintaining them. One utility we interviewed implemented a series of LED streetlight upgrades on lights the utility owned, and transferred responsibility for O&M to the city when the project was complete (while retaining ownership of the lights). This was possible because the O&M needs of LED street lighting are much less frequent, since LEDs have long lives.

Competitive Bids

For public entities and utilities, most street lighting retrofit projects are required through a competitive bid process due to procurement requirements. This involves the leading entity developing specifications for the lighting upgrades they require, and then circulating these specs via an RFP to local contractors or distributors. Market actors noted that there is variation in how detailed these specifications are. Depending on the project, they can include over 200 pages of documentation with detailed engineering specifications, or as one distributor explained, it can be "the wild west – they might just say, 'Give me a 100 Watt lamp,' and select from the options they get in bids." The detail and specifications of the project usually align with overall success and public acceptance of the lamps: those that put in the time and effort to plan the project have higher rates of success, according to interviewees.

Some utilities provide their own in-house labor for streetlight retrofits, while others hire contractors. Utilities source lighting equipment (as well as the other materials required for a retrofit project, like wire and poles) through a local distributor. Some projects purchase lamps or fixtures directly from manufacturers. However, interviewees said this was infrequent, and did not happen enough to suggest this is a trend.

Street Lighting Maintenance

Street lighting maintenance strategies depend on ownership as well as responsibility for O&M. Regardless of who maintains the lights, LED upgrades lead to much less frequent maintenance. While some utilities and municipalities perform group re-lamping (particularly on legacy systems that require more frequent re-lamping) interviewees said the typical approach to streetlight maintenance is spot re-lamping in response to requests from customers.

One interviewee cited an example of a homeowners' association (HOA) that had O&M responsibility for the streetlights in their area. The HOA paid a flat fee to the city for the cost of power, but hired a contractor to perform maintenance like replacing burnt out lamps in their aging HPS streetlights. The HOA developed a plan to upgrade to LED lamps by retrofitting the existing fixtures, and went to the local utility to see whether they would be eligible for an incentive. Since they paid a flat fee for power, the HOA would not see any savings on their electric bill. Nonetheless, the HOA decided to move forward with the project: the maintenance savings, with the cost reduction from the utility incentive, were substantial enough to motivate the HOA to invest in LED streetlights. As far as the interviewee knew, the city never adjusted the flat energy fee the HOA paid to reflect the energy savings of the upgrade.

Specialty Outdoor Applications: Sports Venues, Gas Stations, and Car Dealerships

The research team interviewed several market actors who had insight on specialized applications in outdoor lighting: sports venues, gas stations, and car dealerships. These findings represent a small number of interviews, so they are anecdotal and provide some insight into these particular niches within the outdoor lighting market.

Sports Venues

One interviewee specialized in retrofitting large sports venues with LED lighting. This contractor explained that sports venues are a very particular market, with different motivations from other non-residential end-users. Municipalities typically own major sports venues, which are often high-profile facilities that garner much public attention. For this reason, some facility owners and market actors see sports venues as good opportunities for energy-efficient retrofits because of the high visibility and the accompanying chance to promote programs, products, or values to viewers. For example, some of the contractor’s customers collaborated with their local utility to implement an LED upgrade, with utility sponsorship, to promote their energy efficiency programs to spectators at games and events. Similar sponsorship arrangements occur with lighting manufacturers, with the sports venue benefitting from a price reduction on a lighting product and the manufacturer benefitting from the brand visibility and good publicity associated with the LED upgrade.

Despite the favorable opportunities for sponsorship, the contractor mentioned two barriers to upgrading sports venue lighting. One is that many professional sports leagues have very specific lighting requirements, and although LED products can meet these requirements, the testing and re-certification process can be arduous. The other barrier is that by nature of their use for special events, sports venues tend to have very low hours of use. Therefore, lighting retrofit projects often have a long payback period, making some facilities reticent to invest in an upgrade, particularly if there is no outside sponsorship.

Gas Stations

Gas stations represent an attractive opportunity for lighting retrofit projects, as they tend to be brightly lit and have long hours of operation, with many stations open 24 hours a day. One manufacturer representative we interviewed had previously specialized in gas station lighting, and had converted a large number of Northwest stations to LED canopy lights and parking lot lights. This interviewee changed his focus to commercial and industrial customers in early 2016, because he observed that the gas station market has largely already converted to LED. The busy gas stations along the I-5 corridor were the first to convert, and he estimated that 70% of all gas stations and convenience stores in Washington have already converted to LED. Among the remaining locations, the biggest barrier to an LED retrofit is a lack of up-front capital. These businesses tend to be “mom and pop” locally owned small businesses, and they do not have the available capital to invest in lighting upgrades.

Car Dealerships

Three of the market actors interviewed mentioned car dealerships as an eager adopter of LED lighting and controls. These retailers are highly motivated by the improved visibility and improved color rendering that LED lights can achieve, particularly in contrast to legacy systems using HPS lamps, for example. These factors motivate car dealerships to retrofit their lighting in hopes of increasing car sales. The energy savings and reductions in maintenance costs are also attractive, but market actors unanimously considered them secondary to the promise of increased sales in terms of their ability to motivate this customer segment.

Car dealerships behave similar to other retailers in terms of their emphasis on aesthetics and visibility, and accordingly they follow retailer behavior when it comes to maintenance. Market actors reported that car dealerships do not want a single light out on their lot. Therefore, the long lives of LED lights are also a key attraction for car dealerships.

Car dealerships often opt to include controls in their lighting retrofits. The typical controls described by interviewees included scheduled dimming after midnight (and perhaps a second dimming after 2:00 am), coupled with occupancy sensors that bring the lights back up to full brightness if someone enters the lot. This controls configuration is attractive to car dealerships both for 24-hour visibility and for security purposes, as well as the energy savings achieved by late night dimming.

Appendix 1: Interview Strategy and Methodology

This appendix includes additional detail about the research strategy, methodology, and interview guide.

Research Questions

The research team developed research questions from each area of inquiry. Interview guides for each market actor incorporated specific questions from the below.

Table A-1: Research Questions by Area of Inquiry

Area of Inquiry	Research Question Number	Research Questions
Market Evolution	ME1	Has the product flow changed and are new or different market actors becoming influential? Are any market actors declining?
	ME2	What is the mix of applications in installed stock, and how has that mix changed?
	ME3	What is the mix of technologies within each application in installed stock?
	ME4	How do market actors foresee the mix of installed stock changing going forward?
	ME5	What is the mix of applications in sales?
	ME6	What is the mix of technologies within each application in sales?
	ME7	How do market actors foresee the mix of sales changing going forward?
	ME8	What new products are gaining market share? (Quality? Price?)
	ME9	How do the application mix and the technology mix differ between existing and new construction?
	ME10	Are distributors/retailers/manufacturers “destocking” any products this year? (i.e., getting rid of products that are not selling well)
Purchase Decisions	PD1	How does the product flow from manufacturer to end-user, and who are the market actors involved?
	PD2	What factors influence product choices?
	PD3	Do certain sectors choose higher efficiency products more often than other sectors?
	PD4	How do technologies compete with each other and what are the distributions of each competing technology within a given application?
	PD5	What is the turnover rate for non-residential lighting applications? What factors influence this rate? What triggers a system change-out?
	PD6	What happens in the field when equipment (lamps, ballasts, systems) fails?

	PD7	How are decisions made around lighting maintenance? (e.g., is lighting maintenance performed on a group or spot basis?) *Note: TO16 survey found 18% of businesses perform group re-lamping.*
	PD8	What are the current practices and industry recommendations regarding maintaining or changing light levels (lumens?) in retrofits?
	PD9	How do economic conditions affect purchase decisions?
Regional Variation	RV1	What differences exist between urban and rural markets for non-residential lighting?
	RV2	What differences exist between the Northwest states for non-residential lighting?
	RV3	How do urban customers' purchase decisions differ from those of rural customers?
	RV4	How does contractor behavior differ between urban and rural markets?
	RV5	Does the mix of applications in installed stock differ between urban and rural markets or between states?
	RV6	Does the mix of technologies in installed stock differ between urban and rural markets or between states?
	RV7	Does the mix of applications in sales differ between urban and rural markets or between states?
	RV8	Does the mix of technologies in sales differ between urban and rural markets or between states?
Industrial	IND1	What are the key segments within the industrial sector and what are their key characteristics?
	IND2	What market actors exist that serve industrial niche lighting needs?
	IND3	What are the dominant lighting technologies in industrial sites?
	IND4	What are the major applications within industrial lighting?
	IND5	What is the mix of applications in installed stock and in sales for the industrial sector?
	IND6	What is the mix of technologies within each application in installed stock and in sales for the industrial sector?
	IND7	What factors determine technology mix (end-use, industry, facility size?)
	IND8	What changes have occurred in technology mix during the 6th plan period? How do market actors foresee the mix changing over time?
	IND9	How do industrial sector purchase decisions differ from other sectors?
	IND10	What factors cause industrial customers to change their lighting systems?
Outdoor	OUT1	What are the key segments of outdoor lighting and what are their key characteristics?

OUT2	What are the major applications within outdoor lighting?
OUT3	What is the mix of applications in installed stock and in sales for outdoor?
OUT4	What is the mix of technologies within each application in installed stock and in sales for outdoor?
OUT5	How are the various segments of outdoor lighting serviced? (parking lots, street lighting, gas stations, others) How big are the various segments within outdoor lighting?
OUT6	What are the various forms of street lighting ownership, and how are decisions made around technologies? How do utilities track street and roadway lighting data?
OUT7	What are the average lighting systems at gas stations? What drives lighting demand at gas stations? (e.g., number of pumps? Convenience store?)
OUT8	How did the NW Power and Conservation Council model the outdoor sector?

Source: Non-Residential Market Actor Interview Strategy, 2016.

Interviewee/Market Actor Descriptions

Table A-2: Market Actor Descriptions

Market Actor	Description
Manufacturer Representatives	Residential interviews (TO16) shed light on these potentially influential market actors at LightFair 2015, and additional interviews are needed to improve understanding of their role in the market.
National Account Decision Makers	Large chain businesses (also called national accounts) make choices about lighting retrofits for multiple business locations at the corporate level. Interviews with market actors involved in these decisions are needed to understand whether these purchases occur outside of distribution channel and what factors are influential.
Outdoor and Street Lighting Professionals	These experts on outdoor and street lighting, such as members of the Illuminating Engineering Society, or others are directly engaged in manufacturing, designing, and selling outdoor and street lighting products. Previous research has not focused on this sector, so interviews will be exploratory and inform future research plans.
Industrial Lighting Professionals	These experts on industrial lighting are directly engaged in manufacturing, designing, and selling lighting products for industrial applications. Particular focus on dominant Northwest industries like food processing, pulp and paper.
Electrical Distributors	Electrical distributors sell commercial lighting products at the local level. They provide sales data to the research team, which is a foundational input to quantifying momentum savings. Interviewees will be knowledgeable about industry and sales trends.
Manufacturers	Manufacturers of commercial lighting products are a key market actor: they have deep insight into market trends, new technologies and products, and market structure. Interviewees will be knowledgeable about non-residential lighting products specifically.
Installation Contractors and Maintenance Firms	Installation contractors install lighting equipment and perform lighting retrofits for commercial buildings. Maintenance firms provide lighting maintenance services (e.g., lamp replacement, repairs) to commercial buildings. There may be overlap between these categories and both may be trade allies of utility programs.

Source: Non-Residential Lighting Market Actor Interview Strategy, 2016.

Types of Interviews

The research team conducted in-depth and short interviews depending on the market actor and target count. Table A-3 provides definitions to differentiate the two types of interviews.

Table A-3: Types of Interviews

Interview	Description
In-Depth Interview	These tend to be one hour long, and have the advantage of being able to collect detailed information about a topic in a semi-structured format that allows for probing for detail and asking follow-up questions. In-depth interviews are suitable for exploratory interviews and those looking to gather detailed and nuanced information about a market actor. Their disadvantages include requiring a substantial time commitment from the interviewee and requiring qualitative analysis, which can be time consuming.
Short Interview	These tend to be approximately 15 minutes long. They share some of the advantages of in-depth interviews without as much time burden. These are appropriate for market actors that are busy and difficult to schedule longer interviews with. They are also suitable for gathering information on targeted topics.

Source: Non-residential Lighting Market Actor Interview Strategy, 2016.

Interview Sampling and Outreach Strategy

Sampling Considerations

The research team considered the following when selecting interviewees.

- High Priority Interviewees
- Population Size
- Variation within population
- Prior coverage by TO16

Contact Sources

The research team utilized the following sources for each interview target category. The research team logged all contacts, communication efforts, and interview status updates in a tracker to maintain well-coordinated communication.

- **Manufacturer Representatives:** Snowball sample starting with prior interviewees.
- **National Account Decision Makers**: Work with NEEA, BPA program managers, and other stakeholders to identify decision makers. Snowball sample as necessary.
- **Outdoor & Street Lighting Professionals:** Trade Allies from Evergreen, Utilities involved in outdoor lighting projects via BPA.

- **Industrial Lighting Professionals:** Contacts made at LightFair, Trade Allies from Evergreen who have worked on industrial projects.
- **Manufacturers:** Contacts made at LightFair.

Distributor Web Survey

In conjunction with the research team's collection of sales data from distributors, the research team fielded a brief online survey consisting of seven questions to understand emerging trends in the non-residential lighting market. Fifteen distributors completed the survey. To avoid overburdening distributors participating in both BPA's research and NEEA's Reduced Wattage Lamp Replacement Initiative (RWLR), the research team did not ask RWLR participants to complete the survey. Therefore, the make-up of fifteen distributor respondents was:

- 8 full-line electrical distributors
- 2 lighting-only distributors
- 1 maintenance repair and operations (MRO) distributor
- 4 "other" lighting purveyors (these distributors identified themselves as a full service lighting contractor, energy service company, utility distributor, and a lighting manufacturer)

Of the respondents, 14 serve both urban and rural areas, with the one remaining distributor serving only urban areas. Roughly half of respondents (8 out of 15) noted that less than 25% of lighting sales (in terms of dollars) go to industrial customers. Nearly all of respondents (13 out of 14) noted that less than 25% of lighting sales go to agricultural customers.

Master Interview Guide

The research team prepared a master interview guide, which we tailored to fit the specific role and expertise of each market actor group by removing or modifying questions as needed. The research team mapped each interview question is to a specific research question, in order to facilitate adequate coverage of all relevant topics, as well as the analysis of response data.

Interview Guide

Thank you for taking the time to speak with us today. This interview is part of BPA's research on the Non-Residential Lighting market in the Pacific Northwest. The main goals of this research project are to inform energy efficiency program strategy and to understand the energy savings happening outside of utility programs in the region.

Today, we're interested in understanding current trends and characteristics of the non-residential lighting market from the perspective of [*insert market actor group]*.

Interviewee	
Company	
Position	
Interviewer & Other Attendees	
Date & Time	

Research Question	Question Number	Question	Answer
Context	1	Please describe your role in your company as it pertains to non-residential lighting.	
Context	2	Do you specialize in any specific market segments or geographical areas?	
Context	3	Are your company's operations divided into regional territories? If so, which region(s) includes Washington, Oregon, Idaho, and Montana?	
ME9	4	Do you work with new construction projects, retrofit projects, or both?	
Market Evolution			
ME1	5	[Tailor to respondent's market role as needed.] Over the past year, have any new players become prominent in the lighting market (e.g., online-only resellers, LED resellers, new manufacturers)?	
ME1	6	[If Q5=yes] Is their market share increasing?	
ME1	7	[If Q5=yes] Are they influencing more customer decisions?	
ME1	8	Are there any types of companies (e.g., full-line distributors, MRO companies) whose market shares are declining?	
ME1	9	Are there any types of companies (e.g., full-line distributors, MRO companies) whose customer influence is declining?	

ME6	10	What categories of lighting are shifting toward LED the fastest? [Probe to cover all applications: Linear 4ft, General Purpose Screw-base, Downlight, Track lighting, High bay, Candelabra and Globe lamps, Street/roadway lamps, Parking lot, Parking garage, Building exterior, other]
ME7	11	How do you foresee sales/use of high-efficiency lighting products (including, but not limited to LEDs) changing going forward?
ME8	12	What new lighting products are gaining market share? [Specify: specific products, or categories of products.]
ME8	13	Are these products becoming more popular because of increases in quality, decreases in price, utility incentives, or other reasons? Which factor would you say is most important?
ME10	14	In addition to the new products coming into the market, we're interested in what products are phasing out. Have you (or your suppliers) stopped stocking/producing any products in the past year? Which ones? Why?
ME9	15	Do new construction projects tend to include more high-efficiency lighting products than the average lighting retrofit project? If so, why?
Purchase Decisions		
PD1	**16**	What percentage of your company's lighting product unit sales would you estimate are non-residential versus residential?
PD1	**17**	Please walk me through how a typical large non-residential lighting project works from start to finish. [Probe for details: How do you identify/contact customers? Who makes the sale? Who on the customer side makes the decision? What other parties are involved in sales or decision making? Who pays whom? How do the products physically get to the customer site? Who installs products, etc.?]
PD1	**18**	Do you work with national accounts? If so, can you walk me through a typical customer's decision making process for those projects? [Probe for details: Who are the key decision makers, how does the decision get made, what are the key factors that drive decision making, are there third parties involved, etc.?]

PD1	19	For commercial and industrial lighting products, what percent of your sales revenue comes through: Contractors, End-user/building owners, Builders, Other
PD2	20	What types of customers are most likely to purchase high-efficiency lighting products? (Contractors, End-user/building owner, Builders, Other)Please explain why.
PD3	21	Does this differ in specific industries, and if so, how?
PD2	22	Are there any particular distributors in the Northwest that specialize in high-efficiency products?
PD5	**23**	We are interested in understanding how often customers change out their lighting systems (i.e., perform a lighting retrofit project). We know this can vary based on customer type. Can you estimate how often this happens for your customers? [Ask for specifics on outdoor and industrial if applicable; Probe for detail by CBSA building type – Office, Retail/Service, Warehouse, Assembly, School, Lodging, Residential Care Grocery, Restaurant.]
PD5	**24**	Do particular customer segments change more often, e.g., retail, restaurant?
PD5	25	Probe for each category: What factors influence this rate? What triggers a system change-out?
PD1	26	Please walk me through how a typical large lighting project works from start to finish: who makes the decision, what types of vendors do you work with, who pays whom, who installs products, etc.?
PD1	27	Are projects implemented regionally, nationally, on a store-by-store basis?
PD6	28	When equipment (lamps, ballasts, systems) fails, how do your customers (or you) decide on what type of lighting to replace that failed equipment with?
PD7	29	How are decisions made around lighting maintenance? (e.g., is lighting maintenance performed on a group or spot basis?) Note: TO16 survey found 18% of businesses perform group re-lamping.
PD8	30	What are the current practices and industry recommendations regarding maintaining or changing light levels (lumens?) in retrofits?

PD8	31	Does this vary at all by sector or building/space type?
PD8	32	What about new construction?
PD9	33	How do economic conditions affect purchase decisions?
Regional Variation		
RV1	34	We're interested in understanding how urban markets differ from rural markets for non-residential lighting. In your business, how do the lighting needs in these markets differ? Please provide details about the products more frequently sold in one market or the other.
RV2	35	Are there differences between the Northwest states for non-residential lighting? (Washington, Oregon, Idaho, Montana)
RV3	36	If you serve different locations [mention specific urban and rural examples if possible], how do your customers' purchase decisions differ between those locations?
RV4	37	Do you do business differently in urban and rural markets? E.g., do you market different products to urban versus rural customers?
Industrial		
IND1	38	Do you work with industrial customers? If so, what are the main categories of industrial customers you work with? (e.g., manufacturing, food processing) [If not: skip to next section]
IND1	39	Do you offer any industrial-specific lighting products?
IND2	40	Can you walk me through how your company serves industrial lighting customers?
IND2	41	What other companies/types of companies are involved in the industrial lighting market?
IND4	42	Is there anything that makes industrial customers different from commercial customers?
IND9	43	How is decision making about lighting different in the industrial sector compared to other sectors (e.g., commercial)?
IND10	44	What factors cause industrial customers to change their lighting systems?
IND1	45	For each category of industrial customer you mentioned, what factors determine which lighting systems those customers typically choose (e.g., price, lifetime, controllability, other functionality)?

IND3	46	What are the dominant lighting technologies in industrial sites? (By segment if possible)
IND6	47	Would your company be able to share any data about the types of products you sell to industrial customers in the Northwest?
IND8	48	What do you foresee in the future of industrial lighting? Changes in product types?

G. Analysis of BPA Program Data Memo

The following memo, submitted to BPA on January 22, 2016, presents the research team's findings of its review of the BPA non-residential lighting program data.

Memorandum

To: Carrie Cobb, Bonneville Power Administration

From: Rob Carmichael, Kate Bushman, and Katie Arquiette, Cadeo; Laura Tabor and Robin Maslowski, Navigant

Date: January 22, 2016

Re: Bonneville Power Administration Program Data Findings

Introduction

This memo presents the research team's findings of its review of the Bonneville Power Administration (BPA) non-residential lighting program data. The program data included measure-level details of non-residential lighting projects completed since October 2013. The primary objectives of the review were to:

- **Identify and characterize the most common non-residential lighting "applications" in the BPA program data.** The research team defines an application as a specific lighting need (e.g., high bay, downlighting, streetlighting) that a set of technology choices can meet. The research team will eventually calculate market average baselines for each identified application based on market-wide data. These applications will form the basis of the Momentum Savings model.
- **Evaluate the relative size of savings in each sector and assess the extent to which the mix of lighting technologies varies by sector.** These findings will inform the modeling team's decision on which sectors to model independently.

Executive Summary

The research team presents the following key takeaways from the fiscal year 2015 (FY15) BPA program data:

- **Outdoor lighting composed 46% of total savings.** The conversion of high-intensity discharge (HID) to light-emitting diode (LED) exterior fixtures accounted for 83% of outdoor savings and 38% of all program savings**.**
- **LED measures represented 87% of all savings.** By comparison, LED measures accounted for 77% of all savings in FY14.
- **HID lamps represented the most common pre-condition technology.** Sixty-one percent of savings came from replacing HIDs with more efficient technology. HID replacement was the dominant measure for savings in all sectors, except commercial.

- **Tubular LEDs (TLEDs) were the most frequently incentivized lamp in programs, nearly twice as popular as T8 lamps.** Interestingly, BPA projects removed more T8 lamps from Northwest ceilings than they did T12 lamps, illustrating the extent to which the region has moved past T12 lamps as a meaningful efficiency opportunity.

In addition to these findings, the research team modified the data to analyze which technology conversions were most prevalent in the program. Table 1 presents the conversion that generated the most savings.

Table 1: Savings (aMW) by Existing-to-New Technology

Existing → New Technology	Savings (aMW)	Percentage of Total Savings
HID → LED Exterior	2.09	38%
HID → LED High Bay	0.67	12%
Incandescent → LED Small Lamp/Fixture	0.56	10%
T8 → LED Tube	0.48	9%
HID → Linear Fluorescent	0.33	6%
T12 → LED Tube	0.19	4%
Incandescent → LED Exterior	0.14	3%
T12 → Linear Fluorescent	0.14	3%
Other	0.89	16%
Total	**5.50**	**100%**

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

This analysis identified lighting applications that appear frequently in the lighting data to inform the research team's subsequent baseline analysis and model construction. Table 2 has the following structure:

- The column headers show the most common non-residential lighting applications found in the program data.[1]
- The technologies listed beneath each application represent the mix of lighting products currently used in the market to meet the needs of each application. The research team drew these competing technologies from both the pre- and post-case measure characterization data.

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[1] The research team will compare these applications with those from the Department of Energy, regional midstream programs, and the Commercial Building Stock Assessment. Based on the findings from this research and input from regional stakeholders, the research team will calculate market average baselines for each application.

Table 2: Most Common Non-Residential Lighting Applications

High Bay	**Linear Troffer**	**Small Lamp—** *Reflector Screw*	**Small Lamp—** *Hardwired/ Pin-Based*	**Small Lamp—** *General Purpose Screw*	**Exterior** *—Street and Area*	**Exterior—** *Parking Garage*	**Exterior —** *Building Exterior*
T8	T8	All Reflectors	CFL Hardwired	LED	LED	LED	LED
T12	T12	PAR	GU 24 Base	Halogen	HPS	HPS	HPS
TLED	LED Troffer	MR16		CFL	MH	MH	MH
T5	TLED			Incandescent		Linear Fluorescent	CFL
HID	T5SO						

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

Note on technology definitions: compact fluorescent lamp (CFL); high-pressure sodium (HPS), parabolic aluminized reflector lamp (PAR); T5 standard output (T5SO); pin-based lamp (GU); metal halide (MH); multifaceted reflector (MR16)

About the Data

Time frame. The program dataset included projects completed from October 2013 through October 2015. To reflect the most current trends in programs, the team performed the analysis on the most recent complete fiscal year (October 2014–September 2015).

Scope. The data contain projects completed from 90 Option 1 utilities and one Option 2 utility in the Pacific Northwest. The data do not include:

- Any other Option 2 utilities
- Any lighting projects submitted as custom projects before November 2015
- Any lighting projects associated with the Energy Smart Grocer program
- Any lighting projects associated with the Energy Smart Industrial program
- Any new construction[2] projects

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[2] Pending confirmation from BPA's non-residential lighting program staff that the dataset excludes new construction projects as the research team suspects.

Data limitations. The dataset contained several limitations. The primary limitations are listed here, followed by a description of how the research team modified the data to overcome these shortcomings when possible:

- **The data do not explicitly provide the pre-condition installed wattage for the measures, fixtures, or lamps.** However, using the following equation, the research team calculated a proxy for existing condition wattage for each measure[3]:

  *(pre-condition equipment kWh / space use type annual operating hours) * 1000*

  The research team then calculated the per-lamp existing condition wattage using the following equation:

  existing condition wattage / lamp count

- **Some technologies lacked product definitions.** "LED exterior" accounts for a large portion of the savings but is undefined as a technology, making it difficult for the research team to categorize with any granularity. Secondarily, the "post-case" included many 28W lamps. It is impossible to determine from the data, however, which of these 28W lamps were reduced wattage T8s and which were T5 standard output lamps (which are also 28W). Assuming they are all reduced wattage T8s might overstate their presence in the programs.
- **The original data do not include an "outdoor" sector classification**. In the program data, outdoor measures are reported in commercial, industrial, or agricultural. To assess "outdoor" as a standalone sector, the team used information in other data to flag all "outdoor" measures and assign them to a new sector ("outdoor"). Specifically, the team flagged measures as "outdoor" if they were categorized as "exterior" under "space use type," "exterior 24 hour" under "building type," or "LED exterior" under "technology." Creating this fourth sector effectively reallocated savings from the other three sectors, primarily commercial. Although the team recognizes this methodology for outdoor categorization is not foolproof, the team is confident it captures the vast majority of outdoor lighting measures.

General Findings

In this section, the research team presents analysis findings along the following five dimensions:

1. Sector
2. Building type
3. Existing technology
4. Efficient technology
5. Existing-to-new technology combination

The team will use findings from each of these research areas to identify the baseline applications for the non-residential lighting model as well as to direct BPA toward program opportunities. Each of the

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[3] The existing condition average wattages account for both the ballast and ballast factor. In addition, the average lamp wattage calculation assumes fixtures and lamps are replaced on a one-to-one basis.

following sections highlights the research team's key findings for the five areas of data that the research team analyzed.

Savings by Sector

The program reports projects in one of three sectors: agricultural, commercial, or industrial. Table 3 shows program savings across those sectors.

Table 3: Savings (aMW) by Sector, Without Separating Outdoor

Sector	Agricultural	Commercial	Industrial	Total
Savings (aMW)	0.16	4.43	0.91	**5.50**
Percentage of Total	3%	81%	17%	**100%**

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

When the research team groups savings from outdoor lighting measures into their own sector, the outdoor sector becomes the largest of the four, with 46% of the portfolio. Because most of the outdoor sector was originally classified as commercial, commercial sector savings fall by 43% when outdoor lighting is removed from the portfolio. Table 4 displays the total portfolio savings redistributed among the sectors, with the outdoor sector separate.

Table 4: Savings (aMW) by Sector, with Outdoor Broken Out

Sector	Agricultural	Commercial	Industrial	Outdoor	Total
Savings (aMW)	0.08	2.09	0.79	2.53	**5.50**
Percentage of Total	2%	38%	14%	46%	**100%**

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

Savings by Building Type

The dataset also categorized projects by building type. The "industrial," "street and area lighting," and "other" building types represent more than half of the total savings in Table 5. As "other" topped the list, the team investigated the technologies and space use types in this category and found that almost half of the savings in the "other" building type is "LED exterior."

Table 5: Savings (aMW) by Building Type

Building Type	Savings (aMW)	Percentage of Total
Other	1.11	20%
Industrial Plant (all shifts)	0.86	16%
Street and Area Lighting (photo sensor controlled)	0.89	16%
Retail Mini Mart	0.50	9%
Warehouse	0.32	6%
Retail 5,000 to 50,000 sf	0.29	5%
Lodging	0.30	5%
Retail Supermarket	0.30	5%
Office (all sf)	0.19	3%
Exterior 24-Hour Operation	0.11	2%
Restaurant	0.10	2%
School K–12	0.09	2%
Automotive Repair	0.08	2%
Parking Garage	0.07	1%
Retail Big Box >50,000 sf One-Story	0.07	1%
Assembly	0.06	1%
Hospital	0.06	1%
Retail Boutique <5,000 sf	0.05	1%
Other Health, Nursing, Medical Clinic	0.03	1%
College or University	0.01	0%
Library	0.00	0%
Total	**5.50**	**100%**

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

Savings by Existing Technology

Table 6 displays savings by existing technology. More than 60% of savings is from the replacement of inefficient HID lamps. Replacement of HID technology dominates the outdoor sector, as Table 7 shows.

Table 6: Savings (aMW) by Existing Technology

Existing Technology	Savings (aMW)	Percentage of Total
HID	3.36	61%
Incandescent	0.76	14%
T8	0.68	12%
T12	0.45	8%
Other	0.25	4%
Total	**5.50**	**100%**

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

Table 7: Savings (aMW) from HID Replacements, by Sector, as a Percentage of Sector Total

Sector	Savings (aMW)	Percentage of Sector Total Savings
Outdoor	2.22	88%
Industrial	0.67	84%
Agricultural	0.05	55%
Commercial	0.43	21%
Total	**3.36**	**n/a**

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

Savings by New Technology

LEDs are, unsurprisingly, the dominant replacement technology. As Table 8 shows, half of all savings came from outdoor LED lamps. To improve comparability among the listed technologies, the research team removed savings from decommissioning (which represents 13% [0.70 aMW] of savings) in Table 8.

Table 8: Savings (aMW) by New Technology (Excluding Decommissioning)

New Technology	Savings (aMW)	Percentage of Total
LED Exterior	2.06	43%
LED Small Lamp/Fixture	0.77	16%
LED Tube	0.70	15%
LED High Bay	0.57	12%
Linear Fluorescent	0.43	9%
LED Troffer	0.09	2%
Other	0.17	4%
Total	**4.80**	**100%**

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

Table 9 illustrates the relative frequency of the most common lamps in the program, displaying lamp counts by wattage of the efficient technology. TLEDs were the most frequently incented lamp type, usually replacing 32W linear fluorescents. Although most technologies clustered in predictable wattage bins, LED exterior lamps are surprisingly evenly distributed across a wide wattage range, perhaps illustrating the diversity of applications in the outdoor lighting sector.

Table 9: Count of Lamps Sold Through Program, by Wattage and Type

Technology	0–29W	30W–39W	40W–49W	50W–99W	>100W	Total	% of Total
TLED	46,449	434	0	0	2	**46,885**	**28%**
LED Small Lamp/Fixture	40,398	758	452	290	1	**41,899**	**25%**
T8	7,669	18,404	0	0	0	**26,073**	**17%**
LED Exterior	3,403	1,207	4,272	6,537	5,597	**21,016**	**13%**
T5	0	0	2,130	10,202	0	**12,332**	**6%**
LED Troffer	440	1,074	1,945	641	0	**4,100**	**2%**
LED High Bay	0	0	12	349	3,093	**3,454**	**2%**
Other	8,101	381	77	85	439	**9,083**	**6%**
Total	**106,460**	**22,258**	**8,888**	**18,104**	**9,132**	**164,842**	**100%**

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

Savings by Pre- and Post-Case Technology Combinations

The team also sought to understand which combinations of pre- and post-case technologies are most common in the program. Table 10 shows the most common combinations across all sectors. Moving from HID to LED exterior was the most common replacement scenario, representing more than one-third of all savings.

Table 10: Savings (aMW) by Existing to New Technology

Existing → New Technology	Savings (aMW)	Percentage of Total
HID → LED Exterior	2.09	38%
HID → LED High Bay	0.67	12%
Incandescent → LED Small Lamp/Fixture	0.56	10%
T8 → LED Tube	0.48	9%
HID → Linear Fluorescent	0.33	6%
T12 → LED Tube	0.19	4%
T12 → Linear Fluorescent	0.14	3%
Incandescent → LED Exterior	0.14	3%
T8 → LED Troffer	0.12	2%
HID → LED Small Lamp/Fixture	0.11	2%
Other	0.65	12%
Total	**5.50**	**100%**

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

Findings Related to Model Development

The research team also queried the data based on explicit model development questions. Specifically, how do technology mixes in the agricultural, industrial, and outdoor sectors compare with those in commercial? Also, how do the savings from each sector compare in size? The research team found the following answers.

Agriculture Sector. Almost 90% of agricultural savings are from moving to LED technology. Table 11 shows the most frequent changeouts from existing to efficient. Compared with the commercial, industrial, and outdoor sectors, the agricultural sector generates a higher share of savings from the replacement of incandescent technology.

Table 11: Agricultural Technology Mixes

Existing →Efficient Technology	Percentage of Sector Savings
HID → LED Small Lamp/Fixture	27%
HID → LED High Bay	22%
Incandescent → LED Small Lamp/Fixture	16%
T12 → LED Small Lamp/Fixture	13%
HID → Linear Fluorescent	5%
Incandescent → Linear Fluorescent	5%
T8 → LED Tube	4%
T12 → Linear Fluorescent	4%
Other	3%
Total	**100%**

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

Industrial Sector. More than 80% of industrial sector savings come from replacing HID. LED technology accounts for a relatively lower percentage of the sector's savings (60%) compared with the other sectors, with linear fluorescent systems accounting for 27% of the sector total. Table 12 displays the most common pre- to post-case technology scenarios in the industrial sector.

Table 12: Industrial Technology Mixes

Existing →Efficient Technology	Percentage of Sector Savings
HID → LED High Bay	60%
HID → Linear Fluorescent	23%
T12 → Linear Fluorescent	4%
T8 → LED Tube	3%
T5 → LED High Bay	2%
Other	8%
Total	**100%**

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

Outdoor sector. As in the industrial sector, savings in the outdoor sector were heavily reliant on replacing HIDs. Table 13 shows that LEDs accounted for more than 95% of outdoor savings.

Table 13: Outdoor Technology Mixes

Existing →Efficient Technology	Percentage of Sector Savings
HID → LED Exterior	83%
Incandescent → LED Exterior	6%
Incandescent → LED Small Lamp/Fixture	3%
HID → HID MH	2%
HID → LED Small Lamp/Fixture	1%
T12 → LED Tube	1%
Other	4%
Total	**100%**

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

Savings are spread across technologies in the commercial sector. Table 14 shows the wide variety of existing to efficient technology changeouts, although LED technology is the dominant efficient case.

Table 14: Commercial Technology Mixes

Existing →Efficient Technology	Percentage of Sector Savings
Incandescent → LED Small Lamp/Fixture	23%
T8 → LED Tube	21%
HID → LED High Bay	8%
HID → Linear Fluorescent	7%
T12 → LED Tube	7%
T8 → LED Troffer	6%
T12 → Linear Fluorescent	5%
CFL → LED Small Lamp/Fixture	3%
HID → LED Small Lamp/Fixture	3%
T5 → Linear Fluorescent	3%
T8 HP → LED Tube	2%
Other	13%
Total	**100%**

Source: Navigant and Cadeo analysis of BPA commercial and industrial lighting program data (extracted November 15, 2015; time period analyzed October 2014–September 2015)

Developed for the Bonneville Power Administration ● www.bpa.gov

Developed by Navigant Consulting, Inc.

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