Memorandum

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

From: Navigant and Cadeo Residential Lighting Team

Date: March 13, 2017

Subject: Residential Lighting Momentum Savings Methodology

This memo documents the Navigant and Cadeo team's (the research team's) methodology for estimating residential lighting Momentum Savings for the Northwest Power and Conservation Council's (the Council's) Sixth Power Plan (Sixth Plan) period (2010-2015). The methodology follows Bonneville Power Administration's (BPA's) Four Question Framework, which is BPA's standard analytical framework for estimating Momentum Savings.

The first section of this memo summarizes how BPA typically uses the Four Question Framework. The next four sections detail the methodology the research team used to answer each of the Four Questions for the residential lighting market and describe the key data sources, technical decisions, and assumptions underpinning the results.

Momentum Savings Analysis Framework

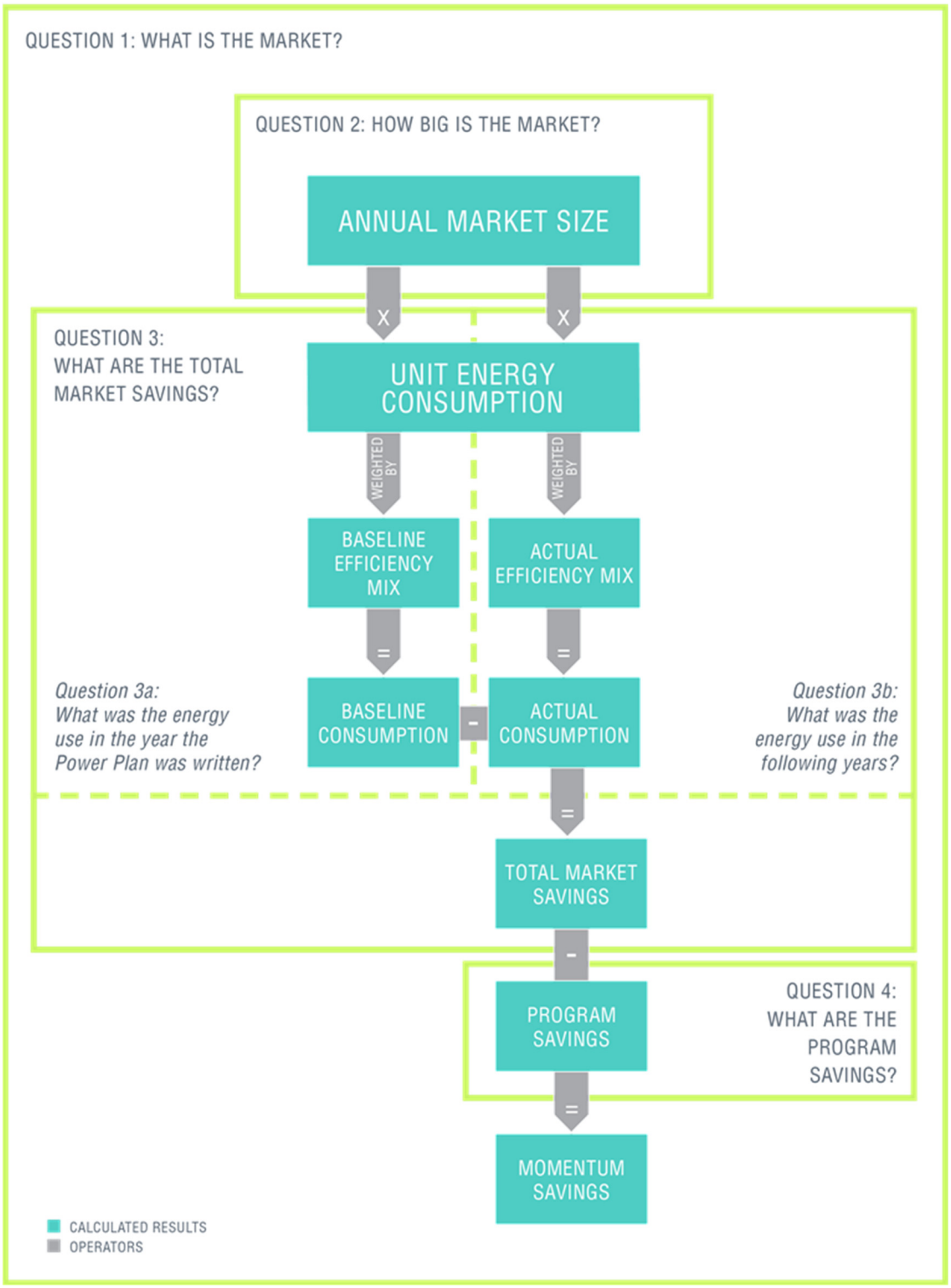
The research team organized its methodology, as well as this memo, around the following Four Questions:

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 Northwest Energy Efficiency Alliance's (NEEA's) net market effects. Figure 1 summarizes how the questions fit together to estimate Momentum Savings.

While Momentum Savings analyses typically define the market in terms of sales, the research team defines the residential lighting market in terms of installed stock. As explained in more detail in the following sections, this change in approach was necessary because of the difference in the average lifetime (and, therefore, the turnover rate) of lamps between the baseline and actual cases. Regardless of the method of calculation, any resulting savings are solely the result of differences in the efficiency mix of sales between the actual and baseline cases.

Figure 1: Overview of the Momentum Savings Analysis Framework



In the following sections, the research team answers each of the Four Questions for residential lighting.

Question 1: What is the market?

A complete and precise market definition clarifies the scope of the analysis. The research team defines the residential lighting market in the Pacific Northwest using the elements summarized in Table 1 and discussed in detail in the remainder or this section.

Table 1: Market Definition

Element	Definition	Notes
Product Scope	Screw-in lamps, linear lamps	Includes all Regional Technical Forum (RTF) categories
Unit of Account	Installed stock of lamps	Departure from typical Momentum Savings approach, which focused on sales
Sector and Housing Type	All residential housing types (single family, multifamily, and manufactured homes)	Includes multifamily units but excludes common areas in multifamily buildings
Geographic Scope	BPA service territory (Oregon, Washington, Idaho, and Western Montana)	Consistent with the Council's Power Plans
Purchase Triggers	Lamp failure and new construction	Model turnover is driven by lamp failure (e.g., replace-on-burnout); the research team did not identify reliable information to also include an early retirement purchase trigger

Product scope. At the highest level, the market definition—and, therefore, this Momentum Savings analysis—focuses on two residential lighting product categories: **screw-in lamps and linear lamps**. The research team further divided each of these product categories into their constituent applications and lumen bins (or, in the case of linear lamps, lamp length bins), as shown in Table 2.

Not every lamp currently installed in the region falls into one of the lighting application and lumen bin/lamp length combinations found in Table 2. However, the overwhelming majority do. According to the team's analysis of NEEA's Residential Building Stock Assessment (RBSA), 93% and 91% of the Northwest residential lighting stock by sockets and watts, respectively, fall into one of the model's application and lumen bin/length categories.[1]

[1] The majority of the lamps the research team excluded from the stock were defined in the RBSA in a way that precluded valid categorization for this analysis. For example, the RBSA lamp type data field held values of N/A or #N/A for some excluded lamps.

Table 2: Market Definition by Lumen Bin or Lamp Length for Applications Included in the Analysis

Application	Lumen Bin/Lamp Length		
General Purpose	250-1049 lumens	1050-1489 lumens	1490-2600 lumens
Reflector	250-1049 lumens	1050-1489 lumens	1490-2600 lumens
Decorative and Mini-Base	250-1049 lumens	1050-1489 lumens	1490-2600 lumens
Globe	250-1049 lumens	1050-1489 lumens	1490-2600 lumens
3-Way*			250-2600 lumens
Outdoor General Purpose	250-1049 lumens	1050-1489 lumens	1490-2600 lumens
Outdoor Reflector	250-1049 lumens	1050-1489 lumens	1490-2600 lumens
Linear	2-foot**	4-foot	

**The research team assigned 3-way lamps to a single lumen bin (250-2600) due to the small number of 3-way lamps in the lighting stock as well as the lamp's ability to produce varying light outputs. **The analysis includes 2-foot linear lamps in the 4-foot length bin (e.g. one 4-foot lamp represents two 2-foot lamps).*

Three primary aims drove the research team's decisions regarding which applications to include and how to divide them:

1. Maximize the value of the available sales data by creating definitions to which the sales data, with its varying quality and granularity, could be mapped with integrity
2. Align the applications and lumen bins with regional definitions established by the Regional Technical Forum (RTF) and Council, where possible
3. Align definitions with the scope of federal regulations, where possible

Appendix 1d provides a more detailed description of the research team's rationale for defining applications and lumen bins.

Unit of account. This specifies the metric by which the research team quantifies the market. In this analysis, the team defined the unit of account as the installed lamp **stock**. That is, the research team defines the market by the number of lamps operating in residential homes in each year of the analysis period.[2] While the stock changes over time based on the **flow** of new lamps (i.e., annual sales[3]), the market's unit of measure for savings is the installed **stock**.

Sector and housing type. The market for this analysis includes the lamps listed in Table 2 that are sold and installed in residential single family homes, manufactured homes, or multifamily units. The research team excluded common areas of multifamily buildings and all other non-residential applications from the analysis.

[2] In contrast to other Momentum Savings analyses, this analysis arrives at its first-year savings estimate through an examination of the stock's energy consumption—not the flow.

[3] To simplify the terminology throughout this memo, the research team uses the term "sales" to describe the volume of new units flowing into the stock, although the term "new installations" would be more precise. The team recognizes that customers may not always purchase and install a lamp in the same calendar year.

Geographic scope. For this analysis, the market includes all lamps purchased and installed in Oregon, Washington, Idaho, and Western Montana.[4]

Purchase triggers. Purchase triggers—newly constructed homes, product failure, and early retirement—drive the purchase and installation of new lamps. The market definition for this analysis includes all identified residential lamps regardless of whether they were installed for new construction, replace-on-burnout, or early retirement. The research team considered tracking early retirement and replace-on-burnout purchase triggers separately. However, a lack of reliable information regarding the frequency and prevalence of early retirements prevented the team from creating a separate trigger. Instead, the team treated all non-new construction sales as replacement sales.

Question 2: How big is the market?

For this analysis, the market size is the number of in-scope lamps (as defined in Question 1) installed in residential homes in Oregon, Washington, Idaho, and Western Montana in a given year. In this section, the research team describes its methodology for estimating the market size.

Estimating Market Size

The market size—or the installed stock—is the product of the number homes in the region and the number of lamps per home in any given year. During the analysis period (2009-2015), the market size grew annually due to two factors: growth in the housing stock (new construction) and a higher number of lamps per home in new construction relative to the existing stock.

Housing stock. The research team used housing stock estimates from the Seventh Power Plan (Seventh Plan)[5] for each of the three housing types over the 2009-2015 analysis period. To align with the Seventh Plan, the team excluded housing stock in Eastern Montana from its analysis. The overall housing stock grew each year due to new construction.

Number of lamps per home. The research team used data from the 2011 RBSA to calculate the average number of lamps per home by application and housing type in 2011. By multiplying this number by the number of homes in the stock, the team calculated the total installed lamp stock for 2011.

To determine the number of lamps in each new construction home, the research team accounted for changes in home size (square feet per home) and lighting density (lamps per square foot). To calculate this, the team used the RBSA to develop a time series of lamps per square foot by year of construction. As shown in Equation 1, the team multiplied the number of lamps per square foot in each year by the average square footage of newly constructed homes in that year to calculate the number of lamps per home in new construction.

[4] Because some of the data sources used for this analysis reflect all of Montana, the research team had to make adjustments to reflect only Western Montana. The team notes throughout this memo where it adjusted (or did not adjust) input data sources to exclude Eastern Montana.

[5] While the Sixth Plan is contemporary to the analysis, the housing counts it contains are a forecast rather than the actuals found in the Seventh Plan.

Equation 1: Lamps per New Construction Home

$$\text{Lamps per Home in New Construction} =$$

$$\text{Average Lamps per Square Foot} \times \text{Average New Construction Home Size}$$

The research team then calculated the number of lamps per home in existing homes in each year of the analysis by examining how new construction shaped the overall stock over time. Starting with the number of lamps per home in 2011 as estimated by the RBSA, this approach assumes that the existing stock of homes in any year is comprised of new construction homes from years prior and accounts for annual demolitions. Equation 2 illustrates how the team calculated the time series of lamps per home in the existing stock starting in 2012, the year after the RBSA.

Equation 2: Lamps per Home in All Stock

$$\text{Lamps per Home in All Stock}_{2012} =$$

$$((\text{Average Lamps per Home in New Construction}_{2012} \times \text{New Construction Homes}_{2012}) +$$

$$(\text{Average Lamps per Home in Existing Stock}_{2011} \times (\text{Existing Stock Homes}_{2011} - \text{Demolitions}_{2012})) / \text{All Stock Homes}_{2012}$$

The total lamp stock in any given year is the product of the number of homes and the number of lamps per home in the stock. The research team developed a time series of total installed lamps in each year of the analysis period using Equation 3, which is shown below.

Equation 3: Installed Stock of Lamps

$$\text{Installed Stock of Lamps} =$$
$$\text{Average Lamps per Home in All Stock} \times \text{Number of Homes in All Stock}$$

Table 3 shows the resulting residential lighting market size for each year.

Table 3: Total Installed Lamp Stock by Year

Year	Installed Lamps
2009	296,388,304
2010	297,555,570
2011	298,722,829
2012	300,504,309
2013	302,622,528
2014	305,336,907
2015	309,129,638

Source: Residential Momentum Savings Model

Question 3: What are the total market savings?

Total market savings are the difference between baseline energy consumption and actual energy consumption in average megawatts (aMW). If the actual market energy consumption modeled by the research team is lower than the baseline energy consumption in any given year, the difference is the total

market savings. In this analysis the team compares the actual market consumption to two distinct baseline cases, each of which yields different estimates of total market savings.

Below the research team discusses the four key inputs that drive energy consumption in both the baseline and actual cases and then describes how and why the inputs vary in each case.

Calculating Annual Energy Consumption

Comparing the energy consumption of the baseline case to that of the actual case results in the savings for each year of the analysis period. By energy consumption, the research team means the annual energy usage of the total market as defined by Questions 1 and 2 (i.e., all installed lamps in the Northwest).

As shown in Equation 4, the team calculates energy consumption based on installed lamp stock and the unit energy consumption (UEC) of each lamp type and age cohort. The team's model determines the number of installed lamps by simulating stock turnover, whereas the UEC comes directly from input assumptions.

Equation 4: Energy Consumption

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

Where:

a = application

b = lumen bin

h = housing type

i = installation year

t = technology

y = year in the study period

The following sections describe the components that influence the energy consumption calculations. The first step is determining UEC estimates for each lamp type. The second step is determining how the energy consumption of the installed lamp stock changes over time, for which the model relies on three key factors:

1. Market size
2. Application (and lumen bin) mix in the installed stock
3. Efficiency mix of the installed stock

Unit Energy Consumption of Each Lamp Type

The first step in calculating the market's energy consumption is to determine the UEC associated with each lamp type. The UEC refers the amount of energy (kWh) a given lamp type consumes in one year. By "lamp type," the research team means each technology-application-lumen bin permutation. For example, one such permutation—or lamp type—is an incandescent, reflector lamp with a lumen output between 250 and 1049 lumens; another is a general purpose, LED lamp between 1050 and 1489 lumens. With up to

four technologies and three lumen (or length) bins within each of the eight applications, there are 80 unique lamp types, each with its own UEC.[6] Each lamp type's UEC is a function of the average wattage and daily hours of use (HOU), as shown in Equation 5.

Equation 5: Unit Energy Consumption

$$UEC = \text{Average Wattage} \times \text{Hours of Use} \times 365.25$$

Each of these inputs is described below.

Average Wattage

The research team used the regional sales and shelf data, weighted using the Chain Logic Method (discussed in detail in The Chain Logic Method section below), to estimate the average wattage for each technology within each application and lumen bin. For example, Table 4 shows the average wattage of general purpose lamps by lumen bin and technology in 2015. Since the efficacies of individual technologies have improved over time (most notably for LEDs), the research team computed a different average wattage for each year of the analysis period.

Table 4: Average Wattage by Technology and Lumen Bin, General Purpose Lamps: 2015

Lumen Bin	Incandescent	Halogen	CFL	LED
250-1049	51	41	13	9
1050-1489	97	66	20	13
1490-2600	151	72	24	16

Source: Residential Momentum Savings Model

Hours of Use

The research team used HOU data from the RTF's most recent baseline analysis.[7] The HOU inputs vary by application and lumen bin, but not by technology. Table 5 shows the daily HOU for each application and lumen bin, which the team multiplied by 365.25 to estimate annual HOU.

[6] There are 80 unique combinations (not 96) because the analysis uses a single lumen bin for three-way lamps, two length bins for linear lamps, and only two technologies (T8 and T12) for linear lamps.

[7] https://rtf.nwcouncil.org/measures/res/ResLighting_Bulbs_v4_2.xlsm

Table 5: Daily HOU by Application and Lumen Bin

Lumen Bin	General Purpose	Decorative and Mini-Base	Globe	Reflector	3-Way	Linear	Outdoor: General Purpose and Reflector
250-1049 (24 in)	1.77	1.92	1.33	2.40	1.85		
1050-1489 (48 in)	1.87	1.88	1.54	2.51	2.33	1.89	3.70
1490-2600 (96 in)	1.82	1.32	1.94	2.06	2.27		

Source: Regional Technical Forum

Using the above inputs, the research team calculated an average UEC for each application-lumen bin-technology permutation in each year of the analysis. Again, as an example, Table 6 shows the results for general purpose lamps in 2015.

Table 6: Annual UEC (kWh) by Technology and Lumen Bin, General Purpose Lamps: 2015

Lumen Bin	Incandescent	Halogen	CFL	LED
250-1049	33	26	8	6
1050-1489	67	45	13	9
1490-2600	100	48	16	11

Source: Residential Momentum Savings Model

Market Size: Number of Lamps in the Installed Stock

The market size is the total number of lamps installed in the Northwest in any given year. Because the research team defined the market as the total lighting stock (not lamp sales), the market size grew each year—due to new construction—between 2009 and 2015. However, it is important to note that the market size for any given year is the same in both the baseline and actual cases: what changes is the mix of technologies within each application.

Application (and Lumen Bin) Mix in the Installed Stock

The application mix reflects each lamp application's share of the total installed lamp stock. Because lamps of the same technology (e.g., incandescent) have different wattages across applications, the application mix must be taken into account to calculate the market's overall energy consumption.

The research team derived the stock application mix using three steps. First, the team mapped each lamp type captured in the 2011 RBSA to one of the six lighting applications included in the market definition. Table 7 shows how the team mapped RBSA lamp types to each modeled application, as well as which RBSA lamps types the team excluded from the analysis. As evident in the table, the RBSA lamp types the team excluded from the analysis are less common types that collectively represent approximately 9% of the total installed watts in the residential sector.

Table 7: Model Applications Mapped to RBSA Lamp Types

Model Applications	RBSA Lamp Types	Count of Lamp Types	Share of Total Installed Residential Wattage
General Purpose (Indoor and Outdoor)	A-Shape Bulb, Circline (Screw Base), Clear, Colored, LED Exterior, LED Interior, Standard A-Lamp, Straight Tube, Twist	9	91%
Decorative and Mini-Base	Decorative, Mini-Base	2	
Globe	Globe	1	
Reflector (Indoor and Outdoor)	Flood, MR, PAR, Reflector	4	
3-Way	3-Way CFL, 3-Way Incandescent	2	
Linear	T-12, T-8	2	
Excluded	Fluorescent Other, Fluorescent Unknown, Heat Lamp, High Pressure Sodium, Low Pressure Sodium, Mercury Vapor, Metal Halide, Other, Pin base, Quartz Tube, T-4, T-5	12	9%

Source: Research team analysis of NEEA's 2011 RBSA

Second, the research team assigned each lamp in the RBSA to a lumen bin within each application. Because the RBSA does not collect the lumen output of each inventoried lamp, the team estimated lumen output by multiplying each lamp's wattage by the average efficacy (lumens per watt) for that specific technology in 2011. After estimating each lamp's lumen output, the research team calculated the share of lamps in each of the lumen bins in each application. The team excluded lamps with lumen outputs that fell outside of the lumen range given by the market definition (either <250 or >2600 lumens) from the analysis. Because the defining characteristic of the linear fluorescent lamp application is lamp length, not lumen output, the research team divided the linear application into the two most common residential lamp lengths: 2-foot and 4-foot. The team excluded all other lengths from the analysis.

The third step to develop the stock application mix was to create additional application mixes for exterior applications. The research team developed the same data cuts (application and lumen bin) for the RBSA's exterior lighting datasets. However, the team opted to include only exterior applications for general purpose lamps and reflectors in the analysis since these applications constituted 89% of all outdoor lamps. The research team allocated the lamps to each application and lumen bin based on the combined interior and exterior weighted lamp counts, with the sum of all applications and lumen bins totaling 100% in each housing sector and geography.

The team calculated these application and lumen bin mixes for each of the three housing types: single family, multifamily, and manufactured homes and assumed the application mix was constant throughout the analysis period for each housing type.

Efficiency Mix of the Installed Stock

The efficiency mix of the installed stock is the fourth key input to the calculation of total market energy consumption in each year. It is a function of several variables, the most important of which is the efficiency mix of *sales* in prior years. Conceptually, the stock is simply the accumulation of prior years' sales: the more efficient the sales mixes, the more efficient the resulting stock mix.

Momentum Savings analyses have typically focused on first-year consumption of the market's actual *sales* mix because that allows for a direct comparison to the efficiency mix implied by the current practice baselines assumed in the Council's Power Plans. However, as discussed in the introduction and in Question 1, this analysis defines the market *as the installed stock*. As such, total energy consumption in any given year is a function of the total number of lamps in the stock and the average UEC of *those lamps* (rather than the average UEC of the lamps sold in the market).

In this stock-focused approach, the comparison between the baseline sales mix and actual sales mix is still the driver of savings. The difference is that the savings occur by comparing two installed stock efficiency mixes: one that results from the assumed baseline sales mixes year after year and one that results from actual sales mixes year after year. Put differently, instead of comparing the baseline and actual sales mix to calculate savings, the research team compares how those respective sales mixes *change the installed stock*.

To estimate the installed stock efficiency mix in any given year, four primary inputs are required:

1. Characterization of the installed stock (size, mix, and age of the lamps in the stock)
2. Estimate of how fast the existing stock turns over each year
3. Estimate of how fast the stock grows due to new construction in each year
4. Efficiency mix of sales in each year of the analysis period

A stock turnover model, summarized in Figure 2 and described immediately below, drives the first three of these inputs. A description of the team's method for estimating the efficiency mix of sales in each year, the fourth primary input, follows.

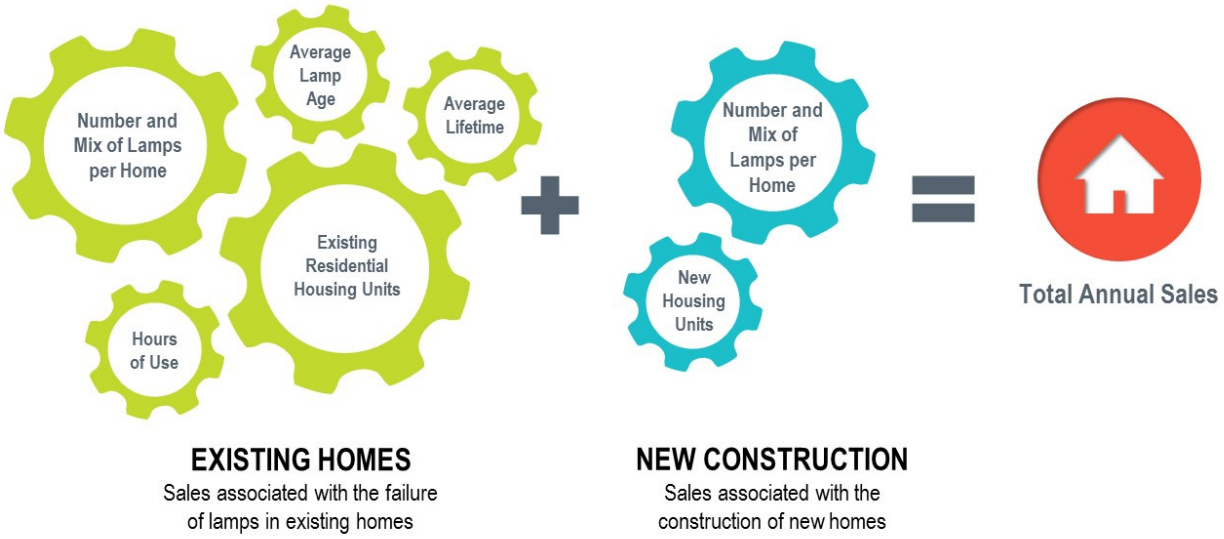
Stock Turnover Model

The underlying premise of the stock turnover model is that lamp sales are triggered when lamps in the existing housing stock fail and require replacement. The model calculates failures in the existing stock based on the age and average life (in years) of each lamp in the stock. For example, if a given lamp has a three-year life then lamps of that type installed in 2009 should, on average,[8] fail in 2012, triggering sales in that year.

Figure 2 illustrates the key components of the stock turnover model in calculating the installed stock's turnover (replacement sales) and growth (new constructed homes). The following sections discuss each of these components.

[8] This is a simplified example meant to illustrate the replacement cycle conceptually. In reality, the model employs survival distributions such that the population of lamps (in this example) would fail, on average, after three years of use.

Figure 2: Stock Turnover Method for Estimating Turnover



Stock Turnover Logic

Three key inputs drive the calculation of how quickly the stock turns over (and, therefore, how quickly the stock efficiency mix can change) in the research team's stock turnover model.

1. **Mix and age distribution of lamps in the initial installed stock.** The number of lamps in the stock that will fail in a given year depends on the age distribution and the technology mix of the lamps in the stock. Accordingly, the research team developed an age and mix distribution of the installed stock in the initial year (2009) of the analysis period.[9] The team details its method of backcasting from the 2011 RBSA installed stock in Appendix 2d.
2. **Average lifetime of each of the lamp types that make up the installed stock.** The research team used lamp lifetimes that are consistent with the US Department of Energy's (DOE's) recent models of national LED adoption.[10] Table 33 provided in Appendix 2a details these lifetimes by technology.
3. **HOU of the lamps.** Operating hours vary by application. As discussed in Table 5, the research team used the operating hours determined through the 2011 RBSA metering study[11] and used by the RTF for its most recent residential lighting measure update (v4.2).[12] It is important to note that

[9] In contrast to other stock turnover models, the research team did not assume the lamp stock turns over at a rate of 1/lifetime, as this common stock modeling assumption is inappropriate for the lighting market. When competing technologies in a market have different lifetimes (such as with lighting) and the mix of those technologies has not been stable in the stock (such as with lighting), one must estimate the age of each lamp in the stock to predict when it would fail (on average).

[10] http://energy.gov/sites/prod/files/2015/07/f24/led-adoption-report_2015.pdf

[11] https://neea.org/docs/default-source/reports/residential-building-stock-assessment--metering-study.pdf?sfvrsn=6

[12] http://rtf.nwcouncil.org/measures/res/ResLighting_Bulbs_v4_2.xlsm

the team adjusted the RBSA HOU data to align RBSA application-specific HOU values with the set of applications in the model. Since HOUs vary by room type, the team weighted each of these values to account for the prevalence of each application and lumen bin in each RBSA-designated room type.

Taken together, 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.

The model employs failure distributions for each technology; these prescribe the percentage of lamps of a certain age that will fail in any given year. The failure distribution is based on a Weibull distribution having a mean value equal to each lamp's expected lifetime (as described above), along with a shaping factor of five.[13] The Weibull distribution assumes that a greater portion of lamps fail before the expected lifetime as opposed to a normal distribution, which would assume equal numbers of lamps failing before and after the mean (expected) lifetime.

Replacement sales are calculated as shown in Equation 6 through Equation 8.

Equation 6: Failure Distribution

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

Where:

a = application

b = lumen bin

g = age

h = housing type

i = installation year

t = technology

y = year in study period

The model tracks the age of every installed lamp, which allows the research team to apply the appropriate failure percentage to each age cohort. For every year of the study period, the model predicts the quantity of lamps that fail from each age cohort using Equation 7.

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

Equation 7: Failures by Vintage

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

Those failures are then subject to replacement. Upon replacement, a lamp may switch from one technology to another depending on the sales mix for that particular year. Though the technology can change, the lumen output (or length) of the lamp remains the same.

Equation 8: Replacements

$$\text{Replacements}_{a,b,h,t,y} = \left(\sum_{i,t} \text{Failures}_{a,b,h,i,t,y}\right) \times \text{Sales Mix}_{a,b,h,t,y}$$

Stock Growth

In addition to changes in the existing stock mix due to the stock turnover function described above, the installed stock of lamps grows over time due to new construction. If the overall sales mix is different than the existing stock mix (which is almost always the case), this stock growth impacts the stock's overall efficiency mix, albeit slightly. The research team described the method of calculating new construction stock in Question 2 above.

Sales Efficiency Mixes

The sales efficiency mix is the final critical input to determine how the overall stock efficiency mix changes. The sales efficiency mix is the market share of products sold in a given year at each different efficiency level. For the purposes of this analysis, efficiency levels correspond to four technologies: incandescent, halogen, compact fluorescent, and LED. While the stock turnover logic and stock growth inputs determine how many lamps flow into the installed stock each year, the sales efficiency mix determines *how* efficient those lamps are.

The analysis uses three different sets of efficiency mixes: two represent alternative baseline scenarios and one represents the actual market as observed by available retail sales and shelf-stocking data. Below the research team discusses the two baseline sales efficiency mixes and then describes how it estimated the actual sales mixes.

In each scenario, the model's total sales volume is driven by lamp failures and does not include any lamp purchases that might go into storage. Since the 2011 RBSA found that CFLs were overrepresented in storage relative to their share of the stock—CFLs in storage were 23% of the sum of all CFLs installed and in storage; this value was 12% for incandescents and other technologies. This implies that 11% more CFL sales go into storage than other technologies, either due to bulk purchasing or equipment removal. To account for this effect the research team applied a 5% uninstall rate to the CFL sales.[14] During the calibration process, the team performed sensitivity analysis on this parameter to gauge the effect on model results, specifically ensuring that the CFL stock saturation share aligned with the 2011 RBSA data.

[14] The research team used 5% because this value could decrease over time as customers realize that CFLs do not burn out as often.

Baseline Efficiency Mix

Unlike other Momentum Savings analyses, the research team developed two different baseline efficiency mixes for this model: a frozen efficiency baseline and an RTF baseline. These two baselines provided two different scenarios against which the team measured total market change. Each baseline scenario offers a different perspective on the change in regional residential lighting energy consumption between 2009 and 2015. The frozen baseline offers an estimate of total market change since 2009, while the RTF baseline estimates market savings relative to the baseline used by most regional utility lighting programs. The research team describes each baseline efficiency mix in detail below.

Frozen efficiency. The first baseline efficiency mix freezes the market efficiency mix of sales in the model's base year (2009) for the duration of the analysis (2010-2015). The research team determined and applied the 2009 average market efficiency mix for each application and lumen bin; Table 8 shows the largest lumen bin in the general purpose application.[15] The method for calculating the efficiency mix in 2009 is the same as the method for estimating the actual efficiency mix, which is described below. These shares include the 5% CFL adjustment described above.

Table 8: Frozen Efficiency Baseline Mix, General Purpose Bulbs (250-1049 Lumens)

Year	Incandescent	Halogen	CFL	LED
2009	71%	0%	29%	0%

Source: Residential Momentum Savings Model

RTF baseline. The second baseline case allows the baseline efficiency mix to change over the analysis period to be consistent with the RTF's baseline for that year. In the case of the RTF baseline, the overall baseline market efficiency of sales increases over time in contrast to the frozen baseline case, in which the baseline sales mix is constant.[16] Figure 3 shows the timing of the RTF baseline updates.

[15] When viewing results, reviewers may notice that average technology mixes—and, therefore, efficacies and wattages—do vary slightly at the application level. This is due to the different technology mixes by lumen bin: since lifetime varies by technology, each lumen bin turns over at a different rate. This leads to variations in the sales mix over time at the application level.

[16] Note that while the sales mix remains constant, natural turnover results in changing stock consumption in the frozen baseline over time because the 2009 sales mix is more efficient than the 2009 stock.

Figure 3: RTF Baseline Updates[17, 18]

<table>
<tr><th></th><th>LED</th><th>CFL</th><th>Specialty CFL</th></tr>
<tr><td>4/10/2010</td><td></td><td>Incandescent lamp (CFL 1.5)</td><td></td></tr>
<tr><td>6/1/2011</td><td></td><td rowspan="2">Incandescent lamp, capped at EISA (CFL 2.1)</td><td></td></tr>
<tr><td>12/11/2012</td><td></td><td rowspan="3">Incandescent lamp (Specialty CFL 1.3)</td></tr>
<tr><td>8/20/2013</td><td rowspan="2">RBSA, adjusted for EISA and IRL (LED 3.0)</td><td></td></tr>
<tr><td>10/15/2013</td><td>RBSA, adjusted for EISA and IRL (CFL 3.0)</td></tr>
<tr><td>4/23/2014</td><td colspan="3">RBSA, adjusted for EISA and IRL (3.3)</td></tr>
<tr><td>8/18/2015</td><td colspan="3">Shelf/Sales data, adjusted for EISA and IRL (4.1)</td></tr>
</table>

Source: Regional Technical Forum

With a time step of one year, the model cannot directly replicate the midyear timing of each RTF baseline change. Therefore, the research team rounded the RTF updates to the nearest year (considering the Energy Independence and Security Act of 2007's [EISA's] implementation schedule) and grouped the RTF's separate LED and CFL baselines into a combined general purpose application.

This process resulted in the research team converting Figure 3 into Table 9, which shows the baselines used in the model for the general purpose application and all specialty applications (reflectors, decorative and mini-base, globe, and 3-way). Table 9 also cites the relevant RTF residential lighting measure workbook that the team used to develop the baseline. The research team extracted the baseline efficiency mix in terms of both the technology and average wattage from these RTF workbooks.

[17] EISA refers to The Energy Independence and Security Act of 2007; IRL refers to the Incandescent Reflector Lamp Standard that was finalized in 2009 and came into effect in 2012.

[18] The information in parentheses (e.g., CFL 1.5) indicates the relevant RTF residential lighting measure workbook version.

Table 9: Adjusted RTF Baselines by Year and General Purpose/Specialty

Year	General Purpose	Specialty
2010	Incandescent (CFL v1.5)	Incandescent (Specialty CFL v1.3)
2011	Incandescent (CFL v2.1)	Incandescent (Specialty CFL v1.3)
2012	Incandescent lamp. Capped at EISA levels for 2012 (100 > 72W) (CFL v2.1)	Incandescent (Specialty CFL v1.3)
2013	Incandescent lamp. Capped at EISA levels for 2012 (100 > 72W) and 2013 (75W > 53W) (CFL v2.1)	Incandescent (Specialty CFL v1.3)
2014	RBSA (Called for EISA; all levels) (CFLandLEDLamps v3.3)	RBSA (Called for EISA; all levels) (CFLandLEDLamps v3.3)
2015	RBSA (Called for EISA; all levels) (CFLandLEDLamps v3.3)	RBSA (Called for EISA; all levels) (CFLandLEDLamps v3.3)

Source: Research team analysis of Regional Technical Forum data

Table 10 shows the year by year efficiency mix assumed in the RTF baseline scenario. Again, the research team uses the general purpose lamp—the most prevalent application—as an example.

Table 10: RTF Baseline Mix, General Purpose Lamps

Year	Incandescent	Halogen	CFL	LED
2010	100%	0%	0%	0%
2011	100%	0%	0%	0%
2012	92%	8%	0%	0%
2013	81%	19%	0%	0%
2014	0%	61%	39%	0.6%
2015	0%	61%	39%	0.6%

Source: Research team analysis of Regional Technical Forum data

Actual Sales Efficiency Mix

The actual sales efficiency mix in each year of the analysis is the primary driver of total market savings. The research team used a two-pronged approach to estimate the actual sales mixes in each year of the analysis period. First and foremost, the team relied on any and all available sales data and other market data to estimate the sales mix whenever possible. Second, the team calibrated the stock turnover model to those estimates and used the model's turnover logic (described above) to backcast sales mixes in years where no data was available. Specifically, the team had sufficient market data to estimate the market's efficiency mix from 2011 to 2015 using a methodology called the Chain Logic Method, which is described in the following section. The team backcast sales mixes for 2009 and 2010 using the stock turnover model.

The Chain Logic Method

The Chain Logic Method is an analytical framework for logically combining disparate data sources to estimate a given market's sales efficiency mix. Ultimately, it provides a means of weighting various data points into a market average—in this case, the market average efficiency mix in each year of the analysis.

The research team followed a six-step analytical process to estimate the efficiency mix:

- Step 1: Develop the efficiency mix for each retailer for which the team has data
- Step 2: Segment the market into distinct channels; assign a market share to each market channel
- Step 3: Assign each retailer to a market channel (i.e., market segments)
- Step 4: Determine the relative market share of each retailer within each channel
- Step 5: Compute each retailer's market share of the overall market
- Step 6: Compute the overall market efficiency mix

Step 1: Develop the Efficiency Mix for Each Retailer for Which the Team Has Data

For the purposes of this analysis, an efficiency mix reflects the market share of lamps sold in a given calendar year among four technologies: incandescent, halogen, compact fluorescent, and LED.

Data Sources

The research team used three primary data sources to characterize the efficiency mixes of individual retailers: NEEA shelf-stocking data, Nielsen sales data, and online retailer sales data. The following describes each of these data sources as well as others that the research team reviewed to corroborate the primary data analysis.

NEEA shelf-stocking data. Since 2005, NEEA has undertaken the Northwest Residential Lighting Long-term Market Tracking (LTMT) study. NEEA uses the study, repeated on an annual basis, to track regional lighting market metrics and to estimate the market transformation savings generated by its previous CFL program. NEEA completed the most recent report in 2015.[19] The LTMT study explores a wide variety of lighting topics including customer awareness, retailer/manufacturer perceptions of efficient products, and stocking practices. It is the latter resource—shelf-stocking data—that is of particular interest to the research team, as it provides insight into purchasing preferences for each year.

The research team is aware that stocking practices do not perfectly reflect consumer purchasing behavior, as merchandising strategies and other market factors greatly affect the product volume and placement on shelves. However, the team determined during interviews with major do-it-yourself (DIY) and mass merchandise retailers that these retailers develop their shelf planograms with the goal of achieving a 1:1 ratio between the number of products on the shelves and actual sales. These retailers explained that the goal of aligning shelf space and sales is mainly about restocking efficiencies: ideally these retailers want to restock everything at once each night. They shared that stocking the shelves to mirror sales levels enabled this process and avoided inefficient, ad hoc restocking throughout the day.

Nielsen sales data. To complement the shelf-stocking data collected through the LTMT study, NEEA purchased retailer sales data gathered by Nielsen, a consumer insights company. Unlike the shelf-stocking data, the Nielsen data reflects the actual sales that occurred annually from 2011 through 2015 for a subset

[19] https://neea.org/docs/default-source/reports/northwest-residential-lighting-long-term-market-tracking-study.pdf?sfvrsn=4

of contributing retailers. The Nielsen data is extremely detailed and provides insight into sales by technology, wattage, lumen bin, and pack size. However, the Nielsen data is not fully representative of the entire residential retail lighting market, as several high-volume lighting retailers do not provide sales data to Nielsen. The research team estimates that the retailers providing data to Nielsen represent approximately 23% of the total residential retail market.

Online retailer sales data. As part of its ongoing non-residential lighting distributor data collection efforts, BPA solicited 2015 sales data from a prominent online retailer. Based on customer information and shipping addresses, the online retailer estimated that 30% of its total sales (in terms of units) are to residential customers.

The research team also reviewed the following sources which were not directly incorporated into the analysis:

CLEAResult-tracked retailer data. The CLEAResult dataset is a mixture of program and non-program lamp data collected from Northwest retailers. However, the dataset is limited: it only includes CFLs and LEDs (i.e., no inefficient technologies); it does not include any stock keeping unit details; and it is a mixture of actual and estimated sales.

The research team compared the CLEAResult data with the Nielsen sales and NEEA shelf-stocking data above. The research team found that the CLEAResult data was generally similar with regard to technology and lamp type mixes to the Nielsen and NEEA data. This finding validated the team's decision to rely primarily on the Nielsen and NEEA data, which are more detailed and comprehensive (i.e., contain efficient and inefficient technologies) than the CLEAResult data. The research team was able to use the CLEAResult data, which reports sales by retailer, to develop the team's market share estimates for individual retailers.

National Electrical Manufacturers Association (NEMA) shipment data. The research team compared annual results for the Pacific Northwest to national sales data reported by NEMA. The team found the regional data generally mirrored national trends, which validated the reasonableness of its regional data sources. It is important to note that NEMA shipment data is limited to general purpose lights only.

Data Cleaning and Mapping

Each of the raw datasets uses different naming conventions for bulb shapes, bases, and technologies. The research team created standardized naming conventions in order to map the data to its model applications. The lamp types for the analysis and lamp styles from the data assigned to each are shown in Table 11. To the extent possible, the research team matched the binning choices made by the RTF in the current measure workbook.

Table 11: Summary of Lamp Styles and Base Types by Application

Application	Lamp Types Included	Base Types Included
General Purpose and Dimmable	A-Lamp, Spiral/Twister, Edison, Tube	Medium, Intermediate
Globe	Globe	Medium, Intermediate
Reflector	Downlight, PAR, Reflector, MR Type	Medium, Intermediate
Decorative and Mini-Base	C-Type, Chandelier, Decorative, Globe, T Type	Candelabra, European (E14), Mini Candelabra
3-Way	A-Type, Reflector, Globe, Tube	Medium, Intermediate
Linear	T12, T8, T5	Pin Base

Step 2: Segment the Market into Distinct Channels; Assign Market Share to Each Market Channel

There are many ways to segment a market. The research team elected to divide the residential brick and mortar retail market into three channels: DIY home stores (e.g., Home Depot, Lowe's), mass merchandise retailers and club stores (e.g., Walmart, Costco), and small hardware (e.g., ACE Hardware, True Value Hardware). The team chose these channels, first and foremost, because it had foundational data on the market share associated with these groupings, which a major retailer presented at the 2014 ENERGY STAR Partners Meeting. Additionally, these categories left little doubt as to what stores belonged to them, reducing any uncertainty in assigning retailers to the correct channel.

This channel share data did not include the online sales channel. The research team estimated the share of residential lighting sold through the online category based on a November 2015 interview with a prominent online retailer, as well as the team's subsequent analysis of that retailer's 2015 unit sales data by sector. Using this information, the research team estimated that approximately 4% of total residential lamp purchases are made online. The team reduced the market shares of the three brick and mortar channels proportionally, resulting in the channel shares shown in Table 12.

Table 12: Market Share by Retailer Channel, Including Online

Retailer Channel	Market Share
DIY	50%
Mass Merchandise and Club Stores	32%
Small Hardware	14%
Online	4%

Source: Research team analysis of sales and interview data

Step 3: Assign Each Retailer to a Market Channel (i.e., Market Segments)

The research team then assigned each retailer in the Nielsen data, NEEA's shelf-stocking data, and the online channel data to one of the market channels (Table 13). Each retailer could belong to only one channel.

Table 13: Retailers by Retail Channel

Retailer Channel	Retailer
DIY	The Home Depot
	Lowe's
Mass Merchandise and Club Stores	Walmart
	Target
	K-Mart
	Fred Meyer
	Costco
	Sam's Club
	Other Mass Merchandise and Club Store Retailers
Hardware	Ace Hardware, True Value Hardware
	Other Small Hardware
Online	Bulbs.com
	1000Bulbs.com
	Amazon

Source: Research team analysis

Step 4: Determine the Relative Market Share of Each Retailer within Each Channel

Next, the research team estimated the market share of each retailer within its market channel. For the DIY and hardware categories, the team used retailer store counts in the Pacific Northwest (obtained from retailer websites in 2016) as well as the average number of lamps stocked by each retailer (determined through NEEA's shelf studies) to estimate each retailer's relative market share within each retailer channel.

Since NEEA's lighting LTMT did not visit every retailer within a given channel, the research team created an "Other" category to reflect the market share held by these retailers. The team used professional judgment to assign channel market shares to the "Other" hardware and mass merchandisers retailer categories.[20] The research team assumed the efficiency mix of the retailers associated with the "Other" designation was the weighted average of the known retailers in that category. Table 14 provides an illustrative example of this methodology.

[20] The research team worked with regional program staff to determine that insufficient DIY retailers existed—beyond those visited through the LTMT—to merit creating a similar "Other" category for the DIY channel.

Table 14: Example of Retailer Share Calculation for Hardware Channel, Including Other

Retailer	Store Count (A)	Average Lamps/Store from Shelf Survey (B)	Total Regional Lamps Stocked (A*B)	Market Share
Hardware #1	30	500	15,000	23.75%
Hardware #2	60	750	45,000	71.25%
Other Hardware	N/A	N/A	N/A	5.0%

Note: Illustrative example, not actual data.

The research team followed this same approach for the DIY channel, the hardware channel, and—with one modification—the mass merchandise and club channel. The modification resulted from the research team having actual sales totals for one retailer in this latter category from CLEAResult and the sales total of all other retailers in the category from Nielsen. The team used these two sales totals to estimate the channel market share of the single retailer. The team then assigned the remaining market share to the other retailers in the channel using store counts and average lamps per store data, as described above for the hardware stores.

The team only had sales data from one retailer in the online channel, so it extrapolated that retailer's efficiency mix to the entire online channel because that retailer estimated its mix was consistent with the others in the channel.

Retailer market share over time. The retailer store counts, shelf data, Nielsen data, and CLEAResult data that informed the calculation of retailer market shares were based upon 2014 data. The research team held the retailer market shares constant across the analysis period due to lack of information about shifts in retailer market share between 2011 and 2015.

Step 5: Compute Each Retailer's Market Share of the Overall Market

The research team then converted each retailer's market share within each channel into a market share of the total market. To do this, the team multiplied each retailer's market share within each channel by the market share of the channel to which the retailer belonged. For example, as shown by the illustrative data in Table 15, the DIY 1 retailer has a 55% share of the channel to which it belongs, while the channel itself constitutes 50% of the market. Taken together, that means the DIY 1 retailer has 27.5% of the overall market. The final share represents the weight applied to the efficiency mix calculated in this retailer's sales data.

Table 15: Example of Combining Channel and Retailer Market Shares (Illustrative Only)

Channel	Market Share of Channel	Vendor	Vendor Market Share of Channel	Vendor Market of Overall Market
DIY	50%	DIY 1	55%	27.5%
		DIY 2	20%	10.0%
		DIY 3	25%	12.5%

Note: Illustrative example, not actual data.

Step 6: Compute Overall Market Efficiency Mix

After estimating each retailer's efficiency mix (Step 1) and overall market share (Step 5), computing the market's overall efficiency mix is done by taking the weighted average of those two results. Table 16

shows the actual technology mixes the research team calculated using the Chain Logic Method as described.

Table 16: Estimated Actual Efficiency Sales Mixes by Year, General Purpose Bulbs (250-1049 Lumens)

Year	Incandescent	Halogen	CFL	LED
2011	63%	0%	35%	1%
2012	49%	6%	42%	2%
2013	42%	18%	31%	10%
2014	23%	31%	30%	16%
2015	9%	34%	27%	30%

Source: Research team analysis of sales and shelf data

The research team made select adjustments to individual application and lumen bin efficiency mixes from this analysis when there was insufficient data.[21]

Model Calibration and Gap Filling

The stock turnover model must replicate the resulting efficiency mixes to represent the actual market sales mix and, ultimately, energy consumption. The research team also used the stock turnover model to backcast the efficiency distributions for 2010 and 2009, years for which the team had no sales data. This section describes the research team's approach to these tasks.

The research team developed an approach that utilizes both the available sales data and a set of structured economic and consumer choice assumptions to model market shares segmented by the aforementioned model dimensions. The goal of this approach is to ensure the most accurate results possible by using sales data and maintaining the ability to fill in data gaps and backcast market shares for 2009 and 2010 (due to lack of market data) with a consistent and transparent method. Backcasting both sales and stock simultaneously depends on many factors and is inherently uncertain. In order to improve confidence in the 2009 and 2010 sales and stock estimates, the research team sought to both align the 2011-2015 modeled sales with the actual sales data and ensure that the stock saturation in 2011 aligned with the RBSA.

The team developed a Bass diffusion framework coupled with a logit model to estimate customer adoption decisions among different technologies. The logit model predicts rational consumer choice behavior using economic factors (first cost and operating cost), while the Bass diffusion helps capture non-economic factors that may cause adoption to differ from strictly economic predictions. The Bass and logit models provide a formulaic structure for determining the mix of sales among technologies whenever

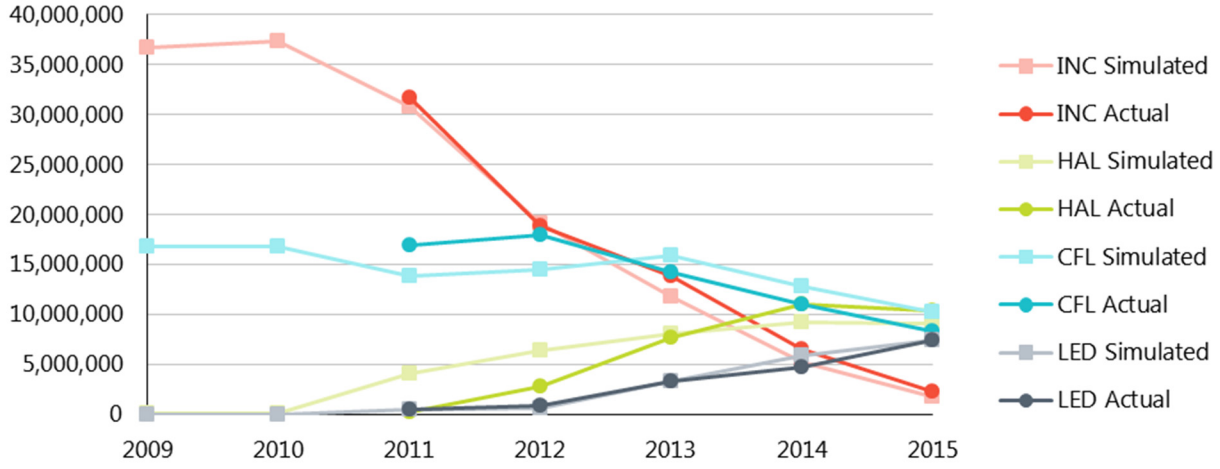
[21] In the Decorative and Mini-Base 250-1049 lumen bin, the research team replaced 2011 shares with the 2012 shares, as the CFL share was unrealistically high (20% higher than 2012). The team believes this is because of small lumen bins and less detailed data in 2011 compared to later years. In the Decorative and Mini-Base 1050-1489 lumen bin, the team replaced 2014 and 2015 shares with 2013 shares to remove odd trends in the halogen shares. In the Globe 250-1049 lumen bin, the research team replaced 2011 shares with 2012 shares. The CFL share was unrealistically high, and the 2011 data was less detailed than in later years.

actual sales data does not exist or is incomplete. The research team calibrated the formulaic portion of the model to the actual sales data, ensuring that the calibrated Bass diffusion and logit structure would fill in data gaps with a logically consistent algorithmic approach while still using sales data directly where it existed. The team used the following process:

1. **Use stock model to estimate market size.** As described above, the research team leveraged data from the RBSA (historical lighting saturation) and Seventh Plan analysis (existing stock of homes and new construction rates).
2. **Perform initial calibration of model to sales data shares using goal-seeking logic.** The research team used non-linear optimization algorithms to solve for a modeled market that aligns with the available sales data for each application and lumen bin. This automated process set initial input parameters for the logit and provided a starting point for the more manual iteration steps, which helped refine the sales mixes.
3. **Compare results to sales and stock data.** The research team looked at the high-level and dimension-specific results and compared them to the sales data as well as the expected trends from the team's market research. With each iteration and sensitivity analysis, the team reviewed the results for the following:
    a. Do modeled sales follow the same overall trend as actual sales?
    b. Do the modeled sales diverge from the actual sales more at the beginning or end of the actual sales period?
    c. Does the resulting stock mix align with the RBSA? If not, are the backcast years contributing significantly to the error?
4. **Iterate results.** The research team iterated the results using both the optimization and manual adjustments until the model and sales aligned and the 2011 stock mix stayed within 4% of the RBSA CFL saturation across applications. At the application level, the team focused on the largest lumen bins to improve the overall results. Thus, results for smaller lumen bins (and, to a lesser extent, very small applications such as Globe and 3-Way) are not as tightly calibrated as the dominant lumen bin for each application. The research team limited manual adjustments to the following:
    a. In order to align the results with the RBSA CFL stock saturation, the team reduced CFL sales shares for 2011 for the decorative and mini-base, and reflector and outdoor reflector applications. For example, using the sales mix directly from the chain logic analysis yielded 2011 decorative and mini-base CFL sales that exceeded the number of CFLs in the 2011 end-of-year stock in that application as estimated from the RBSA data. This adjustment also caused the modeled CFL sales to decrease in 2009 and 2010.
    b. As described in the Sales Efficiency Mixes section, the team applied an uninstall/in-storage rate to CFLs to account for the RBSA finding that more CFLs end up in storage than other technologies relative to their stock saturation. The team performed a sensitivity analysis on reducing CFL sales by 1% to 10% and selected a value of 5% because it yielded the best alignment with the 2011 CFL stock saturation in the RBSA.

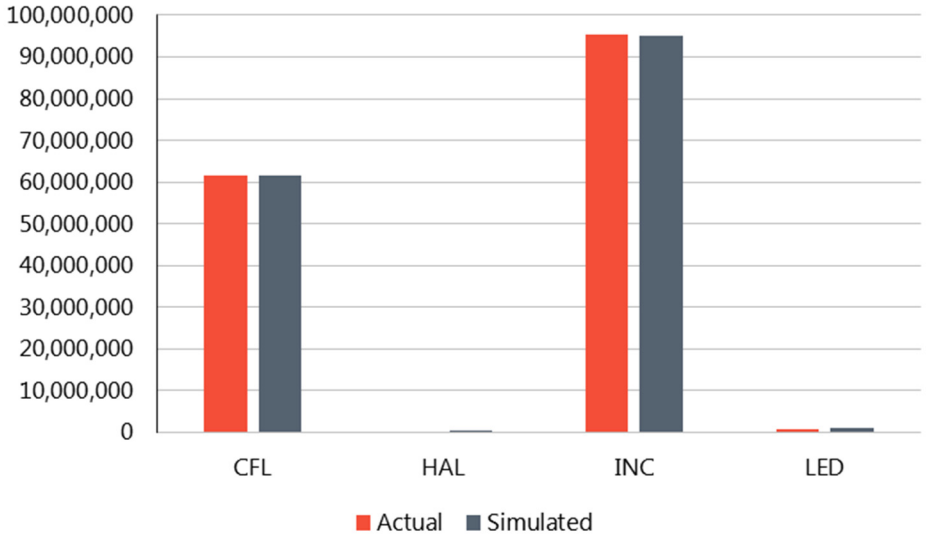
Figure 4 shows the modeled sales for 2009-2015 as well as the actual sales for 2011-2015 to which the team calibrated. Figure 5 shows the modeled stock for 2011 compared to the technology mix in the 2011 RBSA. The team performed this calibration for each unique application and lumen bin.

Figure 4: Calibrated Model Outputs for General Purpose Application (All Lumen Bins)



Source: Residential Momentum Savings Model

Figure 5: Calibrated 2011 Stock for the General Purpose Application (All Lumen Bins)



Source: Residential Momentum Savings Model

Table 17 shows the efficiency mixes for general purpose bulbs.

Table 17: Applied Efficiency Mixes by Year, General Purpose Bulbs

Year	Incandescent	Halogen	CFL	LED
2009	70%	0%	30%	0%
2010	70%	0%	30%	0%
2011	65%	0%	33%	1%
2012	48%	7%	43%	2%
2013	36%	20%	35%	9%
2014	20%	34%	32%	15%
2015	8%	37%	28%	27%

Source: Residential Momentum Savings Model

Again, the sales efficiency mixes determine how the efficiency mix of the stock changes each year. The stock efficiency mix is the final key input (along with the number of lamps in the installed stock, the application mix, and the UEC of each lamp type—all described above) to the calculation of the market's total annual energy consumption.

Market Energy Consumption

The research team calculated market energy consumption for each year of the analysis period for each of the two baseline cases and the actual case using Equation 9. The only difference between the cases is the stock efficiency mix, which is driven by the different sales efficiency mixes assumed in each case. Where:

a = application

b = lumen bin

h = housing type

t = technology

y = year in study period

Table 18 shows the results of the team's findings.

Equation 9: Market Energy Consumption

$$\text{Annual Energy Consumption} = \sum_{h,a,b,t} \text{Installed Lamp Stock}_{h,y} \times \text{Stock Application Mix}_{h} \times \text{Stock Efficiency Mix}_{h,y,a,b,t} \times \text{Average Unit Energy Consumption}_{y,a,b,t}$$

Where:

a = application

b = lumen bin

h = housing type

t = technology

y = year in study period

Table 18: Annual Market Energy Consumption (aMW)

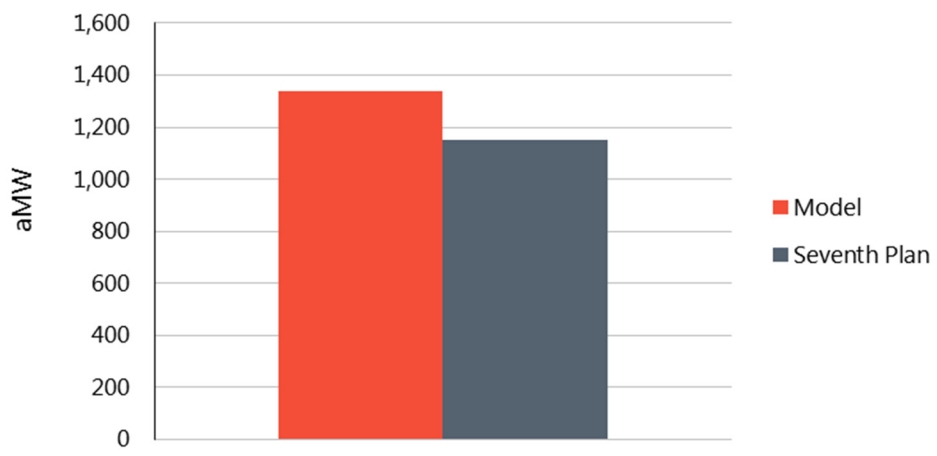
Year	Frozen Baseline	RTF Baseline	Actual
2009	1,338	1,338	1,338
2010	1,285	1,380	1,284
2011	1,244	1,374	1,209
2012	1,215	1,360	1,102
2013	1,194	1,341	989
2014	1,186	1,158	894
2015	1,188	1,002	813

Note: Does not account for HVAC interaction effects
Source: Residential Momentum Savings Model

Comparison to Seventh Plan

The team validated the reasonableness of the model's estimate of total lighting energy consumption in its base year (2009) by comparing it to the comparable estimate from the Council's Seventh Plan. As shown in Figure 6, the team's model (1,338 aMW) and Seventh Plan (1,150 aMW) estimates were within 16% of each other.

Figure 6: Comparison of Model and Seventh Plan 2009 Total Lighting Energy Consumption



Note: Does not include HVAC interaction effects
Source: Residential Momentum Savings Model, Seventh Power Plan end-use load data

Calculating Total Market Savings

The research team subtracted the actual stock energy consumption from each 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 yields **cumulative** energy savings—savings that includes efficiency improvements in prior years. In contrast, Momentum 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 10 and Equation 11, isolates first-year savings in each year of the analysis.[22]

Equation 10: Cumulative Savings

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

The busbar factor in Equation 10 converts energy savings at the customer's 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 11).

Equation 11: First-Year Savings

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

Where:

y = the analysis year

Table 19 and Table 20 show the first-year market savings by year calculated against the frozen baseline case and the RTF baseline case, respectively.

The actual stock consumption declines as CFL, halogen, and LED sales increase and become a larger portion of the installed stock.

The frozen baseline stock consumption also declines, though not as quickly as the actual consumption. Since the majority of failures are incandescent lamps (due to their shorter lifetime) and the 2009 sales mix is about 20% CFL, CFL saturation initially increases, which decreases consumption—even in the frozen baseline. Once CFL saturation plateaus, total consumption begins to grow along with the building stock due to new construction.

The resulting market savings relative to the frozen baseline are small to start. Since all efficient market share present in 2009 is part of the frozen baseline, only incremental gains in efficient technologies between 2009 and 2010 produce savings. For example, even though overall 2010 sales were 21% CFL, the CFL sales share only increased by 0.01% between 2009 and 2010. Thus, 2010 savings are small, but as the

[22] 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.

CFL and LED sales shares grow relative to the frozen baseline and these technologies grow in the stock, savings increase throughout the Sixth Plan period.

Table 19: First-Year Market Savings by Year against the Frozen Baseline

Year	Frozen Baseline aMW	Actual aMW	Cumulative Market Savings	First-Year Market Savings
2009	1,338	1,338	0	0
2010	1,285	1,284	2	2
2011	1,244	1,209	30	28
2012	1,215	1,102	94	64
2013	1,194	989	168	73
2014	1,186	894	237	69
2015	1,188	813	302	65

Note: Consumption estimates do not account for HVAC interaction effects

Source: BPA Residential Momentum Savings Model

The RTF baseline stock consumption increases initially because the sales mix for 2010 and 2011 is 100% incandescent. With incandescent lamps replacing all failures during this period—and most failures in 2012 and 2013—the incandescent share of the stock increases until the RTF baseline sales mix becomes nearly all halogen and CFL in 2014. At this point, the efficiency of the stock technology mix improves rapidly and stock consumption drops accordingly.

Unlike the frozen baseline scenario, the sales shares in the RTF baseline scenario differ greatly from the actual scenario in 2010, yielding large annual market savings. These annual savings decline once the RTF baseline becomes more efficient. The negative market savings in 2014 and 2015 imply that the RTF baseline is more efficient than the actual sales in those years.

Table 20: First-Year Market Savings by Year against the RTF Baseline

Year	RTF Baseline aMW	Actual aMW	Cumulative Market Savings	First-Year Market Savings
2009	1,338	1,338	0	0
2010	1,380	1,284	75	75
2011	1,374	1,209	128	53
2012	1,360	1,102	205	77
2013	1,341	989	283	78
2014	1,158	894	208	-75
2015	1,002	813	146	-62

Note: Consumption estimates do not account for HVAC interaction effects

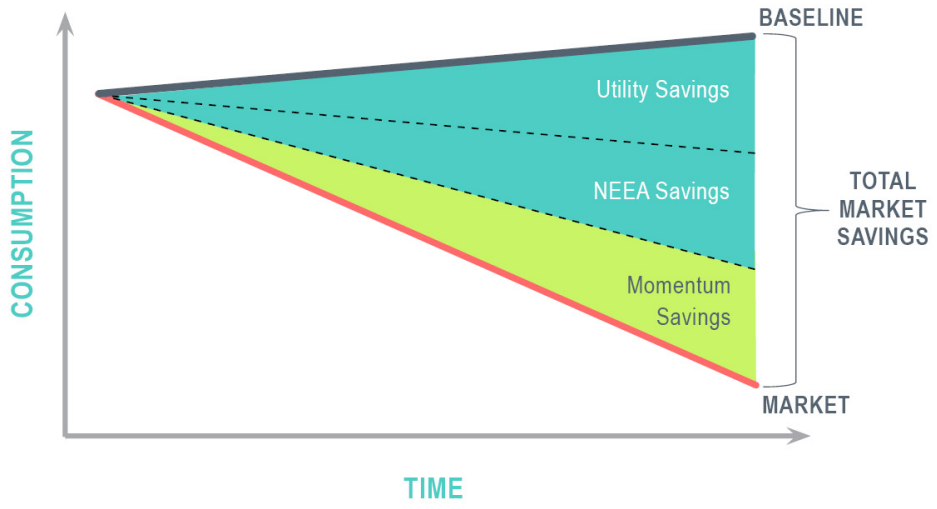
Source: BPA Residential Momentum Savings Model

Question 4: What are the program savings?

The final step in the Momentum Savings Analysis Framework corresponds to Question 4: What are the program savings? The actual energy consumption estimated in Question 3 relied, in part, on sales data that includes high-efficiency units, such as CFLs and LEDs, some of which were incentivized by programs or claimed by NEEA initiatives. Therefore, the last step in the Momentum Savings analysis is to subtract all reported residential lighting program savings from the total market savings calculated in Question 3. After subtracting these program savings, any remaining savings are Momentum Savings.

Figure 7 summarizes the methodology graphically.

Figure 7: How Momentum Savings Account for Program and NEEA Savings



To determine the residential lighting savings generated by regional upstream utility programs and NEEA initiatives, the research team gathered information regarding the following:

- **Utility program activity,** i.e., the number and type (that is, general purpose or specialty) of CFLs and LEDs incentivized through public utility and investor-owned utility (IOU) lighting programs in each year during the Council's Sixth Plan period
- **RTF savings,** i.e., the relevant per-unit savings, by lamp type and year, as determined by the RTF from 2010 to 2015
- **HVAC interactive effects,** i.e., the effect that changes in lighting technologies have on heating and cooling usage and, therefore, total residential energy consumption
- **Cross-sector sales,** i.e., the percentage of residential utility upstream lighting program sales installed in non-residential applications
- **NEEA net market savings,** i.e., NEEA's claimed savings for its CFL market transformation initiative and long-term market tracking efforts

Utility Program Activity

The research team primarily relied upon data from two types of utilities to determine total lighting program activity in the region; one provided information regarding public utility programs and the other provided information on IOU programs.

- **Public utilities.** The research team worked with BPA to extract the relevant program data from its IS2.0 database[23] in order to determine public utility program activity. BPA uses the IS2.0 database as a central repository to report program savings for its customer utilities. For lighting, the team extracted program details for BPA's Simple Steps, Smart Saving program[24] as well as any other lighting programs offered independently by BPA utilities.[25] From the database, the research team determined the total number of lamps—by lamp type, year, and program delivery (e.g., upstream, direct install, mail)—incentivized in each year from 2010 to 2015. The public utility program counts include both CFLs and LEDs.
- **IOUs.** Each year NEEA conducts a survey of local utilities to gather program information for all measures that NEEA tracks. As part of the effort, NEEA asks each regional IOU,[26] as well as BPA, to report the total number of general purpose and specialty CFLs[27] that the entity incentivized in the previous year. NEEA combines this programmatic information with a long-term forecast of CFL growth to calculate any ongoing net market effects savings that result from its historical intervention in the region's CFL market.[28] To inform the research team's Momentum Savings efforts, NEEA provided the team the program counts it collected from IOUs from 2010 to 2015. The program survey data is less granular than the public utility data available through IS2.0. However, the data did provide the team with total program lamps by lamp type, year, and program delivery. Also, since NEEA did not collect LED program counts prior to 2015, the research team identified LED counts for 2014 from IOU program evaluations and annual reports available online.[29] The team reached out to select IOUs when unable to find this information in publically available documents.

The research team combined the public utility and IOU program participation data provided by BPA and NEEA, respectively, to quantify total regional utility activity for upstream, direct install, and give-away lighting programs (Table 21).

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[23] https://www.bpa.gov/EE/Policy/Solutions/Pages/default.aspx

[24] http://simplestepsnw.com/partners

[25] The research team determined which public utility lamps were part of Simple Steps, Smart Savings (S4) and which were incentivized through other public utility lighting programs using data collected by CLEAResult, which implements S4 for BPA. BPA's IS2.0 database can combine counts of multiple programs into single records when the programs involve overlapping measure reference numbers. Given that CLEAResult's data is a comprehensive account of all S4 measures completed, the team linked the counts in CLEAResults's data to the IS2.0 data on the basis of serving utility and reference number. Any remaining counts in the IS2.0 data beyond those present in CLEAResult's data were deemed to be from utility lighting programs unaffiliated with S4.

[26] Includes Avista (WA and ID), Idaho Power, Northwestern, Pacific Power WA, Rocky Mountain Power, Puget Sound Energy, and the Energy Trust of Oregon (Portland General Electric and PacifiCorp). Since only a portion of Northwestern's utility falls within the Columbia Basin—which establishes the bounds of the Council's regional planning efforts—the research team adjusted total reported program sales for Montana by 57%. This is consistent with how the Council and the research team adjusts RBSA data for Montana.

[27] Beginning in 2015, NEEA also began collecting program sales for LEDs.

[28] NEEA stopped directly incentivizing CFLs in 2008 but continues to claim net market effects savings due to its earlier market transformation effort through their long-term market tracking of residential lighting efforts.

[29] Prior to 2014, LEDs made up a very small portion of total programs sales. For examples, only 1.4% of the lamps incentivized by public utilities in 2013 were LEDs.

Table 21: Regional Upstream Lighting Program Participation (lamps): 2010-2015

Lamp Type	Year	Public Utilities	IOUs	Total
General Purpose	2010	4,126,022	3,016,331	7,142,353
Specialty	2010	742,942	2,534,778	3,277,720
General Purpose	2011	4,859,525	5,985,877	10,845,402
Specialty	2011	2,802,167	2,972,823	5,774,990
General Purpose	2012	3,310,219	5,029,940	8,340,159
Specialty	2012	821,437	2,928,638	3,750,075
General Purpose	2013	3,227,840	5,032,831	8,260,671
Specialty	2013	1,024,570	3,068,986	4,093,556
General Purpose	2014	3,604,793	7,527,188	11,131,981
Specialty	2014	1,370,567	4,529,095	5,899,662
General Purpose	2015	3,142,818	9,220,789	12,363,607
Specialty	2015	746,485	2,916,681	3,663,166
Total		**29,779,385**	**54,763,956**	**84,543,341**

Note: Includes Simple Steps, Smart Savings and other public utility lighting programs

RTF Savings

To convert the general purpose and specialty lamp counts detailed in Table 21 into energy savings, the research team determined the relevant RTF residential lighting measure unit energy savings (UES) for each lamp type and year. Since upstream or retail lighting programs represented the majority (~90%) of utility program savings between 2010 and 2015, the research team used the RTF's upstream UES to populate the model and estimate total programmatic savings.[30]

In some years (e.g., 2010), the RTF only had a single UES for either upstream general purpose or specialty lamps. However, in other years, the RTF offered more detailed UES values, which varied based on the lamp's application and/or lumen output. For these years, the research team calculated a weighted average UES that reflected the mix of the most common CFL and LED program lamps incentivized in that year.[31,32]

Table 22 summarizes the RTF UES values used by the research team to estimate program savings by lamp type and year.

[30] The team also did not have sufficient information about where direct install lamps were installed to accurately estimate direct install savings; the RTF savings vary by room type.

[31] Specifically, the research team determined the UES associated with the 10 most common lamps and used these values to calculate a sales weighted UES for that particular lamp type and year. In most years, the top 10 lamps represented well over 90% of all program lamps.

[32] The team found relatively small differences in the annual per-unit savings between CFLs and LEDs, the latter of which became a larger part of program offerings in 2014 and 2015.

Table 22: Relevant RTF Unit Energy Savings

Lamp Type	Year	RTF UES
General Purpose	2010	24.00
Specialty	2010	18.80
General Purpose	2011	24.00
Specialty	2011	18.80
General Purpose	2012	19.27
Specialty	2012	18.80
General Purpose	2013	16.01
Specialty	2013	19.01
General Purpose	2014	16.03
Specialty	2014	19.83
General Purpose	2015	14.04
Specialty	2015	20.56

Source: Research team analysis of Regional Technical Forum data

HVAC Interaction Factor

The RTF UES values shown in Table 22 account for HVAC interaction effects—that is, the impact the lighting upgrade has on heating and cooling usage and, consequently, on total electric energy consumption.

As a result, the research team also needed to account for these impacts when comparing program savings with modeled regional lighting consumption. Again, the team relied on the RTF, using the same HVAC interaction factors (Table 23) employed as part of the RTF's most recent residential lighting measure.[33] The factors vary by both application and lumen bin since these characteristics affect the amount of heating load increased by switching to a more efficient CFL or LED that puts less heat into the conditioned space.

Table 23: HVAC Interaction Factors by Application and Lumen Bin

Lumen Bin	General Purpose	Decorative and Mini-Base	Globe	Reflector	3-Way	Linear	Outdoor: General Purpose and Reflector
250-1049 (24 in)	67%	70%	74%	69%	75%	86%	100%
1050-1489 (48 in)	61%	70%	72%	52%	75%	86%	100%
1490-2600 (96 in)	59%	71%	64%	22%	75%	86%	100%

Source: Research team analysis of Regional Technical Forum data

[33] https://rtf.nwcouncil.org/measures/res/ResLighting_Bulbs_v4_2.xlsm

Cross-Sector Sales

Since the research team is assessing the changes in energy consumption in the residential lighting market, it should only subtract program savings that occurred within the residential sector from the team's assessment of total residential market savings. An evaluation of Puget Sound Energy's (PSE's) upstream residential lighting program in 2015 determined that 8% of the lamps incentivized by the program were purchased by customers that installed them in non-residential applications.[34]

Table 24: Results of PSE Upstream Lighting Intercept Surveys

Sector	Percentage of Total Program Lamps
Residential	92%
Non-Residential	8%
Overall	**100%**

Source: Puget Sound Energy

As a result, the research team multiplied the utility program lamp counts and their corresponding savings shown in Table 22 by 92% to limit those savings to only those lamps that were installed in residential applications.

Important context regarding PSE's evaluation:

- The 92% residential installation rate shown in Table 24 is an overall weighted average (by program participation) of different residential installation rates by store type: DIY (90%), warehouse (93%), and big box (96%).
- PSE's evaluator intercepted customers at three different DIY retailers but was unable to complete intercepts at warehouses or big box locations. As a result, PSE relied on secondary data from a multiyear study by Commonwealth Edison for non-residential purchase rates for warehouses and big box locations.
- PSE's evaluator intercepted any customer buying an LED whether it was a program lamp or not. They also intercepted all applications—not just general purpose.[35]

NEEA Net Market Savings

As noted previously, NEEA uses its annual regional lighting survey to estimate net market effects that result from its long-term support of CFLs in the Pacific Northwest. Table 25 summarizes NEEA's CFL net market effect savings by lamp type and year.

Important context for NEEA's net market effects saving claims includes:

- NEEA's savings methodology, which leverages regional market data collected and reported by CLEAResult, accounts for both CFL retirement and other utility lighting programs. In other words,

[34] http://www.utc.wa.gov/_layouts/CasesPublicWebsite/GetDocument.ashx?docID=157&year=2013&docketNumber=132043.

[35] The evaluation did not find statistically different rates by application.

NEEA does not claim savings for CFLs that replace CFLs, and their savings—similar to Momentum Savings analyses—are mutually exclusive of savings already claimed by regional programs, thus avoiding any potential double counting.

- Although NEEA tracked the regional CFL market throughout the entire Sixth Plan period, they stopped claiming savings associated with general purpose CFLs after 2012. As show in Table 25, NEEA did not claim any net market effects for this lamp type between 2013-2015. In fact, NEEA's market tracking methodology, found that general purpose CFL retirements peaked in 2013, which resulted in a greater number of retirements than new purchases.
- Unlike general purpose CFLs, NEEA was able to claim savings for specialty CFLs for the entire Sixth Plan period. However, similar to general purpose CFLs in 2013, NEEA determined that the number of specialty CFL retirements and units incentivized through regional utility programs in 2015 was greater than new specialty lamp sales in that year. As a result, NEEA did not claim any net market for specialty CFLs in 2015.
- As shown in Table 25, NEEA calculated and applied it's own per-unit savings (kWh/unit). These values differ from the comparable RTF UES values (Table 22). For regional consistency, the research team applied the same set of RTF UES values to both utility program and NEEA net market savings. As a result, the total NEEA net market savings—by lamp type and year—determined through the model differ somewhat from the total savings claimed by NEEA and shown below.

Table 25: NEEA CFL Net Market Savings: 2010-2015

Year	General Purpose			Specialty		
	Units	kWh/Unit	Total Savings	Units	kWh/Unit	Total Savings
2010	3,002,877	30.07	10.3 aMW	1,906,744	23.55	5.1 aMW
2011	651,916	30.07	2.2 aMW	886,023	23.55	2.4 aMW
2012	364,727	24.25	1.0 aMW	1,303,339	23.55	3.5 aMW
2013	-	0.00	0 aMW	1,636,184	23.55	4.4 aMW
2014	629,517	0.00	0 aMW	1,145,321	14.40	1.9 aMW
2015	289,500	0.00	0 aMW	-	14.40	0 aMW

Source: NEEA

Summary

Table 26 combines the cross-sector-sales-adjusted utility program lamps with the lamps claimed by NEEA for each lamp type and year.

Table 26: Total Lamps Claimed through Regional Efficiency Efforts, 2010-2015

Lamp Type	Year	Utility Programs (Adjusted for Cross-Sector Sales)	NEEA*	Total
General Purpose	2010	6,570,965	3,002,877	**9,573,842**
Specialty	2010	3,015,502	1,906,744	**4,922,246**
General Purpose	2011	9,977,769	651,916	**10,629,685**
Specialty	2011	5,312,990	886,023	**6,199,013**
General Purpose	2012	7,672,946	364,727	**8,037,673**
Specialty	2012	3,450,069	1,303,339	**4,753,408**
General Purpose	2013	7,599,818	0	**7,599,818**
Specialty	2013	3,766,072	1,636,184	**5,402,256**
General Purpose	2014	10,241,423	0	**10,241,423**
Specialty	2014	5,427,689	1,145,321	**6,573,010**
General Purpose	2015	11,374,519	0	**11,374,519**
Specialty	2015	3,370,112	0	**3,370,112**

**NEEA's net market effects analysis is limited to the residential sector and does not require a cross-sector adjustment. Also, as noted above, NEEA did not claim any net market effects savings for general purpose CFLs after 2012 or for specialty lamps in 2015.*
Source: Research team analysis of public utility, IOU and NEEA data

As illustrated in Figure 7, the research team needed to remove the savings associated with program and NEEA market effect lamps from the team's estimates of total market savings to arrive at an estimate of residential lighting Momentum Savings. Table 27 converts the lamp counts shown in the previous table, using the RTF UES values, into aMW savings. The removal of the program savings in Question 4, from the market savings calculated in Question 3 resulted in Momentum Savings.

Table 27: Total Savings Claimed through Regional Efficiency Efforts: 2010-2015 (aMW)

Lamp Type	Year	Upstream Program Savings (Adjusted for Cross-Sector Sales)	NEEA Net Market Effects Savings	Total Program Savings
General Purpose	2010	20	9	**29**
Specialty	2010	7	4	**12**
General Purpose	2011	30	2	**32**
Specialty	2011	12	2	**15**
General Purpose	2012	18	1	**19**
Specialty	2012	8	3	**11**
General Purpose	2013	15	0	**15**
Specialty	2013	9	4	**13**
General Purpose	2014	20	0	**20**
Specialty	2014	13	3	**16**
General Purpose	2015	20	0	**20**
Specialty	2015	9	0	**9**

Source: Research team analysis of program and RTF data

Appendix

This appendix is organized into six sections with the following subsections:

1. **Model Dimensions**
    a. Housing Type
    b. Application
    c. Technologies
    d. Lumen Bin and Lamp Length
2. **Stock Turnover Model Inputs**
    a. Lifetimes
    b. Establishing Base Year (2009) Lamp Vintages
3. **Annual Lighting Sales Estimates**
    a. Top-Down (NEMA)
    b. Bottom-Up (Nielsen)
4. **Supporting Chain Logic Model Details**
    a. Quality Control
5. **Supporting RBSA Details**
    a. Calculating Lumens
    b. Linear Fluorescent Lamp Stock
    c. Applying Market Data by Home Type
    d. Applying Market Data to Outdoor Applications
6. **Sensitivity Analysis Findings**

1. Model Dimensions

Table 28 shows the four dimensions of the residential lighting model. The table also lists the values associated with each dimension. The research team constructed the model in a manner that allows the user to view the results along any of these dimensions.

Table 28: Summary of Model Dimensions and Associated Values

Housing Type (3)	Application (8)	Technology (7)	Lumen Bin/ Linear Length (3)
Single Family	General Purpose	Incandescent	250 to 1049 OR 24 in
Multifamily	3-Way	Halogen	1050 to 1489 OR 48 in
Manufactured	Decorative and Mini-Base	CFL	1490 to 2600 OR 96 in
	Globe	LED	
	Reflectors	T-12	
	Outdoor General Purpose	T-8	
	Outdoor Reflectors	T-LED	
	Linear		

In this section of the appendix, the research team discusses the decision points and rationale for both segmenting the model into these dimensions and selecting the values within each.

1a. Housing Type

The model will produce results for three different residential housing types: single family homes, multifamily homes, and manufactured homes. The team will leverage housing type-specific data collected through the RBSA to model lighting stock, including the number of each type of home and key lighting characteristics within each home type. These include the average number of sockets, the mix of applications, and the existing technologies installed.

1b. Application

In the model, the most common lamp types (e.g., general purpose screw-in, reflector, etc.) are referred to as applications. It is within these applications that different technologies (e.g., halogen or LED) compete for a given socket.

To determine the appropriate set of applications for modeling residential lighting Momentum Savings, the research team investigated the following factors:

- **Regional consistency.** What applications did the Council model in the Sixth and Seventh Plans? What applications does the RTF use for its residential lighting measure?

- **Comprehensiveness.** Do the Council/RTF applications sufficiently capture the residential market for the purpose of modeling Momentum Savings? For example, do they include linear fluorescents or are they limited to screw-in lamps? What about less common, niche applications—Christmas lights, night lights, and lamps with less than 250 or more than 2600 lumens? Do any of these merit inclusion in the team's analysis?
- **Data availability.** Is the necessary data available—both in the RBSA (stock) and Nielsen/shelf-stocking data (sales)—to develop inputs at this level of granularity?
- **Consistency with program data.** Does reporting on program activity support analysis by these applications? That is, will the research team be able to account for program sales at the same level of granularity?

After completing this investigation, the research team decided on the following applications (Table 29).

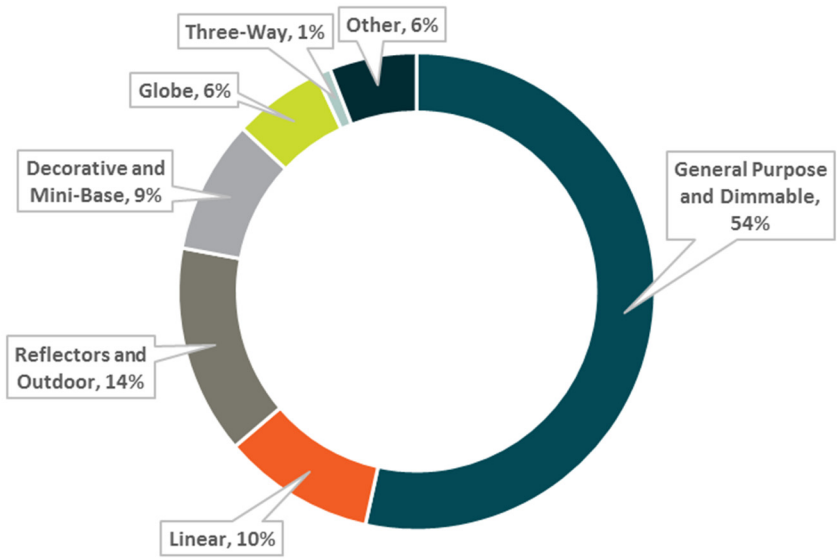
Table 29: Model Applications

Application	Notes
General Purpose	Many of the applications are dimmable (i.e., it is not a mutually exclusive category). As a result, the research team does not believe dimmable should be called out explicitly as part of general purpose (as done by the Council and RTF). Similarly, the team does not believe it should be a separate application.
3-Way*	Creating a distinct 3-way application is consistent with the Council's Plan but not the RTF. The RTF opted to group 3-way lamps with general purpose and dimmable to prevent a scenario where 3-way savings are much higher than general purpose (because they are EISA-exempt) due to concern that this might result in programs over-supplying 3-way lamps. However, this is not a concern for the research team's analysis.
Decorative and Mini-Base*	Consistent with both the Council and RTF.
Globe*	Consistent with both the Council and RTF.
Reflectors*	Both the RTF and the Council include outdoor with reflectors. However, non-reflector lamps are commonly used in outdoor fixtures. The research team will model the turnover of outdoor general purpose and reflector lamps separately, as these lamps are subject to greater HOU.
Outdoor General Purpose	Similar to dimmable lamps, outdoor is not a mutually exclusive application (i.e., residential customers use a wide range of applications in outdoor sockets). Rather than create a separate outdoor sub-application for each one, the research team will use two: outdoor general purpose and outdoor reflector, which, per the RBSA, collectively represent 89% of all residential outdoor applications.
Outdoor Reflectors*	
Linear	Represents 10% of lamps per the RBSA.

**In the regional lighting program parlance, these applications are all specialty lamps.*

Additionally, the research team reviewed the mix and prevalence of applications identified through the 2011 RBSA and determined the proposed model applications represent 93% of the residential lighting stock (Figure 8).

Figure 8: 2011 RBSA Lamp Applications



Source: Research team analysis of 2011 RBSA for all socket types

1c. Technologies

Within a given application, the model will compete the relevant subset of seven technologies found in Table 30 against each other, four of which pertain to screw-in lamps and three to linear applications.

Table 30: Model Technologies and Mapping to Applications

Technology	Relevant Applications
Incandescent	All non-linear applications (i.e., screw-in lamps)
Halogen	
CFL	
LED	
T-12	Linear
T-8	
T-LED	

1d. Lumen Bin and Lamp Length

Residential customers can install lamps with a wide range of wattages and/or lumen levels in a given application (e.g., a 40W, 60W, 75W, or 100W equivalent lamp in any given medium screw base socket). Thus, the research team will model lumen bins. Including lumen bins as a model dimension provides several benefits.

First, modeling lumen bins allows the research team to more accurately account for EISA and its impact on the RTF residential lighting measure updates, which the US DOE phased in incrementally by lumen bin over a three-year period.

Second, as noted previously, including lumen bins as a model dimension ensures that the existing and replacement technology (once the model turns over a given socket) deliver similar light output.

The research team investigated the lumen bins used by the Council and RTF to determine the most appropriate lumen bins for the model. The team determined that the RTF's most recent residential lighting measure (v4.2) and the Council's Seventh Plan use the same three lumen bins: 250-1049, 1050-1489, and 1490-2600 lumens. After confirming these three lumen bins encompassed 92% of total screw-in lamps sales and wattages based on analysis of 2014 sales data, the research team decided to use these same bins in its analysis (Table 31).

Table 31: Model Lumen Bins

Lumen Bin
250-1049
1050-1489
1490-2600

It is important to note that these lumen bins differ from EISA's lumen bin categories (310-749, 750-1049, 1050-1489, and 1490-2600). In essence, the RTF opted to group and slightly expand (from 310 to 250 lumens) the first two EISA lumen bins. The rationale behind this was that "current incandescent and halogen products marketed as '60W equivalent' fall in the 310 to 749 lumen range, whereas CFL and LED products marketed as "60W equivalent" fall into the 750 to 1049 lumen range."[36] Since these technologies will compete within the model for similar light-producing sockets, the RTF's aggregation of EISA lumen bins also makes sense for estimating Momentum Savings.

While lumen bins are important parameters for bounding screw-in lamp turnover decisions (i.e., consumers typically replace lights with similarly bright bulbs, regardless of the technology), the replacement decision for linear lamps is different. Customers replacing failed linear lamps search out lamps of similar length that fit their existing fixture. As a result, the research team categorized the linear application by length rather than lumen bin.

Specifically, the research team modeled two lamp lengths: 2-foot (24 in) and 4-foot (48 in). The RBSA found that T-8 and T-12 lamps for these two lengths capture nearly 80% of total linear lamps in residential homes. (See Table 41 in the Supporting RBSA Details section of the appendix). It is also worth noting that

[36] http://rtf.nwcouncil.org/measures/res/ResLighting_Bulbs_v4_2.xlsm

T-LEDs, while a technology included in the team's analysis, were not found in any homes at the time of the RBSA.

Table 32: Model Linear Lengths

Linear Length
2-Foot (24 in)
4-Foot (48 in)

2. Stock Turnover Model Inputs

2a. Lifetimes

The research team used the lifetimes shown in Table 33 from the US DOE's national lighting model to inform the team's stock turnover model. The model combines lamp lifetimes (in hours) with operating hours to calculate the lifetime (in years) for each combination of technology and application.

For CFLs, the team adjusted the rated lifetime due to the effects of switching using the ratio of in situ to rated lifetimes for ENERGY STAR CFLs in the RTF measure workbook. This de-rated lifetime estimate is based on a 2008 study on the effects of switching on residential CFL lifetimes.[37] The RTF measure workbook also specifies a maximum measure life of 15 years for linear lamps and 12 years for all other lamps. The "Modeled Lifetime" column reflects the CFL de-rate factor and the maximum lifetime caps.

[37] Jump, C. et al. "Welcome to the Dark Side: The Effect of Switching on CFL Measure Life." 2007 ACEEE Summer Study.

Table 33: Model Lifetimes

Technology	Application	Rated Lifetime	Modeled Lifetime
CFL	Decorative and Mini-Base	10	5.1
CFL	General Purpose	10.3	5.2
CFL	Reflector	10	5.1
CFL	3-Way	10.3	5.2
CFL	Globe	10.3	5.2
Halogen	Decorative and Mini-Base	1.2	1.2
Halogen	General Purpose	1.5	1.5
Halogen	Reflector	3	3
Halogen	3-Way	1.5	1.5
Halogen	Globe	1.5	1.5
Incandescent	General Purpose	1.4	1.4
Incandescent	Reflector	2.5	2.5
Incandescent	3-Way	1.4	1.4
Incandescent	Decorative and Mini-Base	1	1
Incandescent	Globe	1.4	1.4
LED	Decorative and Mini-Base	25	12
LED	General Purpose	25	12
LED	Reflector	25	12
LED	3-Way	25	12
LED	Globe	25	12
T-8	Linear	21	15
T-12	Linear	15	15

Sources: US DOE lighting model input data, RTF workbook "ResLighting_Bulbs_v4_2.xlsx"—"Lifetime" tab

2b. Establishing Base Year (2009) Lamp Vintages

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 stock prior to the baseline year. The model accounts for the lifetimes and survival distributions of various technologies, the historic rate of growth in sales,[38] retrofit rates (if considered), and building stock demolition rates. With information about the rate of growth in sales, the model accumulates sales for each technology beginning in 1984 (25 years prior to 2009) and simulates like-for-like replacement for lamp turnover. By tracking these dynamics for 25 years, the model can determine a reasonable approximation of the age distribution of the stock at the beginning of 2009.

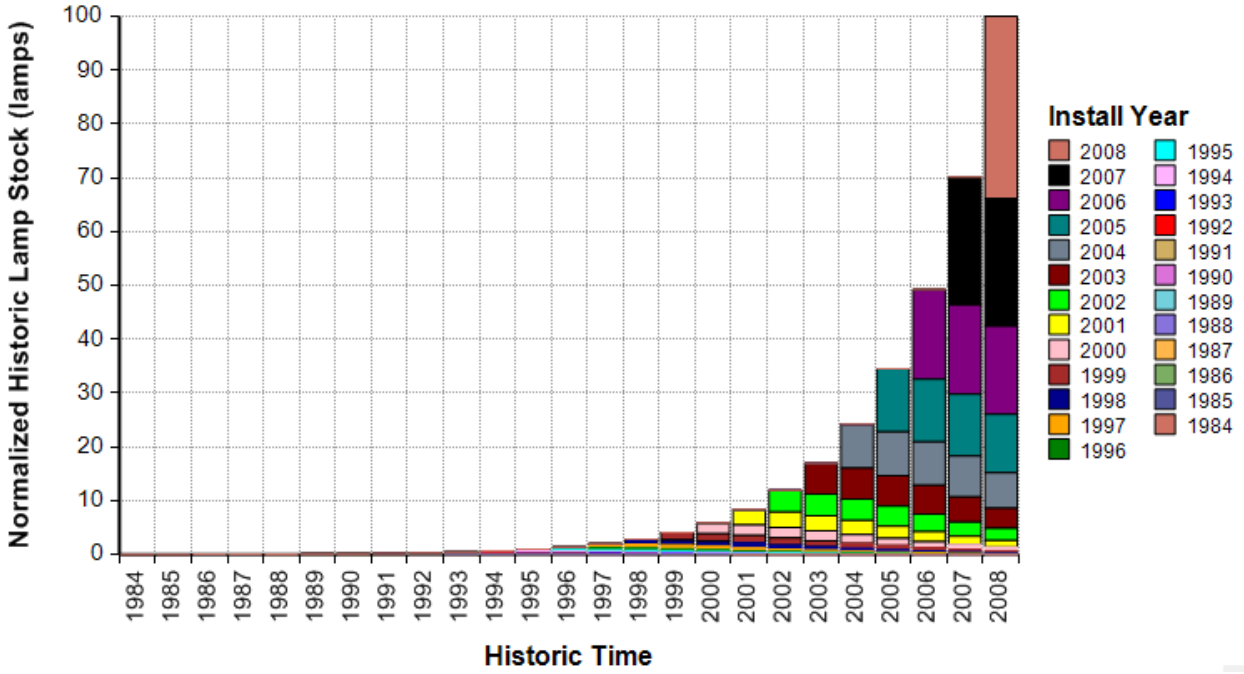
[38] Where data was available, the model used historic rate of growth in sales. When data was not available, the model used historic building stock growth rates as a proxy for the growth rate in sales.

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; rather, it is tied to historic growth rates.

As shown in Figure 9, 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 stock comes from different installation years. This information inherently captures the age of lamps included in the residential model's initial lamp stock for its baseline year.

Figure 9: Illustrative Normalized CFL Lamp Stock for Historic Years (Lamps)



Source: Residential Momentum Savings Model development

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 34, 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 housing type.

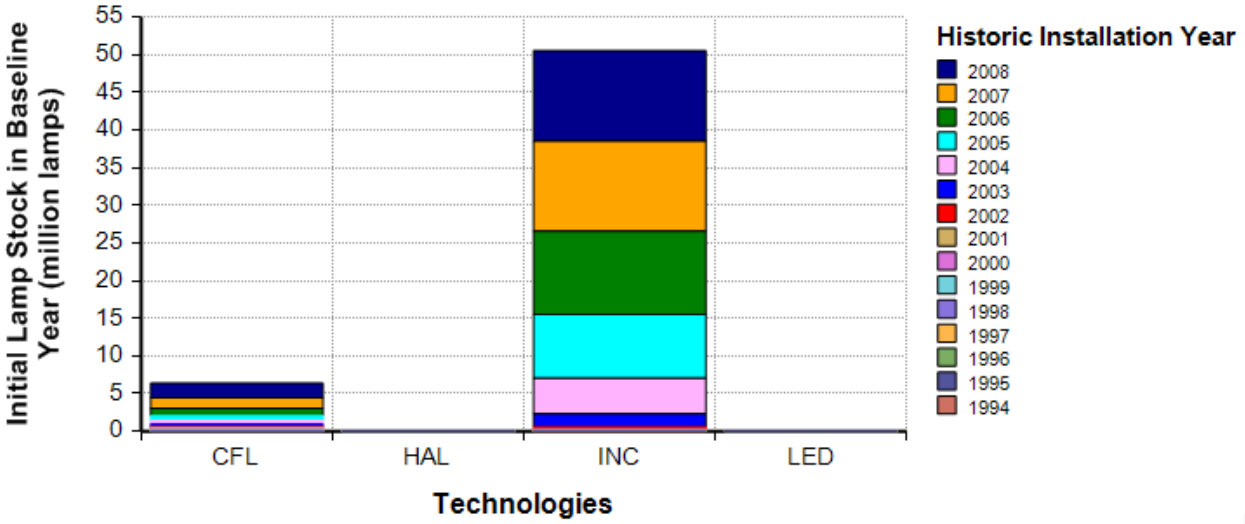
Table 34: Illustrative Base Year Age Distribution by Application for CFLs in Single Family Homes

Installation Year (Proxy for Age)	Decorative and Mini-Base	General Purpose	Globe	Outdoor: General Purpose	Outdoor: Reflector	Reflector	3-Way
1995	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1996	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%
1997	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%
1998	0.0%	0.1%	0.5%	0.0%	0.0%	0.0%	0.1%
1999	0.2%	0.4%	0.9%	0.0%	0.0%	0.0%	0.3%
2000	0.6%	1.0%	1.5%	0.0%	0.0%	0.1%	0.9%
2001	1.5%	1.9%	2.3%	0.0%	0.0%	0.5%	1.8%
2002	3.0%	3.3%	3.5%	0.0%	0.0%	1.9%	3.2%
2003	4.9%	5.1%	5.1%	0.6%	0.4%	4.2%	5.0%
2004	7.5%	7.5%	7.4%	4.3%	3.9%	7.4%	7.5%
2005	11.1%	10.9%	10.6%	11.1%	10.9%	11.4%	10.9%
2006	15.9%	15.6%	15.1%	18.4%	18.6%	16.6%	15.7%
2007	22.7%	22.3%	21.6%	27.0%	27.3%	23.8%	22.4%
2008	32.5%	31.8%	30.9%	38.5%	39.0%	34.0%	32.1%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Source: Residential Momentum Savings Model development

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 end result is a baseline lamp stock with the correct number of lamps for 2009 and a robust estimation of the age distribution. Figure 10 provides an illustrative example.

Figure 10: Illustrative Lamp Stock in Baseline Year (2009) by Technology (Million Lamps)



Source: Residential Momentum Savings Model development

3. Annual Lighting Sales Estimates

The research team estimated the number of screw-in and linear lamps installed in homes each year in the Pacific Northwest through the stock turnover model. As discussed previously, the model estimated lamp failures within a given year—and consequently replacement sales and installations in that same year—using a series of key model inputs including the age and technology mix of the existing lighting stock, annual HOUs, expected lamp lifetimes, and changes in the annual retail technology mix.

To test the reasonableness of the annual lighting sales estimated by the model, the research team estimated total annual sales outside the model. Due to data limitations, the team was only able to independently estimate 2014 sales for general purpose lamps. However, the team did employ complementary approaches to develop these separate estimates and compare them against the model results.

- **Top-down:** The research team's top-down approach centered on scaling down national lamp shipment indices from the NEMA to reflect likely shipments—and subsequently sales—in the Pacific Northwest.
- **Bottom-up:** The team's bottom-up approach relied on detailed retail sales data collected by Nielsen. Since only a subset of regional retailers provide sales information to Nielsen, the research team combined the total sales observed in the Nielsen data with its estimates of individual retailer market shares (described earlier in The Chain Logic Method section) to estimate the total market size in the Northwest. The team completed a second, similar bottom-up market size analysis using CLEAResult data in place of Nielsen data.

The following sections detail the data sources and assumptions for each approach. It is important to repeat that the research did not use either of these annual sales estimates to model total market or Momentum Savings. Rather, the team used these estimates to validate the reasonableness of the sales estimated by the stock turnover model. The research team's 2014 modeled sales of roughly 33 million lamps for general purpose applications is just below the lowest of the top-down and bottom-up estimates

described here. While general purpose 2014 sales are not within the range of the team's top-down and bottom-up estimates, the model sales for the entire market over time are consistently higher than NEEA's estimates—though they show a similar trend.

Table 35: 2014 Northwest General Purpose Lamp Sales

Approach	Estimated Lamp Sales	Model Estimate of Lamp Sales	Ratio
Top-Down (NEMA)	34,408,139	33,207,566	97%
Bottom-Up (Nielsen)	61,227,731		54%
Bottom-Up (CLEAResult)[39]	50,112,916		66%
Simple Average	48,582,929		68%

Source: BPA Residential Lighting Momentum Savings Model, research team analysis

Table 36: Total Northwest Residential Lamp Sales over Time

Year	Model Estimate of Lamp Sales	NEEA Estimate of Lamp Sales	Ratio
2010	99,548,686	63,000,000	158%
2011	93,585,034	60,000,000	156%
2012	85,906,164	61,000,000	141%
2013	82,748,457	60,000,000	138%
2014	74,142,950	57,000,000	130%
2015	66,532,024	53,000,000	126%

Source: BPA Residential Lighting Momentum Savings Model, NEEA data provided by Ryan Brown

Table 37: Total Northwest Residential CFL Sales over Time

Year	Model Estimate of Lamp Sales	NEEA Estimate of Lamp Sales	Ratio
2010	20,540,990	18,721,049	110%
2011	22,325,098	16,454,685	136%
2012	25,617,768	17,254,906	148%
2013	21,445,308	16,867,125	127%
2014	16,590,545	14,935,976	111%
2015	12,569,281	11,052,650	114%

Source: BPA Residential Lighting Momentum Savings Model, NEEA data provided by Ryan Brown

[39] The evaluation team is unable to provide a detailed summary of the bottom-up approach using CLEAResult data (similar to Sections 3a and 3b below) since the estimate relies on non-public sales data.

3a. Top-Down (NEMA)

Table 38: Top-Down Market Share Estimation Details

Data Point	Units	Sources and Assumptions
National NEMA A-line Shipments	825,025,437	**Assumptions:** • Shipments are equal to sales. • NEMA A-line shipments include only non-dimmable medium screw base A-line lamps under 2600 lumens. **Source:** The research team scaled up shipments from actual 2010 NEMA shipments using an estimated NEMA sales index and estimated the sales index using the text and charts in quarterly press releases.
National Non-NEMA Shipments	91,669,493	**Assumption:** • Non-NEMA shipments make up 10% of the market. **Source:** Research team's assessment of NEMA members list.[40]
Total National Shipments	916,694,930	Represents combined total of NEMA and non-NEMA shipments.
Rounded Total National Shipments	900,000,000	Rounded to avoid false precision.
National Residential Shipments	828,000,000	**Assumption:** • 8% of A-line shipments go to non-residential sector. **Source:** PSE 2014-2015 Residential Retail Lighting Impact Evaluation, August 26, 2015.
Total Pacific Northwest Residential Shipments	**34,408,139**	**Assumptions:** • Population size directly correlated with lamps per home. • Pacific Northwest is 4% of US market size. **Source:** US Census Bureau, Annual Estimates of the Resident Population of the United States, Regions, States, and Puerto Rico, 2014.

[40] NEMA Members List: https://www.nema.org/About/Pages/Members.aspx

3b. Bottom-Up (Nielsen)

Table 39: Nielsen Data Bottom-Up Market Share Estimation Details

Data Point	Units	Sources and Assumptions
Nielsen Sales	15,652,464	**Assumption:** The general purpose category includes A-lamp and tube-style lamps, which are general purpose twisted CFL lamps. **Source:** Nielsen sales data on general purpose lamp sales in 2014.
Total Regional Sales	66,606,230	**Assumption:** Nielsen sales data represents 23.5% of the total residential lighting market. **Source:** Research team's Chain Logic Method retailer market share estimate.
Total Pacific Northwest Sales	**61,227,731**	**Assumption**: 8% of A-line sales go to the non-residential sector. **Source:** PSE 2014-2015 Residential Retail Lighting Impact Evaluation, August 26, 2015.

4. Supporting Chain Logic Method Details

4a. Quality Control

The research team continually reviewed input and output data to ensure reasonable results. At the outset of its analysis, the team cleaned each dataset to safeguard against inconsistencies in field names and values that can introduce errors when combining datasets. The team's process included the following:

- Identifying and screening out lamps outside the scope of the team's Momentum Savings analysis (e.g., heat lamps, candle wax warmers)
- Identifying and screening out records with values outside a reasonable range (e.g., lumens = 5601280)
- Standardizing inconsistent field formats (e.g., wattage value of "13; 19 ;23" compared to "50 100 150" for 3-way lamps)

Simultaneously, the research team validated and corrected specific records within each dataset. This included the following:

- Updating technology, application, lamp base (i.e., size and type), lumens, and watts values for over 1,600 records (corresponding to over 56 million units) in the Nielsen data based on model-specific research. The team updated these values while validating details for the specific records that represent the highest proportion of overall units.
- Verifying model numbers representing nearly 29 million lamps and 80% of incandescent lamps in the Nielsen data. This ensured the incandescent lamps did not include miscategorized halogen bulbs, an issue identified in a separate but related project.

Next, the team conducted a review of the cleaned and standardized datasets. This step included confirming the following:

- Data was loaded accurately (e.g., the correct number of records pre- and post-load)
- Results were reasonable, and observed ranges were within ranges the team expects to see for a given field (e.g., wattages for general purpose incandescent lamps in the 1050-1489 lumen bin were between 50W and 100W)
- Consistency (e.g., rules have been applied consistently across similar products)
- Accuracy (e.g., T-8 and T-12 lamps correspond to the linear category and not general purpose)

As part of this review, the research team also assessed the data using standardized queries, including:

- Overall record and lamp counts
- Record and unit counts by attributes such as stock code/UPC, state, year
- Record and unit counts by attributes such as bulb style (e.g., A-line, twist, reflector), base (e.g., medium screw, mini-base), application, technology, and an indicator field indicating if a specific record is flagged for exclusion from the analysis[41]
- Average wattage, lumen, and efficacy ranges
- Unique application and technology groupings

After analyzing the cleaned, standardized, and loaded data, the research team reviewed its results through multiple steps:

- Manually double-checked important calculations in Excel
- Reviewed detailed results for counterintuitive trends and anomalies, such as increasing overall average wattage, decreasing efficiency, or increasing LED costs over time
- Validated results through expert review as well as by comparing them to external resources such as national lighting sales indices published quarterly by NEMA

If the research team identified any issues during any of this process, it made the necessary corrections and repeated the validation process until it found no more issues.

5. Supporting RBSA Details

5a. Calculating Lumens

Since the RBSA did not collect information on lumens, the research team needed to map each RBSA lamp to one of the model's three lumen bins. To do so, the team used the same lamp efficacies as the RTF. Specifically, the team used the RTF table of lumens for each unique lamp wattage found in the RBSA. Because the RBSA made no distinction between bare bulb and covered bulb CFLs, the team used the "CFL – bare" lumens for all CFLs in general purpose applications and the "CFL – covered" lumens for all other applications. This follows the assumption that decorative, globe, 3-way, and reflector lamps are, by definition, covered bulbs. To limit the size of Table 40, the team only shows lamps less than or equal to 100W. As this analysis was specific to mapping RBSA data to the model lumen bins, values may not match

[41] This review ensures analysis exclusion rules are applied consistently and accurately.

the average market efficacies for each technology, application, and lumen bin in the model. The model does not rely on efficacy to determine sales or stock shares.

Table 40: Wattage and Lumen Output by Application and Technology: 2011

Unique Lamp Wattages in the RBSA	Incandescent	Halogen	CFL (Bare)	CFL (Covered)	LED
0	0	0	0	0	0
1	10	14	62	49	63
1.6	16	22	99	78	101
2	20	27	124	97	127
3	30	41	186	146	190
4	40	54	248	194	254
5	50	68	310	243	317
6	60	81	371	292	381
7	70	95	433	340	444
8	80	109	495	389	507
9	90	122	557	437	571
10	100	136	619	486	634
11	110	149	703	551	698
12	120	163	767	601	761
13	130	176	831	651	824
14	140	190	907	710	888
15	150	204	971	760	951
16	160	217	1036	811	1015
17	170	231	1101	862	1078
18	180	244	1166	913	1142
19	190	258	1230	963	1205
20	200	271	1295	1014	1268
21	210	285	1360	1065	1332
22	220	299	1425	1157	1395
23	230	312	1548	1209	1459
24	240	326	1616	1262	1522
25	250	339	1683	1335	1585
26	260	353	1750	1513	1649
27	270	366	1848	1571	1712
28	280	380	1917	1630	1776

Unique Lamp Wattages in the RBSA	Incandescent	Halogen	CFL (Bare)	CFL (Covered)	LED
29	290	394	1985	1688	1839
30	300	407	2054	1746	1903
31	310	421	2122	1804	1966
32	320	434	2191	1862	2029
33	330	448	2259	1921	2093
34	340	461	2328	1979	2156
35	350	475	2396	2037	2220
36	360	489	2464	2095	2283
37	370	502	2533	2153	2347
38	380	516	2601	2212	2410
39	390	529	2670	2270	2473
40	490	543	2738	2328	2537
41	502	556	2807	2386	2600
42	515	570	2875	2444	2664
43	527	785	2944	2503	2727
45	551	822	3081	2619	2854
46	564	840	3149	2677	2917
48	588	876	3286	2794	3044
49	600	895	3354	2852	3108
50	613	860	3751	2910	3171
52	637	894	3901	3026	3298
53	649	880	3976	3085	3361
54	662	897	4051	3143	3425
55	674	913	4126	3201	3488
56	686	930	4201	3259	3551
57	698	946	4276	3317	3615
58	711	963	4351	3376	3678
60	840	965	4501	3492	3805
65	910	1045	4876	3783	4122
67	938	1078	5026	3899	4249
67.5	945	1086	5063	3929	4281
68	952	1094	5101	3958	4312
70	980	1126	5251	4074	4439

Unique Lamp Wattages in the RBSA	Incandescent	Halogen	CFL (Bare)	CFL (Covered)	LED
71	994	1142	5326	4132	4503
72	1008	1280	5401	4190	4566
73	1022	1298	5476	4249	4630
74	1036	1316	5551	4307	4693
75	1190	1315	5626	4365	4756
76	1206	1333	5701	4423	4820
77	1222	1350	5776	4481	4883
80	1269	1403	6001	4656	5074
83	1317	1455	6226	4831	5264
85	1349	1490	6376	4947	5391
86	1365	1508	6451	5005	5454
87	1380	1525	6526	5063	5517
90	1428	1578	6751	5238	5708
95	1507	1666	7126	5529	6025
96	1523	1683	7201	5587	6088
100	1690	1753	7501	5820	6342

Source: Research team analysis of RBSA data

5b. Linear Fluorescent Lighting Stock

To determine the more relevant lamp length for inclusion in the Momentum Savings model, the research team analyzed the prevalence of linear lamps observed through the RBSA. Table 41 summarizes the RBSA's linear fluorescent lamp findings by lamp length and technology. This table excludes all linear lamp

lengths and technologies listed by NEEA as "Other." As noted previously, the RBSA did not identify any linear LED lamps or fixtures; all linear lamps found in the audits were fluorescent.

Table 41: RBSA Linear Lighting Stock by Lamp Length and Technology

Lamp Length (Inches)	T-12	T-8	T-4	T-5	Total
12	0.1%	0.4%	0.5%	0.5%	1.5%
16	0.0%	0.2%	0.1%	0.1%	0.4%
18	0.2%	0.4%	0.1%	0.2%	0.8%
20	0.0%	0.0%	0.0%	0.1%	0.2%
22	0.1%	0.1%	0.0%	0.0%	0.2%
24*	**2.6%**	**1.5%**	**0.2%**	**0.7%**	**4.9%**
32	0.0%	0.2%	0.0%	0.0%	0.3%
36	1.4%	0.9%	0.3%	0.4%	3.0%
40	0.5%	0.0%	0.0%	0.0%	0.5%
44	0.9%	0.2%	0.0%	0.0%	1.1%
46	0.2%	0.0%	0.0%	0.0%	0.3%
47	0.2%	0.0%	0.0%	0.0%	0.2%
48*	**56.1%**	**18.5%**	**1.9%**	**0.5%**	**77.0%**
60	0.5%	0.3%	0.0%	0.1%	0.9%
72	0.3%	0.0%	0.2%	0.0%	0.5%
96	6.7%	0.2%	0.0%	0.1%	7.0%
Overall	**70.6%**	**23.3%**	**3.4%**	**2.8%**	**100.0%**

**Included in model*

Note: Table omits all lamp lengths that total less than 0.1% of the linear fluorescent lamp RBSA stock.
Source: Research team analysis of RBSA lighting data

5c. Applying Market Data by Home Type

Lacking data on the ultimate destination of lamp sales (i.e., which housing types accounted for which lamp sales), the research team decided to distribute the available retail sales/shelf data uniformly across all three home types. The RBSA supports this assumption—that customers that live in single family, multifamily, and manufactured homes do not make different lighting decisions because of their house type. While the RBSA found some minor differences in the technology mixes between single family, multifamily, and manufactured homes (Table 42), the differences are not statistically significant.

Table 42: RBSA Distribution of Lamps by Home Type

Technology	Single Family	Multifamily	Manufactured Home
Incandescent	58.7%	61.8%	61.0%
Halogen	5.3%	3.0%	1.7%
Compact Fluorescent	26.2%	28.0%	28.4%
Other	0.4%	0.2%	0.1%
Linear	9.5%	7.0%	8.8%

Source: Research team analysis of RBSA lighting data

5e. Applying Market Data to Outdoor Applications

It is not possible to tell from the market data whether a given general purpose or reflector lamp was sold for an interior or exterior application. Accordingly, the research team used the same technology mix observed in the overall market data for both interior and exterior applications for general purpose and reflectors. The team is confident that this assumption has little impact on the overall analysis as the technology shares between the interior and exterior applications of general purpose and reflector lamps in the stock are quite similar.

Table 43: RBSA Distribution of Technologies between Interior and Exterior Applications

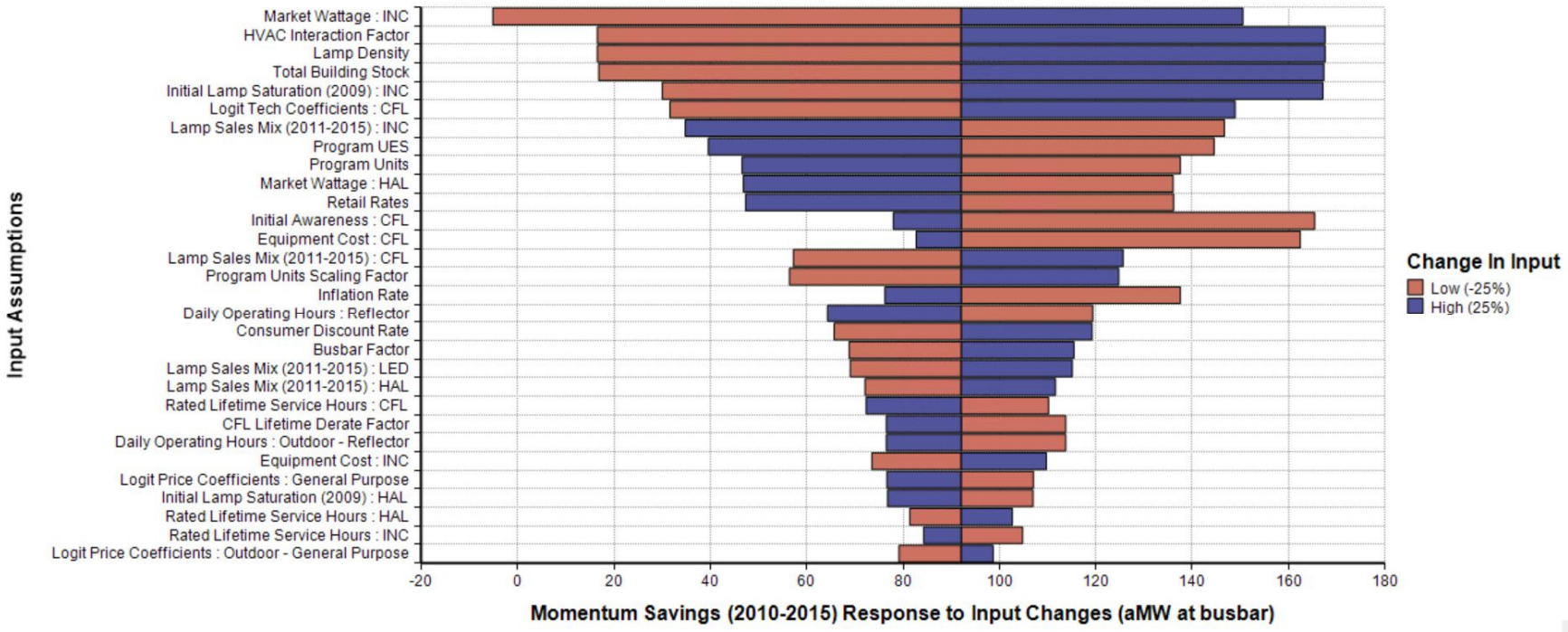
Technology	General Purpose		Reflector	
	Interior	Exterior	Interior	Exterior
Incandescent	60%	62%	54%	51%
Halogen	0%	0%	27%	37%
Compact Fluorescent	39%	37%	20%	12%
LED	1%	1%	0%	0%

Source: Research team analysis of RBSA lighting data

6. Sensitivity Analysis Findings

The research team built a sensitivity module into the model to assess the effects of changing individual parameters on the overall results. Figure 11 summarizes the effect of increasing and decreasing parameters by 25%, with results ranked from the most to least effect on momentum savings. These results are approximate as the model does not recalibrate every time an input changes; thus, for example, while CFL cost and logit parameters affect results, changes to these inputs could also result in unrealistic sales mixes. Some parameters, such as lamp wattages, hours of use, and stock and sales mixes—may be worth additional research. Others, such as the stock size, are already well-researched. Calibration parameters are difficult to inform through primary or secondary research: the team has included them in the sensitivity analysis for context, but the best gauge of whether the calibration parameters are reasonable is review of the sales and stock alignment with existing data. Unsurprisingly, two of the inputs with the largest effect are those that drive the size of the market: lamp density and building stock. Other important factors include lamp wattages, which drive total consumption and savings, and the HVAC interaction factor, which is a multiplier directly affecting savings.

Figure 11: Ranked Sensitivity Diagram



Source: Residential Momentum Savings Model