LED Incremental Cost Study
Overall FINAL Report

February 2016

Prepared for:

The Electric and Gas Program Administrators of Massachusetts

Part of the Residential Evaluation Program Area

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Executive Summary

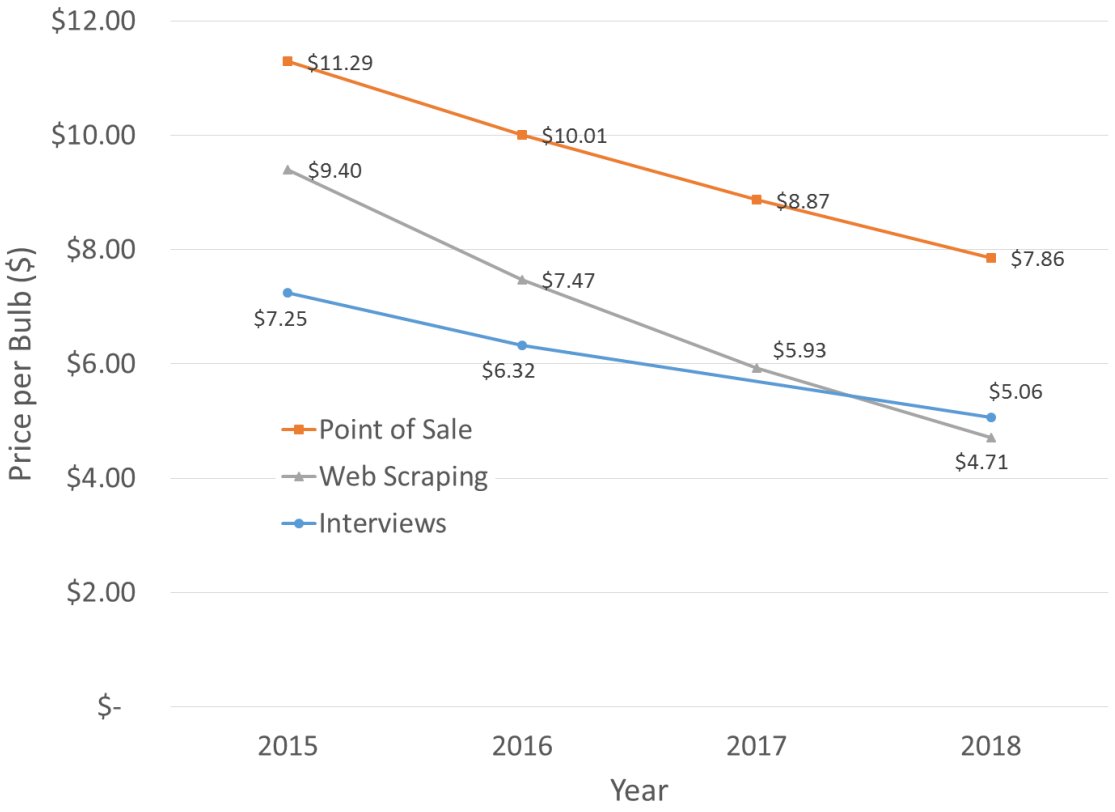
This report prepared for the Program Administrators (PAs) of the Massachusetts Residential Lighting Program and the Energy Efficiency Advisory Council (EEAC) Consultants presents the methods and findings from three separate exercises or approaches designed to develop near-term future prices of residential lighting technologies through the year 2018 with the purpose of understanding the incremental bulb purchase cost of light-emitting diodes (LEDs) relative to compact fluorescent lamps (CFLs) and halogen bulbs (with additional extrapolations through 2020 included in Appendix A). The three data sources used for various extrapolations are 1) in-depth interviews with suppliers and high-level retail buyers (supplier/retailer interviews), 2) a regression assessment based on historical point-of-sale (POS) pricing data, and 3) an exponential regression analysis based on web-scraping data. Preliminary results of the supplier interviews and web-scraping exercises also informed the separate Lighting Net-to-Gross Study, specifically the development of prospective NTG ratios for 2016 to 2018, as described under separate cover.[1]

Figure 1 shows projected average prices for an LED A-line bulb using each of the three approaches for the period from 2015 through 2018.[2] This figure shows all three approaches project a decline in cost per bulb relative to 2015 prices. A major difference between the extrapolations, stemming from the different data collected and market areas included in the analysis (described in more detail below), is the starting price per bulb. The POS and interview techniques both show similar relative declines in price, while the web-scraping forecast shows a more aggressive price decline over the period examined.

1 NMR, Cadmus, and DNV-GL. 2015. *Multistage Lighting Net-to-Gross Assessment: Overall Report FINAL.* Delivered to the PAs and EEAC Consultants, August 2015.

2 The three methods in this study looked at general service, non-specialty A-line LEDs, CFLs, and halogens, the supplier interviews and web scraping methods also looked at reflector LEDs, CFLs, and halogens.

Figure 1: Projected Average Price per Bulb for LED A-Line bulbs, by year and data source



The Evaluation Team (the Team) conducted the supplier interviews in March and April of 2015; interviewees were representatives of bulb manufacturers and large-scale bulb buyers (for retail distribution chains). The Team asked interviewees to project average retail prices for several time-points through 2020 and to provide reasons for the price changes they projected. Interviewees were also asked to project relative market shares of several bulb technology types from 2015 to 2020 under two scenarios, with and without the Massachusetts ENERGY STAR Lighting Program, and to provide reasons for their predictions. Average price and market share responses are reported here, as well as the distribution of reasons cited for each. The rationale for interviewee projections are included to provide the reader with a deeper understanding of the forces that drive the forecasted changes in the lighting marketplace and of potential deviations from the forecasts, should market circumstances change relative to the identified interviewee rationales cited.

The POS regression exercise is based on historical pricing data purchased through a third-party market monitor. The Team engaged in a data cleaning process designed to limit the database to general service bulbs, which represent the most common lighting applications (i.e., eliminating applications such as nightlights, bug lights, and appliance lights), and then modeled the prices of bulbs (operationalized as price per watt) in states that did not have residential energy-efficiency LED program incentives in place between 2009 and 2014, the period covered by the historical data. The Team limited the analysis to general service, non-specialty LED, CFL, and halogen bulbs and non-program states to best represent a

"pure" market scenario so price changes do not include impacts from energy efficiency programs. These data were used to generate technology-specific time-trend coefficient estimates using a log-linear multivariate regression (described in more detail in the Point-of-Sale methods section of the report). Those coefficient estimates were then used to project prices for each technology type through 2020.

The third method used a regression technique based on price data gleaned from a web-scraping algorithm that enables remote collection of in-store pricing information. Data were collected for locations in the Natick and/or Framingham regions, as well as Washington, D.C., which has characteristics similar to those of Massachusetts (see Appendix B on the selection of Washington, D.C.). The resulting data set of historical bulb prices is extensive, but it also displays a significant amount of price variation. Specifically, most of the light bulbs are concentrated at lower prices, but a few are priced significantly higher. Since LEDs have a wide range of characteristics and pricing and are a rapidly changing technology, the Team concluded that using an unweighted average for calculating typical price would lead to inaccurate estimates. The ideal statistic would be a sales-weighted average, but since the web-scrape data do not provide insights on relative sales, this is not possible. Therefore, following findings from existing empirical literature, typical historical purchase prices were estimated using the 25th percentile of the web-price distribution since it is more robust and less sensitive outlier effects. The trend in these prices was extrapolated forward using an exponential function to generate forecasted prices.

Each of the three approaches presented has relative strengths and limitations.

- The ***supplier interview*** approach creates estimates that are relevant to the geographical area of interest and represent the expectation of experienced professionals with an interest in this particular market. However, this approach may be subject to the biases and opinions of the particular interviewees.
- The ***POS*** extrapolation relies on actual sales and price data collected from retailers between 2009 and 2014; however, the data set lacks representation of the hardware and home improvement channels—retailers that sell numerous LEDs and other bulbs. Likewise, the limitation of the model to non-program states may introduce biases related to systematic differences in program vs. non-program markets (e.g., economic, social, demographic, and cultural).
- The ***web-scraping*** work uses actual pricing data drawn from Massachusetts and a similar market, but utilizes a proxy approach to estimate sales-weighted pricing values.

The Team presents the results of all three approaches to give the reader the most robust, triangulated understanding of the projected market trends, drawing on the strengths and limiting the weaknesses of each approach.

Figure 2 shows projected prices for A-line LED bulbs in terms of the decline from 2015 prices for each of the extrapolation approaches. By normalizing the 2015 starting price per bulb, the change in trends becomes more readily apparent. In this figure, the POS and supplier interview approaches show very

similar relative price decline trends over time, while the more aggressive price reduction developed by the web-scraping method stands in contrast.

Figure 2: Projected Price Decline for LED A-Line bulbs relative to 2015, by year, data source

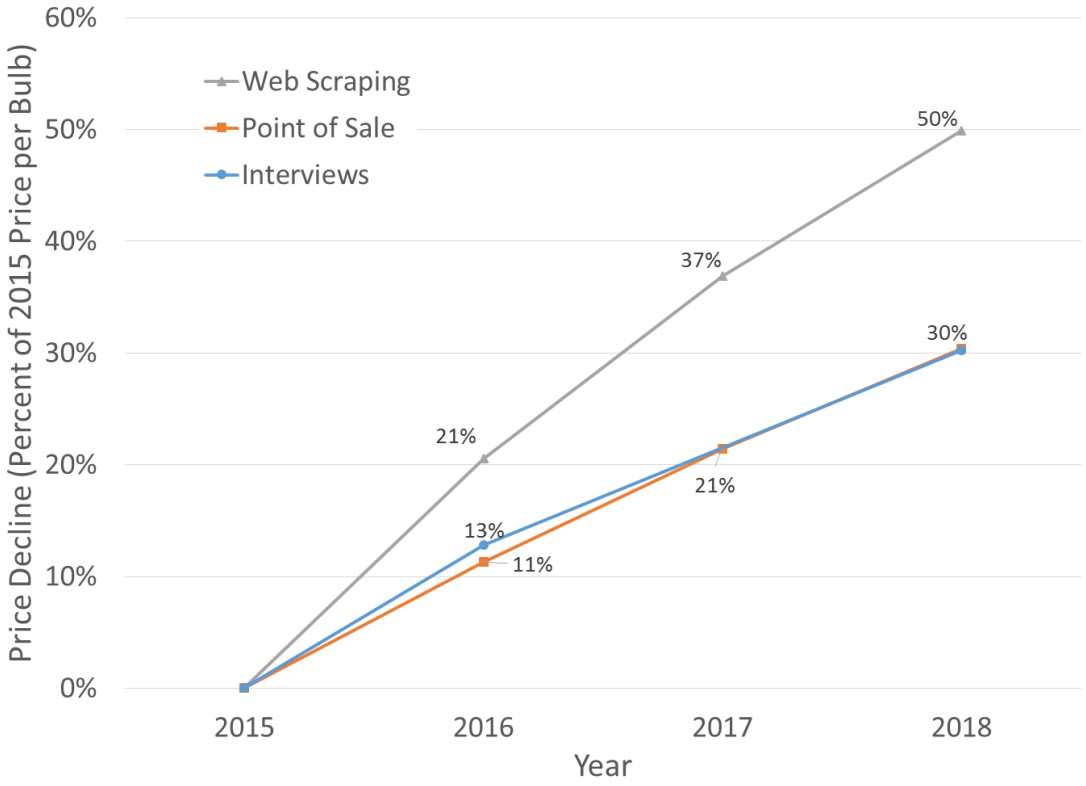


Figure 3 shows each approaches' future prices for each of several bulb types—technology and shape—in 2015 and 2018 (the POS method combines bulb types per contractual agreement with the third-party source). Table 1 displays the predicted incremental cost of LED bulbs compared to CFL and halogen bulbs from 2016 to 2018, which correspond to the next program cycle. The price of LED bulbs drops in all cases between 2015 and 2018, both in absolute terms as well as relative to the price of comparable CFL and halogen bulbs. Yet, the methods also exhibit some important variations. The POS trend suggests that a substantial price premium remains from 2016 and 2018 between LEDs and other bulb types, but the other two data sources suggest smaller incremental costs. The variations in extrapolated prices and incremental costs reflect the nature of the data used in each method as well as their relative strengths and weaknesses. Of particular note is the fact that the POS data combine prices for A-line and reflector bulbs and are limited to prices in states currently lacking LED programs. The other two methods were able to separate A-line from reflector bulbs, but only the web-scraping approach attempted to limit price estimates to non-program-supported bulbs. However, while the web-scraping approach provides estimates for non-program-supported bulbs, these do include both ENERGY STAR and non-ENERGY STAR qualified products.

Figure 3: Relative Bulb Price Predictions in 2015 and 2018, by bulb type and data source

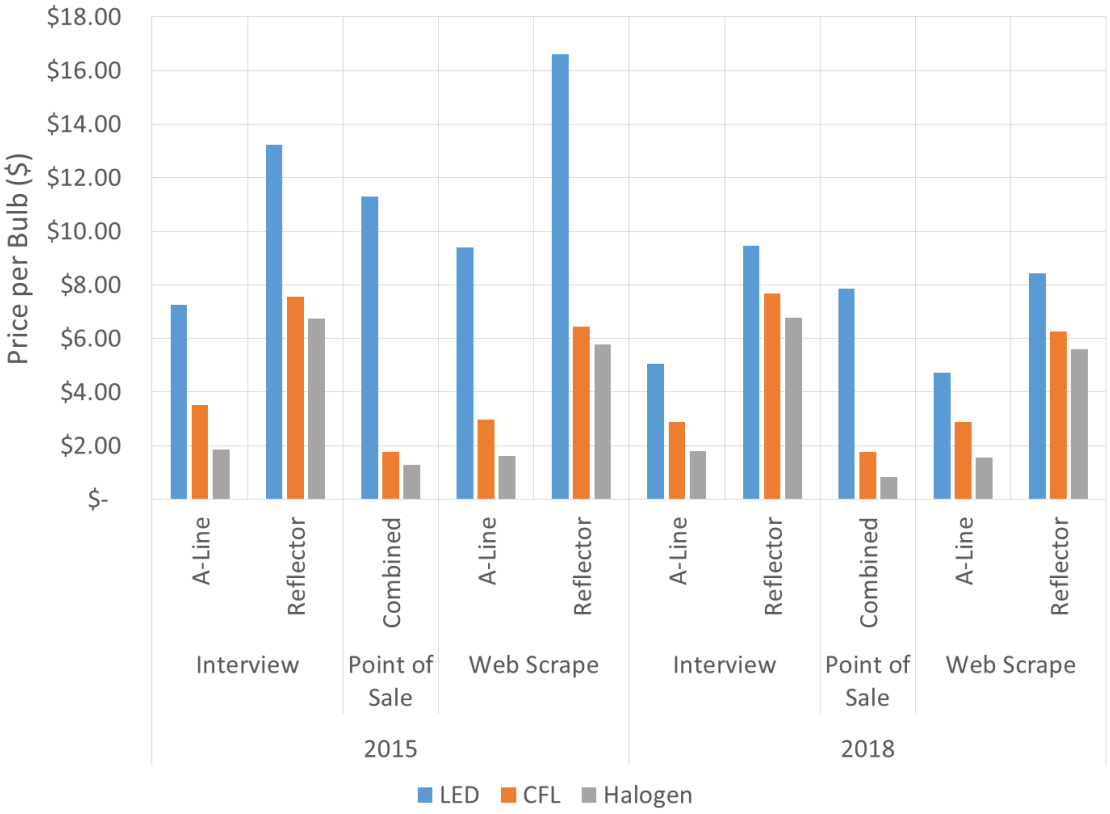


Table 1: Predicted incremental purchase cost of LED bulb compared to selected bulb technologies, 2016 to 2018

Approach	Product	2016	2017	2018
Interviews	CFL A-Type	$3.07	-	$2.19
	CFL Reflector	$4.43	-	$1.78
	Halogen A-Type	$4.49	-	$3.26
	Halogen Reflector	$4.87	-	$2.69
Point of Sale	CFL, generic	$8.23	$7.09	$6.09
	Halogen, generic	$8.90	$7.90	$7.02
Web-Scraping	CFL A-Type	$4.52	$3.01	$1.82
	CFL Reflector	$6.86	$4.23	$2.16
	Halogen A-Type	$5.87	$4.34	$3.14
	Halogen Reflector	$7.53	$4.89	$2.81
Average of Predicted*	CFL A-Type	$5.27	-	$3.37
	Halogen A-Type	$6.42	-	$4.47
* Includes "generic" category from POS modeling, as most bulbs in the dataset were A-type.				

Conclusions, Recommendation, and Consideration[3]

All three incremental cost methods predict that LED prices will continue to decline. The magnitude of decline varies by method; interviews and POS suggest a 30% decline in estimated prices between 2015 and 2018, and web-scraping estimates a 50% decline in price relative to 2015 by 2018. There was also a large spread in the estimate of starting LED prices ranging from $11.29 to $7.25 (in 2015). The variance in price decline might be attributed to the different distribution channels and associated data that are available within each incremental cost method. The web-scraping approach draws published bulb prices from home improvement and hardware retail channels because grocery stores and similar channels do not offer online retail options. Conversely, the majority of bulbs considered in the POS model were those offered in grocery and drug stores because most big box channels are not includes in the POS data. These factors considered together mean that the data do not provide clear guidance on selecting a single incremental cost for the program years 2016 to 2018. These findings lead to the following recommendation and considerations.

Recommendation 1: Due to the various strengths and weaknesses of the data sources used and the variation in the extrapolations, the Team **recommends** using the range of incremental price values for 2016 to 2018, as shown in Table 1, to inform program planning. Any sort of future price predictions extrapolated from historical price data in the context of a quickly changing lighting market will be subject to high levels of uncertainty, and the team recommends caution when considering these predicted values.

Consideration 1: If program planners or other parties find that they need a point estimate, the Team believes they should **consider** selecting either the mean (i.e., $3.37 as the incremental cost of A-line LEDs compared to CFLs in 2018).

Consideration 2: If quarterly POS data become available, the Team suggests **considering** having more frequent quarterly updates in the POS and web-scraping outlooks to match the rapidly evolving nature of the lighting marketplace.

[3] This study captures the pricing trends of various types of bulbs sold in retail locations and is not exclusive to the specific bulbs supported by the PAs during a given year. Therefore, as part of the 2016-2018 Demand Side Management (DSM) plan, the average year-to-year percentage decline was used to estimate the incremental cost of PA supported bulbs, instead of the specific incremental costs that were estimated in this study. The plan is available at: http://ma-eeac.org/wordpress/wp-content/uploads/Exhibit-1-Gas-and-Electric-PAs-Plan-2016-2018-with-App-except-App-U.pdf.

Introduction

This report presents the methods and findings from three separate exercises designed to provide estimates of projected prices of residential lighting technologies through the year 2018 with the purpose of understanding the incremental cost of light-emitting diodes (LEDs) relative to compact fluorescent lamps (CFLs) and halogen bulbs. The report was prepared for the Program Administrators (PAs) of the Massachusetts Residential Lighting Program and the Energy Efficiency Advisory Council (EEAC) Consultants by the Residential Evaluation Team ("the Team") led by The Cadmus Group, with NMR Group, DNV-GL, and Navigant performing the research. The approaches described here use three different data sources. The techniques for extrapolations and data sources are 1) in-depth interviews with suppliers and high-level retail buyers (supplier interviews), 2) a regression model using historical point-of-sale (POS) pricing data, and 3) an exponential regression analysis based on web-scraping data.[4]

Study Goals and Objectives

The goal of this study is to estimate the likely incremental costs for LEDs when compared to halogen bulbs and CFLs in 2016 through 2018. The study examines trends for A-line, medium screw-base bulbs as well as reflectors.

Specific objectives include the following:

- To query lighting manufacturers (including product developers) and high-level buyers of lighting products for major retailers ("high-level buyers") about future price trends of LEDs, CFLs, and halogens
- Test 3 ways in which to generate extrapolated estimates of near-future prices and incremental costs.
- To understand manufacturer and high-level buyer predictions of market share for various lighting products in the presence and absence of Massachusetts program incentives

Table 2 summarizes the activities described in this report.

[4] Preliminary results of the supplier interviews and web-scraping exercises also informed the development of prospective net-to-gross ratios, as described in NMR, Cadmus, and DNV-GL. 2015. *Multistage Lighting Net-to-Gross Assessment: Overall Report.* Final delivered to the PAs and EEAC Consultants August 2015.

Table 2. Evaluation Activities

Activity	Method
Supplier Interviews	The Team conducted interviews with manufacturers (including product developers) and retail buyers to gain insights into bulb pricing trends and forecasts and predictions of market share.
Point Of Sale (POS) Data Modeling	The Team used the 2009 to 2014 LightTracker dataset. Regression models were developed using prices and time to determine pricing trends for LEDs, CFLs, and halogens bulbs. These were then used to extrapolate to future price estimates.
Web-Based Price Modeling	The Team used the data obtained through a web-scraping effort to model pricing trends for LEDs, CFLs, and halogens bulbs and extrapolate to price estimates for 2016-2018.

Study Approaches, Methods, and Analysis Procedures

Supplier Interviews

The Team conducted in-depth interviews with 20 lighting manufacturers and six high-level retail buyers (buyers of lighting products for large retail chains) who supplied or sold light bulbs through the 2014 Massachusetts ENERGY STAR Lighting Program.[5] These interviews were completed from March to April 2015. The purpose of these interviews was to gain respondents' insights into past, current, and future price trends and market shares for these bulbs. The Team spoke with representatives involved in shipment, sales, and upstream program participation as well as those with knowledge of LED product development.

During the interviews, manufacturers and retail buyers predicted average Massachusetts retail prices for 2015, 2016, 2018, and 2020 for CFLs, LEDs, halogens, and incandescents and gave supporting reasons for their price predictions. In order to ensure obtaining the most reliable information, information from knowledgeable individuals, the Team only allowed the manufacturers and retail buyers to make price predictions for lighting products that they sold.

Because we were asking the lighting manufacturers and retail buyers to provide price predictions for a wide variety of lighting products and time periods, in order to avoid respondent fatigue we were not able to double the number of predictions by asking them also to provide a separate "with/program" and "without/program" price prediction for each bulb type and time period. So these price predictions incorporate whatever assumptions the lighting market actors might have had about the Massachusetts lighting program's future design, levels of spending and rebate levels.

Yet the interviews did give the lighting market actors some opportunities to assess the magnitude of program influences over future bulb price trends. First, the interview guide asked the lighting market actors to explain their price predictions and this gave them the opportunity to cite program influences, as some of them did. Second, we also asked lighting manufacturers and retail buyers to predict average Massachusetts market shares for both standard spiral/A-line and reflector lamps (LED, CFL, halogen, and incandescent) under two hypothetical scenarios. In the first scenario, the Massachusetts ENERGY STAR Lighting Program continues to offer CFL and LED incentives for A-line or reflector lamps through 2020. In the second scenario, the Massachusetts ENERGY STAR Lighting Program ends incentives for CFL and LED A-line and reflector lamps in 2015. Respondents gave market share estimates for 2014 and then

[5] Although these interviews only focused on participating manufacturers, evidence from past lighting market characterization studies as well as shelf survey data have found that these participating manufacturers also account for the vast majority of non-program sales. While the price predictions of the participating retail buyers may not represent the views of all Massachusetts retailers, they do represent the perspectives of the highest-volume lighting retailers in the state. In addition, many smaller retailers lack the broader market knowledge to make informed predictions about future price directions.

predictions for each year from 2015[6] to 2020. Manufacturers and retail buyers also were asked to describe the reasoning for their market share predictions, including program impacts on bulb prices. All respondents were allowed to make market share predictions for all bulb types even if they did not manufacture or sell all three types.

The Team developed average retail price predictions and market share predictions for CFL, LED, halogen, and incandescent lamps from the interview responses. In order to appropriately take responses to a market-level total the evaluators used the lighting market actors' 2014[7] CFL and LED sales through the Massachusetts program to weight their price and market share predictions for these bulb types. This could not be done for interviewee market share predictions for halogen and incandescent bulbs because the program does not rebate these lamp types, and therefore there was no program tracking data to use for weights. In addition, the evaluators did not have information on the lighting market actors' halogen and incandescent sales. So for the halogen and incandescent price predictions a straight average of the prices estimates was calculated, with no attempt to weight these predictions.

Point-Of-Sale (POS) Data Regression Modeling

The POS data were purchased through LightTracker, an initiative of the Consortium for Retail Energy Efficiency Data (CREED), and represent bulb sales data captured at the POS for select retail channels for 44 states across six years (2009-2014). The primary variable for this project is the retail price by bulb type. The price is the final retail price which would include any price changes due to upstream incentive programs. In order to examine price changes for time trends the price analyzed could not include the incentives. Therefore, the Team addressed this by using the detailed POS data to model the impact of time on LED, CFL, and halogen pricing in 16 states without active LED residential lighting programs through 2014 (see Table 3 below).

A shortcoming of the price data is the absence of home improvement and hardware retail channels, both of which can account for substantial light bulb sales in Massachusetts and many other states. In prior research, it was estimated that the POS data capture roughly one-quarter of market-level sales in Massachusetts, and consumers very often name hardware and home improvement stores as the source of recently purchased bulbs.[8] Therefore, the extent to which the results of the current effort reflect bias that limits their generalizability depends on the *unknown* difference in the concentration of LED sales in

[6] 2014 values were predictions, not actual market shares. Evaluators obtained actual market shares for 2013 and asked respondents to predict for 2014 to 2020.

[7] First three quarters of 2014

[8] NMR Group, Cadmus Group. 2015. *Results of the Massachusetts On-site Lighting Inventory, 2014.* http://ma-eeac.org/wordpress/wp-content/uploads/On-Site-Lighting-Inventory-Final-Results.pdf

reporting and non-reporting channels in the 16 non-program states compared to the excluded program states.

POS Data Cleaning

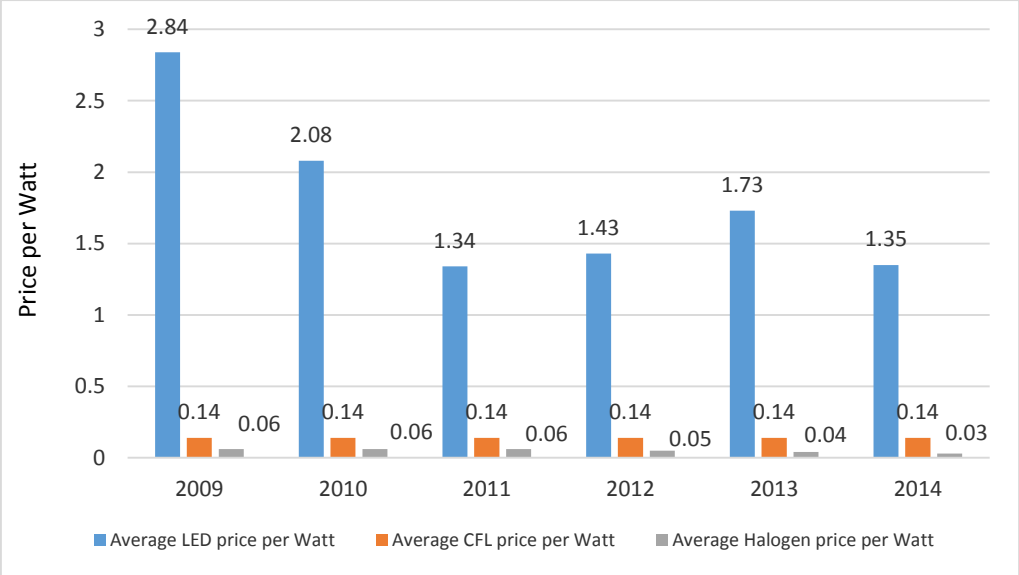
The Team cleaned the POS data in order to refine the data set to reflect typical lighting purchases. A key step was removing certain types of specialty bulbs, which included nightlights, appliance lights, aquarium lights, black lights, bug lights, string lights, and flashbulb lights. The Team also eliminated possible data reporting errors (in the original third party data) by inspecting price per bulb and bulb count per package; when either of these values was abnormally high or low, the Team used the more detailed bulb description to identify whether the data were erroneous.[9] All records that did not have price information were dropped, and proven bulb count per package errors were corrected.[10] Lastly, the Team cleaned the data of outlier prices (e.g., extremely low or extremely high prices), even if these were not believed to be erroneous. The Team identified outliers as bulbs with prices that were more than six standard deviations from the mean bulb price of each bulb type (the data included records for bulb prices that were up to nine standard deviations greater than the mean price of a particular bulb type).

Importantly, while CFL prices varied little over time and halogen prices declined rapidly, the price of LEDs counterintuitively increased for much of the study period. Also, LED program support did not start in earnest until about 2013 and 2014, meaning that we would not expect dramatic differences between program and non-program state LED pricing until 2013 or 2014. During the course of the data cleaning process, the Team found that the increase in average LED prices was being driven by increased Wattage per bulb. In response, the Team normalized the bulb prices by taking the ratio of average price per bulb to average Wattage. Figure 4 plots the average price per Watt for each technology by year; this graph shows that the average price per Watt declines for halogen bulbs, remains steady for CFLs, and declines overall for LEDs though the LED price per Watt does bounce around quite a bit.

[9] An example of an abnormal bulb count and price per bulb might be a record of 100 LED bulbs per package with the price per bulb being $0.10 per LED—in such a case, the Team would use the model description to look up the bulb and find that the bulbs in question are actually string lights. A bulb count of three LED bulbs per package at a price of $10 per bulb would not merit further investigation.

[10] The Team identified extreme bulb per package values and, when we were able to use the bulb description to look up and identify a bulb per package error, we corrected the value in the data set.

Figure 4. Price per Watt by Bulb Type and Year in non-LED Program States



POS Program Activity

The Team used non-program states only in the models for two reasons, the first of which is to exclude program-subsidized prices in our forecasts—and the only way we can be sure that our data do not include subsidized bulbs is by eliminating states with active LED programs. This is also an advantage of this approach over the supplier interview efforts, in which respondents were not asked to provide predictions for prices in the presence and absence of the program (although they did provide this differentiation in their estimates for market share). By eliminating states with active LED programs from the analysis, we ensure that we do not bias the data and subsequent analysis. The second reason for estimating a non-program model is to provide estimates of future bulb price without program support. The presence of an LED lighting program therefore was a key aspect of research. The Team utilized and updated the program research conducted during the 2015 Massachusetts Saturation and Stagnation study to determine whether a state has supported residential LEDs at any point during the 2009-2014 period. If a state did support residential LEDs at any time during the analysis period, it was considered a "program state" and excluded from the non-program models. There were 16 states without active LED programs during the analysis period that were included in the models; note that some of these states did have CFL programs or commercial LED programs (Table 3).

Table 3. States without Active LED Residential Lighting Programs from 2009-2014

Alabama	Indiana	Mississippi	Tennessee
Florida	Kansas	Nebraska	Utah
Georgia*	Kentucky	Ohio	Virginia
Idaho	Louisiana	South Dakota	West Virginia
Georgia Power had a mail-in rebate LED program in 2014 a less aggressive program than the buy down programs in other program states, Georgia will not be considered a non-program state after 2014.			

POS Price Regression Models

In order to extrapolate price out to 2018 (and to 2020, in Appendix A), the Team estimated a series of state-level fixed-effects panel regression models using a time and bulb type interaction variable to estimate the average price per Watt. All parts of the interaction term were included in the model so as to not bias the estimate. The fixed-effects model estimates bulb price as a function of time and bulb type. The regression uses the natural logarithm of average price per Watt as the dependent variable in order to estimate a log-linear model under the assumption that the relationship between price and time is not linear. The regression form used is as follows:

$$\log(Average\ \ Price\ per\ Watt_{it}) = \beta_1(T_{it}) + \beta_2(BulbType_{it}) + \beta_3\big((T_{it}) * (BulbType_{it})\big) + \delta_i + \varepsilon_{it}$$

Where:

log(Average Price per Watt)= Natural logarithm of the State average annual price per Watt by type *i* and year *j*.

$T_{i,j}$=T=Year-2008

$BulbType_{i,j}$=Categorical classification of bulbs (1=LED, 2=CFL, 3=Halogen) with LED as the reference type—meaning that every bulb type coefficient is being compared to the LED. For example, if the CFL coefficient for bulb type is -2.77, it is referencing LEDs—it means that the CFL is $2.77 less than an LED.

$T_{i,j}$*$BulbType_{i,j}$=Interaction between bulb T and BulbType

δ_i =State fixed effects that capture time-invariant state specific fixed effects in average bulb price.

$\epsilon_{i,j}$ = Error term clustered by state.

The Team presents the 2009-2014 model results in Table 4, while we discuss the implications for price projections in the Results section that follows. The model shows that time was a significant predictor of price per Watt by bulb type. By adding additional years of data, we were able to decrease the standard error around the estimates and increase the precision of the coefficients (2009-2012 and 2009-2013

models are described in detail in Appendix E). The 2009-2014 model shows a close fit between the explained variance (within R-squared) and the explained variance due to independent variable impact on the dependent variable (adjusted R-squared. The accurate price per Watt predictions, reduced standard error, compared to 2009-2012 and 2009-2013 models, and high R-squared values, indicate that the 2009-2014 model is preferred over the 2009-2012 and 2009-2013 models.

Table 4. Price Forecast Models

Variables	2009-2014
Intercept	0.97 (0.04)
CFL* T	0.12 (0.01)
Halogen* T	-0.02 (0.01)
CFL	-2.95 (0.04)
Halogen	-3.50 (0.04)
T	-0.12 (0.01)
Additional Details	
Number of States	16
Number of Observations	288
Within R-squared	0.989
Adjusted R-squared	0.988

Web-Scraping

Web-scraping is a technique used for extracting information from websites, thereby transforming unstructured data on the web into structured data that can be stored and analyzed. The approach has been previously used to forecast LED prices. For example, Lawrence Berkeley National Laboratory (LBNL) recently used the approach to estimate price trends for LEDs.[11,12] The Team employed the web-scraping software WebHarvy to collect LED pricing and performance specification data automatically from online retailers. The WebHarvy tool enabled us to remotely collect in-store pricing information from Home Depot, Lowe's, Walmart, and Ace Hardware locations in the Natick and/or Framingham region, as well

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

12 The web-based price data collected by LBNL comes from both online only and home improvement retailer websites. The majority, 85%, was collected from online only retailers such as Amazon, 1000bulbs.com, etc. which only offer non-incentivized LED bulbs. The remaining 15% came from home improvement websites such as Home Depot, Lowes, etc.

as from retailers including Best Buy, Target, Grainger, 1000bulbs.com, Amazon, BulbsAmerica.com and ProLighting.com, which do not offer locational pricing on their websites. Once these data were collected, the following three-part methodology was used to conduct a price regression and incremental LED cost analysis for Massachusetts:

1. Clean all LED, CFL, halogen and incandescent data by correcting any errors in the pricing and specifications collected via the web-scraping tool. This also includes cross-referencing product model numbers to remove any obvious rebates.
2. Compare the locational pricing data collected at big box retailer locations in Massachusetts to in-store pricing data collected for the Washington, D.C., metropolitan area. This will confirm whether historical locational LED pricing data for the Washington, D.C., metropolitan area is similar to Massachusetts and can be used as a proxy.[13]
3. Construct price trends using historical web-based data, supplement with current Massachusetts prices, and develop regression analysis expected to be used in forward-looking estimates of price for the residential lighting product.[14]

Web-Scrape Data Cleaning

The web-scraping tool automatically collects pricing and specification data and organizes it into spreadsheet form. However, in order to maintain high data quality, the web-scraped data must be thoroughly checked and cleaned, as this is essential to producing robust regressions of product price. In order to correct for any organizational issues and errors in the pricing information, several queries are run to ensure that products are classified in the correct technology (LED, CFL, halogen, and incandescent) and product category bins (A-type, candle/flame, globe, etc.). In addition, we make an effort to remove utility rebates for LEDs and CFLs in both Massachusetts and Washington, D.C., offered at the big box retailers such as Home Depot, Lowe's, Walmart, and Ace Hardware. To do this, the model numbers of LED and CFL products are cross-checked at each location and are also compared to prices offered via online retailer websites such as 1000bulbs.com, Amazon, BulbsAmerica.com, and ProLighting.com.

Web-Scrape Washington, D.C., Metropolitan Area and Massachusetts Price Comparison

The Massachusetts web-scraping effort gathered a total of 1,014 LED bulb price points in Q1 2015, as well as 515 for CFLs and 818 for halogen and incandescent bulbs. Prior to this data collection effort, the Team had available pricing data for the Washington, D.C., metropolitan area (D.C.). The ability of the web-scraping approach to develop and extrapolate price trends hinged on the comparability of Massachusetts and D.C. LED price data. The Team examined whether the 2015 D.C. data were comparable to the Massachusetts data, and concluded that the data were very comparable (see

[13] To be clear, Washington, D.C., is *not* being used as a non-LED-program comparison area; instead, it serves as a proxy for Massachusetts, increasing the sample size available for the regression analysis.

[14] This price analysis only utilized pricing data collected using web-scraping tools, no additional pricing data sources such as in-store incentive offerings (which are not available through web-scraping tools) were used.

Appendix B), and that conducting the web-scraping regression and extrapolation using the combined Massachusetts and D.C. data was appropriate.

Specifically, the Team conducted t-tests to determine whether it is reasonable to assume that price data for the Washington, D.C., metropolitan area and Massachusetts are comparable, since there are no LED lamp categories for which the difference in mean price is significant at the 95% level of confidence (alpha = 0.05). Detailed results of the hypothesis testing and sample size are provided in Appendix C. Combining the Washington D.C. and MA pricing data allowed for a total analysis dataset of 1,628 price points for LED A-Type, 841 for Candle/Flame, 384 for Globe and 5,158 for reflector lamps.

Web-Scrape Price Regression Approach

In order to compute a regression of the web-scraped pricing data, we first needed to select a statistic to characterize the time series data. This is critical to ensure that forward-looking predictions adequately characterize the typical purchase price for each point in time. Using an unweighted average price would lead to inaccurate estimates, since LEDs are a rapidly changing technology and have a wide range of performance and pricing. The ideal statistic would be a sales-weighted average, but since the web-scraped data does not include insights on relative sales, this is not possible. For a recent LED web-scraping analysis, LBNL conducted a consumer survey, finding that more than 80% of respondents purchased a lamp at or below the 25th percentile price, and more than 90% purchased at or below the median price. From the survey, LBNL concluded that the mean and median are volatile metrics that represent the tail of the purchase distribution, and that the 25th percentile of their web-scraped data best represents the characteristic price for LED lamps. Based on this assessment, we determined that the 25th percentile is sufficient to characterize the typical purchase price for LED lamp types.[15] For consistency the 25th percentile was also used for CFL, halogen, and incandescent lamp types. This assumption for CFL, halogen, and incandescent lamp types is based on the residential consumer preference for lower priced product, and that there was no evidence to support the use of an alternative statistic. However, this assumption could be a limitation since conventional lighting products are lower cost and typically have less price variation compared to LEDs.

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

After having computed the aggregated 25th percentile for each LED lamp type, we then fit these data to an exponential model in order to describe the overall time trends. A power and linear function were also tested with the pricing dataset; however, the Team chose an exponential function, as it produced greater R-squared values (hence better fit) for all lamp types when performing sum-of-squares minimization. In addition, LBNL also concluded that the following exponential form demonstrated the best fit for their regression analysis of LED web-scraped pricing data.

$$P(y) = e^{-\propto(y)}$$

Where $P(y)$ is the predicted LED lamp price;
$\propto$ is the fractional annual rate of price decline;[16] and
y is the year.

[16] The exponential function in its traditional decay form has a constant rate of change (1/α).

Results

Overview of Findings

All three incremental cost methods predict that LED prices will continue to decline. The magnitude of decline varies by method; interviews and POS modeling estimate a 30% decline by 2018, and web-scraping estimates a 50% decline in price by 2018. Moreover, while the estimated values of the current 2015 price and the forecasts through 2018 differ, they suggest that LED prices will remain double the current price of CFLs through the time period in question. This section also addresses suppliers' perspective on market share and the reasons for their predictions of future prices and market share for various bulb types.[17]

Supplier Interviews

This sub-section contains results from in-depth interviews that the Team conducted with 20 lighting manufacturers and six high-level retail buyers (buyers of lighting products for large retail chains) who supplied or sold light bulbs through the 2014 Massachusetts ENERGY STAR Lighting Program. Included are average retail price predictions for CFL, LED, and halogen bulbs and market share predictions for CFL, LED, halogen, and incandescent bulbs as well as a summary of supporting reasons given by interview respondents for their predictions.

Retail Price Predictions

Table 5 presents average Massachusetts retail price predictions for LED, CFL, and halogen bulbs obtained from interviews with manufacturers and retail buyers. Included are CFL and LED average price predictions weighted by lamp counts of retail sales for the first three-quarters of 2014 using program tracking data and unweighted average retail price predictions for halogens. The sample sizes in the table are smaller than the total sample (n=26) because we only allowed the manufacturers and retail buyers to make predictions for lighting products that they sold. In addition, in some cases, respondents provided reasons but not price predictions.

The table shows that lighting market actors predicted that only LED bulbs would see significant price decreases in the next five years. The table also shows that they expect covered A-line CFLs to have a modest price decline, while the price trend for other bulb types is relatively flat. We discuss the reasons for these predicted trends—which range from economies of scale efficiencies to technological factors—later in this section.

[17] In the supplier interviews, responses were solicited through 2020. This differs from what is presented for the other two extrapolation methods. In the main text of the report that follows, results of the supplier interviews are shown in full (to 2020) while the extrapolation methods are shown to the target date of 2018. The difference in reporting reflects the fact that some suppliers based their 2016 to 2018 estimates on what they assumed would happen in the 2019 and 2020 markets. Appendix A shows results of the two extrapolation methods extended beyond 2018 to 2020.

Table 5. Average LED, CFL, and Halogen Retail Price Predictions, 2015-2020

Lamp Type	2015 Sales Weighted Simple Avg Retail Price	2016 Sales Weighted Simple Avg Retail Price	2018 Sales Weighted Simple Avg Retail Price	2020 Sales Weighted Simple Avg Retail Price	n=
LEDs*					
A-line*	$7.25	$6.32	$5.06	$4.31	20
Reflector*	$13.24	$11.65	$9.45	$8.53	20
CFLs*					
Standard Spiral*	$1.66	$1.61	$1.58	$1.66	17
Covered A-line*	$3.52	$3.25	$2.87	$2.74	12
Reflector*	$7.57	$7.22	$7.67	$7.31	14
Halogens**					
A-line**	$1.86	$1.83	$1.80	$1.77	8
Reflector**	$6.75	$6.78	$6.76	$6.77	9

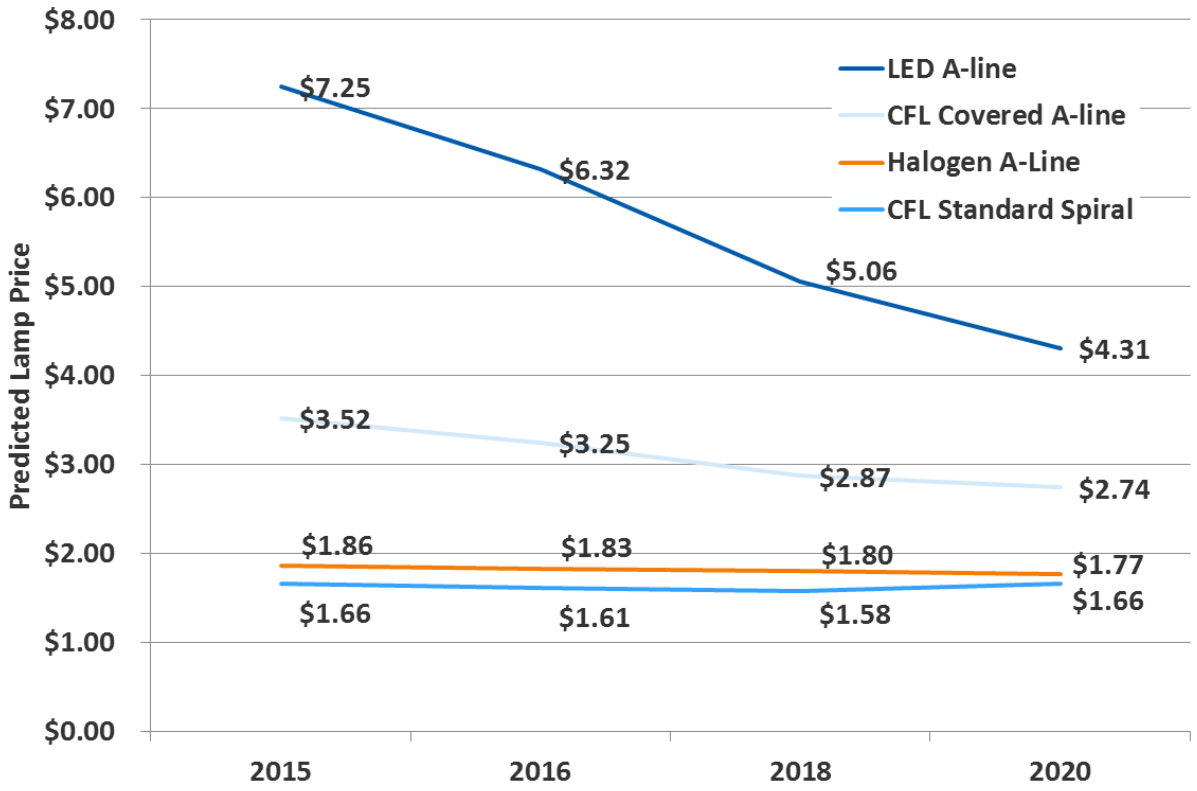
*CFL and LED market shares weighted by lamp counts of retail sales for the first three quarters of 2014

**Halogen average prices not weighted by program tracking data

Figure 5 displays the average retail price predictions for A-line/standard spiral LEDs, CFLs, and halogens from 2015 to 2020. Manufacturers and retail buyers predicted average retail prices for LED A-line bulbs will drop by 41% over the 2015 to 2020 period. Respondents also predicted a 22% drop in average retail prices for CFL covered A-lines and a 5% drop in average retail prices for halogen A-lines over the same period.

While the chart shows that the LED A-line bulbs are predicted to experience the most significant drop in price of any bulb type, it also shows that despite this steep drop, LED A-line bulbs are still expected to be significantly more expensive in 2020 than other similar bulb types. Additionally, the evaluators did not directly ask the suppliers whether they assumed that upstream lighting programs would continue when making these predictions (we did ask them to explain their predictions, and we did ask them directly about program effects for the bulb market share predictions we discuss later). Yet because upstream programs significantly discount LED prices and do not discount halogen/incandescent bulbs, if all the predictors assumed that upstream lighting programs would continue in 2020, then this chart should be depicting the narrowest possible price gap between the LEDs and the halogen/incandescent bulbs. Any predictions that assumed some cessation of upstream lighting programs would presumably show a wider gap between LED prices and halogens/incandescents due to the removal of LED subsidies. If this forecast is accurate, it suggests that some program price support for LEDs will still be needed in the future to get these bulbs into the houses of more price-sensitive shoppers.

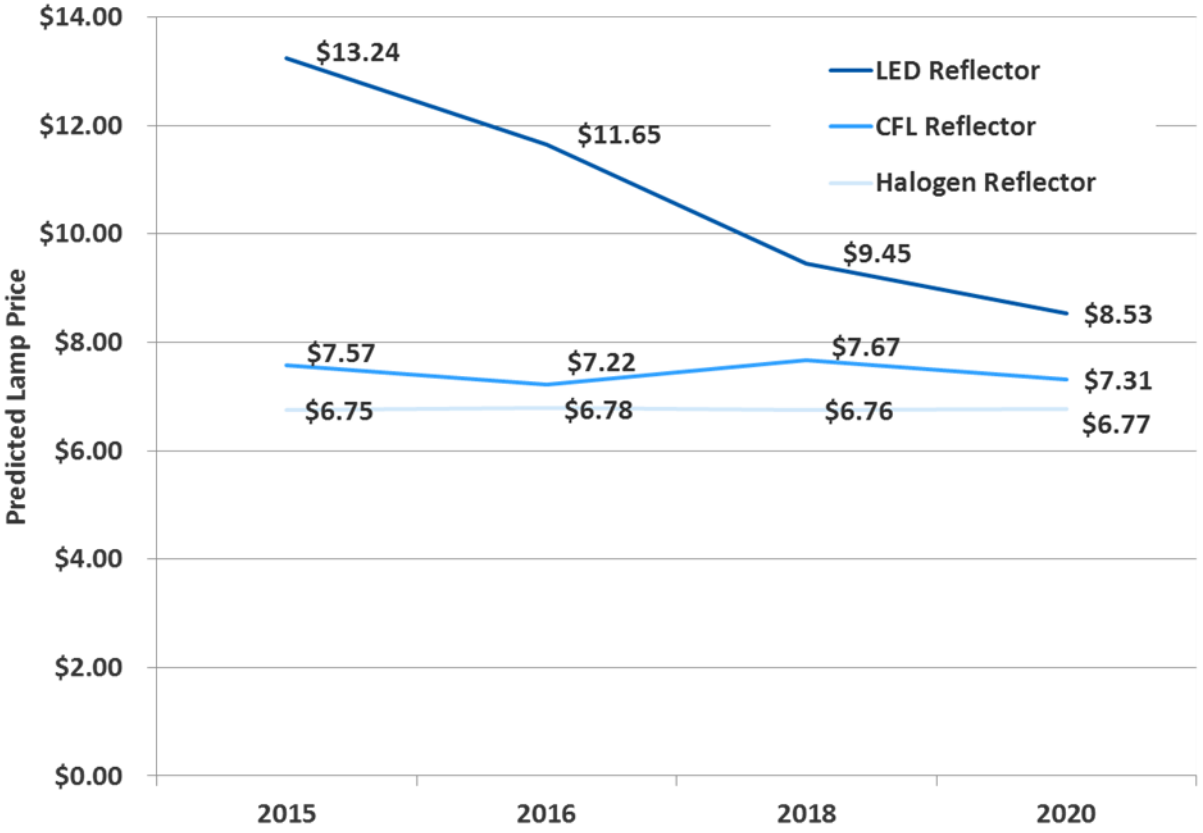
Figure 5. Average A-line/Standard Spiral LED, CFL, and Halogen Retail Price Predictions from Suppliers, 2015-2020*



* The number of estimators for the various bulb types were A-line LEDs (20 respondents), spiral CFLs (17), covered A-line CFLs (12) and A-line halogens (8). The Team only allowed respondents to provide price predictions for bulb types which they manufactured or sold. The Team weighted the CFL and LED price predictions and market shares by the respondents' Massachusetts Energy Star program lighting sales for the first three-quarters of 2014. However, it did not sales weight the average halogen prices because the program does not discount halogens and therefore there were no program tracking data available.

Figure **6** displays the average retail price predictions for LED, CFL, and halogen reflectors from 2015 to 2020. Manufacturers and retail buyers predicted that average LED reflector retail prices will drop by 36% over the forecasted 2015 to 2020 period. Respondents also predicted a slight decline (3%) in average retail prices for CFL reflectors from 2015 to 2020 and essentially no change in the average retail price for halogen reflectors during the same period. As was the case with the LED A-line bulbs, the chart shows that while the LED reflectors are expected to experience a significant price decline, the lighting manufacturers and retail lighting buyers still expected LED reflectors to remain the most expensive bulb type in 2020.

Figure 6. Average Reflector LED, CFL, and Halogen Retail Price Predictions from Suppliers, 2015-2020*



* The number of estimators for the various bulb types were reflector LEDs (20 respondents), reflector CFLs (14), and reflector halogens (9). The Team only allowed respondents to provide price predictions for bulb types which they manufactured or sold. The Team weighted the CFL and LED price predictions and market shares by the respondents' Massachusetts Energy Star program lighting sales for the first three-quarters of 2014. However, it did not sales weight the average halogen prices because the program does not discount halogens and therefore there were no program tracking data available.

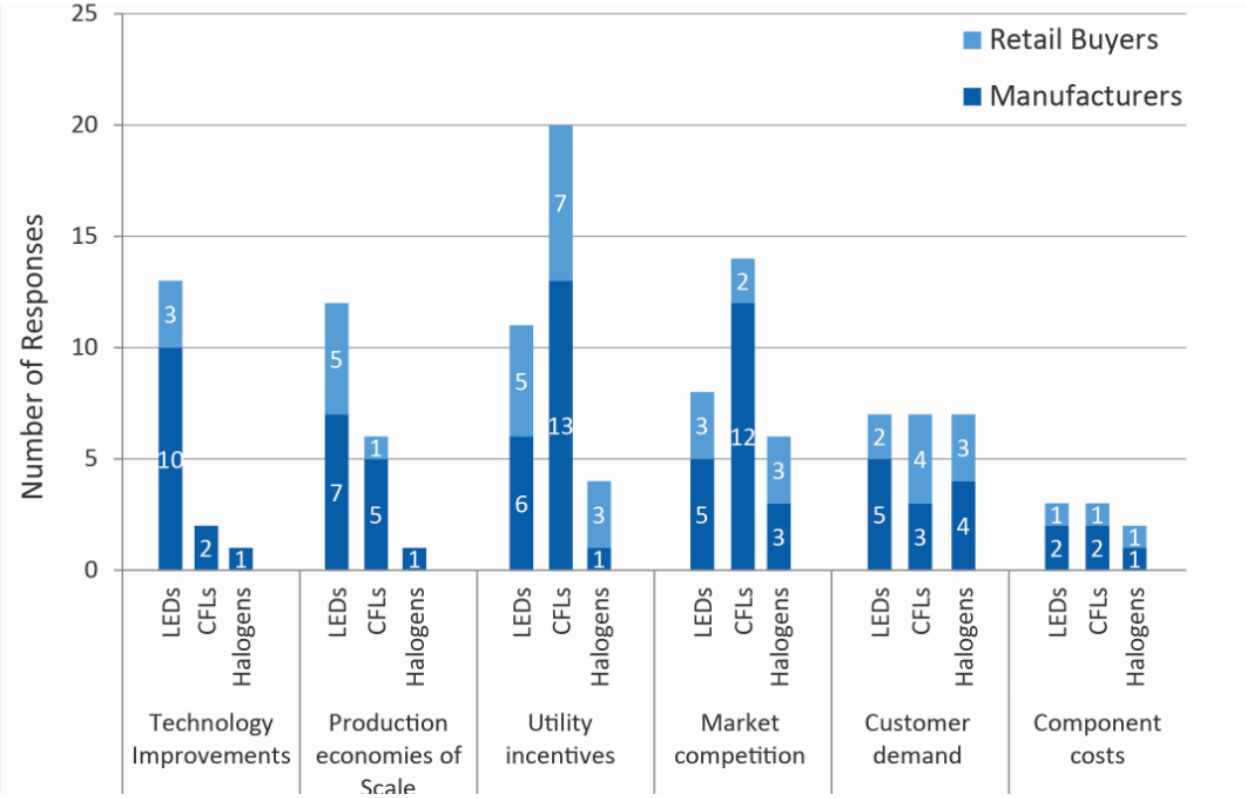
In the following subsection we present the reasons that manufacturers and retail buyers cited to support their price predictions for LEDs, CFLs, and halogens.

Reasons for Supplier LED, CFL, and Halogen Price Predictions

Figure 7 displays reasons cited by manufacturers and retail buyers when predicting LED, CFL, and halogen bulb prices. As shown in the figure, manufacturers and retail buyers reported that technology improvement was significantly more important for LED price predictions than for CFLs or halogens. The LED improvements they had in mind included the LED bulb overall as well as for components such as heat sinks, driver materials, lenses, and different types of materials. Most respondents forecasted that average prices would decline as these improvements are diffused more broadly throughout the industry. The next most frequently cited reasons were production economies of scale and utility incentives. Respondents mentioned that as LED sales expand, production economies of scale will also

continue to grow, resulting in lower wholesale and retail prices. “We see tremendous growth in the market, and certainly those volumes and economies of scale continue to help drive prices down,” reported one respondent. Interestingly, the presence of utility incentives affected price predictions for CFLs more than for LEDs, according to interviewees.

Figure 7. Factors Impacting LED, CFLs, and Halogen Retail Price Trends as Reported by Suppliers*



Note: multiple responses accepted.

*The number of interviewees providing factors impacting price trends for various bulb types were LEDs (19 manufacturers and 7 retail buyers), CFLs (17 manufacturers and 7 retail buyers), and halogens (6 manufacturers and 4 retail buyers).

Eight respondents mentioned market competition as contributing to lower retail prices. About one-half of these respondents reported new market entrants selling LED lamps they described as lower price and quality than other LED brands. One respondent explained, *“These Johnny-come-lately, non-brand LED manufacturers making the low-end version of the bulbs are trying to capitalize on the [LED] trend and are making product claims that are not necessarily living up to the expectations of the consumer.”*

Another respondent agreed, describing these LEDs as *"cheap, poor quality*" LEDs which are flooding the market and driving down average retail prices.[18]

When asked about the possible impacts of the EISA 2020 standard change, most manufacturers and retail buyers said that economies of scale and technology improvements were the major drivers of LED bulb prices and that, compared to these, the impacts of the EISA 2020 standard change were likely to be relatively minor. A few respondents also reported being unsure of the impact of the EISA 2020 standard change.

Manufacturers and retail buyers disagreed on whether lamp prices are decreasing faster for A-line or reflector LEDs. About one-half of the respondents thought A-line prices were dropping faster because of the larger overall sales volume and manufacturing economies of scale as well as intense price competition among manufacturers. The other half of respondents thought reflector lamp prices were dropping faster because manufacturers are focused on improving the reflector heat sinks.

When predicting CFL prices, retail respondents most frequently cited utility incentives as the driver for lower CFL prices. The second most frequently cited reason was market competition from other lamp technologies—primarily LEDs and, to a lesser extent, halogens. One respondent mentioned, "I think [CFLs] will just slowly wane as popularity, awareness, and acceptance of the LED technology takes over." This respondent reported that LED price decreases make this lamp more cost competitive with CFLs. In addition, some respondents mentioned that competing lamp technologies such as LEDs and halogens do not have some of the negative attributes of CFLs (e.g., poor dimmability, mercury). Another respondent stated, "A lot of retailers don't want a CFL because they can get an LED at a nominal amount of more money." A substantial minority of respondents said they thought covered A-line CFLs would no longer be sold by 2018.

When predicting halogen retail prices, suppliers' most frequently cited reasons were customer demand and market competition. Many respondents reported strong demand for halogens because these lamps are similar to incandescents, cost significantly less than LEDs, and do not have the perceived negative attributes of CFLs (e.g., mercury). However, when forecasting for 2018 to 2020, many of these respondents thought LEDs might overtake halogen market share and negatively affect halogen lamp economies of scale and price. A few respondents reported that halogen lamps may not be sold in five years because of LED lamp advancements and price declines as well as increase in customer acceptance of LEDs. The samples sizes were smaller for halogens because only a small subset of manufacturers produces these bulb types.

[18] It is important to note that some major lighting manufacturers are also starting to introduce less expensive, lower performing (e.g., non-dimmable) LED bulbs, likely to compete with these cheaper manufacturers (see "Lower-Cost LEDs Offer Some Competition to Compact Fluorescent Lamps," *New York Times*, June 3, 2015).

Market Share Predictions

We asked the lighting manufacturers and retail buyers to predict average Massachusetts market shares for two lamp types—standard spiral/A-line bulbs and reflectors. In addition, for each of these lamp types we requested that they predict these market shares under two different hypothetical scenarios. In the first scenario, the Massachusetts ENERGY STAR lighting program continues to offer CFL and LED incentives for A-line bulbs or reflectors through 2020. In the second scenario, the Massachusetts ENERGY STAR lighting program ends incentives for CFL and LED A-line bulbs or reflectors in 2015. We also asked the manufacturers and buyers to describe the reasoning for their predictions. While we had restricted the price predictions to only those who manufactured or sold those lamp types, we allowed all respondents to make market share predictions. However, some chose not to make such predictions but only commented on market trends. The two subsections below present market share predictions for standard spiral/A-line bulbs and for reflectors, by lamp technology, and provide the reasons that respondents gave for their predictions.

Standard Spiral/A-Line Market Share Predictions

Table 6 presents average Massachusetts market share predictions for standard spiral CFL as well as A-line halogen, LED, incandescent, and other lamps under Scenario 1 where the Massachusetts ENERGY STAR Lighting Program continues to offer CFL and LED incentives through 2020. Table 7 presents average Massachusetts market share predictions for standard spiral CFL, A-line halogen, LED, incandescent, and other lamps under Scenario 2 where the Massachusetts ENERGY STAR program ends CFL and LED incentives in 2015.

Both tables include sales-weighted average Massachusetts market share predictions for CFLs and LEDs and unweighted average market share predictions for the remaining lamp types. Because we used program shipment data from the tracking data for the sales weighting, we were unable to sales weight the halogen, incandescent, and other lamp types since the program does not rebate them.

Table 6. Scenario 1: Average Massachusetts Retail Market Share Predictions If MA ENERGY STAR Program Continues through 2020: A-Line/Standard Spiral, 2014-2020 (n= 20)

Lamp Type	2014[19] MA Retail Market Shares	2015 MA Retail Market Shares	2016 MA Retail Market Shares	2017 MA Retail Market Shares	2018 MA Retail Market Shares	2019 MA Retail Market Shares	2020 MA Retail Market Shares	n=
Standard Spiral CFL*	33%	32%	29%	27%	24%	23%	21%	20
A-line halogen**	16%	18%	20%	20%	20%	20%	22%	20
A-line LED*	12%	19%	24%	29%	36%	41%	45%	20
A-line Incandescent**	40%	34%	27%	24%	20%	19%	13%	20
Other**	3%	3%	3%	3%	3%	4%	3%	20

*CFL and LED market shares weighted by lamp counts of retail sales for the first three quarters of 2014

** Average prices not weighted by program tracking data.

Note: Columns do not sum to 100% because they contain both weighted and unweighted data.

Table 7. Scenario 2: Average Massachusetts Market Share Predictions If Massachusetts ENERGY STAR Program Ends CFL/LED Discounts in 2015: A-Line/Standard Spiral, 2014-2020 (n=18)

Lamp Type	2014[20] MA Retail Market Shares	2015 MA Retail Market Shares	2016 MA Retail Market Shares	2017 MA Retail Market Shares	2018 MA Retail Market Shares	2019 MA Retail Market Shares	2020 MA Retail Market Shares	n=
Standard Spiral CFL*	33%	31%	23%	18%	16%	15%	14%	18
A-line halogen**	19%	25%	28%	29%	31%	31%	36%	18
A-line LED*	12%	12%	15%	18%	20%	22%	24%	18
A-line Incandescent**	42%	37%	34%	31%	28%	26%	20%	18
Other**	2%	2%	2%	2%	2%	2%	2%	18

*CFL and LED market shares weighted by lamp counts of retail sales for the first three quarters of 2014

** Average prices not weighted by program tracking data

Note: Columns do not sum to 100% because they contain both weighted and unweighted data.

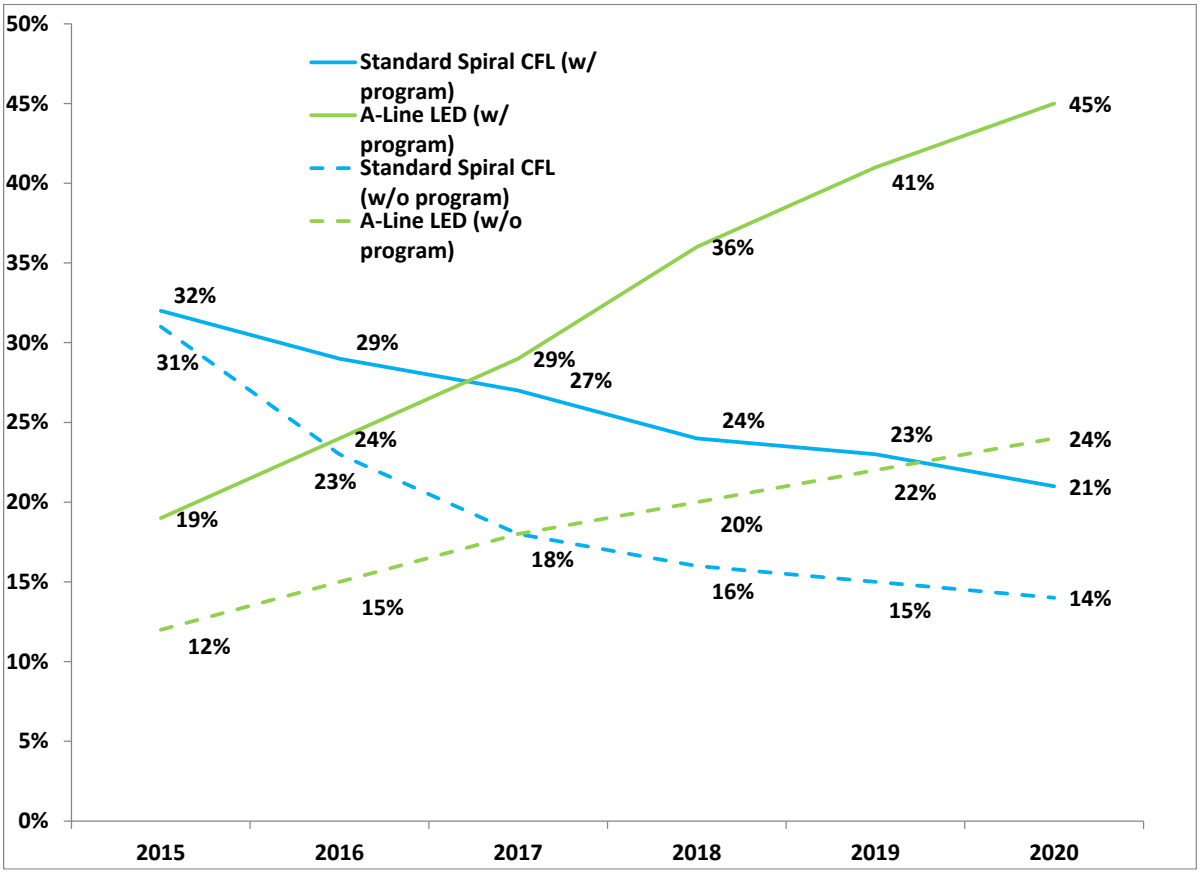
Figure 8 shows the respondents' market share predictions for A-line LEDs and spiral CFLs. The chart represents the predicted market shares, assuming continued program support, with solid lines and the predicted market shares, assuming 2015 cessation of the program, with dashed lines. The chart suggests that the continuance of the Massachusetts ENERGY STAR lighting program will nearly double the LED A-

[19] 2014 values are predictions, not actual market shares. We obtained actual market shares for 2013 and asked respondents to predict for 2014 to 2020.

[20] 2014 values are predictions, not actual market shares. We obtained actual market shares for 2013 and asked respondents to predict for 2014 to 2020.

line market share from 24% in 2015 to 45% by 2020. It also indicates that the continuance of the program will increase the CFL market share by half (from 14% to 21%).

Figure 8. Predicted A-line/Spiral Bulb Market Share for A-Line LEDs and Standard Spiral CFLs, With and Without the Massachusetts ENERGY STAR Lighting Program, 2015 to 2020

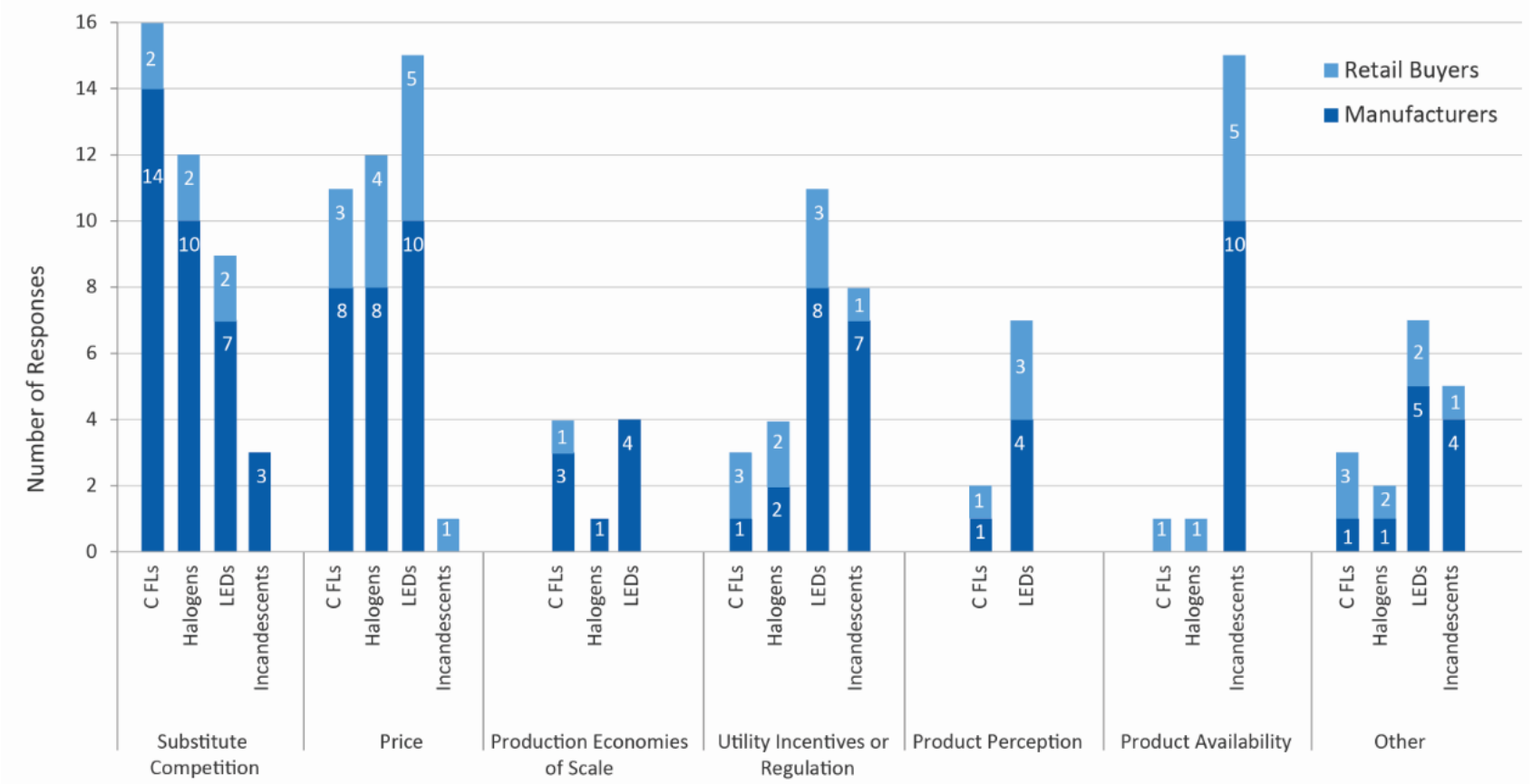


In the following subsection, we present reasons that respondents gave for their market share predictions for CFL standard spiral and A-line bulb technologies.

Factors Influencing Standard Spiral/A-line CFL, Halogen, LED, and Incandescent Market Share Predictions

Figure 9 presents average Massachusetts market share predictions for CFL, halogen, LED, and incandescent lamps, as reported during interviews with manufacturers and retail buyers.

Figure 9. Factors Considered to Predict Average Massachusetts Market Share for Standard Spiral/A-Line CFL, Halogen, LED and Incandescent Bulbs*



Note: multiple responses accepted.

*The number of interviewees providing factors impacting price trends for various bulb types were CFLs (19 manufacturers and 6 retail buyers), halogens (19 manufacturers and 6 retail buyers), LEDs (18 manufacturers and 7 retail buyers), and incandescents (17 manufacturers and 7 retail buyers).

Nineteen manufacturers and six retailers mentioned factors that influenced their market share predictions of standard spiral CFLs. The most common factors they cited were substitute competition (e.g., market share displacement by other lamp technologies) and price. Most of these respondents forecasted that CFLs would lose market share to low-priced halogens as well as high quality LEDs that are declining in price. Many respondents also reported that the relative prices of CFLs, halogens, and LEDs would largely decide CFL market share and whether CFL standard spirals would continue to be sold. Few respondents cited incandescent bulbs as a factor in CFL standard spiral market share predictions. Some respondents mentioned that if CFLs started to lose price advantage and market share, they would enter a cycle of losing manufacturing capabilities, leading to price increases that would further accelerate market share loss.

Nineteen manufacturers and six retailers mentioned factors that influenced their market share predictions of A-line halogens. Similar to reasons given for standard spiral CFL predictions, the most common factors influencing market share for A-line halogens were substitute competition and price.

Regarding competition, many respondents indicated that while the market share of halogens is going to be negatively impacted as LEDs continue to advance, a few respondents also noted that halogens will likely be the choice for people who are used to purchasing incandescents and dislike CFLs. Concerning price, while the current cost of halogens is noticeably lower than that of LEDs, moving forward it is thought that LED prices will continue to come down and take away market share from halogens.

Eighteen manufacturers and seven retailers mentioned factors that influenced their market share predictions of A-line LEDs. Price, utility incentives/regulation, and substitute competition were the most frequently cited factors for an increase in LED market share. Many respondents indicated that declining prices will lead to increased LED market share. Regarding utility regulation, respondents noted that without incentives, the cost of LEDs will be prohibitive for many people. In relation to substitute competition, respondents indicated that LEDs are taking over CFL and halogen market shares because it is a better performing product.

Seventeen manufacturers and seven retailers mentioned factors that influenced their market share predictions for A-line incandescent bulbs. Product availability and utility incentives/regulations were the most frequently cited reasons for a decrease in market share for incandescent bulbs. Many of the retailers indicated that they have a dwindling supply or are out of incandescent bulbs and cannot restock their shelves because these bulbs are no longer being manufactured. Manufacturers also noted that while incandescent bulbs are being sold on eBay and Amazon, their numbers are in decline. Both manufacturers and retailers mentioned that EISA is causing incandescents to disappear and be replaced by LEDs and halogens.

Reflector Market Share Predictions

Table 8 presents average Massachusetts market share predictions for halogen, LED, incandescent and other reflectors under Scenario 1 where the Massachusetts ENERGY STAR program continues to offer

CFL and LED incentives through 2020. Table 9 presents average Massachusetts market share predictions for halogen, LED, incandescent and other reflectors under Scenario 2 where the Massachusetts ENERGY STAR program ends CFL and LED incentives in 2015.

Table 8: Scenario 1: Average Massachusetts Retail Market Share Predictions If MA ENERGY STAR Program Continues through 2020: Reflectors (n=17)

Lamp Type	2014 MA Retail Market Shares	2015 MA Retail Market Shares	2016 MA Retail Market Shares	2017 MA Retail Market Shares	2018 MA Retail Market Shares	2019 MA Retail Market Shares	2020 MA Retail Market Shares	n=
CFL Reflectors*	17%	15%	11%	8%	6%	5%	5%	17
Halogen Reflectors**	25%	28%	27%	26%	26%	24%	24%	17
LED Reflectors*	14%	20%	27%	34%	40%	43%	46%	17
Incandescent Reflectors**	36%	31%	28%	25%	21%	19%	14%	17
Other**	3%	3%	3%	3%	3%	3%	3%	17

*CFL and LED market shares weighted by lamp counts of retail sales for the first three quarters of 2014

**Average prices not weighted by program tracking data

Note: Columns do not sum to 100% because they contain both weighted and unweighted data.

Table 9: Scenario 2: Average Massachusetts Market Share Predictions if MA ENERGY STAR Program Ends All CFL/LED Discounts in 2015: Reflectors (n=16)

Lamp Type	2014 MA Retail Market Shares	2015 MA Retail Market Shares	2016 MA Retail Market Shares	2017 MA Retail Market Shares	2018 MA Retail Market Shares	2019 MA Retail Market Shares	2020 MA Retail Market Shares	n=
CFL Reflectors*	16%	13%	9%	8%	7%	7%	6%	16
Halogen Reflectors**	29%	35%	36%	38%	37%	37%	40%	16
LED Reflectors*	14%	16%	17%	18%	20%	22%	23%	16
Incandescent Reflectors**	37%	34%	34%	31%	29%	27%	20%	16
Other**	*1%	1%	1%	1%	1%	1%	1%	16

*CFL and LED market shares weighted by lamp counts of retail sales for the first three quarters of 2014

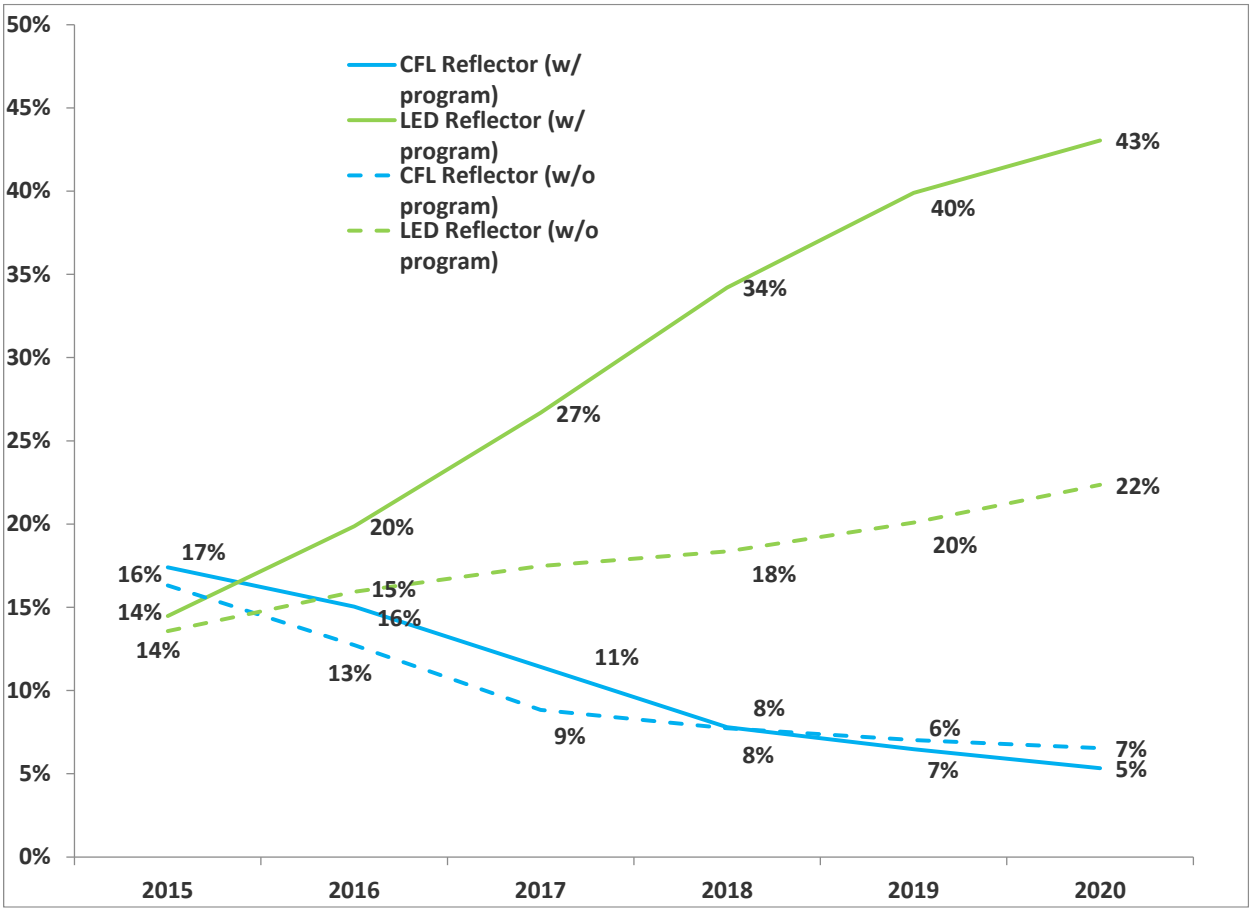
**Average prices not weighted by program tracking data

Note: Columns do not sum to 100% because they contain both weighted and unweighted data.

Figure 10 shows the Massachusetts market share predictions of the lighting manufacturers and retail lighting buyers for reflector bulbs. The solid lines represent the scenario with the Massachusetts upstream lighting program continuing, while the dashed lines represent the scenario with the discontinuation of the program. The figure shows that predictors believed that the program's support for LED reflectors, if continued, would nearly double this bulb's share of the reflector market (from 22%

to 43%). However, the lighting market actors did not believe the program would do anything to arrest the predicted decline in CFL reflector sales.

Figure 10 : Predicted Reflector Bulb Market Shares for LEDs and CFLs, with and without the Massachusetts ENERGY STAR Lighting Program, 2015 to 2020

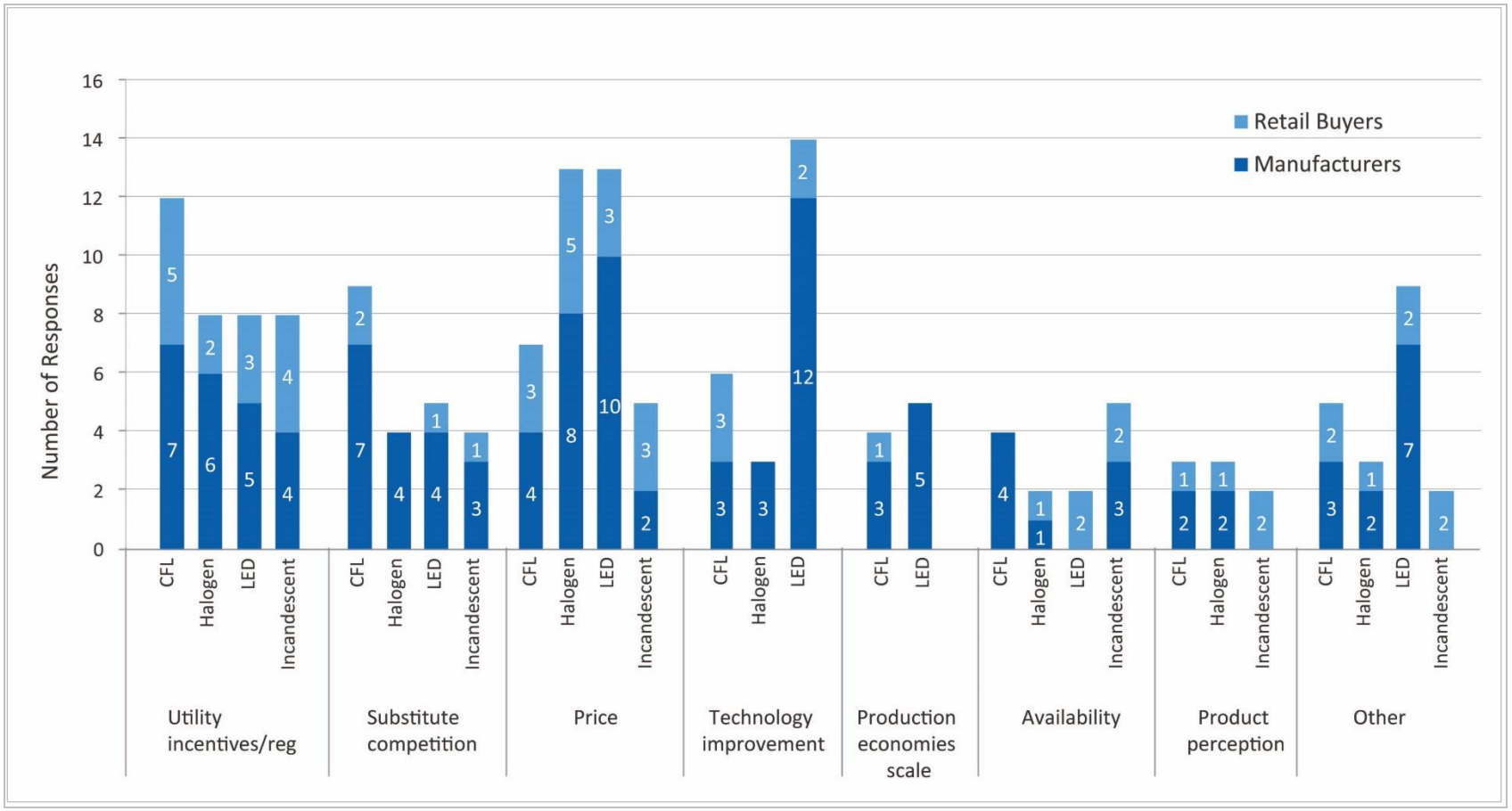


In the following subsection, we present reasons that respondents gave for their reflector market share predictions.

Factors Influencing CFL, Halogen, LED, and Incandescent Reflector Market Share Predictions

Figure 11 presents factors considered to predict Massachusetts market share predictions for CFL, halogen, LED, and incandescent bulbs, as reported during interviews with manufacturers and retail buyers.

Figure 11: Factors Considered to Predict Massachusetts' Average Market Share for Reflector CFL, Halogen, LED, and Incandescent Bulbs*



Note: multiple responses accepted.

* In total, 20 manufacturers and 7 retail buyers provided factors impacting price trends for various bulb types for each bulb technology including CFL, halogen, LED, and incandescent.

Respondents forecasted that LED reflectors would rapidly take away market share from other reflector lamp types (i.e., CFLs, halogens, and incandescents). According to respondents, this market transformation, which includes a decline in both incandescent and CFL reflector market share, is driven largely by price. The Massachusetts ENERGY STAR program, which buys down the price that retail buyers (and, in turn, consumers) pay for LED reflectors, is moving the market toward more energy-efficient LED reflector light bulbs.

In the second scenario, respondents reported differing impacts on lighting technology market share if the Massachusetts program ended CFL and LED incentives in 2015. Many respondents predicted that the rate at which LED reflectors would displace other reflector bulb types would slow considerably when compared to the scenario where the program continues through 2020. In fact, market share for the far less efficient (but relatively less expensive) halogen reflector bulbs actually increases in the hypothetical absence of the program. Since the program buys down the cost of LEDs, this indicates that price is a driving factor for LED reflector market share.

Similar to A-line predictions, technology improvement was significantly more important to LED reflector price trends than other bulb technologies, according to manufacturers and retail buyers. In addition, interviewees indicated that price was a factor in determining market share for all four reflector bulb types. It was the leading factor for halogen reflectors, mainly because without the program halogen reflectors would be cheaper than both of the more energy-efficient technologies of LED reflectors and CFL reflectors. For LED reflectors, price was second only to technology improvement as a leading factor in the determination of reflector bulb type market share.

Manufacturers and retail buyers were asked to name the factors that impacted the market share for CFL reflectors in relation to the other three reflector types (halogen, LED, and incandescent). Utility incentives and regulation (e.g., EISA) were the leading determinants of CFL reflector market share. Substitute competition was mentioned as the second leading factor. Competition was especially important for manufacturers who compete globally and occupy the upstream position in the lighting marketplace. These two leading factors were followed by price, technology advancement, production economies of scale, product availability, and consumer perception. One manufacturer also mentioned the detriment of CFLs containing toxic mercury.

Interviewees reported price as the most important factor in determining halogen reflector market shares, followed by utility incentive/regulation. Four manufacturers mentioned substitute competition. One respondent pointed out that halogen reflectors are larger than LED reflectors, which puts halogen reflectors at a relative disadvantage because LEDs will fit in some fixtures where halogens may not fit. Three respondents factored technology improvements and product perception into their halogen market share predictions, and two respondents mentioned product availability as a factor.

According to the manufacturers and retail buyers interviewed, technology improvements and price were the leading determinants of market share predictions for LED reflectors, followed by utility incentives

and regulation. Additional factors mentioned include production economies of scale, substitute competition, product perception, and availability. Some other factors included improved energy efficiency, rising energy prices, better and more diverse product features/options (e.g., dimmability, longer product life and warranty, smaller size) and better lighting quality. One manufacturer even mentioned that with the rapidly expanding LED market, patent litigation has grown which, in turn, threatens to slow the fast pace of innovation.

Respondents most frequently cited utility incentive/regulation driving incandescent reflector market share, followed by price, product availability, and substitute competition. These factors all point to EISA regulations under which most traditional incandescent lamps do not meet minimum efficacy standards and can no longer be manufactured. Respondents predicted significant market share declines as retailers sell through existing stocks of these incandescent lamps. Two retail buyers mentioned consumer product perception as a market share determinant. One of these two retail buyers and a third (not mentioning product perception) said that rising energy prices would impact the market share of incandescent reflectors.

POS Modeling

This subsection presents the results of price projections based on the 2009-2014 POS regression model. Table 10 displays the average price per Watt by bulb type for program states, non-program states, and all states. The price trends per Watt in the POS data are fairly straightforward, though there are some points of interest. LED price per Watt declines throughout the program period but does bounce around from year to year. This is likely due to new technologies, such as bulbs that can be controlled by a smart device entering the market and inflating the price per Watt. There is not much movement in CFL price per Watt during the analysis period. It appears that halogen price per Watt is also stagnant but, in reality, the low price of six cents per Watt at the beginning of the analysis period was halved by 2014. Again, it is worth noting that prices in non-program areas for LEDs sometimes fall below those in program areas, which may reflect the types of channels reporting and/or the costs of living in the two types of areas-it is also worth noting that most LED program support did not begin until 2013 or 2014.

Table 10. Average LED, CFL and Halogen Prices per Watt and Extrapolated Price per 60-Watt Incandescent Equivalent Bulb: 10-Watt LED, 13-Watt CFL, 43-Watt Halogen

Year	Price per Watt in Program States n=28	Price per Watt in Non-Program States n=16
LED		
2009	$2.89	$2.84
2010	$2.11	$2.08
2011	$1.53	$1.34
2012	$1.55	$1.43
2013	$1.70	$1.73
2014	$1.22	$1.35
CFL		
2009	$0.16	$0.14
2010	$0.15	$0.14
2011	$0.15	$0.14
2012	$0.15	$0.14
2013	$0.15	$0.15
2014	$0.15	$0.14
Halogen		
2009	$0.06	$0.06
2010	$0.06	$0.06
2011	$0.06	$0.06
2012	$0.05	$0.05
2013	$0.04	$0.04
2014	$0.03	$0.03

The Team used a fixed effects panel regression analysis to extrapolate a price trend for the price per Watt by bulb in three separate non-program state models to produce three separate sets of predictions. The estimates are based on models that reflect sales data from 2009-2012, 2009-2013, and 2009-2014 (see Appendix E for the 2009-2012 and 2009-2013 models and discussion). The Team compared the estimated price per Watt to the actual price per Watt for 2014 and then extrapolated the price per Watt out through 2018. Finally, we used the extrapolated price per Watt to calculate the price of a bulb equivalent to a 60-Watt incandescent or, in other terms, a bulb that produces an output of 640 lumens.

The Team began the analysis by running a 2009-2012 and a 2009-2013 model and using the output to extrapolate through 2018; full details of these models can be found in Appendix E. The 2009-2012 and 2009-2013 had wider gaps between predicted price per watt and observed price per Watt than did the 2009-2014 model. The narrower gap between predicted and observed price in the 2009-2014 model, compared to the other models, is evidence that all recommendation will be based solely on the 2009-2014 model.

The final set of extrapolated prices is based on a non-program state 2009-2014 model; it is the model and projection the Team recommends. The model under-predicts the price per Watt of LEDs by eight cents, while predicting the 2014 price per Watt for CFLs and halogens exactly (Table 11). The extrapolated price per Watt for LEDs decreases by 38% from 2014 to 2018, meaning that the average price of a 10-Watt LED in 2018 would be about $7.86 (Table 12 and Table 13). Predicted CFL price per Watt stays stagnant throughout the prediction period. Halogens continue to decrease in price per Watt through 2018, and the average price per 43-Watt halogen bulb by 2018 should be around $0.84. Note that this approach yields higher price and incremental costs compared to web-scraping and supplier interviews.

Table 11. Predicted Wattage Prices for 2014 based on 2009-2014 model

Bulb Type	Observed Non-Program State Average Value	Predicted Value (90% CI)	Difference (predicted-actual)
LED	$1.35	$1.27, ±(0.05)	-$0.08
CFL	$0.14	$0.14, ±(0.01)	$0.00
Halogen	$0.03	$0.03, ±(0.0013)	$0.00

Table 12. Price per Watt through 2018 based on 2009-2014 model with Delta Method Standard Errors

Year	LED		CFL	Halogen
2014	$1.27, ±(0.05)		$0.14, ±(0.01)	$0.03, ±(0.001)
2015	$1.13, ±(0.06)		$0.14, ±(0.01)	$0.03, ±(0.001)
2016	$1.00, ±(0.07)		$0.14, ±(0.02)	$0.03, ±(0.001)
2017	$0.89, ±(0.08)		$0.14, ±(0.02)	$0.02, ±(0.001)
2018	$0.79, ±(0.08)		$0.14, ±(0.02)	$0.02, ±(0.001)
The Team used Stata to estimate predictive margins at 90% confidence to extrapolate Watt prices, which are shown in parentheses. The predictive margins were calculated using a delta method which allowed for the calculation p-values.				

Table 13. Example Prices for a 640-Lumen Bulb based on a 2009-2014 model

Year	10-Watt LED	13-Watt CFL	43-Watt Halogen
2014	$12.75	$1.78	$1.48
2015	$11.29	$1.78	$1.28
2016	$10.01	$1.78	$1.11
2017	$8.87	$1.78	$0.97
2018	$7.86	$1.77	$0.84

Web-Scraping

The Team utilized a database of web-scraped LED product pricing and specifications stores that contained data for A-type LEDs since 2009 as well as data for all analyzed product categories on a yearly basis since 2012 and on a quarterly basis since Q2 2013. As discussed in the previous section, based on the LBNL assessment of web-scraping price data, the Team determined that the 25th percentile is appropriate for characterizing the mean purchase price for all LED product categories. Table 14 presents the mean (25th percentile) price estimates for the following product categories: A-Type, Candle/Flame, Globe, and Reflector lamps.

Table 14. Web-scraping Mean (25th Percentile) Price Estimates for Major LED Product Categories

Data Collection Date		A-Type	Candle/ Flame	Globe	Reflector
Year	Quarter				
2009	**Q1**	$39.99	$16.97	$16.15	--
2010	**Q1**	$29.49	--	--	--
2011	**Q1**	$25.62	--	--	$38.30
2012	**Q1**	$21.85	$11.48	$12.98	$33.69
2013	**Q1**	$14.97	$9.98	$12.98	$27.65
2013	**Q3**	$14.97	$9.34	$9.98	$23.21
2013	**Q4**	$13.07	$9.57	--	$19.31
2014	**Q1**	$10.97	$9.34	$10.17	$21.37
2014	**Q2**	$9.97	$8.99	$11.65	$18.17
2014	**Q3**	$9.97	$9.71	$10.98	$19.14
2014	**Q4**	$9.47	$8.99	$9.37	$18.10
2015	**Q1**	$9.49	$8.06	$10.21	$17.60

* Historical price data are not provided if sample was too low to generate a mean estimate.

An exponential price model was then used to fit this historical data and describe future LED pricing for each product category. The exponential model predicts a significant price decline in Massachusetts for all LED product categories, with A-Type expected to have the greatest year-over-year price decline of 21% and Globe to have the least at 8%. LED reflector lamps[21] are also expected to see significant annual price drops of 21%. Despite the range of price decline, all LED product categories analyzed are expected to cost less than $10 by 2018, with Globe lamps being at the top of this range and A-type being at the lower end. While it is logical to predict an exponential price decline in the near term, a constant year-over-year price decline will not continue indefinitely. Rather, the rate of decline for several of these LED

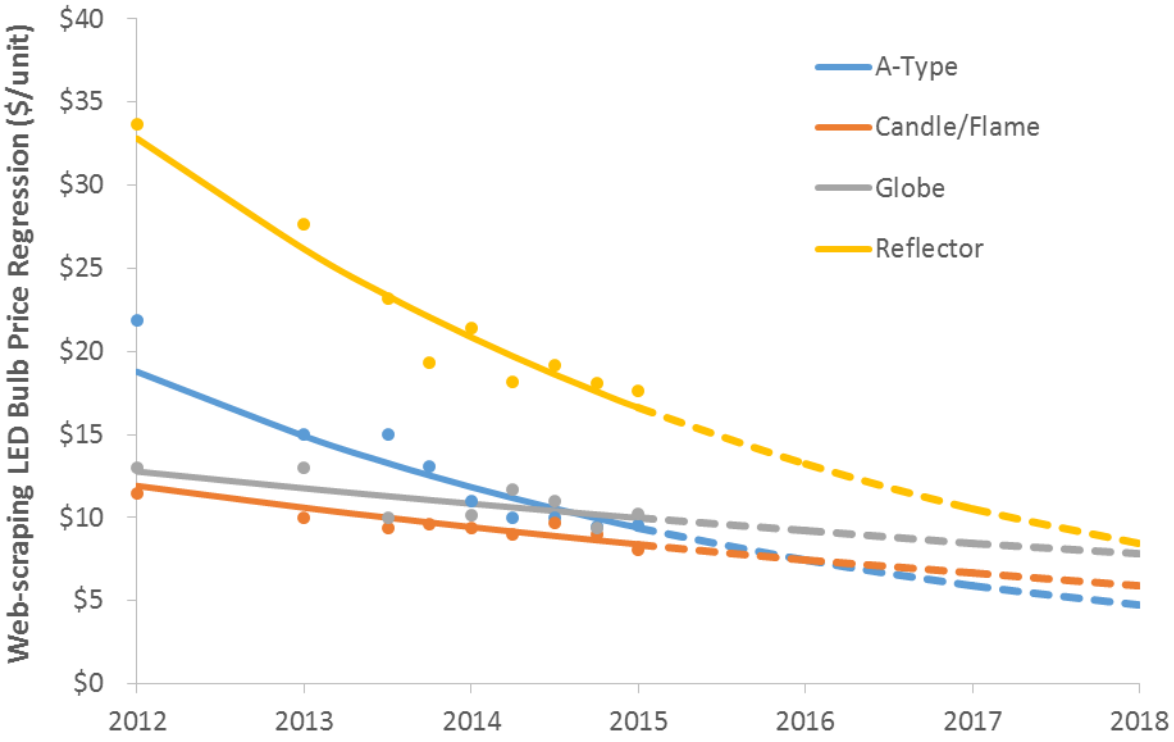
[21] The regression analysis for 'Reflector' LEDs is based on a weighted average of NEMA shipments for all reflector lamp shapes. Price estimates for each individual reflector lamp shape (MR16, PAR20/R20/BR20, PAR30, R30/BR30, PAR38, R40/BR40, and downlight retrofit lamps) are provided in Appendix B.

product categories is expected to slow within the timeframe of this projection analysis. Table 15 and Figure 12 present the modeling results for 2014 to 2018.

Table 15. LED Price Regression Results by Product Category

LED Product Categories	2014	2015	2016	2017	2018	Annual Price Decline (%)
A-Type	$11.84	$9.40	$7.47	$5.93	$4.71	21%
Candle/Flame	$9.43	$8.40	$7.47	$6.65	$5.92	11%
Globe	$10.84	$9.98	$9.20	$8.47	$7.80	8%
Reflector	$20.85	$16.62	$13.25	$10.56	$8.42	20%

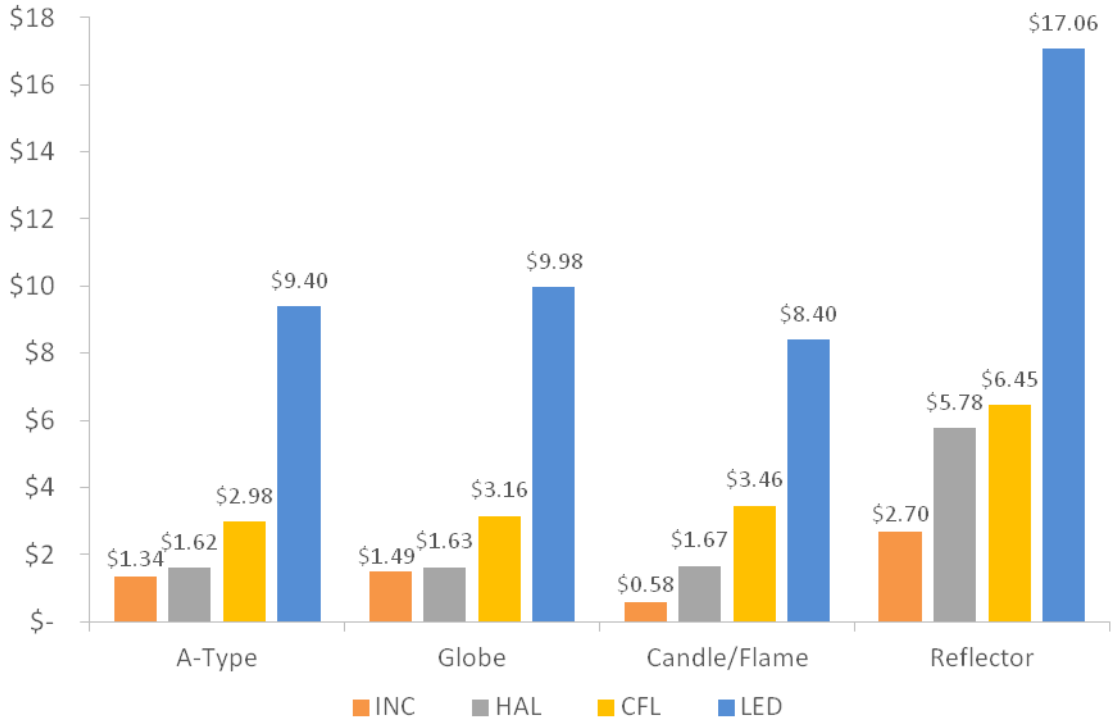
Figure 12. LED Price Regression Results by Product Category



In addition to evaluating the current and future price of LED lighting in Massachusetts, we also analyzed pricing for conventional incandescent, halogen, and CFL options (only products of equivalent lumen

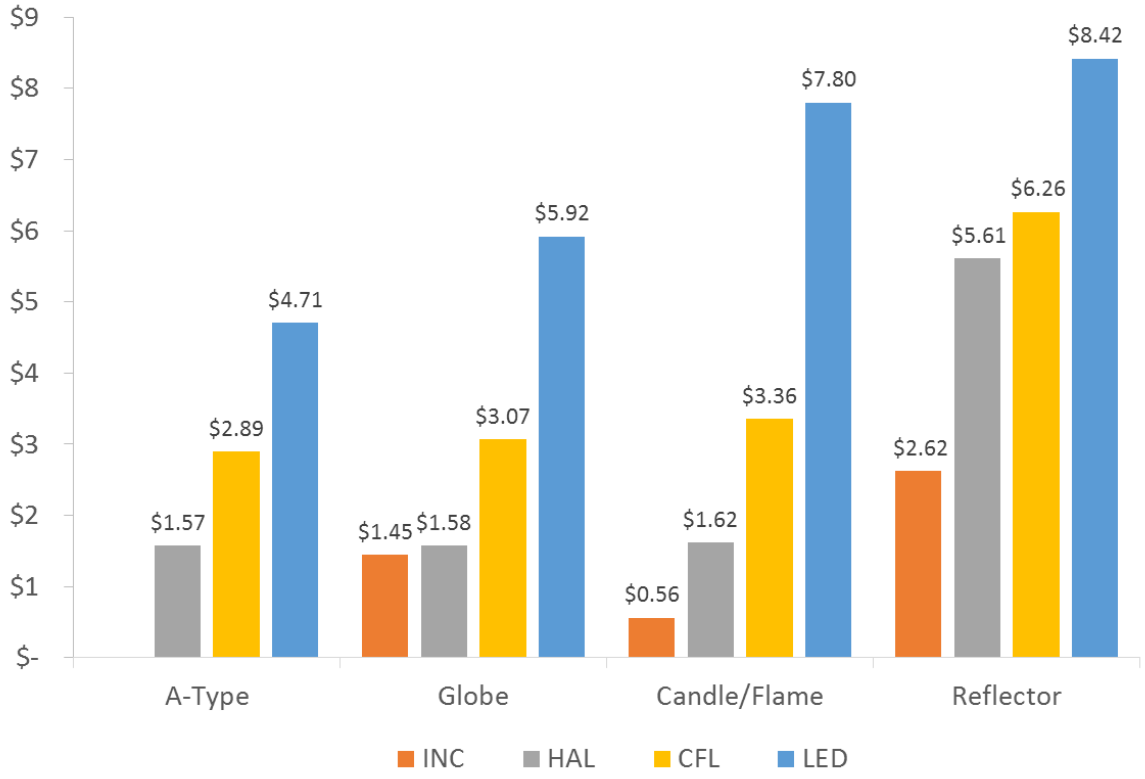
output were compared). The web-scraping tool was used to collect current pricing for incandescents, halogens, and CFLs in the Natick and/or Framingham region, and prices were extrapolated assuming a 1% annual decline.[22] Future LED pricing estimates reflect the results of the exponential regression analysis discussed above. Figure 13 and Figure 14 below illustrate the 2015 and 2018 purchase price estimates for Massachusetts LED, CFL, halogen, and incandescent lamps by product category.

Figure 13. 2015 Price Comparison for Incandescent, Halogen, CFL, and LED



[22] Assumption for the annual percent decline for incandescent, halogen and CFL lamps was determined based on insights gleaned from pricing discussions with manufacturers as well as input from the U.S. DOE Solid-State Lighting Program.

Figure 14. 2018 Price Comparison for Incandescent, Halogen, CFL, and LED [23]



In 2015, LED products are the most expensive across all categories. When comparing the purchase price for each technology, the cost of LEDs is more than twice that of CFLs, three times that of halogen lamps, and over seven times the cost of incandescent lamps.

The 2018 projection, shown in Figure 14, illustrates the same pricing hierarchy as in 2015; however, the LED incremental costs are significantly lower. Conventional technology prices have also decreased, but at a much slower pace. Table 16 displays the 2015 and 2018 LED incremental cost estimates.[24]

[23] Based on conversations with retailers and manufacturers, it is expected that inventories of incandescent A-type lamps at all major retailers will be exhausted by 2017.

[24] See 0 for incandescent, halogen, and CFL price extrapolations and **Error! Reference source not found.** for LED incremental cost estimates for 2015, 2016, 2017, 2018, and 2020.

Table 16: 2015 and 2020 LED Incremental Cost, Web-Scraping Method

Product Category	2015			2018		
	Incandescent	Halogen	CFL	Incandescent	Halogen	CFL
A-Type	$8.06	$7.78	$6.42	-	$3.14	$1.82
Globe	$6.91	$6.77	$5.24	$4.47	$4.34	$2.85
Candle/Flame	$9.40	$8.31	$6.52	$7.24	$6.18	$4.44
Reflector	$13.92	$10.84	$10.17	$5.04	$3.50	$2.85

Conclusions and Recommendations: Incremental Purchase Costs

Table 17 shows the predicted incremental initial purchase cost of LED bulbs, compared to CFL and halogen counterparts, by data source for each year from 2015 to 2018. It also presents the average incremental costs for A-type bulbs. All methods project declining incremental costs for LED bulbs over the time-horizon examined, with the largest declines in the web-scraping exponential regression method and the smallest, but still significant, declines in the POS projection method. All methods agree that the price premium will be largest in comparison to halogen bulbs (i.e., halogen bulbs will remain the cheapest of the three in terms of retail prices).

More specifically, suppliers estimate a 30% decline by 2018, as does the POS modeling estimate, and web-scraping estimates a 50% decline in price by 2018. Each method also contributed unique—and often widely varied—extrapolations of LEDs in the lighting market. The estimated incremental cost for LEDs versus CFLs (all types) in 2015 is between $3.73 and $10.17 and is predicted to be between $2.19 and $6.09 by 2018. Likewise, compared to halogens, the current incremental cost for LEDs is estimated as $5.39 to 10.84 in 2015, and is predicted to be between $2.69 and $7.02 by 2018. Market actors anticipate that LED bulbs' market share will increase during the prediction period but assert that the rate of LED adoption would be cut in half without continued program support. The bottom two rows of Table 17 present the average incremental cost of LEDs versus A-type CFLs and A-type halogens for years with estimates from all methods. The Team cautions against using these averages as point-estimates of incremental costs due to the wide variations in estimated prices (including those for 2015), divergent predictions of the rate of LED incremental cost decline, and uncertainties inherent in each of the estimations methods.[25]

[25] While the strengths and weaknesses of the methods in part balance each other out, it is not clear that the balance is sufficient enough to allow use of a simple average. The Team also rejected a weighted average—prioritizing some methods over others—because none of the methods is sufficiently "stronger" or "weaker" than the others to warrant this approach.

Table 17: Incremental purchase cost of LED bulb compared to selected bulb technologies, 2015 to 2018

Method	Product	2015	2016	2017	2018
Interviews	CFL A-Type	$3.73	$3.07	-	$2.19
	CFL Reflector	$5.67	$4.43	-	$1.78
	Halogen A-Type	$5.39	$4.49	-	$3.26
	Halogen Reflector	$6.49	$4.87	-	$2.69
Point of Sale	CFL, generic	$9.51	$8.23	$7.09	$6.09
	Halogen, generic	$10.01	$8.90	$7.90	$7.02
Web-Scraping	CFL A-Type	$6.42	$4.52	$3.01	$1.82
	CFL Reflector	$10.17	$6.86	$4.23	$2.16
	Halogen A-Type	$7.78	$5.87	$4.34	$3.14
	Halogen Reflector	$10.84	$7.53	$4.89	$2.81
Average of Predicted	CFL A-Type*	$6.55	$5.27	-	$3.37
	Halogen A-Type*	$7.73	$6.42	-	$4.47
* Includes "generic" category from POS modeling, as most bulbs in the dataset were A-type.					

Recommendation and Consideration[26]

The Team predicts that LED prices will decrease by anywhere from 30% to 50% by 2018. There was a large spread in the estimate of starting LED prices ranging from $7.25 to $11.29 (in 2015). Due to the identified differences between the methods, their relative strengths and weaknesses, and the variation in initial estimates of 2015 prices and future incremental costs, each method may be more or less relevant to future policy application, depending on what actually happens in the lighting market. In fact, at the time of writing, ENERGY STAR had recently finalized its "Lamps V2.0 Specification."[27] At this time, it is the Team's understanding that no CFLs meet the specification. This decision may dramatically alter the price trends described here. Additionally, the DOE has yet to release its final decision regarding its interpretation of whether increased lighting efficacy standards for 2020 apply to the average of all bulbs on the market or to each individual bulb model on the market. Again, this decision will have critical impacts on the decisions of lighting manufacturers and retailers over the next few years, including how

[26] This study captures the pricing trends of various types of bulbs sold in retail locations and is not exclusive to the specific bulbs supported by the PAs during a given year. Therefore, as part of the 2016-2018 Demand Side Management (DSM) plan, the average year-to-year percentage decline was used to estimate the incremental cost of PA supported bulbs, instead of the specific incremental costs that were estimated in this study. The plan is available at: http://ma-eeac.org/wordpress/wp-content/uploads/Exhibit-1-Gas-and-Electric-PAs-Plan-2016-2018-with-App-except-App-U.pdf.

[27] For more information, see documents and summaries posted at https://www.energystar.gov/products/spec/lamps_specification_version_2_0_pd.

they price bulbs. With this information in mind, the Team offers the following recommendation and two considerations.

Recommendation #1: Given the fast-moving nature of the market for residential lighting products, the Team **recommends** using the range of values for 2016 to 2018 presented in Table 17 above rather than a single point-estimate. Any sort of future price predictions extrapolated from historical price data in the context of a quickly changing lighting market will be subject to high levels of uncertainty, and the team recommends caution when considering these predicted values

Consideration #1: If such a point-estimate is required, the Team suggests **considering** the average ($3.37 for CFLs and $4.47 for halogen A-line bulbs) as the incremental cost of A-line LEDs compared to CFLs and halogens in 2018).

Consideration #2: If quarterly POS data become available, the Team suggests **considering** having more frequent quarterly updates in the POS and web-scraping outlooks to match the rapidly evolving nature of the lighting marketplace.

While short a recommendation or consideration, the team also suggests a future line of inquiry. Combined, the POS, supplier interviews, and web scraping data can be used in the future to complement one another to provide the most comprehensive lighting forecasting model. For example, the POS data provide the most reliable estimate of sales from specific retailers, and provide an important calibration and sales weighting tool for the other sources. The supplier interview data provide sales estimates for the "big box" stores, which have not submitted POS data to date, as well as other store types that have provided data. Supplier interviews also inherently account for industry decision making and planning regarding the lighting market. Lastly, the web-scraping data provide a clean, coded inventory of bulb attributes that can be cross-checked with the prior sources to ensure that all bulbs are included and properly assigned to the correct bulb type, style, wattage, and lumens. The web-scraping will also provide an observed price-point that can be compared against the prices reported by in the POS and supplier interview data, allowing for a validity check on all three sources of data. If generally found to be aligned, web-scraping price data could potentially provide a means to replace missing or outlying data in the POS database.

Appendix A. Market Projections to 2020

In addition to the near-future extrapolations included in the main text of the report, the Team extended its extrapolations to 2020 to match the time-horizon of the supplier interviews. Below are tables and figures reproduced from the main body of the report with the extrapolations extended to 2020. These extended extrapolations should be considered in the context of the limitations of projecting market characteristics in the rapidly evolving lighting market, along with the caveats noted in the text of the report.

Figure 15: Projected Average Price per Bulb for LED A-Line bulbs, by year and data source (extended version of Figure 1)

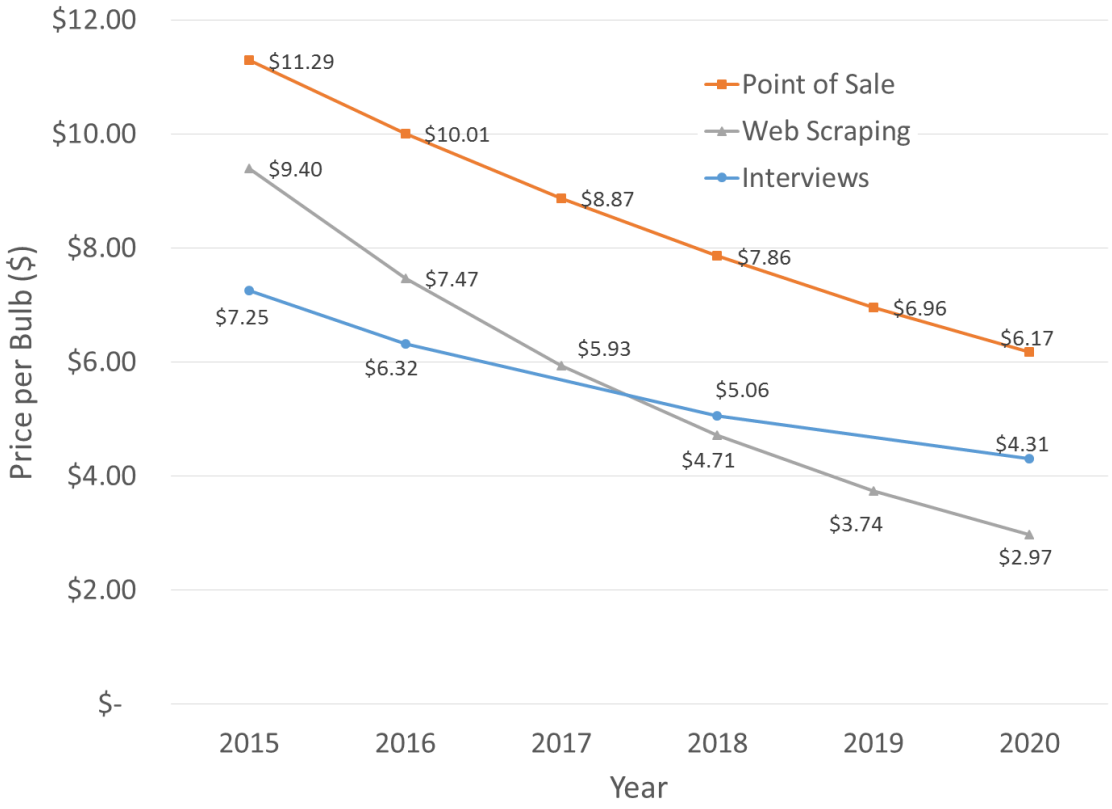


Figure 16: Projected Price Decline for LED A-Line bulbs relative to 2015, by year, data source (extended version of Figure 2)

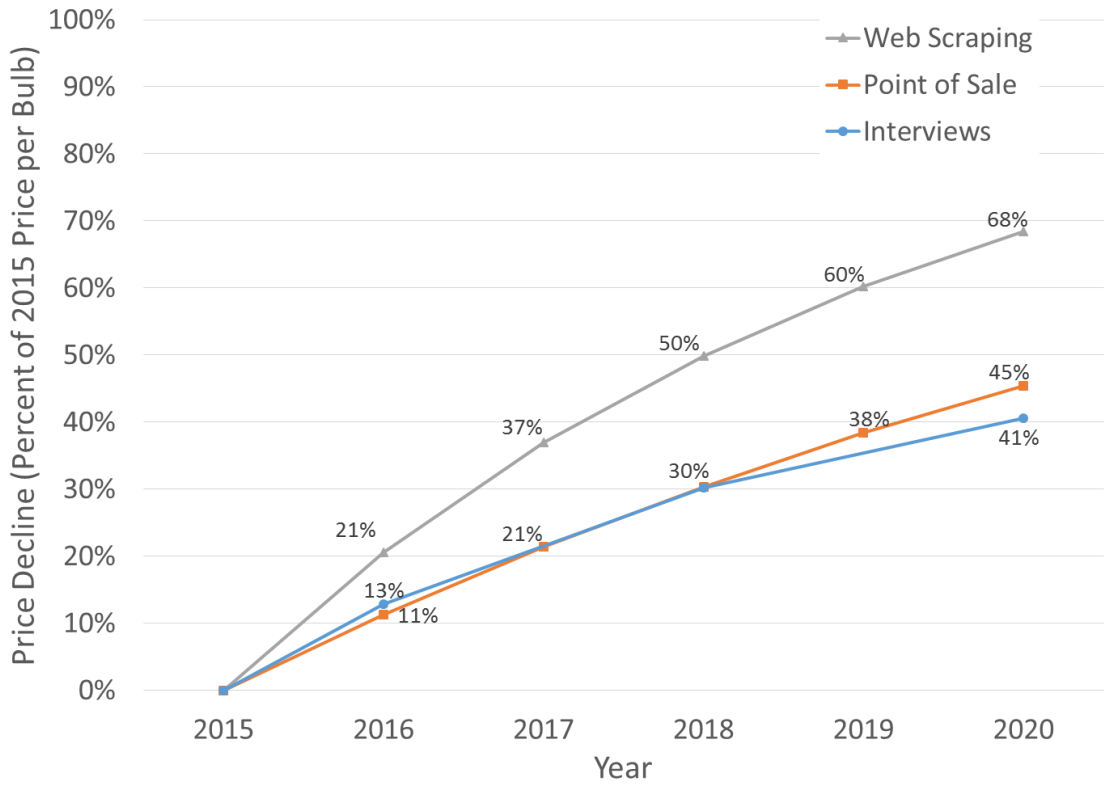


Figure 17: Relative Bulb Prices in 2015 and 2020, by bulb type and data source (extended version of Figure 3)

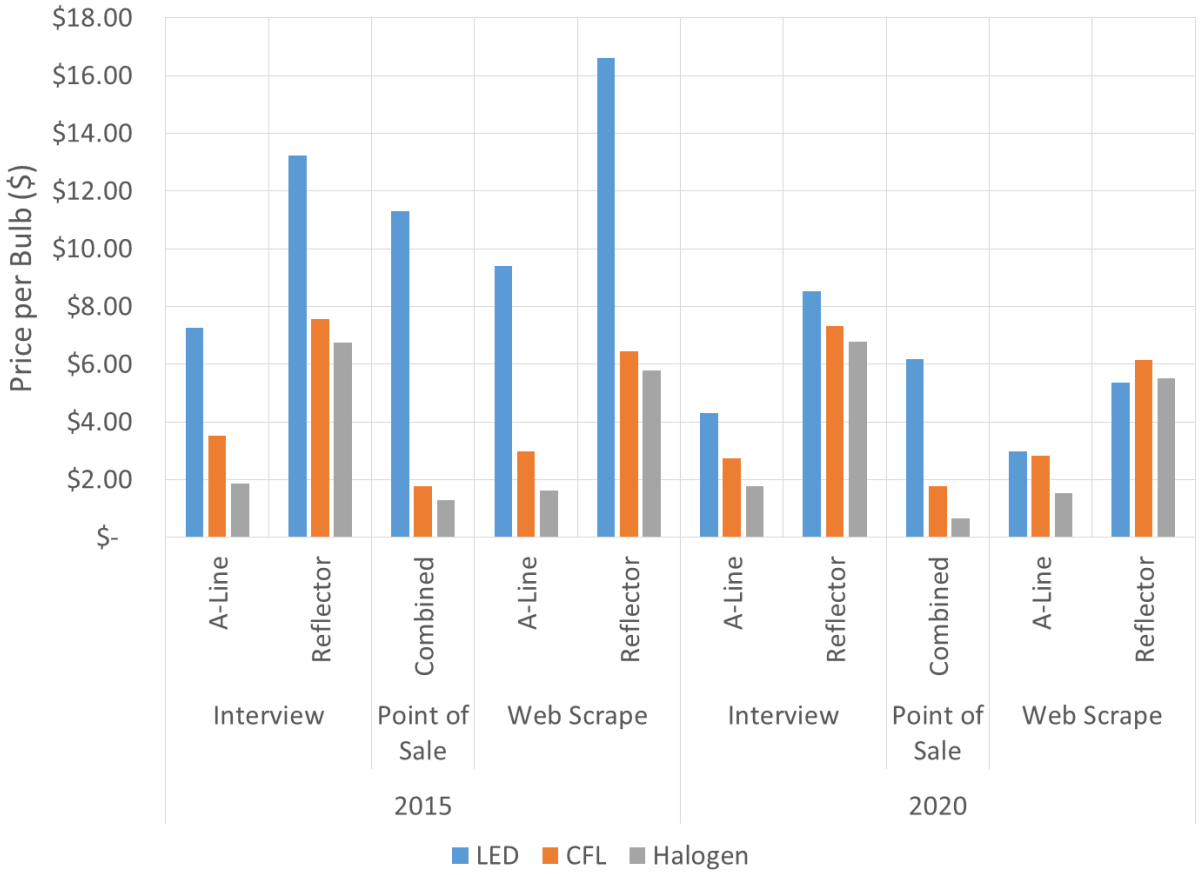


Table 18. Price per Watt through 2020 based on 2009-2014 POS model (extended version of Table 12)*

Year	LED	CFL	Halogen
2014	$1.27, ±(0.05)	$0.14, ±(0.01)	$0.03, ±(0.001)
2015	$1.13, ±(0.06)	$0.14, ±(0.01)	$0.03, ±(0.001)
2016	$1.00, ±(0.07)	$0.14, ±(0.02)	$0.03, ±(0.001)
2017	$0.89, ±(0.08)	$0.14, ±(0.02)	$0.02, ±(0.001)
2018	$0.79, ±(0.08)	$0.14, ±(0.02)	$0.02, ±(0.001)
2019	$0.70, ±(0.08)	$0.14, ±(0.02)	$0.02, ±(0.001)
2020	$0.62, ±(0.08)	$0.14, ±(0.02)	$0.01, ±(0.001)
*Predictive margins at 90% confidence shown in parentheses.			

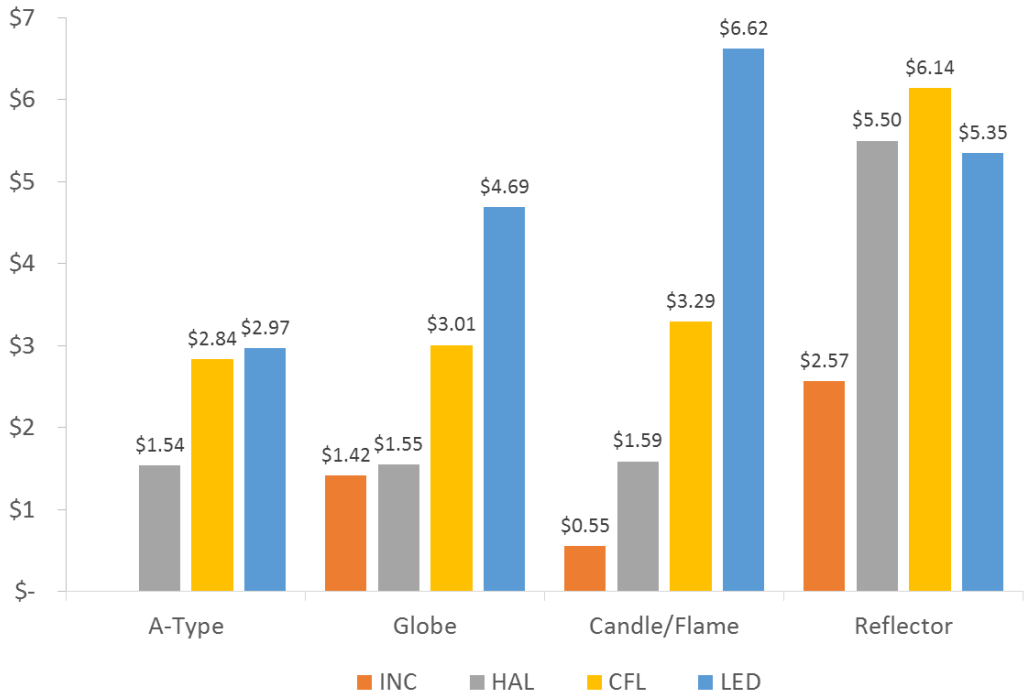
Table 19. Example Prices for a 640-Lumen Bulb based on a 2009-2014 POS model (extended version of Table 13)

Year	10-Watt LED	13-Watt CFL	43-Watt Halogen
2014	$12.75	$1.78	$1.48
2015	$11.29	$1.78	$1.28
2016	$10.01	$1.78	$1.11
2017	$8.87	$1.78	$0.97
2018	$7.86	$1.77	$0.84
2019	$6.96	$1.77	$0.73
2020	$6.17	$1.77	$0.64

Table 20. LED Price Web-Scrape Regression Results by Product Category (extended version of Table 15)

LED Product Categories	2014	2015	2016	2017	2018	2019	2020	Annual Price Decline (%)
A-Type	$11.84	$9.40	$7.47	$5.93	$4.71	$3.74	$2.97	21%
Candle/Flame	$9.43	$8.40	$7.47	$6.65	$5.92	$5.27	$4.69	11%
Globe	$10.84	$9.98	$9.20	$8.47	$7.80	$7.19	$6.62	8%
Reflector	$20.85	$16.62	$13.25	$10.56	$8.42	$6.71	$5.35	20%

Figure 18. 2020 Web-Scrape Price Comparison for Incandescent, Halogen, CFL, and LED * (additional projection beyond that shown in Figure 14)



* Based on conversations with retailers and manufacturers, it is expected that inventories of incandescent A-type lamps at all major retailers will be exhausted by 2017.

Table 21: 2015 and 2020 LED Incremental Cost, Web-Scraping Method (extended version of Table 16)

Product Category	2015			2020		
	Incandescent	Halogen	CFL	Incandescent	Halogen	CFL
A-Type	$8.06	$7.78	$6.42	--	$1.43	$0.13
Globe	$6.91	$6.77	$5.24	$3.27	$3.14	$1.68
Candle/Flame	$9.40	$8.31	$6.52	$6.07	$5.03	$3.33
Reflector	$13.92	$10.84	$10.17	$2.78	($0.15)	($0.79)

Table 22: LED Incremental Costs by Comparison Bulb Type, Estimation Method, and Year (extended version of Table 17)

Method	Product	2015	2016	2017	2018	2019	2020
Interviews	CFL A-Type	$3.73	$3.07	-	$2.19	-	$1.57
	CFL Reflector	$5.67	$4.43	-	$1.78	-	$1.22
	Halogen A-Type	$5.39	$4.49	-	$3.26	-	$2.54
	Halogen Reflector	$6.49	$4.87	-	$2.69	-	$1.76
Point of Sale	CFL, generic	$9.51	$8.23	$7.09	$6.09	$5.19	$4.40
	Halogen, generic	$10.01	$8.90	$7.90	$7.02	$6.23	$5.53
Web-Scraping	CFL A-Type	$6.42	$4.52	$3.01	$1.82	$0.88	$0.13
	CFL Reflector	$10.17	$6.86	$4.23	$2.16	$0.51	($0.79)
	Halogen A-Type	$7.78	$5.87	$4.34	$3.14	$2.18	$1.43
	Halogen Reflector	$10.84	$7.53	$4.89	$2.81	$1.16	($0.15)

Appendix B. Details of the Washington, D.C., Metropolitan Area and Massachusetts Price Comparison

Once clean, the Massachusetts web-scraping effort gathered a total of 1014 LED bulb price points in Q1 2015, as well as 515 for CFLs and 818 for halogen and incandescent bulbs. The Team had available historical pricing data for the Washington, D.C., metropolitan area (D.C.) and believe it comparable to Massachusetts. In order to increase the sample size and allow for a regression analysis of historical LED pricing data the Team examined whether the recent Q1 2015 D.C. data was comparable to the Massachusetts data and the appropriateness of adding that pricing data to the MA data for regression work.

In order to increase the sample size for the regression modeling of historical LED prices for Massachusetts, we first confirmed the assumption of regional LED price equality with the current Q1 2015 price data for the Washington, D.C., metropolitan area and Massachusetts. A two-sided heteroscedastic t-Test ("t-Test: Two-Sample Assuming Unequal Variances") was selected as the best method to test for equality of population means. This hypothesis test is a conservative method used frequently when the population variances are unknown. [28,29,30]

T-Tests on price were conducted between the Washington, D.C., metropolitan area and Massachusetts for all the residential LED product categories combined together and also individually. For each product category, the calculated test statistic (t-Stat) and the Student's T critical value (t-critical) are reported in Table 23 below. If the t-Stat is greater than the t-critical value, the null hypothesis that the Washington, D.C., metropolitan area and Massachusetts populations have the same mean is rejected (i.e., there is a statistically significant difference between population means). The results shown below indicate that there are no product categories for which the difference between the Washington, D.C., metropolitan area and Massachusetts population means is significant at the 95% level of confidence (alpha = 0.05).

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

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

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

Table 23. Summary of t-Test Results for the Washington, D.C., metropolitan area and Massachusetts

Lighting Category	|t-Stat|	t-critical (2-sided, alpha = 0.05)	Significance
All LED Lighting Products	0.21	1.96	t-stat < t-critical, not significant
A15, A19, A21	1.11	1.97	t-stat < t-critical, not significant
PAR30	0.21	2.01	t-stat < t-critical, not significant
PAR38	0.06	2.00	t-stat < t-critical, not significant
Downlight Retrofit Lamps	0.93	2.05	t-stat < t-critical, not significant
MR16	0.07	2.00	t-stat < t-critical, not significant
Candle	0.55	1.99	t-stat < t-critical, not significant
Globe	1.36	2.04	t-stat < t-critical, not significant
BR40/R40	0.74	2.05	t-stat < t-critical, not significant
BR30/R30	0.43	2.00	t-stat < t-critical, not significant
PAR20/BR20/R20	0.48	1.99	t-stat < t-critical, not significant

Based on the results of the t-Tests, we concluded that it is reasonable to use historical pricing data for the Washington, D.C., metropolitan area, supplemented with current Massachusetts prices, for the purpose of extrapolating prices of LED lighting products sold in Massachusetts. Table 24 presents the sample sizes.

Table 24. MA and Washington, D.C. Combined Sample Size for LED Web-Scraping Price Analysis

LED Product Type	Total Sample Size
A-Type	**1,628**
Candle/ Flame	**841**
Globe	**384**
Reflector	**5,158**
Total	**8,011**

Appendix C. Web-Scraping Price Modeling
Actual Prices and Predictive Results

The exponential model demonstrated a good fit for all product categories (see Table 25 for more details), with all having an R-squared value of greater than 80% and several having an R-squared value of greater than 90%. In general, we found that goodness of fit increases with the sample size for each product category—the exponential model has the best fit with the LED A-Type (n=2,265; R-squared=.96) and the worst with BR30/R30 (n=825; R-squared=.80). Figure 19 demonstrates the fit for both LED A-type and BR30/R30. We found that the sample size of each LED product category data set was highly dependent on the number of products available at each retailer at each point in time as well as on the historical availability of each product category. Since LED technology is relatively new, historical data for some less common product categories such as BR30/R30, BR40/R40, and downlight retrofit are more sparse, resulting in smaller sample size and typically a lower goodness of fit.

Figure 19. Price Regression Results for LED A-Type and BR30/R30

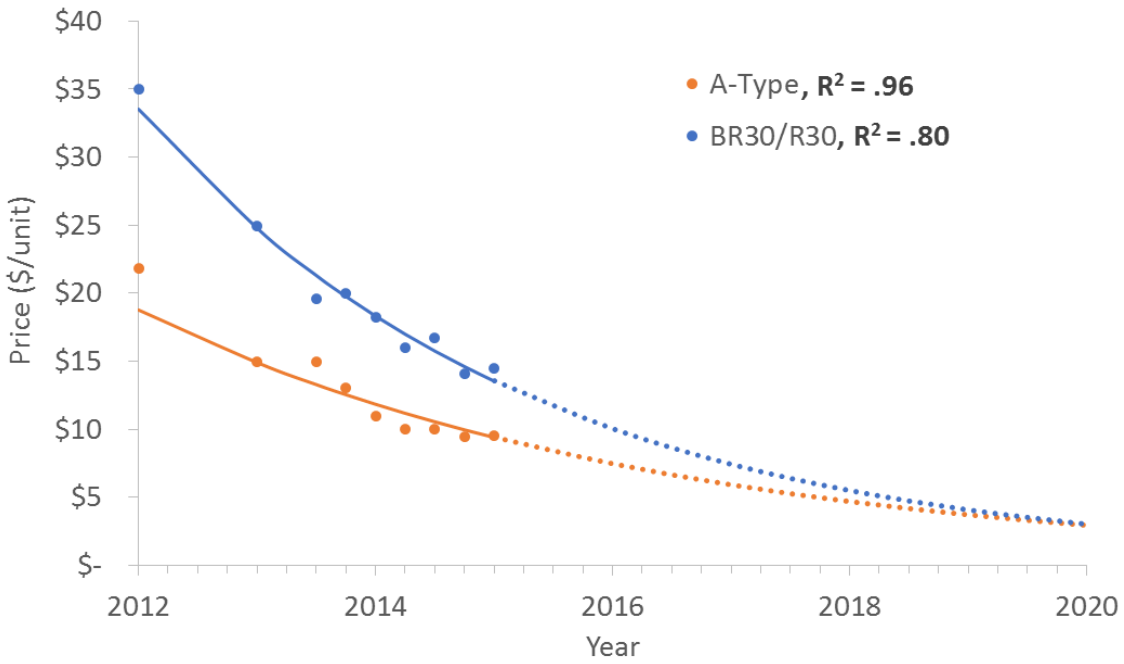


Table 25. Price Modeling Actual Prices and Predictive Results for Reflector Lamp Shapes

	BR30/R30		BR40/R40		PAR20/BR20/R20		PAR30		PAR38		MR16		Downlight Retrofit	
R^2 Value	80%		81%		95%		92%		89%		83%		86%	
	Actual	Predict	Actual	Predict	Actual	Predict	Actual	Predict	Actual	Predict	Actual	Predict	Actual	Predict
2012	$35.02	$33.54	$33.47	$31.60	$24.97	$23.72	$35.73	$35.24	$39.72	$42.34	$19.97	$22.27	$43.10	$46.84
2013	$24.98	$24.79	$29.98	$26.08	$21.47	$20.45	$31.97	$29.86	$36.97	$35.03	$19.91	$19.41	$36.12	$36.12
2013.5	$19.58	$21.31	$20.00	$23.69	$19.45	$18.99	$29.94	$27.48	$32.97	$31.86	$16.73	$18.12	$31.72	$31.72
2013.75	$19.97	$19.76	$20.49	$22.58		$18.30	$29.96	$26.37	$32.97	$30.38	$17.97	$17.51		$29.73
2014	$18.23	$18.32	$19.99	$21.52	$17.49	$17.64	$26.98	$25.30	$29.98	$28.98	$17.97	$16.92	$29.47	$27.86
2014.25	$15.97	$16.99	$19.66	$20.51	$14.97	$17.00	$20.00	$24.27	$24.97	$27.63	$16.81	$16.35	$27.47	$26.11
2014.5	$16.72	$15.75	$19.99	$19.55	$17.97	$16.38	$19.99	$23.29	$24.99	$26.35	$17.97	$15.79	$29.97	$24.46
2014.75	$14.10	$14.61	$20.10	$18.64	$15.87	$15.78	$23.88	$22.34	$24.97	$25.13	$16.57	$15.26	$20.90	$22.92
2015	$14.47	$13.54	$19.40	$17.76	$15.12	$15.21	$20.96	$21.44	$24.48	$23.97	$13.17	$14.74	$17.61	$21.48
2016		$10.01		$14.66		$13.11		$18.16		$19.83		$12.85		$16.57
2017		$7.40		$12.10		$11.31		$15.39		$16.40		$11.20		$12.78
2018		$5.47		$9.98		$9.75		$13.04		$13.57		$9.76		$9.85
2019		$4.04		$8.24		$8.41		$11.05		$11.23		$8.51		$7.60
2020		$2.99		$6.80		$7.25		$9.36		$9.29		$7.41		$5.86

Appendix D. Web-Scraping Incandescent, Halogen, and CFL Price Extrapolations

Table 26: Incandescent Price Extrapolation

Incandescent Price Extrapolation						
Product Category	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
A-Type*	$1.34	$1.33	--	--	--	--
Globe	$1.49	$1.48	$1.46	$1.45	$1.43	$1.42
Candle/Flame	$0.58	$0.57	$0.57	$0.56	$0.56	$0.55
Reflector**	$2.70	$2.67	$2.65	$2.62	$2.59	$2.57
MR16	--	--	--	--	--	--
PAR20/R20/BR20	$2.46	$2.43	$2.41	$2.38	$2.36	$2.33
PAR30	--	--	--	--	--	--
R30/BR30	$2.66	$2.64	$2.61	$2.58	$2.56	$2.53
PAR38	--	--	--	--	--	--
R40/BR40	$3.16	$3.13	$3.10	$3.07	$3.04	$3.01

* Based on conversations with retailers and manufacturers, it is expected that inventories of incandescent A-type lamps at all major retailers will be exhausted by 2017.

** The price extrapolations for "Reflector" are based on a weighted average of NEMA shipments for all reflector lamp shapes. Price estimates for each individual reflector lamp shape (MR16, PAR20/R20/BR20, PAR30, R30/BR30, PAR38, R40/BR40, and downlight retrofit lamps) are provided below.

Table 27: Halogen Price Extrapolation

Halogen Price Extrapolation						
Lamp Shape	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
A-Type	$1.62	$1.60	$1.59	$1.57	$1.56	$1.54
Globe	$1.63	$1.61	$1.59	$1.58	$1.56	$1.55
Candle/Flame	$1.67	$1.65	$1.64	$1.62	$1.60	$1.59
Reflector*	$5.78	$5.72	$5.67	$5.61	$5.55	$5.50
MR16	$4.74	$4.70	$4.65	$4.60	$4.56	$4.51
PAR20/R20/BR20	$6.98	$6.91	$6.84	$6.77	$6.70	$6.64
PAR30	$6.75	$6.68	$6.62	$6.55	$6.48	$6.42
R30/BR30	$4.33	$4.28	$4.24	$4.20	$4.16	$4.11
PAR38	$6.18	$6.12	$6.05	$5.99	$5.93	$5.87
R40/BR40	$7.49	$7.41	$7.34	$7.26	$7.19	$7.12

* The price extrapolations for "Reflector" are based on a weighted average of NEMA shipments for all reflector lamp shapes. Price estimates for each individual reflector lamp shape (MR16, PAR20/R20/BR20, PAR30, R30/BR30, PAR38, R40/BR40, and downlight retrofit lamps) are provided below.

Table 28: CFL Price Extrapolation

CFL Price Extrapolation						
Lamp Shape	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
A-Type	$2.98	$2.95	$2.92	$2.89	$2.86	$2.84
Globe	$3.16	$3.13	$3.10	$3.07	$3.04	$3.01
Candle/Flame	$3.46	$3.43	$3.39	$3.36	$3.32	$3.29
Reflector[Error! Bookmark not defined.]	$6.45	$6.39	$6.33	$6.26	$6.20	$6.14
MR16	--	--	--	--	--	--
PAR20/R20/BR20	$5.99	$5.93	$5.87	$5.81	$5.75	$5.69
PAR30	$9.83	$9.74	$9.64	$9.54	$9.45	$9.35
R30/BR30	$5.34	$5.28	$5.23	$5.18	$5.13	$5.08
PAR38	$6.56	$6.49	$6.43	$6.36	$6.30	$6.23
R40/BR40	$7.97	$7.89	$7.81	$7.73	$7.66	$7.58

Appendix E. Additional Point-of-Sale Models

2009-2012 and 2009-2013 Price Forecast

Both the 2009 to 2012 and 2009 to 2013 models showed that time was a significant predictor of price per Watt by bulb type. By adding additional years of data, we were able to decrease the standard error around the estimates and increase the precision of the coefficients. All models showed a close fit between the explained variance (within R-squared) and the explained variance due to independent variable impact on the dependent variable (adjusted R-squared); the models are virtually identical and above 90% (Table 29).

Table 29. Price Forecast Models

Variables	2009-2012	2009-2013
Intercept	1.23 (0.05)	1.00 (0.04)
CFL* T	0.25 (0.02)	0.14 (0.02)
Halogen* T	0.21 (0.02)	0.03 (0.01)
CFL	-3.20 (0.06)	-3.00 (0.05)
Halogen	-3.98 (0.05)	-3.61 (0.05)
T	-0.25 (0.04)	-0.14 (0.01)
Number of States	16	16
Number of Observations	192	240
Within R-squared	0.994	0.989
Adjusted R-squared	0.993	0.988

2009-2012 and 2009-2013 Model Results

The Team began the POS modeling analysis by running a 2009-2012 model and using the output to extrapolate through 2018. The model was a poor predictor of LED 2014 prices and under-predicted the actual 2014 LED prices by more than 40%. When these modeled values were extrapolated out to 2018, the LED prices were very low, only $2.81 (**Table 30, Table 31, and Table 32**). The Team developed a few hypotheses on why the 2009-2012 model was such a poor foundation for extrapolation. First, the presence of non-specialty LEDs was not the norm in the channels represented by our data during the years 2009-2010. By restricting the data to the 2009-2012 period, we model a different market that does not incorporate the "typical" affordable A-line LED.

Table 30. Predicted Wattage Prices for 2014 based on 2009-2012 model

Bulb Type	Observed Non-Program State Average Value	Predicted Value (90% CI)	Difference (predicted-actual)
LED	$1.35	$0.76, ±(0.06)	-$0.59
CFL	$0.14	$0.13, ±(0.01)	-$0.01
Halogen	$0.03	$0.05, ±(0.0023)	$0.02

Table 31. Price per Watt Forecast through 2018 based on 2009-2012 model with Delta Method Standard Errors

Year	LED	CFL	Halogen
2014	$0.76, ±(0.06)	$0.13, ±(0.01)	$0.05, ±(0.002)
2015	$0.60, ±(0.06)	$0.13, ±(0.02)	$0.05, ±(0.003)
2016	$0.46, ±(0.06)	$0.13, ±(0.02)	$0.05, ±(0.003)
2017	$0.36, ±(0.06)	$0.13, ±(0.02)	$0.05, ±(0.003)
2018	$0.28, ±(0.06)	$0.13, ±(0.02)	$0.04, ±(0.004)
*Predictive margins at 90% confidence shown in parentheses.			

Table 32. Example Forecasted Prices for a 640-Lumen Bulb based on a 2009-2012 model

Year	10-Watt LED	13-Watt CFL	43-Watt Halogen
2014	$7.64	$1.75	$2.20
2015	$5.95	$1.74	$2.12
2016	$4.64	$1.73	$2.04
2017	$3.61	$1.72	$1.97
2018	$2.81	$1.72	$1.89

Table 33 shows the price per Watt extrapolated from a 2009-2013 model; the estimates are close to the actual 2014 price per Watt. The predicted value of the 2014 LED price per Watt is 14 cents lower than the actual price per Watt, the predicted CFL estimate is exact, and the halogen estimate is within a cent of the actual 2014 price per Watt. In our model, the predicted price per Watt for LEDs decreases by a little less than half by 2018. When the price per Watt is applied to a 10-Watt LED bulb, we see the price drop from an average of $12.08 in 2014 to an average of $7.03 in 2018 (Table 34 and Table 35). Predicted CFL price per Watt shows a slight increase throughout the prediction period, while halogen price per Watt continue to decrease and, when extrapolated to a 43-Watt bulb, decreases in price by 36% from 2014 to 2018.

Table 33. Predicted Wattage Prices for 2014 based on 2009-2013 model

Bulb Type	Observed Non-Program State Average Value	Predicted Value (90% CI)	Difference (predicted-actual)
LED	$1.35	$1.21, ±(0.06)	-$0.14
CFL	$0.14	$0.14, ±(0.01)	$0.00
Halogen	$0.03	$0.04, ±(0.0018)	$0.01

Table 34. Price per Watt through 2018 based on 2009-2013 model with Delta Method Standard Errors

Year	LED	CFL	Halogen
2014	$1.21, ±(0.06)	$0.14, ±(0.01)	$0.04, ±(0.002)
2015	$1.06, ±(0.07)	$0.14, ±(0.01)	$0.03, ±(0.002)
2016	$0.92, ±(0.08)	$0.14, ±(0.02)	$0.03, ±(0.002)
2017	$0.81, ±(0.09)	$0.14, ±(0.02)	$0.03, ±(0.002)
2018	$0.70, ±(0.09)	$0.14, ±(0.02)	$0.02, ±(0.002)

Table 35. Example Prices for a 640-Lumen Bulb based on a 2009-2013 model

Year	10-Watt LED	13-Watt CFL	43-Watt Halogen
2014	$12.08	$1.83	$1.66
2015	$10.55	$1.84	$1.49
2016	$9.22	$1.85	$1.34
2017	$8.05	$1.86	$1.20
2018	$7.03	$1.87	$1.07