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Memo to:

Massachusetts Program Administrators Research Team and Energy Efficiency Advisory Council EM&V Consultants

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Project 75 LED Market Monitor Study: Lighting Market Model Summary Memorandum

1 LIGHTING MARKET MODEL OBJECTIVES

This memo summarizes DNV GL's analysis of the commercial and industrial (C&I) lighting market in Massachusetts and investigation into future market share forecasts with and without program intervention. As part of this LED Lighting Market Monitor study, DNV GL provided the Massachusetts Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) consultants with current information and data on the LED commercial and industrial (C&I) lighting market in Massachusetts by compiling sources of market information in Massachusetts and other comparable regions. DNV GL utilized this information to develop a topic-level summary memo and a stock adjustment model to forecast LED market share and energy savings associated with the future adoption of efficient lighting.

The research objectives addressed by this model include:

1. Developing a detailed first year inventory of the installed stock of lighting equipment in Massachusetts C&I facilities, including the number of lamps installed by building type, lighting application, and equipment technology. This first-year inventory reflects conditions in the population of Massachusetts C&I facilities as of 2015, the completion date for data collection used in the on-site commercial market characterization study.[1]

2. Developing algorithms for forecasting annual changes in the installed stock through 2026 that can support future planning efforts, including research into the future industry standard practice (ISP) for C&I lighting.[2] These algorithms are based on awareness of LED lighting and the benefit-cost ratios associated with each technology.

3. Estimating annual energy use for the actual or forecasted installed inventory by building type, lighting application group, and equipment technology for the 2015-2026 period.

[1] DNV GL, "MA C&I Market Characterization On-Site Assessments and Market Share and Sales Trends Study: Volume I - Main Report" (Massachusetts Program Administrators and Energy Efficiency Advisory Council, November 2016), http://ma-eeac.org/wordpress/wp-content/uploads/MA-CI-Market-Characterization-Study.pdf.

[2] The forecast period extends to 2026 to better understand what the future ISP looks like through 2026 which is required for calculating lifetime savings of retrofit lighting in the 2019-2021 planning cycle. Existing linear lighting technology generally has a life of 15 years, and the assumption is that the remaining useful life of existing equipment is ⅓ of the effective useful life. Calculating the lifetime savings of equipment installed in 2019-2021 requires the future ISP in 2024-2026.

The model produces results for two market development scenarios:

- **Program Scenario:** This scenario represents our best estimate of what the installed stock and market share of equipment technologies will be from 2015 through the end of forecast period using actual program data from 2016 through 2018 and assumptions about the program for the remainder of the forecast period.
- **No Program Scenario:** This scenario represents our best estimate of what the installed stock and market share of equipment technologies will be from 2015 through the end of forecast period in the absence of PA programs to promote efficient C&I lighting.

Appendix A provides details on the inputs and sources of data used in the model. The results of the model are available in a Microsoft Power BI dashboard, which allows users to see installed stock of lamps, market share, consumption, and savings over time in both scenarios. The interactive dashboard can show the whole market over time or be filtered to isolate specific market segments at a point in time. In addition to the interactive dashboard, we also provide high-level market share results in Appendix B. Appendix B also provides instructions on how to access the Power BI dashboard, and Appendix C provides instructions for accessing the bibliographic database.

In the following sections, we describe the methodology of for developing the model, and the inputs used in the model.

2 MODEL APPROACH

The model developed for this study uses a stock adjustment modeling approach to forecast the size and composition of the stock of C&I lighting each year and the energy consumption associated with that stock. Each year, a portion of the total installed stock of lamps is assumed to be replaced, because of equipment failure, equipment retrofits, or new construction. The replacement lamps in each year consist of a variety of technologies based on that year's sales mix. The modeling framework removes the lamps that are replaced from the analysis, includes the newly installed lamps, and calculates the consumption and savings associated with the installed stock in that year. The following sections explain how we calculated stock and energy consumption in the baseline year (2015) and how the model estimates stock turnover and forecasts annual sales mix in each scenario.

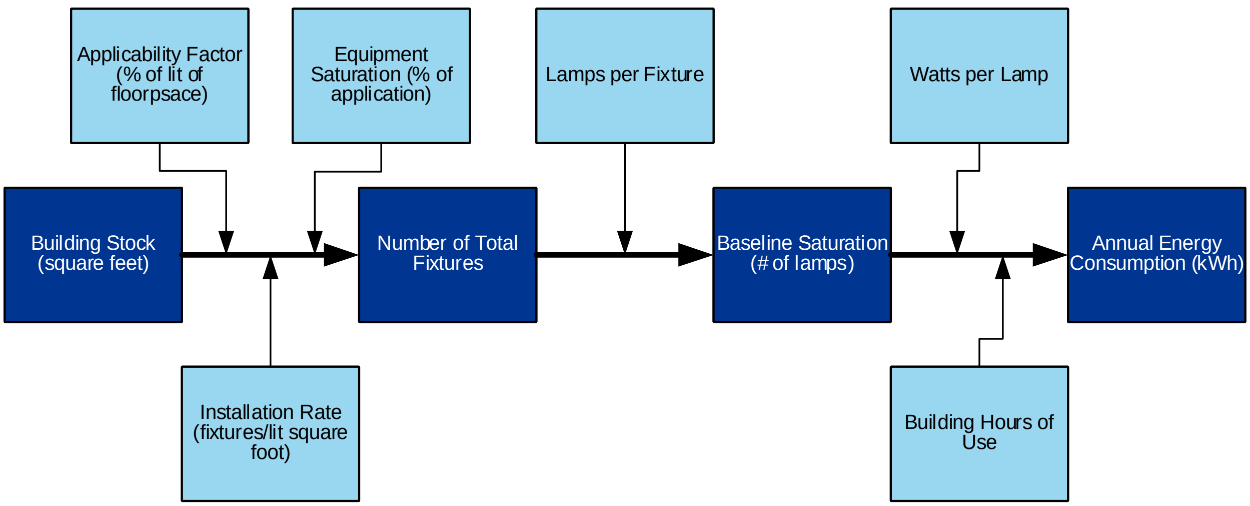
The model produces results by building type, application type, and equipment type. The model includes 13 unique building types, 5 major interior and exterior lighting applications (e.g. linear and screw-based), and 14 specific equipment types (e.g. CFL, LED). See Appendix A for a detailed list of the market segments and description of all the inputs used throughout the model.

2.1 Determining Baseline Saturation and Energy Consumption

To determine the baseline installed stock, the model derives input parameters from the on-site commercial market characterization study that inventoried sites in 2014 and 2015. These parameters include the applicability factor (% of floorspace lit by lighting application), installation rate (fixtures/lit ft^2), equipment saturation within the lighting application, and the average lamps per fixture. Combining these factors for each market segment yields the total number of lamps installed in the C&I

sector in 2015. To calculate the consumption associated with each market segment, we multiplied the total number of installed lamps by the respective wattage of each lamp type and operating hours of the building type.[3] Figure 1 diagrams the inputs used to calculate baseline saturation and the sum of annual energy consumption. Equation 1 and 2 show how unit energy consumption (UEC) and annual energy consumption (AEC) are calculated for each market segment.

Figure 1. Calculating Baseline Saturation and Consumption



Equation 1. Unit Energy Consumption

$$\textit{Unit Energy Consumption} = \textit{Average Wattages}_{a,e,t} \times \textit{Annual Operating Hours}_{b}$$

where a=application, b=building type, e=equipment, and t=year

Equation 2. Annual Energy Consumption

$$\textit{Annual Energy Consumption}_{y} = \sum_{a,b,t} (\textit{Installed Lamps}_{a,b,e,t} \times \textit{Unit Energy Consumption}_{a,b,e,t})$$

where a=application, b=building type, e=equipment, and t=year

3 Operating hours are derived the Massachusetts TRM, where appropriate, or other TRMs from the Northeast. The operating hour assumptions are included in Appendix A of this memo.

2.2 Forecasting Annual Stock Turnover and the Annual Sales Mix

2.2.1 Available Stock

In each year, a portion of the stock is expected to be eligible for upgrade through one of two purchase events that create opportunities for stock turnover: replace on burnout (ROB) and retrofit or early replacement. New construction introduces additional opportunities for the adoption of various lighting technologies.

The stock turnover rate for ROB lamps is calculated by dividing the installed equipment's rated lifetime operating hours by the building type's effective lighting hours of use; this rate, once applied to annual stock in the preceding year, determines the eligible ROB stock each year. Because the lifetime operating hours of incandescent and halogen lamps are very low while the effective lighting hours of building types is high, the maximum turnover for these equipment types is set at 50% per year. Without this cap, these lamps would turnover more than once per year, which is likely unrealistic compared to the actual market. The remaining stock after the ROB stock is determined is available for retrofit; the actual amount of stock that is ultimately retrofit is determined as a function of awareness and the benefit-cost ratio, which are explained in the following subsections. New construction, represented by annual growth in total floorspace by building type, creates an opportunity for lamp installation as well.

2.2.2 Awareness

In our model, to be eligible for upgrade, a lamp must be available for replacement through ROB, retrofit, or new construction and the customer must be aware of the more-efficient technology. If the stock is not available for upgrade or the customer is unaware of the more-efficient technology at the time of replacement, the technology type is unchanged until the lamp is available for upgrade and the customer is aware of the efficient option.

There are three types of awareness that serve as inputs in this model and contribute to overall technology awareness: market awareness, program starting awareness, and new program awareness.

- **Market Awareness**. Market awareness is the amount of awareness in the market that can be assumed to exist because of the measure's cost-effectiveness. We assume that the benefits of the measure is spread through word of mouth in the marketplace and that a higher benefit cost ratio results in more market awareness.

  In the Program Scenario, this level of awareness will be higher for incentivized equipment than in the NO Program Scenario because the benefit-cost ratio will be greater. We used the level of LED technology awareness, 27%, from the comparison area customer surveys conducted for the 2015 LED Market Effects Baseline Study[4] to calibrate the market awareness. We chose to use this value because it isolates the level of awareness that comes directly from the cost-benefit ratio of LEDs and is not influenced by program efforts.

[4] DNV GL, "Final Draft Report of Massachusetts LED Market Effects: Baseline Characterization" (Massachusetts Program Administrators and Energy Efficiency Advisory Council, March 1, 2015), http://ma-eeac.org/wordpress/wp-content/uploads/LED-Market-Effects-Baseline-Characterization-Final-Draft.pdf.

- **Program Starting Awareness**: Program starting awareness represents the level of energy efficiency program awareness among Massachusetts' C&I customers in 2016. As the NO program scenario intends to look at the future market share if the program were discontinued after 2015, we set the 2016 program starting awareness to be equal for both scenarios. Furthermore, our 2015 saturation estimates are based on observed saturation from 2014 and 2015 that has been influenced by program efforts. Thus, our NO program scenario intends to forecast market share if the program were discontinued in 2016 rather than predict what the market may have looked like absent the program entirely.

  As such, we use the same program starting awareness for both scenarios as it corresponds with awareness at the beginning of 2016 when we assume the program is discontinued in our analysis. The model assumes 63% as the level of program starting awareness based off the 2016 Massachusetts statewide marketing campaign report[5] which stated 63% of C&I customers knew energy-saving programs could help their business save energy.

- **New Program Awareness**: New program awareness builds customer awareness, on an annual basis, in the Program Scenario based on the program marketing budget for each event type and an advertising effectiveness ratio (cost to make a "lamp" known to consumers via increasing customer awareness of the program). To calculate this, the model assumes a portion of sockets change from consumers being unaware of the program to aware of the program based on the amount of marketing dollars (see Table 11) that are spent in a year and how effective the advertising is in reaching those sockets.

2.2.3 Implementation Rate and the Benefit Cost Ratio

The final stage in determining the level of technology adoption in each year is to develop an implementation rate using a diffusion curve modeling process. The implementation rate determines the percent of aware stock that will adopt a specific technology, as a function of the benefit-cost ratio.

Using a diffusion curve approach to estimating customer adoption ensures that customer adoption of technologies is not linearly related to the benefit cost ratio as customers need to overcome various market barriers before adopting a measure. The diffusion curve shape is dependent on three parameters: max, mid, and fit. Equation 3 shows the implementation rate calculation and Figure 2 shows the shape of a diffusion curve using example parameters.

Equation 3. Implementation Rate

$$F(x_i) = \frac{Max_j}{\left(1 + e^{(-\ln(0.25 * BC_i))}\right) * \left(1 + e^{(-\operatorname{fit}_j(mid_j * BC_i))}\right)}$$

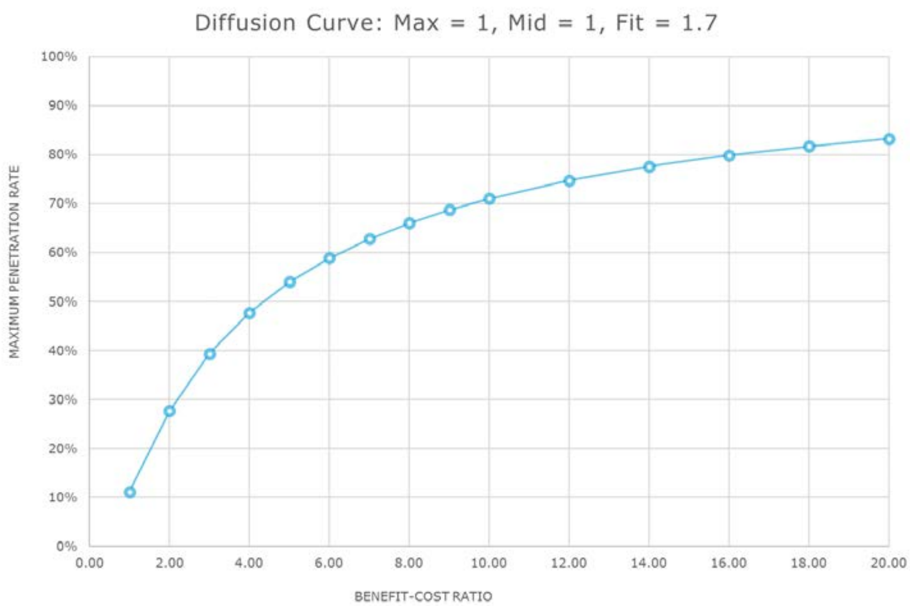
Where:

- $F(x_i)$ = Implementation rate for measure x under scenario *i*
- Max_j = Max Parameter for end use and segment *j*

[5] Opinion Dynamics, "2016 Massachusetts Statewide Marketing Campaign: Post-Campaign Report," March 14, 2017, http://ma-eeac.org/wordpress/wp-content/uploads/PY2016-Mass-Save-Awareness-Campaign-Report-1.pdf.

  - *The maximum portion of the population that will ever adopt the EE technology*
- BC_i = Benefit Cost Ratio for measure x under scenario *i* in a given year
- Fit_j = Fit Parameter for end use and segment *j*
  - *Determines the steepness of the curve*
- Mid_j = Mid Parameter for end use and segment *j*
  - *Determines the inflection point of the S curve*

Figure 2. Example of an Equipment Type Diffusion Curve



For this analysis, we used the benefit-cost ratio based on the savings and incremental cost between the existing equipment (or standard equipment if the existing technology is no longer available in the market) and each potential replacement technology. The lamp costs and methodology for calculating LED prices are explained in the Price Forecasts and Program Budget section of Appendix A and presented in Table 8 and Table 9. Benefit-cost also contributes to overall market awareness as explained in the previous section, but in this section of the model, it is directly correlated with the implementation rate. It is also important to note that this model does not allow for any backsliding. A socket does not necessarily have to be upgraded, but it is never replaced with a less efficient technology, even though it is possible that this is happening in the market.

The diffusion curve calculation assumes that as the benefit-cost ratio increases, the implementation rate increases. The main difference between the Program and the NO Program Scenario is the price of efficient equipment due to program incentives; thus, the benefit-cost ratios and implementation rate of efficient technologies are higher in the Program Scenario. However, as noted above, this does not happen linearly and the shape of the curve, as determined by the parameters, impacts the rate of increase.

The max parameter assumes that potential adopters have different degrees of resistance to change and that some may never adopt a new measure despite the benefits. This parameter can also be understood as the theoretical saturation level, which once achieved, no additional measures will be adopted. The mid parameter determines the inflection point of the diffusion curve. This can be considered the point where the increase in penetration for every unit increase in the benefit cost ratio begins to decrease. The fit parameter determines the steepness of the diffusion curve as it passes through the midpoint of the diffusion curve.

The curves for each efficient equipment technology were calibrated using these parameters and by comparing model results in the early years to claimed savings from 2015 and 2016 tracking data. We used a max of 1, a mid of 1, and a fit of 1.7, typical parameters from the 2015 National Grid Potential Study lighting technologies, as a starting point and then adjusted the curves from that point to better reflect actual savings from 2015 and 2016. The forecasted year results were compared against national[6] and regional forecasts[7] of equipment type saturation. Diffusion curves are unnecessary for base equipment since the model assumes that all sockets that are not upgraded remain the base technology. As more data becomes available from 2017 and 2018, we can improve the calibration of the curves to increase the accuracy of forecasted years.

3 MODEL INPUTS, RESULTS, AND FUTURE IMPROVEMENTS

The LED market model discussed in this memo relies on a set of input assumptions and algorithms. While we discuss the algorithms in previous sections of this memo, Appendix A details the inputs used in the model, including how the input was used and the source. The model incorporates as much data from Massachusetts as possible, and is calibrated using the tracking data available at the time of this study (May 2017). However, some of the assumptions in the model are based off limited data or data that is not specific to Massachusetts, such as 2014-2015 saturation data or price forecasts from 2015.

One of the strengths of this model is that it can be updated with relative ease. DNV GL built this model in Microsoft Excel with a structure that allows for updates as more information becomes available. Updated data points that can easily be plugged into the model include:

- Price of LED lamps ($/kilolumen)
- Efficacy (lumens/watt)
- Watts per lamp
- Lamp lifetime operating hours
- Lamps per fixture
- Saturation (fixtures/lit square foot)

[6] U.S. Department of Energy, "Energy Savings Forecast of Solid-State Lighting in General Illumination Applications" (Solid-State Lighting Program, September 2016), https://energy.gov/sites/prod/files/2016/10/f33/energysavingsforecast16_0.pdf.

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

- Building floorspace growth rate
- Building type effective lighting hours of use
- Cost of electricity
- Incentive amounts
- Program budgets for marketing and advertising by event type
- Savings assumptions.

As the implementation rate is a function of the benefit-cost ratio, updating incentive levels, price and efficacy forecasts, and watts per lamp will have the largest impact in improving the accuracy of the model.

There are also other opportunities to improve the model. As explained in the previous section, we calibrated the diffusion curves against 2015 and 2016 claimed savings from the tracking data as well as national and regional forecasts of LED saturation from 2016 through 2035. Additional research in Massachusetts can offer more recent data that will provide insight to further calibrate the diffusion curves. Some of the ongoing research efforts in Massachusetts that may inform this model include:

- Project 53-C&I Lighting and Controls Market Effects Study: In-depth interviews with market actors and panel surveys of distributors
- Project 78-Upstream LED NTG Study: On-site surveys with participant customers
- Project 81-Upstream Process Evaluation: CATI and on-site surveys with participant and non-participant customers

Future research efforts to investigate current practices in new construction will also be a valuable source of information for this model as it will provide a clearer picture of what is being installed in new facilities as linear LED technologies continue to advance.

In addition to updating the model inputs, there are also opportunities for expanding the functionality of the model. The model is currently structured at the lamp level and uses lamp replacement as a proxy for all types of replacement including retrofit kits. This structure also assumes application type does not change over time, i.e., a screw-based fixture is not replaced with a linear fixture. However, the structure of the model was designed so that more types of lighting equipment can be included and the algorithms can be adjusted to show different types of equipment replacement.

While the model was built in the excel, DNV GL developed a Microsoft Power BI dashboard to provide a more interactive display of the results. This dashboard allows the user to compare the Program and NO Program Scenario and isolate the market segments of interest. It allows the user to focus on specific lighting applications and/or different years and to easily visualize the intended results. To view the dashboard of results, see the instructions in Appendix B for access. Appendix C also provides instructions on how to access the bibliographic database, which includes details on C&I lighting research conducted for this study.

APPENDIX A. INPUTS AND SOURCES OF DATA

Building Characteristics

The starting points for building the model is the total C&I floorspace in Massachusetts. Building square footage and site weights from the 2015 MA C&I Market Characterization On-Site Assessments and Market Share and Sales Trends Study[8] were used to estimate the total amount of floorspace for 13 building types. These building types were used throughout the model. The rate of new construction is shown through the growth in total floorspace, and the model uses growth forecasts from the U.S. Energy Information Administration's 2014 Energy Outlook[9] that was also used in the U.S. Department of Energy's forecast of solid-state lighting.[10] The effective lighting hours of use for each building type was based off the MA Technical Resource Manual (MA TRM);[11] however, the hours of use in four building types produced consumption estimates that were higher than expected. The four building types that differ from the MA TRM are Healthcare, Hospitals, Lodging, and Public Assembly. The hours of use for these building types were replaced with hours of use from other research with more appropriate hours of use. Table 1 below details the building type characteristics.

Table 1. Building Characteristics

Building Type	Floorspace in 2015 (ft^2)	Floorspace Growth Rate	Effective Lighting Hours
Campus	106,434,950	1.00%	3,255
Education	345,177,802	1.00%	2,596
Food Sales	47,217,557	1.00%	6,074
Food Service	48,590,699	1.00%	5,110
Healthcare	77,163,034	1.00%	3,748*
Hospitals	47,372,415	1.00%	7,674*
Lodging	146,818,627	1.00%	4,015*
Manufacturing or Industrial	198,000,683	0.24%	4,730
Office	419,059,542	1.00%	3,610
Other	514,385,532	1.00%	3,951
Public Assembly	390,375,977	1.00%	3,035*
Retail	459,452,812	1.00%	4,089
Warehouse	181,027,036	1.00%	3,759

*=hours of use not from the MA TRM

[8] DNV GL, "MA C&I Market Characterization On-Site Assessments and Market Share and Sales Trends Study: Volume I - Main Report."

[9] U.S. Energy Information Administration, "Annual Energy Outlook 2014 with Projections to 2040," April 2014, https://www.eia.gov/outlooks/archive/aeo14/pdf/0383(2014).pdf.

[10] U.S. Department of Energy, "Energy Savings Forecast of Solid-State Lighting in General Illumination Applications" (Solid-State Lighting Program, August 2014), https://www1.eere.energy.gov/buildings/publications/pdfs/ssl/energysavingsforecast14.pdf.

[11] Mass Save, "Massachusetts Technical Reference Manual for Estimating Savings from Energy Efficiency Measures: 2016-2018 Program Years-Plan Version," October 30, 2015, http://ma-eeac.org/wordpress/wp-content/uploads/2016-2018-Plan-1.pdf.

Lighting Application and Equipment Technology Characteristics

Within each building type, there are five interior and five exterior lighting applications. These applications each contain specific equipment types. When a stock turns over, it is the equipment type within an application that can be replaced with a more efficient technology within the same lighting application. To calculate the total number of fixtures in the baseline, the total floorspace was multiplied by the applicability factor—the percent of floorspace lit by a lighting application—and the saturation rate, which is the fixtures per lit square foot. Table 2 and Table 3 list these factors for each building type and lighting application.

To move from the numbers of fixtures within an application to the number of fixtures for each equipment type, we applied an installed stock market share percentage. This shows the percent of sockets within each lighting application that belong to the equipment types available in the application. The sum of these percentages should be 100% in each lighting application. To calculate the total number of lamps, we applied an average lamps-per-fixture. To simplify how the equipment types were upgraded, we applied the lamps-per-fixture that was the same across lighting applications. All the factors presented in this subsection use the data from the Market Characterization On-Site Assessments and Market Share and Sales Trends Study.[12] Table 4 and Table 5 list the percent of installed stock and the average lamps per fixture. The wattages and lifetime operating hours presented in Table 6 and Table 7 are based off ratings of some of the most popular equipment types within the lighting application. These factors, combined with the building effective lighting hours, determine the annual consumption in each year and dictate the burnout rate of the different equipment types. They also determine the benefit-cost ratio for each equipment type alternative. However, the wattages and building effective lighting hours do not determine the total savings or net savings presented on the results dashboard.

[12] DNV GL, “MA C&I Market Characterization On-Site Assessments and Market Share and Sales Trends Study: Volume I - Main Report.”

Table 2. Lighting Applicability Factor (% of floorspace lit by lighting application)

Application	Campus	Education	Food Sales	Food Service	Healthcare	Hospital	Lodging	Manufacturing or Industrial	Office	Other	Public Assembly	Retail	Warehouse
Indoor HID Lamp	20.1%	40.8%	7.1%	0.5%	6.9%	30.8%	3.6%	10.0%	5.6%	37.7%	6.9%	13.3%	26.6%
Indoor Linear Lamp	41.1%	97.1%	89.6%	72.2%	78.8%	84.9%	70.8%	83.9%	83.7%	82.7%	141.8%	97.9%	94.4%
Indoor Screw-Based Decorative	1.7%		1.4%	33.5%	9.5%	3.9%	40.1%	0.0%	0.4%	12.4%	77.1%	0.1%	
Indoor Screw-Based General	35.6%	55.8%	37.8%	91.1%	75.1%	77.7%	85.5%	31.4%	68.3%	77.6%	140.4%	59.3%	40.2%
Indoor Screw-Based Other	11.9%	11.8%	30.4%	23.2%	15.3%	23.0%	6.0%	4.9%	12.1%	1.0%	69.9%	21.3%	5.2%
Outdoor HID Lamp	20.7%	20.4%	25.0%	11.7%	15.7%	48.9%	9.7%	37.5%	26.2%	21.4%	22.7%	6.9%	33.5%
Outdoor Linear Lamp	0.4%	1.0%	0.9%	10.0%	7.1%	9.4%	6.1%	0.4%	7.6%	2.9%	0.9%	1.3%	
Outdoor Screw-Based Decorative			1.4%	3.1%	2.9%		2.3%		0.0%	0.1%	0.0%		
Outdoor Screw-Based General	36.3%	20.6%	10.4%	21.5%	17.5%	28.3%	46.4%	11.8%	18.5%	3.5%	17.0%	3.4%	26.7%
Outdoor Screw-Based Other	20.2%	36.9%	7.4%	5.2%	20.6%	25.2%	9.3%	17.6%	16.3%	48.2%	8.3%	3.8%	8.4%

Table 3. Lighting Saturation Rate (fixtures/lit ft²)

Application	Campus	Education	Food Sales	Food Service	Healthcare	Hospital	Lodging	Manufacturing or Industrial	Office	Other	Public Assembly	Retail	Warehouse
Indoor HID Lamp	0.0001	0.0003	0.0007	0.0020	0.0006	0.0002	0.0014	0.0006	0.0004	0.0003	0.0007	0.0015	0.0021
Indoor Linear Lamp	0.0077	0.0099	0.0132	0.0060	0.0079	0.0051	0.0039	0.0057	0.0118	0.0058	0.0034	0.0096	0.0040
Indoor Screw-Based Decorative	0.0001		0.0016	0.0040	0.0018	0.0002	0.0028	0.0001	0.0001	0.0004	0.0003	0.0005	
Indoor Screw-Based General	0.0039	0.0012	0.0026	0.0136	0.0074	0.0009	0.0209	0.0013	0.0044	0.0030	0.0033	0.0049	0.0007
Indoor Screw-Based Other	0.0018	0.0020	0.0027	0.0036	0.0028	0.0004	0.0042	0.0009	0.0041	0.0015	0.0008	0.0024	0.0013
Outdoor HID Lamp	0.0002	0.0003	0.0005	0.0016	0.0002	0.0003	0.0003	0.0002	0.0003	0.0008	0.0008	0.0014	0.0008
Outdoor Linear Lamp	0.0002	0.0001	0.0050	0.0045	0.0011	0.0002	0.0017	0.0001	0.0005	0.0014	0.0001	0.0081	
Outdoor Screw-Based Decorative			0.0011	0.0007	0.0007		0.0005		0.0011	0.0004	0.0005		
Outdoor Screw-Based General	0.0005	0.0001	0.0006	0.0015	0.0009	0.0001	0.0003	0.0003	0.0008	0.0058	0.0013	0.0016	0.0006
Outdoor Screw-Based Other	0.0001	0.0002	0.0004	0.0006	0.0013	0.0001	0.0005	0.0002	0.0007	0.0001	0.0012	0.0019	0.0002

Table 4. Percent of Installed Stock by Lighting Application (Year=2015)

Application	Mercury Vapor	Metal Halide	Sodium Lamp	Area LED	Fluorescent U-Tube	Linear LED	Linear Fluorescent Low Wattage T8	Linear Fluorescent Standard T8	Linear Fluorescent T12	Linear Fluorescent T5	CFL	Halogen	LED	Incandescent
Indoor HID Lamp	2.0%	89.8%	8.2%	0.0%										
Indoor Linear Lamp					7.9%	4.0%	21.1%	46.3%	15.3%	5.4%				
Indoor Screw-Based Decorative											2.9%	0.3%	5.1%	91.7%
Indoor Screw-Based General											49.2%	8.5%	26.6%	15.7%
Indoor Screw-Based Other											3.6%	10.9%	82.9%	2.7%
Outdoor HID Lamp	4.5%	66.5%	28.9%	0.0%										
Outdoor Linear Lamp						9.3%	29.2%	28.2%	16.8%	16.5%				
Outdoor Screw-Based Decorative											24.0%		4.8%	71.1%
Outdoor Screw-Based General											41.0%	9.7%	19.8%	29.5%
Outdoor Screw-Based Other											0.3%	16.3%	83.1%	0.3%

Table 5. Lamps per Fixture

Application	Mercury Vapor	Metal Halide	Sodium Lamp	Area LED	Fluorescent U-Tube	Linear LED	Linear Fluorescent Low Wattage T8	Linear Fluorescent Standard T8	Linear Fluorescent T12	Linear Fluorescent T5	CFL	Halogen	LED	Incandescent
Indoor HID Lamp	1.05	1.05	1.05	1.05										
Indoor Linear Lamp					2.35	2.35	2.35	2.35	2.35	2.35				
Indoor Screw-Based Decorative											4.40	4.40	4.40	4.40
Indoor Screw-Based General											1.25	1.25	1.25	1.25
Indoor Screw-Based Other											2.10	2.10	2.10	2.10
Outdoor HID Lamp	1.13	1.13	1.13	1.13										
Outdoor Linear Lamp					2.13	2.13	2.13	2.13	2.13	2.13				
Outdoor Screw-Based Decorative											2.25	2.25	2.25	2.25
Outdoor Screw-Based General											1.38	1.38	1.38	1.38
Outdoor Screw-Based Other											1.16	1.16	1.16	1.16

Table 6. Watts per Lamp

Application	Mercury Vapor	Metal Halide	Sodium Lamp	Area LED	Fluorescent U-Tube	Linear LED	Linear Fluorescent Low Wattage T8	Linear Fluorescent Standard T8	Linear Fluorescent T12	Linear Fluorescent T5	CFL	Halogen	LED	Incandescent
Indoor HID Lamp	275	250	225	97										
Indoor Linear Lamp					30	15	28	32	34	24				
Indoor Screw-Based Decorative											10	28	6	40
Indoor Screw-Based General											13	43	8	60
Indoor Screw-Based Other											18	53	14	75
Outdoor HID Lamp	275	250	225	97										
Outdoor Linear Lamp					30	15	28	32	34	24				
Outdoor Screw-Based Decorative											10	28	6	40
Outdoor Screw-Based General											13	43	8	60
Outdoor Screw-Based Other											23	72	18	100

Table 7. Equipment Type Lifetime Operating Hours

Application	Mercury Vapor	Metal Halide	Sodium Lamp	Area LED	Fluorescent U-Tube	Linear LED	Linear Fluorescent Low Wattage T8	Linear Fluorescent Standard T8	Linear Fluorescent T12	Linear Fluorescent T5	CFL	Halogen	LED	Incandescent
Indoor HID Lamp	24,000	10,000	24,000	50,000										
Indoor Linear Lamp					24,610	50,000	24,610	24,610	20,000	30,760				
Indoor Screw-Based Decorative											10,250	1,800	25,000	1,000
Indoor Screw-Based General											10,560	2,000	25,000	1,800
Indoor Screw-Based Other											10,250	3,080	25,000	2,560
Outdoor HID Lamp	24,000	10,000	24,000	50,000										
Outdoor Linear Lamp					24,610	50,000	24,610	24,610	20,000	30,760				
Outdoor Screw-Based Decorative											10,250	1,800	25,000	1,000
Outdoor Screw-Based General											10,560	2,000	25,000	1,800
Outdoor Screw-Based Other											10,250	3,080	25,000	2,560

Price Forecasts and Program Budget

The main component of the cost side of the benefit-cost ratio is based on lamp prices. The model uses the 2015 commercial sector technology performance from the U.S. Department of Energy solid-state lighting forecast report[13] to determine the lamp price of non-LED lighting. The model assumes that these prices remain constant through the forecast period of the model. For non-LED lighting, prices were set using the same report's projections for dollars per thousand lumens for LED lighting applications combined with efficacy forecasts to determine the price per LED lamp based on its wattage. The price trend in the report was determined using an automated web-scraping software. We used a best-fit polynomial line to connect the forecasts that were given for every 5 years. Table 8 and Table 9 detail the actual prices used in the model. The incentive levels, shown in Table 10, used in the Program Scenario were based off actual data provided by CLEAResult for years 2016-2018. The incentive levels for 2019-2026 are set to 2018 levels.

The benefit side of the benefit-cost ratio is determined by multiplying the consumption differences (equipment wattage and building hours of use) between lighting technologies and the cost of electricity. The cost of electricity is set at $0.1579 per kilowatt hour[14] and the total benefit is calculated using a discount rate of 6% to put the benefit in real dollars. The benefit-cost ratio is used throughout the model to set both the implementation rate of equipment technologies and the level of market awareness.

Section 2.2.2 above describes how new program awareness adds to the total awareness within in stock. This type of awareness is directly tied to the amount of marketing dollars spent through the program on each type of event (ROB, retrofit, new construction). Table 11 lists the budget for each event type. The model incorporates evaluated or planned dollars for years 2016-2018, and years 2019-2026 are determined using the same budget growth rate per year as between 2017 and 2018; these data came from the EEAC annual reports.[15] This budget must be allocated in the model to the different building types, and this ratio is based on the proportion of the total number of lamps in each building type installed in the baseline year. Table 12 lists these allocations.

To calculate the effectiveness of the marketing dollars, the model uses an ad effectiveness ratio that assumes that for every $0.02 spent on marketing, there is an incremental increase in consumer awareness of the program and energy efficiency options. While this type of awareness is measured in the number of sockets made aware to be equivalent to other modeling assumptions, marketing efforts are targeted at the consumer level.

DNV GL calculated the ad effectiveness ratio used in the model based off 2016 upstream results and stock turnover. We first divided the 2016 upstream lighting marketing dollars by the total number of upstream lamps sold through the program to obtain the marketing cost per purchased upstream lamp ($0.135). Since the ad effectiveness ratio is the cost to "reach a lamp" prior to adoption, more lamps had to be reached than only those installed through the program in 2016; we assumed that only 13.5%

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

[14] U.S. Energy Information Administration, "Average Price (Cents/Kilowatthour) by State by Provider, 1990-2016," April 24, 2018, https://www.eia.gov/electricity/data.php#sales.

[15] MA EEAC, "Energy Efficiency Data Tables: 2016 Plan Year Report Overview," May 1, 2017, http://ma-eeac.org/results-reporting/.

of lamps would be eligible for a ROB upgrade based on the turnover rate for T8 lamps. Thus, we assumed lamps had to be eligible for upgrade and an appropriate level of awareness needed to be reached for LED adoption to occur; we calculated ad effectiveness to be $0.02 to “reach a lamp” ($0.135 * 13.5%).

The model also includes an awareness decay rate that assumes awareness does not continue in perpetuity and consumers will forget the benefits of the program over time. This rate differs between purchase events and is based off previous research. Table 13 lists these values.

Table 8. LED Lamp Price Forecasts

Application	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Indoor HID Lamp	$192.84	$158.21	$132.41	$113.95	$101.43	$93.62	$89.41	$87.80	$87.96	$89.15	$90.79	$92.41
Indoor Linear Lamp	$25.09	$19.06	$14.54	$11.28	$9.02	$7.56	$6.70	$6.27	$6.12	$6.13	$6.20	$6.25
Indoor Screw-Based Decorative	$14.26	$10.29	$7.35	$5.24	$3.82	$2.94	$2.47	$2.30	$2.33	$2.48	$2.68	$2.87
Indoor Screw-Based General	$8.85	$6.60	$4.91	$3.69	$2.84	$2.30	$2.00	$1.86	$1.84	$1.89	$1.98	$2.07
Indoor Screw-Based Other	$17.82	$15.16	$13.07	$11.48	$10.28	$9.42	$8.83	$8.44	$8.21	$8.08	$8.02	$8.00
Outdoor HID Lamp	$192.84	$158.21	$132.41	$113.95	$101.43	$93.62	$89.41	$87.80	$87.96	$89.15	$90.79	$92.41
Outdoor Linear Lamp	$25.09	$19.06	$14.54	$11.28	$9.02	$7.56	$6.70	$6.27	$6.12	$6.13	$6.20	$6.25
Outdoor Screw-Based Decorative	$14.26	$10.29	$7.35	$5.24	$3.82	$2.94	$2.47	$2.30	$2.33	$2.48	$2.68	$2.87
Outdoor Screw-Based General	$8.85	$6.60	$4.91	$3.69	$2.84	$2.30	$2.00	$1.86	$1.84	$1.89	$1.98	$2.07
Outdoor Screw-Based Other	$22.91	$19.49	$16.81	$14.75	$13.22	$12.12	$11.35	$10.86	$10.56	$10.39	$10.32	$10.29

Table 9. Non-LED Prices (all years constant)

Application	Mercury Vapor	Metal Halide	Sodium Lamp	Area LED	Fluorescent U-Tube	Linear LED	Linear Fluorescent Low Wattage T8	Linear Fluorescent Standard T8	Linear Fluorescent T12	Linear Fluorescent T5	CFL	Halogen	LED	Incandescent
Indoor HID Lamp	$45.30	$40.00	$51.00											
Indoor Linear Lamp					$6.00		$5.40	$4.40	$5.70	$6.20				
Indoor Screw-Based Decorative											$5.40	$4.60		$3.10
Indoor Screw-Based General											$3.00	$1.90		$0.50
Indoor Screw-Based Other											$5.40	$0.50		$0.50
Outdoor HID Lamp	$45.30	$40.00	$51.00											
Outdoor Linear Lamp					$6.00		$5.40	$4.40	$5.70	$6.20				
Outdoor Screw-Based Decorative											$5.40	$4.60		$3.10
Outdoor Screw-Based General											$3.00	$1.90		$0.50
Outdoor Screw-Based Other											$5.40	$0.50		$0.50

Table 10. Maximum Incentive Levels

Lighting Application	Equipment Type	2015	2016	2017	2018-2026
Indoor HID Lamp	Area LED			$100.00	$125.00
Indoor Linear Lamp	Linear LED	$5.00	$5.00	$4.00	$3.00
Indoor Linear Lamp	Linear Fluorescent Low Wattage T8	$2.00	$1.00		
Indoor Linear Lamp	Linear Fluorescent T5	$2.00	$1.00		
Indoor Screw-Based Decorative	LED	$5.00	$5.00	$5.00	$4.00
Indoor Screw-Based General	LED	$5.00	$5.00	$4.00	$3.00
Indoor Screw-Based Other	LED	$10.00	$10.00	$10.00	$9.00
Outdoor HID Lamp	Area LED			$50.00	$50.00
Outdoor Linear Lamp	Linear LED	$5.00	$5.00	$4.00	$3.00
Outdoor Linear Lamp	Linear Fluorescent Low Wattage T8	$2.00	$1.00		
Outdoor Linear Lamp	Linear Fluorescent T5	$2.00	$1.00		
Outdoor Screw-Based Decorative	LED	$5.00	$5.00	$5.00	$4.00
Outdoor Screw-Based General	LED	$5.00	$4.00	$4.00	$3.00
Outdoor Screw-Based Other	LED	$10.00	$10.00	$10.00	$9.00

Table 11. Marketing and Advertising Budget by Event Type

Event Type	2016	2017	2018	2019-2026 Annual Budget Growth
Retrofit	$53,353	$171,618	$175,320	2.16%
Replace on Burnout	$73,959	$50,312	$51,779	2.92%
New Construction	$237,573	$225,070	$223,388	-0.75%

Table 12. Allocation of Program Budget for Each Building Type

Building Type	Budget Ratio
Campus	1.6%
Education	13.0%
Food Sales	2.3%
Food Service	2.6%
Healthcare	2.9%
Hospitals	0.8%
Lodging	7.9%
Manufacturing or Industrial	3.7%
Office	18.5%
Other	12.1%
Public Assembly	12.0%
Retail	19.6%
Warehouse	2.9%

Table 13. Ad Effectiveness and Awareness Decay Rate

	Retrofit	Replace on Burnout	New Construction
Ad Effectiveness Ratio	$0.02	$0.02	$0.02
Awareness Decay Rate	0.03	0.02	0.2

Savings Assumptions

Rather than calculating savings by comparing the consumption between the Program and NO Program Scenario, the model incorporates the same savings assumptions that the PAs use to calculate upstream lighting savings. The watts saved per lamp and the hours of use for 2016 and 2017 came from the 2015 upstream lighting initiative, but then the savings values are multiplied by the delta watts technology adjustment factor calculated in the 2015 Upstream Lighting Impact Evaluation.[16] The delta watts technology adjustment factor for linear LEDs was 161.6% while the realization rate for screw-based lamps (category 3 from the report) was 94.4%. The savings factors for 2018-2026 use the prospective application of results from the same report to update the savings factors. These values are listed in Table 14. Because there was no value available for area LED lamps, the model assumes that the savings for 2018-2026 is the difference between metal halides and area LEDs (52 watts) and the hours of the use is the same as screw-based other lamps. There are no savings associated with area LEDs in 2016 and 2017 since they were not part of the program.

Table 14. Savings Assumptions (2016-2026)

		2016-2017		2018-2026	
Lighting Application	**Equipment Type**	**Watts Saved per Lamp**	**Hours of Use**	**Watts Saved per Lamp**	**Hours of Use**
Indoor HID Lamp	Area LED			53	3,281
Indoor Linear Lamp	Linear LED	8.51	3,410	13.8	4,426
Indoor Linear Lamp	Linear Fluorescent Low Wattage T8	6.16	3,410		
Indoor Linear Lamp	Linear Fluorescent Standard T8	3.52	3,410		
Indoor Linear Lamp	Linear Fluorescent T5	4	3,410	4	3,410
Indoor Screw-Based Decorative	LED	21.07	3,901	13.6	2,400
Indoor Screw-Based General	LED	33.53	3,901	21.7	2,400
Indoor Screw-Based Other	LED	23.4	3,901	22.1	3,281
Outdoor HID Lamp	Area LED			53	3,281
Outdoor Linear Lamp	Linear LED	8.51	3,410	13.8	3,410
Outdoor Linear Lamp	Linear Fluorescent Low Wattage T8	6.16	3,410		
Outdoor Linear Lamp	Linear Fluorescent Standard T8	3.52	3,410		
Outdoor Linear Lamp	Linear Fluorescent T5	4	3,410	4	3,410
Outdoor Screw-Based Decorative	LED	21.07	3,901	13.6	2,400
Outdoor Screw-Based General	LED	33.53	3,901	30.5	2,400
Outdoor Screw-Based Other	LED	23.4	3,901	38.1	3,281

16 DNV GL, "Impact Evaluation of PY2015 Massachusetts Commercial and Industrial Upstream Lighting Initiative," November 22, 2017, http://ma-eeac.org/wordpress/wp-content/uploads/Upstream-Lighting-Initiative-Impact-Evaluation-PY2015.pdf.

APPENDIX B. ACCESS TO POWER BI DASHBOARD WITH RESULTS

To facilitate the segmentation and presentation of results, DNV GL developed a Power BI dashboard using the modeled market share forecasts and associated savings and consumption data. The Power BI dashboard file is available on the Project 75 SharePoint site. However, to be able to access the file, users will need to have a version of Power BI desktop. For users that don't already have the desktop application of Power BI, it can be downloaded for free online by following this link: https://powerbi.microsoft.com/en-us/desktop/

After downloading the Power BI application, users can download and open the dashboard file from the Project 75 SharePoint site: https://meet.dnvgl.com/sites/MA_CIEC_teamsite/P75/Stage%205%20final%20report

Users having trouble logging into Power BI, or users who do not have access to the report and would like access should contact:

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In addition to the complete set of results in the Power Bi dashboard described above, we provide high-level market share results for specific lighting applications in the figures 3 through 5 below.

Figure 3. Screw-Based Lamp Market Share

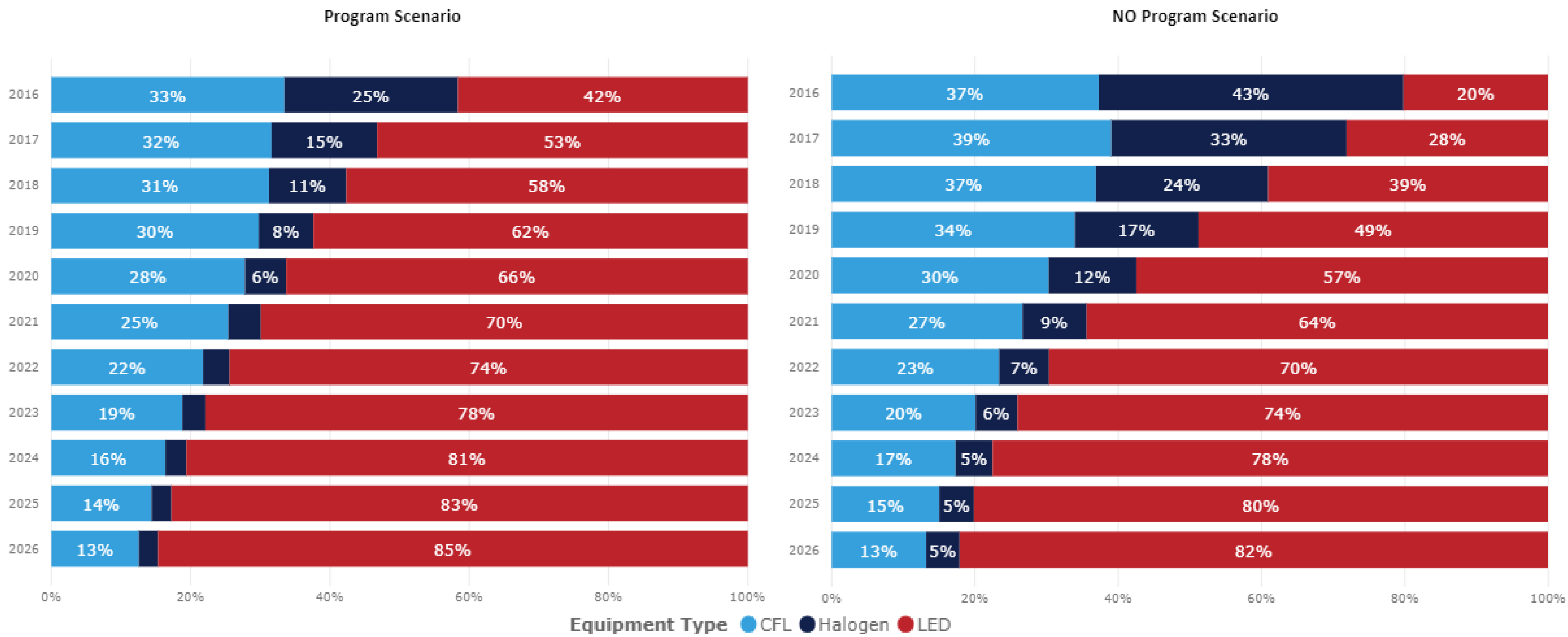


Figure 4. Linear Lamp Market Share

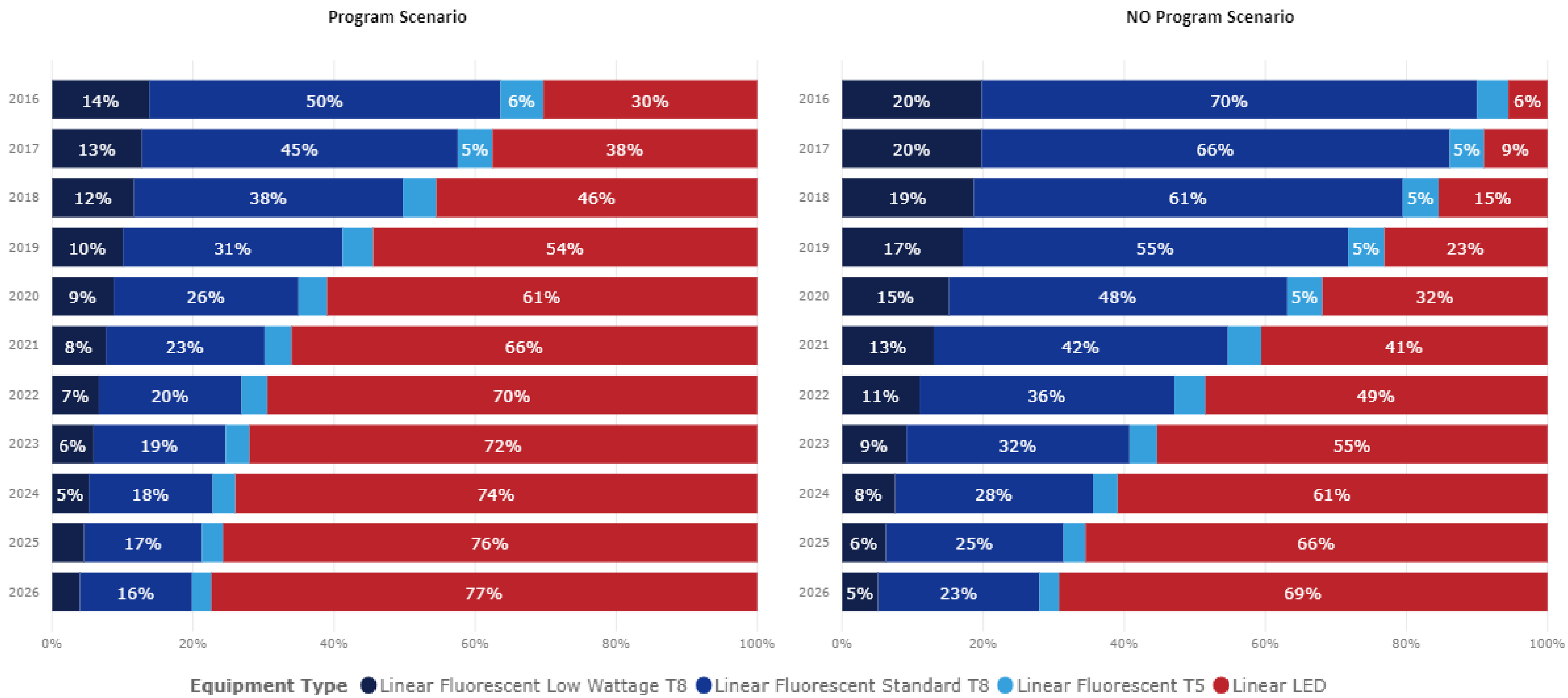
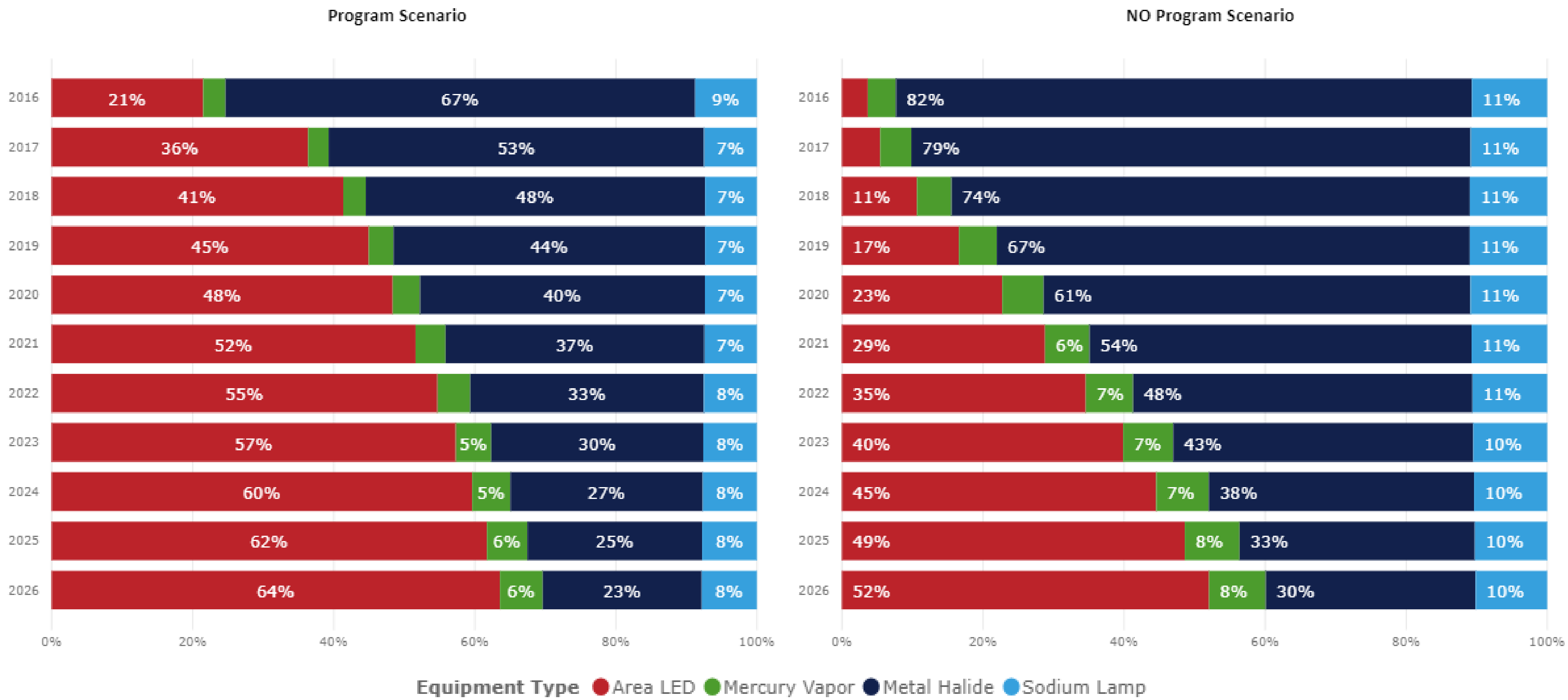


Figure 5. HID/Area Lamp Market Share



APPENDIX C. ACCESS TO BIBLIOGRAPHIC DATABASE

The bibliographic database contains an evaluation of recent research on C&I lighting. Each source is assessed based on relevance, applicability to MA, and its overall relevance to the LED market model. The information applicable to this project is summarized in a topic-level summaries memo.

The database and topic-level summaries memo are stored on SharePoint and can be accessed here: https://meet.dnvgl.com/sites/MA_CIEC_teamsite/P75/Stage%205%20final%20report