ETAC AND ADVANCED BUILDINGS SOLID STATE LIGHTING AND CONTROLS MARKET ADOPTION CURVE ANALYSIS

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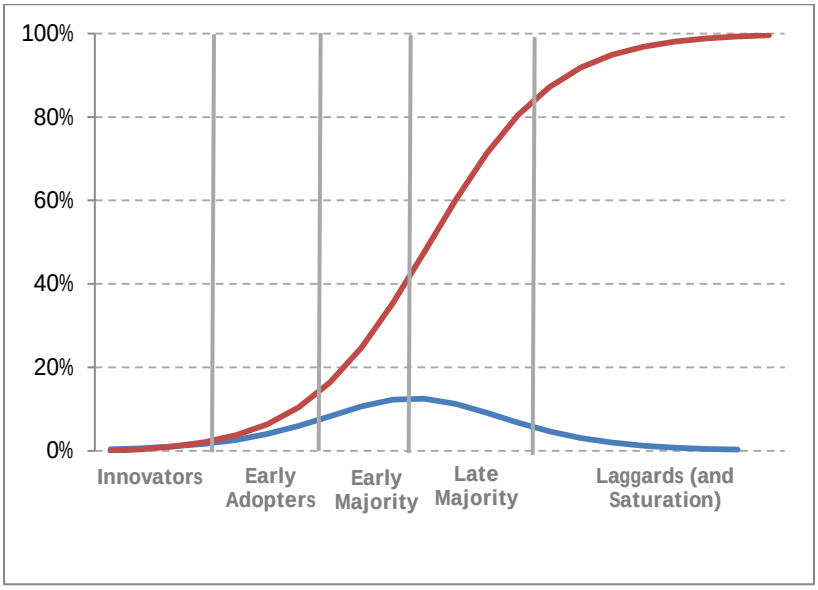
Executive Summary

NYSERDA's Emerging Technologies and Accelerated Commercialization (ETAC) Program seeks to accelerate the commercial adoption of underused, emerging high-performance, high-efficiency building technologies and strategies. The high-level objective of the program is to improve the performance and reliability of New York State's building stock. This report focuses on solid-state lighting (SSL), an area of focus for ETAC demonstration projects where multiple demonstrations have taken place across the residential, multifamily, and commercial/institutional sectors. SSL refers to a type of lighting using semiconductor light-emitting diodes (LEDs) rather than conventional illumination sources, such as electrical filaments.

To inform potential NYSERDA actions in the SSL market, this report examines the use of theoretical and empirical "market adoption curves." Market adoption curves, such as those shown in Exhibit 1, depict the spread and absorption (i.e., adoption) of a new technology in a market. The red line in Exhibit 1 represents *overall market saturation*, that is, the total proportion of the market that has adopted the technology in question; the blue line represents only *incremental adoption* in a given period, that is, the number of end users that began to use the technology in that period.

Exhibit 1. Typical Market Adoption Curve



In particular, this report focuses on two technologies:

1) Light-emitting diodes (LEDs); and

2) LEDs with networked controls, i.e., LEDs governed by software that generate additional efficiencies and savings by altering lighting patterns.

Methodology

The market adoption curves estimated in this report are based on the Bass Diffusion Model, a standard product adoption model that follows the s-curve shape to describe the total adoption of a technology or product within a population. This report relies on two surveys conducted with New York State lighting market participants to quantify key market indicators for SSL technologies in New York State. One survey was conducted among commercial and institutional (C/I) lighting end users, i.e., facility owners and/or managers who make decisions about lighting to use at their facilities. The other survey focused specifically on contractors who install lighting in the course of their projects in the residential new construction, residential retrofit, multifamily retrofit, and C/I retrofit sectors.

To provide a set of curves that accurately reflects the array of respondent answers and provides useful information to inform NYSERDA decision-making, this report generates a range of market adoption curves for each of ten "scenarios" consisting of a technology (i.e., LEDs or LEDs with networked controls), a market participant (i.e., end user or contractor) and a market segment (i.e., residential new construction, residential retrofit, multifamily retrofit, or C/I retrofit). Specifically, this report generates market adoption curves using the array of 25th percentile, 50th percentile, and 75th percentile survey responses for each "scenario."

Results

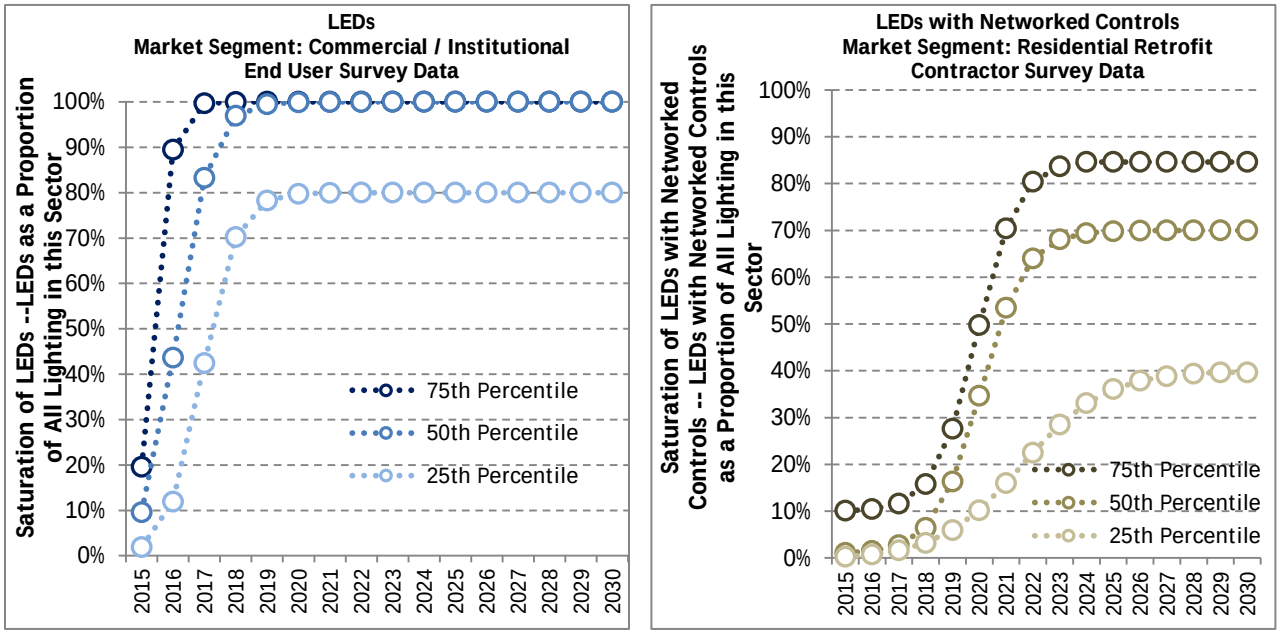
- There appears to be a general trend of optimism regarding market adoption of LEDs in the commercial / institutional sector among end users. Rapid adoption is anticipated; therefore, NYSERDA's opportunity to impact this market may be limited.

- Contractor survey responses suggest a pattern of very rapid adoption approaching near-term (i.e., within approximately three to four years) saturation in the 75th percentile curves for LEDs across all segments, suggesting that any action by NYSERDA in this market should be immediate, and in some segments of the LED market (e.g., residential new construction) action may be unnecessary. However, responses in the 25th and 50th percentile curves for LEDs within retrofit segments identify a delay in market adoption of LEDs beyond current levels in those segments, (i.e., saturation may be achieved in five-plus years instead). Retrofit segments may therefore represent a specific opportunity to increase the speed of LED adoption, as it appears that many contractors do not expect substantial gains in adoption of LED technologies in retrofit projects until at least 2019 and beyond.

- The market adoption curves for LEDs with networked controls feature considerably lower current saturation of this technology, and lower maximum saturation, than comparable curves for LEDs. Adoption of LEDs with networked controls is also expected to proceed much more gradually than adoption of LEDs according to end users, even in the 75th percentile scenario. It is possible that a lack of awareness, familiarity, or understanding of LEDs with networked controls is presenting a challenge or barrier to increased adoption and use of this technology. To the extent that this is the case, NYSERDA actions targeted at increasing knowledge of LEDs with networked controls may expedite adoption of this technology and/or increase its potential maximum saturation as a proportion of all lighting.

Exhibit 2 contains two sets of representative market adoption curves, with LEDs in the C/I sector based on end user survey data on the left, and LEDs with networked controls in the residential retrofit sector based on contractor survey data on the right.

Exhibit 2. Representative Market Adoption Curves for LEDs and LEDs with Networked Controls



Addressing Barriers to Adoption of SSL Technologies

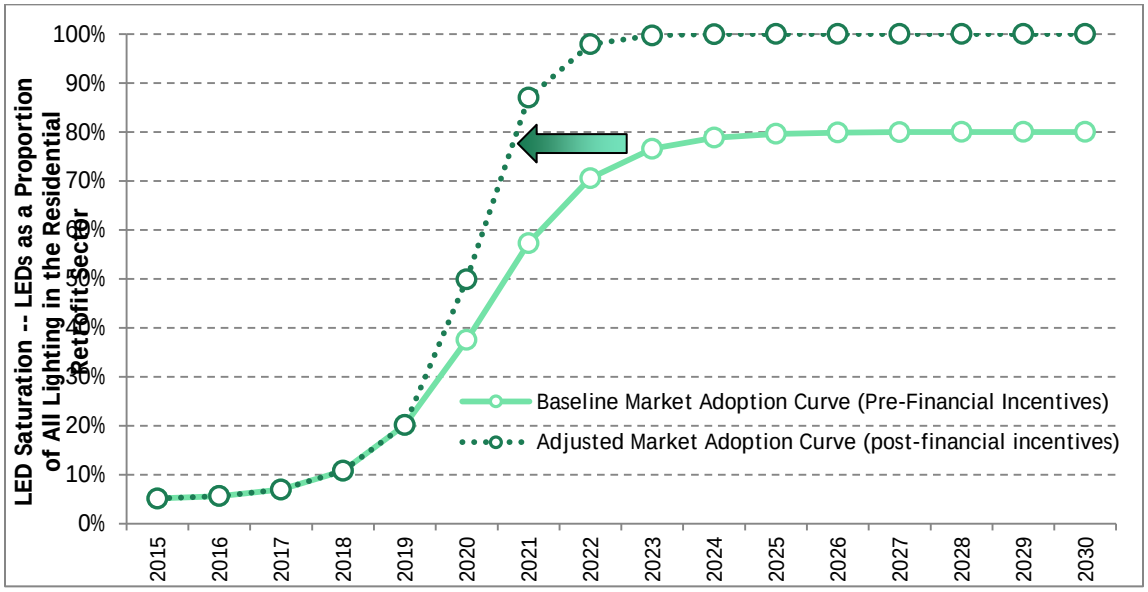
For LEDs, the most commonly emphasized barrier across both end user and contractor respondents was the cost to acquire and install LED lighting. For LEDs with networked controls, end users again emphasized the cost factor as the critical barrier to greater adoption and use of these components. In addition, some end users (i.e., facility owners and/or managers) indicated a lack of familiarity or awareness as an impediment to their purchase of LEDs with networked controls. Therefore, potential NYSERDA opportunities in the SSL technology arena broadly include additional interventions aimed at cost or financing, or at raising awareness and/or understanding of SSL technologies.

The market adoption curves in this report can be used in two ways to illuminate or examine NYSERDA's opportunities and potential market impacts. First, market adoption curves can provide an overview of the current and expected future state of the market, based on experiential and prognosticated quantitative data from market participants. These curves can help identify opportunities for market intervention across use cases, and market segments. Second, market adoption curves can be used in combination with iterative, regularly-performed data collection to examine the impacts of NYSERDA actions. Specifically, iterative data collection enables a comparison of market adoption curves over time. Because the curves already contain a temporal component, current levels of adoption can be compared to past adoption projects, as

well as used to examine whether the slope or shape of the market adoption curve has shifted or changed in response to NYSERDA interventions.

As a preliminary example of how market adoption curves can be used to assess NYSERDA impacts of addressing barriers, Exhibit 3 illustrates the potential effect of additional financial incentives (e.g., rebates, etc.) that NYSERDA could undertake to accelerate adoption of LEDs in the residential retrofit sector. Specifically, for purely illustrative purposes, Exhibit 3 uses the 25th percentile market adoption curve for the residential retrofit sector as the "baseline" market adoption curve. To show a hypothetical, potential effect of additional NYSERDA financial incentives for LEDs in the residential retrofit sector, Exhibit 3 uses a dotted line to show an "adjusted" market adoption curve, represented by the 50th percentile market adoption curve for the residential retrofit sector.

Exhibit 3. Hypothetical Effect of Financial Incentives on Future Adoption of LEDs in Residential Retrofit Sector



Based on the curves in Exhibit 3, a parameter that measures the associated impact, in terms of energy savings, cost savings, or another meaningful outcome, could be used to assess the effects of this intervention. For example, as shown in Exhibit 3, the difference between the baseline and adjusted curves in 2020 is a 12 percent change in saturation of LEDs, and there are additional changes in later years, including a consistent 20 percent difference in the maximum saturation amount. To the extent that the costs and benefits of transitioning to LED lighting can be quantified (e.g., by estimating the costs of installation and the energy savings and avoided environmental impacts at a per unit or per project level) then NYSERDA can use market curves to help estimate and display the monetized impacts of its market interventions.[1]

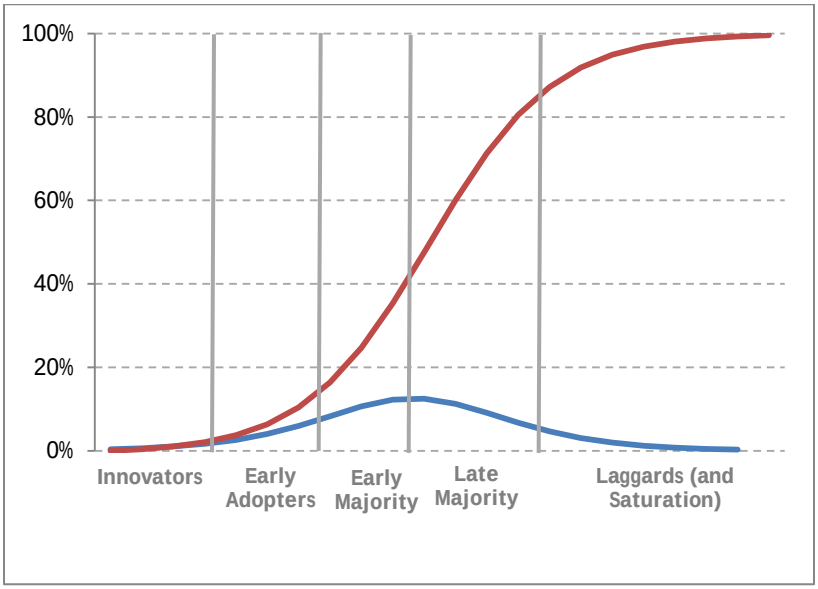
[1] The extent to which this can be done requires reliable estimates of both the unit changes and the total market (or universe) of potential projects.

Introduction

NYSERDA's Emerging Technologies and Accelerated Commercialization (ETAC) Program seeks to accelerate the commercial adoption of underused, emerging high-performance, high-efficiency building technologies and strategies. The high-level objective of the program is to improve the performance and reliability of New York State's building stock. Although ETAC demonstration projects include a range of technologies, this report focuses on solid-state lighting (SSL), an area of focus where multiple demonstrations have taken place across the residential, multifamily, and commercial/institutional sectors. SSL refers to a type of lighting using semiconductor light-emitting diodes (LEDs) rather than conventional illumination sources, such as electrical filaments.

To inform potential NYSERDA actions in the SSL market, this report examines the use of theoretical and empirical "market adoption curves." Market adoption curves, such as those shown in Exhibit 4, depict the spread and absorption (i.e., adoption) of a new technology in a market. Theoretical market adoption curves are typically S-shaped, reflecting a sigmoid function featuring slow initial growth/adoption, followed by a tipping point and rapid growth/adoption until the slope decreases as the technology approaches and reaches maturation.

Exhibit 4. Typical Market Adoption Curve



The red line in Exhibit 4 represents *overall market saturation*, that is, the total proportion of the market that has adopted the technology in question, with a ceiling that represents the total possible extent of the presence of the technology in market, measured in units sold or in some other representation such as total lumen output across a given geographic area and time horizon. Meanwhile, the blue line represents only *incremental adoption* in a given period, that is, the number of end users that began to use the technology (where they previously did not) in that period. In other words, the blue line represents the incremental change (or slope) of the red line in each period.

Market adoption curves can be used retrospectively, where data have been collected, to examine the progress of the uptake of a new technology. They can also be used prospectively, using extrapolated or forecasted data in order to examine potential future technology adoption scenarios and examine the potential impact of policies and programs.

This report uses survey data from end users and installers who participate in New York State's lighting markets to develop and estimate market adoption curves for LED technologies across an array of market segments. The purpose of this report is twofold:

- First, this report measures and presents prospective trends in the adoption of LED technologies in New York State, based on survey data collected from market participants; and

- Second, this report presents a market adoption curve-based methodology to evaluate the feasibility of this methodology for NYSERDA's use in forecasting and/or evaluating the potential impacts of its programs.

In particular, this report focuses on market adoption curves for two technologies:[2]

1) Light-emitting diodes (LEDs); and

2) LEDs with networked controls, i.e., LEDs governed by software that generate additional efficiencies and savings by altering lighting patterns.

The remainder of this report first describes the methodology used to estimate market adoption curves across different lighting market segments, then presents a suite of curves for the technologies and market segments surveyed, focusing on the current state of the market and the expected state of the market in the future, noting the implications of the derived curves for potential NYSERDA actions in the SSL lighting market. Finally, the analysis considers barriers to further adoption or usage of SSL technologies and examines the use of market adoption curves to measure the effects of NYSERDA actions on the pace of the market adoption of these technologies.

A companion piece to this report, *ETAC and Advanced Buildings Solid State Lighting and Controls Market Characterization and Assessment*, by EMI Consulting, Inc. ("the MCA") provides additional information on the survey data collected, as well as findings and outcomes from in-depth interviews with participants in New York State's lighting market. Where relevant, these data are referenced throughout this report for additional context and clarification.

[2] A third technology type, organic LEDs (OLEDs), was also briefly addressed in the surveys used to inform the analyses in this report, but not covered in depth by these surveys. The data collected for OLEDs were not sufficient to craft the array of analyses included for LEDs and LEDs with networked controls in this report.

Methodology for Estimating Market Adoption Curves using Survey Data

The market adoption curves estimated in this report are based on the Bass Diffusion Model, a standard product adoption model that follows the s-curve shape to describe the total adoption of a technology or product within a population. Like other product adoption models, the Bass model results in a sigmoid curve that features initially slow growth in market saturation that accelerates before slowing again as production adoption plateaus. The Bass model plots the passage of time (on the x-axis) against technology adoption (on the y-axis) and can be adjusted to fit an array of input parameters while retaining its sigmoid shape. The U.S. Department of Energy (DOE) has applied Bass models in various contexts related to forecasting the market for SSL and energy-efficient lighting technologies.[3]

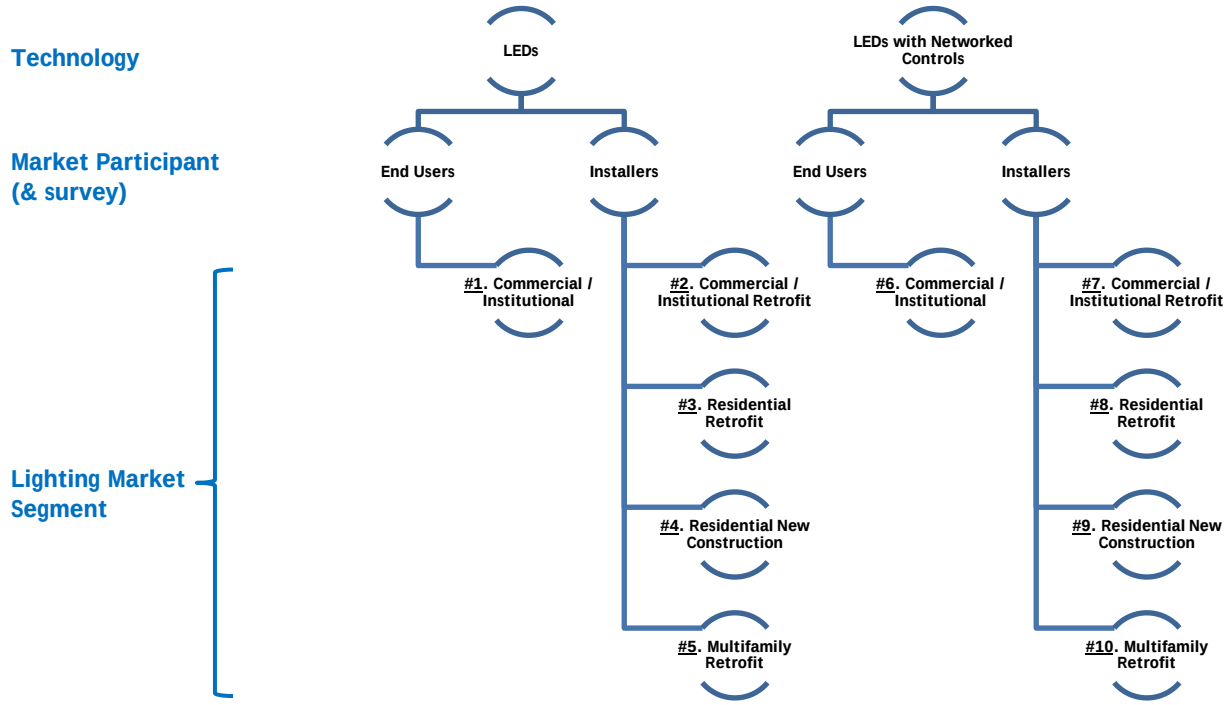
This report relies on two surveys conducted with New York State lighting market participants to quantify key market indicators for SSL technologies in New York State. One survey was conducted among commercial and institutional (C/I) lighting end users, i.e., facility owner and/or managers who make decisions about lighting to use at their facilities. The other survey focused specifically on contractors who install lighting in the course of their projects in the residential new construction, residential retrofit, multifamily retrofit, and C/I retrofit sectors.[4]

For clarity, Exhibit 5 provides the array of the ten technology, market participant, and lighting market segment combinations for which we develop and analyze market adoption curves in this report.

[3] For example, see Farese, Philip et al. "A Tool to Prioritize Energy Efficient Investments." National Renewable Energy Laboratory (NREL). August 2012 and Navigant Consulting, Inc. "Energy Savings Potential of Solid-State Lighting in General Illumination Applications." Solid State Lightning Program, Building Technologies Program, Office of Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy. January 2012.

[4] There is likely substantial overlap in the market segments addressed across the two surveys, though the population of respondents differs. Within this report, analyses informed by the two surveys are always presented separately, rather than commingled. The four sectors targeted by the second survey align most closely with ETAC's SSL demonstration projects.

Exhibit 5. Summary of Technologies, Market Participants, and Lighting Market Segments Analyzed



We use survey data to generate prospective market adoption curves based on respondents' survey answers. The generation of market adoption curves requires the following data points, each of which are extracted from the survey data collected:

- **Current market saturation** – of all currently installed lighting, the proportion that is currently LEDs (or LEDs with networked controls);
- **Maximum market saturation** – of all currently installed lighting, the proportion that could eventually be LEDs (or LEDs with networked controls);
- **Adoption horizon** – the length of time (in years) before all lighting that could be LEDs (or LEDs with networked controls) uses LEDs (or LEDs with networked controls), as opposed to other lighting types;[5]

[5] In other words, the length of time it will take to reach the point of maximum market saturation for LEDs (or LEDs with networked controls).

- **Market saturation in five years** – the proportion of all lighting that is projected to be LEDs (or networked controls) in five (5) years.[6,7]

The end user and contractor surveys included questions that specifically aligned to each of these four parameters for both LEDs and LEDs with networked controls. Each survey respondent provided estimates for each of these four parameters across these two technologies, along with other information. Therefore, each respondent theoretically provided the information necessary to develop a respondent-specific market adoption curve. To develop a robust assessment of the current and expected future state of the SSL technology market, we combined answers across survey respondents in order to develop an array of aggregated inputs that inform market adoption curves representative of the respondent base as a whole, rather than any individual respondent.[8]

Key Decisions and Assumptions

Aggregation of Survey Responses

To provide a set of curves that accurately reflects the array of respondent answers and provides useful information to inform NYSERDA decision-making, we generated a range of market adoption curves for each of the ten "scenarios" examined in this report (see Exhibit 5). We array all responses for each of the four parameters necessary to estimate a market adoption curve and consider the 25th percentile, 50th percentile (i.e., median), and 75th percentile responses. We then generate a market adoption curve using the array of 25th percentile responses across the four parameters, as well as the array of 50th percentile and 75th percentile responses.

To explore the impact of cases in which an individual respondent's parameters were internally inconsistent or missing (because the respondent did not answer the survey question corresponding to the parameter), we also generate a set of curves using only responses from those respondents with complete, fully internally consistent data. This secondary set of curves generally aligns with the initial set of curves presented in the following section, because relatively few respondents featured incomplete or internally inconsistent data, and their responses were in line with their peers even when doing so.

Therefore, the primary set of market adoption curves presented in this report are based on respondents' individual answers for each parameter, that is, if a given respondent provided a response for *current market saturation* but not for *maximum market saturation*, the market adoption curve incorporates the data point for *current market saturation* from this respondent into its aggregated dataset, while it does not include the lack of a response for *maximum market saturation*. In contrast, the secondary set of market

[6] Note that where the adoption horizon is five or fewer years, this parameter is equal to the maximum market saturation parameter and is not necessary to generate the market adoption curve.

[7] Unlike the other three parameters listed, this parameter is not strictly necessary to develop and estimate a market adoption curve. However, it adds additional nuance and definition to the curve by informing on the rate of adoption through a five-year period.

[8] Note that in some cases, survey respondents may not have provided answers to each parameter necessary for market adoption curve estimate, while in other cases, some respondent answers were self-contradictory. The data aggregation methodology adjusted for these instances to ensure that they did not preclude the development of market adoption curves.

adoption curves would not incorporate the *current market saturation* data point from this respondent, due to the lack of a complete response.

Weighting of Survey Responses

The end user survey (but not the contractor survey) included questions identifying the number of facilities for which each respondent is responsible, as well as the average or typical size of these facilities. This allows for a weighted assessment of end user survey responses based on total lighting volume, and a separate set of market adoption curves based on weighted end user responses. However, as similar volume data were not collected within the contractor survey, and because weighted end user data are heavily skewed by a small subset of respondents with responsibility for a high volume of large facilities, we focus our analysis on *unweighted* end user-based market adoption curves.

Results – Market Adoption Curves[9]

This section presents market adoption curves at the 25th, 50th, and 75th percentiles for the ten "scenarios" described in Exhibit 5, focusing first on adoption of LEDs across end user and contractor responses, and then on LEDs with networked controls.

As noted in the MCA that serves as a companion piece to this report, an earlier (2012) market characterization report prepared for New York State estimated that the statewide market potential for lighting upgrades totaled approximately 26 percent of all building space statewide. Furthermore, over half of the contracts surveyed for that report indicated that between 50 percent and 90 percent of their region's total commercial floor space could be retrofitted. While these findings are relatively dated, they remain consistent with the results shown in Exhibits 6 and 7 below, as market participants generally indicate similar potential for further adoption of LEDs in retrofit applications in the immediate future. In fact, the more recent survey data used to inform the market adoption curves in Exhibits 6 and 7 suggest that considerably more than half of all market participant survey respondents believe that the vast majority of lighting applications will be served by LEDs in the immediate future.

Results: LEDs – End User Survey

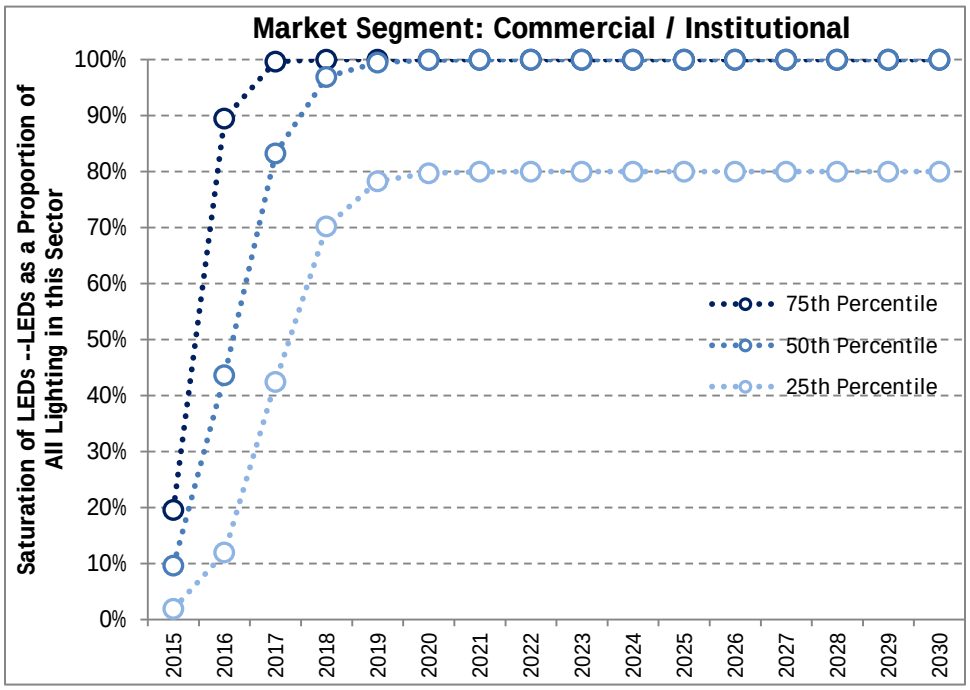
Exhibit 6 reflects the 25th percentile, 50th percentile, and 75th percentile market adoption curves based on unweighted survey responses for the end user survey. The y-axis in Exhibit 6 reflects the saturation (adoption) of LEDs as a proportion of all lighting in facilities owned or managed by end user respondents.

As shown in Exhibit 6, end user responses suggest that despite relatively low current (i.e., 2015) levels of LED use in commercial/institutional applications based on end users' experience with these technologies, adoption of LED lighting is expected to grow rapidly and approach saturation before 2020. While some respondents anticipate that less than 100 percent of all commercial/institutional lighting can feasibly be upgraded to LED lighting (reflected in the 25th percentile estimates), the median response in this survey predicts that all (i.e., 100 percent) of lighting will be upgraded to LEDs within five years.

The difference in maximum saturation for LEDs across the three curves shown in Exhibit 6 reflect different perspectives from different respondents, many of whom believe that all lighting applications will be LEDs in the future, while some of whom indicated in their responses that a proportion of lighting applications cannot be upgraded to LEDs. Follow-up to this work may wish to examine market participant awareness and understanding of LED technologies in the context of their views on future market adoption, in order to determine whether responses that maximum saturation of LEDs falls below 100 percent of all lighting is based on technical aspects of lighting applications or is the result of a lack of familiarity with LED capabilities and applications.

[9] Note that the data relied upon throughout this report, and specifically this section, are the same data referenced and presented in Chapter 5 of the MCA that serves as a companion piece to this report. However, the data presented in Chapter 5 of the MCA generally depict the *average* rather than the median (or 25th / 75th percentiles) of a given parameter. Therefore, the data do not align. However, the mean and median of the parameters are generally relatively close, given a lack of substantial outliers in most market segments.

Exhibit 6. Market Adoption Curves – LEDs – End User Survey Data



While the curves themselves represent aggregation of respondent survey data, it may be helpful to conceptualize them as reflective of end users at different levels of sophistication with regard to lighting technologies. For example, the 75th percentile curve may be representative of an early or advanced adopter of LED technologies: this type of respondent may already be using LEDs for 20 percent of the lighting at their facilities and anticipates upgrading to use 90 percent LED lighting within one year as well as fully using LED lighting within two years. Meanwhile, the 25th percentile curve may be representative of an "imitator" who trails in the adoption of new technologies; based on the 25th percentile curve, this type of respondent may have zero or very few LEDs installed, but still anticipates upgrading to over 40 percent LED lighting within two years, and reaching saturation at 80 percent LED lighting within four to five years.

Implications and Opportunities for NYSERDA

Based on end user survey responses aggregated into market adoption curves in Exhibit 6, there appears to be a general trend of optimism regarding market adoption of LEDs in the commercial / institutional sector among end users. Even within the 25th percentile curve, rapid adoption is anticipated. Therefore, NYSERDA's opportunity to impact this market may be limited.

Results: LEDs – Contractor Survey

Exhibit 7 similarly reflects the 25th percentile, 50th percentile, and 75th percentile market adoption curves for the four sectors considered within the contractor survey. The y-axes of the four charts in Exhibit 7 reflect the saturation (adoption) of LEDs as a proportion of all lighting across projects initiated or completed by the contractor within the given market segment.

Market adoption curves based on survey responses across four sectors in the contractor survey feature a number of patterns that span sectors, including:

- 75th percentile market adoption curves with current substantial proportions (50 percent and up) of LED saturation, with rapid continuing adoption to reach maximum saturation in the next five years or fewer;

- 25th and 50th percentile market adoption curves with some level of current LED saturation, but a delay of four or more years until LED usage will begin to grow beyond current levels, and then rapid growth until maximum saturation is achieved;[10]

- Maximum feasible market saturation for LEDs of 100 percent (i.e., all lighting in the relevant segment is LED lighting) in the 50th and 75th percentile market adoption curves, with lower, but still high (80 percent and up) maximum saturation estimates in the 25th percentile curves;[11]

- Across all curves in Exhibit 7, including the 25th percentile market adoption curves, maximum feasible saturation of LED lighting appears to be reached within 10 years (i.e., by 2025); and

- From a comparison of the residential new construction and residential retrofit sectors, greater current saturation of LEDs and more aggressive adoption of LEDs in the immediate future.

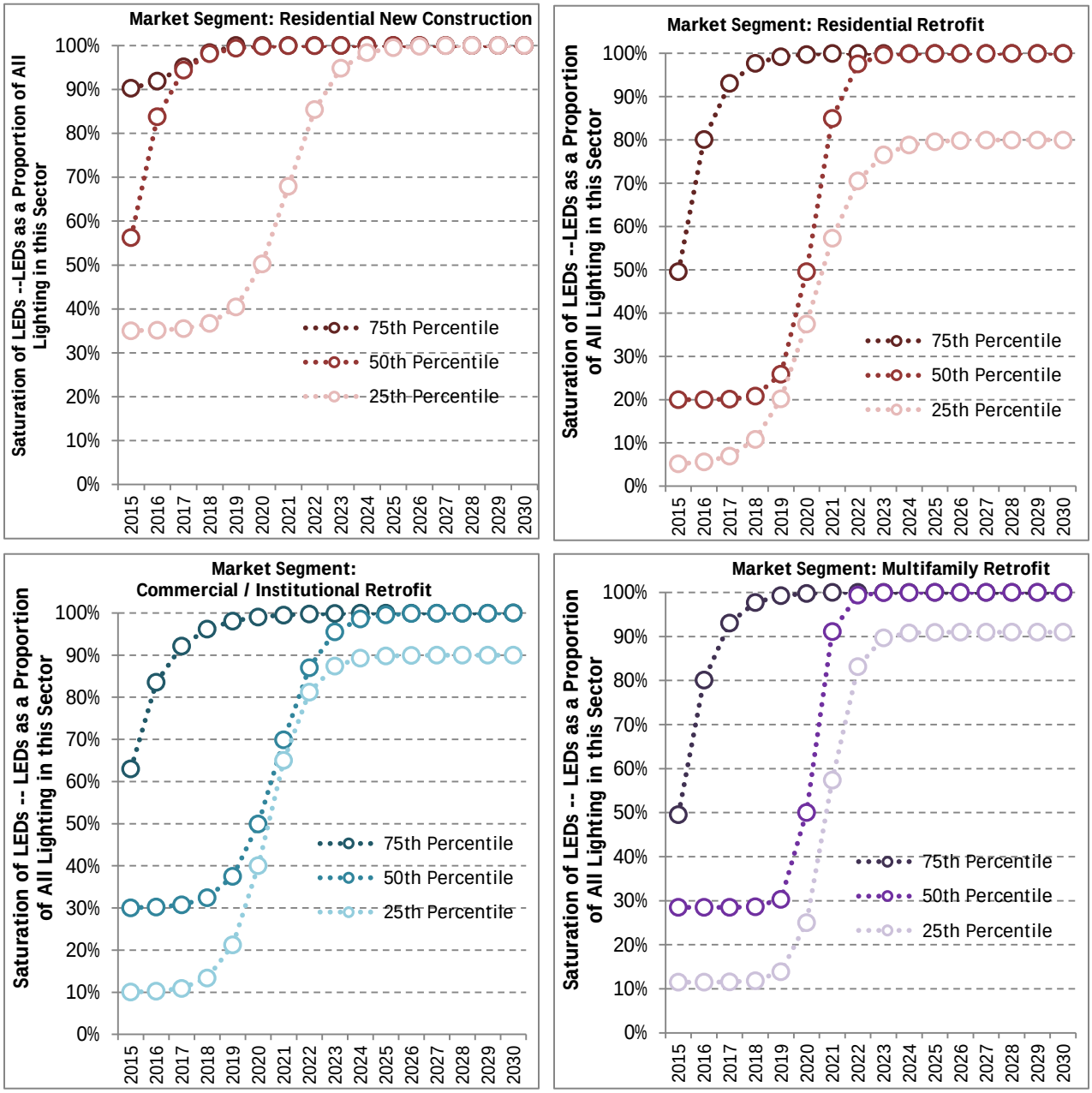
Data collected as part of the MCA that serves as a companion piece to this report indicate that a number of distributors estimate that between eight percent and 50 percent of lighting sales consist of LEDs. This is roughly consistent with the findings in Exhibit 7, where current saturation generally ranges from five percent to 50 percent, with some 75th percentile curves featuring higher current saturation in the residential new construction and commercial / institutional retrofit segments.

Note that these data for the commercial / institutional retrofit market segment are consistent with additional data collected for the MCA that serves as a companion piece to this report. Specifically, distributors interviewed as part of the data collection effort for the MCA estimated that between 20 and 50 percent of all lighting sales in the commercial sector were LEDs. These figures are consistent with the 50th percentile curve for this segment in Exhibit 7, though notably, are somewhat higher than the saturation of LEDs reported by end users for the commercial / institutional sector (see Exhibit 6).

[10] Generally, market adoption curves modeled using the Bass Diffusion Model formulae assume that production adoption begins with zero percent market saturation, and increases to 100 percent or a different maximum saturation figure following the s-curve shape. However, many respondents indicated a "saturation in five years" parameter similar to or slightly higher than the "current market saturation" parameter, while also suggesting that maximum saturation would be achieved within approximately ten years. Therefore, to fit the standard s-curve model, early growth in these cases must be very slow in order to accommodate very rapid adoption growth in a short period to reach maximum saturation at the estimated date.

[11] This is consistent with distributor data collected as part of the MCA that serves as a companion piece to this report: the distributor indicated that growth in LED lighting in the commercial / institutional sector would continue over the next ten years until hitting a maximum saturation point of 85 percent to 90 percent, which roughly reflects the three market adoption curves for this segment in Exhibit 7.

Exhibit 7. Market Adoption Curves – LEDs – Contractor Survey Data



Implications and Opportunities for NYSERDA

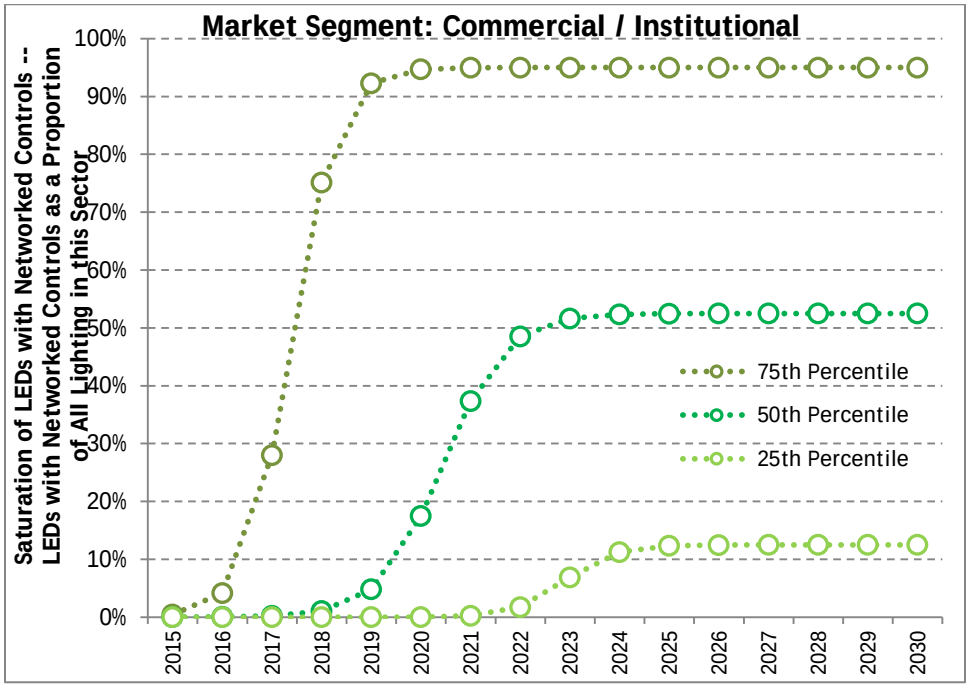
Contractor survey responses informing Exhibit 7 suggest a pattern of very rapid adoption approaching near-term saturation in the 75th percentile curves for all segments, suggesting that NYSERDA's role, if any, should be near term. Responses do identify a delay in market adoption of LEDs beyond current levels in retrofit-related market segments. This may represent an opportunity where growth in LED adoption could be expedited, as it appears that many contractors do not expect substantial gains in adoption of LED technologies in retrofit projects until at least 2019 and beyond.

Results: LEDs with Networked Controls – End User Survey

LEDs with networked controls are a subset of the broader suite of LEDs displayed in Exhibits 6 and 7. Not all LED applications can feasibly be replaced with LEDs with networked controls; therefore, maximum saturation for LEDs with networked controls may potentially be lower than maximum saturation for all LEDs, as there may be use cases where it does not make sense to add networked controls to an existing LED application.

Exhibit 8 reflects the 25th, 50th, and 75th percentile market adoption curves for LEDs with networked controls, based on the end user survey. Again, the y-axis in Exhibit 8 is the saturation of LEDs with networked controls among all lighting at the facilities owned or managed by end user respondents.

Exhibit 8. Market Adoption Curves – LEDs with Networked Controls – End User Survey Data



Unlike LED-based responses from the end user survey, growth in LEDs with networked controls is estimated to be more gradual and measured, with considerably lower current and maximum saturation parameters, especially in the 25th and 50th percentile curves. Furthermore, relative to all LEDs, LEDs with networked controls do not appear to be substantially used by end users in the commercial / institutional sector at present: all three curves in Exhibit 8 indicate current market saturation between zero and one percent of all lighting.

Maximum saturation for LEDs with networked controls in the 50th percentile curve is approximately 53 percent, compared to 100 percent for all LEDs. Therefore, based on the data supplied by the median end user survey respondent, approximately 47 percent of LED applications are considered non-feasible for LEDs with networked controls in the commercial/institutional sector. As noted previously, additional

follow-up may be warranted to determine the extent to which this "gap" of 47 percent based on the median response reflects a technical challenge for LED with networked control applications, versus a lack of familiarity and/or understanding of the capabilities and uses of LEDs with networked controls.

Implications and Opportunities for NYSERDA

Unlike the curves for LEDs based on end user respondent data (Exhibit 6), the market adoption curves for LEDs with networked controls feature considerably lower current saturation of this technology, and lower maximum saturation, especially in the 50th and 25th percentile curves. Adoption of LEDs with networked controls is also expected to proceed much more gradually according to end users, even in the 75th percentile scenario.

Given lower current usage of LEDs with networked controls and lower estimated maximum saturation rates for this technology in the 25th and 50th percentile curves relative to LEDs as a whole, it is possible that a lack of awareness, familiarity, or understanding of LEDs with networked controls is presenting a challenge or barrier to increased adoption and use of this technology. To the extent that this is the case, NYSERDA actions targeted at increasing knowledge of LEDs with networked controls may expedite adoption of this technology and/or increase its potential maximum saturation as a proportion of all lighting. However, if end user respondents indicated a maximum saturation below 100 percent as a result of technical challenges, then it is unlikely that NYSERDA can push LEDs with networked controls towards 100 percent usage in the long run due to practical or technical obstacles to doing so.

Results: LEDs with Networked Controls – Contractor Survey

Exhibit 9 reflects the 25th percentile, 50th percentile, and 75th percentile market adoption curves for the four sectors considered within the contractor survey. Similarly to Exhibit 8 relative to Exhibit 6, the market adoption curves for LEDs with networked controls shown in Exhibit 9 generally feature lower maximum saturation estimates based on contractor respondent data, especially in the 25th and 50th percentile curves.

Market adoption patterns for LEDs with networked controls vary, both across sectors and in relation to the market adoption curves estimated for the broader set of LEDs (including both those with and without networked controls) displayed in Exhibit 7.

- Generally, and especially with regard to market adoption curves at the 25th and 50th percentiles, maximum saturation of LEDs with networked controls is considerably below estimated maximum saturation for LEDs as a whole (i.e., compare Exhibit 9 to Exhibit 7). This suggests that not all applications can feasibly incorporate LEDs with networked controls, and moreover, that only some respondents believe that their buildings or projects can eventually be lit entirely by LEDs with networked controls.[12] However, as shown in Exhibit 7, many respondents believe that their

[12] Again, it is unclear the extent to which the responses indicating maximum saturation for LEDs with networked controls below 100 percent stem from a lack of awareness or understanding of the technology, or technical considerations forestalling this outcome (or a mix of both).

buildings or projects can eventually be lit entirely be LEDs, albeit LEDs without networked controls.[13]

- Unlike the LED adoption curve for residential retrofits versus residential new construction, there does not appear to be a similar pattern for adoption of LEDs with networked controls in residential projects. Whereas it is perhaps intuitive that it would be easier to install LEDs in newly-constructed residential buildings rather than retrofitting LEDs into existing buildings, the shapes of the top two sets of curves in Exhibit 9 appear relatively similar. Therefore, whereas the data in Exhibit 7 suggested that many contractors engaged in residential new construction projects are heavily using LEDs and anticipating continuing to rapidly integrate LEDs into their projects until LEDs reach maximum saturation, the data from these respondents on LEDs with networked controls do not suggest that LEDs with networked controls are, or will be, used in these projects to the same extent as LEDs without networked controls.

- The market adoption curves for LEDs with networked controls generally feature low current saturation of this technology, with substantial adoption growth not occurring until post-2018, in contrast to the curves for LEDs as a whole, which show substantial adoption and accelerating growth taking place in the present and immediate future (see Exhibit 7).[14]

On a segment-by-segment basis, the key differences between the adoption curves estimated for LEDs versus LEDs with networked controls include:

- Residential, new construction: considerably lower maximum saturation for LEDs with networked controls relative to LEDs as a whole in the 25th and 50th percentile curves; considerably lower current saturation of LEDs with networked controls relative to LEDs; a longer time frame until maximum saturation is reached for the 50th and 75th percentile curves, though the 25th percentile curve reaches a (much lower) maximum saturation bound faster for LEDs with networked controls than for LEDs as a whole.

- Residential, retrofit: considerably lower maximum saturation for LEDs with networked controls relative to LEDs as a whole; considerably lower current saturation of LEDs with networked controls relative to LEDs; a gradual increase in LED with networked control adoption in the 75th percentile curve, compared to the 75th percentile curve for LEDs in this sector, which features 50 percent current saturation approaching maximum saturation within three years.

[13] For example, based on contractors who provided data on expected maximum saturation for LEDs and LEDs with networked controls in the residential new construction market segment, 19 respondents indicated 100 percent maximum saturation for LEDs and less than 100 percent for LEDs with networked controls, while only nine respondents indicated 100 percent maximum saturation for both LEDs and LEDs with networked controls. Similarly, based on contractors who provided data for the residential and commercial/institutional retrofit sectors, 38 indicated 100 percent maximum saturation for LEDs and less than 100 percent for LEDs with networked controls, while only 23 indicated 100 percent maximum saturation for both LEDs and LEDs with networked controls. For contractors who provided data for the multifamily retrofit sector, these numbers are 11 respondents (100 percent LED maximum saturation, less than 100 percent LED with networked controls maximum saturation) and three respondents (100 percent maximum saturation for both LEDs and LEDs with networked controls).

[14] This is consistent with indications from distributor data collected as part of the MCA that serves as a companion piece to this report, where two distributors indicated that LED controls are only ordered as needed for special projects. One distributor specifically noted, “controls have not caught on quite yet.”

- Commercial / institutional, retrofit: considerably lower maximum saturation for LEDs with networked controls relative to LEDs as a whole in the 25th and 50th percentile curves; considerably lower current saturation of LEDs with networked controls relative to LEDs; a gradual increase in LED with networked control adoption in the 75th percentile curve, compared to the 75th percentile curve for LEDs in this sector, which features approximately 75 percent current saturation approaching maximum saturation within three years.[15]

- Multifamily, retrofit: considerably lower maximum saturation for LEDs with networked controls relative to LEDs as a whole; considerably lower current saturation of LEDs with networked controls relative to LEDs; a gradual increase in LED with networked control adoption in the 75th percentile curve, compared to the 75th percentile curve for LEDs in this sector, which features current saturation of over 50 percent approaching maximum saturation within three years.

Data collected for the MCA that serves as a companion piece to this report indicates that according to one controls manufacturer, maximum saturation in commercial retrofit projects for LEDs with networked controls is approximately 50 percent, based on the ability to capture energy savings and operational efficiencies. This is consistent with the 25th and 50th percentile curves for this market segment in Exhibit 9; however, notably, this controls manufacturer estimated current saturation of LEDs with networked controls at approximately 25 percent, which is consistent with the 75th percentile curve for this market segment (see Exhibit 9).

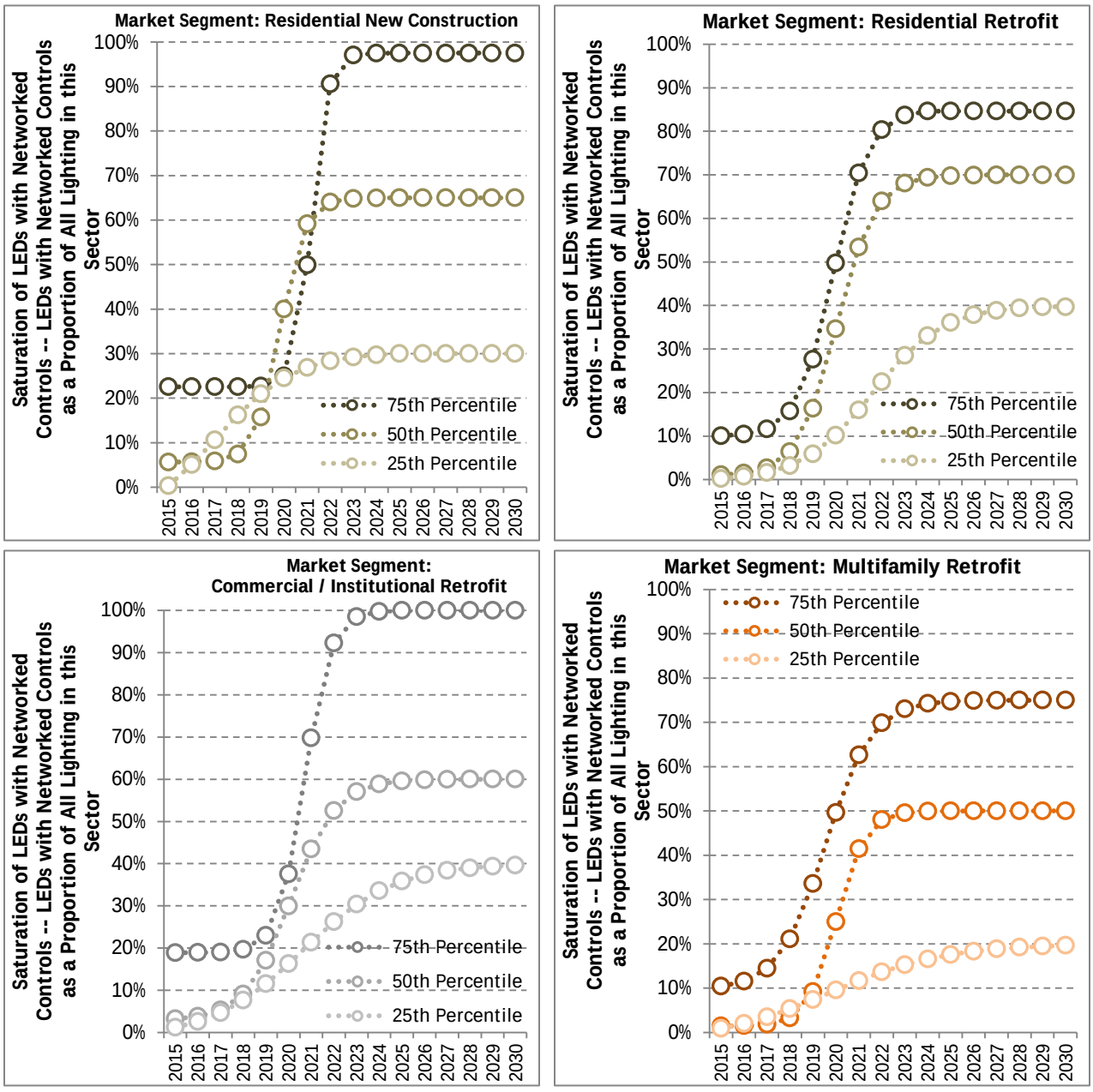
Implications and Opportunities for NYSERDA

Unlike the curves for LEDs based on contractor respondent data (Exhibit 7), the market adoption curves for LEDs with networked controls feature considerably lower current saturation of this technology, and lower maximum saturation. Adoption of LEDs with networked controls is also expected to proceed much more gradually according to end users, especially in the 75th percentile scenario.

Given lower current usage of LEDs with networked controls and lower estimated maximum saturation rates for this technology relative to LEDs as a whole, it is possible that a lack of awareness, familiarity, or understanding of LEDs with networked controls is presenting a challenge or barrier to increased adoption and use of this technology. To the extent that this is the case, NYSERDA actions targeted at increasing knowledge of LEDs with networked controls may expedite adoption of this technology and/or increase its potential maximum saturation as a proportion of all lighting. However, if end user respondents indicated a maximum saturation below 100 percent as a result of technical challenges, then it is unlikely that NYSERDA can push LEDs with networked controls towards 100 percent usage in the long run due to practical or technical obstacles to doing so.

[15] Additionally, the MCA that serves as a companion piece to this report notes that interviews of lighting distributors suggested that advanced lighting control systems, including LEDs with networked controls, were generally only made as part of "special order" sales within the commercial / institutional market segment. This is roughly consistent with Exhibit 9 for the commercial / institutional retrofit segment, where the 25th and 50th percentile curves feature very low current saturation of LEDs with networked controls as a proportion of all lighting.

Exhibit 9. Market Adoption Curves – LEDs with Networked Controls – Contractor Survey Data



Summary of Potential Market Opportunities

It is unclear whether NYSERDA market interventions (e.g., additional financial incentives, etc.) could increase a given market adoption curve's maximum limit (i.e., the maximum possible or feasible saturation of LED technologies relative to all lighting), or whether the maximum saturation as provided by survey respondents represents a technical upper limit not driven by market considerations. However, the survey data indicate that respondents disagree substantially as to the maximum possible saturation for a given technology (LEDs as a whole, or LEDs with networked controls); therefore, it is possible that

NYSERDA market interventions may effectively grant some “late adopter” respondents greater confidence about LED technologies, therefore potentially increasing the maximum saturation threshold for these technologies.

Given the market adoption curves displayed in Exhibits 6 through 9, there appear to be greater opportunities to further accelerate and drive adoption of SSL technologies in terms of LEDs with networked controls, as survey respondents generally indicate adoption of LEDs approaching maximum possible LED saturation in the immediate future. Based on contractor respondents’ replies, multifamily and residential retrofit projects may represent two sectors where NYSERDA market interventions may have the most impact, based on current and expected future installation of LEDs with networked controls across the array of survey responses.

Addressing Barriers to Adoption of SSL Technologies

Barriers to Adoption of SSL Technologies

The survey data upon which the market adoption curves in the previous section were developed also included a set of open-ended responses from end users and contractors identifying barriers to further or faster adoption of LEDs and LEDs with networked controls.

For LEDs, the most commonly emphasized barrier across both end user and contractor respondents was the **cost** to acquire and install LED lighting. This is consistent with the earlier market characterization of SSL technologies conducted by EMI Consulting, Inc., which noted that lighting manufacturers, controls manufacturers, and distributors playing key roles in the New York State lighting market all listed the cost of LED technology as the primary barrier to the growth of the LED market.[16]

For LEDs with networked controls, end users again emphasized the cost factor as the critical barrier to greater adoption and use of these components. In addition, some end users (i.e., facility owners and/or managers) indicated a lack of familiarity or awareness as an impediment to their purchase of LEDs with networked controls. A small minority of contractors also mentioned compatibility concerns associated with this technology as a barrier to use.

Beyond the primary barrier of cost for LED technologies, EMI's market characterization also noted some additional barriers emphasized by some key market actors, including:

- Limited knowledge of LED products;
- Performance concerns; and
- Lighting compatibility and characteristics issues, such as the need for dimmable bulbs by end users.

However, the cost of LED technologies, including its effect on extending the payback period of switching from conventional lighting to LEDs or LEDs with networked controls, appears to be the primary challenge currently limiting LED adoption and market growth. Notably, as indicated by the market adoption curves in this report, most end user and contractor survey respondents expect that LED technologies will grow rapidly in the immediate future to saturate the lighting market, despite any current barriers posed by cost considerations.

Critically, one distributor interviewed for the MCA that serves as a companion piece to this report indicated that cost was only the "biggest barrier up until probably six months ago." This is consistent with the findings in Exhibits 6 and 7 in particular, which show that despite the potential barrier posed by the cost of LED technologies, they are rapidly being absorbed by the market as end users and contractors move swiftly towards maximum market saturation, usually at or near 100 percent of all lighting.

[16] See also Tables 4-2, 5-2, and 5-3 of the MCA that serves as a companion piece to this report, which reinforces these findings.

Therefore, the importance of cost as an impediment to further and/or complete adoption of LEDs may be waning over time, especially relative to earlier studies and data collection efforts.

With that said, limited awareness of LEDs, and especially LEDs with networked controls, may also play a substantial role in slowing or preventing adoption of SSL technologies. Specifically, as seen in the relatively lower maximum saturation parameters in Exhibits 8 and 9 (especially relative to Exhibits 6 and 7), limited awareness or understanding of LEDs with networked controls may be slowing and/or limiting the maximum possible adoption of this technology.

Therefore, potential NYSERDA opportunities in the SSL technology arena broadly include:

- Additional interventions with regard to cost or financing, aimed at reducing the payback period or otherwise enhancing the ability for end users or contractors to acquire and use LEDs and/or LEDs with networked controls in retrofit and/or new construction projects. These may take the form of increasing the reliability of program funding and making rebates available for projects that have longer development timelines.

- Additional interventions with regards to raising awareness and/or understanding of SSL technologies, with the ultimate goal of accelerating the adoption of these technologies, increasing the maximum potential saturation of these technologies, or both. These may take the form of additional seminars and classes provided by NYSERDA.

Measuring NYSERDA's Impact Using Market Adoption Curves

The market adoption curves in this report can be used in two ways to illuminate or examine NYSERDA's opportunities and potential market impacts.

First, as shown in the previous sections, market adoption curves can provide an overview of the current and expected future state of the market, based on experiential and prognosticated quantitative data from market participants. These curves can help identify opportunities for market intervention across use cases, and market segments. For example, as shown in Exhibits 6 and 7 above, market participants believe that adoption of LEDs is rapidly progressing and will reach maximum saturation of 100 percent of all lighting in many cases and sectors in the immediate future. However, as shown in Exhibits 8 and 9, there may be substantial opportunities to speed the adoption and/or increase the maximum potential saturation level of LEDs with networked controls.

Second, market adoption curves can be used in combination with iterative, regularly-performed data collection to examine the impacts of NYSERDA actions. Specifically, iterative data collection enables a comparison of market adoption curves over time. Because the curves already contain a temporal component, current levels of adoption can be compared to past adoption projections, as well as used to examine whether the slope or shape of the market adoption curve has shifted or changed in response to NYSERDA interventions.

This retrospective analysis can also be combined with parameters that measure the effectiveness or impacts of NYSERDA interventions beyond market adoption metrics. For example, if the additional use of LEDs can be expressed in terms of energy and/or cost savings per percent of a given market segment using LEDs in lieu of conventional lighting, then an adoption curve-shifting NYSERDA intervention can similarly be expressed in terms of market-level savings based on increased adoption of LEDs for a given point in time. In order to complete such an analysis, the following data points and parameters are necessary:

- A set of baseline, pre-intervention market adoption curves for the segment(s) within which the intervention will be targeted;

- A set of post-intervention market adoption curves, preferably based on an iterative data collection effort performed as a follow-up to the data collection effort that generated the baseline market adoption curves; and

- A set of unit-level parameters used to express the impact of the intervention in terms of increases in adoption rate. For example, the additional energy and/or cost savings associated with a one percent increase in LED use as a proportion of all lighting in a given market segment.

Preliminary Example – Additional Incentives for LEDs

Based on the current survey data and key market actor interview data collected for EMI's earlier market characterization, NYSERDA's potential impact on the pace of adoption of SSL technologies is likely directly related to the specific barrier or barriers that NYSERDA's actions will attempt to address or ameliorate. Therefore, NYSERDA actions that reduce the most-emphasized barrier, cost considerations, could potentially have a greater impact on further adoption of LEDs (and/or LEDs with networked controls) than actions focused at other barriers, such as a lack of awareness or information on LED technologies.

Exhibit 10 illustrates the potential effect of additional financial incentives (e.g., rebates, etc.) that NYSERDA could undertake to accelerate adoption of LEDs in the residential retrofit sector. Specifically, for purely illustrative purposes, Exhibit 10 uses the 25th percentile market adoption curve for the residential retrofit sector (Exhibit 7, upper right-hand corner chart) as the "baseline" market adoption curve. This curve, represented by the solid line in Exhibit 10, features:

- Current saturation of LEDs: five percent of all lighting in residential retrofit projects;

- Maximum possible saturation of LEDs: 80 percent of all lighting in residential retrofit projects;

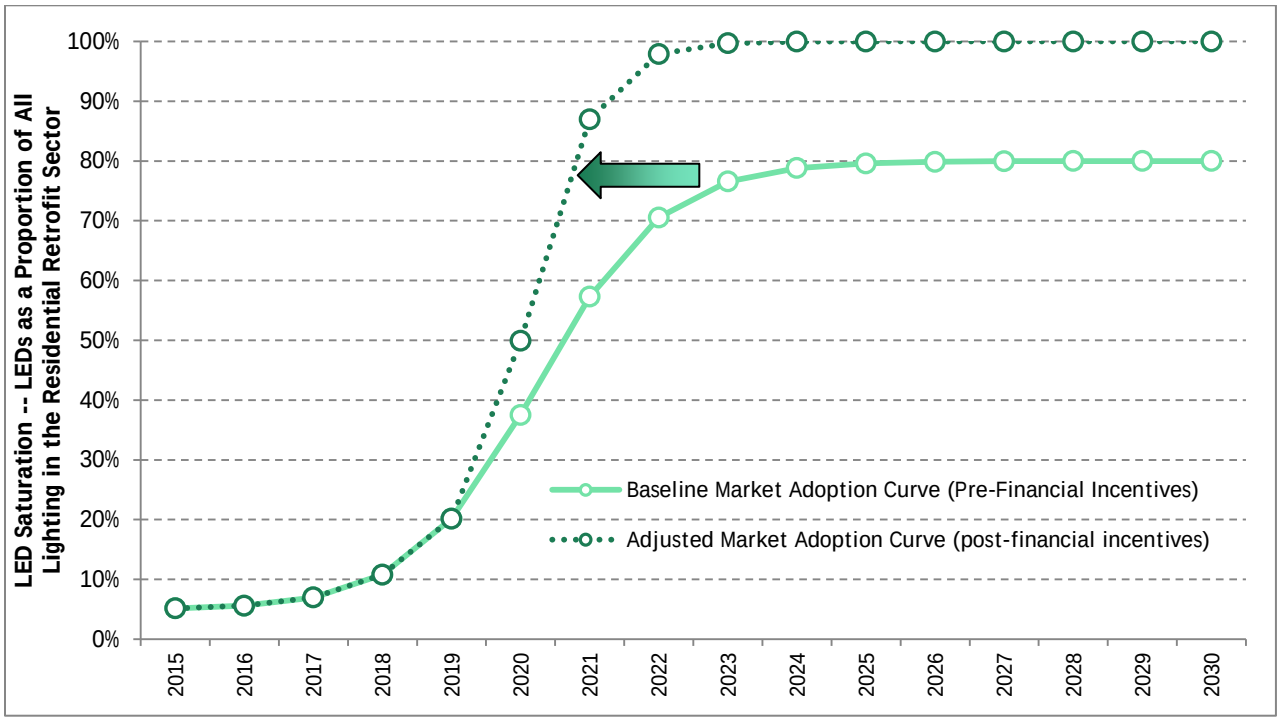
- Years until maximum possible saturation of LEDs in this sector achieved: 10 years; and

- Saturation of LEDs in five years: 37.5 percent.

To illustrate a hypothetical, potential effect of additional NYSERDA financial incentives for LEDs in the residential retrofit sector, Exhibit 10 uses a dotted line to show an "adjusted" market adoption curve, represented by the 50th percentile market adoption curve for the residential retrofit sector (Exhibit 7, upper right-hand corner chart). This curve features:

- Maximum possible saturation of LEDs: 100 percent (up from 80 percent);
- Years until maximum possible saturation of LEDs achieve: eight years (down from 10 years); and
- Saturation of LEDs in five years: 50 percent (up from 37.5 percent).

Exhibit 10. Hypothetical Effect of Financial Incentives on Future Adoption of LEDs in Residential Retrofit Sector



The potential shift in the market adoption curve illustrated in Exhibit 10 reflects two different impacts on its parameters:

- First, the shape of the curve changes to feature steeper growth. In real world terms, this reflects faster adoption of LED technology in the residential retrofit sector. In the given example, this may reflect financial incentives lowering the cost and/or payback period of LED technologies to spur more widespread adoption.
- Second, the curve's maximum limit may increase. In real world terms, this reflects an increase in the proportion of projects that could feasibly incorporate LEDs.

As described above, a parameter that measures the associated impact, in terms of energy savings, cost savings, or another meaningful outcome, could then be used to assess the effects of this intervention. For example, as shown in Exhibit 10, the difference between the baseline and adjusted curves in 2020 is a 12 percent change in saturation of LEDs, and there are additional changes in later years, including a consistent 20 percent difference in the maximum saturation amount. To the extent that the costs and benefits of transitioning to LED lighting can be quantified (e.g., by estimating the costs of installation and the energy savings and avoided environmental impacts at a per unit or per project level) then NYSERDA can use market curves to help estimate and display the monetized impacts of its market interventions.[17]

[17] The extent to which this can be done requires reliable estimates of both the unit changes and the total market (or universe) of potential projects.