DNV

WHEN TRUST MATTERS

LIGHTINGPLUS MARKET CHARACTERIZATON

A Joint Program Administrator Study

REPORT

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Acknowledgments

First and foremost, the research conducted by the DNV team would not have been possible without the participation of our sponsors including Ameren Illinois, Ameren Missouri, Avangrid, Consumers Energy, Energy Trust of Oregon, Focus on Energy, IESO, Rhode Island Energy, Tacoma Power, Xcel Energy, and our lead sponsor, ComEd. We are also thankful to the Program Administrators (including their implementation vendors), manufacturers, and contractors who participated in our primary research efforts. Lastly, we would like to acknowledge our partner firms, Electrical Transitions and Michaels Energy.

1. INTRODUCTION

Commercial and Industrial (C&I) lighting has traditionally comprised a significant portion of energy efficiency savings portfolios. Energy-efficient solid-state lighting is saturating lighting markets, diminishing opportunities to generate energy savings that have typically resulted from replacing legacy lighting systems with LEDs. However, solid-state technology also enables sophisticated controls, new applications, and higher efficacy products. This study brings together program administrators (PAs) from the U.S. and Canada to jointly explore the commercial ambient linear and high/low-bay market to:

- Quantify the remaining commercial legacy lighting stock still available for LED replacement through 2030 and characterize the nature of this market
- Assess the viability and potential savings of next-generation (NextGen) opportunities for LED products beyond legacy fluorescent to LED conversions

Eleven PAs from across North America and DNV collaborated on this research. In addition to this aggregate report, each sponsor is receiving their own tailored Market Model workbook reflecting their jurisdiction's stage of the ambient linear and high-bay market. The workbook includes a recommended scenario for each sponsor to model the LED saturation in their jurisdiction based on contractor responses, but also allows users to adjust between low, medium, and high market share scenarios.

Overview of study findings

There is broad consensus that the majority of linear ambient and high/low bay fixtures in the field are LEDs and that the size of the legacy market will continue to decline. Further, the remaining market is located primarily in smaller buildings and in more limited subsectors with fewer staff and economic resources and/or in harder-to-serve communities. Additionally, while there are viable opportunities to replace existing LED installations with Next Generation (NextGen) technologies such as higher efficacy products or controls, these opportunities do not have the same energy savings potential as legacy conversion measures and will come at a higher cost. PAs will no longer be able to rely on lighting

to provide low-cost, high- volume savings and will instead need to transition lighting program designs and approaches to access these higher-cost savings while still capturing the remaining viable savings.

Legacy conversions

Through interviews with 112 program implementers, program vendors, manufacturers, and lighting contractors and the development of a bottom-up stock turnover model, this study reached a consensus that the commercial market has entered the "late majority stage" of market adoption.

While there are some jurisdictional differences, the C&I lighting market has largely reached the "late majority stage" where on average, LEDs represent 60% of linear fixtures in the field and 75% of national sales. While a large number of facilities across North America still have legacy technologies in place, upgrading lighting in those facilities will require program adaptations to target smaller buildings in harder-to-reach communities where much of the remaining potential lies.

NextGen

Study partners identified six commercial NextGen lighting opportunities that are most likely to produce significant program savings or have generated market attention. The NextGen findings leveraged the interviews mentioned above, secondary research, and subject matter expertise to estimate typical savings and cost scenarios for each. DNV used the outputs of the Market Model to estimate the total program potential. We assigned each NextGen opportunity a grade indicating its attractiveness. Grades A and B opportunities are viable across large parts of the market and with the potential to deliver meaningful program savings. There is also a clear path to delivery through midstream or downstream programs. Grade C and D opportunities are feasible in small niche markets, with modest savings potential, and a more complex delivery.

Table 1-1 summarizes these findings.

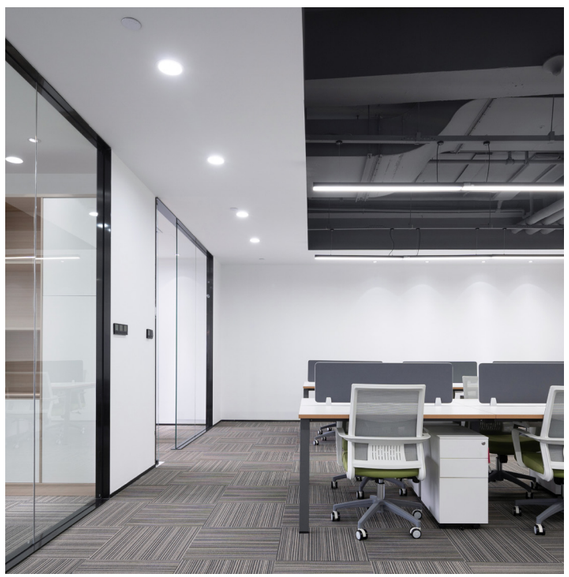
Table 1-1. Assessment of NextGen opportunities

	Higher-efficacy products LED to LED	Advanced lighting controls (ALC)	Redesign LED to LED retrofit	Demand management with lighting	Germicidal UV (GUV)	Tunable lighting
Grade	A	B	C	C	D	D
National potential (MWh)	1,280,415	1,914,727	545,381	Niche	Niche	Niche

The NextGen opportunities are described in more detail below:

1. **Higher-efficacy products LED to LED**. Replace existing LEDs one-to-one with higher-efficacy LEDs. Efficacy is the measure of product efficiency in lumens per watt.
2. **Advanced lighting controls (ALC)** including network lighting controls (NLC) and luminaire-level lighting control with integrated controls (LLLC) that are not networked.
3. **Redesign LED to LED retrofit.** Replace existing LEDs with a full redesign to meet the lighting requirements of the space, remove old products, reconfigure the ceiling grid, and select new products. This differs from a one-for-one replacement of fixtures which often requires much less labor but cannot realize as much savings due to the persistence of improper lighting levels which only redesign can address.
4. **Demand management with lighting.** Use lighting as a demand management resource by dimming or turning it off.
5. **Germicidal UV (GUV).** Deploy UV lighting technology to sterilize air supplied to occupants in commercial settings to reduce the spread of infectious diseases. This measure allows a facility to offset a portion of outdoor air with return air from the conditioned space, thus reducing heating and cooling loads.
6. **Tunable lighting.** Deploy specialized LED lamps or fixtures that can modulate both the lumen output (dimming and brightening) and the color mix or spectrum of the light to enhance occupant wellbeing by matching natural daylight. Tunable lighting is also deployed in indoor agriculture settings.

While DNV did not explicitly calculate the savings potential of legacy conversions, rough estimates show that legacy conversions and NextGen opportunities have a similar magnitude of savings potential in 2025. NextGen opportunity equipment costs and absolute savings per installed unit are both expected to decline, making it difficult to predict cost-effectiveness trends.



2. METHODOLOGY

The two study objectives to characterize the legacy market and assess the potential of NextGen opportunities were supported by three joint research activities:

112
interviews
with program implementers, program vendors, manufacturers, and lighting contractors

quantitative
market model
developed

engineering-oriented
desk reviews
completed

DNV synthesized the results of these three activities to produce the findings and conclusions of this study. We presented these findings through a combination of in-person and virtual workshops to discuss and brainstorm ideas for program changes and offerings with all project sponsors.

Interviews

Primary data collection included market actor interviews. Market actor categories and interview objectives are as follows:

- Program administrators (including their implementation vendors) from the U.S. and Canada (17 interviews completed)
  - Understand program experience and identify recent program redesigns and changes
  - Characterize how program offerings have been performing compared to historical trends and how programs have shifted
  - Capture how NextGen opportunities contribute to program savings
- Manufacturers of LED technologies and controls, and industry experts from the U.S. and Canada
  - Understand the state of commercial readiness for the NextGen opportunities.

  DNV conducted 10 interviews, 3 with industry experts and 7 with manufacturers. Table 2-1 shows each manufacturer's region of operation.

Table 2-1. Manufacturer interviews by region

OEM	Region of operation
OEM 1	US
OEM 2	US, Canada, Central America
OEM 3	Globally
OEM 4	Globally
OEM 5	US, Canada
OEM 6	US, Canada, Mexico and Latin America
OEM 7	Globally

- Program participating contractors located within each project sponsor's jurisdiction (85 interviews completed)
  - Provide on-the-ground perspective of the remaining market and NextGen opportunities
  - Identify the customers they currently serve and who they believe are the customers with legacy products
  - Determine their familiarity with NextGen products, their baselines, and where they might apply

DNV selected a sample of contractors to interview from each jurisdiction and within three size segments, as shown in Table 2-2. We categorized each sponsor's participating lighting contractor data into small, medium, and large segments according to the cumulative annual savings represented by each contractor.

Table 2-2. Contractor size segment thresholds

Segment	Percentage of cumulative annual savings
Excluded	0-5%
Small	5-33%
Medium	33-66%
Large	66-100%

The smallest saving contractors, representing the first 5% of cumulative annual savings, were excluded from the sample. Where each sponsor's contractor data allowed, DNV randomly selected 15 contractors from each size segment. For the few sponsors that were not able to provide annual savings with their contractor data, DNV defined contractor size using the number of lighting projects the contractor self-reported completing in the past year compared to the response of contractors whose size was determined using the sponsor savings data.

Table 2-3 summarizes the distribution of interviews by jurisdiction and size.

Secondary data collection and analysis consisted of gathering reputable, publicly available sources of lighting market information (e.g., lighting stock data, cut sheets, market potential studies, etc.) and producing models and desk reviews to estimate the remaining potential for each NextGen lighting opportunity included within the scope of work.

Table 2-3. Contractor interview completes by jurisdiction and size

Sponsor	Small contractors	Medium contractors	Large contractors	Interviews completed
Ameren Illinois	3	2	3	8
Ameren Missouri	2	4	3	9
Avangrid	3	3	2	8
ComEd		5	1	6
Consumers Energy	2	4	2	8
Energy Trust of Oregon	6	1	1	8
Focus on Energy	1	5	5	11
IESO	7	5	1	13
Rhode Island Energy	3	1	1	5
Xcel Energy	3	2		5
Tacoma Power	4			4
TOTAL	**34**	**32**	**19**	**85**

Modeling building stock

The primary goal of the modeling effort was to model the number of fixtures by technology (TLED, LED, T5, T8, T12, HID, etc.) currently in buildings (the saturation) and forecast how that will change through 2030. The number of fixtures in the field in any given year is a primary driver of potential (more fixtures equal more savings).

DNV adapted an existing stock turnover model to estimate the saturation and market share of lighting technologies in linear ambient and high/low bay applications. This model has been tested in jurisdictions across the country and validated against field-determined saturations.

The model produced estimates of installed stock, annual sales, and saturation of various lighting technologies in ambient linear and high/low bay applications. The outdoor lighting market was not included in the scope of this project. The market share of each technology, defined as a percentage of annual sales, is a key input in the model for predicting saturation, defined as the percentage of the installed stock.

For this study, DNV developed three market share scenarios representing low, medium, and high LED adoption rates. The market share scenarios follow this standard adoption curve with several adjustments reflective of market conditions that result in varying levels of LED saturation, such as starting market share value, what year rapid growth in LED markets began, and how steep the growth was during the rapid growth phase. DNV developed market share scenarios using data from previous market model studies and available national and subnational lighting market research. Additional information on the market share scenarios is included in the model workbook. We developed the medium scenario to model the national average LED market share from 2016 to 2030. We compared the results of the model to the 2020 DOE Lighting Market Characterization study to confirm that estimates and assumptions aligned with national findings.

The model estimates the stock that has burned out (based on hours of operation and equipment life), stock added via new construction (based on rates of new construction), stock that will be retrofitted, and the balance of the stock remaining (referred to as existing in this study). The distribution of equipment sales for available stock in any year (burned out, new construction, and retrofit) is based on the market share of products for that year. To calculate the composition of the new stock each year, the model applies the annual market share values to the total pool of available stock from burn-out, retrofit, and new construction to determine the total volume of new stock by equipment category. The output from the model includes annual estimates of total sales and installed stock by equipment category in the ambient linear and high/low bay submarkets.

National model estimates will be presented in this report, and each jurisdiction will receive a workbook with their specific modeled results. The workbook will include a recommended scenario for each PA to model the LED saturation in their jurisdiction based on contractor responses, but the model also allows users to adjust between low, medium and high market share scenarios.

NextGen opportunity desk reviews

Each opportunity focuses on a technology innovation. The goal of the desk review was to identify specific energy efficiency measures associated with the technology that could be incorporated into an energy efficiency program. The group selected the 6 opportunities for this study (higher-efficacy products LED to LED, ALC, Redesign LED to LED retrofit, Demand management iwth lighting, GUV, and tunable lighting) based on their likelihood of producing significant program savings or their market attention.

Each opportunity considers two to three measure configurations or scenarios to address different technology applications like retrofit vs. new construction, or market niches where a measure is most cost-effective. The DNV team reviewed market research, product specification sheets, historical project files, and other documentation to understand past lighting projects, baselines for NextGen technologies, and cost-effectiveness from customer and program perspectives. We used TRM-type savings estimates and cost research to calculate various metrics such as annual average unit savings, lifetime savings, customer simple payback, and estimated program cost per first-year kWh.

Estimating program potential starts with narrowing the total number of linear ambient and high/low bay fixtures to those that could be served by the opportunity. The addressable market is first limited to only TLEDs and/or LED fixtures. The market is further refined by event type (retrofit, replace-on-failure, or new construction) and the portion of buildings expected to either be large buildings or have higher lighting hours of use. The achievable market is calculated as the product of the addressable and the achievable market potential (the percent of the addressable market that passes through the program). Program uptake is impacted by the customer payback, the ease of implementation, program delivery, and non-program impacts. Program potential (MWh) is calculated as the product of the achievable stock and the unit savings. Note that the achievable market potential can be adjusted in the stock model.

Sponsor workshop and reporting

DNV hosted a hybrid in-person/virtual workshop with project sponsors to review the results of the activities described above, challenge the recommendations, and brainstorm solutions for possible program design changes and offerings. The workshop served as a forum for study participants to think about the status of the market in each jurisdiction and what solutions may enable PAs to maximize savings in a quickly changing market.

The results, recommendations, and considerations for follow-up research are presented below.

3. WHAT DOES THE REMAINING LEGACY OPPORTUNITY LOOK LIKE?

This section discusses the stock and market saturations of linear and high/low bay products and the implications for remaining opportunities for traditional programs that focus primarily on retrofitting legacy technology with LED and TLED fixtures.

3.1 Market status and forecast

DNV asked PAs and contractors about the present state of lighting markets in their service area. To provide quantitative expressions of market status, we asked them specifically about estimated characterizations of the market status on a standard market adoption curve (S-curve), as well as numerous estimates of LED market saturation, market share, and overall market penetration. Independently of this data collection effort, DNV also used the stock turnover model to estimate and forecast national market share and saturation.

Technology adoption over time is often demonstrated through an S-curve. At the beginning of the curve, adoption is slow with a relatively flat slope. The theory is that as time passes and the technology becomes more accepted (due to technology improvements, lowered costs, etc.), adoption increases, and the slope curves upwards with increasingly rapid adoption. As the market progresses, there often remain holdouts who do not change over or adopt the new technology, and the slope again flattens, slowly moving until it eventually reaches maximum adoption, which may not be 100%. If and when a market reaches the late majority phase, it has become standard practice in nearly all applications. Contractors and program staff were asked to estimate where along the adoption curve the lighting market in their jurisdiction was.

Figure 3-1 shows the national market share scenario for sales by year. The model estimates that the national lighting market is in the late majority stage. Thirty-six percent of contractors and 46% of program staff reported that the lighting market in their jurisdiction was in the late majority stage. The difference is not unexpected since contractors in the business of lighting retrofits are focused on the 30%-40% of the customers with legacy technology, so most of what they see are legacy products. Customers who have already installed LEDs aren't inviting contractors in to assess their lighting.

Figure 3-1. LED market share (sales) scenario

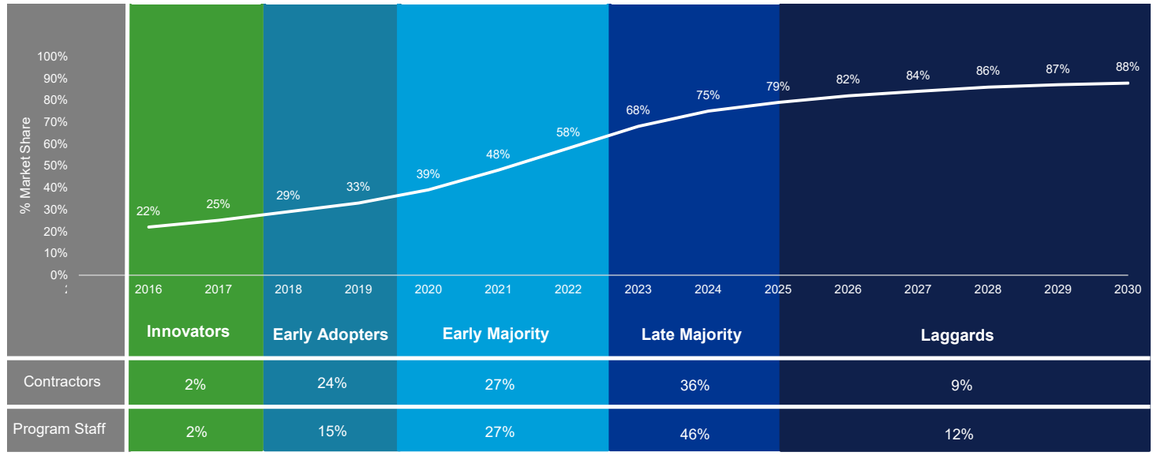
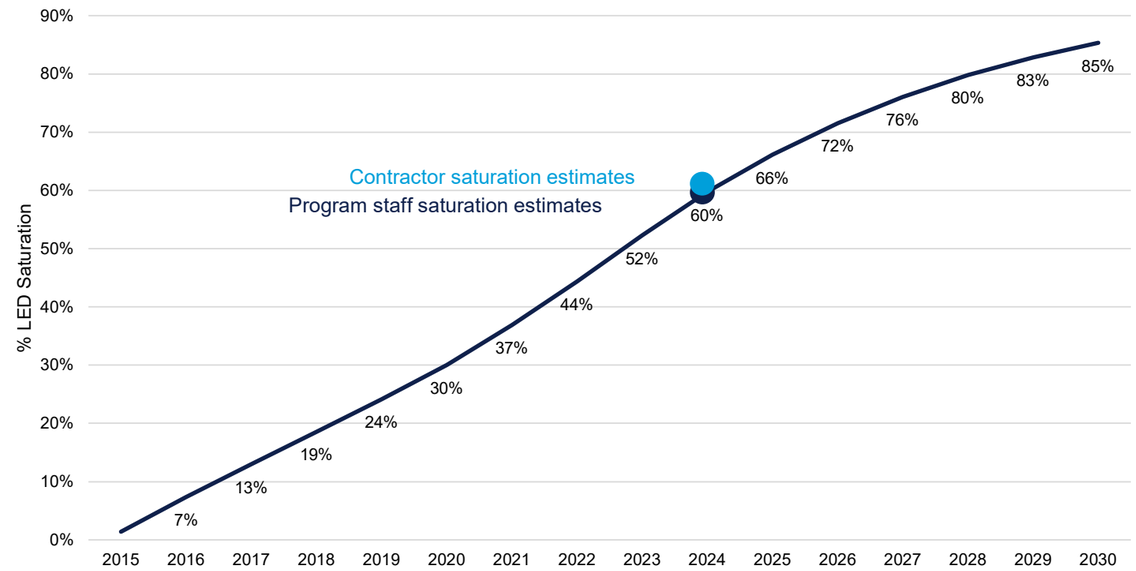


Figure 3-2 shows the modeled national LED saturation in the ambient linear and high/low bay submarket. The model estimates that in 2024, national LED saturation, or the percentage of all fixtures in the field, is 60% in the linear submarket and that the lighting market will be dominated by LED technologies by 2030. Across sponsor jurisdiction program staff estimated that LED saturation in 2024 was 60% and contractors estimated 62% LED saturation.

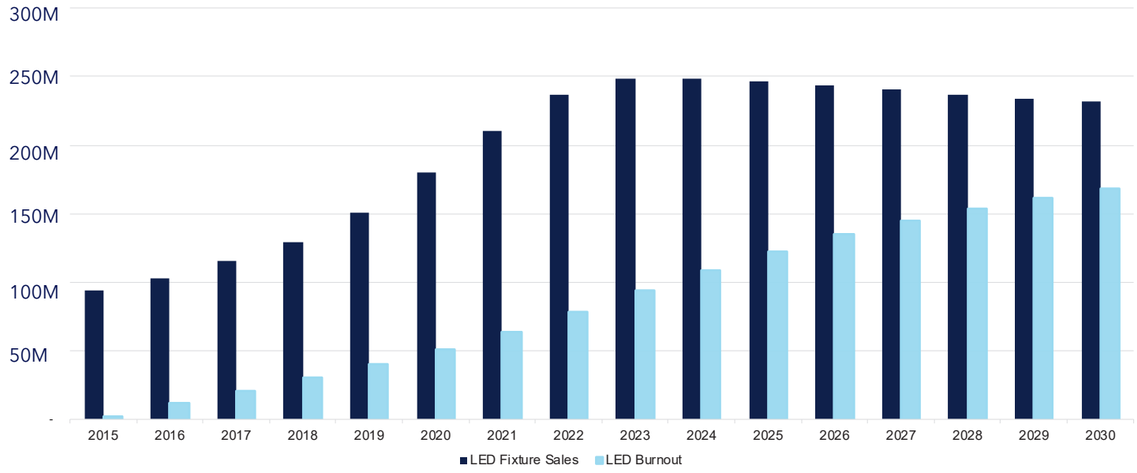
Figure 3-2. National LED saturation in the ambient linear bay submarket (existing stock in the field)



In Figure 3-3, the light blue bars show the annual number of LED fixtures in the linear submarket that will burn out annually, according to model estimates. Burnout rates are based on lamp lifetime hours and annual hours of use by building type. The dark blue bars show the number of LED fixtures in the linear submarket that will be sold annually, according to model estimates.

Figure 3-3 shows that LED sales peaked in 2023 and will start to slowly decline, due to the long lifetime hours of LED technologies leading to less frequent replacement on burnout (ROB). In 2015, LED sales were replacing LED burnout, but a significant amount of the sales were replacing fluorescent technologies or being installed in retrofits and new construction. By 2030, most LED sales will be replacing LED burnout, limiting the opportunity for traditional program intervention.

Figure 3-3. National ambient linear submarket burnout and installed fixtures under medium adoption scenario



Tapping the remaining opportunity

With the market having largely adopted LED lighting, it's important to identify the remaining opportunities for conversion and what must be done to capture them. DNV interviewed 85 program participating contractors to gain insights into the profile of customers with legacy technology, how the contractors are positioned to serve that market, and program improvements that might lead to better uptake of program offerings.

First, we asked contractors about the customers they currently serve:

- **New construction versus retrofit** – Contractors reported about half of their work is in new construction or major renovation projects.
- **Serve small business** – 43% of contractors completed projects in buildings under 10,000 sq ft, and 34% completed projects in buildings over 100,000 sq ft.

- **Underserved communities** – Only 26% of contractors reported that they regularly work in underserved communities (defined to contractors as those with disproportionately limited access to clean energy resources and services compared to the broader population, and a lack of resources). Contractors who reported not typically working in underserved communities also said the following:
  - *"No specific or pointed work with these communities. Whoever wants work [hires us] gets it."*
  - *"Give an extra cut to schools, elderly housing, low-income housing, even jails. Places where vulnerable or underserved people exist."*
  - *"Focus on underserved communities. Programs aren't in tune with those audiences. Lighting is done in nicer areas because they can pay for it. It's not necessarily the money, but the budget. Programs aren't flawed, but distribution of the budget is flawed."*

While the market as a whole may have largely shifted, there are certain sectors where contractors believe LED saturation is lower. Contractors see the biggest opportunities in these areas:

- **Small businesses –** 89% of contractors said the largest proportion of the remaining opportunity is with small businesses although there are still some opportunities in medium and large buildings. Contractors said the following:
  - *"Smaller retails and mom and pop are harder since they don't have as many funds."*
- **Specific sectors –** Contractors mentioned buildings with more opportunities include warehouses, offices, religious organizations, and schools.
- **Retrofit –** Contractors reported that 80% of the remaining opportunities are in retrofits.

Contractors identified barriers to replacing legacy technology with LEDs and program improvements to help overcome those barriers. Table 3-1 presents the barriers to conversion most often cited by the contractors and their proposed solutions. Somewhat surprisingly, contractors identified customer perceptions of the product as often as financial barriers. Unsurprisingly, they offered more financial-oriented solutions than marketing solutions.

Table 3-1. Primary barriers and solutions to LED adoption for legacy conversions

	Contractor proposed barriers & percentage of contractors	Contractor proposed solutions & % of contractors
Financial factors 52%	Cost (36%)	• Increase incentives (30%) • Improve program processes to reduce burden (25%) • Financing options (22%)
	Access to capital (16%)	
Product perceptions 56%	Awareness (31%)	• Marketing and outreach (35%)
	Resistance to change (25%)	

Some specific recommendations made by contractors to improve program processes were:

- Streamline the application process
- Simplify program calculations
- Provide a contact to help with program processes
- Provide training for trade allies in sales and marketing, outreach, and rebate processing

Contractors recommended the following financing options to support program processes:

- On-bill financing options
- Low-interest financing options

Lastly, contractors recommend several marketing and outreach improvements:

- Increase marketing and outreach to boost awareness and understanding of technology
- Include case studies highlighting measurable success

3.2 Conclusions and recommendations

While there are some jurisdictional differences, the C&I lighting market has largely reached the "late majority stage" where LEDs currently represent 60% of linear fixtures in the field and 75% of sales on average. As a result, there is a broad consensus that the majority of linear ambient and high/low bay fixtures in the field are LEDs and that the size of the legacy market will continue to decline. Further, the remaining market with legacy technologies—about 40%—is chiefly located in smaller buildings or limited subsectors with fewer staff and economic resources and/or in harder-to-serve communities. Additionally, while there are viable opportunities for replacing existing LED installations with higher-efficacy products or adding controls, these opportunities do not have the same energy savings potential as legacy conversion measures and will come at a higher cost. PAs will no longer be able to rely on lighting to provide low-cost, high-volume savings and instead will need to transition lighting program designs and approaches to access these higher-cost but viable savings while still capturing the remaining viable savings.

These conclusions lead to two broad recommendations:

Maximize the quality, efficacy, and functionality of LEDs for customers that are looking to install LEDs.

Considering the high cost of customer acquisition, especially when the remaining legacy products are harder-to-reach customer sites, **each customer touch should maximize savings by installing quality, most-efficient, and functional products**. This will increase customer satisfaction and minimize stranded savings. However, the goal of minimizing stranded savings can be in tension with cost-effectiveness. Program designers will need to consider the trade-off between high product efficiency standards, which will maximize the savings per customer touch, but **may reduce the number of participants and increase costs. Structuring around savings tiers in a midstream program and better screening downstream customers are ways to optimize these factors.**

The High-Efficacy Products Opportunity described in the next section directly addresses the value of directing customers to better products.

Target hard-to-reach segments of the market and other market laggards.

Participating contractors are serving small, medium, and large customers roughly equally as a percentage of their projects. Contractors report that larger customers often have institutional resources, brand image, a strong customer-facing profile, and/or are served by utility account representatives that small and medium customers often lack. Smaller customers (non-profits, churches, small businesses, schools, multifamily, etc.) frequently have fewer resources and/or are located in areas without a strong contractor base (e.g., inner city, rural). Contractors report that cost is a major barrier to serving their customers, with resistance to change as a distant second barrier. **Seventy-four percent of contractors said they do not pursue projects in hard-to-reach or underserved market segments.**

To motivate late adopters, programs must adapt. For example, offering higher incentives for hard-to-reach segments will increase contractor interest. Narrowly focused and short-term outreach campaigns can target a specific location to gain some economies of scale. Marketing and outreach messaging can be tailored to educate laggard businesses and combat skepticism. A direct-install model might best help convert hard-to-reach legacy systems (although this model can cost three to five times more than a rebate program).

Contractors will need more support and incentives to increase their focus on retrofits located in hard-to-reach markets.

While contractors report that about two-thirds of the legacy conversion opportunity is in retrofit, about half of their work is in new construction/major renovation (although this represents only 1-2% of all fixtures), which does not address legacy stock conversions. Contractors also claim that 80% of the opportunities are in retrofit.

On a positive note, programs targeting hard-to-reach and direct install programs, while more expensive, may evaluate more favorably. Well-run direct install programs usually have high gross realization rates and net-to-gross ratios. Recent research in Connecticut, for example, showed a significantly higher net-to-gross ratio in disadvantaged communities.

4. WHAT DO NEXTGEN OPPORTUNITIES LOOK LIKE?

DNV evaluated six NextGen opportunities as part of this study. Each opportunity received a grade indicating the opportunity's potential fit for generating savings through a traditional program model, summarized once more in Table 4-1.

Table 4-1. Assessment of NextGen opportunities

	Higher-efficacy products LED to LED	Advanced lighting controls (ALC)	Redesign LED to LED retrofit	Demand management with lighting	Germicidal UV (GUV)	Tunable lighting
Grade	A	B	C	C	D	D
National potential (MWh)	1,280,415	1,914,727	545,381	Niche	Niche	Niche

- As shown in Table 4-1, DNV found that three of the six opportunities are **mass market** opportunities, and three of the six opportunities are **niche market** opportunities. The niche market opportunities will likely apply to customer-to-customer site-specific conditions and, while beneficial for a small number of customers, do not lend themselves to mass adoption or a traditional, scalable program offering.

The following sections summarize DNV's assessment of each NextGen opportunity based on desk reviews, stock model results, and market actor interviews. The DNV team has combined these three inputs to produce a well-rounded, concise assessment of the program potential for each of the six next generation opportunities. Each opportunity includes two to three scenarios for different common base conditions or to distinguish between a retrofit measure and a lost opportunity measure, which includes replace-on-burnout (ROB) and new construction.

Each of the in-depth assessments begins with a table of key metrics illustrating the value proposition to the customer and the PA. These metrics are intended to be average values and in principle, equivalent to a deemed savings value or technical resource manual (TRM) followed by a high-level narrative summary.

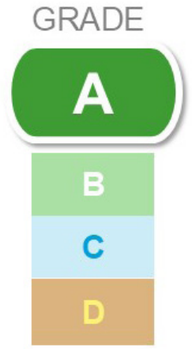
Customer perspective: the simple payback (without incentives) and the unit energy savings.

PA perspective: the program measure cost metric (the program cost divided by the first-year savings) and the estimated annual program savings (MWh).

Incentives: the cost to buy down the measure to a 4-year customer payback. Program costs are the sum of incentives plus PA adder.

Incremental cost (IMC): the incremental material and labor cost of the measure from the customer perspective without incentives.

4.1 Higher-efficacy products LED to LED



This opportunity leverages the range in LED efficacy (lumens per watt) offered in the market. Data shows a sustainable 20% savings trend between baseline and highest efficacy products in the next five years. DNV examined three scenarios that will consistently produce savings in LED-to-LED, one-for-one replacements with higher efficacy products that are summarized in Table 4-2.

- **Possible program opportunity:** Replace any burned-out LED product with a high-efficacy equivalent product in a midstream program. In an existing downstream program, this opportunity also is suitable for the early replacement of a Gen1 TLED with a high-efficacy TLED and Gen1 LED high/low-bay fixtures with a high-efficacy fixture with above-average hours of operation.
- **Baseline measure:** Industry standard practice (ISP) efficacy LED products. DesignLights Consortium (DLC) Version 5.1 standard and premium thresholds are currently at the lowest efficacy tiers (in the 5-25% efficacy range of the DLC ranking), indicating that standard practice is low and allowing PAs an opportunity to establish higher efficacy tiers for more savings.

Table 4-2. LED-to-LED replacement (higher efficacy) scenarios

Opportunity characteristics	Scenario 1: ROB with high-efficacy products	Scenario 2: Retrofit an existing TLED with high-efficacy TLEDs	Scenario 3: Retrofit an existing LED fixture with a high-efficacy LED fixture
Applicable market	All LED stock that requires replacement due to burn-out	All stock with Gen1 TLEDs	High bay unchanged GEN1 LED stock with high hours of operation
Opportunity unit	2' by 4', 2-lamp linear	2' by 4', 2-lamp linear	100w high bay
First-year kWh savings	29	77	290
IMC $/unit	$2	$26	$267
Simple payback	0.6	2.3	6.1
Program savings (MWh)	368,662	909,280	2,473
Customer incentive	$4.00	$15.00	$100
Program $/kWh	$0.17	$0.23	$0.41

Grade: A – Expansive market opportunity, good customer paybacks, known program model and additional savings from other applications like exterior lighting

High-efficacy products are promising. This measure leverages the range of product efficacy listed in DLC and the data shows a sustainable 20% savings trend between the baseline and highest efficacy products in the next five years. DLC lists an estimated 80% of products sold and contains ratings for about 1 million products. Currently, the DLC Standard and Premium efficacy requirements are in the bottom quarter of the efficacy ranking, indicating that a broad range of products is available in the upper tiers of the ranking. Research indicates that higher-efficacy products are only marginally more expensive than lower-efficacy products.

The high-efficacy products opportunity is large in part because it addresses the entire LED burn-out market. Retrofitting existing TLEDs with higher-efficacy products is cost-effective. High/low bay applications with higher hours of operation can also be cost-effective.

The opportunity was well-received by manufacturers and contractors, and contractors are very familiar with the technology's application in the market. This indicates that there should be a strong uptake in a midstream program. This measure could also add marginal savings to existing direct install and rebate program savings.

A challenge for the program designer will be to set the standards for highest-efficacy products and design appropriate incentive levels. The designer will want to optimize the number of products that are program-eligible while capturing higher unit savings. Different efficacy tiers might be a strategy. Research also indicates that incremental costs are low and that incentives should be designed to incentivize the selection of the product, rather than offset incremental cost.

Because this program is influencing the market to move to higher efficacies, it is a candidate for market transformation and indirect savings could add substantially to the savings.

Desk review

Through the desk review process, the DNV team found that:

- This opportunity **leverages the range** of LED efficacy offered in the market. Data shows a sustainable trend of savings between ISP and highest efficacy in the mid-term of about 15% savings for mid-efficacy products and 20% (about 3.5 watts/TLED 4' lamp) for the highest-efficacy products.
- **Incremental cost differential is negligible.** A research study of six major LED manufacturers shows that cost does not correlate with efficacy . The biggest determinant of cost is lumen output followed by manufacturer, DLC qualification, and CRI—not efficacy; thus, the incremental cost for a higher-efficacy product is theoretically small. However, there may be product constrictions, like fewer products available in the highest tier, that produce upward price pressure, so the estimates include a small cost premium. ROB provides well under a one-year customer payback.
- **Incremental cost differential for retrofit is a barrier.** Retrofit payback is positive for TLEDs, but not usually for existing LED fixtures except in more limited scenarios, which aligns with contractor perspectives citing cost as a barrier.
- **There is a large addressable market.** All existing stock that burns out and all existing TLED stock are likely to be suitable for this opportunity.
- **Opportunities within midstream and downstream programs.** This opportunity is likely well-suited to existing midstream programs and can provide an added margin of savings in downstream markets. Incentives are designed to incentivize the selection of the product, rather than offset incremental cost. By explicitly targeting the highest-efficacy products, these measures may induce market transformation, creating a basis for claiming large indirect savings.

Market and program uptake

The (relatively) higher potential of this opportunity is because burnout replacements constitute about 10% of all stock each year, presenting ample opportunities for efficacy upgrades. Customer uptake of the program offer should be brisk (estimated to be 10% of all burnouts) for Scenario 1 because a large portion of products are expected to qualify, customer paybacks are excellent, and the replacement can be logically integrated into existing midstream programs. The proportion of existing stock is much higher than the burnout stock for the same technology; therefore, the addressable retrofit market for the next two scenarios is large. The unit savings for retrofits are also higher than the burnout replacement. However, customer uptake is expected to be lower (2% in the models) due to customer resistance to retrofits, longer customer paybacks, and the more limited mechanisms of downstream programs. The sum of the scenarios is equal to 1,280,415 MWh when accounting for a small amount of overlap within each scenario.

Market actor interviews

DNV collected the following input about LED-to-LED replacements (higher-efficacy products) from contractors, manufacturers, and PAs.

Contractors

- **While fixture retrofit opportunity works well in most buildings** and locations, better opportunities would be found in large buildings (e.g., warehouses and industrial).
- **The most common retrofit barriers** are cost, leading to a long return on investment, and lack of awareness.
- **PAs could address these barriers** through increased incentives. Contractors also mentioned enhanced marketing and education and simplifying the application process.

Manufacturers

- **LED-to-LED replacement** with higher-efficacy products was found to be a viable NextGen opportunity among roughly 70% of manufacturers interviewed.
- **The most common barrier is cost,** as early replacement is not likely cost-effective for the customer.
- **Fixtures are soon expected** to have an efficacy range of 160–200 lm/W.
- **One manufacturer stated,** *"I think [this NextGen opportunity] will be a repeat of 2008–2012. New construction is down for every manufacturer; retrofits are where the opportunity lies. There's a ton of early LEDs that need to be replaced. Can't think of a single manufacturer that had a product that will still be doing what it should. Opportunities for first and second generation we're seeing are huge. If it can't be fixed, it must be replaced."*

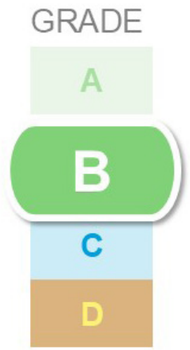
PAs

- Early LED replacement and new LED pathways provide opportunities for generating savings. Early LEDs were not as efficient as currently available products. One PA indicated that they are going through old program records to identify opportunities for outreach and leads.

4.2 Advanced lighting controls

Advanced lighting controls (ALC) for the purposes of this study are defined as networked lighting controls (NLC) at the fixture or zone level with centralized access or NLC. Luminaire-level lighting controls (LLLC) with integrated sensors and logic provide granular-level control without a network and are an attractive option for smaller buildings. Table 4-3 summarizes three strategies.

- **Possible program opportunity:** A stunning 63% reduction in hours of operation was achieved by NLC with fixture-level control in a well-executed study of 100 buildings (although these are not representative of the general population). About half of the savings is from properly setting trim. The scenarios and their outcomes are as follows:
  - **Scenario 1:** Complete retrofit scenario including replacing existing LED fixtures (one-for-one) with NLC-enabled high-efficiency products and an NLC. Larger buildings improve cost-effectiveness.
  - **Scenario 2:** Incremental addition to new construction, adding an NLC to a well-designed lighting system. Larger buildings improve cost-effectiveness.
- **Scenario 3:** One-for-one replacement of existing LED fixtures with non-networked LLLC. This illustrates the opportunity for one-for-one fixture upgrades with integrated control as a retrofit. LLLCs work well on a small scale. LLLCs are the most scalable form of ALC.
- **Baseline measure:** For retrofit, existing LED systems (Scenario 1 and 3). For new construction (Scenario 2), new standard practice LED fixtures that are NLC-ready. For all scenarios, assume code-compliant controls like manual switching and local occupancy controls.
- **Long existing hours** of operation are required for cost-effectiveness.



NLC with networked fixtures (versus networked zones of multiple fixtures) reduces equivalent full load lighting hours of operation by 63% on average (i.e., will reduce 6,000 EFLH to 2,200, although the study notes about half of the savings are from trim that is properly setting the base lumen-output of the fixture). However, the measure has about a 10-year payback, even in facilities with intense baseline lighting (higher watts/sq. ft., high hours of operation). Solutions scale with building size, so larger buildings tend to be more cost-effective. LLLCs with integrated sensors and control logic (not networked) have about a 5-year payback and can be installed in smaller buildings and spaces. While LLLC savings are expected to be about half of NLC savings, the costs are much lower. LLLC and NLC fixture costs are similar; however, the LLLC does not require the networking, central hardware, or programming and commissioning of an NLC.

While ALC can significantly reduce hours of operation, lighting power densities (watts/sq. ft.) are shrinking, resulting in lower savings per hour-reduced, a trend that is likely to continue. Like electronics generally, the cost of NLC equipment will drop and become more sophisticated at the same time. However, some costs, like commissioning, have an intrinsically labor-driven component that is likely to remain stable.

Future reductions in the cost premium of an LLLC with integrated sensors and controls and a standard LED fixture will shorten paybacks and make this product more attractive over time.

Table 4-3. ALC and LLLC scenarios

Opportunity characteristics	Scenario 1: Retrofit Gen1 LEDs 1-to1 with new HE fixtures and NLC	Scenario 2: New construction lighting with NLC	Scenario 3: Retrofit – non-networked LLLC
Applicable market	Existing LED stock in high hours of operation facilities	Existing LED stock in high hours of operation facilities	Existing LED stock in high hours of operation facilities
Opportunity unit	Per sq. ft.	Per sq. ft.	Per sq. ft.
First-year kWh savings	4.3	2.1	2.5
IMC $/unit	$4.72	$3.00	$1.97
Simple payback	7.3	9.4	5.2
Program savings (MWH)	804,441	397,380	712,907
Customer incentive	$2.70	$1.73	$0.45
Program $/kWh	$0.76	$0.98	$0.21
Grade: B – High paybacks lead to less measure up-take; however, customers value other benefits.			

Commissioning is vital to successful implementation, even for LLLCs that require trim setting and enabling controls. Commissioning for NLCs is more complex requiring zone and strategy assignments for every fixture. Commissioning costs may be reduced by automation but will likely remain significant in ALC projects; ongoing customer attention to systems is the Achilles' heel in realizing sustained savings.

Desk review

Through the desk review process, the DNV team found that:

- **System features are evolving**, and today's high-end features will migrate to lower-cost systems in the future. Networking topology is evolving to favor fixture-level control in a hub-spoke configuration or mesh. Bluetooth, Zigbee, or wi-fi-enabled individual fixtures can reduce wiring costs. Customer site specifics may favor different topologies.
- **Savings potential is high, but cost-effectiveness requires long hours of operation.** Networked lighting controls (NLCs) can achieve roughly 50% savings in the right scenario, with the best designs (NLC with fixture-level control) achieving a 63% reduction. LLLCs are cost-effective with high hours of operation, with about a 5-year payback.
- **NLCs favor larger buildings.** Implementing an NLC requires fixed-cost components like design, contracting, and programming, which do not scale by the size of the building and thus can be cost-prohibitive for smaller buildings. Non-energy benefits, for example, leveraging NLC-recorded occupancy data to analyze building occupancy patterns, require manpower to extract and analyze and likely won't warrant the effort except for the largest buildings.
- **Non-networked LLLCs are an option for smaller buildings.** LLLCs are "plug and play" and will harvest occupancy and dimming savings with modest commissioning. DNV did not find high-quality research to confirm savings fractions although multiple TRMs provide deemed savings fractions.
- **System features and costs are constantly changing.** Costs decreased by 30-40% from 2017 to 2022, a trend that will likely continue. At the same time, lighting power densities are also decreasing, which reduces the lighting load that is controlled by lengthening paybacks.

- **Commissioning** is in the $1-2/sq. ft. range for NLCs, although a common evaluation finding is that not all projects receive proper commissioning. Commissioning costs may be reduced by automation but will likely remain a significant cost in ALC projects and on-going customer attention to the proper operation of the system is the Achilles Heel to realizing sustained savings.
- **Point(s) of caution:** results are dependent on-site site-specific conditions, and it can be challenging to reliably predict ex ante savings. Commissioning presents challenges.
- **Stacking benefits.** With an NLC, other benefits like demand management or integration with HVAC can be added to help programs make the sale, although this may increase the risk of free-ridership. Stacked benefits and are discussed in Section 4.7, Stacked opportunities.

Market size and uptake

The addressable market for Scenarios 1 and 3 consists of existing linear and ambient high/bay stock with higher hours of operation. Customer uptake for NLCs is estimated to be 2% based on customer resistance to retrofits, long customer paybacks, and the more limited reach of downstream programs. Lighting non-energy impacts will contribute to the uptake. LLLCs, with their shorter payback and the relative ease of installation, are expected to have a higher uptake. The addressable market for Scenario 2 is new construction/major renovation which accounts for only about 1-2% of all stock.

Market actor interviews

DNV collected the following input about advanced lighting controls from contractors, manufacturers, and PAs.

Contractors

- **Contractors indicated a wide range of applicable scenarios for this measure:** office, schools, commercial, warehouse, and industrial were all frequently mentioned building types that could benefit from ALCs. Contractors tended to favor urban areas over rural or suburban, noting that skepticism of NLC technology is more prevalent in rural and suburban areas. A plurality of contractors said these controls should be paired with retrofit projects.
- **Contractors stated that the most valuable customer benefits** from this measure are energy and cost savings, O&M savings, and non-energy benefits such as comfort.
- **Cost, awareness, and complexity** were the primary barriers contractors mentioned.
- **Increased incentives and education/marketing** were the program approaches contractors mostly recommended. In this case, the issue of complexity is an interesting one—there may be a need for education about how to get the most out of this technology after it is installed.

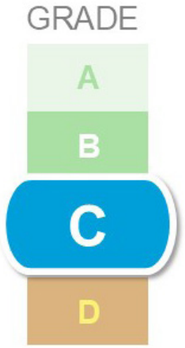
Manufacturers

- **100% of manufacturers** stated that they view networked lighting controls as a viable NextGen opportunity and that customers value the non-energy benefits associated with the measure.
  - *"[NLCs] will play a very big role—the new frontier of energy savings will come from controls."*
  - *"LED adoption went really quickly, and I think NLC will increase, but at a much slower rate than LED adoption. The driver for increased adoption is less about the energy savings and more about the other benefits of controls."*
- **Manufacturers also emphasized the potential for Bluetooth** mesh systems to significantly impact lighting systems and the potential for further integrating lighting network controls within the overall building system (e.g., HVAC).
- **Manufacturers stated that the market will see growth of controls** embedded in fixtures, with some respondents reporting that this will become the new norm.

PAs

- **When respondents were asked to comment on the future of lighting programs,** the most common response involved controls. Lighting controls offer opportunities for additional savings outside of the lamps themselves, which benefits programs.
- **Programs can be designed to incentivize controls independently** to capture savings in the portion of the market that has transitioned to LED lighting or coupled with continued LED transition to further incentivize the laggards that have not yet begun to install LED lighting measures.
- **PAs are increasingly seeing more sophisticated, packaged solutions** brought directly to customers as the next opportunity, with low-hanging fruit, the focus of standalone programs, gone from the market.
  - *"Combination of tech, not strictly lighting, controls, deeper retrofits combining technology is the path of the future."*
  - *"Look to invest more in controls and training of service provider market, education to customers as to reason to invest in those systems."*

4.3 Redesign LED-to-LED retrofit



DNV examined the opportunity for retrofitting an existing lighting system with a redesigned system as summarized in Table 4-4. The key difference between these two scenarios is whether the fixtures are ready for integration with networked lighting controls.

- **Possible program opportunity:** Redesigning existing LED lighting for quality, efficient lighting requires traditional design methods conducted by a lighting designer. Implementation typically requires modifying the existing ceiling grid, additional power wiring, and design services, which is a much more labor- and skill-based scope than one-for-one replacements. Feasibility depends on customer-to-customer site-specific conditions and this likely requires custom delivery.
- **Baseline measure:** Higher lighting intensity buildings. Sites with fluorescent fixtures fitted with TLEDs or where there was a one-for-one retrofit of existing fluorescent fixtures with LED fixtures are likely not optimally designed and thus are better candidates. Higher hours of operation also help cost-effectiveness.

Table 4-4. LED-to-LED replacement (redesign) scenarios

Opportunity characteristics	Scenario 1: Retrofit with redesign – not NLC-ready	Scenario 2: Retrofit with redesign – NLC-ready
Applicable market	Existing TLED or LED stock, annual lighting consumption >4 kWh/ sq. ft.	Existing TLED or LED stock, annual lighting consumption >4 kWh/ sq. ft.
Opportunity unit	Per sq. ft.	Per sq. ft.
First-year kWh savings	2.9	2.9
IMC $/unit	$3.61	$4.23
Simple payback	8.3	9.7
Program savings (MWH)	272,691	272,691
Customer incentive	$1.87	$2.49
Program $/kWh	$0.78	$1.04
Grade: C – Small market, custom delivery. Paybacks are not attractive.		

DNV found that the retrofit of existing LEDs or TLEDs through redesign is only cost-effective where the current installed watts/sq. ft. and run hours are at the upper range of a typical building, greater than 4 kWh/sq. ft. (lower where electric costs are higher). Even with high baseline consumption, customer paybacks are long; thus, it will likely require larger incentives to consider a retrofit and induce participation. While most contractors interviewed are familiar with this application of the technology, the relatively slim addressable market combined with modest annual savings does not make this opportunity a priority for the NextGen programs. Additionally, the extended work of demolishing existing fixtures, reworking the ceiling grid, and adding wiring compared to a one-for-one replacement disrupts the customer workspace for an extended period and may add to customer reluctance to participate.

Desk review

Through the desk review process, the DNV team found that:

- **Redesign leverages superior lighting distribution of LED.** LED technology is photometrically more efficient, potentially 20% more efficient, than fluorescent tubes because the light is directed to the lit surface rather than distributed radially in all directions. Likely, spaces lit with TLEDs in fluorescent fixtures or where fluorescent fixtures were retrofitted one-for-one with LEDs are not optimally designed. A redesign will identify the correct lumen requirements of the space, properly select lower lumen output products, and optimally locate them within the space.
- **Lighting design is inherently a custom process.** Optimized lighting matches the lumen output to a space's task requirements, optimally distributes the lumens through appropriate fixtures, and correctly places them in the space. The result is a high-quality lighting experience with maximized energy savings. Notably, inputs and outputs are extremely site-specific. Attempts to "templatize" designs have not decreased costs or increased uptake. For example, a large PA in the Northeast U.S. ran a lighting redesign track intended to foster and simplify redesign. This track comprised less than 1% of all custom and deemed lighting projects completed in 2017 and 2018.
- **Control-ready fixtures add to costs.** Adding NLC-ready fixtures adds about $0.50 per sq. ft. to the installed cost without adding savings.

Market size and uptake

The addressable market is the existing linear and ambient high/bay stock with higher hours of operation. DNV assumes that customer uptake will be low (1% used in the models) due to customer resistance to retrofits, the disruption to occupants during construction, long customer payback times, and the more limited reach of downstream programs. Executing a lighting redesign with or without controls does not yield a substantial difference in savings and adding controls extends the expected payback period by about a year. Scenario 2, while more expensive in the near term, offers more potential for savings in the future. Both scenarios require a custom program delivery that could limit uptake.

Market actor interviews

DNV collected the following input about replacing existing LED stock with a redesigned system including reworking the ceiling grid from manufacturers and PAs.

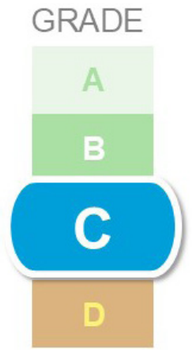
Manufacturers

- **This technology can reduce space requirements** needed to meet the necessary lighting requirements, which would benefit the transportation and installation of fixtures and lead to a lower installed cost.
- **Cost-effectiveness is achieved** through fixture efficacy, higher output luminaires, and high hours of use per day.
- One manufacturer stated, *"[this would allow] the design to be more efficient, getting more light out or putting the light where it actually needs to be and avoid spraying it pointlessly around."*

PAs

- **PAs stated that LED redesign could be an underutilized savings opportunity**. Respondents stated they believe retrofit opportunities should exist in all segments.
- **One PA noted their experience** seeing incorrect lighting design and one-for-one replacements leaving too much lighting installed.
- **Incentives for this measure type** could be modified to encourage more latitude within retrofit projects for customers to achieve savings and a lower fixture count through redesign.

4.4 Demand management with lighting



Sophisticated NLCs can ramp down lighting by about 30% with minimal occupant impact, thus offering a scalable resource in a building's load management portfolio. DNV examined 3 load management value streams (i.e., annual $ benefits) lighting in response to demand reduction signals, as summarized in Table 4-5. Typically, an energy efficiency program could not incentivize a pure demand response opportunity, so program incentives and program costs are not calculated. Instead, the table presents the added benefit of successfully implementing the strategy.

- **Possible program opportunity:** Use an existing NLC to capture additional value from modulating lighting systems in response to high-demand signals. These value streams are:
  - Participating in ISO or DISCO demand response program (control can be less sophisticated)
  - Modulate lighting to manage monthly billing demand charges
  - Incorporate lighting into a "virtual capacity" strategy to keep building demand below a hard limit

These three strategies are predicated on an existing NLC system with the flexibility to implement complex sequences to ramp select lighting up and down.

- **Baseline measure:** NLC already controls building lighting but has not been adapted for demand response. For bill management or virtual capacity, the building also has a demand management system (DMS) to control other demand resources like HVAC or EV chargers.

Table 4-5. Virtual capacity scenarios

Opportunity characteristics	Scenario 1: Lighting as an ISO/IOU demand response resource	Scenario 2: Lighting as a billing demand management resource	Scenario 3: Lighting as a virtual capacity resource
Applicable market	LED fixtures in all building types	LED fixtures in all building types	LED fixtures in all building types
Opportunity unit	Per sq. ft.	Per sq. ft.	Per sq. ft.
First-year kWh savings	0.014	0.046	0.023
IMC $/unit	<< $0.01	$0.33	$0.33
Operating $/unit	$0.01	$0.08	$0.08
Simple payback	<< 1 year	<< 1 year	<< 1 year
Customer added benefit	$0.05	$9.21	$4.62
Grade: C – Can add value to an existing NLC. Requires a sophisticated customer, especially for the last two scenarios. This is likely a growing market.			

This opportunity quantifies value streams from the sophisticated control of lighting as a demand resource within a larger demand management strategy. NLC is an enabler for capturing the additional dollar benefits from lighting.

The first strategy entails participation in existing ISO or DISCO demand response programs, which are well-established mechanisms for customers with demand response capability. The next two strategies have emerged in response to new types of building load such as battery storage, EV chargers, and renewables as part of a building load profile. These highly variable loads that release and/or consume energy have created a need for building demand management (DMS).

While there are DMSs on the market designed to manage building loads, they are in the early stages of market-readiness. However, demand management is likely to become widespread in larger buildings and lighting can be an important resource. Demand management strategies have the potential to add a significant value stream to an NLC system. This opportunity will require pre-existing NLCs and a sophisticated, highly engaged customer with the knowledge and resources to implement the solution. While this strategy may not be eligible as an energy efficiency measure, programs can leverage these value streams when pitching NLCs.

Desk review

Through the desk review process, the DNV team found that:

- **Sophisticated networked lighting control** (NLC or LLLC) can ramp down lighting by about 30% with minimal occupant impact, thus offering a scalable resource in a building's load management strategy.
- **Demand response program.** In a DISCO or ISO demand response program, a customer receives an incentive for per-kW reductions per hour of decrease during events called by the DISCO/ISO PA. These programs have been around for 20 years.
- **Demand Management System (DMS).** In addition to NLC, a DMS is also required for managing billing demand and for virtual capacity. A DMS forecasts building loads minute by minute and controls a portfolio of building resources (i.e., lighting, HVAC, EV chargers, solar) to 1) minimize facility billing demand, or 2) maintain the building demand below physical limits, like transformer capacity. DMS is in its early stages and evolving and therefore these last two measures are emerging, and any participant is an early adopter. The challenges that battery storage, EV charging, and renewables present for building load are driving improvements in this market and will likely lead to less expensive, easier to maintain, and better-performing solutions in the future.
- **Managing billing demand.** Theoretical potential high-value billing savings if systems operators are vigilant, since any error can set the peak demand for the month or year, depending on the demand rate structure. The best candidate buildings have a "spikey" load profile with short peak periods. Capturing savings every month requires deploying equipment reductions for hundreds of hours throughout the year.
- **Virtual capacity.** Modulate lighting as part of a "virtual capacity" strategy to keep building demand below a hard limit imposed by hardware constraints. The value of this strategy is in deferring the upgrade of existing electrical infrastructure to meet the unmanaged capacity need.
  - **Buildings ~500,000 sq. ft.** or greater provide a sufficient resource of ~100 kW of "harvestable" lighting load, a common minimum threshold for participating in an ISO/DICO program. More importantly, larger buildings have better access to dedicated staff overseeing the control systems (NLC, DMS and EMS) to ensure they are operating as intended.
- **A few unique customers** are expected to adopt these strategies, and the overall market potential is expected to be small, as the market itself is small and not easily linked to a submarket. This opportunity was not modeled in the stock model.
- **Point(s) of caution:** This is not an energy efficiency measure. Algorithms to forecast and control demand are not mature; however, EVs and battery parties are engaged in the problem. Proactive/attentive customers are required for this opportunity to be successful.

Market actor interviews

Sophisticated DNV collected the following input about virtual capacity from contractors. We did not interview manufacturers and PAs about this opportunity.

Contractors

Approximately half (49%) of the contractors said they install this measure, which is likely to reflect ISO-type program participation. Considering the low sample size, DNV recommends that readers exercise caution in interpreting these findings.

- **Contractors indicated that industrial customers** would most commonly be interested in this measure. They also mentioned large customers, commercial/retail, and warehouses.
- **Cost savings and maintenance savings** were the primary benefits mentioned by contractors.
- **Contractors cited cost as the most substantial barrier** and recommended higher rebates to counteract it.

4.5 Germicidal UV

Germicidal ultraviolet (GUV) disinfection of indoor air saves energy by cleaning indoor air instead of ventilating with clean outdoor air. UV lights can be installed in ductwork or located above head height. A second scenario using UV light to reduce biofouling of cooling coils was not feasible. Table 4-6 summarizes the opportunity.

- **Program opportunity:** GUV disinfection of indoor air saves energy by cleaning indoor air instead of ventilating with clean outdoor air. This is attractive for customers adopting ASHRAE Standard 241, a voluntary standard for increasing clean air (via outdoor or sterilized air) for select spaces.
- **Baseline measure:** No existing LED UV disinfectant in HVAC supply.

Table 4-6. GUV disinfecting scenarios

Opportunity characteristics	Scenario 1: UV disinfection	Scenario 3: UV coil biocide
Applicable market	Healthcare and Public Assembly sector; spaces with clean air requirements above ASHRAE 62.1	Tropical climates where AC coils accumulate biological matter
Opportunity unit	Per sq. ft.	Per sq. ft.
First-year kWh savings	4.3	Not a viable measure in sponsor climates
IMC $/unit	$4.00	
Simple payback	6.1	
Program savings (MWh)	Niche	
Customer incentive	$1.50	
Program $/kWh	$0.40	

Grade: D – Attractive to a small number of customers that voluntarily adopt clean air standards that exceed current code requirements. A second scenario using UV to retard the biofouling of coils is beneficial in tropical climates, but not in North America.

This opportunity uses UV lighting to disinfect occupant air, by placement either in ductwork to disinfect return air or directly in the occupied space at heights sufficient to prevent occupant exposure to UV. Both methods save energy by reducing the amount of fresh air introduced to the space, thus reducing heating and cooling consumption. This opportunity is attractive to customers who want to comply with ASHRAE Standard 241 air exchange standard to reduce viral and bacterial loads. AHSRAE 62.1, which is usually the basis of building codes for required minimum air, is sufficient in most space types to meet CDC recommended air exchanges.

However, fresh or disinfected air rates would increase in high-occupancy spaces like waiting rooms, classrooms, and gyms. If a state adopts ASHRAE Standard 241 as part of the building code, the market for the product would substantially increase.

While this technology gained some traction during COVID, its popularity has waned, and cost-effective use cases are uncommon. Customers can achieve similar disinfecting solutions through avenues apart from UV fixtures.

Modeling was not performed for this opportunity.

Desk review

Through the desk review process, the DNV team concluded that:

- **Energy savings is achieved** by reducing the amount of fresh air introduced to a space, thus reducing heating and cooling requirements. In most indoor spaces, the requirement for clean air is easily met by the ASHRAE 62.1 ventilation requirements intended to reduce odors and CO2 in occupied spaces. AHSRAE Standard 241 is a voluntary code that sets higher equivalent clean air standards for some spaces increases energy to due to longer HVAC fan run hours and conditioning the outside air.
- **Two GUV technologies** are an alternative to introducing fresh air to reduce infectious agents in supply air:
  - **HVAC UV:** UV fixtures placed inside ductwork disinfect return air for remix with supply air. This competes with HEPA air filtration, which is usually cheaper, unless other factors prevent installation.
  - **Upper Room Germicidal UV (UR GVC):** UV fixtures placed over 8′ high in occupied spaces disinfect air present in the room. Height is required to prevent dangerous UV exposure to occupants.
- **ASHRAE Standard 241** was partially set up in response to COVID. It is a voluntary code that some unique customers might consider adopting in health care or potentially as a luxury amenity. The market size would expand greatly if ASHRAE Standard 241 were adopted into building codes, although there is no indication this will happen.
- **Dangers of UV.** There are some health concerns since UV light can create ozone, OH radicals, and volatile organic compounds that are all unhealthy to breathe. Some authorities recommend a mix of UV and fresh air to mitigate this risk. The UR GVC risks occupant UV exposure if the products are installed incorrectly, although UR GVCs have been used for germicidal applications in occupied space for decades.
- **Coil UV is a separate application** that reduces the biofouling of HVAC heat and cooling coil surfaces, improving coil and fan efficiency in hot, damp climates.
- **A few unique customers are expected to adopt these strategies,** and the overall market potential is expected to be small. This market is small and not easily linked to a submarket. This opportunity was not modeled in the stock model.
- **Point(s) of caution:** the UV disinfection fixture itself increases load, while the savings opportunity is through reducing HVAC needs.

Market actor interviews

DNV collected the following input about UV disinfection from contractors and manufacturers. We did not interview PAs about this opportunity.

Contractors

Less than one-fourth (23%) of contractors indicated they install these measures. Considering the small sample size, DNV recommends that readers exercise caution when interpreting these findings.

- **Contractors indicated** that the main sector where this measure is relevant is healthcare.
- **The main benefits** contractors thought this measure brings are increased safety and reduced O&M costs.
- **Cost** is the primary barrier.
- **Contractors said that programs** could help by providing incentives, increasing marketing, and making sure the process is easy.

Manufacturers

- **No respondents viewed UV disinfecting solutions** as a viable NextGen opportunity.
- **Respondents stated that common barriers** to adoption are high costs, consumer skepticism of technology, and health safety concerns due to misapplication and exposure risks.

4.6 Tunable lighting

Tunable lamps and/or fixtures will modulate the spectral output or color temperature independently from the total fixture lumen output providing potential health benefits for humans when indoors and for the production and quality of cannabis as summarized in Table 4-7. Tunable lighting for human occupation is typically installed for its non-energy benefits. This opportunity also examines the benefit of HID to LED conversions in cannabis production.

- **Possible program opportunity:** The scenarios are distinct:
  - **Human occupants**. Select tunable versus standard fixtures in facilities equipped with an NLC and modulate the fixture output and lighting temperature to mimic natural lighting through the day, increasing occupant wellbeing and achieving energy savings with reduced light levels in afternoon and evening hours. The baseline is NLC-controlled LED fixtures with or without the tunable features.
  - **New construction cannabis grow house**. Replace baseline HID fixtures with LED fixtures. This measure is highly cost-effective with large site-specific savings in jurisdictions where cannabis is legal to grow for commercial distribution and where regulations do not require LEDs.
  - **New construction cannabis grow house with spectral modulation**. Replace LED fixtures with fixtures and systems that modulate the spectral output of the fixture. The baseline is an LED fixture without dimming.

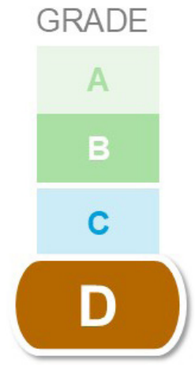


Table 4-7 summarizes these scenarios.

Table 4-7. Tunable lighting scenarios

Opportunity characteristics	Scenario 1: Add-on circadian spectral modulation (SM)	Scenario 2: Horticultural HID to LED, new construction	Scenario 3: Horticultural modulation, new construction
Applicable market	New construction, LED, >6500 hours of operation, over 150k sq. ft.	Agricultural, indoor cannabis grow house	Agricultural, indoor cannabis grow house, >10,000 sq. ft.
Opportunity unit	Per sq. ft.	Per sq. ft. cannabis production	Per sq. ft. cannabis production
First-year kWh savings	0.6	75	19
IMC $/unit	$1.30	$34	$20
Simple payback	14.3	3.0	7.2
Program savings (MWH)	Niche	Niche	Niche
Customer incentive	$0.94	$1.00	$8.92
Program $/kWh	$1.86	$0.02	$0.57
Grade: D – High payback and boutique-type non-energy benefits limit customer willing to uptake this measure for human occupants. Where cannabis is legal, the measures apply to a unique market of a few producers, although HID to LED conversions are excellent projects.			

This opportunity uses NLC control of specialty fixtures to dim and brighten and modulate the spectrum of lighting output. For ambient lighting in occupied spaces, lighting output is modulated to match occupants' circadian rhythms, improving wellbeing and health. The modulation can produce energy savings, especially for spaces that operate late into the evening. However, paybacks are long, and since the health benefits have not been monetized in the literature, it is difficult for a PA to claim non-energy benefits to offset the costs.

There are excellent savings opportunities for the conversion of HID lighting to LED in cannabis grow houses due to the high intensity of the base case wattage (55 watts/sq. ft.). The standard practice for a cannabis grow house is HID unless regulated by the jurisdiction. Dimming is not standard practice but is used in some facilities to reduce plant shock in transitioning between growth stages. Because plant growth is highly correlated with lamp output, dimming, while reducing energy consumption, will also lower plant production.

Some larger grow facilities install tunable lighting, often referred to as spectral modulation, in implementing a proprietary recipe designed to produce a particular product profile and production rate. The research is inconclusive on the effect of spectral modulation and how much it may increase cannabis yield. However, for the analysis, a 3% increase was assumed.

Desk review

Through the desk review process, the DNV team found that:

- **For human occupancy, adjusting light color and fixture output** (dimming and brightening) can produce modest energy savings. Tunable lighting is adjusted via a signal from an NLC to modulate the lumen output and adjust the wavelengths, or perceived colors. Lighting for circadian wellness can produce energy savings in a 24/7 setting, through reduced and warmer lighting in late afternoon and evenings which offsets increases in energy consumption earlier in the day when the lighting is brightened.
- **Non-energy benefits** are key customer drivers of specific benefits or designs rather than energy savings. However, DNV's research did not identify any claimable non-energy benefits.
- **The largest energy savings are available in 24/7 settings** where health benefits are premium, like hospitals.
- **For cannabis production**, tunable lighting is installed as part of implementing a proprietary recipe designed to produce a particular product profile and production rate. The research is inconclusive on the effect of spectral modulation on its increase in cannabis yield or how much savings might be associated with dimming on a per-pound of production basis.

A few unique customers are expected to adopt these strategies and the overall market potential is expected to be small. This market is small and not easily linked to a submarket. This opportunity was not modeled in the stock model.

Market actor interviews

DNV collected the following input about tunable lighting from contractors, manufacturers, and PAs.

Contractors

- **The opportunity is a good fit** for indoor agriculture and schools.
- **The most common barriers are cost.** Contractors recommended increased program incentives.
- **Respondents viewed comfort** as the most valuable measure impact for the customer. Enhanced control, increased productivity, and energy savings were all mentioned as secondary benefits.

Manufacturers

- **Most respondents viewed tunable lighting** as a viable NextGen opportunity.
- **Most respondents stated this opportunity** would be a good fit for schools, offices, and hospitals/ caregiving facilities.
- **Respondents stated that common barriers** to adoption are high costs, sales difficulties due to individual space preferences, and a limited number of viable use cases.

PAs

- **Respondents viewed tunable lighting** as an opportunity for indoor agriculture, most applicable in jurisdictions where cannabis has been legalized for growth in indoor agricultural environments.
- **Non-energy benefits of tunable lighting,** such as circadian rhythm alignment, increased productivity, and beneficial outcomes in healthcare settings are not supported by programs represented within this study.

4.7 Stacked opportunities

This class of opportunities considers combinations of scenarios identified in the six NextGen opportunities described above. These opportunities, summarized in Table 4-8, leverage the desk reviews and interviews from other sections.

Table 4-8. Stacked scenarios

Opportunity characteristics	Scenario 1: Adding NLC system to a redesigned lighting system with NLC-ready fixtures	Scenario 2: NLC with capacity benefits	Scenario 3: NLC integrated with HVAC
Applicable market	Customers redesigning an existing system	Customer with an NLC	Customer with an NLC
Opportunity unit	Per sq. ft.	Per sq. ft.	Per sq. ft.
First-year kWh savings	5.00	4.32	5.15
IMC $/unit	$7.23	$5.05	$9.72
Simple payback	9.6	Short	12.5
Program savings (MWH)	Niche	Niche	Niche
Customer incentive	$4.66	NA	$6.62
Customer added benefit	NA	$0.05 to $9.85	$0.05
Program $/kWh	$0.84	NA	$1.54

Adding NLC to a new lighting redesign. This scenario considers the added benefit and cost of adding the hardware, software, programming, and commissioning to a retrofit redesign lighting system redesign. This scenario draws on Redesign NLC-Ready Scenario 2 and ALC New Construction Scenario 2. The redesign scenario captures the benefits of adding NLC to an optimized layout for new high-efficacy fixtures with NLC-enabled products, but with code-compliant controls. This application requires a building with long hours of operation to be feasible.

In the combined scenario, the redesigned lighting with NLCs improves the lighting intensity of the site from 6.2 kWh/sq. ft. (7,800 hours, 0.8 watts/sq. ft.) to a highly efficient 2.0 kWh/sq. ft. (4,600 hours, 0.43 watts/sq. ft.). However, the payback is longer than either of the scenarios alone, largely because the NLC system controls an extremely efficient space (low watts/sq. ft.), reducing the absolute savings compared to standard practice new construction without reducing in installed costs.

Adding capacity management benefits to an NLC project. This scenario considers the added benefits and costs of adding the hardware, software, programming, and commissioning to an NLC project for harvesting demand management value streams. This scenario draws on the ALC Scenario 1 retrofit Gen1LED with HE fixtures and NLC (payback of 7.3 years) and the Capacity Management scenarios.

The benefit of participating in an ISO/IOU program is on the order of $0.05/sq. ft., which does not meaningfully impact the payback. Implementing an aggressive billing demand management regime could harvest substantial billed savings essentially paying for the system in the order of $10/sq. ft. However, in practice, this level of control is extremely challenging, and the technology has not evolved to a point where it is ready for wide commercial application.

A few unique customers are expected to adopt these strategies, and the overall market potential is expected to be small. This market is small and not easily linked to a submarket. This opportunity was not modeled in the stock model.

Integrating an NLC into HVAC controls. In this scenario, the NLC's very granular measurement of occupancy and daylighting is used as an input to HVAC control logic. HVAC systems typically do not adjust to occupancy directly, but rather use occupancy schedules as an indicator of when to switch to unoccupied mode. By looping in NLC occupancy data at the room level, the HVAC control logic can adjust fresh air to match occupancy or sequence sleep or unoccupied stage operations. An NLC reduces the full equivalent hours of lighting by about 30% through occupancy control and the DLC indicates a potential HVAC reduction of 5-10%.

5. CONCLUSIONS AND RECOMMENDATIONS

DNV analyzed the six NextGen opportunities, identified common and best-case scenarios within each opportunity, and calculated key metrics which are summarized in Table 4-9. We offer our recommendation below the table.

Table 4-9. NextGen opportunity summary

	Higher-efficacy products LED to LED	Advanced lighting controls (ALC)	Redesign LED to LED retrofit	Demand management with lighting	Germicidal UV (GUV)	Tunable lighting
Grade	A	B	C	C	D	D
Savings potential (MWh)	1,280,415	1,914,727	545,381	Niche	Niche	Niche
Technology	Highest lumen/watt products	Fixture level control with networked and non-networked systems	Retrofit with redesign w new fixtures, new placement	Add benefit stream to NLC using lighting as a capacity resource	UV to replace OA with sterilized return air	Improve occupant wellbeing and agricultural production
Program	Midstream Direct/ Deemed	Custom Direct install	Custom	Not an EE offering	Custom	Custom
Customer payback (years)	ROB: 0.5 Retro: 2-6	NLC: 7-10 LLLC: 5	8-10	<1 year with the right project	6	Amb: 7 Ag: 7
Program $/ kWh	ROB: $0.17 Retro: $0.41	NLC: $0.80 LLLC: $0.21	$0.80	Not an EE measure	$0.40	$0.60

Regularly monitor the state of the NextGen market.

NextGen opportunities and their context is evolving. As examples:

- DLC efficacies will continue to increase which will change the absolute savings of a measure over time.
- ALC costs are expected to decline further while functionality is expected to increase. At the same time, lighting power densities will also decline, which will lower savings and cost-effectiveness. Long-term trends in cost-effectiveness are unclear.
- Regulations and code adoptions greatly influence opportunity feasibility. Adopting ASHRAE Standard 241 into code will create GUV opportunities, while more stringent building code standards for lighting will reduce opportunities over time for higher efficacy products and ALCs.

Sponsors should consider regularly assessing the state of the market for these opportunities to consider how changes in costs, functions, or regulations impact their cost-effectiveness and how they factor into the energy efficiency portfolio.

5.1 About DNV

DNV is a global quality assurance and risk management company. Driven by our purpose of safeguarding life, property and the environment, we enable our customers to advance the safety and sustainability of their business. We provide classification, technical assurance, software and independent expert advisory services to the maritime, oil & gas, power and renewables industries. We also provide certification, supply chain and data management services to customers across a wide range of industries. Operating in more than 100 countries, our experts are dedicated to helping customers make the world safer, smarter and greener.

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