LED Program Strategies: Synthesizing Recent Research

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ABSTRACT

Light Emitting Diode (LEDs) have the potential to deliver high energy savings. They have high efficacy, long lifetimes, and they provide some features that customers prefer and fluorescent lamps may lack. However, utilities struggle to successfully incorporate LEDs into their programs, because of challenges with cost effectiveness tests and customer skepticism.

Here we present LED-related findings from four primary research studies, and various secondary sources, in the residential and nonresidential market. Price is the main barrier for customers, and residential customers generally prefer to spend less than $20 per LEDs, although this price point may vary by lamp type (e.g., slightly more for reflectors). Codes are important in encouraging LED adoption, both through high efficacy requirements, and by requiring controls or dimming, as these features are more easily met with LEDs. Performance specifications are also critical, because they encourage the installation of high quality LEDs, which will help ensure that a customer's early LED experience is positive. Pilot projects can be used to demonstrate cost effectiveness of LED projects, and to reduce customer skepticism. There are various evaluation issues, such as considering participant and nonparticipant spillover, and including the cost of all lamp replacement and maintenance in cost effectiveness calculations.

Based on these and other findings, we present guidance for utilities in their design of cost-effective market interventions that also help overcome customer skepticism.

Introduction

LED lamps (referred to here as "LEDs") provide an exciting opportunity for delivering high energy savings. They have high efficacy, enable additional savings technologies (such as controls and dimming) better than competing technologies, and have long lifetimes. In addition to the energy savings benefits, they provide some features that residential customers prefer, but that compact fluorescent lamps (CFLs) or other types of fluorescent lamps may lack, including high color rendering index (CRI), no mercury content (OSG 2011, U.S. EPA 2011), better compatibility with dimming controls (if matched with compatible dimmers), and instant start (NMR 2013). Nonresidential customers are also motivated by energy savings, improved light quality, controllability, and reduced maintenance costs (HMG 2013, KEMA (2013).

But, while residential and nonresidential customers have expressed interest in LEDs, there are several barriers inhibiting their widespread adoption. LEDs continue to be significantly more expensive than competing technologies per luminaire, and many customers are hesitant to pay this higher incremental first cost. In addition, many customers report a general skepticism towards new lighting technologies and products, which may in part be due to poor experiences with other new lighting technologies in the past.

The purpose of utility energy efficiency programs is to help overcome these types of adoption challenges, by reducing customer skepticism, and (when needed) by reducing first costs for efficient products through incentives. However, many utilities struggle with some LED measures and their cost effectiveness test results. Incentives must be high enough to influence customers to purchase LEDs, but energy cost savings from the LEDs must be greater than the cost of the incentive, to meet program cost effectiveness tests. It is also challenging for utilities to reduce customers' skepticism, particularly when LEDs vary in product quality.

Here we present findings from various studies that investigated several critical aspects of the LED market in the residential and nonresidential sectors. Based on the findings, we present guidance and conclusions for utility market interventions.

Study Descriptions

This paper draws on LED findings from both primary and secondary research. The primary research is summarized below.

Table 1. Data Collection Overview

Study Title (Study Abbreviation, Reference)	Overview	Data Collection Overview
Northwest Energy Efficiency Alliance (NEEA) Comprehensive Commercial Lighting Initiative Pilot Evaluation (CCLI Evaluation, HMG 2013); and Lighting Retrofit Market Characterization (NEEA Market Characterization, TRC 2014a)	NEEA's CCLI encouraged commercial retrofit projects to use an integrated, design-based approach with greater lighting controls, through trade ally training and tiered incentives. TRC conducted a process evaluation of the pilot, and a market characterization of the lighting retrofit market in the Pacific Northwest.	CCLI Evaluation: Interviews with program implementer, lighting manufacturers, and trade allies; file reviews of pilot projects and a sample of traditional rebated projects. NEEA Market Characterization: Electronic survey of lighting retrofit contractors in the Northwest
Pacific Gas & Electric (PG&E) Warehouse LED High-Bay Lighting and Controls project (Warehouse Lighting Retrofit, TRC 2013a)	PG&E supported a retrofit of a warehouse high bay lighting project, in which metal halides with no controls, were replaced with LEDs with several layers of controls. TRC measured energy savings.	Lighting energy savings measurements from the entire system, and from individual components by activating different combinations of controls; and occupant surveys
Idaho Power Residential Lighting Program Process Evaluation (Idaho Power Lighting Process Evaluation, TRC 2013b)	TRC conducted a process evaluation of the Idaho Power Company's upstream residential lighting program.	Interviews with participating retailers, manufacturers, staff, and Bonneville Power Administration (BPA), which manages the regional partner program
PG&E On-line LED Rebates Pilot (On-line LED Rebate Pilot, unpublished)	PG&E launched a pilot program to provide rebates for eight LED products through an on-line retailer, over four weeks. TRC provided evaluation support.	Pilot sales data analysis; electronic participant survey

Results

Market Motivations and Barriers for LED Adoption

As described above, residential and nonresidential customers cite various reasons for their interest in LEDs, including energy savings and various lighting quality characteristics. Results of the electronic On-line LED Rebated Pilot survey, while small, indicate that the participating customers purchased the LEDs for a variety of reasons. Seventeen participants (7% of total) completed the survey. As shown in Figure 1, the top four motivations apply to LEDs sold both in-store and on-line: lower energy bills, affordable price, prior experiences with LEDs, and environmental reasons. Five participants reported that product details influenced their decision. While there are some product details listed on products, the on-line channel presents the opportunity to provide more details.

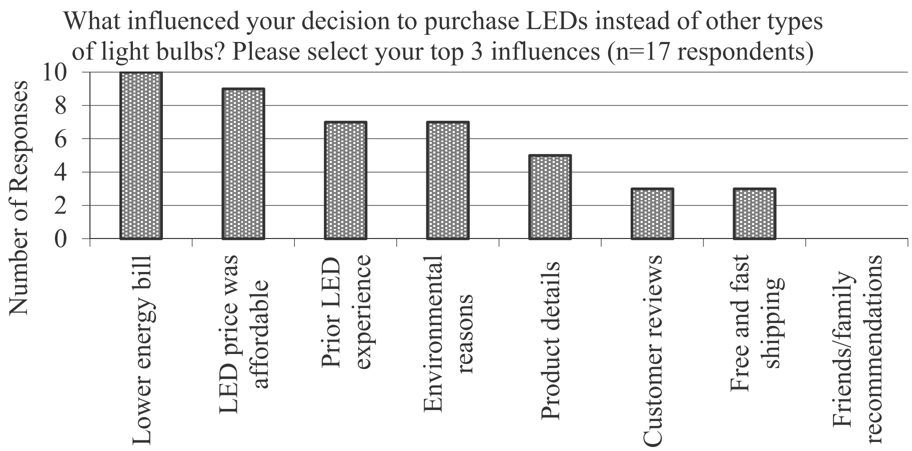

Figure 1. Survey Results of Customer Motivations for Purchasing LEDs through an On-line Rebate Pilot.

For residential customers, price is by far their major barrier to adopting LEDs (ODC 2012, KEMA 2012). In addition to cost, residential customers are wary of LED technologies due to little to no direct experience with the technology, and negative past experiences with CFLs. Customers are concerned about lighting quality (including color), ability to dim without flicker, and realization of longevity claims (ODC 2012, KEMA 2012). A survey of 240 Massachusetts store managers found that, of those not selling LEDs, 19% reported that the lamps were too expensive for their customers, 14% lacked an LED supplier, and 14% reported the LEDs did not fit in well with the rest of their product line (NMR 2013). KEMA (2012) also noted that, although residential customers have cited poor CFL brightness as a reason for not purchasing CFLs, there are few LED replacement lamps on the market, as of 2012, with lumen output in the range of traditional 75 watt and 100 watt incandescent lamps.

Price is a barrier for the nonresidential market as well. Performance concerns, including dimming capabilities, are also a barrier (KEMA 2013).

Effect of Code on LED Adoption

While customer preference will heavily influence LED adoption, current and upcoming code changes will also have an impact. KRC (2013) surveyed 300 U.S. residential customers about their plan to respond to the national phase out of traditional incandescent lamps as part of the 2007 Energy Independence and Security Act (EISA). Roughly half (46%) reported they will switch to CFLs, a quarter (24%) to LEDs, 13% to halogens, and 16% are not sure (KRC 2013). The 16% of unsure customers represents a significant fraction of potential energy savings.

The latest California 2013 Building Energy Efficiency Standards (Title 24 part 6), effective July 1, 2014, does not specifically require the use of LEDs, but encourages their use through lighting power density limits and controls requirements. For example, for residential buildings, kitchen and bathroom lighting must meet high efficacy requirements, with partial exemptions for controls. This should encourage the use of LEDs, because many LEDs will comply with the efficacy requirements, and because LEDs are better suited for controls than competing technologies. For nonresidential buildings, there are new requirements for multi-level indoor lighting. While these do not specify technologies, LED technology may more easily meet them than other high efficacy technologies, because LED light sources are inherently multi-level capable. Similarly, new bi-level lighting requirements for outdoor lighting are most easily met via LED technology. These requirements for multi-level controllable lighting increase the base technology cost, helping to decrease the cost gap. However, these types of code requirements complicate the issues of base technology and free ridership in evaluations, since they encourage LED adoption, but do not do not directly specify LEDs.

Testing and Specifications

Testing and specifications have helped encourage the market to choose high quality LEDs. A Pacific Northwest National Laboratory (PNNL) study noted that, when LED products were first introduced in the market, many products had unrealistic and unsupported performance claims (PNNL 2014). Various programs (e.g., Commercially Available LED Product Evaluation and Reporting [CALiPER], LED Lighting Facts, ENERGY STAR, Design Lights Consortium [DLC]), have supported market adoption of LEDs by verifying product claims and assuring stakeholders that products have been tested and reviewed by an independent entity. PNNL (2014) also encourage these programs to share testing results, to save costs by avoiding duplication of testing.

The California Energy Commission (CEC) recently released a performance specification for LEDs (CEC 2013). The efficacy requirements match those of ENERGY STAR (U.S. EPA 2008), but the CEC quality requirements are more rigorous and specify color temperature range, color quality, dimming capability, lamp life, and light distribution performance. The specification must be met for LEDs incentivized by California utility programs, but it is voluntary for non-incentivized LEDs.

These LED specifications at the relatively early stages of market adoption contrast with the timeline for the development of CFL specifications. CFLs entered the market in the 1970s, and early utility programs for CFLs started in the 1980s (PNNL 2006). ENERGY STAR released its criteria for CFLs in 1999, because of the lack of federal regulations for CFLs (U.S. EPA 2003). The original ENERGY STAR criteria covered efficacy, lumen maintenance, and product lifetime; performance specifications were added later (U.S. EPA 2003). Thus, many customers may have purchased CFLs that did not meet the ENERGY STAR CFL performance criteria. This development of LED specifications (at least at the voluntary level) early in the market adoption process may help customers have a more positive initial experience with LEDs than they did with CFLs.

Pilot Programs

Pilot programs have illustrated successful applications of LEDs. The Warehouse Lighting Retrofit illustrated how an LED retrofit can be cost effectiveness and improve occupant satisfaction (TRC 2013a). As shown in the figure below, the retrofit achieved 50% lighting electricity and demand savings just from LEDs, and 93% lighting electricity savings when all controls were implemented. The most cost effective strategy was when the full system was installed. Based on the net present value of annual energy savings, LEDs coupled with occupancy controls led to a payback of 4 years, while payback with just LEDs was 8 years.

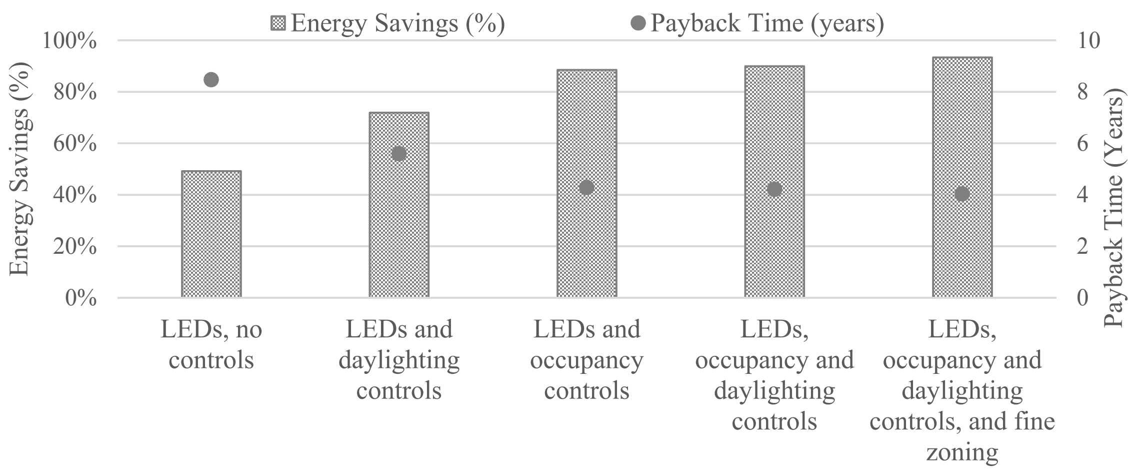

Figure 2. Energy savings and payback time from warehouse lighting retrofit pilot. (Lighting retrofit tested in stages.)

If reduction in maintenance is accounted for, the payback was approximately 4 years with just LEDs, and 3 years with all controls incorporated. Design costs were not included in these payback calculations, but this was a one-for-one replacement, so the design was minimal. The retrofit also increased light levels, from a range of 5 to 8, to 15 footcandles, and occupant surveys found an increase in satisfaction with the new LED lighting. While this is only one site, it represents typical California warehouse lighting layout and operation, and the energy savings can be considered a reasonable expectation for a similar space type with a similar baseline lighting system.

Based on a review of CCLI Pilot projects and comparison (traditional one-for-one) retrofits, several of the CCLI Pilot projects included LEDs and controls, and they had higher energy savings and were more cost effective (including design costs, where applicable) for the owner than the average traditional project (HMG 2013).

The Warehouse Lighting Retrofit and the CCLI Pilot Evaluation illustrate that deep lighting retrofits combining LEDs and controls can achieve high energy savings and fast payback times, if designed and installed well. Trade allies that participated in the CCLI Pilot reported the training they received was critical to the success of their lighting retrofit. This training including guidance on fixture lay-out design and the choice of controls, and sales support for how to communicate expected energy savings and payback to customers (HMG 2013). The figure below, adapted from the NEEA Market Characterization, shows the sources that lighting contractors in the Pacific Northwest report using to stay up-to-date with lighting technologies and design trends. As shown, trade shows, manufacturer information, publications, utility trainings, and professional organizations are all heavily used (TRC 2014a).

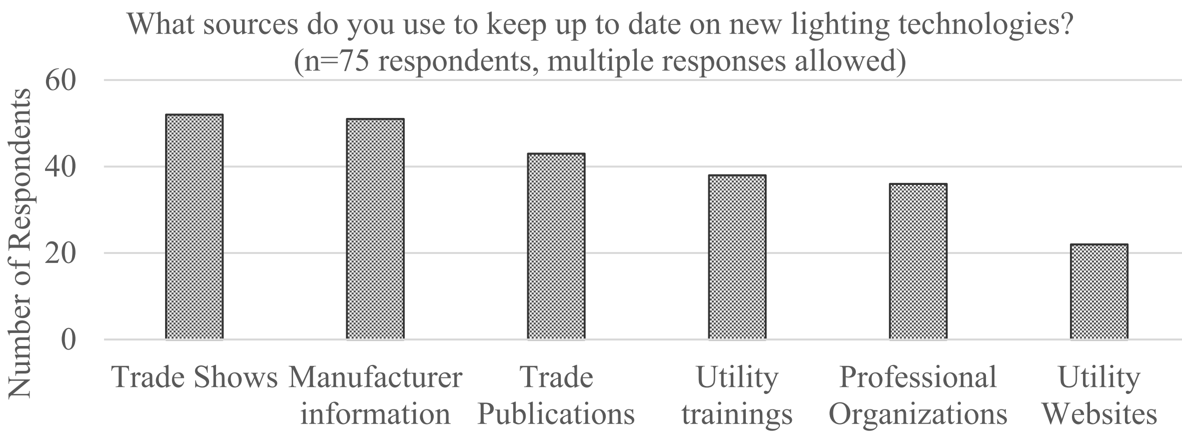

Figure 3. Education and Training Sources, Self-Reported by Northwest Retrofit Lighting Contractors.

LED Price Points and Incentive Structures

On behalf of the U.S. Department of Energy (DOE), Navigant developed the following projections for LEDs, which shows LED efficacy increasing as their price decreases.

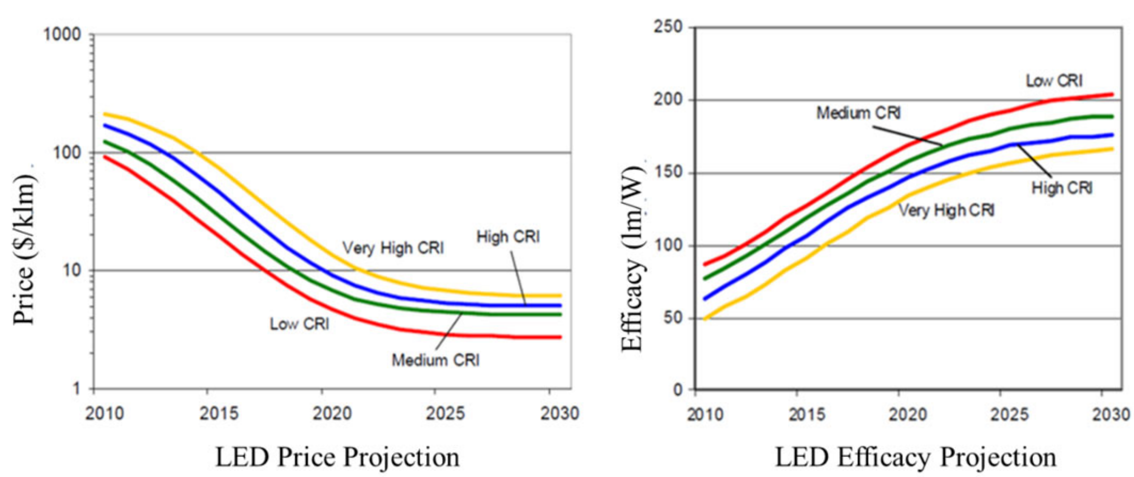

Figure 4. LED Price and Efficacy Projections (Source: Navigant 2010).

The predicted drop in LED price will be important for widespread customer adoption. Based on a literature review, residential customers are unwilling to spend more than $20 per lamp, although the acceptable price may vary by lamp type. A survey of over 1,000 PG&E residential customers found they are generally unwilling to spend more than $20 on any type of LED, but would prefer a price of $5.99 or less for LEDs (OSG 2011). A Massachusetts residential survey of 600 households generally supports the general $20 price point for LEDs: these customers reported that they wanted to move to LEDs as their preferred lighting source, but were hesitant to spend over $20 per lamp (NMR 2012). Another residential study found that customers indicated they would pay as much as, but no more than, $10 for LED A-lamps and $30 for LED Reflectors (R/PAR lamps) (ODC 2012). Results also indicate a willingness of residential customers to spend more on LEDs than other technologies. For example, the OSG (2011) study found that customers' preferred price point for CFLs is $1.99.

The results of the On-line LED Rebate Pilot support the price points described above. The eight rebated LEDs ranged in original price from $13 to $54, and $8 to $49 with the rebate. Participants purchased a total of 228 LEDs with the rebates. As shown in the figure below, all of the rebated products that participants purchased were less than $20 (with the rebate). The best-selling products, accounting for 94% of the rebated products sold, were the two least expensive reflector products, both priced at $15 with the rebate. The four more expensive reflector lamps, ranging from just under $30 to $49 with the rebate, did not sell at all. The remainder of rebated products purchased (6%, or 14 lamps) were the two A-lamp LEDs.

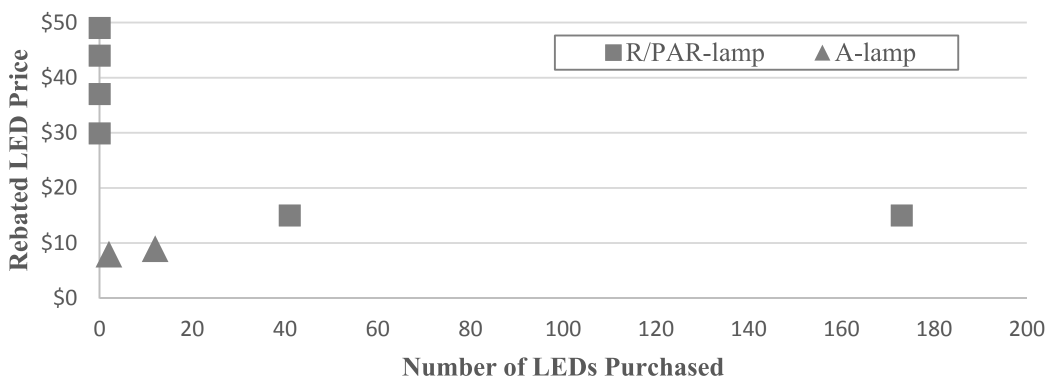

Figure 5. Sales of Rebated LEDs Purchased through an On-line Pilot, by Price and by Lamp Class.

At the time of the Idaho Power Lighting Process Evaluation, the program did not incentivize LEDs, because the utility's calculations showed that LED incentives would not be cost effective to the utility. Almost all interviewees (manufacturers, retailers, and Idaho Power staff) reported that they wanted to see LED products incentivized, primarily because of high customer interest in LEDs. One retailer mentioned that LED incentives would be important to their lighting product sales going forward, and the manufacturers reported that they expect programs in the region to shift more towards LED, especially replacing specialty CFLs. Consequently, the evaluation noted it would be important for the program to include some LED in the near future (TRC 2013b). After the evaluation, Idaho Power revisited the cost effectiveness calculations; one change was to include the NPV of the cost of all replacement lamps over the LED's lifetime. The base technology assumes a combination of incandescent lamps, CFLs, and other technologies. Based on the results, Idaho Power was able to include select LEDs in the program.

TRC also interviewed staff with the regional Bonneville Power Administration (BPA) Energy Efficiency Residential Lighting program, which works in conjunction with the Idaho Power program, through the evaluation and in follow-up conversations. The BPA program began offering incentives for LEDs (select types of A-lamps, reflectors, and down light retrofit kits) in

April 2013, with incentives of about $3 per lamp. BPA developed this incentive amount based on a maximum value of $0.20/kWh of savings over the measure life (ideally $0.08-0$0.11/kWh for lighting), and a maximum value of 70% of the incremental cost compared to the base measure. For LEDs, this baseline assumes a mix of incandescent lamps, halogens, and CFLs. While the full market influence of the program is not yet known, one participating retailer reported that sales of the rebated LED products have increased 30% since the rebates went into effect, based on information provided by BPA.

LED Classes and Applications

There are few published studies that have included large on-site inventories of LEDs to categorize the number and type of LEDs installed in homes or commercial buildings. However, an on-site lighting inventory of 150 homes in Massachusetts found that 7% of households had LEDs, and most of these LEDs were used as track or under cabinet lighting and were not A-lamp LEDs; only two of the 150 LEDs were found in storage (NMR 2012c). A national CFL Market Profile found that living rooms, dining rooms, bathrooms, and home exteriors have the greatest untapped potential for CFLs; and that kitchens, while having higher fluorescent penetration, had less potential for CFLs, because fewer sockets are compatible with them (D&R 2010). These rooms may present opportunities for LED installations, particularly if customers are concerned about color quality, dim ability, or other criteria better met with LED technology.

The retail market appears to be adopting LEDs in some applications. Of forty-seven retail lighting contractors surveyed for the NEEA Market Characterization, 41% reported at least half of their retail lighting retrofits included LEDs for display or refrigerator cases, and 37% reported at least half included LED spotlights (TRC 2014a). A Northeast trade ally forum found that LEDs are replacing exterior incandescent and high-intensity discharge (HID) and special display lighting, and incandescent and halogen lighting for retail applications (ERS 2013). This study also found that flat panel LED lighting is showing promise as general space lighting (ERS 2013).

LEDs have also made significant penetrations in outdoor lighting. In 2012, LED products represented 1% of the total 54 million parking luminaires, and 2% of the total 44 million streetlight luminaires, with several municipalities starting to retrofit all of their traditional streetlight luminaires with LED luminaires (e.g., Raleigh, NC, San Francisco and Oakland, CA, San Antonio, TX, Seattle, WA, Portland, OR) (TRC 2014b). This market adoption of LEDs may be driven by their generally longer lifetimes (leading to lower maintenance), improved color consistency, and directionality, and because LEDs can withstand lower operating temperatures better than competing technologies.

LEDs are installed in other applications as well, although published data is sparse. As noted by Navigant (2013), “while some LED reflector replacements are likely installed in ambient or general lighting applications, such as down lighting, there is currently no data available to help distinguish where these LED products are being installed”. Research is underway, including an LED market effects study by the California Public Utilities Commission.

Recommendations

Based on the findings above, we provide the following guidance and recommendations for utility market interventions to encourage the adoption of high quality, efficient LEDs.

Use product quality specifications to encourage the adoption of high quality LEDs. LED performance remains inconsistent across products, and customers' skepticism of LEDs comes from concerns about color quality, potentially overstated product lifetimes and efficacy, and dim ability. Color quality continues to be a particular challenge for LEDs, where products with identical color temperature or color rendering may have noticeably different visual appearance. Utilities should require that incentivized LEDs meet minimum efficacy and performance specifications, verified by third party entities. This requirement will encourage customers to select LEDs that will give them a positive initial experience with LEDs. Performance standards were developed for CFLs after some utilities had launched CFL programs. This may have caused some customers to have unsatisfactory initial experiences with CFLs, thereby discouraging the market from adopting CFLs long-term.

National laboratories and other entities that develop performance standards should collaborate to develop common specifications. The various sources for performance standards generally do not compete, but there are exceptions (e.g., the minimum lumen limits on some product types in the DLC Qualified Products List versus the Lighting Design Lab's Qualified Products List). Performance testing organizations should also share test results, as recommended by PNNL (2014), or make them publicly available.

Select a few classes of LEDs for incentives now, rather than incentivizing a wide range of LEDs. The price of LEDs is rapidly decreasing while efficacy increases, and many types of LEDs do not pass utilities' cost effectiveness tests under current assumptions. Consequently, utilities should incentivize a few types of LED product types that perform relatively well in the cost effectiveness test now. While there is no silver bullet of classes of LEDs to incentivize, utilities should generally incentivize LEDs that replace low efficacy technologies and are installed in areas of high use (for utility cost effectiveness concerns), but meet quality specifications. Custom or comprehensive programs will continue to be important to allow for other types of LEDs, particularly novel product types.

For residential customers, utilities could continue to encourage the use of LED down light technologies, which generally have significantly higher fixture efficacies than CFL down lights. This could include retrofit kits for kitchen incandescent down lights, which (because they are more permanent replacements than LED lamps), are less likely to be removed. Kitchens also represent a good opportunity, because of their higher hours of use, and the lower potential for CFLs, since many CFLs are not designed for enclosed fixtures (because of heat build-up).

For nonresidential programs, lighting applications vary by building type, and the applications best suited for LEDs will also vary. For example, the Warehouse Lighting Retrofit showed that high bay LEDs were cost effective in a warehouse application, particularly when coupled with controls. Similarly, the NEEA Market Characterization indicates that LEDs can be well suited for feature lighting and refrigerated case lighting in retail. The classes of LED that utilities incentivize should vary by the market sector targeted by the program. For general programs or mid- and upstream programs, programs may need to train trade allies on which classes of LEDs to recommend to which types of customers, and for which applications, to keep incremental costs acceptable to customers.

LEDs are well suited for outdoor lighting, because of their inherent tendencies for long lifetime, color consistency, directionality, performance in low temperatures, and better enabling of controls. The general incumbent technology is a high pressure sodium or metal halide, both of which are typically less efficacious than LEDs and which cannot be dimmed as effectively. In particular, parking lot and exterior building mounted lighting offer incentive opportunities, as these have longer hours of use and high wattage. While there is some natural market adoption of LEDs in these applications, the penetration is still low.

Incentivize LEDs that are close to the acceptable price points for LEDs. Various utilities are challenged to provide incentives high enough to influence customers' decisions, yet low enough and appropriately scaled (based on energy savings) to pass the utility's cost effectiveness test. One partial solution may be to choose LEDs that meet the quality specifications described above, but are close to the acceptable price point for LEDs, so that rebates can bring these LEDs down to customers' acceptable price level. Preliminary findings indicate that residential customers are more likely to purchase LEDs priced below $20 in general, and $10 and $30 for A-lamp and reflector LEDs, respectively. Studies indicate that customers may also be willing to pay more for LEDs than competing technologies. In addition, according to one retailer participating in the BPA program, which provides upstream rebates of $3 per LED, this incentive has increased sales 30%. Thus, incentives may only need to reduce the price of LEDs somewhat; customers may be willing to pay some of the incremental cost.

Provide codes and standards support to encourage requirements for higher efficacy and greater controls. LED products are better suited to advanced controls than fluorescent and high-intensity discharge (HID) alternatives, and combining them with controls can provide substantial additional savings, depending on the application. Thus, codes and standards that include requirements for higher efficacy, and requirements for multiple levels of controls will effectively accelerate LED adoption, by making LED features more cost competitive. Minimum product quality specifications should also be used, although less stringent requirements could be used for LEDs allowed by code than incentivized LEDs. Utilities can also look for opportunities to promote LEDs and controls together, such as through comprehensive retrofit programs.

Provide education to encourage the proper installation of LEDs. LEDs have the capability of providing better dimming than fluorescents, if matched with compatible dimmers. Utilities can provide more education on the performance of LEDs and on LED interactions with dimmer controls, such as lists of compatible dimmers and other guidance to overcome the technical challenges of LEDs with dimmers, including avoidance of flicker and minimum lighting wattage. As found in the NEEA Market Characterization, lighting contractors use a variety of sources to stay current with lighting trends, so utilities should use a multi-pronged educational approach. Utilities should disseminate information through their websites and trainings, trade shows, and trade ally organizations; and encourage manufacturers to provide similar information for their products.

Use demonstrations to overcome customers' skepticism. Utilities can use in-store demonstrations, by partnering with retailers participating in upstream programs, and utility demonstration sites, to help customers and trade allies overcome their skepticism of LEDs. Hands-on demonstrations will allow customers and trade allies to see the actual color, light level, dimming capabilities, and other performance features of LEDs, and they provide a venue for utilities to provide information on proper LED installations. Utilities could also work with manufacturers to develop, and then showcase through demonstrations, LEDs to meet specific needs. For example, utilities could work with manufacturers to develop an LED retrofit for residential bathroom applications, such as an LED replacement for the traditional globe incandescent bathroom vanity, and/or LEDs with a base compatible with GU-24 lamps. While bathrooms have lower hours of use, this application may be an important positive experience for the skeptical consumer, and it may be a room where customers value high color quality (for personal grooming).

Include spillover in LED evaluations. Lighting programs that have minimum performance requirements for LEDs (as recommended above) should help manufacturers produce, and trade allies and customers select, high quality LEDs. This should help with long-term market transformation, because it will increase the likelihood that customers have a positive initial experience with LEDs. To better understand and estimate the full impact of the utility interventions, evaluators should account for spillover, including the additional LEDs purchased by the participant (participant spillover), and potentially some of the LEDs purchased by nonparticipants in the utility territory (nonparticipant spillover). While it is challenging to capture spillover, evaluators could continue to investigate methods that track both participants and non-participants over time to understand pre-program baselines, the influence of the program on purchasing decisions, and additional LEDs purchased, and use comparison states or territories to investigate the effects of programs on non-participants in program territories. However, this comparison data must be analyzed carefully, as many vendors operate nationally.

Include the cost of all lamp replacement and maintenance in evaluations. Because of the long measure life of LEDs, one LED will replace multiple baseline technologies if left in-place. The present value of the cost of all residential replacement lamps should be included in cost effectiveness tests, as these represent real costs to customers. For commercial programs, the labor for fixture maintenance and lamp and ballast replacement should also be included. Given the very long life of LEDs, there is not yet a good understanding of how long a typical LED will actually remain in place. Research is needed to understand not only actual technical life, but useful life and occupant behaviors that may impact persistence.

Conclusions and Future Research

LEDs present a unique opportunity for utility market interventions. They are generally an efficient technology, and customers have expressed interest in them. However, customers have voiced skepticism over LED performance (including color quality, lifetime, and energy savings), and many utilities struggle with LEDs passing their cost effectiveness tests. In addition, because LED efficacy continues to increase while LED prices drop (Navigant 2010), utilities may question whether they should intervene in the market now.

Based on our findings, we recommend that utilities consider a market intervention in some LED segments now. Utilities' early influence on an emerging market can have a very positive effect: The supported products may displace lower quality products, increase customers' overall satisfaction with LEDs, and improve customers' early general impressions of LED technology. All of these factors will encourage future long-term adoption of LEDs.

While there are many research gaps, we note a few critical needs for guiding utilities in LED market interventions.

- Investigate baseline technology assumptions. Research must investigate the types of lighting products that customers would buy instead of LEDs, broken out by LED class.

Results will need to be updated periodically as the market shifts. The baseline technology assumptions will assist utilities with identifying preferred LEDs to incentivize (e.g., those replacing low efficacy base technologies), and the appropriate values for evaluation.

- Explore how to best support introduction of LED technologies without negatively interfering with other lighting efficiency efforts, such as programs incentivizing fluorescent systems. LEDs inherently have different strengths than fluorescent lamps, which are somewhat reflected in the categories with the highest LED market share. The natural fit of LED in these applications is an ideal place to consider early incentives.
- Explore how to encourage LED adoption, while discouraging customers from installing more LED lamps than they would if they were to install a competing technology. For example, as prices drop, customers may be tempted to create special ambiance effects using more LED lamps than if they installed linear fluorescents or other technologies. This potential rebound effect would decrease energy savings.
- Develop uniform color temperature metrics. Manufacturers use different metrics to describe color temperature. By developing a uniform metric, the lighting industry could assist customers in identifying the preferred LED for each application.

Utilities and other organizations have helped accelerate the adoption of LEDs through quality specification, codes and standards, incentives, education, and other strategies. These efforts should be continued and enhanced to accelerate market adoption, and to ensure longer-term acceptance of LEDs.

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