Lighting the Great Outdoors: LEDs in Exterior Applications

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ABSTRACT

Recent progress in the development of white light LEDs promises great impact by opening up the huge potential for LED illumination in new areas. One such area is general illumination for exterior applications. For example, there are an estimated combined 60.5 million roadway and parking installations in the U.S. These lights account for an estimated 53.3 TWh of electricity usage annually -- nearly 7% of all lighting. If LEDs could provide the same light performance with just 25% greater efficiency, savings of over 13 TWh could be achieved.

In 2007, the authors assessed emerging LED lighting technologies in a parking garage and on a city street. The purpose of these tests was to enable a utility to determine whether energy efficiency programs promoting white light LED products might be justified. The results have supported the great promise of LEDs in exterior applications, while also highlighting the barriers that continue to hinder their widespread adoption. Such barriers include 1) inconsistent product quality across manufacturers; 2) lack of key metrics for comparing LEDs to conventional sources; and 3) high upfront cost of LED luminaires compared to conventional luminaires.

This paper examines these barriers, ways in which energy-efficiency programs could help to overcome them, and the potential for energy and financial savings from LED lighting in these two exterior applications

Potential for Savings

Lighting represents one of the largest uses of electricity in the Unites States. In fact, it has been estimated that nearly one-quarter of all electricity generated in the U.S. is used for lighting (Navigant Consulting, 2002). Fortunately, the potential for electrical savings through efficiency improvements in lighting is great; of the 765 TWh of electricity used for lighting, 42% is being used by incandescent sources – the least efficient technology (Navigant Consulting, 2002).[1] If the efficiency of that portion alone could be increased by 25%, the savings would be over 80 TWh annually.

Despite the great potential, more widespread adoption of efficient lighting technologies has been limited for a number of reasons. Some of these reasons have been technical, such as the inability of fluorescent sources to replace incandescent lamps in directional applications due to the diffuse nature of the light that they provide. Other reasons have been cultural, such as the

[1] Although market penetration of CFLs has increased in recent years, it is not likely to have had a large effect on this figure; in 2002, CFLs accounted for less than 2% of light sockets nationally, compared to over 85% for incandescents (Fulbright, 2003). Unfortunately, it is now difficult to obtain accurate data on CFL market penetration, as “key retailers Home Depot and Wal-Mart have removed themselves from the tracking surveys routinely conducted by industry analysts.” (Sandahl, 2006)

slow acceptance of modern compact fluorescent lamps (CFLs) into the residential marketplace. Recently however, progress in the development of white LED technology has shown that it has the potential to transcend a number of these challenges and improve efficiencies across all sectors. Indeed, it has been estimated that LEDs could reduce electrical use for lighting by as much as 50% nationally by 2025 (OIDA, 2001).

Whereas the applicability of LEDs had previously been limited by their color (first came red, then green and blue), white LEDs have opened up huge potential for solid-state illumination. While there are still technical limitations reducing the applicability of white LEDs, the technology has been advancing at a remarkable rate. The US Department of Energy (DOE) reports that overall, the performance of LED luminaires is advancing in efficiency at a rate of approximately 35% annually, with costs decreasing at a rate of 20% annually (Navigant Consulting, 2006).

With proper design, it is feasible that LEDs could replace many current light sources. In so doing, they could potentially provide the benefits of long lifespan, low maintenance, high color rendition, and low energy usage. As of this report, LED general lighting is already feasible in some applications, such as general exterior illumination, and is predicted to become feasible in many more very soon. The potential for energy savings in this realm alone are very significant, however; the estimated combined 60.5 million roadway and parking installations in the U.S. account for an estimated 53.3 TWh of electricity usage annually -- nearly 7% of all lighting (Navigant Consulting, 2002). If LEDs could provide the same light performance with just 25% greater efficiency, savings of over 13 TWh could be achieved.

As one of the first major applications where LED illumination is becoming feasible, the barriers that exist to widespread adoption of LED technology are especially relevant to general exterior area illumination. This paper examines those barriers, two case studies which exemplify both those barriers and the great potential of the technology, and ways in which energy-efficiency programs could help to overcome the barriers.

Market Barriers

Any new technology will, at least initially, face numerous barriers to widespread adoption. Some of these barriers, such as the inertia inherent in the marketplace, are well documented. Others however are, if not unique, particularly relevant to LEDs. The most significant of these to date have been inconsistent product quality, a lack of metrics to compare LEDs to conventional light sources, and high initial cost.

Inconsistent Product Quality

Inconsistent product quality has the potential to slow adoption of LED products by modifying expectations and perceptions of LED lighting in general. If consumers come to see LEDs as inadequate replacements for conventional lighting technologies the reputation of the technology could be significantly damaged, with correspondingly slowed adoption. This was one of the major problems with the entrance of compact fluorescent lamps in the market (Sandahl et. al., 2006). It is generally agreed that fluorescent lighting was marketed to the residential sector before the technology had reached an acceptable maturity for residential consumers, and that this has significantly slowed the adoption of the technology. There is potential for this mistake to be repeated with LEDs, especially in the current marketplace where companies and consumers strive to find the "greenest" technology available.

The US Department of Energy (DOE) is wary of this potential for the same problems with LEDs as CFLs, and is actively trying to prevent similar problems from occurring. While the rapid advancement of LED technology bodes well for its potential in the future, it has also led to large variations in the performance of LED products. This is because previous generations of LEDs tend to be significantly cheaper than the most recent versions when first released, but also tend to perform at a significantly lower level. One DOE program, CALiPER, acts as an independent third-party evaluator of commercially available LED luminaires. Since December of 2006 when the program started, efficacies for current LED products have been measured to vary by a full order of magnitude (DOE, 2008).

Varying product performance also has a potential to become a barrier to consumer acceptance when the differing products are similarly positioned. Disparate claims have the potential to increase consumer confusion regarding LED technology, and lead to the sentiment that LED technology is not mature enough for adoption. As one example of this in the realm of general exterior lighting, an LED luminaire manufacturer at one point marketed an LED low-bay luminaire producing 2,500 lumens as 'equivalent' to a 175 metal halide. Another LED luminaire manufacturer's similarly 'equivalent' fixture produced lumen output on the order of 6,500 lumens. Considering mean lumens and accounting for 70% fixture efficiency, the metal halide lamp can be expected to provide on the same order of 6,500 useful lumens. It is not unreasonable to assume that consumers replacing their existing lamps with the first of these LED products would be disappointed with the results, while consumers replacing their existing lamps with the other product may be more satisfied. This barrier may be further exacerbated by the fact that even savvy consumers may be misled by inaccurate ratings of LED products by the manufacturers. The most recent CALiPER report found only 1 of 15 manufacturers tested during the round to accurately rate their product, with 9 of the 15 manufacturers overstating product performance by up to 600% (DOE, 2008).

Lighting output and efficiencies also vary among LED products, because manufacturers of LED technology do not always have a lighting background. Some were "chip" (solid state devices or microchips) manufacturers and have only recently entered the lighting industry when the market for LED general illumination lighting developed. That situation, coupled with the immaturity of the technology overall, means that manufacturers and luminaire designers are still working on optimization of the luminaire. Issues involved in optimization include determining the best types of secondary optics, evaluating the need for secondary optics, and determining how to operate the LEDs themselves.

Like any light source, LEDs have a certain inherent lighting distribution. Due to the directionality of light produced by LEDs, and the general use of a significant number of individual LEDs in each luminaire, this distribution can be altered on the fixture level simply by aiming the LEDs. While the distribution resulting from this technique may be acceptable in many applications, it has emerged that the ability to further modify this distribution may be worth the light loss that results from utilizing a secondary optic in some cases. This can be accomplished with either a single optical element for an array of LEDs, or individual optics for each LED. Taking different approaches, manufacturers have had varying results in both achieving proper lighting distributions for general exterior illumination, and in maintaining high luminaire efficacies.

Finally, the performance of LEDs is highly dependent on the way in which they are operated. Both the light output and lumen depreciation behave nonlinearly with operating current and junction temperature. As a result, some luminaire manufacturers have taken the approach of reducing cost by driving higher currents through less efficient LEDs or a smaller number of LEDs, with resulting raised operating temperatures that lead to reduced LED life-spans. Other manufacturers have driven LEDs on lower currents, necessitating better and/ or more LEDs, but providing better lumen maintenance. This tradeoff between cost and performance, while common in all lighting technologies, is exacerbated by the technical attributes of LEDs. It is particularly important in general exterior illumination, where high light output is required and maintenance costs associated with replacement can be significant. Along with the other differences in LED luminaires, this has contributed to the wide variation in LED luminaire performance that must be addressed in order to smooth the way for wider adoption of general LED lighting technology.

Lack of Metrics for Comparison

Perhaps just as significant a barrier to LED adoption is the lack of proper metrics to compare LED light sources to conventional sources. Due to the substantially different technical attributes of LEDs from conventional lighting sources, comparison based on commonly used metrics can be misleading or, at worse, impossible. The most significant examples of this are the difficulties in suitably comparing the different lifespans and lighting performances of LEDs to those of conventional technologies.

Lifespan. The rated life of conventional light sources is the point at which 50% of a large group of lamps can be expected to fail (based on 10 or more operating hours per start). Of the lights commonly used in exterior applications, rated lives range from roughly 10,000 to 24,000 hours; rated life of MH lamps range between 10,000 – 20,000 hours, HPS lamps 16,000 – 24,000+ hours, and Mercury Vapor lamps between 15,000 – 18,000 hours. In contrast, LEDs have rated lives of 20,000 – 100,000+ hours depending on the LED chips used, the luminaire design, and the ambient conditions. In addition, whereas conventional sources tend to completely fail, LED sources tend to simply fade in light output over time until they are no longer useful.

The emerging metric for analyzing LED lifespan is the number of hours until the LED has depreciated to 70% of its initial lumen output, known as L70. This metric is useful for providing both comparability among LEDs and for comparisons between LEDs and conventional lighting technologies, though it is not without drawbacks. One drawback is that conventional technologies, rated based on failure, can experience various levels of depreciation by the end of their expected life.

Lumen depreciation curves can vary significantly by lighting technology. In the case of metal halide lamps for example, the lumen depreciation curve is such that they may reach 70% of the initial lumen output by the time that they reach 40% of their rated life. At the end of its rated life, the lumen output can be below 50% of the initial output. For this reason, lighting technologies are generally specified based on mean lumens, which in the case of metal halide lamps is reached at approximately 40% of rated life (NLPIP, 2005). However, this methodology drastically over-lights areas during the early portion of the replacement cycle to maintain adequate lighting near the end of the cycle. This has significant electrical and material cost, because additional or more powerful luminaires are required for much of the lifecycle. LED lights are generally not subject to such steep depreciation curves, so this phenomenon would be less prevalent. L70 rating of LEDs thusly may put them at a disadvantage compared to conventional technologies, because the rating of lifespan is comparatively more demanding: in the case of metal halide lamps, a more comparable LED lifespan standard would be L50, which would indicate significantly longer useful life.

Table 1 below shows the lumens delivered by three luminaires, one with a 320W Pulse-Start Metal Halide (PMH) lamp, one with a 250W High Pressure Sodium (HPS) lamp, and an LED luminaire. The table shows the steep decline in lumen output in the initial operating hours by the PMH lamp and the relatively low decline in output by the HPS lamp. The LED decline is very gradual. The PMH lamp should have been replaced roughly 5 times and the HPS lamp 4+ times by the time that the LED luminaire is at end-of-life (L70).

Table 1. Comparison of Lumens Delivered by Luminaires over Time

Year of Luminaire Operation	Cumulative Operating Hours	320W PMH (365W Input Power)	250W HPS (305W Input Power)	LED Luminaire (310W Input Power)
Year 1	4,000	16933	13931	19523
Year 2	8,000	15694	13707	19249
Year 3	12,000	14455	13482	18980
Year 4	16,000	14310	13469	18714
Year 5	20,000	14167	13455	18452
Year 6	24,000		13442	18194
Year 25	100,000	Replaced 5 times	Replaced 4+ times	13860

Table Lumen values based on delivered light by luminaire, HPS and MH luminares are assumed to be 70% efficient. The LED values are from a hypothetical luminaire with an approximately 25 year L70 rating.

Another drawback of the L70 rating system, at least as it pertains to the LEDs themselves, is that it does not account for variations in performance among individual LEDs within each product line. As a result, one manufacturer has recommended also measuring the percentage of LEDs that fall below the acceptable level – such as 70% maintenance – over time. In luminaires which utilize a large number of LEDs, the effect of individual variations is likely to be minimal. In applications that utilize few LEDs though, which will likely increase as individual LEDs become more powerful, it is unknown how significant this variation will be.

Finally, where lumen maintenance below 70% may be acceptable the shallow depreciation curve of LED lights would provide even greater useful life. As a result, a secondary end-of-life rating based on 50% lumen depreciation might be taken along with the L70 rating. However this could have the effect of deterring adoption by adding another layer of complexity to specification, and thereby make switching to LED technology from conventional technologies more difficult.

Lighting characteristics. Another difficulty in comparing LED luminaires to conventional luminaires is in analyzing lighting performance itself. Due to the nature of LEDs, there are significant differences on how they provide illumination compared to conventional sources. The most prominent differences are that they are inherently directional, and that they produce light with different color spectra than conventional sources.

As opposed to conventional luminaires, which are designed around a lamp and use optics (lamp with lens, reflector, or refractor) to create the light distribution, LED luminaires can use the optics integral to the LEDs themselves to provide the light distribution. The inherent directionality in LEDs means that they have the ability to provide 100% of their light output in the desired direction. This potential is especially evident in general exterior lighting applications, where small variations in lighting distribution may be less important than in other applications. It is unlike conventional sources, where the portion of light that would otherwise be wasted must be redirected. Luminaire efficiency is the ratio of luminous flux (lumens) emitted by a luminaire to that emitted by the lamp or lamps used therein (IESNA, 2000). A luminaire might have relatively the same efficiency for a MH or a HPS light source for example, so luminaire efficiency has been less of a concern in the design community because designers had to make do with the available equipment. Since most LEDs luminaires emit virtually all of the light generated, conventional luminaire efficiency now matters as well as other factors. When comparing a conventional lamp to an LED, a first glance, the conventional source appears to be more efficacious. Luminaire efficacy takes in account the actual light generated by the luminaire divided by the input power. When luminaire efficacy is used as a metric, LED-based luminaires are quite competitive with and even better than some conventional sources in terms of pure light emitted by the luminaire. Luminaire efficacy is gaining traction within the industry, but is not generally presented in photometric reports for conventional sources, so it requires work to calculate.

The inherent directionality of LEDs, as well as the fact that a large number of chips may comprise a single luminaire, can also lead to better light distribution than would result from conventional luminaires. This is true whether the desired lighting pattern is a tight beam, such as in much decorative lighting, or if it is a large uniform area. In the latter case, LEDs benefit from the ability to be individually aimed and/ or dispersed, allowing for enhanced optical control. In the case of general area lighting by conventional sources, it is often the case that the area directly below the luminaire is significantly over-lit in order to achieve suitable lighting levels in all areas served by the luminaire. This creates 'hot spots' underneath the luminaires, which not only represent wasted light, but can also reduce visibility due to increased contrast with darker areas. The increased performance of the lighting system resulting from reduced hotspots with LED lighting is difficult to account for. While uniformity ratios can give an indication of the magnitude of hotspots, they do not give a good indication of their extent, and as a result can't be used directly to determine how much of the light provided is extraneous or detrimental.

The potential efficiency benefits from improved uniformity of LED lighting can also be difficult to realize given current human perceptions about lighting. Greater uniformity of distribution means that overall lighting levels can be reduced while still ensuring that minimum requirements are met across the lighted space; however, initial reactions to visibly reduced lighting levels can be negative. In other words, initial reaction to reduction of over-lit hot spots may not be negatively perceived as a reduced level of service, unless glare or other notable problems of the previous overlighting are also visibly impacted. Lighting specifiers may be reluctant to approve reduced lighting levels for this reason.

In addition, while conventional luminaires tend to be limited in their correlated color temperature, LEDs offer the possibility to fine-tune the color output. This has potential to increase consumer acceptance, such as in the case of exterior lighting where the very low color temperatures of some conventional lighting technologies can be replaced with potentially more pleasing and effective light from LED sources. However, this benefit is difficult to quantify.

There is also some controversy over the energy efficiency benefits that may be associated with varying color temperatures. Human perception of light follows two distinct response curves, which determine how our eyes adapt to the available light. Which of the two response curves dominates depends on the light level. The spectral response curve that dominates during typical daytime conditions (when luminance levels are greater than 3 cd/m^2) is the photopic response curve, and results from the "cones" in human eyes. While the other receptors in our eyes – the "rods" – are significantly more sensitive, they dominate only in very low light conditions (luminance levels below 0.01 cd/m^2). As a result, light levels have traditionally only been measured in accordance with the photopic response curve. Mesopic vision occurs in moderately low light conditions, when both response curves are important. This is often encountered in exterior lighting. Since the relative importance of each is still uncertain, it is difficult to measure the actual perceived light level in those conditions.

The standard lumen value is based on the Photopic Luminous Efficacy Function and peaks at approximately 555 nm. HPS lamps produce a great deal of energy in and around this wavelength, so the source is considered to be extremely efficacious. The Scotopic Luminous Efficacy Function peaks near 507 nm. MH, Mercury Vapor, and most white LEDs produce more energy in the lower region of the visibile spectrum. Although the Mesopic Luminuous Efficacy Function has not been formally jointly accepted by the Illuminating Engineering Society of North America (IESNA) and the Commission Internationale de I'Eclairage (CIE), it is believed to peak somewhere between 507 and 555 nm. At some point in the future, it might be accepted to use sources that are spectrally attuned to the relevant type of vision. If that happens, then MH and most LEDs would be considered more efficacious for exterior lighting.

It is also uncertain what the effects of varying degrees and types of color rendition are. The commonly used metrics, correlated color temperature and color rendition index, can yield different results depending on the precise spectrum of light produced by a light source. This is also of particular importance in outdoor area, where conventional technologies can have very low levels of color rendition.

High Upfront Cost

Finally, perhaps the most significant barrier that exists to the widespread adoption of LED technology is cost. LEDs remain significantly more expensive than equivalent conventional lighting technologies. While this upfront cost can sometimes be recouped through energy and maintenance savings, the initial expense is considerable. Fortunately these prices are coming down relatively rapidly. Currently the majority of this cost is comprised of the cost of LEDs, which, as mentioned earlier, is declining rapidly. Haitz's Law predicts that the light output of LEDs increases by a factor of 20 every 10 years, while the cost decreases by a factor of 10 over the same period of time. This has held approximately true beginning with red LEDs in the late 1960's and continuing with the more recent white LEDs (Steele, 2006). At the same time, the cost per lumen output has declined at a rate of 20% per year (Navigant, 2006). The remainder of the luminaire cost includes research and development costs, design, general overhead, manufacturing, and other material costs. As LED technology continues to mature, many of these costs can also be expected to decline.

Case Studies

Despite these barriers to adoption, the benefits of LED lights for general illumination are such that they are beginning to be utilized by early adopters in certain applications. One such area is in general illumination for exterior applications, such as parking and roadway lighting. LEDs are beginning to be installed in these applications because of their ability to provide greater control of light dispersion, significant maintenance savings compared to traditional sources, and changing industry perception of higher quality light for exterior use. The authors have conducted two technology demonstration projects: one with low-bay luminaires, and the other with street luminaires, which when combined comprise the majority of exterior area lighting. The results of both these projects exemplify the opportunities – electrical savings, maintenance savings, and improved lighting performance – and challenges – inconsistent product quality, lack of metrics to compare to conventional technologies, and high upfront cost – of LED lighting technology.

Electrical savings. Both the low-bay and street lighting demonstration projects showed significant potential to reduce electrical use. The low-bay demonstration, conducted in a covered parking lot in Northern California, compared low-bay LED luminaires of nominal 85 watts to 175 nominal watt MH luminaires. The low-bay LED luminaires used roughly 87 watts on average, while the MH luminaires used 202 watts due to ballasting. However, their performance characteristics were such that two low-bay LED luminaires were required to replace each MH luminaire. The resulting savings were approximately 27 watts per MH luminaire. In the street lighting demonstration, 100 nominal watt HPS luminaires were replaced by 78 watt LED street light luminaires on a Northern California street. The HPS luminaires used roughly 121 watts, while the LED luminaires averaged roughly the nominal 78 watts, resulting in energy savings of 43 watts per luminaire. This amounts to 13.5% and 35.8% energy savings for the low-bay and street lighting luminaires, respectively. The higher efficacy of the LED streetlights may be partially explained by the timing of that demonstration after the low-bay demonstration, which may resulted in availability of more efficient LED chips.

Table 2. Comparative Electrical Performance of LED and Conventional Luminaires

	Power (w)	Rated Life (hr, from manufacturer estimates)	Estimated Annual Electrical Use (kWh)	Estimated Lifetime Electrical Savings (kWh)
Low-Bay: Metal Halide	202	10,000	1,770	-
Low-Bay: LED	174.8 (- 13.47%)	50,000	1,531	1,360
Streetlight (120' spacing): High-Pressure Sodium	121	30,000	469	-
Streetlight (120' spacing): LED	77.7 (- 35.79%)	~100,000	319	4,330

Maintenance savings. The low-bay and street lighting project also both demonstrated the opportunity for LED luminaires to provide maintenance savings compared to conventional technologies. Whereas the bulbs installed in the MH fixtures for the low-bay project had been under a 1-year replacement cycle due to concerns regarding lumen depreciation, the low-bay LED luminaires were predicted to last nearly 6 years before having to be replaced. In the streetlight demonstration, the HPS lamps were estimated to require replacement in approximately 6 or 7 years, depending on the maintenance scheme. Information from the manufacturer of the LED streetlights on the other hand, indicates that those luminaires could last nearly 25 years before 30% lumen depreciation. It should be noted however, that no comparable luminaire has been operated for this length of time, so no independent data is available to corroborate this estimate. Maintenance savings may also result from the absence of conventional luminaire components such as ballasts and starters in LED luminaires.

Lighting performance. Finally, the potential that LED luminaires have for increased lighting performance was also exemplified by each of these projects. In the street lighting project, lighting uniformity ratios were generally decreased, indicating more even light distribution. While average photopic illuminance also decreased in this demonstration, this may in fact reflect improved performance. This is because a significant amount of light from the HPS luminaires was wasted in hotspots which increase average levels, but can in fact reduce visibility. Indeed, 17 out of 20 respondents to a neighborhood survey indicated that the LED luminaires were at least as preferable as the HPS luminaires, with 12 of the 20 saying they strongly preferred the LEDs.

In the low-bay demonstration, average photopic illuminance was increased by the LED luminaires while also reducing uniformity ratios. However, the increase in uniformity may be largely the result of the 2-for-1 replacement scheme that was implemented. In addition, the amount of light that reached the walls of the garage was decreased by the LED luminaires, which concerned the host customers. The luminaires tested had the LED chips on a flat plane though, and shortly after the demonstration the manufacturer introduced a product which aimed the LEDs based on a pyramidal geometry. While these new fixtures may still have required a 2-for-1 replacement, they would likely have had a better distribution.

Table 3. Comparative Lighting Performance of LED and Conventional Luminaires

	Minimum Illuminance (fc)	Average Illuminance (fc)	Avg. to Min. Uniformity	Max. to Min. Uniformity
Low-Bay: Metal Halide	0.22	5.0	22.25	100.04
Low-Bay: LED	0.38 (+ 72.73%)	5.6 (+ 12.00%)	14.64 (- 34.20%)	73.81 (- 26.22%)
Streetlight (120' spacing): High-Pressure Sodium	0.09	0.80	8.66	40.00
Streetlight (120' spacing): LED	0.09 (+ 0.00%)	0.53 (- 33.75%)	5.68 (- 34.42%)	16.00 (- 60.00%)

Evident market barriers. In addition to the great potential for LED lighting that these projects demonstrated, they also demonstrated some of the challenges that they must overcome before they will be widely adopted. The first of these is the inconsistent product quality that has resulted from the rapid technical advancement of the technology. As mentioned above, at the time of testing, the LEDs on the low-bay luminaires were on a flat plane. This was quickly followed by luminaires with the LEDs pointed at different angles to achieve better light distribution. Also, while the low-bay luminaires tested had an efficacy of roughly 38 lumens/ watt, the manufacturer now claims to have a similar luminaire that produced 49 lumens/ watt, using the same 85 nominal watts. The luminaires that were tested during the final phase of the street light project had an efficacy of roughly 58 lumens/ watt, and followed a number of previous product generations available during the 2 months preceding that final testing. This rapid advancement, as well as the difference between these two manufacturers, is indicative of both the rapid development of LED technology and the inconsistency of product performance in the current market place.

Despite the potential electrical and maintenance cost savings, the LED luminaires in both demonstration projects had relatively long simple payback periods. In the low-bay demonstration the simple payback was estimated at roughly 12 years for a retrofit scenario, not accounting for the expected replacement of the LED luminaires due to lumen depreciation. If replacement was taken into account, the LED luminaires did not pay back because the upfront cost was too high. Their economic performance was predicted to be significantly improved if the fixtures were instead installed on a 1-for-1 basis, which is likely before the end of 2008. The LED streetlights were estimated to have simple payback periods ranging from roughly 20 to 25 years in the retrofit scenario, depending on the maintenance schedule utilized on the HPS fixtures they replaced. In this demonstration too, the lengthy payback period was due to high upfront cost of the LED luminaires. However, it should be noted that the manufacturer plans to have a similarly performing luminaire available by mid-2008 for less than $500 (Ruud, 2008).[2] In addition, other manufacturers may already have products which have better economic performance in both applications.

The uncertainty regarding the LED street light manufacturers claims of luminaire useful life is only one example of the lack of metrics for LED lighting that was demonstrated in these projects. During discussions about the low-bay LED luminaires, the host customers indicated that they felt the LED luminaires gave off more and 'sharper' light, allowing details to be more easily seen. In addition, they commented on reduced glare as compared to the MH luminaires. Neither of these visibility factors is easily quantifiable by current metrics, however. As another example, while photopic illuminance measurements generally decreased in the street lighting demonstration with the LED luminaires, scotopic illuminance measurements increased. As previously noted, the exact interplay of these two types of light is not well established however, which makes quantitative comparisons difficult.

Potential for Energy Efficiency Programs

For LED lighting technology to quickly begin to fulfill its potential, the technology must overcome the challenges that it currently faces. One way in which this could be accomplished is through energy efficiency programs. With the goal of realizing the potential energy savings of LED lighting, energy efficiency programs can provide both assistance and guidance to consumers. They can do this by reducing upfront costs through rebate programs, or by providing quality vetting and education.

[2] This is a 29% reduction from the list price as of the time of the study. The payback numbers were calculated based on large scale purchase prices at the time, which were approximately 13% less than the list price.

Reducing Upfront Costs

By capitalizing on estimated future energy savings, energy efficiency programs can help to reduce the initial investment corresponding to the purchase and installation of LED lighting technologies. This would both reduce the initial capital investment required and shorten the simple payback times for LED luminaires. As a result, LED lighting technology would be more economically competitive with conventional lighting technologies, removing one of the major barriers to its adoption. Further consumer adoption of LEDs has the potential to then provide a positive feedback cycle with technology advancement, as manufacturing capacity scales up and more research money is invested.

Efficiency programs of this type are already happening in some places. Realizing that LED lighting has the potential to save customers significant amounts of energy, for example, California utilities are actively investigating LED lighting technologies. The Emerging Technologies and incentive program staff at Pacific Gas and Electric Company (PG&E) are working closely with the LED industry, DOE, US Environmental Protection Agency, and the standards and testing community. Over the past few years, they have provided incentives for specific LED products, including LED exit signs, channel letter signage, and LED refrigerated case lighting. PG&E and other utilities are optimistic about LED lighting. This is because, despite the challenges, a few manufacturers have developed high performance LED lighting fixtures that take advantage of LED directionality and provide good thermal management. Further, work on LED components in the lab is advancing rapidly, raising expectations that manufacturers will be able to produce more high-performance products at lower cost. Nonetheless, the utilities are taking a cautious stance toward offering incentives for new applications of LED lighting.

A DOE program, the Retailer Energy Alliance (REA), is in part focusing on procurement of LED products to help accelerate the price drop of LED technology. The procurement process involves either a mass-buydown or a performance specification that sets a minimum threshold of performance for products purchased by REA members. Each of these methods helps lower the initial cost of the technology as manufacturers compete for the large market represented by the Alliance. In February, a webcast was presented to the members of the REA that included LED-based parking lot lighting.

In addition, energy efficiency programs can provide guidance on economic analysis; although upfront cost is usually the first consideration in many lighting decisions, Life-Cycle Cost analysis is much more relevant to evaluating a potential investment and may be essential to economically justify an LED product. Due to the anticipated long and reliable lifetimes of LED products, maintenance costs savings may in fact exceed energy savings given the relatively low prices paid for electricity. Maintenance includes replacing a conventional lamp (and ballasts if they fail), and can become quite costly in applications such as roadway lighting. Such applications typically require a truck with a lift, multiple personnel, possibly shutting down a roadway, related insurance and other costs. Maintenance savings may be the primary motivator in such situations, with energy savings simply comprising an added bonus.

Product Vetting and Quality Control

Energy efficiency programs also have the potential to provide guidance by setting minimum standards for products that qualify for incentives. Due the wide variety of products available, as well as the technical sophistication required to properly analyze the products, energy efficiency implementers are in a unique position to provide information to consumers regarding the technology. By providing incentives only for products that meet certain technical standards, they can help to mitigate consumer uncertainty and dissatisfaction.

Many customers already look to utilities as an unbiased source when considering energy efficient technologies. For example, as stated by one customer regarding PG&E's efforts with LED lighting technologies, "Please continue your efforts to create an environment where novice LED customers can purchase products with confidence so that we can achieve our cost-efficiency and green house gas reductions goals nationwide." As industry-adopted testing standards come into effect, new LED rebate programs should include product qualifying standards to help ensure customer satisfaction and long-term energy savings.

The DOE has examined earlier introductions of energy-efficient technologies, such as CFLs, and is actively striving to avoid repeating the mistakes of the past. The ENERGY STAR® Program for Solid-State Lighting is a quality-related effort that has taken a different approach than the CFL ENERGY STAR® Program. DOE also supports the development of luminaire test standards for purposes of product quality, working with both the lighting industry and the Illuminating Engineering Society of North America (IESNA). Two current standards include LM-79 (recently released) which establishes procedures for performance testing, such as photometry, and LM-80 (currently in the IESNA review process and expected to be released shortly) which establishes how to measure (and extrapolate) the expected life of an LED luminaire based on its initially observed lumen depreciation rate.

Education

Education is critical to advancing widespread adoption of LED lighting. Utilities and other energy efficiency groups can lead efforts to provide educational programs related to the many unique aspects of LED lighting, including important considerations for lighting design in new construction and retrofit situations. These programs should be offered to a wide audience: customers, lighting designers, architects, electrical engineers, energy-efficiency consultants, and other professionals involved in lighting design and installation. California's IOU Emerging Technologies and incentive program teams collaborate and share in product assessments. This work provides both IOUs and manufacturers the opportunity to evaluate new products with customer feedback on performance and satisfaction, and thus help to mitigate some of the barriers to LED adoption.

Conclusion

There are many challenges that LED lighting technology currently faces, with the potential to slow its widespread adoption. It is already beginning to make inroads in the realm of general exterior lighting, but it faces the same challenges in these applications. As indicated here, LED lighting technology holds great potential if these challenges can be mitigated, possibly through well designed energy efficiency rebate programs. If this can be done, the LED lighting holds great potential for energy and cost savings, as well as increased lighting performance, across a wide variety of applications.

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