LED Lighting: Applying Lessons Learned from the CFL Experience

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ABSTRACT

Light emitting diode (LED) technology has emerged as an exciting new lighting alternative with the potential for significant energy savings. There is concern, however, that white light LEDs for general illumination could take a long, bumpy course similar to another energy-efficient lighting technology – compact fluorescent lights (CFLs).

Recognizing the significant potential energy-efficient lighting has to reduce U.S. energy consumption, Congress mandated in the Energy Policy Act of 2005 that the U.S. Department of Energy (DOE) develop Solid State Lighting (SSL) through a Next Generation Lighting Initiative. DOE's first step was to analyze the market introduction of compact fluorescent lighting to determine what lessons could be learned to smooth the introduction of SSL in the United States (Sandahl et al. 2006). This paper summarizes applicable lessons learned from the market introduction of CFLs and describe how DOE and others are applying those lessons to speed the development and market introduction of energy-efficient LED lighting for general illumination applications. A description of the current state of LED technology and compares LEDs to incandescent, fluorescent, and halogen lights is also provided.

Introduction

Lighting accounts for more than 20% of U.S. electricity use and lighting energy costs exceed $40 billion per year. DOE estimates that LED lighting could reduce lighting energy used by 50% by 2025 (from year 2000 levels), eliminating the need for more than one hundred 1000-MW power plants and saving over $100 billion (DOE 2008a, Dowling 2007).

Achieving these potential energy savings will require the widespread replacement of traditional (incandescent and fluorescent) light sources with higher efficiency LEDs. In spite of inroads by compact fluorescent lights (CFLs) in recent years, incandescent sources still accounted for almost 90% of residential lighting energy use in 2005 (based on a California study, RLW Analytics 2005). LED technology isn't ready to take over yet but it is improving rapidly in both lighting output and efficiency. Depending on the application, many LED-based lights today are more energy efficient than incandescent sources and a few products exceed the efficiency of fluorescent and high-intensity discharge (HID) systems.

The challenge for the SSL industry over the next five years will be to develop and commercialize LED products that are significantly more efficient than even the most efficient fluorescent and HID light sources, at an affordable price. DOE's challenge is to help maintain the pace of product development while meeting both energy-efficiency goals and consumer expectations of excellent lighting quality, long life, and competitive pricing.

In 2006 DOE conducted an analysis of the market introduction of CFLs in America and identified lessons learned that might be applicable to the market introduction of LED lighting (Sandahl et al. 2006). This paper summarizes those lessons learned and describes how DOE and others are applying them to speed the market introduction of energy-efficient LED lighting for general illumination applications. The paper begins with an overview of the current state of LED technology and a comparison of LEDs to CFLs and other lighting sources.

The State of the Technology

LEDs have had a brief but dazzling trajectory so far. Will they be just a flash in the pan or will they pan out? Below is a brief history, discussion of their improvements in performance, current status of the technology, and comparison to other lighting technologies.

Are We There Yet? – The Pace of LED Technology Development

LED technology still has some distance to go in terms of realizing its potential, but the rapid pace of LED technology development makes CFL's journey to market look like a cart ride down a long and bumpy road.

LED lighting starts with a tiny (about 1 mm^2) chip of semi-conducting material, mounted on heat-conducting material and enclosed in a lens or encapsulant (Figure 1). The resulting device is mounted separately or in arrays of LEDs on a circuit board, which is then installed in a fixture, ideally one designed to effectively manage heat generated by the LEDs. LEDs are solid state devices, while incandescent, fluorescent, and high-intensity discharge (HID) lamps all have glass enclosures containing a filament or electrodes and fill gases.

The first LED was developed at General Electric (GE) in 1962; it was a red LED producing 0.001 lumens. During the 1960s through 1980s first red then green LEDs were developed and light output grew from 0.01 to 0.1 lumens. In the 1990s Nichia created the first blue LED; it emitted 1 lumen and led the way to the development of white light from LEDs (achieved either by mixing the light from red, green, and blue LEDs, known as RGB systems, or by coating a blue LED with phosphor to emit white light, known as phosphor-converted or PC LED). In 2008, white LED devices capable of emitting close to 100 lumens from a nominal 1-watt device have become commercially available. In contrast to this rapid pace, the first fluorescent light was patented in 1901 but fluorescent lighting didn't become widespread in commercial settings until the 1970s. GE demonstrated a "swirly" compact fluorescent light bulb in 1976 but compact fluorescents did not become widely available for home lighting until around 2000 because of performance and marketing barriers (Sandahl et al. 2006).

LEDs have made phenomenal improvements in both light output and cost decreases during the past 5 years, with the output per luminaire improving at a compound rate of about 35% per year while cost per lumen has decreased 20% per year (Dowling 2005). LED device efficacy (output of lumens per watt) has increased from about 10 lm/W in 2005 to 50 lm/W for warm white LEDs in 2008 and from 30 lm/W in 2005 to 80 lm/W for cool white LEDs (as of October 2007). In fact, the technology is changing so fast that DOE has revised its projections three times in the past three years and as of March 2008 predicts that commercially available cool white LED devices will reach an efficacy of 188 by 2015 while commercial warm white LED devices will achieve an efficacy of 162 lm/W.

At the same time, retail prices for LED devices have dropped dramatically, from more than $200 per thousand lumens (/klm) in 2001 to $30/klm in 2007 and they are predicted to drop to $3/klm by 2015, which will make solid state lighting less expensive than compact fluorescents on a first-cost basis (DOE 2008a).

Comparison of LED and Other Light Sources

Although high-performance fluorescent and HID may be more cost-effective than LEDs on a first-cost basis now, those technologies can be considered mature, thus only incremental technology improvements are anticipated. Significant improvement is still expected in LEDs. While incandescent lamps still have a very low first cost and high lumen output compared with LEDs, LEDs have a much longer lifetime and consume far less power. The best warm white LED devices available today can produce about 45 to 50 lumens per watt (lm/W) (when looking at the LED device alone, not overall luminaire efficiency). However, many of the white LED consumer products currently available are only marginally more efficient than incandescent light sources. Incandescent lamps typically produce 10 to 15 lm/W while CFLs produce at least 35 to 70 lm/W. However, LED device efficacy does not tell the whole story. Well-thought-out luminaire designs that take advantage of LED features such as their inherent directionality can yield light fixtures that are more energy-efficient than CFL and incandescent sources, which put out light in all directions and can suffer fixture losses of up to 50% in applications like recessed cans. Most currently available LEDs are not intended to replace screw-in lamps in existing fixtures; instead they are sold to the consumer already integrated into a luminaire product.

Unlike other light sources, LEDs don't burn out; instead they get dimmer over time. LED useful life is usually based on the number of operating hours until the LED's light output drops below 70% of its initial light output. Good-quality white LEDs have a useful life of 30,000 to 50,000 hours. Incandescent lamps last about 1,000 hours; CFLs last 8,000 to 10,000 hours, and the best linear fluorescent lamps last more than 30,000 hours. LED light output and useful life are strongly affected by temperature. Contrary to popular belief, LEDs do generate heat, not from the light-emitting side of the LED but via conduction through the mounting base, so some sort of heat sink must be incorporated into the fixture design to conduct heat away from the die; otherwise, the excess heat will degrade performance by reducing lumen output.

Until recently, most white LEDs had very high correlated color temperatures (CCTs), often above 5000 Kelvin. High CCT light sources appear "cool" or bluish-white to the human eye. For most interior lighting applications, warm white (2700K to 3000K) and in some cases neutral white (3500K to 4000K) light is appropriate. Neutral and warm white LEDs are now available. They are generally less efficient than cool white LEDs, but have improved significantly to levels almost on par with CFLs.

The ability of light sources to render colors is measured by the color rendering index (CRI). A minimum CRI of 80 is recommended for interior lighting. The CRI measuring system has been found to be inaccurate for LED systems but is still in use until a new metric can be developed. In the meantime it is recommended that color rendering of LED products be evaluated in person and in the specific application if possible. The leading high-efficiency LED manufacturers now claim a CRI of 80 for phosphor-converted, warm-white LEDs and 70 to 75 CRI for cool and neutral white light LEDs (Cree 2006, Philips Lumileds 2007 a and b).

Due to the lack of standardization in LED product reporting, it is somewhat difficult to make broad general comparisons of LEDs to other lighting types across all of these measures but here is an example in one product category – undercabinet lighting. Table 1 (Kinzey 2008) lists luminous efficacy, linear flux, and color temperatures, along with cost at the time of testing, for three LED undercabinet products, plus one halogen and one fluorescent product. These results were obtained from independent product tests sponsored by the DOE Solid State Lighting Program, except where noted. While the halogen and fluorescent values in the table will likely continue to be representative of typical products, the LED values are quickly becoming out of date as improvements in LED cost and performance continue to occur.

Table 1. Comparison of LED, Fluorescent, and Halogen Under-cabinet Lighting Fixtures

Undercabinet Product	Date Tested	Luminaire Efficacy *(lm/W)*	Linear Flux *(lm/foot)*	Color Temperature	Total Equipment Cost *($/foot)*
A – LED	02/2008	34.3	190	2926K	$65.00
B – LED	07/2007	30.5	140	2767K	*
C – LED	07/2007	34.4	225	2800K	$66.67
Fluorescent	11/2007	23.2	243	3865K	$21.97
Halogen	**	7	230	3000K	$33.26

*Commercial prototype; not purchased.
**Represents a compilation of commonly available products, as reported in http://www.netl.doe.gov/ssl/PDFs/UndercabinetLigting.pdf

The unique qualities of LEDs may offer advantages over other light sources in many applications (see Table 2) (Gordon 2008c).

Table 2. Characteristics of LED Lights and Its Advantages over other Light Sources

Characteristic	Comparison	LED Advantage/Application
Directional light	CFLs & incandescents send light out in all directions LED light is directional; hemispherical not spherical. Fixture losses in recessed cans are up to 50% for CFLs & incandescents, 0% for LEDs.	Light is not "lost" in fixtures. Great in directional applications – recessed can down lights, spot lights, undercabinet lighting, etc.
Low-profile, compact size	Linear fluorescents & incandescents 2" to 6" high, LEDs ¼"	Thin light source for undercabinet, in-cabinet, etc.
Vibration & breakage resistant	CFLs & incandescents use glass, fragile filaments. LEDs are solid state with epoxy covering	Safe in sports arenas, health care, food prep, manufacturing facilities, children's rooms, ceiling fans
Performs better in cold temps	CFLs need amalgam and have slow start in cold temps. LEDs perform better in cold temp than warm.	Great for outdoor lighting, Christmas lights, refrigerator & freezer lights
Instant on, no warm-up	CFLs 3 min. to full bright. Metal halide and sodium lamps 5-10 minutes warm up. LEDs instant on, 200 milli-seconds faster than incandescent.	Increased safety & security for outdoor, hallway, motion sensor lights
Unaffected by rapid cycling	Frequent switching on-off weakens incandescent's filament, erodes emitter coating in fluorescents. HIDs can't re-start if hot. LEDs have instant restart, no lumen loss from frequent on-offs.	Works well with occupancy and daylight sensors, flashing light displays. Longer life for general lighting.
No infrared or ultraviolet emissions	Metal halide lamps emit UV, dangerous to people, fabrics, and art unless shielded; LEDs emit no IR or UV.	Safe for people, furniture, art.

Applying Lessons Learned From CFLs to LEDs

In 2006, the U.S. Department of Energy's Solid State Lighting Program released the report *Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market* (Sandahl et al. 2006), which provided an analysis of the market introduction of CFLs in the United States and identified issues that hindered their introduction. Many of the lessons learned from that study are applicable to solid state lighting. These lessons are summarized below in italics along with notes on the actions DOE and others are taking to apply these lessons to LEDs.

National Collaboration

1. *Coordinate and collaborate with national organizations.*

Manufacturers came together in 2003 to form the Next Generation Lighting Industry Alliance (NGLIA), an alliance of for-profit lighting manufacturers formed to accelerate solid-state lighting development and commercialization through government-industry partnership. Administered by the National Electrical Manufacturers Association (NEMA), members include 3M, Acuity Brands Lighting, Air Products & Chemicals Inc., CAO Group Inc., Color Kinetics Inc. (Now known as Philips Solid State Lighting Solutions), Corning Inc., Cree Inc., Dow Corning Corporation, Eastman Kodak Company, General Electric Company, Light Prescriptions Innovators LLC, LSI Industries, Lumination, OSRAM Opto Semiconductors Inc., OSRAM Sylvania Inc., Philips Electronics North America Corporation, QuNano, and Ruud Lighting.

DOE signed a Memorandum of Agreement with NGLIA in February 2005 detailing a strategy to enhance the manufacturing and commercialization focus of the DOE portfolio by utilizing the expertise of NGLIA (DOE 2008a). DOE also signed a Memorandum of Understanding with the Illuminating Engineering Society of North America (IESNA) in July 2006 to strengthen their ongoing partnership and commitment to improve the efficient use of energy and to develop standards with a strong energy efficiency focus. Both NGLIA and IESNA are involved with DOE in project development, review of technical specifications, development of new standards and test procedures, and cosponsoring of DOE events.

Research and Development

2. *Study market structure to see how best to introduce the new technology.*
3. *Don't launch a product until performance issues are ironed out!*

Performance claims must be accurate. The problem of hyperbole in LED ads has been pointed out (Dowling 2007). Exaggerated CFL claims led to "burned" buyers who rejected early CFL products and told their friends to do the same. DOE has taken a strong early role in research and development with the SSL industry to improve the quality of LEDs. The Energy Policy Act of 2005 issued a directive to the Secretary of Energy to carry out a "Next Generation Lighting Initiative" to support the research and development of solid-state lighting based on white light-emitting diodes. The current DOE portfolio totals more than $74.8 million in cumulative government and industry investment. DOE directs the research dollars it receives to the national laboratories, industry, and universities. Support of SSL research has yielded 64 patent submissions since 2000. This support has resulted in dramatic and rapid increases in product performance and numerous applied engineering advances. DOE also funds field demonstrations and commercialization activities to assist market channel members such as luminaire manufacturers, designers, retailers, builders, etc. in smoothing the way for high-performance SSL products. Federal support for SSL is significantly higher than was support for CFL development. The government has provided $60.75 million for SSL between 2003 and 2007 and proposes $350 million more between 2007 and 2013, while DOE funding for CFLs totaled $4.3 million between 1978 and 2000 and part of that was shared with contractors (NRC 2001). The early and earnest involvement of industry in standards efforts and collaborative efforts through NGLIA, and the independent product testing through DOE's CALiPER program are strong motivators to ensure accuracy in performance claims and keep bad products off the shelves.

Niche Applications

4. *Introduce new lighting technology first in niche applications where benefits are clearly defined and consistent with buyers' needs.*
5. *Focus message where the technology can meet/exceed expectations.*

Since their introduction, colored LEDs have taken over the market for indicator lights in consumer electronics. In the last decade cell phones, exit signs, and traffic signals have also been great markets for SSL products. Now with the development of white light SSL products, LEDs are showing promise in several general illumination niche applications, for example, under-cabinet lighting, adjustable task and display lighting, recessed downlights, cove lighting, outdoor lighting, step and path lighting, decorative lighting, accent lights, and holiday decorations. Other applications that take advantage of LED strengths include refrigerator case lighting, retail display case lighting, elevator lighting, and lighting of food preparation areas and spaces with occupancy sensors. DOE is promoting the development of niche applications through research funding, demonstrations, ENERGY STAR, and the SSL Lighting for Tomorrow design competition.

Performance Standards

6. *Manufacturers and energy-efficiency groups should coordinate to establish minimum performance requirements.*
7. *Back up long-life claims with guarantees.*

The unique nature of LEDs means that current test procedures to measure and evaluate traditional lighting sources cannot all be applied to LED product testing. As a result, DOE has been working on the development of new standards in cooperation with the industry and existing standards bodies. With collaboration and coordination on the part of numerous parties, national specifications and standards for LED performance are on track for approval and implementation on several fronts: (Gordon 2008b)

- ENERGY STAR® SSL Luminaire performance criteria were issued Sept. 12, 2007, effective Sept 30, 2008 – includes requirements for CCT, CRI, color spatial uniformity and maintenance, off-state power and thermal management, lumen depreciation (lifetime), power supply, with luminaire efficacy requirements for specific near-term applications including under-cabinet kitchen lighting, undercabinet task lighting, portable desk lamps, recessed downlights, and outdoor wall-mounted porch, step, and path lights.

- ANSI C78.377-2008 – regards chromaticity of solid state lighting products; was published in February 2008 and is available for download from the ANSI website.
- IESNA LM-79-08 – regards photometric testing; approved and available for download from IESNA in May 2008.
- IESNA LM-80 – regards lumen maintenance; is in review and approval is anticipated in summer 2008.

ENERGY STAR requires all luminaires to include a warranty covering repair or replacement of defective electrical parts (including light source and power supplies) for 3 years or more from date of purchase.

Product Testing

8. Be aggressive about dealing with technology failures that affect main benefit claims.

DOE found manufacturer performance claims on early LED products were significantly overstated. While standards are being developed, there is an immediate need for reliable, unbiased product performance information to protect consumers – and to protect LED's reputation through these early stages of development in the white light/general lighting arena. To address this need, DOE sponsored the Commercially Available LED Product Evaluation and Reporting (CALiPER) program (initially known as the Commercial Product Testing Program). DOE's pro-active action to start CALiPER is a result of the lesson it learned from the CFL experience where a national independent testing program was initially lacking and early promotional efforts suffered from the introduction and distribution of poor-quality products. This was somewhat rectified when the Natural Resources Defense Council (NRDC) and a number of utilities, together with DOE and the U.S. Environmental Protection Agency (EPA), jointly established an independent CFL testing program called PEARL (Program for the Evaluation and Analysis of Residential Lighting) in 1999 (Titus 2005).

PEARL's budget in 2003 was $500k, with 50% coming from CFL manufacturers, 15% coming from retailers, 15% coming from fixture manufacturers, and 20% coming from utilities. In 2003 PEARL was testing 20 CFL products per cycle and 10 CFL fixtures per cycle and was about to start its sixth cycle. By 2005, PEARL had tested 120 models for compliance with ENERGY STAR specifications (Titus 2005). Test results were only given to the product's manufacturer and members of PEARL's board, which did not include manufacturers or retailers. In 2008 PEARL will be rolled into DOE and EPA's respective CFL and ENERGY STAR residential fixture programs. All funding at that point will come from the agencies and the testing fees charged to manufacturers.

While PEARL began three years after the ENERGY STAR CFL specifications came out, CALiPER was launched in October 2006, three years before ENERGY STAR specifications for LEDs will be implemented in September 2008. CALiPER is a DOE-funded program that conducts secret shopper purchases of commercially available general illumination LED products and sends them to independent testing laboratories. CALiPER seeks to test a broad range of applications, product categories, performance characteristics, manufacturers, devices, and geometric configurations. Luminaires are tested for light output and distribution, color qualities (spectral power distribution, CCT, CRI, spatial distribution of color), reliability (lumen maintenance and thermal management), and electric characteristics (power factor and off-state power use). Manufacturers are given the opportunity to comment on test results prior to report completion. Summaries of test results are available on the DOE SSL website. These reports include analysis and benchmarking comparison to conventional light sources. Product-specific results can be obtained by email request after agreeing not to use the data for commercial purposes.

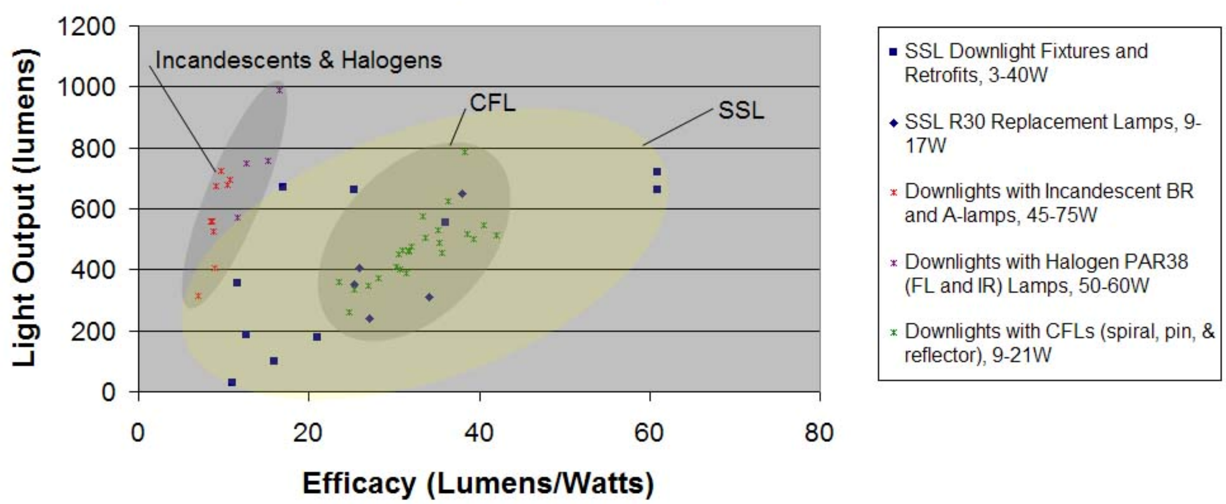
As of March 2008, CALiPER has tested more than 100 products. Testing thus far has yielded a wide range of results from excellent to poor (Figure 5). CALiPER has also seen some wide disparity between performance claims in marketing literature and actual tested luminaire performance.

Accurate Reporting

9. *Know and admit technology limitations.*
10. *Delay program launch rather than introduce inferior products; first impressions are long lasting.*

Identifying and admitting technology limitations is critical with LEDs, since there are certainly technology limitations for most applications. DOE is using CALiPER test results (Figure 1), demonstrations, DOE national workshops, the website (www.netl.doe.gov.ssl), fact sheets, and R&D updates, etc., to clarify and report the state of the technology. Most energy-efficiency organizations and utilities are delaying introduction of LED programs until the ENERGY STAR specifications take effect.

Figure 1. CALiPER Testing of Downlights Found a Wide Range of Performance for LED Products (DOE 2008b)



--Values for SSL downlight products are from CALiPER testing.
--Values for CFL and incandescents are assembled from CALiPER testing, earlier photometric testing and product catalogs.
--Fixture efficiencies are applied to replacement lamp values (factor depends on lamp type).

National and Regional Product Promotion

11. Join forces with others in national energy-efficiency programs.

DOE works with national and regional energy efficiency organizations including the Northeast Energy Efficiency Partnerships (NEEP) and the Consortium for Energy Efficiency (CEE), utilities, state and local energy offices, lighting trade groups, and other stakeholders through the DOE Technical Information Network for Solid-State Lighting (TINSSL). Members share information about the technical progress of SSL technologies through monthly teleconferences, national events, and distribution of fact sheets, market studies, and technical reports. DOE also hosts an annual SSL Program planning workshop and other information exchanges that draw together experts from industry, academia, research organizations, and the national laboratories.

In July 2007, representatives of DOE, Wal-Mart, Whole Foods, Target, IESNA, ASHRAE, and the U.S. Green Building Council met to discuss collaborative efforts to improve the energy efficiency of retail buildings via a new organization called the Retail Energy Alliance (REA). By March 2008, the REA Steering Committee had grown to nine retailers plus supporting organizations, including Best Buy, Food Lion, Home Depot, Kohl's, McDonalds, and Staples, in addition to those already mentioned. DOE intends to offer technology procurements as part of this effort; one is already underway for LED parking lot lights; Wal-Mart has expressed interest in equipping 1,000 of its stores with LED parking lot lights.

Fixture Development

12. Collaborate to address fixture issues and compatibility.

Fixture manufacturers had several issues to contend with when CFLs first came out - oddly shaped and oversized lamps, concerns about pin incompatibility, where to put the ballast, etc., and it took several years to resolve these issues. Industry collaboration helped then and is paving the way now for LEDs, along with a DOE research leadership.

LEDs are no ordinary light bulb – while their unique features may be good news for energy savings, they spell a steep learning curve for lighting fixture manufacturers trying to learn how to put them into fixtures designed for general illumination lighting. In fact the LEDs currently under development are not intended as direct replacements for screw-in incandescent bulbs. Most current research is focused on LED luminaires that include the fixture as part of the product; due to their long life, the whole luminaire may be replaced before the bulb "burns out."

Two big issues to deal with in LED fixture design are heat management (vital because LEDs lose lumen output faster if exposed to too much heat) and power quality (vital because of the potential for lost efficiency and for being shunned by power grid operators). Luminaire makers must design in a thermal path to conduct heat away from the lamp. The directional nature of the LED light source is another difference to contend with for fixture manufacturers used to near-spherical light emission of incandescent and CFL sources.

In comparison, designing for incandescents and CFLs may seem relatively simple, since the primary concerns are style, photometrics, input voltage, size, and agency approval. With LEDs, designers also need to convert AC to DC; control the drive current; keep the emitters cool; add optics; address EMI/RFI (electromagnetic and radio frequency interference), color temperature, CRI, light appearance, and agency issues; and "still make it look good." Designers have two options when putting together LED-based fixtures - go with off-the-shelf components or use custom components (Venhaus 2007).

The lack of consistent reporting requirements has hampered LED fixture designers. Luminaire manufacturers are concerned that vendor data sheet values do not represent what is achievable in real-world applications. Requirements aren't in place yet for the LED manufacturers to be consistent about what information they will provide. Because standards haven't been in place, it's been difficult to compare the claims of one vendor against another. Data sheets typically list the LED's thermal resistance, viewing angle, maximum LED junction temperature, maximum DC current, temperature coefficient of voltage, CCT, maximum DC forward current, forward voltage at a given current, and luminous flux. Electrical, thermal and optical factors all affect the amount of delivered lumens per watt for a given luminaire (McClear 2007) but no standard test procedures exist for rating individual LED devices; thus, there are no standards to confirm the information that LED manufacturers provide on their product data sheets. IES-LM-79-08, published in April 2008, is a test procedure for measuring electrical and photometric properties of LED products in full LED luminaires and integrated replacement lamps but it does not deal with the LED devices alone.

Marketing and Program Design

13. Retailer and consumer education are critical.

The CFL lessons learned report drew many conclusions about program design and marketing that will be relevant as more consumer products for general lighting become available; these are particularly for utilities and energy efficiency organizations wishing to develop lighting programs centered on LED products. First the report noted that education, of both consumers and retailers, is critical to new product introduction. Retailers should be provided with brochures, posters, and in-store displays. Products should be promoted through several mediums including TV, radio, newspaper and magazine ads, press events, utility bill stuffers, and demonstrations at fairs and home shows. Product packaging can be a powerful way to convey product benefits as long as claims are accurate and information is given in terms consumers can understand, such as equating light output to that of a 60-watt incandescent. Consumer research would be helpful in understanding what buyers do and don't know. Manufacturers can educate retailers, who can in turn help educate customers. There is a role for energy efficiency organizations to play here with both parties, as is already being done by DOE in collaboration with manufacturers and retailers through associations such as NGLIA, TINSSL, and the Retailer Energy Alliance and through DOE's Solid State Lighting program outreach through websites such as www.netl.doe.gov/ssl, articles in lighting magazines, hosting of national workshops, and participation in the Dallas Lighting Market and other trade shows.

In terms of program design, giveaways, coupons, utility mail-in programs, and other early market introduction programs that distributed CFL products outside normal retail channels experienced some backfire when consumers went to the store to buy more CFLs and found out what full price was; thus these types of programs should be avoided. Promoting LEDs as a technology purchase is a more realistic approach since buying LEDs will involve purchasing whole new lighting systems (i.e., whole fixtures), not just replacing a light bulb. Promoting LEDs this way will help overcome the cost barrier of these initially substantially more expensive products. CFL manufacturers cautioned that many people will not try a new product, no matter how much energy it saves, until the purchase price drops to a range near that of existing products providing similar functionality.

Conclusions

DOE is collaborating with industry to develop energy-efficient LED lighting products for general illumination. DOE identified several lessons learned from US experience with CFL lighting that could help smooth the market introduction of LED lighting. DOE and others are already applying these lessons to LED development:

- Form national collaborations – DOE is working with NGLIA, an alliance of lighting manufacturers, and IESNA, the standards body, to accelerate SSL development and standards.
- Support research and development – Congress has spent $60.75 million on funding for SSL from 2003-2007 compared to $4.3m for CFLs 1978-2000.
- Focus on niche applications - DOE is promoting the development of niche applications through research funding, demonstrations, ENERGY STAR, and design competitions.
- Develop performance standards – DOE is working with industry and standards organizations to fast track standards and ENERGY STAR criteria.
- Product testing is vital – DOE started the CALiPER program to independently test commercial products.
- Accurate reporting is needed – DOE uses websites, conferences, meetings, trade press articles, and fact sheets to keep stakeholders informed about technology developments and to make CALiPER testing and demonstration project results available.
- Do national promotion – DOE works with NEEP, CEE, TINSSL, REA, and others to share information and plan development efforts.
- Address fixture development issues – DOE is funding research and supporting industry collaboration and standards development to address technology and standardization issues.
- Use marketing to educate consumers – DOE is laying the ground work in collaboration with other industry partners to provide a consistent message and clear information to consumers as general illumination LED products become more available.

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