
2011 DOE Solid-State Lighting
MARKET INTRODUCTION WORKSHOP
July 12-14, 2011 • Seattle, Washington

# SSL MARKET INTRODUCTION WORKSHOP REPORT

Solid-State Lighting Portfolio
Building Technologies Program
Office of Energy Efficiency and Renewable Energy
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## 1. Introduction

More than 275 lighting leaders from across North America gathered in Seattle July 12–14, 2011, for the sixth annual Solid-State Lighting (SSL) Market Introduction Workshop, hosted by DOE. The diverse audience ranged across the spectrum: industry, government, efficiency organizations, utilities, municipalities, designers and specifiers, and retailers and distributors. The purpose was to share the latest insights, updates, and strategies for the successful market introduction of high-quality solid-state lighting products.

*Attendees listen to opening remarks at the sixth annual SSL Market Introduction Workshop, July 12–14, 2011, in Seattle, Washington.*

## 2. Pre-Conference Events

### 2.1 Tutorials

The two-day workshop was preceded by an optional half-day of free, beginner-level tutorials on July 12. Attended by more than 185 people, the tutorials covered the basics on LED lighting and were intended not only for those new to SSL, but also for those with limited SSL knowledge or in need of a refresher course.

Michael Poplawski of Pacific Northwest National Laboratory (PNNL) reviewed 18 key concepts for understanding LED lighting, from the physics of LED light production, to electric loads, to the difference between LED efficacy and system efficacy. LEDs are a narrow-band light source that can be made to emit white light in various ways; Poplawski noted their directionality and discussed such major issues as lifetime, marketing hype, and driver compatibility.

Lisa Pattison of SSLS, Inc., talked about the current status of OLED technology. She outlined the technology basics, including OLED physics and structure, and highlighted the unique features and advantages of OLEDs—such as transparency, flexibility, color tunability, and diffuse light. Pattison examined current OLED performance levels and compared them with projected targets. She reviewed the major barriers that need to be overcome, emphasizing brightness, stability, and cost.

Jason Tuenge of PNNL discussed DOE's CALiPER program, which tests market-available LED lamps and luminaires, focusing on the most recent test results for selected product categories. Noting a continuation of the steady increase in overall efficacy, he pointed out that Round 12 results confirm that LED recessed downlights and track lights are now able to provide high-efficacy alternatives to their traditional counterparts. Tuenge observed that the results of Round 12 were also encouraging for SSL A-lamps, which showed significant improvements over

previous rounds. He also reviewed Round 12 results for track heads, cove lighting, and T8 replacement lamps.

Bruce Kinzey of PNNL reviewed the real-world performance of LED lighting in DOE's GATEWAY demonstration program, focusing on what the aggregate results show about product performance and cost-effectiveness trends, as well as issues that warrant further study. Improvement in both performance and cost continues, as reflected by the increasing number of economically successful projects, but there is still plenty of misinformation in addition to performance issues. Kinzey concluded that LED retrofitting is not difficult to accomplish with most applications, but due diligence is the key to successful implementation.

Marci Sanders of D&R International described how attendees can best take advantage of DOE's rapidly growing Lighting Facts® program. She highlighted the key differences between DOE's Lighting Facts label and the new Federal Trade Commission lighting label. Sanders focused on the various Lighting Facts resources and tools, such as the searchable database, the Product Performance Scales, and the Product Snapshot. Stressing the importance of Lighting Facts partners, she noted that DOE has started an ongoing verification program to ensure that registered products continue to perform as claimed.

Eric Richman of PNNL discussed three key SSL standards from the Illuminating Engineering Society (IES) of North America and how they relate to the characterization and comparison of LED products. He explained that LM-79 describes how to perform reproducible measurements of LED luminaires and covers total flux, electrical power, efficacy, and chromaticity. LM-80 is an approved method for measuring lumen depreciation of LED light sources, arrays, and modules. The upcoming TM-21[1] standard uses LM-80 data to project the lumen maintenance of an LED source, which can then be used to project its expected lumen output as part of a system.

Kelly Gordon of PNNL reviewed DOE's various SSL online resources, focusing on where and how to access them quickly. Using DOE's SSL homepage as her starting point, she guided the audience through learning SSL basics, staying up to date on standards development, and identifying the latest R&D funding opportunities. Gordon highlighted the webpages of the CALiPER, GATEWAY, and Lighting Facts programs and the Municipal Solid-State Street Lighting Consortium. She also showed how to find a variety of related documents, such as white papers, technology fact sheets, and reports on past conferences.

[1] IES TM-21 was published in September 2011.

### 2.2 Walking Tour

The tutorials were followed by an optional evening walking tour of four LED lighting installations in Seattle, guided by Robert Sawyer of Seattle City Light. The first stop was the Hyatt at Olive 8, a hotel that has retrofitted more than 1,200 LED lamps, including dimmable PAR20s, MR16s, ceiling lights in guest rooms (PAR30s), and ballroom and ballroom pre-function area ceiling downlights (PAR38s). Annual energy savings is projected at nearly 170,000 kilowatt-hours (kWh). The second stop on the tour was the Triple Door/Wild Ginger restaurant, which installed 385 LED lamps in 2010 that were color-adjusted to provide welcoming overhead and mood lighting in the dining room and music lounge. Simple payback is estimated at 3.3 years without considering incentives, with an annual energy savings of nearly 114,000 kWh. The third stop was a Chipotle Mexican Grill restaurant, which was built in 2009 with 100-percent LED lighting in the customer area, including recessed and pendant applications. The LEDs above the food line are color-adjusted to highlight the offerings of the restaurant, which recouped its lighting investment in just 11 months. The tour's final stop was the Pike Brewing Company, where 50 LED MR16 lamps and 83 LED PAR20s were installed in track lighting in the museum lounge and dining room. Annual energy savings is estimated at more than 29,000 kWh, with a simple payback of 2.9 years before incentives.

*The Hyatt at Olive 8 hotel*

*The Triple Door/Wild Ginger restaurant*

*Chipotle Mexican Grill restaurant*

*The Pike Brewing Company*

## 3. Going Head-to-Head

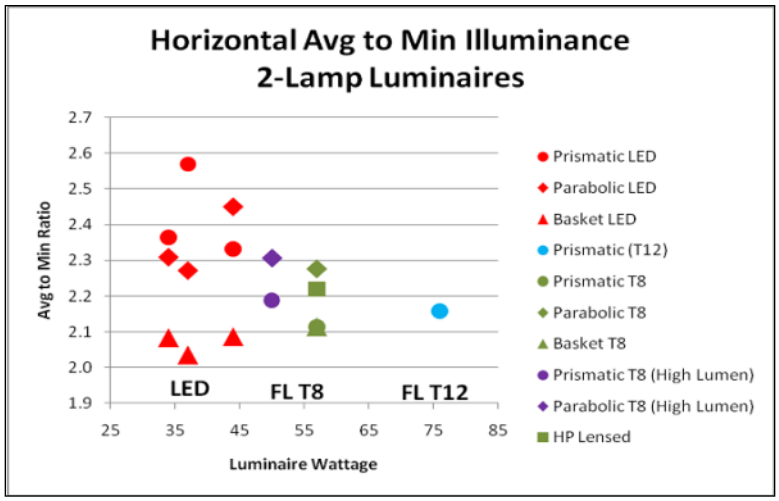
### 3.1 Welcome

On July 13, DOE SSL Portfolio Manager James Brodrick kicked off Day 1 of the workshop by introducing Seattle City Councilmember Bruce Harrell, who welcomed the audience to his city and noted that Seattle is in the process of aggressively converting all its residential streetlights to SSL, which consumes half the energy of the incumbent high-pressure sodium (HPS) system and is anticipated to save $2.4 million in annual energy usage. Brodrick cited the high influx of new LED lighting products coming onto the market, accompanied by a great deal of hype and misinformation, which has increased the need for accuracy. He noted the growing arsenal of available resources developed by DOE and its partners to address this need and help people make sound decisions about SSL in a confusing marketplace, and emphasized collaboration as key to accelerating SSL market acceptance.

### 3.2 Competing with Incumbent Technology

The first panel discussion, "Commercial Ambient Lighting: Can LEDs Compete?," was moderated by Marc Ledbetter of PNNL. He set the stage by noting that 2'x2' and 2'x4' troffers with fluorescent lamps dominate the U.S. commercial market and that, because of their high performance and efficiency, those lamps are stiff competition for the profusion of LED products that are intended to replace them but do not yet measure up. While most of this market focus has been on retrofits, as LED efficiency has improved and cost has come down SSL manufacturers have started coming out with integral replacement products, which compare much more favorably with linear fluorescent lamps. Instead of merely sticking LEDs into a troffer, these manufacturers have rethought the entire design of their integral luminaires in order to take better advantage of SSL's full potential.

Eric Richman of PNNL discussed a GATEWAY study of LED replacements for linear fluorescent lamps, in which fluorescent T8s and T12s were compared with selected high-performing LED replacement products. Although many of the T8 replacements have good efficacy and their lumen output is increasing overall, they still cannot match the light output of their fluorescent counterparts, and their cost is still comparatively high, which is why none of the LED products tested would have paid back within their 50,000-hour reported lifetime. Richman said that for spaces that are over-lighted, LED replacements may provide an effective solution at correct light levels but may still not make as much economic sense as low-wattage T8 high-performance lamps, which have a lifetime of 36,000 hours.




*Results of a GATEWAY study of LED replacements for linear fluorescent lamps show better workplane foot-candle uniformity from fluorescent lamps in prismatic and parabolic troffers.*

Representatives from two manufacturers then talked about their integral LED troffer products and the design thinking that went into making them. While conceding that the high performance of linear fluorescent products makes them "a more challenging target" than other traditional lighting technologies, Colleen Pastore of Philips Lightolier said that her company's Skyway LP integrated LED troffer fixture has an efficacy range of about 73 lumens per watt (lm/W) to 78 lm/W and is priced to achieve a three- to five-year payback in retrofit applications. She explained that costs were kept down by using common components and modules, evaluating a wide cross-section of LED sources, and minimizing the use of raw materials. Pastore also cited the use of an intelligent driver—which can be factory-tuned for different applications—as a key factor,

because it ensures minimal energy use for varied applications. “LEDs are rivaling fluorescents today and have only positive potential for the future,” she said.

Gary Trott of Cree LED Lighting Solutions stated that his company’s CR24 LED troffer series, which ranges in efficacy from 90 lm/W to 110 lm/W, is priced aggressively and can achieve payback in as little as two years for new construction. He said improving the design of the product, and cutting its price, required rethinking every aspect of the luminaire—from chip, to optics, to electronics, to thermal management, to mechanical design. Trott added that Cree’s CR6 LED series of downlights—an application where SSL has made early inroads because of its directionality—has already reached the inflection point where price is low enough and performance is high enough to cause a rapid increase in sales. “The time is now for LED commercial ambient lighting,” he said.

*Integral LED troffer luminaires from Cree and Philips on display.*

*Question-and-Answer Session*

In the Q&A session, Richman explained that dirt depreciation was not considered in the GATEWAY study, only straightforward lamp lumen depreciation. Pastore was asked whether she and her colleagues had thought of defining end of life more in terms of energy savings than in terms of lumens, and she said they’re looking at that right now, because the intelligent drivers this would require are already available. In response to a question about the return on investment for the CR24 LED troffer series, Trott said the payback can be anywhere from three to eight years, and would be around two years for a high-end office construction.

## 4. A Rising Tide


*Marc Maldoff of Lowe’s discusses LED replacement bulbs from a retailer’s perspective.*

The second panel, moderated by John Rivera of D&R International, discussed LED screw-in replacement lamps, which are entering the market in increasing numbers. Jason West of D&R International began with an overview of the May 2011 Lighting Facts Product Snapshot, which focuses on LED replacement lamps. LED replacement lamp light output has been rising steadily, but most A-shape and reflector LED replacement lamps do not yet meet the light output of high-wattage incandescent products. Even when light output is met, many LED products do not meet other performance equivalency metrics, such as color rendering index (CRI), correlated color temperature (CCT), and light distribution. West also noted that the payback period varies when compared to 60W incandescent lamps. LEDs pay back in more than six years because of a current average purchase price of about $40.

Kelly Gordon of PNNL reported on the results of CALiPER LM-79 photometric testing, carried out on a sampling of 33 LED replacement lamps purchased from eight major retailers in the summer of 2010. She noted that large disparities were found between high-performing and low-performing products, as well as wide differences among the retailers themselves, most of whom carried very low-quality products. Gordon observed that most of the LED lamps tested failed to meet basic performance parameters for use as replacements for incandescent or halogen lamps. In addition, differences were found among the manufacturers, some of whose products were very inconsistent across different products. "Obviously, it's in everybody's interest to sell products that will meet the customers' expectations," she said.

Marc Maldoff of Lowe's offered a retailer's perspective on LED replacement bulbs. He described how being a Lighting Facts partner has helped Lowe's hold its suppliers to a higher standard by requiring them to be Lighting Facts partners themselves, to provide LM-79 data for their SSL products, and to utilize the Lighting Facts label. Maldoff explained that this results in a level playing field for all products, easier product comparisons for retailers, and higher customer satisfaction for consumers. He observed that the best lumen outputs of the LED replacement lamps offered by Lowe's essentially doubled from the summer of 2010 to the summer of 2011, and described his company's efforts to educate consumers on available lighting options and the selection process.

**Lowe's Brightest LED Bulb Options-**
*July 2010 vs. July 2011*

| Bulb Type | CRI | | Lumens | |
|---|---|---|---|---|
| | 2010 | 2011 | 2010 | 2011 |
| A19 | 82 | 90 | 350 | 810 |
| PAR20 | 80 | 95 | 250 | 550 |
| PAR30 | 82 | 95 | 500 | 970 |
| PAR38 | 87 | 95 | 550 | 1100 |

*Between July 2010 and July 2011, the lumen outputs doubled across the brightest LED bulbs sold at Lowe's.*

*Question-and-Answer Session*

In the Q&A session, an attendee noted the gap between the top-performing and bottom-performing products and suggested the Lighting Facts program get more "teeth" to prevent this, prompting Rivera to explain that Lighting Facts does not set criteria and standards, but promotes truth in advertising. In response to a question of whether Lowe's sees a correlation between the highest quality and the highest price, Maldoff responded that there was. Another attendee asked whether Lighting Facts plans to use the Color Quality Scale (CQS) developed by the National Institute of Standards and Technology, and West said there are no concrete plans at this time. In response to the same question about CALiPER, Gordon said PNNL will keep an eye on the CQS and include it if and when it becomes an industry standard.

## 5. Partners in Promoting Energy-Efficient Lighting

### 5.1 The DOE Partnership Experience


*Bill Hamilton of The Home Depot emphasized the continuing need to educate consumers.*

The third panel, moderated by James Brodrick of DOE, highlighted partnership opportunities among DOE and utilities, regional efficiency organizations, retailers, designers, and others who are working together to advance market adoption of quality SSL products. Bill Hamilton of The Home Depot, a Lighting Facts partner, observed that LED products already account for nearly 10 percent of his company's retail light bulb business in those regions where there are utility rebates to offset the initial cost—although he emphasized that there is still a huge need to educate consumers, 80 percent of whom remain unaware of the upcoming lighting changes resulting from the Energy Independence and Security Act of 2007, with an equal percentage unaware of the benefits of SSL. Hamilton noted that The Home Depot is working on a multi-pronged educational program for its customers but said that retailers, utilities, manufacturers, and government all have to work together to educate consumers. "Education is paramount," he said. "It's the only way we're going to improve the adoption."

Jon Linn of the Northeast Energy Efficiency Partnerships (NEEP) discussed the DesignLights Consortium (DLC), which was launched by NEEP and has become a major resource for high-quality, energy-efficient commercial lighting design and information. He described how DLC's Qualified Products List for commercial-grade integral LED luminaires came about to help energy efficiency programs distinguish quality energy-efficient lighting products from the rest, and to help them determine whether SSL manufacturer claims are valid, how long the LED product will last, and how comparable it is to its conventional counterpart in terms of light output, color, and light distribution.

| | Product Category | Min Light Output | Zonal Lumen Requirements | Min Luminaire Efficacy | Allowable CCTs | Min CRI | Min LED Lumen Maintenance at 6000h | Min Luminaire Warranty |
|---|---|---|---|---|---|---|---|---|
| 1 | Outdoor Pole/Arm-Mounted Area and Roadway Luminaires | 1,000 lm | ≤100% 0-90°<br><10% 80-90° | 50 lm/W | <6500K | 50 | 95.8% | N/A |
| 2 | Outdoor Pole/Arm-Mounted Decorative Luminaires | 1,000 lm | 95% 0-90° | 40 lm/W | | 50 | 95.8% | N/A |
| 3 | Outdoor Wall-Mounted Area Luminaires | 300 lm | ≤100% 0-90°<br><10% 80-90° | 40 lm/W | | 50 | 95.8% | N/A |
| 4 | Parking Garage Luminaires | 2,000 lm | ≥20% 60-70°<br>≥15% 70-80° | 56 lm/W | | 50 | 95.8% | N/A |
| 5 | Fuel Pump Canopy | 2,000 lm | ≥40% 0-40°<br>≥40% 40-70° | 56 lm/W | | 50 | 95.8% | N/A |
| 6 | Track or Mono-point Directional Lighting Fixture | 250 lm | ≥85% 0-90° | 30 lm/W | 2700K 3000K 3500K 4000K 4500K 5000K | 75 | 95.8% | N/A |
| 7 | Refrigerated Case Lighting | ≥50 lm/ft**<br>≥100 lm/ft* | ≥95% 10-90° | 35 lm/W | | 70 | 95.8% | 5 years |
| 8 | Display Case Lighting | 50 lm/ft** | ≥95% 0-80° | 35 lm/W | | 75 | 94.1% | 3 years |
| 9 | Linear Panels (2x2 Troffers ONLY) | >3,000 lm | ≥50% 30-60° | 55 lm/W | | 80 | 94.1% | 3 years |
| 10 | High-bay & Low-bay fixtures for Commercial and Industrial buildings | >10,000 lm | ≥30% 20-50° | 60 lm/W | 2700K 3000K 3500K 4000K 4500K 5000K 5700K 6500K | 70 | 94.1% | 3 years |
| 11 | High-bay-Aisle Lighting | >10,000 lm | ≥50% 20-50°<br>≥30% 0-20° | 60 lm/W | | 70 | 94.1% | 3 years |

*The DesignLights Consortium's Qualified Products List currently covers 11 categories of LED lighting products.*

Dan Mellinger of Efficiency Vermont, a statewide energy efficiency utility, noted that two-thirds of the lighting energy savings they have achieved since 2009 has come from LED screw-base lamps. "LEDs are a huge part of my program right now, and it's come about rapidly," he said. Mellinger discussed the various ways his organization benefits from DOE's SSL program—from CALiPER and GATEWAY reports, to technology fact sheets, to being a Lighting Facts and L Prize® partner, to membership in the Municipal Solid-State Street Lighting Consortium and the Technical Information Network for Solid-State Lighting (TINSSL). He recommended that other programs emphasize quality in order to maximize savings and maintain customer satisfaction, and that they educate staff, partners, and customers on the technology and best practices.

Lighting designer Jeff Miller talked about how lighting designers are focused on the quality of light without regard to the technology used. "We need a diversity of choice, with solid, dependable, accredited products and methodologies, so that we can deliver the light that's appropriate to live in," he said. Miller predicted that a few years from now, consumers will not be talking about light bulbs in terms of their wattage, but rather in terms of the quality of the light they emit. He acknowledged DOE's contribution to advancing SSL technology, and as evidence of the widespread interest in the topic, he cited the high attendance at a series of regional workshops co-sponsored by DOE and the International Association of Lighting Designers to educate lighting designers about SSL.

*Question-and-Answer Session*

In the Q&A session, Mellinger was asked what might explain the success his program has had with SSL, given that most of the products in question are still quite expensive. He said environmental concern is very strong in Vermont, so there are a lot of early adopters in the state who do not necessarily focus on payback, plus his program also gave out substantial rebates to offset the cost. In response to a question as to whether the retail industry will settle on some kind of consistent color coding for signage and other in-store materials to help consumers better understand the various kinds of energy-efficient lighting products, Hamilton said The Home Depot is conducting focus groups in an attempt to standardize the color coding, but he doesn't think there will ever be commonality across all retailers. Miller was asked what he would like to see from SSL luminaire manufacturers that he isn't already seeing. He answered lower prices and confirmation of operation—e.g., will the product overheat in a ceiling, can it be replaced, will it disassemble, does it coordinate with controls, etc.

### 5.2 Recognition for Lighting Facts Partners

Brodrick concluded the first day of panel discussions by giving special recognition to nine Lighting Facts partners who exemplify how integrating the Lighting Facts program into their everyday business practices can help ensure that quality SSL products are available:

- Lowe's, for making Lighting Facts testing procedures a requirement for all SSL suppliers and incorporating LM-79 test data into its product evaluation process
- Efficiency Vermont, for being the first energy efficiency (EE) sponsor partner to register a program on the Lighting Facts EE Partner Resource, and for encouraging partners and customers to look for the Lighting Facts label
- The Sacramento Municipal Utility District, for using Lighting Facts when researching potential products for incentive programs, and for using the label to educate customers on the benefits of LED products

- Acuity Brands, for supporting the use of Lighting Facts for the commercial, industrial, institutional, and residential markets, and for using it to educate retail customers
- BetaLED, for stressing application-based performance evaluations to meet customer expectations, and for using the Lighting Facts label to enhance credibility with customers
- OSRAM Sylvania, for using the Lighting Facts label when introducing new products, and for including the label on all LED retrofit products, allowing consumers to compare information
- Satco, for submitting every LED product for a Lighting Facts label, and for being committed to educating customers about LED technology
- Grainger, for requiring all LED suppliers to take the Lighting Facts pledge, and for incorporating Lighting Facts into its corporate strategy
- The Home Depot, for requiring all suppliers to complete standardized quality testing and to provide a Lighting Facts label, and for being committed to educating the public on LED technology.

*Nine Lighting Facts partners earn special recognition. Accepting are (front row l-r): Tom Harold, Grainger; Mark Hand, Acuity Brands; Connie Samla, SMUD. Middle row: Brian Brandes, Satco; Jim Brodrick, DOE (presenter); Eric Haugaard, BetaLED. Last row: Bill Hamilton, The Home Depot; Marc Maldoff, Lowe's; Dan Mellinger, Efficiency Vermont; Makarand Chipalkatti, OSRAM Sylvania.*

### 5.3 Reception and Poster Session

Brodrick urged everybody to join the Lighting Facts program, and invited attendees to learn more at the evening reception and partner poster session. At the reception, attendees had an opportunity to browse posters highlighting various partnership opportunities and ask questions of the various poster presenters.

*Attendees network with SSL Lighting Facts partners at an evening poster session and reception.*

## 6. Lessons from the Real World

Moderated by Bruce Kinzey, the fourth panel represented large purchasers who shared perspectives on selecting and implementing LED products. Paul Kistler of the U.S. Navy described several Navy Technology Validation Program projects involving parking lot lighting, including two in Port Hueneme, California, and one in Pearl Harbor, Hawaii. The Navy is mandated to reduce energy use, Kistler explained, and even though the SSL payback periods were long for all three projects, they also want to extrapolate the knowledge gained to other

projects that had longer hours of use. Kistler noted that the security department also liked the quality and uniformity of the LED lighting. He reviewed the factors the Navy considers when evaluating LED lighting products for potential purchase—such as whether the manufacturer has LM-79 and LM-80 test data, whether the energy savings are due to the technology itself or from reduced light levels, and how easy the product is to maintain.

*Replacing HPS fixtures (left) with LED luminaires (right) in a U.S. Navy parking lot in Port Hueneme, CA, improved lighting uniformity and cut electricity use in half.*

Kevin Powell of the U.S. General Services Administration (GSA) discussed his agency's Green Proving Ground program, which tests and evaluates innovative energy-saving technologies and, to date, has done 72 projects that have incorporated some form of LED lighting. He pointed out that lighting accounts for nearly one-third of the energy use of commercial buildings, and talked about "smart" lighting's considerable promise, noting that it can facilitate energy savings through the use of controls and make maintenance easier by reporting lights that are malfunctioning. But Powell also talked about the challenges smart lighting faces, such as overcoming a high first cost. He said that lighting innovation is the key to meeting GSA's mandate of zero net energy by 2020, and that reducing the agency's lighting energy consumption 60 to 80 percent by then is a realistic goal.

Edward Smalley of Seattle City Light, who directs DOE's Municipal Solid-State Street Lighting Consortium, described his city's progress in its plan to replace 41,000 residential streetlights with LED fixtures. In addition to actual energy savings of 48 percent, he cited maintenance savings and improved safety from better lighting quality as among the driving forces behind the project, which began in 2007. Smalley discussed the luminaire selection process he uses and noted that SSL costs are constantly coming down, making the technology more and more affordable. He added that the use of controls, which Seattle is considering, has the potential to save even more energy. "LED street lighting has proven to be a significantly better light source in terms of expected maintenance, energy efficiency, and quality of light," he said.

*Question-and-Answer Session*

In the Q&A session, an attendee mentioned the high cost of erecting additional poles to get the right level of street lighting, to which Smalley replied that taking the time to find the right LED

fixture for the application can take advantage of the fact that SSL tends to have better uniformity than HPS. Asked about the use of DC constant current distribution for lighting, Powell said GSA has two projects piloting its use in the offing.

## 7. DOE's SSL Commercialization Support Plan

Marc Ledbetter previewed the proposed updates to the DOE SSL Commercialization Support Plan, which was originally drafted in 2005 and laid the groundwork for many DOE SSL programs, such as CALiPER, GATEWAY, and Lighting Facts. Among the proposed updates he discussed were integrating CALiPER with Lighting Facts, placing more emphasis on the commercial and industrial sectors, starting an OLED standards development effort, and placing more emphasis on educating electricians and contractors. Ledbetter said that many core programs will likely continue but will be reoriented to take the changes into account. He remarked that a final version of the revised plan is expected by fall 2011. "It's time to reset our course," he said. "We have a big boat to turn."

## 8. Defining Quality of Light

*Color quality panelists Maria Thompson of OSRAM Sylvania, Scott Rosenfeld of the Smithsonian American Art Museum, Daniel Salinas of Nelson Electric, and Chad Stalker of Philips Lumileds*

The fifth panel, moderated by Eric Richman, explored the issue of color quality. Maria Thompson of OSRAM Sylvania discussed defining the quality of light. She explained that color quality has two main aspects: chromaticity, which is the color of white light, and color rendering, which is the color of an object as illuminated by a light source. Thompson said that although chromaticity is mainly measured by CCT, it alone cannot communicate chromaticity when outside the black-body curve, which is why $D_{uv}$, which measures distance from the black-body curve, is also used. Thompson also delved into the subjects of color fidelity and color saturation, noting that while a high CRI means good fidelity, it does not necessarily mean good color saturation, because saturated red is not part of the CRI average. She said the CQS partly addresses this weakness of the CRI.

Scott Rosenfeld of the Smithsonian American Art Museum discussed his experience using LED lighting in retrofit applications. He noted that although a big selling point for LEDs is their lack of ultraviolet light (UV), most art museums use incandescent lighting and thus are not concerned about UV. Rosenfeld cited the controllability of LEDs as being of significant benefit to museums but noted that the screw-base sockets at his facility limited the use of controls. He said that with LEDs he can save energy by reducing voltage and still maintain a suitable color temperature. Rosenfeld mentioned that he needs lamps with a broad range of distribution, which he managed to find by reviewing many different LED products. He cautioned that even if the lamps perform

beautifully today, it is important to determine in advance whether they will maintain that performance over time.

*Smithsonian American Art Museum gallery wall illuminated with LED retrofit lamps. The wall to the right is illuminated with standard PAR30 and PAR36 incandescent lamps.*

Daniel Salinas of Nelson Electric approached the topic of defining the quality of light from the points of view of a lighting designer and an electrical contractor, as he wears both hats professionally. He said that if LED luminaires from various manufacturers are being used on the same project, color uniformity is a critical consideration, and differing control requirements can cause installation conflicts and confusion. Salinas suggested using the same manufacturer's product for similar applications, to minimize any variance in LED color or distribution. He also suggested establishing the acceptable amount of color shift for the project in question and making it part of the binning requirements. Salinas cited accessibility as a major installation consideration, and stressed the importance of ensuring adequate ventilation.

Emphasizing that the quality of light is "more complex than just lumens," Chad Stalker of Philips Lumileds discussed the various performance drivers for LED quality of light. "With light, there are human, economic, and architectural factors," he said. Stalker observed that LEDs can support the broad color spectrum needed for different applications and noted that natural colors render best under sources that mimic natural light. He remarked that staying within three MacAdam ellipses ensures color consistency between light sources, because the human eye cannot detect changes in color in that range. Stalker advocated testing and binning LEDs at operating conditions in order to eliminate unknowns, simplify the design process, and lower costs.

*Question-and-Answer Session*

In the Q&A session, an attendee asked about contractors pricing jobs higher to allow for return visits to prove that a problem, such as driver failure, was not a contractor error. Salinas agreed this is an issue and said that a lot of failures are caused by a lack of education and understanding, and that too many failures will result in increased installation costs. Another questioner said the idea of "color in context" might be slightly overlooked—in a museum or lobby, for example, tight lighting requirements are needed, and for other applications, such as exterior lighting, the spec could be looser, thus bringing a cost benefit. Stalker agreed that in talking to end users, he and his colleagues indeed see more latitude in this regard. He said that is why a

three-step MacAdam ellipse is generally the tolerance limit for interior applications, while outdoor applications can tolerate a five-step MacAdam ellipse.

## 9. In the Driver's Seat


*Moderator Michael Poplawski kicks off a panel discussion on issues surrounding driver design and performance.*

The sixth panel reviewed the challenges involved in designing LED driver solutions that have long lifetime, low flicker, and good dimming compatibility. Moderator Michael Poplawski discussed the increasing attention focused on driver-related performance issues, which involve efficiency, dimming, compatibility with controls and transformers, retrofit challenges, power quality, and color uniformity. "We want to try to improve the understanding of the range of driver performance, and the associated tradeoffs," he said.

Matthew Reynolds of National Semiconductor said innovation—especially with the drive and control of the LED light source—is key to driving the evolution of the still-emerging SSL market. He remarked that although the current focus is on using LEDs to replace and retrofit existing lighting installations, this focus will shift to developing intelligent lighting systems in order to fully realize system efficiency savings. Following that shift, Reynolds added, will be an emphasis on leveraging the controllability of LEDs—for example, tuning the color and controlling the color temperature to optimize the lighting in a particular space. He said electronic drivers and controls will be the keys to unlocking and leveraging the benefits LED light sources offer over all other light sources. "We want to create an SSL system that's as good as, or better than, the incumbent system," Reynolds said.

Julian Zhu of NXP Semiconductors focused on dimming, specifically line voltage, the most popular dimming method. He observed that when using line voltage dimmers, it is more difficult to dim an LED lamp or luminaire than an incandescent lamp. Zhu said line voltage dimmers add design complexity to LED drivers, which can cause the lamp or luminaire to flicker if they are not designed properly. He discussed a number of specific dimming challenges: for example, in order to support the reliable, flicker-free operation of Triac dimmers, the LED driver has to provide the latching and hold current when the system current is not enough, but this adds bleeding loss to the driver, thus making it more challenging to achieve high efficiency.

Pantas Sutardja of Marvell Semiconductor discussed design for high-quality and low-cost SSL with power factor correction. He said that lifetime output control increases the cost slightly, because the feedback sensor design needs to be robust against shading and reflection, but that most of the other costs can be absorbed into the LED driver design. These other costs include the final driver controlled by output voltage and power handling spec, as well as sophisticated features provided by control and sensing circuitry. Sutardja said that high CRI and the desired CCT can be achieved by dual string color mixing, and well-behaved dimming can be made available at almost no extra cost, but driver manufacturers need high sales volume to make this

economically feasible. “We’re really close to having all these things available in the near term,” he said.

*Question-and-Answer Session*
In the Q&A session, an attendee pointed out that the issue of intellectual property had not been addressed. Sutardja agreed, calling the issue “a minefield” and saying that one ends up having to negotiate with the different sources and work out cross-licensing issues. Another questioner wondered whether, since operating conditions for the various lighting applications can differ so widely, there could be minimum performance levels for drivers to help lighting designers and manufacturers pick the right driver for a given application. Reynolds said that sounded more like a power-supply solution than a driver solution and would be very difficult for driver manufacturers to do.

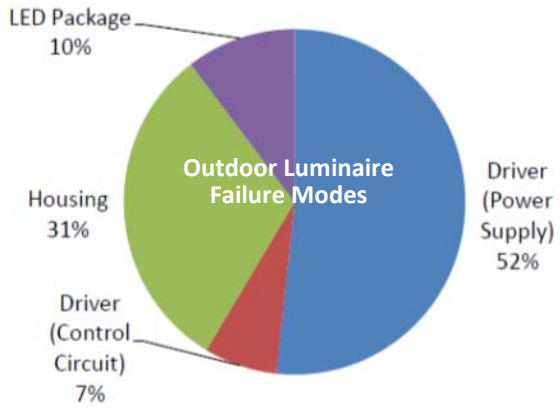
## 10. The Question of Lifetime


*Reliability and lifetime panelists Marc Ledbetter of PNNL (moderator); Fred Welsh, Radcliffe Advisors; Terry Clark, Finelite; and Steve Paolini, Lunera Lighting.*

The seventh workshop panel, moderated by Marc Ledbetter, focused on LED product reliability and lifetime. Emphasizing a system approach to reliability, Fred Welsh of Radcliffe Advisors gave an update on revised recommendations that were published in June by a working group he chairs under the auspices of DOE and the Next Generation Lighting Industry Alliance. The group recommends $L_{70}/B_{50}$—the point in time when 50 percent of the products have fallen below 70 percent of the initial light output for any reason—as the standard way to define SSL lifetime. Welsh stressed that this definition goes beyond gradual lumen depreciation of the LEDs to include any other mechanism that lowers the light output. But since demonstrating $L_{70}/B_{50}$ is complicated and costly, the working group recommends that lifetime be an optional metric on the Lighting Facts label, which could instead show lumen depreciation, a warranty, or a lifetime estimate based on accelerated testing of components.

Terry Clark of Finelite, a member of the working group, focused on the issue of color shift over time. He explained that although it was not part of the standard lifetime definition the group recommended, it is of paramount importance for some applications. Clark reviewed the known causes of color shift in luminaires, which is characteristic of most light engines, including metal halide, incandescent, and fluorescents. What makes it so critical, he said, is that its causes with LEDs are not well understood, and testing shows that color shift in LED-based luminaires can be so pronounced as to constitute failure to an end user. Clark said a lot more work needs to be done on the issue, which is a complex one. “We don’t have a great vocabulary or a common, shared way to describe color, and describing the shift over time is really a challenge,” he said.

Stressing the importance of reliable design, Steve Paolini of Lunera Lighting reviewed the various components of a luminaire that can affect its lifetime. He said that in a well-designed LED luminaire, the LED current is protected from electrical mains transients, and the LED junction and components are kept below the maximum tolerable temperature. Paolini observed that the demand for long life is partly driven by SSL's high initial cost, but long life increases the price because it entails more costly components, requires testing, and is backed up by a warranty. He emphasized that the lifetime required of an SSL product depends on the application, with some—such as those where maintenance is difficult and costly (e.g., bridge lighting)—needing longer lifetimes than others. "Having a shorter-life product may be a good tradeoff," he said.




*Paolini discussed the distribution of failures in 34,000 operating hours for a family of outdoor luminaires. Total number of failures was 29, or 0.56% of installed base of approximately 5,400 fixtures.*

*Source: Appalachian Lighting Systems*

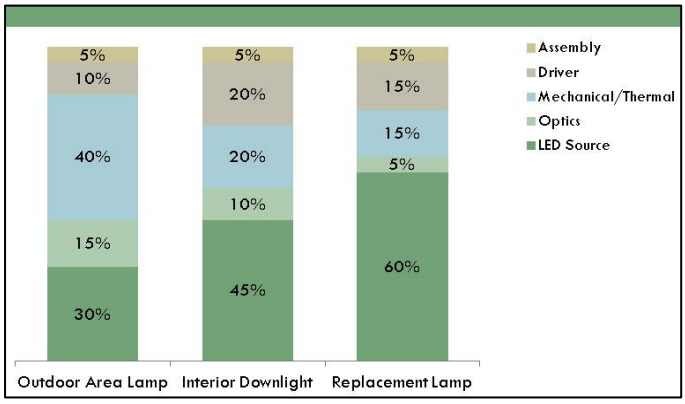
*Question-and-Answer Session*

In the Q&A session, an attendee made the point that long lifetimes are claimed for LED luminaires that are used in climate zones with low average temperatures but brief periods of very high temperatures, and asked whether there is a way to figure out how much damage is done to the luminaire during those brief high-temperature periods. Paolini replied that the manufacturer should give a maximum operating temperature for the product. With regard to LM-79 tests, another questioner asked what the balance should be for the number of hours of testing needed to characterize an SSL system. Clark said it is different for replacement lamps than for, say, outdoor luminaires. "I think we have to break it into segments," he said. In response to a question about adding a humidity component to the lifetime equation, Welsh said that generally some type of sealing is used to protect outdoor luminaires against humidity, which can be a cause of failure but "we don't know how to project that into lifetime."

## 11. SSL Product Price

The workshop's final panel, moderated by James Brodrick, shared DOE's cost expectations for LED packages and luminaires, discussed technology changes that are driving prices down, and addressed performance and price tradeoffs. Reviewing cost trends, Fred Welsh said that high first cost is the most frequently cited impediment to SSL adoption, and that although improvements in performance help to justify some of that higher cost, first costs have to come down to facilitate wide-scale market acceptance. He predicted that the price per kilolumen (klm) in 2012 will be half of what it was in 2010, and that reaching the target of $1/klm by 2020 will make SSL very competitive. Welsh emphasized the need to address all the components of a luminaire, not

just the LEDs, in order to realize significant cost reductions. He noted that there are two emerging approaches to cost reduction: modularity and more integrated designs. “Innovations are what drive costs down, to a large measure,” Welsh said.




*Cost breakdown of three types of LED luminaires. Source: 2011 DOE Roundtable and Workshop Consensus*

Mike Watson of Cree offered a manufacturer’s perspective on cost-reduction strategies. He noted that LED lamp costs have dropped dramatically over the past five years, and the trend should continue. But Watson said the current focus on LED cost is misplaced, because improving LED lamp performance will yield greater cost reduction than optimizing manufacturing or individual LED lamp price, since it will allow for the use of fewer LEDs per package. As an example, he described Cree’s first-generation 650-lumen, 12-watt LR6 downlight, which had 42 LEDs and wholesaled for more than $100 when it appeared in 2007. Working from the first-generation product, Cree engineered the costs down to produce the second-generation 575 lumen, 10.5-watt CR6, with eight LEDs and a retail price of $50, which came out in 2010.

Mark Hand of Acuity Brands talked about how the correct specification can reduce the cost of SSL. He raised the question of whether customers expect longer life, better color quality and distribution, less energy consumption, and more control from LED luminaires because of their high price—or whether their price is high because customers expect such high performance. Emphasizing that many SSL systems are over-specified for the application, Hand examined a number of lighting parameters to show how they each allow considerable leeway, depending on the application. For example, while 50,000-hour lifetimes may be suitable for applications where the lights are operating 24/7, shorter lifetimes may make more sense for less-intensive applications and can lower costs by allowing the LEDs to run hotter, which can result in more lumens and fewer LEDs.

*Question-and-Answer Session*

In the Q&A session, an attendee made the point that when looking at parallels to other industries, cost is a huge issue at first but comes down, though it never becomes as cheap as the incumbent technology because manufacturers add other features. The panel was asked where the point will be for SSL where the cost comes down enough so that it stops being an issue, or where other features are added that justify the cost. Hand said that when SSL products are about 1.2 times the cost of the incumbent technology, controls and extra features will be added that justify the price. Another questioner wondered whether it would be feasible for U.S. utilities to try doing what some utilities in Europe do: namely, give customers the energy-efficient lamp at no upfront cost,

but have them buy the lamp back by paying slightly extra each month for a period of time. Watson called that "a good money proposition" and said utilities here should definitely "get into that business."

## 12. Conclusion

Brodrick concluded the workshop by thanking participants for their input and participation and noting that presentations and materials would be posted online (www.ssl.energy.gov/seattle2011_materials.html). He added that the next DOE SSL workshop is in February 2012—the ninth annual Solid-State Lighting R&D Workshop—and also encouraged attendees to stay apprised of DOE SSL program activities by visiting www.ssl.energy.gov.

After the workshop ended, attendees got a chance to see some of Seattle's LED street lighting installations firsthand on a guided bus tour, which unofficially kicked off the next day's Municipal Solid-State Street Lighting Consortium's one-day regional workshop. Hosted by Seattle City Light, the bus tour was led by Edward Smalley, who shared lessons learned. Attendees visited and evaluated a number of residential and arterial LED streetlight sites throughout the city, and in some instances were able to compare the LED streetlights with the incumbent HPS street lighting.

## APPENDIX: 2011 SSL Market Introduction Workshop Participants

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