SOLID-STATE LIGHTING R&D WORKSHOP REPORT

Lighting Research and Development
Building Technologies Program
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

March 2011

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1. Introduction

More than 350 participants turned out for the eighth annual SSL R&D Workshop in San Diego.

More than 350 lighting technology leaders gathered in San Diego February 1–3, 2011, to participate in the eighth annual Solid-State Lighting (SSL) R&D Workshop hosted by the U.S. Department of Energy (DOE). Researchers, manufacturers, and other industry insiders and observers joined DOE to share perspectives on the rapid evolution of SSL technology. Titled "Transformations in Lighting," the workshop provided a forum for building partnerships and sharing strategies for continuing advances in high-efficiency, high-performance SSL technologies.

2. Redefining Lighting

2.1 Welcome

DOE SSL Portfolio Manager James Brodrick kicked off the workshop by noting the growing number of applications for which LED lighting products are already cost-competitive, but he stressed the considerable potential for further improvements in efficiency and quality. He characterized OLED technology as poised to make the critical transition from prototypes to marketable products. Brodrick emphasized the tremendous opportunities offered by SSL and urged attendees to take advantage of the technology's unique potential by "thinking outside the bulb" in terms of such things as new form factors and innovative approaches to lighting systems.

2.2 Speeding up Market Adoption

Keynote speaker Greg Merritt considered what is needed to advance the SSL Revolution.

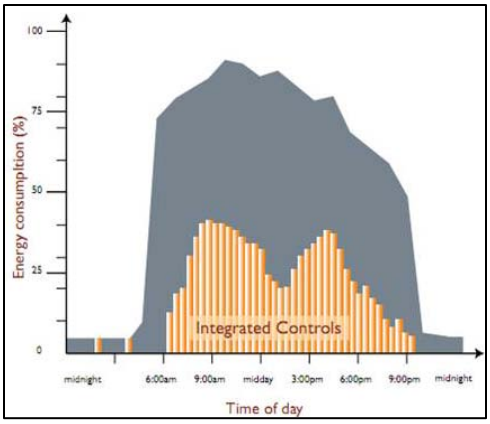
Keynote speaker Greg Merritt of Cree, Inc., presented his views on where the SSL industry should focus to accelerate market adoption and realize significant energy savings. He said that although the LED revolution is already happening, "we are just at the beginning." To accelerate adoption, industry needs to provide solutions that are better than traditional lighting. Merritt stressed the need to reduce the cost of LED lighting and gave an example to illustrate how system improvements lead to reduced costs — comparing a 2006 product with 42 LEDs and a comercial wholesale price of $100 with a 2010 product with eight LEDs and a retail price of $50. He concluded that more focus is needed on system-level innovation, and that ease of integration is crucial to accelerating market adoption.

2.3 SSL Past, Present, and Future

A panel of speakers, moderated by Brodrick, discussed the status of SSL technology today as well as potential future directions. Marc Ledbetter of Pacific Northwest National Laboratory (PNNL) opened the panel by sharing insights gained through DOE's CALiPER and GATEWAY programs, noting how these issues impact market acceptance. For example, CALiPER testing of LED T8 replacement lamps shows steady improvement in efficacy, yet major performance challenges in terms of output, distribution, and color quality remain. Ledbetter highlighted two recent GATEWAY projects that demonstrated notable progress in color quality, as LED lighting solutions met the stringent needs of a museum and high-end hotel. His final observations focused on GATEWAY analysis of occupancy controls; preliminary findings point to both early implementation problems as well as considerable promise to boost energy savings for outdoor LED luminaires.

Mark Hand of Acuity Brands Lighting shared his perspective on market barriers and priorities for SSL. He explored LED street lighting issues (pole spacing and costs, and the effect on glare) and asked, "Is the current LED architecture moving in the right direction?" He also examined the use of broad-spectrum versus yellow light sources, noting that the former has the potential to deliver better light with fewer lumens and significant energy savings, but that more research is needed. He concluded with a discussion of lifetime, calling for more reliability data (for all luminaire components, not just the LEDs) and consistency in terminology.

Jim Anderson of Philips Color Kinetics advocated the use of "smart lighting" for accelerating the market adoption of SSL and increasing energy savings. Citing the inherent controllability of LEDs as well as the low cost of adding a photo cell or occupancy sensor to a luminaire, he suggested that the convergence of SSL, sensors, controls, and networking offers the potential to significantly extend the energy-saving potential of SSL. He listed multiple barriers — including cost, complexity, and lack of interoperability — but noted "we have a lot to gain" by spending more time and money advancing smart lighting controls.



Integrated lighting controls can reduce energy use significantly.

Question-and-Answer Session

Asked whether reducing the weight of the LED luminaires would lower the cost of the pole in street lighting applications, Hand said only by a relatively small amount. In response to a question about whether LED lighting systems will always be limited to being designed to work with legacy systems, Anderson said that although there is a big opportunity to progress to systems designed specifically for SSL, there is such a huge installed base that consumers — particularly on the residential side — will be resistant to wholesale changes such as having to swap out their dimmers. Another participant asked Ledbetter to explain how LED lighting can reduce damage from ultraviolet light. He said LEDs emit very little ultraviolet and infrared light, both of which can damage museum artifacts, but he noted that artifacts can also be damaged by wavelengths in the visible range.

2.4 Novel Lighting Concepts

The panel discussion on novel lighting concepts for large interior spaces, moderated by Norman Bardsley of Bardsley Consulting, was kicked off by Terry Clark of Finelite, Inc. Clark's presentation looked at what is holding back volume sales of general-purpose indoor LED luminaires for offices and schools. He pointed out that competing products — namely, super T8 and T5 fluorescent lamps — are cheap, efficient, long-lasting, easy to maintain, and widely available, and that the energy savings from switching to SSL are not likely to offset these advantages. He closed with an analogy, saying that if LEDs are the equivalent of the ice cream in an ice cream shop, then the cup and the cone — equivalent to the driver and the PC card — are costing more than the ice cream and should be a major R&D focus.

Kieran Drain of Rambus Inc. discussed his company's efforts to apply LED backlighting technology to general lighting, using edge-lit LED light extraction technologies. He described how the use of discrete optical elements — tiny microlenses built into the panel — can control the light and the angle at which it is extracted. This can reduce glare and allow for fewer LEDs. Drain called the deployment of these microlenses "building intelligence into the mold," which he said reduces the cost of the product. "It is not the cost per lumen that is important, but the cost per lumen that reaches the desired location," he said. Drain pointed out that edge-lighting technology has been proven with flat-panel TVs and that his company is simply changing the application.

Jeannine Fisher of Acuity Brands Lighting discussed the opportunities and challenges for OLED lighting in large interior spaces. She noted that such spaces are well-suited for OLEDs because they have many surfaces and are ideal for diffuse lighting. Fisher said manufacturers should take advantage of the novel form factors offered by OLEDs — which can come in virtually any shape — as well as their soft light. She also noted that OLED technology allows for sophisticated digital controls as well as different ways to distribute power to buildings. With OLEDs, Fisher said, "The occupant can have a relationship with the light source that transcends what we are accustomed to."

Question-and-Answer Session

In response to a comment that the "tsunami of LED products" coming onto the market suggests we will end up with an LED "monoculture," Clark disagreed. "I don't think SSL will turn everything on its head for decades," he said, adding that he expects we will have many different types of light sources to choose from for quite some time. Another person asked whether it will be realistic to control directionality in real time, to which Fisher replied that in terms of general lighting design practice, the ability to change light distribution from a single source would be very desirable and would bring a higher level of functionality. Drain was asked which was more efficient for general-illumination purposes, direct lighting or edge lighting. He said that edge lighting "changes the viewing experience" by permitting the use of fewer LEDs, because they can be brighter than with direct lighting and do not require such things as diffusers, which decrease efficiency.

3. DOE SSL Multi-Year Program Plan (MYPP)

3.1 Updating the MYPP

Fred Welsh of Radcliffe Advisors previewed the proposed updates to the DOE SSL R&D Multi-Year Program Plan (MYPP), including feedback from the fall 2010 roundtable discussions on R&D priorities. He noted that the likely MYPP emphasis for 2011 includes pursuing novel design approaches to take advantage of LED technology's special characteristics; moving on to larger areas and practical luminaire designs for OLEDs; and emphasizing color quality, lifetime, and intelligence in addition to efficacy, in order to promote market acceptance.

3.2 Participant Input to DOE R&D Priorities

On Days 2 and 3, workshop participants divided into separate LED and OLED track sessions to explore the proposed priority tasks from DOE's updated SSL R&D MYPP. These breakout tracks are part of DOE's annual, ongoing R&D planning process, which includes structured dialogue with SSL stakeholders. In November 2010, DOE invited SSL technology experts to participate in roundtable discussions to advise DOE on priority research needs to advance SSL products and recommend updates to the 2010 MYPP. The outcomes of these roundtables[1] were presented for further discussion in the LED/OLED track sessions at the San Diego workshop. The recommendations from these track sessions will inform the final updates to the 2010 MYPP, which DOE expects to publish in April 2011, and will guide DOE and the National Energy Technology Laboratory (NETL) in developing upcoming R&D competitive solicitations. DOE expects to issue the next round of competitive solicitations in late summer 2011.

In the workshop track sessions, invited speakers from the November roundtables provided brief presentations to introduce the key topics and issues for discussion. LED speakers included Mike Krames of Soraa, Inc.; Jeff Tsao of Sandia National Laboratories; Bob Karlicek of Smart Lighting Engineering Research Center, RPI; and Fred Maxik of Lighting Science Group. On the OLED side, the speakers included Ching Tang of the University of Rochester, Joe Shiang of GE Global Research, Mathew Mathai of Plextronics, Franky So of the University of Florida, Tom Munters of Philips, and Mike Hack of Universal Display Corporation.

The Day 2 LED track session explored such issues as novel architectures and materials for reducing droop, new packaging and materials, and integrated functionality. The Day 2 OLED track session addressed such topics as methods for improving light extraction, extending lifetime, and increasing brightness. Day 3 track sessions enabled attendees to delve deeper into Day 2 topics, discussing key issues and how they relate to the proposed priority tasks from the updated MYPP.

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[1] Twenty-nine technology experts participated in DOE's November 2010 roundtable discussions. The report, *Roundtable Discussions of the Solid-State Lighting R&D Task Priorities*, is posted on the DOE SSL Web site at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl-rd-roundtable-report_jan11.pdf .

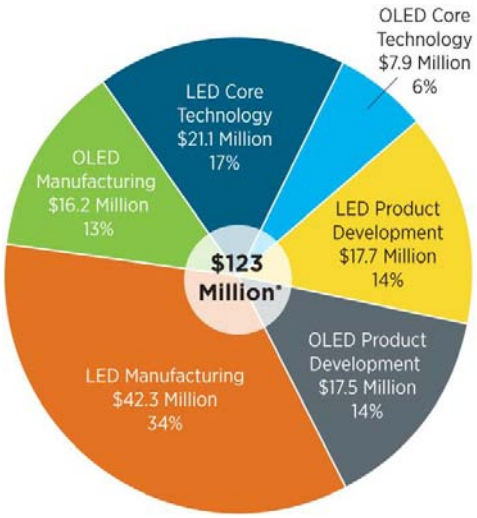
4. DOE SSL R&D Program

4.1 How to Prepare a Comprehensive Proposal

Joel Chaddock of NETL reviewed the DOE selection process for funding SSL R&D projects and provided guidance on how to put together a comprehensive proposal for DOE funding. He outlined the process of solicitation development, described how proposals are evaluated in three stages, and led the audience step-by-step through the submission process. To improve proposal effectiveness, Chaddock advised that applicants clearly describe the proposed research and goals, provide realistic milestones, and thoroughly address all aspects of the evaluation criteria.

4.2 Program Update

Brodrick presented an overview of the DOE SSL R&D portfolio funding and areas of focus. He noted that of the nearly $123 million allocated to active projects in 2010, $79 million went to industry, $24.1 million to small business, $10.4 million to academia, and $9.3 million to national laboratories. LED projects received $81.1 million of that money, and OLED projects received $41.6 million.



*A breakdown of DOE SSL R&D funding in 2010, by program pathway (*figures are rounded).*

From left: Jim Brodrick with R&D achievement award representatives: Mike Hack of UDC, Steve Allen of OSRAM Sylvania, Yongchi Tian of Lightscape Materials, and Monica Hansen of Cree

Brodrick gave special recognition to four project teams that made significant contributions to SSL R&D goals in 2010:

- Universal Display Corporation
- OSRAM Sylvania
- Lightscape Materials, Inc.
- Cree, Inc.

4.3 Invited Presentations on Significant DOE SSL R&D Projects

The workshop highlighted five R&D projects that are tackling particularly tough challenges with the potential for game-changing results:

Florian Pschenitzka discussed how Cambrios Technologies Corporation is working to reduce OLED costs — both cost of material and ownership — and to improve OLED efficiency.

Cambrios is substituting silver nanowires for indium tin oxide (ITO) to form the electrode, in conjunction with a suitably matched hole-injecting material made by Plextronics, Inc. Pschenitzka explained that in addition to the high cost of ITO itself, the current method of depositing it by sputtering is an expensive and energy-intensive process, and no direct patterning is possible. In contrast, his method utilizes an inexpensive and reliable coating technology and allows direct patterning. He described how planarization is carried out by varying the properties of the material used for the hole-injecting layer and noted that the proper choice of solvent system and additives resulted in a big improvement in microscopic coating quality. Due to scattering of the layer, more light will be coupled out and the efficiency of the OLED increases.

Yongchi Tian described Lightscape Materials' research to develop lower-cost, higher-efficiency downconversion materials for use in white LEDs. Because of the lack of phosphors that meet the need for high efficiency at high power and offer appropriate luminance performance, Tian's team is working to develop nitride (red) and oxynitride (green) phosphors for SSL. The goal, Tian said, is a quantum yield of 90%, a thermal quenching loss of less than 10% at 150ºC, luminescence maintenance of more than 90% after 5,000 hours, and a scattering loss of less than 10%. The achievement of these goals, he said, would help address three key SSL issues: color, lifetime, and stability.

Decai Sun presented an overview of Philips Lumileds Lighting's efforts to achieve an efficacy of 130 lm/W with a light output of 1,000 lumens in a warm-white LED. He reviewed the four key areas of high-power LED development: epitaxy and materials, chip design, phosphors, and package. Sun described phosphor technology advances that have resulted in tight color distribution, color stability at high temperatures, higher efficacy and flux, and other improvements. He explained that package extraction efficiency was improved by reducing optical loss and increasing extraction efficiency. Sun said that to date, the prototype his team has developed has achieved 100 lm/W with more than 800 lumens, at CCT under 3,000K and CRI over 80.

Abhinav Bhandari talked about product development at PPG Industries (teamed with Universal Display Corporation) to develop a low-cost, integrated glass substrate for OLED general illumination. He provided a status update on the project's four major tasks: anode layers benchmarking, low-cost anode layer coating process development, light extraction layers and process development, and prototype OLED panel fabrication. Explaining that PPG produces coated thin sheet glass for the architectural industry at a high volume using large-area vacuum thin film deposition technology, Bhandari described how this large-area glass technology may be used to make an OLED substrate with lower-cost "float" glass, coated with an anode layer and light-extraction layers. He explained that this approach may achieve a much lower-cost integrated substrate than the current technology, which uses costly coated display glass.

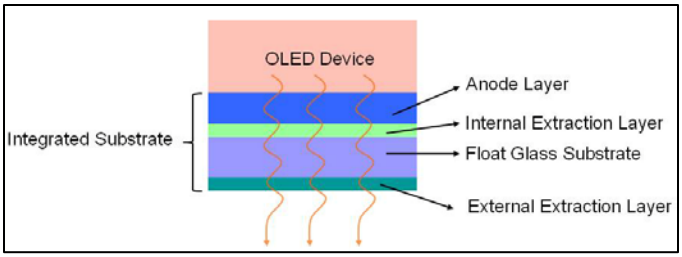


Diagram of PPG Industries' low-cost, integrated glass substrate for general-illumination OLEDs.

Eric Teather discussed how WhiteOptics is working to develop an efficient, low-cost composite reflective coating for light fixtures that improves overall brightness and efficiency. He noted that the coating is based on a flash-spun polymer fiber, and that to date it has achieved a reflectance of 97%, which increased the light output in a cavity-mixing downlight LED fixture by 16% over 89% reflective paint. The goal, Teather said, is to achieve 98% reflectance with a lifetime of at least 50,000 hours under expected LED system thermal and environmental operating extremes. He described the accelerated durability testing that is being conducted in order to ensure that the prototype materials can meet this goal.

Keith Cook of Philips wrapped up the day with a short presentation on the Next Generation Lighting Industry Alliance (NGLIA), an alliance of for-profit corporations formed to accelerate SSL development and commercialization through government-industry partnership. Cook described the alliance efforts to advance SSL and invited attendees to join and participate.

4.4 Poster Session for All Current DOE-Funded SSL R&D Projects

An evening reception sponsored by the NGLIA featured detailed posters of all current DOE-funded SSL R&D projects. The session provided attendees with additional opportunities for discussion, information exchange, and potential partnering. The 2011 Project Portfolio provides more information on each of the current DOE SSL projects.

An evening poster session and reception gave attendees the opportunity to examine details on current DOE R&D projects.

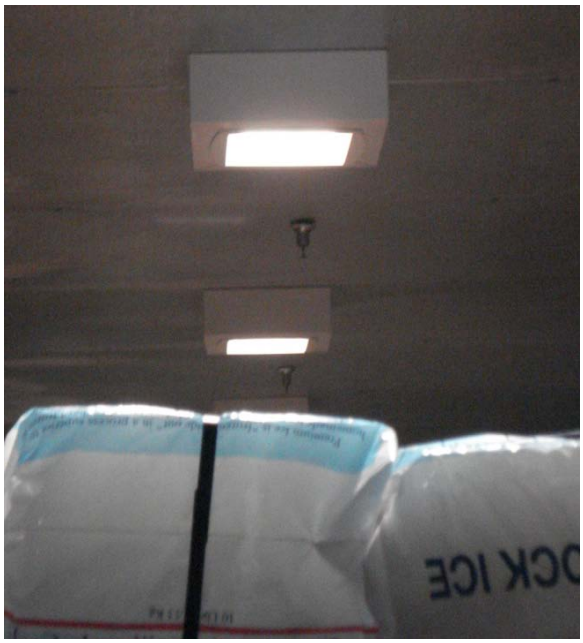
5. SSL in the Real World

5.1 Local LED Lighting Tour

Day 1 closed with an evening LED lighting tour sponsored by the California Center for Sustainable Energy (CCSE), in which more than 50 attendees participated. The first stop was the San Diego Energy Resource Center, a joint program of the CCSE and San Diego Gas & Electric. Here attendees saw a display of the advantages of LEDs over traditional lighting technologies as well as a comparison of the power consumption of incandescent, CFL, and LED sources.

The second stop on the tour was a recently opened Albertsons grocery store featuring LED lighting in a number of areas. Attendees noted the excellent color rendering of the LED refrigerated case lighting and learned that the LED lighting in the frozen food aisle is equipped with motion sensors that allow for dimming down to 20% of peak output when no customers are present. Participants were also invited to see the LED downlight fixtures used in the store's walk-in freezer areas.

Frozen food cases sport LED lighting and motion sensors that dim to 20% output when the aisle is unoccupied.



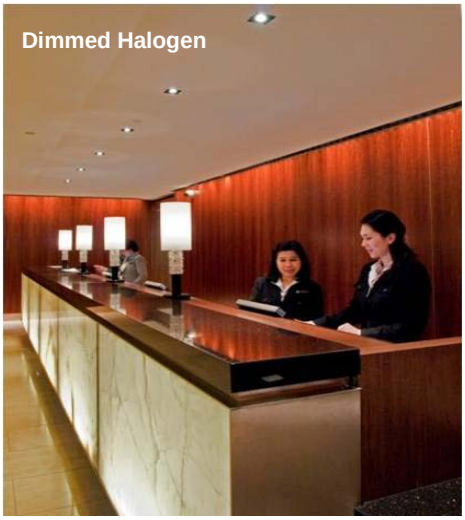
LED downlights illuminate an Albertsons walk-in freezer area.

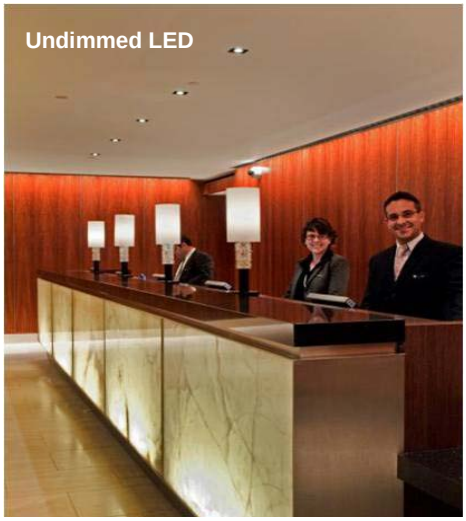
5.2 Lessons from the Field

A panel discussion shared varied perspectives on lessons learned from recent real-world LED lighting installations. Moderated by Bruce Kinzey of PNNL, the panel began with Scott Rosenfeld, a lighting designer with the Smithsonian Institution in Washington, D.C., who reported on his experiences using LED products to light exhibits at the Smithsonian American Art Museum and the Renwick Gallery. These two Smithsonian museums are participating in a GATEWAY project to demonstrate the suitability of SSL products in the museum environment. Rosenfeld described the criteria museums use to evaluate the suitability of a lighting source, including color rendering, color uniformity, intensity, and distribution. Finding lamps with the proper distribution was the biggest challenge, especially wide beam lamps (between 35 and 50º) and narrow beam lamps (4 to 6º).

A wall lit with LED retrofit lamps in the Rose Gallery at the Smithsonian American Art Museum.

Michael Souter of Luminae Souter Associates, LLC, discussed a recent GATEWAY demonstration involving the installation of LED retrofit lamps at San Francisco's InterContinental Hotel. Aesthetic concerns were paramount at this world-class luxury hotel project, and Souter, who was the original lighting designer, was brought in to oversee installations. Souter explained that, while LED products did not prove appropriate for certain hotel areas, in other settings they worked quite well, providing an estimated payback of 1.1 years without compromising the aesthetics. He described the extensive bench-testing that was conducted on all candidate products, noting that many proved disappointing because of such problems as poor color, flicker, transformer incompatibility, abnormally low output, and strobing when dimmed.





"Before and after" reception desk at the InterContinental Hotel, comparing 20W dimmed halogen MR16s with undimmed LED MR16s.

Greg Sullivan of Efficiency Solutions concluded the panel by discussing a nearly completed LED parking lot demonstration at the Nike World Headquarters in Beaverton, Oregon — one of four such demonstrations he is currently involved with. Sullivan explained how the incumbent metal halide (MH) lighting was upgraded to occupancy-based LED products throughout the campus parking lots. He described the amperage monitoring that was done on both the LED and MH fixtures and estimated the energy savings from switching to SSL at 745 kilowatt-hours per year. Sullivan noted several issues with the LED products, including inconsistency in the factory-set delay settings, and false triggering of the sensors from wind blowing nearby leaves and branches.

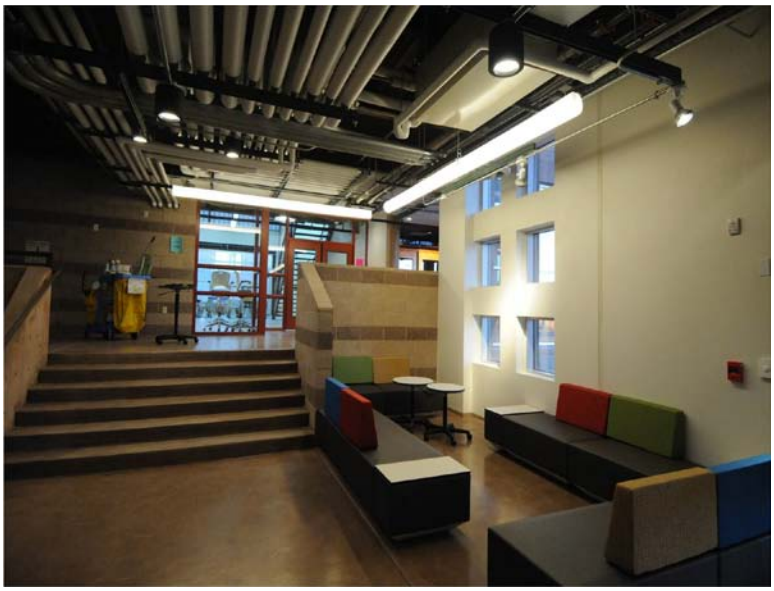
A first-generation, combined LED/ occupancy sensor single luminaire fixture in parking lots at Nike World Headquarters in Beaverton, Oregon.

Question-and-Answer Session

Souter was asked whether there was any leeway to consider LED fixtures for the InterContinental Hotel's GATEWAY demonstration, or if it was restricted to bulb replacements. He answered that they were restricted to existing fixture retrofits, which required them to determine in advance whether the proposed replacement lamps would fit. In response to a question as to whether the frequent blinking on and off of the sensor-controlled fixtures might be an annoyance to Nike employees, Sullivan said that was not a factor he and his colleagues considered. Kinzey added that the Nike parking lots are located on the periphery of the campus, so their distance from the offices may explain why no one has complained about blinking lights.

5.3 Specifying LED Products

Lighting designer Derry Berrigan provided insights on the challenges of specifying today's LED lighting products. Noting that she has been using 90% LED products for all her projects since 2007, she explained that if due diligence is exercised, specifying LEDs is far less challenging than stewarding the adoption of good, sustainable lighting. Berrigan illustrated this by recounting her experience with a recent installation at the Trades and Advanced Technology Center of Santa Fe Community College. She related how she specified that the building — from the classrooms, to public spaces, to the administrative offices — be



A public space at Santa Fe Community College Trades and Advanced Technology Center, where SSL is fully exposed for educational purposes. Photo: Derry Berrigan, Light Think Studios, Inc.

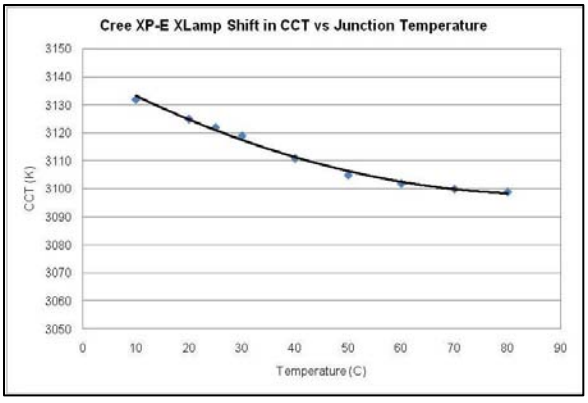
illuminated with 96% LED lighting, equipped with occupancy and daylight sensors. However, despite the college's commitment to sustainable lighting, Berrigan encountered significant resistance from the local network of lighting distributors, sales reps, engineers, and contractors who viewed LED products as a threat to their livelihoods. She explained that she prevailed in the end only because she cared enough about the results to withstand pressures to compromise. "The lack of caring and education is the biggest obstacle we face," Berrigan said.

6. Color Matters

A panel discussion on color quality, consistency, and characterization was moderated by Fred Welsh. Wendy Davis of the National Institute of Standards and Technology (NIST) spoke about the color properties of SSL. She explained that color quality consists of the chromaticity of the light, as well as the way it renders colors. Davis noted that the warm-white light preferred by U.S. consumers can encompass much higher correlated color temperatures (CCTs) than one might assume. She said that in addition to CCT, more attention needs to be paid to D_{uv}, which denotes the distance from the black-body locus. Davis emphasized that narrowband light sources can render colors as well as broadband sources can. "The visual system does not care whether a light is broad-spectrum or not," she said.

Lorne Whitehead of the University of British Columbia followed with a discussion of color constancy. He noted that different spectra can appear to be the same color, and pointed out that changing the color of the light does not necessarily change the perceived color of surfaces. Whitehead explained that people adapt quickly to changes in the color of light sources, but not to perceived surface color changes. He said the importance some people place on color rendering requires objective optimization of spectra, as well as accurate standardization of lamp colors. But Whitehead noted that better color does not have to imply poor efficiency. "It is possible to get great color rendering, so you have to do it right," he said.

Ralph Tuttle of Cree, Inc. explored the chromaticity control of white LEDs. Noting that a shift in CCT is meaningless compared with a shift in chromaticity, he observed that manufacturers of white LEDs can provide very tight color bins that allow users to effectively color-mix to achieve very tight color-point consistency, and he explained that changes in chromaticity can have a significant effect on issues such as droop and the hot/cold factor. Tuttle recommended that manufacturers ask their LED suppliers for data showing the color-point behavior of the LEDs under varying conditions, as well as for LM-80 test data showing the color-point stability over time, and that they reconsider using those LEDs if the suppliers do not provide that information.



Lamp junction temperature is one of the factors that can affect correlated color temperature.

Mark Pugh of Xicato concluded the panel with a discussion of color quality and maintenance in LED lighting systems, based in part on interviews conducted with more than 400 lighting specifiers and architects. From their feedback, he said, "We are getting a good feel for which applications can accept which type of color variations." Pugh noted that eight of the top 10 reasons given for holding back on specifying SSL involved the quality of the light, including color issues. He then reviewed possible sources of color variation, such as a color shift in diffusers or lens/reflector materials, inaccuracies in the drive current, and variations in pump wavelength. Pugh called for a clear and consistent color metric that is applicable to all lighting technologies and recommended optimizing all materials in a luminaire for color shift, as well as setting target values and formalizing a monitoring scheme.

Question-and-Answer Session
In response to an attendee's frustration at having to translate all the different parameters to the operating temperature, Tuttle agreed that this is a valid concern and noted that IES is looking into a standard that will allow for testing at higher temperatures. Pugh was asked whether humans are more sensitive to a shift along the isotherm or along the black-body locus, and he said the latter. Asked what the optimal way is to measure color, Whitehead said, "I do not think we have the answer yet," although he noted that the Color Quality Scale is a "huge improvement" over CRI. Someone else asked whether NIST plans to release standard reference material for color point, to which Davis replied that as a non-regulating agency, NIST does not set standards.

7. Driving Innovation with Lighting Competitions

The final workshop panel discussed how lighting competitions drive technology advances, market adoption, energy savings, and innovation. Moderator Marc Ledbetter reviewed two DOE-sponsored competitions: *Next Generation Luminaires*™ (NGL), which was created to recognize and promote excellence in the design of energy-efficient LED commercial lighting luminaires; and *L Prize*℠, which is intended to spur manufacturers to develop high-quality, high-efficiency SSL products to replace the common light bulb.

Liesel Whitney-Schulte of Focus on Energy, Wisconsin's statewide program for energy efficiency and renewable energy, noted that such competitions not only help programs like hers identify high-quality products, but also keep those programs on the cutting edge and create buy-in from lighting designers and others in the industry. Among the challenges she cited are the fact that energy-savings goals are increasing, and that baseline changes (e.g., due to the upcoming government-mandated tightening of lamp efficacy standards) shrink energy savings. Whitney-Schulte said her expectations for LED products encompass such factors as source efficacy, luminaire efficiency, controllability, long life, cost-effectiveness, color quality, specifiability, reliability, and serviceability.

Makarand "Chips" Chipalkatti of OSRAM Sylvania recapped the progress made in SSL to date and discussed the value of competitions in motivating the industry to go further. "They laughed at us when we said we would make real lighting out of LEDs," he said, referring to the early days of SSL. Chipalkatti observed that merely increasing lamp efficacy will not be enough to

meet SSL energy-saving objectives, and that the industry should also focus on integrating lighting with building controls. He said the technology's energy-saving potential can be exploited by focusing on such things as light management, application efficiency, and LED efficiency. Chipalkatti stated that in order to drive the industry to further advances, competitions should emphasize innovative design and intelligent lighting, as well as affordability, which he believes is the biggest barrier to large-scale adoption. But he stressed that LED lighting is about more than performance and cost, that it comes down to what he termed the "benefits per watt."

The panel concluded with a presentation by John Campsmith of Philips Wide-Lite, a 2009 NGL winner, who noted that his company does not design products to win competitions, but rather to meet or exceed known and potential market needs. Winning competitions, he said, has been an added bonus that has increased market awareness and credibility. Campsmith pointed out that competitions benefit manufacturers and customers in many of the same ways, including vetting product claims, ensuring truth in advertising, and promoting common language and standards. He said competition requirements should keep getting more stringent to spur the introduction of better products. "We believe we should continually evolve and push the envelope," Campsmith said.

Question-and-Answer Session
In response to a question as to how competitions might address the issue of controls, Whitney-Schulte noted that the issue is already being addressed by dimmability requirements, but said it is important that competitions define compatibility. Asked whether light control should be part of the smart grid or in parallel with it, Chipalkatti said he hopes for a convergence of these two paths but imagines that in the near term they might be running in parallel. Someone asked Campsmith to put a dollar figure on the advertising value his company has gotten from competitions, and he said anywhere from $60,000 to $100,000.

8. Conclusion

Brodrick concluded the three-day workshop by thanking participants for their input and participation. He noted two additional DOE SSL workshops in 2011: the SSL Manufacturing R&D Workshop in April and the Market Introduction Workshop in July. He also encouraged attendees to stay apprised of DOE SSL program activities by visiting www.ssl.energy.gov. Presentations and materials from the eighth annual DOE SSL R&D Workshop are posted online at www1.eere.energy.gov/buildings/ssl/sandiego2011_materials.html.

APPENDIX A: 2011 SSL R&D Workshop Participants

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Mary Ashe
Navigant Consulting

James Bachle
WAGO Corporation

Brad Bailey
FireFly LED Lighting, Inc.

Karen Baker
OptoLum, Inc.

Deborah Bamforth
CRS Electronics, Inc.

Steve Barcik
FireFly LED Lighting, Inc.

James Norman Bardsley
Bardsley Consulting

Michael Barnes
Micron Technology, Inc.

Tom Barnett
Masco Corp

Kenneth Barringer
Veeco Instruments

Jay Bartek
Task Lighting Corporation

Dave Bartine
Lighting Science Group

Sarah Bazydola
OSRAM Sylvania

Andrew Beck
Lighting Science Group

Derry Berrigan
Derry Berrigan Lighting Design

Abhinav Bhandari
PPG Industries

Ravi Bhatkal
Cookson Electronics

Robert Biefeld
Sandia National Laboratories

Stephen Bland
SB Consulting

Christopher Bohler
Cooper Lighting

Peter Bolan
Universal Lighting Technologies

Patrick Bournes
Philips Lumileds

Scott Bowden
Sharp

Dennis Bradley
GE Lighting Solutions

Bob Bransome
SESCO

Nanu Brates
Panasonic-ULT

Michael Bremser
Fulham Co., Inc.

Eric Bretschneider
Lighting Science Group

Lori Brock
OSRAM Sylvania

James Brodrick
U.S. Department of Energy

Harry Buhay
PPG Industries

Chad Bulman
Midwest Energy Efficiency Alliance

John Campsmith
Philips Wide-Lite

Anthony Catalano
TerraLUX

Joel Chaddock
DOE National Energy Technology Laboratory

Michael Chan
Digital Lighting, Inc.

ShuKai Chang
Delta Products Corporation

Marc Chason
Marc Chason and Associates, Inc.

Kai Chen
Lawrence Berkeley National Laboratory

Steve Chen
Leader Electronics, (N.A.) Inc.

Makarand Chipalkatti
OSRAM Sylvania

Joe Chow
Para Light

Terry Clark
Finelite, Inc.

Seth Coe-Sullivan
QD Vision, Inc.

Patrick Collins
Acuity Brands Lighting

Michael Coltrin
Sandia National Laboratories

Keith Cook
Philips Lighting

Sarah Cornelius
Akoya

John Cornelson
PECI

Ryan Crabb
UMI

Steven Crimi
LumaStream, LLC

John Curran
LED Transformations, LLC

Ku'uipo Curry
ICF International

Edmond Daniels
Jimway, Inc.

Aurelien David
Soraa, Inc.

Lynn Davis
RTI International

Monica Davis
EMD Chemicals, Inc.

Robert Davis
Litecontrol

Wendy Davis
National Institute of Standards and Technology

Matt Deihimi
Hi-Tech Green Energy

Andy Delano
Honeywell

Richard Demaray
Antropy Incorporated

Mark D'Evelyn
Soraa, Inc.

John Dexheimer
LightWave Advisors, Inc.

Brian Dlugosch
Aixtron Inc.

Elizabeth Donoff
Architectural Lighting Magazine

Brian Dotson
DOE National Energy Technology Laboratory

Kieran Drain
Rambus Inc.

Gerald Duffy
GE Lighting Solutions

Russell Dupuis
Georgia Institute of Technology

Diane Durbin
San Diego Gas & Electric

Christopher Durell
Labsphere, Inc.

Kevin Edwards
Brewer Science, Inc.

Phil Elizondo
Bridgelux

Kevin Elsken
Bayer Material Science

Michael Etienne
Corning Incorporated

Sean Evans
DOE National Energy Technology Laboratory

Greg Ewing
Good Company Associates

Alan Feit
Feit Electric

Valeriy Felmetsger
OEM Group, Inc.

Annette Finsterbusch
Applied Ventures

Paul Ford
The Lighting Quotient

Greg Frankiewicz
Energy Focus, Inc.

Gerard Frederickson
Lightscape Materials, Inc.

Ted Gailhouse
PECI

Jim Gaines
Philips

Francisco Galvez
Los Angeles Department of Water and Power

Karina Garbesi
Lawrence Berkeley National Laboratory

Geoff Gardner
Dow Corning Corporation

Nathan Gardner
Soitec USA

Daniel Gaspar
Pacific Northwest National Laboratory

Gary Gatesman
ElectraLED, Inc.

Richard Gaughan
Mountain Optical Systems Technology

Thomas Geier
3M

Thomas Geist
EPRI

Camil-Daniel Ghiu
OSRAM Sylvania

Geoffrey Gibbs
Nexxus Lighting, Inc.

Christopher Glandt
Visa Lighting

Kelly Gordon
Pacific Northwest National Laboratory

David Grassi
Carclo Technical Plastics

Wendy Graves
Akoya

Yu Guan
VLSI Standards, Inc.

Mahima Gupta
Navigant Consulting

Rahul Gupta
Cambrios Technologies, Inc.

Michael Hack
Universal Display Corporation

Paul Hadley
Green Globe Lighting, LLC

Margaretta Hahn
PPG Industries, Inc.

Caterina Hall
inteLED Corporation

John Hamer
OLEDWorks, LLC

Jinkyu Han
University of CA, San Diego

Jung Han
Yale University

Mark Hand
Acuity Brands Lighting

Mark Hannah
OSRAM Sylvania

Monica Hansen
Cree, Inc.

Neil Hardwick
RTP Company

Adam Harrell
Bridgelux

Terry Hart
PPG Industries, Inc.

Tadao Hashimoto
SixPoint Materials, Inc.

Eric Haugaard
Ruud Lighting

Andrew Hawryluk
Ultratech

Jeff Hinshaw
Delta Products

Jeff Hirsch
San Diego Gas & Electric

Matthew Holland
Eastman Kodak

Sylvia Holt
Xaris, Inc.

Chang-Hee Hong
Chonbuk National University

Noah Horowitz
Natural Resources Defense Center

Po-Chieh Hung
Konica Minolta Laboratory USA, Inc.

Jeffrey Hungarter
Philips Lighting

B T Hwang
HEP Group

Frank Ignazzitto
QD Vision

Chris Isaacson
NuLEDs, Inc.

Norma Isahakian
City of Los Angeles, Bureau of Street Lighting

Jeanette Jackson
Light-Based Technologies

Konrad Jarausch
Passport Capital

Paul Jaster
Pario, LLC

Vachik Javadian
Cree, Inc.

Alain Jean
Luminus Devices, Inc.

David Jenkins
Micron

Ray Johnston
3M

Christopher Jones
Saint-Gobain Crystals

Robert Jorgenson
Lightwave Photonics, Inc.

Ronald Kaneshiro
Glo-USA

Tae Gyu Kang
ETRI

Bob Karlicek
Smart Lighting ERC, RPI

Philip Keebler
EPRI

Jason Keehn
Information Forecast, Inc.

Timothy Kelly
Fusion Optix, Inc.

Bill Kennedy
eLUXtron

Namseog Kim
Seoul Semiconductor

Youjin Kim
ETRI

Robert King
Good Company Associates

Bruce Kinzey
Pacific Northwest National Laboratory

Dave Knapp
FireFly LED Lighting, Inc.

Cliff Knutson
Lime Energy Co.

Daniel Koleske
Sandia National Laboratories

Mike Krames
Soraa, Inc.

Nety Krishna
Redpoint Ventures

Peicheng Ku
Arborlight/University of Michigan

Josh Lampl
Lightwave Photonics, Inc.

John Langevin
Rambus, Inc.

Susan Larson
Soraa, Inc.

Daniel LeCloux
DuPont

Marc Ledbetter
Pacific Northwest National Laboratory

Brian Lee
J.P. Morgan

Louis Lerman
Pteranodon Ventures

Steve Lester
Bridgelux

Peter Levermore
Universal Display Corporation

Lionel Levinson
Vartek Associates

Erhong Li
National Semiconductor

Ming Li
OSRAM Sylvania

Liang-Bih Lin
Nitto Denko Technical Corporation

Jonathan Linn
Northeast Energy Efficiency Partnerships

Ying-Moh Liu
Newport Corporation

Bill Livesay
Goldeneye, Inc.

Min-Hao Lu
Acuity Brands Lighting

Songwei Lu
PPG Industries, Inc.

Ruiqing Ma
Universal Display Corporation

Jimmy Madden
JimWay Inc.

David Maikowski
Guardian Industries Corporation

Theron Makley
Seoul Semiconductor

Karen Marchese
Akoya

Angelo Mascarenhas
National Renewable Energy Laboratory

Mathew Mathai
Plextronics, Inc.

Fred Maxik
Lighting Science Group

Joseph McConnaughey
Rambus

Darren McCosky
Juno Lighting Group

Steve McDaniel
University of Utah

Joanna McKittrick
UC San Diego

Chad McSpadden
H.E. Williams

Jonathan Melman
Intematix Corp.

Hisham Menkara
PhosphorTech

Greg Merritt
Cree, Inc.

Ningliang Mi
Philips

Allen Miao
Opto-Dynamics Group

Jeffrey Miller
Jeff Miller & Company, Inc.

Silvia Mioc
Smart Lighting ERC, RPI

Kailash Mishra
OSRAM Sylvania

Felicia Monti
Globe Electric

Kerry Moore
CAO Group, Inc.

Tom Munters
Philips

James Murphy
GE Global Research

David Neal
Seoul Semiconductor

Kenneth Neighbors
Xaris, Inc.

Guy Newhouse
Philips Lumileds Lighting Company

Scott Newman
U.S. Army Research Laboratory

Hoan Ngo
Ilumisys, Inc.

Sandeep Nijhawan
Siorah

Maura Nippert
Booz Allen Hamilton

Fumito Nishida
Dow Corning Corporation

Yurika Nishihara
Toyoda Gosei

Meredith Nole
American Efficient Lighting

Adele Noon
Procopio

Chris Nye
Leotek Electronics

John Nylander
InteLED Corporation

Joseph Oberle
Delta Products Corporation

James O'Connor
Carclo Technical Plastics

Tomoyuki Ogata
Mitsubishi Chemical Group

Hideaki Okamoto
Mitsubishi Chemical Corporation

Mark O'Neill
Air Products & Chemicals, Inc.

Amy Oriss
Akoya

Dennis O'Shaughnessy
PPG Industries, Inc.

Julian Osinski
Consultant

Michael Ottum
LDPI, Inc

Brian Owen
green Tbiz/LEDs Magazine

Asanga Padmaperuma
Pacific Northwest National Laboratory

Shaoher Pan
SiPhoton, Inc.

Steven Paolini
Lunera Lighting

Seong Eun Park
Samsung LED Co., Ltd.

Ian Parker
DuPont Displays

Bob Parks
International Dark-Sky Association

Umesh Patel
Lights of America, Inc.

Lisa Pattison
SSLS, Inc.

Morgan Pattison
SSLS, Inc.

Jeffrey Perkins
Yole, Inc.

James Petroski
Rambus, Inc.

Edward Petrow
Lincoln Technical Services, Inc.

Jason Pomante
Arkema, Inc.

Chris Primous
Permlight

Florian Pschenitzka
Cambrios Technologies Corp.

Mark Pugh
Xicato Inc.

William Quinn
Veeco

Bianca Ramsey
DB Power of 3

Darren Rawson
Superbulbs

Meredith Reed
U.S. Army Research Laboratory

Seth Reeves
DB Power of 3

Michael Rehberg
The Dow Chemical Company

Greg Rhoads
Cooper Lighting

John Richard
DuPont Displays

Scott Riesebosch
CRS Electronics Inc.

James Robinson
U.S. Department of Energy

Stuardo Robles
Ilika Technologies

Remco Roest
Rentalite

James Rooks
Seoul Semiconductor

Scott Rosenfeld
Smithsonian American Art Museum

Robert Rustin
DuPont Teijin Films

Ameen Saafir
DuPont Displays

Mikhail Sagal
Thermal Solution Resources

Gary Sanders
Philips Lighting

John Sanders
WhiteOptics, LLC

Susan Sanderson
Rensselaer Polytechnic Institute

Kamran Sarmedi
Permlight

Sanwal Sarraf
Brite Lite, LLC

Mark Seitz
Indak

Deepak Sekar
NuPGA

Mehdi Shafaghi
Los Angeles Department of Water and Power

Kirit Shah
Alcoa

Jim Shapiro
Feit Electric

Cathleen Shattuck
Evluma

Yijian Shi
SRI International

Joseph Shiang
GE Global Research

Ahmed Shuja
BritePointe

Ella Shum
Strategies Unlimited

Gary Silverman
Arkema, Inc.

Brook Simmons
Capitol Decisions, Inc.

Jerry Simmons
Sandia National Laboratories

Tom Simpson
3M

Amandeep Singh
CCSE

Alem Sklar
Globe Electric

Patrick Smith
Philips Lighting

Ryan Smith
Arkema, Inc.

Franky So
University of Florida

Phannvileakk Sourm
Elite Lighting USA

Michael Souter
Luminae Souter Associates, LLC

Dan Sperling
Akoya

Jeffrey Spindler
Moser Baer Technologies

Ulrich Steegmueller
Osram OptoSemiconductors GmbH

Robert Steele
Consultant

Michael Stevens
Georgia Power Company

Matthew Stough
OSRAM Sylvania

Greg Sullivan
Efficiency Solutions

Christopher Summers
PhosphorTech

Decai Sun
Philips Lumileds Lighting

Suresh Sunderrajan
NNCrystal Corporation

Christ Surunis
Lutron Electronics

Aijaz Taj
Lights of America, Inc.

Adele Tamboli
Caltech

Ching Tang
University of Rochester

Hirofumi Tani
Toyoda Gosei North America

Eric Teather
WhiteOptics, LLC

Jacqueline Teng
Consultant

Ranjit Thakur
3M

Vincent Thulliez
Solvay

Paul Thurk
ARCH Venture Partners

Yongchi Tian
Lightscape Materials, Inc.

Michael Tischler
Cooledge Lighting

Thomas Trovato
Trovato Mfg., Inc.

Jeff Tsao
Sandia National Laboratories

Ralph Tuttle
Cree, Inc.

Tatsukiyo Uchida
NIST

Anand Upadhyay
Philips

Craig Updyke
NGLIA & NEMA

Graham Upton
Endicott Research Group

Ben Vandertuin
DSA

Mike Virag
Redwood Systems

Nancy Wahl-Scheurich
LittleFootprint Lighting, Inc.

Lauri Walker
California Center for Sustainable Energy

Terrence Walsh
Tempo Industries, Inc.

Alex Wang
Chilin Technology

Dongdong Wang
Lawrence Berkeley National Laboratory

Shaoping Wang
Fairfield Crystal Technology

Richard Warmke
Lunera Lighting

Ronald Weber
Tyco Electronics

Richard Weiss
SinoDiamondLED

Fred Welsh
Radcliffe Advisors, Inc.

Tim Weston
CRI Lighting Sales, Inc.

Christian Wetzel
Rensselaer Polytechnic Institute

Lorne Whitehead
University of British Columbia

Liesel Whitney-Schulte
Focus on Energy

Brian Wilcox
Seoul Semiconductor, Inc.

Howard Wolfman
Lumispec Consulting

Maury Wright
LEDs Magazine

Hiroshi Yagi
IMAnet, Inc.

JeremyYon
Litecontrol

A. Brent York
Tangenesys Ltd.

Zhibin Yu
UCLA Materials Science and Engineering

Regan Zane
University of Colorado

Mei Zegun
LedEngin, Inc.

Shiyong (Shawn) Zhang
OSRAM Sylvania

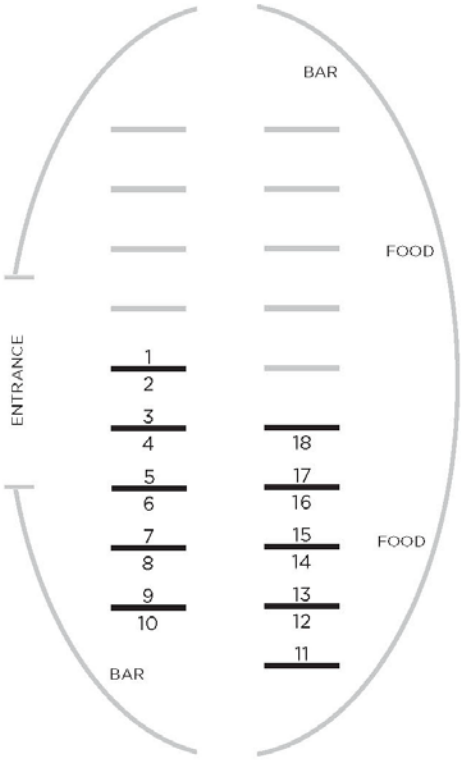
Mingwei Zhu
Applied Materials

APPENDIX B: List of SSL R&D Project Posters

Transformations in Lighting
SSL R&D Workshop

POSTER SESSION

Rio Vista Pavilion
February 2, 2011
5:00 p.m. – 7:00 p.m.



NO.	PROJECT TITLE	PRESENTER
1	Exploiting Negative Polarization Charge at n-InGaN/p-GaN Heterointerfaces to Achieve High Power Green LEDs without Efficiency Droop	**Meredith Reed** Army Research Laboratory
2	SSL Luminaire with Novel Driver Architecture	**Monica Hansen** Cree, Inc.
3	Ultra-Compact High Efficiency Luminaire for General Illumination	**Monica Hansen** Cree, Inc.
4	High Efficiency Colloidal Quantum Dot Phosphors	**Keith Kahen** Eastman Kodak Company
5	Affordable High-Efficiency Solid-State Downlight Luminaires with Novel Cooling	**Mehmet Arik** GE Global Research
6	Optimized Phosphors for Warm White LED Light Engines	**James Murphy** GE Global Research
7	Fundamental Studies of Higher Efficiency III-N LEDs for High-Efficiency High-Power Solid-State Lighting	**Russell Dupuis** Georgia Institute of Technology
8	Development of High Efficiency m-Plane LEDs on Low Defect Density Bulk GaN Substrates	**Aurelien David** Soraa, Inc.
9	Nitride- and Oxynitride-Based Phosphors for Solid-State Lighting	**Yongchi Tian** Lightscape Materials Inc.
10	Lattice Mismatched GaInP Alloys for Color Mixing White Light LEDs	**Angelo Mascarenhas** National Renewable Energy Laboratory
11	Highly Efficient Small Form Factor LED Retrofit Lamp	**Steven Allen** OSRAM SYLVANIA
12	High-Flux Commercial Illumination Solution with Intelligent Controls	**Camil Ghiu** OSRAM SYLVANIA
13	High Efficiency Driving Electronics for General Illumination LED Luminaires	**Anand Upadhyay** Philips Lighting
14	130 lm/W, 1000 lm High-Power, Warm White LED for Illumination	**Decai Sun** Philips Lumileds Lighting, LLC
15	High Extraction Luminescent Materials for Solid-State Lighting	**Christopher Summers** PhosphorTech Corporation
16	High Efficacy Green LEDs by Polarization-Controlled MOVPE	**Christian Wetzel** Rensselaer Polytechnic Institute
17	Novel Defect Spectroscopy of InGaN Materials for Improved Green LEDs	**Andrew Armstrong** Sandia National Laboratories
18	Semi-polar GaN Materials Technology for High IQE Green LEDs	**Dan Koleske** Sandia National Laboratories

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Transformations in Lighting
SSL R&D Workshop

POSTER SESSION

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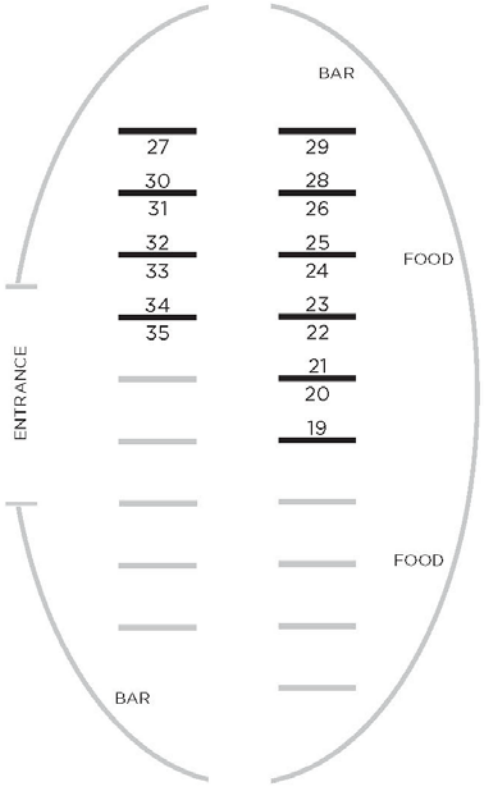

NO.	PROJECT TITLE	PRESENTER
19	Life Cycle Energy Consumption of Solid-State Lighting	**Joe Marriott** Booz Allen Hamilton
20	Low-cost, Highly Lambertian Reflector Composite for Improved LED Fixture Efficiency and Lifetime	**Eric Teather** WhiteOptics LLC
21	Phosphors for Near UV-Emitting LEDs for Efficacious Generation of White Light	**Joanna McKittrick** University of California–San Diego
22	Multicolor, High Efficiency, Nanotextured LEDs	**Han Jung** Yale University
23	Application of Developed APCVD Transparent Conducting Oxides and Undercoat Technologies for Economical OLED Lighting	**Gary Silverman** Arkema Inc.
24	Solution-Processable Transparent Conductive Hole Injection Electrode for OLED SSL	**Florian Pschenitzka** Cambrios Technologies Corporation
25	Solution-Processed Small-Molecule OLED Luminaire for Interior Illumination	**Ian Parker** DuPont Displays, Inc.
26	High Quantum Efficiency OLED Lighting Systems	**Joe Shiang** GE Global Research
27	Investigation of Long-Term OLED Device Stability via Transmission Electron Microscopy Imaging of Cross-Sectioned OLED Devices	**Gao Liu** Lawrence Berkeley National Laboratory
28	Charge Balance in Blue Electrophosphorescent Devices	**Asanga Padmaperuma** Pacific Northwest National Laboratory
29	Development of Stable Materials for High Efficiency Blue OLEDs through Rational Design	**Asanga Padmaperuma** Pacific Northwest National Laboratory
30	Low-cost Integrated Substrate for OLED Lighting Development	**Abhinav Bhandari** PPG Industries, Inc.
31	Energy-Saving Phosphorescent OLED Luminaires	**Peter Levermore** Universal Display Corporation
32	High Efficacy Integrated Undercabinet Phosphorescent OLED Lighting Systems	**Mike Hack** Universal Display Corporation
33	Development and Utilization of Host Materials for White Phosphorescent OLEDs	**Lewis Rothberg** University of Rochester
34	High Efficiency OLEDs for Lighting	**Franky So** University of Florida
35	Energy Savings Estimates of LEDs in Niche Lighting Applications	**Mahima Gupta** Navigant Consulting, Inc.