Multi-Year Program Plan FY’09-FY’15

Solid-State Lighting Research and Development

Prepared for:

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

Prepared by:

Navigant Consulting, Inc.,
Radcliffe Advisors, Inc.,
and
SSLS, Inc.

March 2009

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DISCLAIMER

ACKNOWLEDGEMENTS

The Department of Energy would like to acknowledge and thank all the participants for their valuable input and guidance provided to develop Section 4.0 of the Multi-Year Program Plan (MYPP). The DOE would like to thank those individuals who participated in the solid-state lighting roundtables of September 2008 in Washington, D.C. Finally, the DOE wishes to thank those individuals who participated in the solid-state lighting Technical Committee conference calls in the fall of 2008:

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Asanga Padmaperuma	Pacific Northwest National Laboratories
Linda Sapochak	National Science Foundation
Joe Shiang	GE Global Research
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COMMENTS

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The March 2009 edition of the Multi-Year Program Plan updates the March 2008 edition. Updates were primarily made to Sections 1.0, 3.0, and 4.0.

1.0 Introduction

President Obama's energy and environment agenda calls for deployment of "the Cheapest, Cleanest, Fastest Energy Source – Energy Efficiency."[1] The Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) plays a critical role in advancing the President's agenda by helping the United States advance toward an energy-efficient future.

> ***"LEDs are an obvious area that we can achieve energy savings and we can also achieve economic benefits – job creation."***
> U.S. Senator Jeff Bingaman
> Chair, Senate Energy Committee[2]

Lighting in the United States is projected to consume nearly 10 quads of primary energy by 2012.[3] A nation-wide move toward solid-state lighting (SSL) for general illumination could save a total of 32.5 quads of primary energy between 2012 and 2027. No other lighting technology offers the DOE and our nation so much potential to save energy and enhance the quality of our built environment. The DOE has set forth the following mission statement for the SSL R&D Portfolio:

> *Guided by a Government-industry partnership, the mission is to create a new, U.S.-led market for high-efficiency, general illumination products through the advancement of semiconductor technologies, to save energy, reduce costs and enhance the quality of the lighted environment.*

1.1 Significant SSL Program Accomplishments to Date

Researchers have made considerable progress in the advancement of solid-state lighting since the U.S. Department of Energy (DOE) initiated its work in SSL research and development (R&D) in 2000. In the course of their research, performers supported by the DOE SSL portfolio have won several prestigious national research awards and have achieved several significant accomplishments in the area of solid-state lighting. The following is a list of several of the efficacy records of the SSL portfolio to date:

- September 2008. Cree, Inc. created a prototype cool-white light-emitting diode (LED) that delivers 107 lm/W at 350mA.
- September 2008. The University of Florida demonstrated a blue phosphorescent organic light-emitting diode (OLED) with a record efficiency of 40 lm/W, with a peak external quantum efficiency of 25% using no external light extraction techniques.

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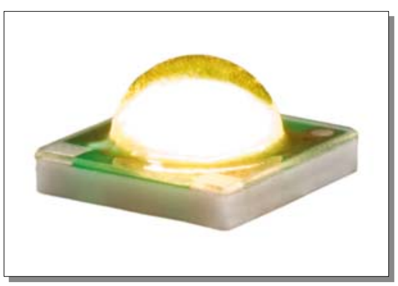
[1] The Agenda – Energy and Environment. Last Accessed February 26, 2009. Available at: http://www.whitehouse.gov/agenda/energy_and_environment/.
[2] Fleck, J. "Bingaman Thinks LEDs a Bright Idea." *Albuquerque Journal*. 10 November 2003.
[3] *Energy Savings Potential of Solid State Lighting in General Illlumination Applications*. Prepared by Navigant Consulting, Inc. for the Department of Energy. Washington D.C. December 2006.

- June 2008. Philips Solid-State Lighting Solutions and Cree, Inc. jointly developed a warm-white multi-chip prototype of an LED PAR (parabolic aluminized reflector) lamp that delivers a luminaire efficacy of 69 lm/W and a luminous flux of 681 lumens.
- June 2008. Universal Display Corporation demonstrated an OLED with a lifetime of 80,000 hours. The performance of the OLED was 50 lm/W at 1,000 cd/m^2.
- June 2008. Universal Display Corporation demonstrated a white-light phosphorescent OLED with a record power efficacy of 102 lm/W at 1000 cd/m^2.
- September 2007. Cree, Inc. developed an LED array prototype that delivers 95 lm/W at 350 mA.
- September 2007. GE Global Research set a new record for solution-processed white OLED devices, demonstrating a performance greater than 14% peak W/W (overall power conversion efficiency). Further improvements will enable the demonstration of a 45 lm/W illumination-quality OLED that proves near-term technology viability as an incandescent replacement for certain applications.
- September 2007. Universal Display Corporation (UDC) fabricated a 6-square-inch OLED panel that produces 100 lumens of light at an efficacy of 31 lm/W and a brightness of 3,000 nits, relatively brighter than today's fluorescent lamps.
- June 2007. Eastman Kodak developed a new device architecture for white-light OLED devices that demonstrates an extraction efficiency of 46%, a tremendous improvement over previous devices.

1.1.1 Recent Research Highlights

Recent research highlights are described below.

Cree, Inc. Pushes Cool White to 107 Lm/W

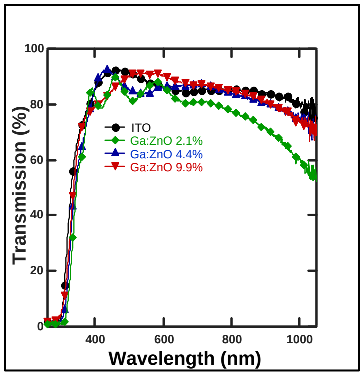


In September of 2008, Cree successfully created a prototype cool-white LED that delivers 107 lm/W at 350mA. This achievement builds on the Cree EZBright® LED chip platform, developed in part with prior funding support from DOE. Cree made the prototype LED under their DOE project focused on developing photonic crystal chips for improved light extraction and novel package technology for higher down-conversion efficiency compared to conventional LEDs. Based on a 1-millimeter-square chip, the new prototype LED produces white light with a correlated color temperature (CCT) of 5500K and a color rendering index (CRI) of 73. Integration of four of these prototype LEDs can produce luminous flux of more than 450 lumens from a single package.

Philips and Cree Create High-Efficacy Warm-White Multi-Chip LED PAR Lamp

In June of 2008, Philips Solid-State Lighting Solutions and Cree, Inc. successfully fabricated a new warm-white multi-chip prototype of an LED PAR lamp delivering a

luminaire efficacy of 69 lm/W and a luminous flux of 681 lumens. This is significantly more efficient than comparable LED PAR 38 lamps on the market. The lamp also features the good color quality (CRI of 91) and warm tone (CCT of 2716K) preferred by consumers. This new hybrid-LED source incorporates advanced LED package and system integration technology plus novel, highly efficient driver technology and a unique optical arrangement. The research team will continue its efforts to improve performance figures over the course of this 18-month project.



PNNL/NREL Team Demonstrates Robust GZO TCO

In January of 2008, the National Renewable Energy Laboratory (NREL) and Pacific Northwest National Laboratory (PNNL) demonstrated a robust transparent conducting oxide (TCO) based on zinc oxide (ZnO) substitutionally doped with gallium (GZO). While GZO has conductivity and transparency comparable or superior to that of the best indium tin oxide (ITO), it is expected to be significantly less expensive. This research team has for the first time demonstrated OLEDs based on gallium doped ZnO with device performance characteristics equivalent to that of ITO-based diodes. This achievement reveals the potential for a new generation of designable TCO materials with enhanced performance at reduced cost.

R&D Achievements Contribute to Market-Ready Products

The following project contributed to products on the market that incorporate underlying research funded by DOE.

Cree XLamp® LEDs Light Olympic Venues

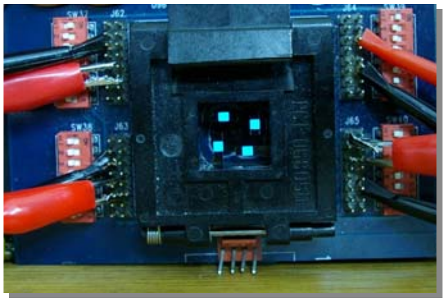
Cree XLamp LED technology provided SSL lighting for several key Olympic venues in Beijing, including the "Bird's Nest" (National Stadium) and the "Water Cube" (National Aquatic Center). Cree's XLamp product utilizes LED technology that was developed in part with R&D funding support from DOE. Approximately 496,000 XLamp LEDs in red, green, and blue were used to illuminate the exterior of the Water Cube. The Bird's Nest exterior featured approximately 258,000 XLamp LEDs providing dramatic lighting effects. The research team at Cree continues to work with DOE to further improve LED device efficiency and drive toward DOE's long-term research goal of 160 lumens per watt in cost-effective, market-ready systems by 2025. (August 2008)

Additional R&D Achievements

The following projects represent a sampling of additional R&D achievements funded by DOE.

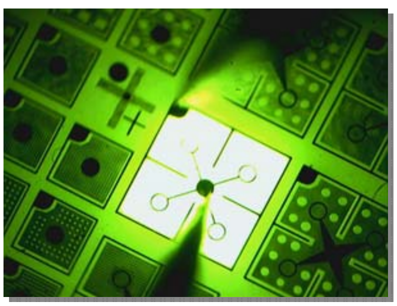
University of Florida Achieves Record Efficiency for Blue OLEDs

The research team at the University of Florida (UF) recently demonstrated a blue phosphorescent OLED with a peak power efficiency of 40 lm/W, with a peak external quantum efficiency of 25 percent, using no external light extraction techniques. This



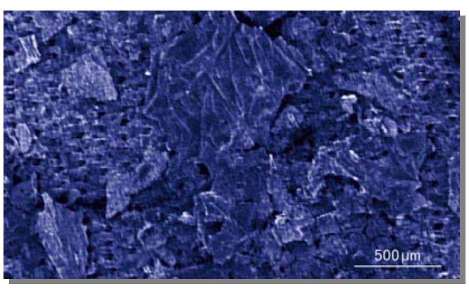
accomplishment is believed to be the highest reported OLED efficiency for blue light in the United States, and among the highest reported worldwide. Blue OLEDs are important in the creation of white light suitable for solid-state general illumination applications, but high-efficiency blue OLEDs with good lifetime and stability have been a significant technical hurdle. Most phosphorescent OLEDs possess an inherent imbalance of charge carriers that limits internal quantum efficiency. The UF team has demonstrated high-efficiency blue OLEDs using a unique charge carrier material with special electrical properties. The team will continue to exploit certain light extraction techniques and special down-converting phosphors that will produce white light from the high-efficiency blue OLEDs developed in their lab. (September 2008)

RPI Demonstrates Efficient Deep-Green Emitting LED Epitaxial Material



The research team at Rensselaer Polytechnic Institute (RPI) demonstrated a significant improvement in the efficiency of deep-green LED materials, which is essential to the color-mixing (red, green, blue) approach for white LEDs. Deep-green LEDs are the least efficient of the three materials required for color mixing. The RPI team demonstrated 555 nanometer deep-green electroluminescence in polar c-axis gallium nitride (GaN) growth, exhibiting 8 mW of light output at 100 A/cm^2. RPI achieved these improved results by reducing defects in the active region of the LED, which involved investigating growth on a variety of polar and non-polar GaN substrates. (August 2008)

Sandia National Laboratory Demonstrates Initial Success in Bulk Crystal Growth



Sandia National Laboratory is working to develop a novel, scalable, cost-effective growth technique for producing low dislocation density bulk GaN substrates for LEDs. Success will impact the efficiency and lifetime of the LED lamp device. Current technology employs an epitaxial structure of a GaN-based semiconductor on a sapphire or silicon carbide substrate, which results in high dislocation densities. Sandia has successfully demonstrated the physics principals of a new proprietary bulk GaN growth technology. The Sandia team will continue this research by growing successively larger boules of crystalline GaN that are suitable as substrates for LEDs. Currently, the lack of quality larger substrates reduces the efficiency and increases the cost of LEDs used in solid-state lighting. (June 2008)

Universal Display Corporation Improves Lifetime of OLEDs

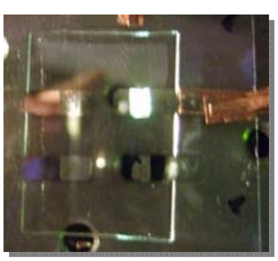
Universal Display Corporation (UDC) researchers continued to improve the feasibility of using OLEDs to replace traditional light sources, and recently demonstrated a lifetime of 80,000 hours in a high-performance OLED device. Lifetimes have previously been a limiting factor to realizing true commercialization potential for general illumination OLED devices, since much of the OLED is organic material. The performance of the measured OLED device was 50 lm/W at 1,000 cd/m^2, which equates to a similar light output from a typical 60-watt incandescent lamp at more than double the efficiency. UDC researchers will continue to advance the efficiency, color, and lifetime of OLED devices. (June 2008)

Universal Display Achieves World Record, Exceeds 100 lm/W in White OLED Performance

In a separate project, UDC successfully demonstrated a record-breaking white OLED

with a power efficacy of 102 lm/W at 1000 cd/m^2. This achievement represents a significant milestone for OLED technology and demonstrates performance that surpasses the power efficacy of incandescent bulbs with less than 15 lm/W and fluorescent lamps at 60-90 lm/W. UDC's achievement is the result of its proprietary, high-efficiency phosphorescent OLED technology, developed in part with R&D funding support from DOE. The achievement represents a major step toward DOE's goal of a 150 lm/W commercial OLED light source by 2015. (June 2008)

University of North Texas Breakthrough Achieves 42 Percent Power Efficiency in White Phosphorescent OLED

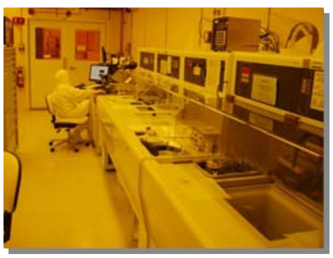


The University of North Texas, partnering with the University of Texas, made significant advances toward their second-year DOE R&D project milestone of 50 percent power efficiency, versus baseline, in OLED devices. The breakthrough relates to obtaining white emission from a single dopant and allows for color tuning by simply varying the doping concentration. Conventional OLEDs obtain white light by employing multiple dopants that produce single colors when combined properly. The UNT strategy results in 42.2 percent power efficiency, compared to baseline, and was determined using electroluminescence. (May 2008)

RTI International Demonstrates Photoluminescent Nanofibers with 70 Percent Quantum Efficiency

RTI International has demonstrated photoluminescent nanofibers containing either yellow or orange quantum dots with quantum efficiencies at 70 percent. To achieve these values, RTI developed a post-fabrication processing routine that improves the quantum efficiency from 30 to 70 percent. This is a significant improvement in phosphor material, which is an essential part of a phosphor-converted LED. Phosphor-converted LEDs use a blue LED with a yellow phosphor coating to produce white light. RTI's photoluminescent nanofibers will be used as the yellow phosphor coating in order to increase the overall efficiency of white LEDs. (April 2008)

LANL Research Defines Trap Mechanisms, Identifies Methods to Increase OLED Efficiency



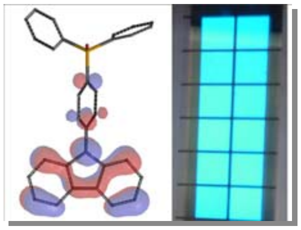
Scientists at Los Alamos National Laboratory (LANL) completed a three-year study for DOE, successfully identifying new ways to increase charge injection and mobility in OLED materials. LANL researchers made significant advances in defining the role of loss mechanisms – called "traps" – that had previously limited efforts to increase device efficiency. Their findings (applicable to both polymeric and small molecule OLEDs) make OLED theoretical models more useful to researchers in the field. Some of their results have already been incorporated into ongoing DOE R&D projects. UDC and General Electric are just two of DOE's R&D partners who are building on the study results to develop practical, inexpensive OLED devices that will meet DOE's future efficacy requirements of more than 50 lm/W by 2012. (February 2008)

Fairfield Crystal Technology Achieves 2-Inch Diameter Aluminum Nitride (AlN) Wafer with Smooth Surface Morphology

Fairfield Crystal Technology demonstrated a 2-inch diameter AlN wafer with smooth surface morphology, a significant improvement over previous AlN wafers, which were limited to a 1-inch diameter. The polished 2-inch wafers have been sent to Yale University for Indium Gallium Nitride deposition, to determine if the larger wafers improve the quality of LED material. The research team is testing the relationship between high-quality AlN wafers and the quality of LED materials in order to make LEDs more efficient for use in general illumination. (February 2008)

PNNL Breakthrough in Material Design Yields Significant Improvement in Blue OLED Performance

Scientists at PNNL made another breakthrough in the development of low-voltage materials key to producing power-efficient blue OLEDs. A new approach to material



design, developed at PNNL, incorporates multiple transport functionalities on suitable host materials for blue organic phosphors. The team has synthesized new host materials that combine hole-transporting fragments with electron-transporting molecules, leading to thermally stable materials that can transport both holes and electrons. The team used these materials to demonstrate 12.6 percent external quantum efficiency at 800 cd/m^2 from a "sky-blue" phosphorescent dopant at only 4.6 V. This is a significant improvement over the previous result of 10.5 percent at 5.3 V, which required doping of the hole transport layer as well as the active layer. (January 2008)

Eastman Kodak Improves Lifetime for All-Fluorescent White OLED
Eastman Kodak Company showed an all-fluorescent white OLED device with a lifetime exceeding 10,000 hours at 1,000 cd/m^2. This achievement was a result of their new

device architecture, where an Internal Extraction Layer (IEL) enables breakthrough extraction efficiency. The research team is working to significantly improve the internal quantum efficiency (IQE), light extraction, device operating voltage, and lifetime of OLED devices. Their approach emphasizes non-phosphorescent designs with the claim that the very high IQE required for success can be achieved using only fluorescent molecules. They continue to make improvements in extraction efficiency and power efficiency, which impacts the device's lifetime. (December 2007)

1.1.2 Recent SSL Program Highlights

February 2009 - DOE SSL R&D Workshop
More than 400 attendees from a variety of sectors interested in SSL - lighting industry leaders, chip makers, fixture manufacturers, researchers, academia, lighting designers, architects, trade associations, energy efficiency organizations, and utilities – participated in the DOE SSL R&D Workshop in San Francisco to share insights and news on technology advances and market developments related to solid-state lighting. Attendees also provided input to guide updates to the DOE SSL R&D Multi-Year Program Plan.

DOE Report Estimates LED Savings in Niche Markets
In September, DOE released analysis findings for niche markets where LEDs compete with or are poised to compete with traditional lighting sources such as incandescent and fluorescent. The report provides estimates of energy savings in 2007 plus potential savings if these markets switched to LEDs overnight. Twelve niche markets were analyzed, comprising four colored-light applications, six indoor white-light applications, and two outdoor white-light applications. LEDs in these markets are already saving consumers nearly $1 billion in electricity costs. If these markets switched to LEDs overnight, energy savings would be the equivalent of taking 16 million residential

households off the grid and could save consumers more than $20 billion in electricity costs. To download a PDF of the report, go to http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/nichefinalreport_october2008.pdf.

Voices for SSL Efficiency 2008: DOE and Northwest Partners Host Market Introduction Workshop

More than 270 attendees gathered in Portland, Oregon, to participate in the "Voices for SSL Efficiency" workshop in July 2008. The workshop, hosted by DOE, Bonneville Power Administration, Energy Trust of Oregon, Northwest Energy Efficiency Alliance, and Puget Sound Energy, was the third DOE meeting to explore how federal, state, and private-sector organizations can work together to guide market introduction of high-performance SSL products. The workshop brought together a diverse gathering of participants – energy efficiency organizations, utilities, government, and industry – to share insights, ideas, and updates on the rapidly evolving SSL market. The three-day workshop included panel discussions on CALiPER testing, ENERGY STAR, and GATEWAY demonstrations, as well as a full day focused on what efficiency programs and utilities are doing now to prepare for high-performance SSL products. A PDF copy of the workshop report is available at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/portland2008_sslreport_d2_final.pdf.

DOE Launches SSL Quality Advocates

At the Portland workshop, DOE announced a new initiative called SSL Quality Advocates. The initiative, jointly developed by DOE and the Next Generation Lighting Industry Alliance (NGLIA), is designed to improve the quality of SSL products and prevent a recurrence of compact fluorescent lamp (CFL) market introduction mistakes. Initial efforts involve the development of guidelines for reporting product performance and a new Lighting Facts™ label, similar to the nutrition label found on food packaging. The label provides essential performance information in five categories – lumen output, luminaire efficacy, power input, correlated color temperature, and color rendering index. These parameters and other recommendations are detailed in a new guide, *Reporting LED Luminaire Product Performance*. In the coming months, DOE will launch a voluntary pledge program to build a growing community of SSL Quality Advocates across the lighting supply chain. Participating manufacturers will agree to follow the guidelines and use the label. Participating partners (retailers, utilities, contractors, designers, and other buyers) will agree to look for and purchase products with this label. To learn more, visit: http://www.lighting-facts.com/.

DOE Initiates Study on Life Cycle Analysis of SSL Technologies

At the Portland workshop, DOE also announced a new study on Life Cycle Analysis of SSL Technologies. The study, under the direction of Dr. H. Scott Matthews, Research Director of the Green Design Institute at Carnegie Mellon University, will focus on a soup-to-nuts assessment of energy and materials costs associated with SSL technology. The first phase will define the parameters of the study, including the identification of key energy and materials issues, the availability of relevant data, and a definition of the study's scope and boundaries. Dr. Matthews will work with industry during this phase in both defining the parameters and acquiring sources of data. The second phase will encompass a comparison of SSL to several mature lighting technologies in both the residential and commercial markets. It will begin with a valuation of raw materials and evolve through the entire product lifecycle, ending with disposal. For DOE, this study is seen as an important step in understanding how the advent of SSL will impact energy consumption, energy and product economics, pollution prevention, and ultimately, environmental decision-making. For additional information, see the workshop report at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/portland2008_sslreport_d2_final.pdf.

L Prize™: Transforming the Lighting Landscape

The Energy Independence and Security Act of 2007 directed DOE to establish the Bright Tomorrow Lighting Prizes (L Prize) competition to accelerate development and adoption of SSL products to replace the common light bulb. In May 2008, DOE launched the L Prize competition at LIGHTFAIR® International. The competition challenges industry to develop replacement technologies for two of today's most widely used and inefficient products: 60W incandescent lamps and PAR 38 halogen lamps. Winners will be eligible for cash prizes, opportunities for federal purchasing agreements, utility programs, and other incentives. Four California utilities – Pacific Gas & Electric, Sacramento Municipal Utility District, San Diego Gas & Electric, and Southern California Edison – worked closely with DOE to establish rigorous technical requirements for the competition. These utilities also signed a Memorandum of Understanding with DOE, agreeing to work cooperatively to promote high-efficiency SSL technologies (see Appendix C). These L Prize partners will conduct field assessments of proposed products and play an important role in promoting and developing markets for the winning L Prize products. Since the competition's launch, a number of additional partners have signed on. For more information, see: www.lightingprize.org.

Lighting Designer Roundtable on SSL Hosted in Chicago

In March 2008, DOE joined with the International Association of Lighting Designers (IALD) and the Illuminating Engineering Society of North America (IESNA) to host an invited group of lighting designers for a Roundtable meeting in Chicago. The focus of the one-day gathering was to examine SSL market and technology issues and to encourage a discussion of the designers' experiences, ideas, and recommendations regarding SSL and the SSL industry. Sixteen lighting designers attended the one-day meeting, along with representatives from DOE. The designers provided valuable input that has already informed DOE planning for several new initiatives, including a new product quality initiative and a life cycle analysis of SSL technology. Attendees also provided feedback on a draft Design Guide developed by IESNA and DOE. A PDF copy of the roundtable report is available at:
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/designer_roundtable_report_final_apr08.pdf.

2008 Transformations in Lighting: Fifth Annual DOE SSL R&D Workshop
In January 2008, more than 300 attendees – lighting industry leaders, chip makers, fixture manufacturers, researchers, academia, trade associations, energy efficiency organizations, and utilities – gathered in Atlanta to share insights and updates on technology advances and market opportunities. The annual DOE SSL workshop provides a forum for building partnerships and strategies to accelerate technology advances and guide market introduction of high-efficiency, high-performance SSL products. At the workshop, DOE recognized four research teams for significant achievements and provided an overview of draft updates to the DOE SSL R&D roadmap for review and comment. Input from attendees guided updates to the DOE SSL R&D Multi-Year Program Plan, published in March. A PDF copy of the workshop report is available at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/workshop_report08.pdf.

DOE Issues Five Competitive Solicitations Related to SSL
During Fiscal Year 2008 (FY'08), DOE issued five competitive solicitations related to SSL:

- Core Technology Research, Round V
- Product Development, Round V
- National Laboratory Call for Core Technology Research, Round V
- Small Business Innovation Research, Phase I
- Small Business Innovation Research, Phase II

In total, DOE reviewed 126 proposals, then selected and initiated 21 projects in FY'08. Selections for Round V solicitations will be made in FY'09.

Results from DOE-Funded Projects: Patents and Publications
As of December 2008, a total of twenty two solid-state lighting patents have been granted as a result of Department of Energy-funded research projects. This demonstrates the value of DOE SSL projects to private companies and notable progress toward commercialization. Since DOE began funding SSL research projects in 2000, a total of 90 patents applications have been applied for or awarded as follows: large businesses - 44, small businesses - 16, universities - 26, and national laboratories - 4.
For the list of patents awarded for DOE funded SSL research, see Appendix E.

1.2 Legislative Directive

Building on the directives issued in the Energy Policy Act of 2005 (EPACT 2005), Pub. L. 109-58, the FY2009 Omnibus Appropriations Act, H.R.1105, enacted on March 11, 2009, authorizes $25 million to the DOE for solid state lighting research and development and directs DOE to implement an Energy Star program for solid state lighting.

> ***"Building Technologies.—The bill provides $140,000,000 for building technologies, to include $33,000,000 for the Commercial Buildings Initiative, and no less than $25,000,000 for solid state lighting research and development. Consistent with section 912(b) of the Energy Policy Act of 2005, the Department shall implement an Energy Star Program for solid state lighting and develop Energy Star specifications for solid state lighting in connection with the nation's efforts to promote the commercialization of these products."***
>
> **FY2009 Omnibus Appropriations Act**

On December 19, 2007, President Bush signed the Energy Independence and Security Act (EISA), Pub. L 110-140 which again builds on EPACT 2005. EISA instituted the "Bright Tomorrow Lighting Prizes." The "Bright Tomorrow Lighting Prizes" establishes prizes for a solid-state lighting product with an efficacy of 90 lm/W to replace an incandescent 60W lamp, a solid-state lighting product with an efficacy of 123 lm/W to replace halogen PAR 38 lamps, and a solid-state lighting product with an efficacy of 150 lm/W. After the prizes are awarded, the Federal Government may purchase the lamps for its own facilities. Excerpts of EISA 2007 that describe all lighting prizes, new energy efficiency standards for lighting, and authorization for a lighting research and development program can be found in Appendix I. More information on the "Bright Tomorrow" Lighting Prizes is at: http://www.lightingprize.org/.

EISA 2007 also mandated increases in the energy efficiency of general service incandescent lamps by 2012 and directs the Secretary of Energy to initiate a rulemaking for general service lamps (LEDs, OLEDs, general service incandescent lamps, and compact fluorescent lamps) by January 1, 2014. This rulemaking is to establish standards for general service lamps that are greater or equal to 45 lm/W by January 1, 2020. EISA 2007 also authorizes a lighting research and development program of $10 million per year for fiscal years 2008-2013, to terminate by September 30, 2015. The legislation specifically directs the Secretary to:

- Support the research, development, demonstration, and commercial application of lamps and related technologies sold, offered for sale, or otherwise made available in the United States
- Assist manufacturers of general service lamps in the manufacturing of general service lamps that, at a minimum, achieve the wattage requirements required by the legislation.

EPACT 2005, enacted on August 8th 2005, issued a directive to the Secretary of Energy to carry out a "Next Generation Lighting Initiative" (NGLI) to support the research and development of solid-state lighting:[4]

> ***"(a) IN GENERAL.—The Secretary shall carry out a Next Generation Lighting Initiative in accordance with this section to support research, development, demonstration, and commercial application activities related to advanced solid-state lighting technologies based on white light emitting diodes.***
> ***(b) OBJECTIVES.—The objectives of the initiative shall be to develop advanced solid-state organic and inorganic lighting technologies based on white light emitting diodes that, compared to incandescent and fluorescent lighting technologies, are longer lasting; more energy-efficient; and cost-competitive, and have less environmental impact…"***
>
> **Energy Policy Act of 2005**

The legislation directs the Secretary of Energy to support research, development, demonstration, and commercial application activities related to advanced solid-state lighting technologies. This law specifically directs the Secretary to:

- Develop SSL technologies based on white LEDs that are longer lasting, more energy-efficient, and cost-competitive compared to traditional lighting technologies.
- Competitively select an Industry Alliance to represent participants that are private, for-profit firms that, as a group, are broadly representative of United States solid-state lighting research, development, infrastructure, and manufacturing expertise.
- Carry out the research activities of the Next Generation Lighting Initiative through competitively awarded grants to researchers, including Industry Alliance participants, National Laboratories, and research institutions.
- Solicit comments to identify SSL research, needs, and progress. Develop roadmaps in consultation with the industry alliance.
- Manage an on-going development, demonstration, and commercial application program for the Next Generation Lighting Initiative through competitively selected awards.

[4] Section 911 of Energy Policy Act of 2005, Pub. L. 109-58, enacted on August 8, 2005, authorizes $50 million for each fiscal year 2007 through 2009 to the NGLI, with extended authorization for the Secretary to allocate $50 million for each of the fiscal years 2010 to 2013. In total, Congress proposed $350 million for R&D investment in SSL.

The Secretary may give preference to participants of the Industry Alliance. Excerpts from EPACT 2005 describing the Next Generation Lighting Initiative can be found in Appendix D.

As a result of the next generation lighting initiative, DOE and the NGLIA signed a Memorandum of Agreement (MOA) detailing a strategy to enhance the manufacturing and commercialization focus of the DOE portfolio by utilizing the expertise of this organization of SSL manufacturers in February 2005. This document can be found in Appendix B.

In addition to signing an MOA with NGLIA, DOE also issued an Exceptional Circumstances Determination to the Bayh-Dole Act to facilitate more rapid commercialization of SSL technologies in June 2005. The determination places guidance on intellectual property generated under the Core Technology program area, which creates technology breakthroughs that can be widely applicable to future products. See Appendix A for a full version of the Exceptional Circumstances Determination.

1.3 International Competition and US Industrial Positioning

The global lighting fixtures market is expected to reach $94 billion by 2010, and solid-state lighting is expected to play a substantial role in the market by that time.[5] Sales of high-brightness LEDs (HB–LEDs), the technology associated with LEDs for lighting applications, were $5.1 billion in 2008.[6] Of these HB-LED revenues, approximately 9% (or $450 million) was attributable to illumination applications.[7]

DOE support of SSL R&D is essential. There is a window of opportunity to establish the United States as a global leader in this technology, retaining intellectual property rights, high tech value-added jobs, and economic growth for the nation. As time passes, foreign companies will try to surpass present U.S. technical know-how and compete with the U.S. to become future suppliers of LED and OLED lighting sources and systems. Losing this emerging industry would mean losing jobs, industry, and more imports. Foreign companies already produce SSL products, which they are marketing in the U.S.

DOE recognizes that steps taken to increase research funding could encourage the production of more energy efficient SSL, thus supporting the conservation goals embedded in the strategic direction of DOE. Through a proactive, collaborative approach, DOE anticipates that its cost-shared projects will deliver substantial energy savings and position U.S. companies as global leaders. SSL R&D investments can help secure our nation's energy future and technological leadership in products, systems and services.

[5] "Lighting fixtures market to exceed $94 billion by 2010." August 2007. Available at: http://www.ledsmagazine.com/news/4/8/3
[6] *Strategies in Light Conference.* Santa Clara, CA. February 18 – 20, 2009.
[7] Does not include signage, mobile appliances, signals, automotive, or electrical equipment.

1.4 Federal Role in Supporting the SSL Initiative

A part of the Department of Energy's overarching mission is to advance the national, economic, and energy security of the United States and to promote scientific and technological innovation in support of that mission. DOE has four strategic goals toward achieving the mission. Of these four goals, the Science Strategic Goal aligns well with the SSL portfolio:

To protect our national and economic security by providing world-class scientific research capacity and advancing scientific knowledge.

The solid-state lighting portfolio funds research, development, and demonstration activities linked to public-private partnerships. The government's current role is to concentrate funding on high-risk, pre-competitive research in the early phases of development. Currently, the majority of the SSL program's activities are in the area of applied technology research and development, which includes efforts that are in our national interest and have potentially significant public benefit, but are too risky or long-term to be conducted by the private sector alone. As SSL activities progress through the stages of developing technology to validating technical targets, the government's relative cost share, although perhaps not its absolute cost burden, will diminish. The government will bring technologies to the point where the private sector can successfully integrate solid-state lighting into buildings and then decide how best to commercialize technologies. And, as this technology advances, the federal role of the Department of Energy will become even more important in order to keep the focus on saving energy.

1.5 DOE Goals and Solid-State Lighting

The SSL Portfolio falls under the Building Technologies Program (BT) in the Office of Energy Efficiency and Renewable Energy. Listed below are the goals of EERE, BT and the SSL Portfolio.

1.5.1 Office of Energy Efficiency and Renewable Energy

The Office of Energy Efficiency and Renewable Energy at the U.S. Department of Energy focuses on researching and accelerating technologies that promote a sustainable energy future. To that end, the strategic goals of EERE are to:

- Dramatically reduce, or even end, dependence on foreign oil;
- Reduce the burden of energy prices on the disadvantaged;
- Increase the viability and deployment of renewable energy technologies;
- Increase the reliability and efficiency of electricity generation, delivery, and use;
- Increase the energy efficiency of buildings and appliances;
- Increase the energy efficiency of industry;
- Spur the creation of a domestic bioindustry;
- Lead by example through government's own actions; and
- Change the way EERE does business.

The EERE mission is to strengthen America's energy security, environmental quality, and economic vitality through public-private partnerships that:

- Enhance energy efficiency and productivity;
- Bring clean, reliable, and affordable energy production and delivery technologies to the marketplace; and
- Make a difference in the everyday lives of Americans by enhancing their energy choices and their quality of life.

David Garman, former Assistant Secretary for Energy Efficiency and Renewable Energy, launched the November 2003 Solid-State Lighting Workshop with a keynote address highlighting the importance of SSL technology. Mr. Garman discussed creating a focused partnership between government and industry, to accelerate SSL technology with the potential to reduce energy consumption, to create affordable long-lasting general illumination technology, to strengthen U.S. leadership in this critical technology area, and to provide the necessary infrastructure (people and policy) to accelerate market adoption. Indicators of success would be two quads of energy per year displaced, a market price of $3 per kilolumen, and the creation of new forms of lighting systems that improve our quality of life.

Mr. Garman outlined the reasons why the United States needs a national research initiative in SSL:

- To maintain its leadership position in SSL, it must compete with other countries' government funding efforts.
- White-light sources represent a higher risk R&D investment that industry is unlikely to fund in the near term.
- The projected energy savings for the U.S. is significant.

1.5.2 Building Technologies Program

The Building Technologies Program is designed to reduce America's growing dependence on energy by developing technologies to increase the energy efficiency of buildings. This mission was chosen because of the benefits associated with reducing building energy consumption, potential energy security, reliability benefits and environmental benefits. Additionally, in support of the President's policies and initiatives, BT has embraced the program goal of developing Zero Energy Buildings (ZEB) to reduce national energy demand.

The mission of DOE's Building Technologies Program is:

> *To create technologies and design approaches that enable net zero energy buildings at low incremental cost by 2025. A net zero energy building is a residential or commercial building with greatly reduced needs for energy through efficiency gains, with the balance of energy needs supplied by renewable technologies. These efficiency gains will have application to buildings constructed*

before 2025 resulting in a substantial reduction in energy use throughout the sector.

1.5.3 Solid-State Lighting Portfolio Goal

The goal of DOE lighting research and development is to increase end-use efficiency in buildings by aggressively researching new and evolving lighting technologies. Working in close collaboration with partners, DOE aims to develop technologies that have the potential to significantly reduce energy consumption for lighting.

To reach this goal, DOE has developed a portfolio of lighting R&D activities, shaped by input from industry leaders, research institutions, universities, trade associations, and national laboratories. Through interactive workshops, DOE and its partners identified SSL as a high-priority research area.

The goal of the SSL portfolio is:

By 2025, develop advanced solid state lighting technologies that, compared to conventional lighting technologies, are much more energy efficient, longer lasting, and cost-competitive by targeting a product system efficiency of 50 percent with lighting that accurately reproduces sunlight spectrum.

This goal of increasing the energy efficiency of lighting technologies directly supports BT's vision of ZEBs. Specifically, SSL sources will "*greatly reduce needs for energy through efficiency gains,"* which reduces the balance of energy consumption that must be supplied by renewable sources. The commercialized efficacy goal of SSL is to reach an order of magnitude increase in efficacy over incandescent luminaires and a two-fold improvement over fluorescent luminaires. Advances in the efficiency of SSL will reduce the number of power plants being constructed and improve the reliability of the grid. This SSL portfolio goal also dovetails directly into EERE's strategic goal to "*increase the energy efficiency of buildings and appliances.*"

This Multi-Year Program Plan provides a description of the activities that the SSL R&D Portfolio will undertake in the period of FY'09 through FY'15 to implement this mission.[8] This plan is a living document, updated periodically to incorporate new analyses and progress, and new research priorities, as science evolves.

[8] In several cases, the technology projections and research task timeline extend slightly beyond this timeframe.

2.0 SSL Technology Status

2.1 Brief History of Lighting Technologies[9]

The last century of lighting has been dominated by incandescent, fluorescent and high-intensity discharge (HID) light sources.

In 1879, Joseph Swan and Thomas Edison independently developed the first electric lamp based on principles of a blackbody radiator. In the United States, Thomas Edison developed the first incandescent lamp using a carbonized sewing thread taken from his wife's sewing box. His first commercial product, using carbonized bamboo fibers, operated at about 60 watts for about 100 hours and had an efficacy of approximately 1.4 lm/W. Further improvements over time have raised the efficacy of the current 120-volt, 60-watt incandescent lamp to about 15 lm/W for products with an average lifetime of 1,000 hours.

In 1901, Peter Cooper Hewitt, an American inventor, patented the first low-pressure mercury vapor (MV) discharge lamp. It was the first prototype of today's modern fluorescent lamp. George Inman, working for General Electric, improved upon this original design and created the first practical fluorescent lamp, introduced at the New York and San Francisco World's Fairs in 1939. Since that time, the efficacy of fluorescent lighting has reached a range of approximately 65-100 lm/W, depending on lamp type and wattage.

In 1801 Sir Humphry Davy, an English chemist, caused platinum strips to glow by passing an electric current through them. In 1810, he demonstrated a discharge lamp to the Royal Institution of Great Britain by creating a small arc between two charcoal rods connected to a battery. This led to the development of high-intensity discharge lighting, but the first high-pressure mercury vapor lamp was not sold until 1932. In 1961, Gilbert Reiling patented the first metal halide (MH) lamp. This lamp demonstrated an increase of lamp efficacy and color properties over MV, which made it more suitable for commercial, street and industrial lighting. The MH lamp was introduced at the 1964 World's Fair. The first high-pressure sodium (HPS) lamp was introduced soon after in 1965. Since that time, the efficacy of HID lighting has reached a range of approximately 45-150 lm/W, a value which again is dependent on lamp type and wattage.

In the 1950s, British scientists conducted experiments on the semiconductor gallium arsenide (GaAs), which exhibited electroluminescence or the emission of a low level of infrared light, leading to the creation of the first "modern" light-emitting diode (LED). In 1962, the first practical visible-spectrum light-emitting diode (LED) was invented at General Electric's Advanced Semiconductor Laboratory.[10] After subsequent improvements in this technology, the first commercial visible (red) light LEDs were fabricated in the late 1960s using gallium arsenide phosphide (GaAsP). In the mid 1970s, green LEDs were produced using gallium phosphide (GaP). The first blue LEDs

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[9] *Lighting a Revolution*. National Museum of American History. Smithsonian Institute.
[10] Holonyak and Bevaqcua, Applied Physics Letter, Volume 1, pp.82-83 (1962).

emerged in the 1990s using gallium nitride (GaN). Combining the red, green, and blue LEDs or coating the blue LEDs with a yellow phosphor led to the creation of white LEDs, a promising, high-efficiency technology for general illumination. Parallel to efforts to create white LEDs, researchers have been working to improve the efficacy of the technology. Present day LED commercial packages have reached efficacies of 101 lm/W, comparable to the efficacies of fluorescent and certain HID lamps.[11, 12]

In the late 1970s, after green LEDs were invented, Dr. Ching Tang at Eastman Kodak discovered that sending an electrical impulse through a carbon compound caused such materials to glow. Continuing research in this vein, Dr. Ching Tang developed the first organic light-emitting diode (OLED). A paper on his research was published in 1987.[13] Since then OLED researchers have developed white OLEDs that have reached efficacies of up to 102 lm/W in the laboratory. Although currently only OLEDs used for display purposes are sold commercially, companies are conducting research in white OLEDs so that commercial products can be sold in the future for general illumination purposes.

The traditional three light sources – incandescent, fluorescent and HID – have evolved to their present performance levels over the last 60 to 120 years of research and development. Industry researchers have studied all aspects of improving the efficiency of these sources, and while marginal incremental improvements are possible, there is little room for significant, paradigm-shifting efficacy improvements. SSL technology, such as LEDs and OLEDs, on the other hand, has potential to achieve a two-fold improvement over some of today's most efficacious white-light sources, based on projections by experts. This projection is illustrated for LEDs below, in Figure 2.1.

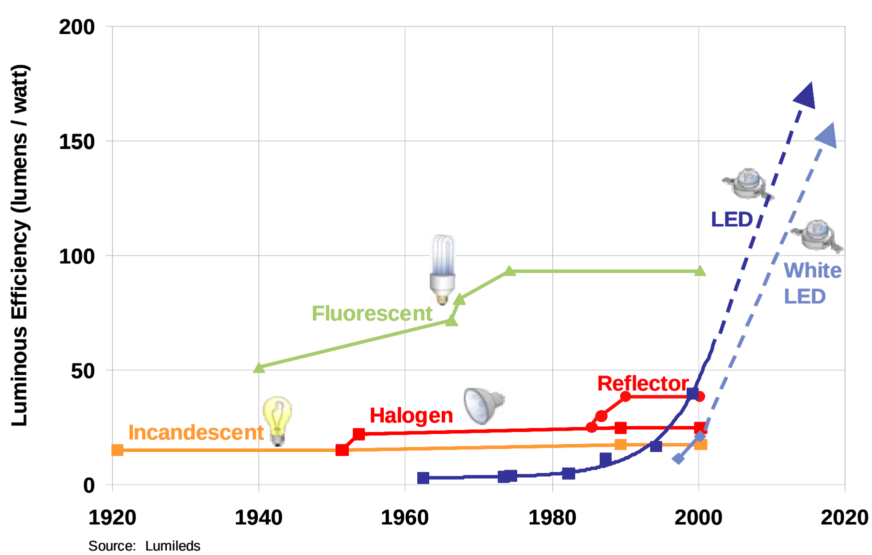

Figure 2.1: Historical and Predicted Efficacy of Light Sources
Source: Lumileds.

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[11] Efficacies of incandescent, fluorescent, and HID lamps from Audin, L., Houghton, D., et al. *Lighting Technology Atlas.* E Source, Inc., Boulder, CO (1997). (p 2.2.5)
[12] For a definition of "LED Package," see Section 4.1.1.
[13] C. W. Tang, S. A. VanSlyke, Organic electroluminescent diodes, Appl. Phys. Lett. 1987, 51, 913

2.2 Current National Lighting Needs

Lighting is the second largest end-use of energy in buildings.[14] New lighting technologies offer one of the greatest opportunities for energy savings potential within the building sector.

2.2.1 Lighting Energy Use in Buildings

In 2001, energy consumption for all lighting in the U.S. was estimated to be 8.2 quads, or about 22% of the total electricity generated in the U.S.[15] Figure 2.2 provides a break-down by end-use sector of the energy consumption for lighting our homes, offices and other metered applications around the country.

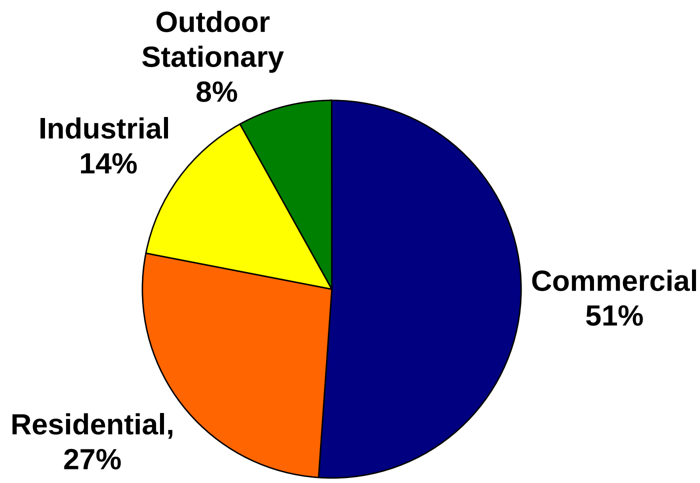

Figure 2.2: Total U.S. Primary Energy Consumption for Lighting by Sector 2001
Source: *U.S. Lighting Market Characterization Volume I: National Lighting Inventory and Energy Consumption Estimate.* Prepared by Navigant Consulting, Inc. for the Department of Energy. Washington D.C. September 2002.

Figure 2.2 shows that more than half of these 8.2 quads consumed in 2001 were for the commercial sector, the largest energy user for lighting. This is one of the principal markets the DOE has targeted to develop more efficient technologies. Lighting also contributes to a building's internal heat generation and subsequent air-conditioning loads.

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[14] Building Energy Databook 2008. Available at http://buildingsdatabook.eren.doe.gov/

[15] In 2001, total energy consumption was 98.3 quads, of which about a third – 37 quads - was used for electricity production. (Annual Energy Outlook, 2002; Table 2 Energy Consumption by Sector and Source) In 2008 total energy consumption was 100.88 quads, of which approximately 41 quads were used for electricity production (Annual Energy Outlook, 2009; Table 2 Energy Consumption by Sector and Source).

Excluding outdoor applications, total energy use for lighting was approximately 6.4 quads. Lighting consumed approximately 17.6% of total building energy consumption across the commercial and residential sectors, or approximately 30.3% of commercial and residential total building electricity use.

2.2.2 Description of Competing Technologies

While Figure 2.2 presented the end-use energy for lighting in terms of primary energy consumption (quads), Figure 2.3 presents the same data, disaggregated by sources, in terms of terawatt-hours per year (TWh/yr). These units represent the electrical energy measured by the site meters for lighting throughout the United States. Figure 2.3 illustrates the end-use electricity consumed by incandescent, fluorescent and high-intensity discharge lamps.

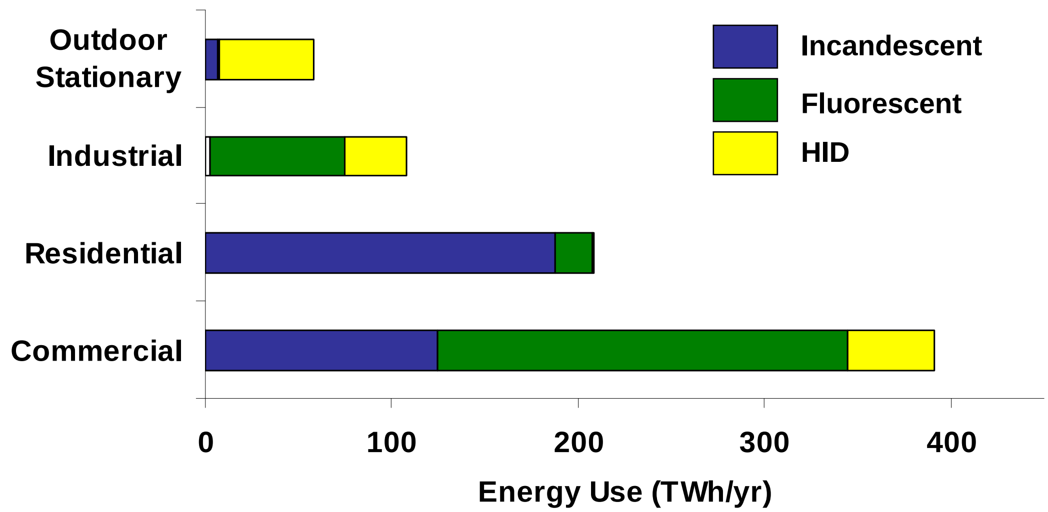


Figure 2.3: Lighting Energy Consumption by Sector & Source
Source: *U.S. Lighting Market Characterization Volume I: National Lighting Inventory and Energy Consumption Estimate.* Prepared by Navigant Consulting, Inc. for the Department of Energy. Washington D.C. September 2002.

The lighting end-use energy consumption chart in Figure 2.3 shows that fluorescent sources in the commercial sector were the single largest energy-consuming segment in the U.S. in 2001, slightly greater than incandescent sources in the residential sector. However, across all sectors, incandescent lighting was the leading energy consumer in the U.S., consuming 321 terawatt-hours per year (TWh/yr). Fluorescent lighting was second with about 313 TWh/yr and HID was third with approximately 130 TWh/yr. As noted in Section 2.4.3, this may change as a result of current legislation.

Figure 2.3 shows that outdoor stationary energy consumption was primarily from HID sources in 2001, which accounted for 87% of its 58 TWh/year of electricity use. The industrial sector had sizable energy shares of both fluorescent and HID sources, 67% and 31% respectively, of this sector's 108 TWh/year consumption. The commercial sector was the largest energy user overall, having large quantities of energy used by all three light sources. Fluorescent and incandescent sources were the two largest commercial lighting energy users, accounting for 56% and 32% of its annual 391 TWh/year of electricity use in 2001. In the residential sector, energy use for lighting was primarily driven by incandescent technologies; 90% of the lighting energy was consumed by this light source.

In September 2005, the DOE published U.S. Lighting Market Characterization Volume II: Energy Efficient Lighting Technology Options.[16] This report looks broadly at energy-efficient options in lighting and identifies leading opportunities. Volume II presents fifty-two technology options that promise to save energy or demonstrate energy savings potential. The options encompass both conventional technologies such as incandescent, fluorescent, and HID, as well as SSL.

2.3 Current Technology Status

2.3.1 Performance of Light Sources

Table 2.3.1 presents the typical performance of 2008 LED products on the market[17] in comparison to conventional technologies. Some of the LED products available today are marketed as "energy-efficient" but actually have very low light output compared to typical light sources. The combination of high price and low light output may actually make them a poor replacement for current technology. It is important to compare new LED products to the most efficient conventional technology (such as fluorescent, incandescent, or metal halide) that could be used for any specific application. As LED technology advances, costs decrease, and efficiency improves, LEDs will build market share in the general illumination market.

[16] *U.S. Lighting Market Characterization Volume II: Energy Efficient Lighting Technology Options.* Prepared by Navigant Consulting, Inc. for the Department of Energy. Washington D.C. September 2005. Available at: http://www.eere.energy.gov/buildings/info/documents/pdfs/ee_lightingvolII.pdf

[17] It should be noted that LED laboratory prototypes reach much higher efficacies than those listed in Table 2.3.1.

Table 2.3.1: Typical Performance of LED Packages and Conventional Technologies

Color	Luminous Output	Wattage	Luminous Efficacy	CCT (Typical)/ Dominant Wavelength	CRI	Lifetime
White	45 lm	1W	101 lm/W	5500°K	70	50k hours
Warm White	20 lm	1W	72 lm/W	3300°K	90	50k hours
Green	53 lm	1W	53 lm/W	530 nm	N/A	50k hours
Blue	16 lm	1W	16 lm/W	470 nm	N/A	50k hours
Red	42 lm	1W	58 lm/W	625 nm	N/A	50k hours
Amber	42 lm	1W	50 lm/W	590 nm	N/A	50k hours
Incandescent	850 lm	60W	14 lm/W	3300°K	100	1k hours
Fluorescent	5300 lm	32W	83 lm/W	4100°K	78	20k hours
HID	24,000 lm	400W	80 lm/W	4000°K	65	24k hours

Notes: For LED packages - drive current = 350ma, 1W device, T_j=25°C, batwing distribution, lifetime measured at 70% lumen maintenance. Lumen output is measure in mean lumens. "LED package" is defined in Section 4.1.1.
Source: Seoul Semiconductor, 2008. CREE, 2008. GE, 2008. Philips Lighting, 2008. OSRAM Sylvania, 2008, Nichia, 2008. Product Catalogs. DOE LED Technical Committee, 2008.

2.3.2 First Cost of Light Sources

The prices of light sources are typically compared on a price per kilolumen basis. The first costs for today's principal lamps indicate the degree of the challenge facing SSL in the marketplace in 2008:

Incandescent Lamp (A19 60W)	$0.30	per kilolumen
Compact Fluorescent Lamp (13W)	$2	per kilolumen
Fluorescent Lamp-and-Ballast System (F32T8)	$4	per kilolumen
Integrated LED Lamp[18]	$170	per kilolumen[19]

Although on a normalized light output basis LEDs are more than 560 times the cost of the incandescent light bulb and almost 90 times the cost of a CFL,[20] the price of the LED has significantly dropped over the years and will continue to drop. However, over the next several years, as performance improves and price drops, LED light sources are projected to become competitive on a first-cost basis.

[18] "Integrated LED lamp" is defined in Section 4.1.1.
[19] Assumes integrated LED lamp, 13 W self-ballasted compact fluorescent lamp, 2-lamp 32 W T8 linear fluorescent lamp-and-ballast system, and 60 W A19 incandescent lamp with 2008 prices.
[20] Because LEDs can be more directional than conventional technologies, comparing them on a lumen per lumen basis based on the lamp may not be entirely accurate. For example, if a CFL and LED lamp emitted the same lumens, there could be more light from the LED luminaire reaching a specific surface than the light from the CFL luminaire.

The following chart, Figure 2.4, shows how the light output of LEDs has increased 20 fold each decade for the last 40 years, while the cost ($/lumen) has decreased ten-fold each decade over that same time period. Figure 2.4 also shows predictions for price and light output over the next two decades.

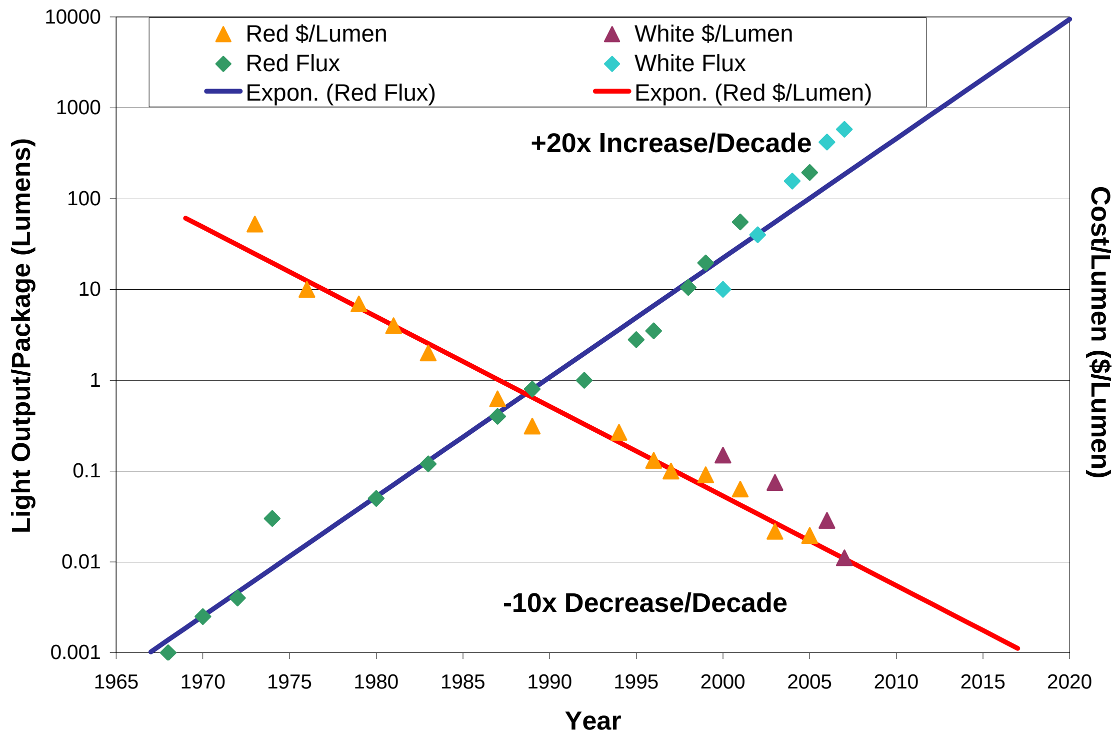


Figure 2.4: Haitz's Law: LED Light Output Increasing / Cost Decreasing
Source: Roland Haitz and Lumileds.
Note: Both lines are on the same numerical scale (with different units)

2.3.3 The Cost of Light[21]

Considering the value of energy savings and lifetime may allow a modest premium over the initial cost of traditional technologies. Life-cycle cost, the effective "cost of light," can be estimated by including lamp cost, energy consumption and maintenance over a lighting service period. The units used for this lighting service period are dollars per kilolumen-hours ($/klm-hr): [22]

[21] "Cost of Light – When does Solid-state Lighting make Cents?" by Kevin Dowling, Color Kinetics, September 12, 2003.
[22] IES Lighting Handbook, 8th Edition. Lighting Economics, p501-2.

$$CostOfLight = \left(\frac{10}{LampLumens}\right) \times \left(\frac{LampCost + LaborCost}{Lifetime} + EnergyUse \times EnergyCost\right)$$ [21]

Where:

LampLumens = the light output of the lamp measured in lumens

LampCost = the initial cost (first cost) of the lamp in dollars

LaborCost = the labor cost necessary to replace a lamp in dollars

Lifetime = the useful operating life of the lamp, expressed in 1000 hours

EnergyUse = the power consumption of the lamp, expressed in watts

EnergyCost = the cost of the electricity necessary to operate lamp in $/kWh

By this measure, it can be argued that LED-based illumination is already a viable alternative for many applications and, due its many non-energy benefits, has already carved out niches in selected markets (see Section 2.4). Due to the advantages of LED-based white-light technology, market penetration is expected to grow into the arena of general illumination.

For instance, although incandescent lamps have a very low cost and high lumen output compared with LEDs, the LED source has a much longer lifetime and consumes far less power. In fact, using the equation above and looking at a finite quantity of light emission (one million lumen-hours), typical LEDs already have a slightly lower “cost of light” than incandescent and halogen sources today. While consumers may not always acknowledge the full lifetime benefit of LED technologies, many will be willing to pay some portion of this energy savings as a first-cost premium.

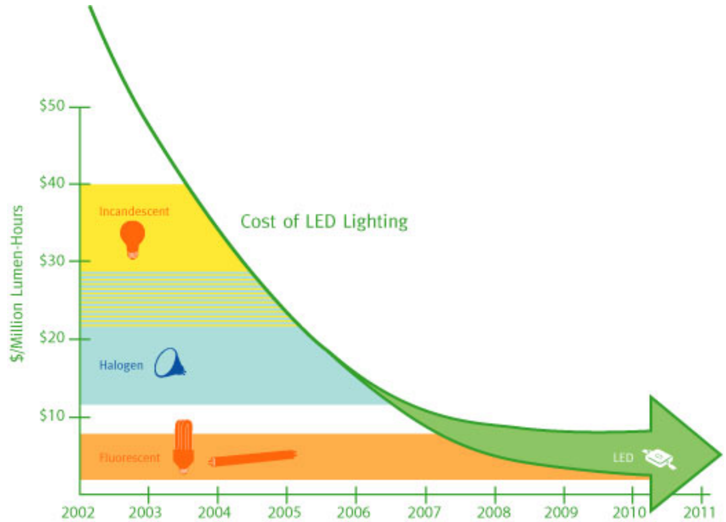


Figure 2.5: Cost of Light

Note/Source: To see how these values were calculated, please see the complete paper: "Cost of Light – When does Solid-state Lighting make Cents?" by Kevin Dowling, Color Kinetics, September 12, 2003 Available at: http://www.colorkinetics.com/support/whitepapers/CostofLight.pdf and http://www.colorkinetics.com/energy/cost/

In the case of conventional technologies, the price and performance are not projected to change drastically, and the cost of light will remain relatively constant. However, as LED efficacy improves and the first cost decreases, the "cost of light" for LED lighting will decrease, and eventually reach the point where it is more cost effective on a life-cycle basis than fluorescent lighting.

In addition, all of the comparisons in this study deal with economics and not the technical features of the light sources. For example, LEDs are ideal for use in extreme environments (e.g., high vibration, extreme cold) or in applications where the light emission must not include UV. The properties of LEDs enable a strong argument for use of LED light sources over traditional technologies.

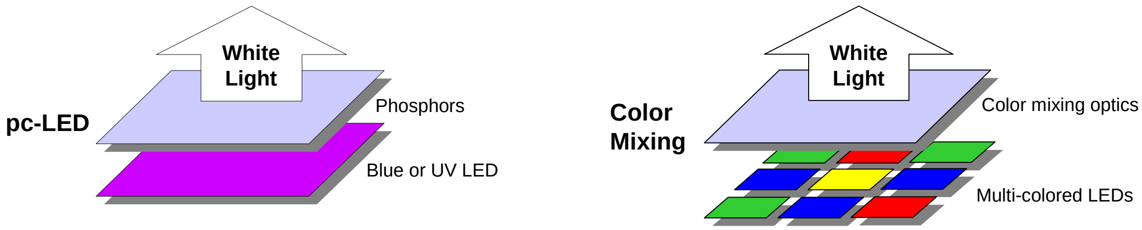
2.3.4 Technology Status: Inorganic Light-Emitting Diodes

In 1962, the first practical visible-spectrum LED was invented at General Electric's Advanced Semiconductor Laboratory.[23] This LED consisted of a GaAsP alloy with a p-n homojunction. The performance of this technology improved over the next few years, culminating in the commercial release of red LEDs in the late 1960s. While the efficacy of these first LEDs was extremely low (~ 0.1 lm/W), researchers continued to improve the technology over the next three decades, achieving higher efficiencies and expanding the range of emission wavelengths through the engineering of new III-V alloy systems, thus providing the wide array of high-brightness LEDs on today's market.

LEDs are discrete semiconductor devices with a narrow-band emission that can be manufactured to emit in the ultraviolet (UV), visible or infrared regions of the spectrum.

[23] Holonyak and Bevaqcua, Applied Physics Letter, Volume 1, pp.82-83 (1962).

Alone, these LED dies[24] are not well suited for general illumination applications as they do not produce the white light required in these applications. To generate white light for general illumination applications, the narrow spectral band of an LED's emission must be converted into white light, or two (or more) discrete emissions must be mixed. White-light LED luminaires are typically based on one of two common approaches: (a) phosphor-conversion, and (b) discrete color-mixing. Figure 2.6 shows these two approaches to white-light production. There are also "hybrid" LED luminaires that generate white light using a combination of phosphor conversion and color-mixing.



(a) Phosphor-Conversion LED (pc-LED) **(b) Color-Mixing LED**

Figure 2.6: General Types of White-Light LED Packages

The phosphor-converting LEDs primarily create white light by blending a portion of the blue light emitted directly from the die with light emission down-converted by a phosphor. Discrete color-mixing packages, on the other hand, utilize color mixing optics to blend together the light output from discrete colored sources, creating white light.

In the phosphor-converting blue LED approach, an LED die emits blue light, generally around 460nm. Some of this light is emitted directly, and some of it is down-converted by a phosphor from the 460nm wavelength (blue) to longer wavelengths (e.g., green, yellow, red) with wide-band emissions that blend with the blue to produce white light. Nichia was the first manufacturer to use this method to produce white-light LED packages on a commercial scale in 1997. It has since been adopted by numerous other manufacturers as a method for generating white light. Some manufacturers have successfully lowered the color correlated temperature and increased the color rendering index by adding a second phosphor to the package, but at a cost to package efficacy. These "warm-white" packages are currently available at high power with an efficacy of 72 lm/W and a CCT of 3000K.

One of the problems confronting manufacturers of pc-LED devices is the difficulty of maintaining consistent-quality white light due to natural variations in LED (blue or UV) wavelength or in the phosphors. The white light produced by pc-LEDs is susceptible to variations in LED optical power, peak emission wavelength, temperature and optical characteristics. Thus, variations in color appearance can occur from one pc-LED to another, a potentially serious problem for many lighting applications.

Although improvements in phosphor technology will help, the Stokes loss is an inevitable limitation to the efficiency. Discrete color-mixing is thought by many, for this reason, to

[24] For a definition of "LED die," see Section 4.1.1.

promise the highest-efficacy device. In color-mixing, LED packages mix discrete emissions from two or more LED dies to generate white light. This approach is accompanied by its own manufacturing challenges for blending the discrete colors. Analysis has shown, however, that with the color-mixing approach, high-quality, efficacious white light can be produced. For example, three discrete color elements can produce white light at a CCT of 4100K with 80 CRI at a cumulative electrical luminous efficacy of approximately 198 lm/W_e, assuming a device efficiency of 69% (see Section 4.2.1).[25] The principal advantage of the color-mixing method is that it does not involve phosphors, thereby eliminating phosphor conversion losses in the production of white light. The largest challenge is the absence of efficient emitters of green light, which significantly limits achievable efficacy. Another drawback is increased complexity. Blending discrete colors potentially requires multi-die mounting and potentially sophisticated optics. It may also require color control feedback circuitry to address the different degradation and thermal characteristics of the discrete LED dies.

2.3.5 Technology Status: Organic Light-Emitting Diodes

OLEDs are thin-film multi-layer devices based on organic carbon molecules or polymers. They consist of: 1) a substrate foil, film or plate (rigid or flexible), 2) an electrode layer, 3) layers of active materials, 4) a counter electrode layer, and 5) a protective barrier layer.[26] At least one of the electrodes must be transparent to light. For a diagram of an OLED, see Figure 4.2.

Materials used in OLED devices have broad emission spectra. This gives OLEDs an advantage over LEDs in that minor changes in the chemical composition of the emissive structure can tune the emission peak of the device. Therefore, getting good-quality white light from OLEDs is easier and it is anticipated that the quality of the white light will improve with the science.

OLED technology for general illumination applications is in a nascent, yet critical, stage of development. Although currently OLEDs used for display applications are being commercialized, experts agree that without a substantial infusion of capital, OLED technologies developed for general illumination applications may not be commercialized until 2015. Currently, only a niche OLED lamp exists; it is produced at a high price and in very limited quantities (see Section 4.2). Companies overseas, with support from their governments, may develop an insurmountable technological lead and make it difficult for U.S. manufacturers to compete. However, as the U.S. government invests in this technology, OLED commercialization may be accelerated in the U.S.[27]

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[25] Electrical luminous efficacy (in lm/W_e) measures the amount of useful visible light out of a device per unit of electrical energy into the device.

[26] *Organic Light Emitting Diodes (OLEDs) for General Illumination: An OIDA Technology Roadmap Update 2002*. Optoelectronics Industry Development Association. November 2002. Available at: http://lighting.sandia.gov/lightingdocs/OIDA_SSL_OLED_Roadmap_Full.pdf.

[27] *Organic Light Emitting Diodes (OLEDs) for General Illumination: An OIDA Technology Roadmap Update 2002.* Optoelectronics Industry Development Association. November 2002.

Although much of the work for this technology is exploratory and far from commercialization, research is being conducted in industry as well as research institutions and academia. For example, SSL divisions of General Electric, Osram Sylvania, and Philips Electronics are participating in the research, positioning themselves to participate in this market when white-light OLEDs become a reality.[28] Currently, the best laboratory OLED devices have efficacies of approximately 102 lm/W.

2.3.6 Technology Trends

While LED and OLED research progresses, conventional lighting technologies are improving in efficacy and cost as well through the efforts of the major manufacturers, raising the bar for market penetration of solid state lighting even higher. This section outlines the research directions for conventional and solid-state lighting technologies and the potential for higher efficacy lamps from this research.

Current incandescent light sources range in efficacy from 3 to 20 lm/W.[29] Research being conducted on higher-temperature incandescent light sources has the potential to raise these efficacies to 26.5 lm/W. Basic and applied research is also being conducted on selective radiators that tailor the spectrum of incandescent emissions to maximize emission in the visible spectrum. Some researchers claim that this technology may allow incandescent sources to achieve efficacies of 80 lm/W.[30]

Fluorescent sources are typically more efficient than incandescent sources. Efficacies for this technology range from 25 to 103 lm/W.[29] Linear and compact fluorescent lamp technology can improve in efficacy through a variety of research efforts. For example, researchers estimate that basic and applied research on multi-photon phosphors has the potential to raise efficacies of this light source to 200 lm/W.[30]

High-intensity discharge lamps are the most efficacious lamps currently on the market, with efficacies ranging from 25 to 150 lm/W.[29] Efforts are underway to improve the energy efficiency of high-intensity discharge lamps (which includes mercury vapor, metal halide and high-pressure sodium lamps).

Commercial LED devices have the potential to surpass the efficacy of conventional light sources. Although the range in efficacy for commercial LEDs is currently 63 to 101

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[28] For the display industry, more than 70 companies--ranging from the OLED pioneer, Eastman Kodak, to DuPont and eMagin, a small microdisplay company based in New York--are ready to bring OLED displays to market. In March 2003, Kodak launched the first digital camera incorporating a full color OLED display. In December 2007, Sony started production on an 11” OLED TV called the XEL-1.

[29] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Final Report: U.S. Lighting Market Characterization, Volume I: National Lighting Inventory and Energy Consumption Estimate. 2002. Washington, D.C. Available at:
< www.eere.energy.gov/buildings/info/documents/pdfs/lmc_vol1_final.pdf>

[30] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Final Report: U.S. Lighting Market Characterization Volume II: Energy Efficient Lighting Technology Options. 2005. Washington D.C. Available at:
http://www.eere.energy.gov/buildings/info/documents/pdfs/ee_lightingvolII.pdf

lm/W,[31] research in a variety of areas, as outlined in this report, may raise the efficacy of LEDs to approximately 230 lm/W. Laboratory efficacies for OLEDs are beginning to surpass efficacies of conventional technologies. The best laboratory efficacy for an OLED device is currently around 102 lm/W. More research needs to be done to realize the potential of this technology for creating efficient white light.

2.4 Current Market Status

2.4.1 Market Status

Presently, BT's SSL R&D portfolio is investing in activities to improve efficiency, performance, lifetime, and quality of light. While SSL sources are just starting to compete for market share in general illumination applications, recent technical advances have made LEDs cost-effective in many colored-light niche applications. LED technology is capturing these new applications because it offers a better quality, cost-effective lighting service compared to less efficient conventional light sources such as incandescent or neon. In addition to energy savings, LEDs offer longer operating life (>50,000 hours), lower operating costs, improved durability, compact size and shorter startup time. Recognizing this fact, EPACT 2005 requires that all exit signs and traffic signals manufactured after January 1st, 2006 conform to ENERGY STAR performance criteria, which in effect, converts these colored-light applications to LED sources.

Applications for white-light LED products include LED task lights, downlights, under-cabinet lighting, and outdoor lights. At the 2007 Solar Decathlon,[32] many of the universities' solar homes featured these products. Figure 2.7 shows photographs from this event of integrated LED lighting products that the university teams chose to incorporate into their designs.

[31] Seoul Semiconductor, 2007. CREE, 2007. GE, 2007. Philips Lighting, 2007. OSRAM Sylvania, 2007. Product Catalogs. DOE LED Technical Committee, 2008.
[32] For more information on this event, see http://www.solardecathlon.org/.

Figure 2.7: LED Technologies Employed during 2007 Solar Decathlon

In addition to the applications listed above, LEDs currently are beginning to compete with HID lamps in street lighting applications. Several cities including Raleigh, NC, Austin, TX, and Ann Arbor, MI have begun installing LED street and area lights to save both on energy and maintenance costs.[33] DOE's Solid-State Lighting GATEWAY program has demonstrated installations of outdoor SSL systems in several other areas across the country.[34] LEDs also have the potential to compete in many other applications. DOE partnered with the partnered with the Illuminating Engineering Society of North America (IESNA) and the International Association of Lighting Designers (IALD) to sponsor a design competition called "Next Generation Luminaires" to encourage the use of LEDs in a variety of applications. In the 2008 competition, winning fixtures included a spotlight, a step light, and jewelry display case lighting.[35] The Memorandum of Understanding between DOE and the IESNA is located in Appendix G, and the Memorandum of Understanding between DOE and the IALD is located in Appendix H.

A 2008 study[36] analyzed the energy savings potential of LEDs in twelve niche markets. Figure 2.8 summarizes the on-site electricity savings and coal power plants avoided from

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[33] Details about the LED city program are available at: http://www.ledcity.org/.
[34] DOE's Solid-State Lighting GATEWAY program is at: http://www1.eere.energy.gov/buildings/ssl/gatewaydemos.html
[35] Details about the "Next Generation Luminaires" competition is available at: http://www.ngldc.org/.
[36] To review the complete analysis, please refer to the report- "Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications," which can be found at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/nichefinalreport_october2008.pdf.

the six of the twelve niche markets. As shown, LEDs are achieving high levels of market penetration for some niche applications.

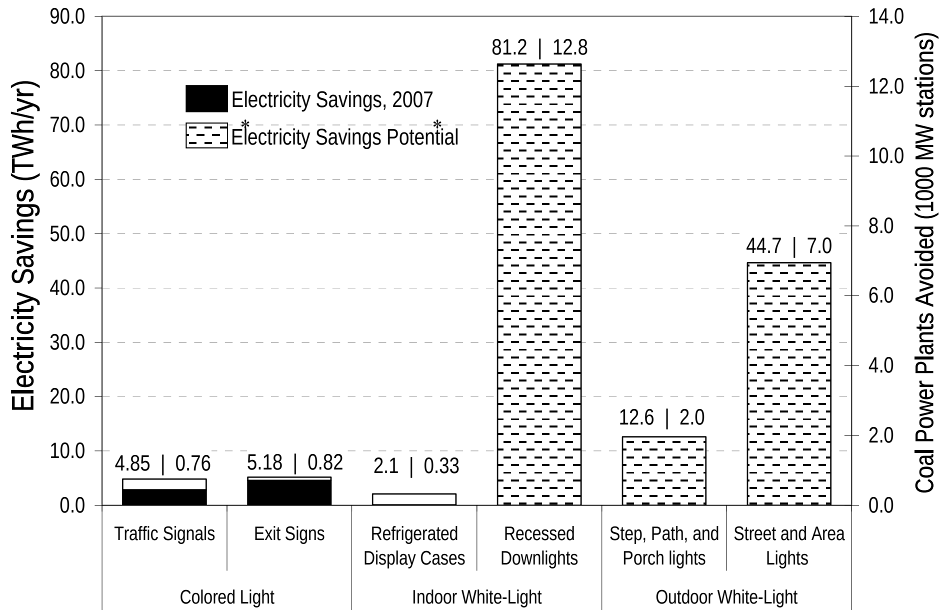

Figure 2.8: Electricity Saved, Coal Plants Avoided, and Potential Savings of Selected Niche Applications

Source: *Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications*. Prepared by Navigant Consulting, Inc. for the Department of Energy. Washington D.C. October 2008.

Considering only those applications that are grid-connected, approximately 8.7 TWh of electricity consumption was saved in 2007, more than the equivalent output of one large (1,000 MW) electric power station.   The following summarizes the findings for three of those niche applications:

Recessed Downlights**.** In 2007, there were approximately 829 million recessed downlights installed in commercial and residential buildings in the United States. These lamps used 103.1 TWh of energy. About 17% of the downlights were CFLs. Currently, the penetration of LEDs into the recessed downlight market is almost negligible. A complete conversion of the installed base of recessed downlights to LED technologies could save the nation about 81.2 TWh, or 876.6 TBtu of primary energy.

Step, Path, and Porch Lights**.** The penetration of LEDs into the residential outdoor step, path, and porch light market has also been negligible. Though 17% of the approximately 265 million step, path, and porch lights were CFLs in 2007, the majority of outdoor lights in these areas (82%) are particularly power-intensive incandescent and halogen systems. A complete conversion of residential step, path, and porch lights over to LED technologies would save the nation 12.6 TWh, or 136.3 TBtu of primary energy.

Street and Area Lights**.** In 2007, the majority of the 131 million street and area lights in the United States were high pressure sodium lamps, with metal halide and mercury vapor technologies comprising additional large portions of the installed base. LED lamps currently have a negligible penetration in this market. 44.7 TWh of energy (about 482.0 TBtu of primary energy) could be saved with a complete conversion of street and area lights to LED technologies. This is about 24% of the maximum energy that could be saved if all of the lamps in the twelve niche markets analyzed by this study were converted to LEDs.

LEDs can currently be found in a range of niche market applications. And, as LED technology advances – reducing costs and improving efficiency – LEDs will build market share in these and other markets.

2.4.2 Market Share

The market share of lighting technologies such as incandescent lamps, compact and linear fluorescent lamps, high-intensity discharge lamps, and solid-state lamps varies by market sector. Table 2.4.1 illustrates the average number of lamps that existed in residential, commercial, and industrial buildings in 2001, disaggregated by technology type. Close to 63% of all lamps in the market were incandescent lamps while almost 35% of these lamps were fluorescent.

Table 2.4.1: Average Number of Lamps per Building and Total Lamps, 2001

Technologies	Residential	Commercial	Industrial	Total Lamps in U.S. (millions)	Percent of Lamps
Incandescent	39	91	33	4,397	63%
Fluorescent	6	324	1340	3	35%
HID	0.04	7	67	105	2%
Solid State	0	0.4	0.3	2	0.03%
Total	45	422	1440	6,977	100%
Number of Buildings (millions)	106.9	4.6	0.2	n/a	n/a

Source: *U.S. Lighting Market Characterization Volume I: National Lighting Inventory and Energy Consumption Estimate.* Prepared by Navigant Consulting, Inc. for the Department of Energy. Washington D.C. September 2002.

Although incandescent lamps accounted for the largest number of installations in 2001, they provided only 12% of the total amount of light delivered in the United States. Fluorescent lamps, on the other hand, provided the majority of light at 62% while HID sources provided around 26% of light delivered in the country.[37] Note that the data in Table 2.4.1 represents the lighting market share for the year 2001. LEDs for general illumination have since increased substantially in efficacy and become less expensive such that they are beginning to enter the market, as described in Section 2.4.3.

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[37] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Energy Conservation Program for Consumer Products: Final Report: U.S. Lighting Market Characterization, Volume I: National Lighting Inventory and Energy Consumption Estimate. 2002. Washington, D.C. Available at: < www.eere.energy.gov/buildings/info/documents/pdfs/lmc_vol1_final.pdf>

2.4.3 Market Views

The lighting market faces major challenges in shifting to more energy-efficient technologies because the people who decide which lighting system to purchase (typically building contractors) are rarely those who pay the electricity of the building (building owners or renters). Because of these "split incentives," building contractors and thus lighting manufacturers focus on low first-cost lighting instead of more expensive energy-efficient lighting products that would cost the consumer less over the long term. Therefore, the federal government must take a leading role in supporting investments in energy-efficient lighting. This section outlines the view of industry and academic partners of the market prospects of the major lighting technologies in the market: incandescents, fluorescents, HID lamps, LEDs, and OLEDs.

After more than a century of dominance, incandescent lamps are facing serious competition in the form of energy-efficient linear and compact fluorescent lamps. The UNDP-UNEP-GEF[38] has a global initiative to support the phaseout of incandescent lamps in non-OECD[39] countries.[40] On April 25, 2007, the Canadian Government announced its commitment to phase out the use of inefficient incandescent lamps.[41] In addition, lamp manufacturers have made voluntary commitments to improve the efficacy of incandescent lamps. For example, in June 2007, European lighting manufacturers proposed standards for incandescent lamps. In addition, EISA 2007 established efficiency standards for incandescent lamps in the U.S. These standards would increase the average efficacy of incandescent lamps to at least 18 lm/W by 2014. In 2020, the efficacies of general service lamps must be at least 45 lm/W. This standard may phase out the use of incandescent lamps entirely.

Compact fluorescent lamps (CFLs), on the other hand, are becoming more popular as lighting energy efficiency standards are being increased and commercial, industrial, and municipal consumers are making energy efficiency retrofits. However, there is still some resistance to switching to CFLs in the residential market because of consumer familiarity with the warm-white light produced by incandescents and the low initial cost of these lamps.

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[38] UNDP-UNEP-GEF is a partnership among the United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), and Global Environment Facility (GEF).

[39] OECD stands for the Organisation for Economic Cooperation and Development. OECD member countries include Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungry, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

[40] International Energy Agency—Energy Efficiency and Environment Division. *European Policy Developments Concerning Incandescent Lighting*. 2007. <ftp://ftp.nrcan.gc.ca/pub/outgoing/lighting/Europe%20-%20%20Paul%20Waide.ppt#355,1,European policy developments concerning incandescent lighting>

[41] Greentech Media. "The Lighting Market by the Numbers, Courtesy of Philips Chairman." October 2008. Available at: http://greenlight.greentechmedia.com/2008/10/22/the-lighting-market-by-the-numbers-courtesy-of-philips-chairman-676/

In the commercial and industrial sector, the market is moving toward the use of more energy efficient electronic fluorescent lamp ballasts. In addition, high-intensity discharge lamps such as mercury vapor, metal halide, and high-pressure sodium lamps have been the most common lighting technologies in use for outdoor area lighting. The less-efficient mercury vapor lamps are currently being replaced by the more-efficient metal halide lamps. Conventional HID lamps are also beginning to face some competition from LEDs for certain niche applications.

High-brightness LEDs are expanding from use as indicator lights in traffic signals and exit signs to usage for general illumination purposes. Sales of HB-LEDs were $5.1 billion in 2008.[6] Of the HB-LED revenues, approximately 9%, or $450 million, was attributable to general illumination applications.[6] LEDs form a small but rapidly growing segment of the global lighting market, estimated at $75 billion a year in 2008.[42] The U.S accounted for approximately 20% of the market ($15 billion).

OLEDs are still being improved in the lab, with a best reported efficacy for a white LED at 102 lm/W. Manufacturers are waiting for OLED efficacies to improve before investing in the capital-intensive manufacturing infrastructure needed to produce commercial products at high volumes.

[42] Lighting Market size from "Building a better, greener light bulb." http://money.cnn.com/2007/02/13/magazines/fortune/gunther_pluggedin_lightbulb.fortune/index.htm?section=magazines_fortune. (2007).

3.0 Current Portfolio and Funding Opportunities

This chapter offers a description of the SSL current funding mechanisms, and an overview of the projects in the current project portfolio.

3.1 Current SSL Project Portfolio

This section provides an overview of the currents projects in the SSL portfolio (as of February 2009). The SSL Project Portfolio is grouped into four topic areas:

Group 1: Inorganic SSL Core Technology Research
Group 2: Inorganic SSL Product Development
Group 3: Organic SSL Core Technology Research
Group 4: Organic SSL Product Development

Within each of the four grouped topic areas, DOE's SSL R&D agenda is further divided into "tasks" and "subtasks." At the consultative workshops, participants discuss each of the tasks and subtasks, and provide recommendations for prioritizing R&D activities over the next 1-2 years. Detail on the current priority subtasks is presented in the tables in this section. Under each subtask there are a number of "projects" representing specific efforts by researchers to address the goals of that subtask.

3.2 Congressional Appropriation and Current Portfolio (March 2009)

Figure 3.1 presents the congressional appropriation for the SSL portfolio from FY2003 through FY2009. The funding request for the current fiscal year (FY2009, which began in October 2008) totals $25 million. The program's funding level increased from $3 million in FY2003 to $30.0 million in FY 2007. For FY2009, the final funded amount was $25 million; about $6 million of additional funding over the Administration request was provided by Congress.

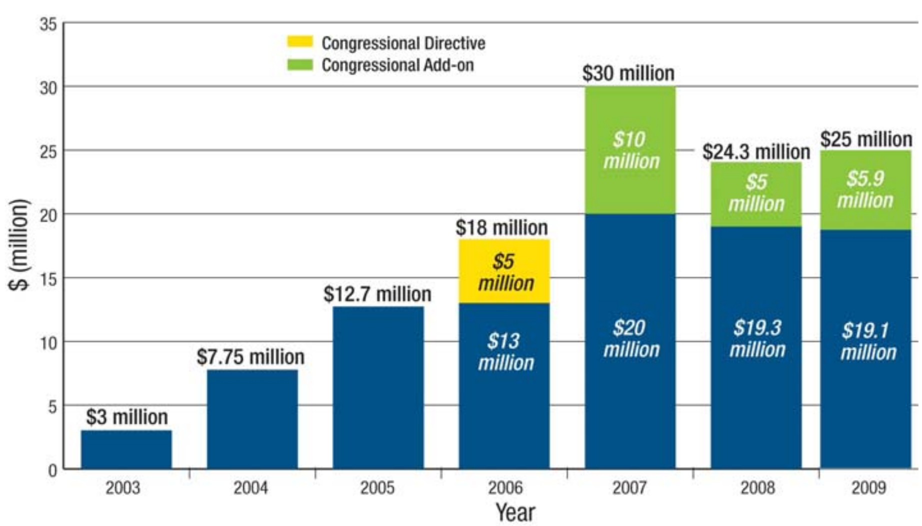

Figure 3.1: Congressional Appropriation for SSL Portfolio, 2003-2009

The current SSL DOE research portfolio[43] (not including completed projects) includes forty-four projects, which address LEDs and OLEDs. Projects balance long-term and short-term activities, as well as large and small business and university participation. The portfolio totals more than $75.1 million in cumulative government and industry investment. Figure 3.2 provides a graphical breakdown of the funding for the current SSL project portfolio; this value represents cumulative funding levels for projects awarded over the last three years. DOE is currently providing $57.2 million in funding for the projects, and the remaining $17.9 million is cost-shared by project awardees. Of the forty-four projects active in the SSL R&D portfolio through September 2008, twenty-six were associated with LEDs and eighteen were focused on OLEDs. The OLED project partners had a lower cost-share contribution ($6.3 million) than the LED project partners ($11.5 million).

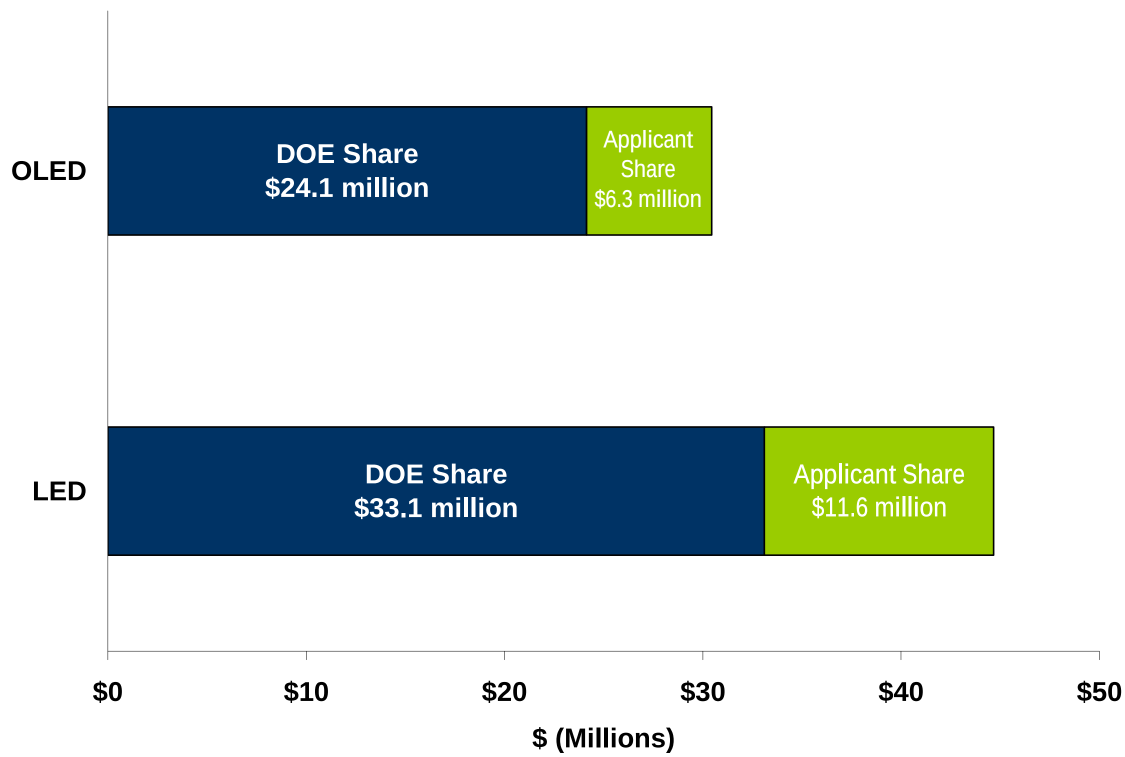

Figure 3.2: Cumulative Funding of SSL R&D Project Portfolio, February 2009

Figure 3.3 shows the DOE funding sources and level of support contributing to the SSL project portfolio, for projects active in February 2009. The Building Technologies Program in the Office of Energy Efficiency and Renewable Energy (EERE) provided the majority of the funding; forty-four projects receive $75.1 million in funding from this source. Approximately 58 percent ($41.5 million) of the BT/National Energy Technology Laboratory (NETL) funds are for Core Technology Research projects and the balance of 42 percent ($30.7 million) supports Product Development projects. The Small Business

[43] As of February 2009.

Innovation Research (SBIR) program in the Office of Science funded seven projects for a total of $2.8 million.

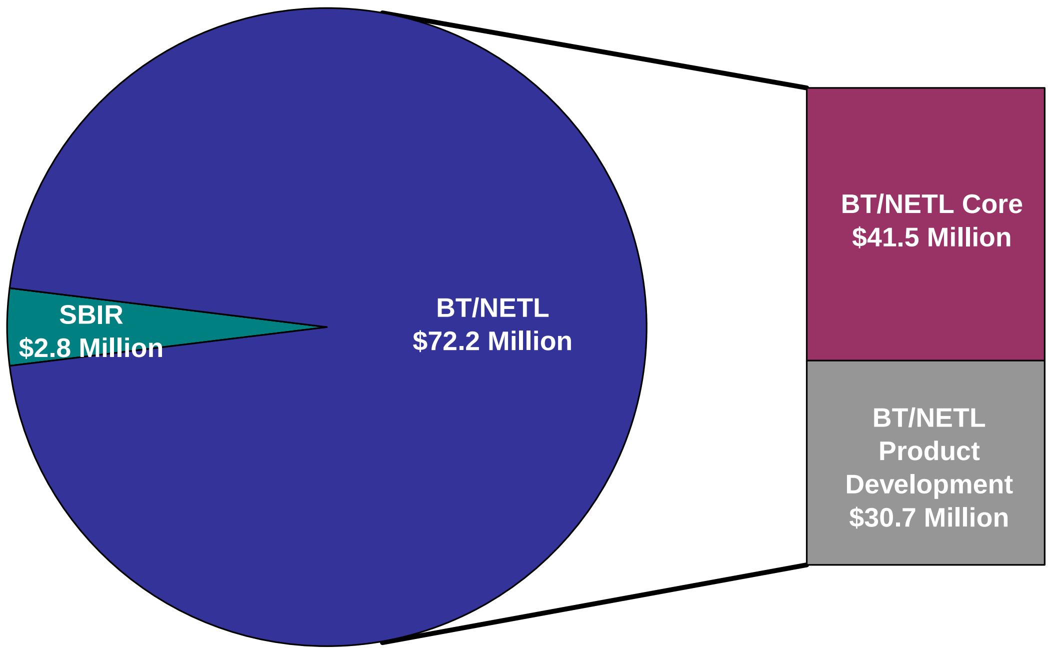

Figure 3.3: Cumulative SSL R&D Portfolio: Funding Sources, February 2009

The DOE supports SSL R&D in partnership with industry, small business, academia, and national laboratories. Figure 3.4 provides the approximate level of R&D funding contained in the current SSL portfolio among the four general groups of SSL R&D partners, as of February 2009. Industry participants receive approximately 37% of portfolio funding, with $28.0 million in R&D activities. Small businesses comprise the next largest category and receive 24%, or $18.4 million, in research funds. Finally, universities and national laboratories comprise 23% and 16% of the R&D portfolio, respectively, and receive $17.05 million and $11.8 million, respectively.

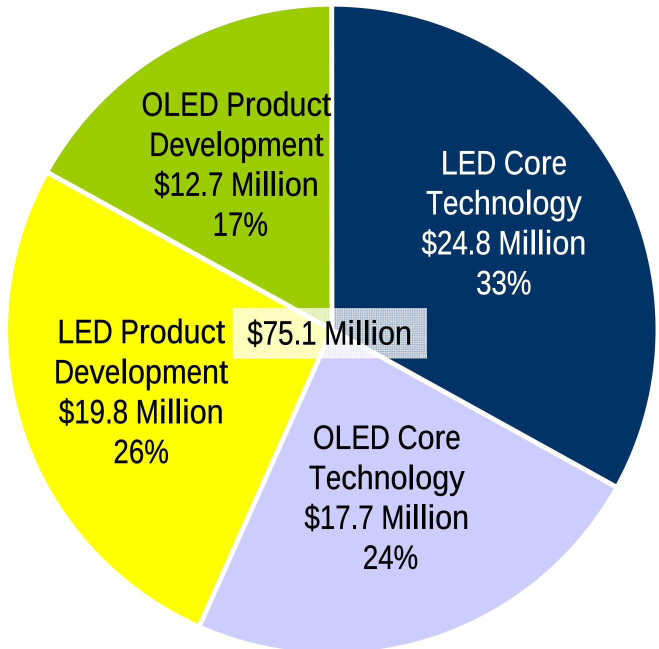

Figure 3.4: Total Funding of Projects in DOE's SSL R&D Project Portfolio, February 2009

Table 3.2.1 and Table 3.2.2 show the total number of projects and total-project funding in the SSL portfolio by subtask (as of February 2009). During the SSL workshop held in November 2003, participants suggested research areas that required emphasis at that time in order to advance SSL technology toward the goal of general illumination. These priorities have been continuously updated since that time. Table 3.2.1 shows the projects that DOE has chosen to fund, in keeping with the evolving priorities, under the *Core Technology* solicitations. Table 3.2.2 shows the projects that are currently funded in *Product Development* (as of February 2009).

Table 3.2.1: SSL R&D Portfolio: Core Technology, February 2009

	Number of Projects	$ Funding (Million)
Light-Emitting Diodes		
Large-area substrates, buffer layers, and wafer research	3	$3.3
High-efficiency semiconductor materials	9	$14.0
Reliability and defect physics for improved emitter lifetime and efficiency	1	$1.3
Strategies for improved light extraction and manipulation	1	$2.5
Phosphors and conversion materials	2	$3.7
Total	**16**	**$24.8**
Organic Light-Emitting Diodes		
Novel materials and device architectures	3	$5.80
Improved contact materials and surface modification techniques to improve charge injection	3	$4.10
Applied research in OLED devices	1	$0.80
Novel strategies for improved light extraction	1	$0.10
Research on low-cost transparent electrodes	2	$2.90
Investigation (theoretical and experimental) of low-cost fabrication and patterning techniques and tools	1	$4.00
Total	**11**	**$17.7**
TOTAL	**27**	**$42.5**

Table 3.2.2: SSL R&D Portfolio: Product Development, February 2009

	Number of Projects	$ Funding (Million)
Light-Emitting Diodes		
Manufactured materials	1	$3.8
LED packages and packaging materials	6	$9.8
Optical coupling and modeling	2	$3.3
Thermal design	1	$2.9
Total LED	**10**	**$19.8**
Organic Light-Emitting Diodes		
Practical implementation of materials and device architectures	2	$3.4
Practical application of light extraction technology.	3	$6.6
OLED encapsulation packaging for lighting applications	2	$2.7
Total OLED	**7**	**$12.7**
TOTAL	**17**	**$32.6**

3.2.1 Summary of Current Research Tasks

For both LEDs and OLEDs, the March 2009 MYPP has a greater emphasis on Product Development in comparison with the March 2008 plan. Prioritized LED Product Development tasks in the March 2009 plan focus on thermal issues, epitaxial growth, and overall system reliability. Prioritized LED Core Technology tasks in the 2009 plan focus on materials, down-conversion, thermal issues, and system reliability modeling. For OLEDs, Product Development tasks in substrates, materials and device architecture issues, electronic components, and luminaire integration were prioritized. Core Technology tasks in the 2009 plan for OLEDs focus on novel materials and device architectures, new substrate and electrode types, fabrication issues, and system reliability modeling methods.

3.3 Research and Development Funding Mechanisms

DOE supports the research, development, and demonstration of promising SSL technologies. As a technology matures, different funding mechanisms are available to support its development, as detailed in Figure 3.5. Solid-state lighting research partners and projects are selected based on such factors as energy savings potential, likelihood of success, and alignment with the SSL R&D plan.

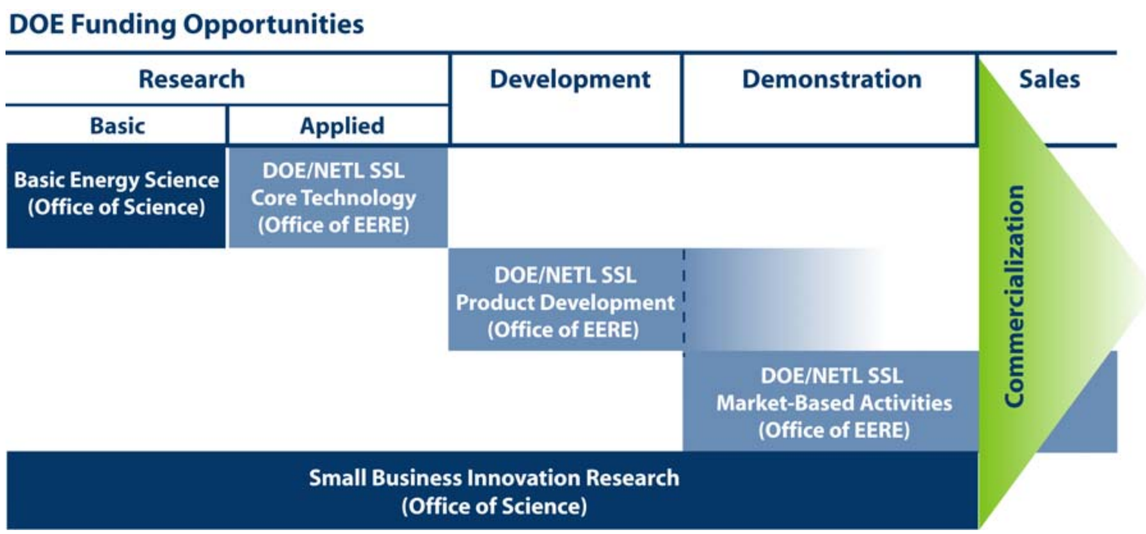

Figure 3.5: DOE Funding Opportunities

DOE funding mechanisms used in the Solid-State Lighting R&D Portfolio include:

- **Basic Research** — Precedes the mission of the DOE Solid-State Lighting R&D program. Grants supporting basic energy science are provided by DOE's Office of Science through an annual solicitation process.

- **Building Technologies Program** — Funds R&D on materials, components, and systems applicable to residential and commercial buildings. Areas of interest include solid-state and conventional lighting, advanced fixtures and controls, space conditioning, building envelope, whole buildings, zero-energy buildings, and other areas of need. Solicitations are issued through the National Energy Technology Laboratory.

- **Small Business Innovation Research (SBIR)** — Seeks to increase participation of small businesses in federal R&D. Supports annual competitions among small businesses for Phase 1 (feasibility of innovative concepts) and Phase 2 (principal research or R&D effort) awards, and includes topics related to solid-state lighting.

- **Solid-State Lighting Competitive Solicitations** — Seeks to advance and promote the collaborative atmosphere of the Lighting Research and Development (LR&D) SSL program to identify product concepts and develop ideas that are novel, innovative and groundbreaking.

3.4 Procurement Strategy

DOE's Office of Building Technologies typically releases at least three competitive solicitations for academia, industry researchers, and national laboratory researchers each year. In prioritizing needs for these solicitations in both Core Technology and Product Development, DOE obtains advice from researchers at the solid-state lighting program planning workshops and from researchers in the SSL partnership. The SSL partnership, composed of manufacturers and allies, was created in June 2004 through a competitive selection process. Proposals received through the solicitation process are reviewed by peer reviewers and DOE staff. DOE expects product proposals to include comprehensive work plans to develop a specific SSL product or product family. Core Technology proposals should support the SSL program by providing problem-solving research to overcome barriers identified by the SSL Partnership.

3.4.1 Performers

Long-term applied research in the Building Technologies solid-state lighting research and development portfolio is typically performed by those academia or national laboratories with the experience and resources to undertake long-term, high-risk pre-commercial research. The Small Business Innovation Research program is targeted to small commercial businesses to encourage their participation in basic and applied research as well. Product development research projects are typically performed by small businesses and industry teams or consortia.

3.4.2 Gaps

Funding for the R&D tasks for solid-state lighting is allocated, to the extent possible, according to the priorities agreed upon by DOE and industry experts during the annual SSL workshops. These priorities are updated annually, based on actual progress, as described in this document. This process may leave some critical tasks unfunded at any given time. These obviously represent gaps that could accelerate the program or improve performance.

3.5 Cross-Area Coordination

The DOE SSL program has coordinated with a variety of agencies and organizations. The following paragraphs describe areas in which this coordination has occurred.

In November 2003, representatives from the DOE Building Technologies Program and Basic Energy Sciences Program, National Science Foundation (NSF), National Institutes of Standards and Technologies's (NIST) Advanced Technologies Program (ATP), and the Defense Advanced Research Projects Agency (DARPA) met with representatives from the solid-state lighting industry in a workshop to coordinate and prioritize public-private research on solid-state lighting technologies.[44] Since then, these offices have continued to share results of research projects and coordinate topics for competitive solicitations for solid-state lighting research, typically released once a year.

The DOE Building Technologies program also coordinates with the DOE Federal Energy Management Interagency Task Force, consisting of representatives from 21 agencies, to support demonstrations of LED products throughout the country in federal installations. The Interagency Task Force meets bi-monthly to address and resolve key issues surrounding the implementation of energy savings programs mandated by the Energy Policy Act of 2005.

The DOE Building Technologies program is an active member of the ENERGY STAR® program with manufacturers of solid-state lighting technologies. ENERGY STAR® labels the highest performers in the solid-state lighting market to educate the consumer about good-quality, energy-saving products. To guide the ENERGY STAR® program, and planning for R&D, technology demonstration, and procurement, DOE supports the Commercially Available LED Product Evaluation and Reporting (CALiPER) Program which provides objective product performance information to the public in the early years, helping buyers and specifiers have confidence that new SSL products will perform as claimed.

DOE is currently collaborating with the National Institutes of Standards and Technology (NIST) to aid the CALiPER program in providing objective product performance information to the public. In addition, DOE is collaborating with NIST and other standards organizations to provide a forum for greater cooperation. In March 2006, DOE hosted an LED Standards Industry Workshop that invited members of the IESNA, the National Electrical Manufacturers Association (NEMA), the National Institute of Standards and Technology, the American National Standards Institute (ANSI), Underwriters Laboratories (UL), the International Electrotechnical Commission (IEC), the International Commission on Illumination (CIE), Federal Communications Commission (FCC), National Fire Protection Association (NFPA) and the Canadian Standards Association (CSA). With DOE support and leadership, the group will continue to coordinate, update progress, and accelerate the development process of LED testing

[44] *Illuminating the Challenges: Solid State Lighting Program Planning Workshop Report.* Office of Energy Efficiency and Renewable Energy Building Technologies Program. Prepared by Navigant Consulting. February 2004.

standards. A second workshop was held in October 2006, and a CALiPER roundtable was held in November 2007. Another CALiPER roundtable was held in March of 2009.

In the DOE SSL Technology Demonstration GATEWAY Program, DOE collaborates with utilities, manufacturers, and host sites to feature high-performance SSL products for general illumination in a variety of commercial and residential applications. Results provide real-world experience and data on product performance and cost-effectiveness while connecting DOE technology procurement efforts with large-volume purchasers. Performance measures include energy consumption, light output, color consistency, and installation/interface/control issues. The first "Invitation to Participate" was issued in March 2007. A second invitation followed in November 2007 and remained open through May 2008. To date, GATEWAY demonstration projects include LED roadway and walkway lighting, LED residential lighting, and LED parking garage lighting. DOE seeks to assemble demonstration teams that match host sites with appropriate products and partners. DOE GATEWAY demonstrations are open to all participants, subject to certain eligibility parameters. Potential participants are encouraged to submit expressions of interest using the application forms available at: http://www1.eere.energy.gov/buildings/ssl/gatewaydemos_results.html.

DOE must coordinate with the American Lighting Association (ALA) and the Consortium for Energy Efficiency (CEE) in the Lighting for Tomorrow competition. This competition encourages technical innovation, stimulating the market for attractive, energy-efficient residential lighting fixtures that use a fraction of the electricity of standard incandescent fixtures. The competition focus extends to marketing, promotion, and sales through primary distribution channels for both new construction and renovation markets. Lighting for Tomorrow was launched in 2002, with an initial focus on CFL fixtures. In 2006, a category for solid-state lighting was added, attracting 30 entrants. In 2007, two dozen companies submitted 45 solid-state lighting entries. In January of 2008, the 2008 Lighting for Tomorrow competition was launched at the Dallas Lighting Market. Lighting for Tomorrow judges are drawn from across the lighting industry, creating a diverse panel of experts who sell, design, evaluate, and write about residential lighting design. Winners of the 2008 solid-state lighting portion of the competition included LED downlight and under-cabinet lighting, LED task lights, an LED spotlight, an LED ceiling lay-in, and a linear LED module. For more information about Lighting for Tomorrow, see http://www.lightingfortomorrow.com/.

The DOE Technical Information Network for Solid-State Lighting (TINSSL) is managed collaboratively with competitively selected partners, the Northeast Energy Efficiency Partnerships (NEEP) and the Consortium for Energy Efficiency (CEE). TINSSL is designed to increase awareness of SSL technology, performance, and appropriate applications. TINSSL members include representatives from regional energy efficiency organizations and program sponsors, utilities, state and local energy offices, lighting trade groups, and other stakeholders. NEEP and CEE work closely with DOE to produce SSL information and outreach materials, host meetings and events, and support other outreach activities. TINSSL members receive regular updates on technical progress of SSL technologies, upcoming meetings and events that address market issues related to SSL, and outreach materials developed for target audiences. To join the network, visit http://www1.eere.energy.gov/buildings/ssl/technetwork.html.

4.0 Technology Research and Development Plan

The U.S. Department of Energy supports domestic research, development, demonstration, and commercialization activities related to SSL to fulfill its objective of advancing energy-efficient technologies. DOE's SSL R&D Portfolio focuses on meeting specific technological goals, as outlined in this document, that will ultimately result in commercial products that are significantly more energy-efficient than conventional light sources.

Improving the efficiency and decreasing the cost of SSL will have a large contribution toward DOE's goal of a net-zero energy building. Lighting constitutes approximately 12 percent of residential building energy consumption and 25 percent of commercial building energy consumption. This electricity consumption figure does not include the additional loads due to the heat generated by lighting, which is estimated to be up to 40 percent in a typical "stock" building. Further technology and cost improvements and market acceptance of SSL technologies will dramatically reduce lighting energy consumption, and thereby the total energy consumption, of residential and commercial buildings by 2025.[45]

A part of DOE's mission, working through a government-industry partnership, is to facilitate new markets for high-efficiency general-illumination products that will enhance the quality of the illuminated environment as well as save energy. Over the next few years, SSL sources will expand their presence in the general illumination market, replacing some of today's lighting technologies. DOE's R&D activities will work to ensure that U.S. companies remain competitive suppliers of the next generation of lighting technology in this new paradigm.

This chapter describes the objectives and work plan for future R&D activities under the SSL program for the next 6 years, with some general observations to 2025. Actual accomplishments will result in changes to the plan over this time period which will be reflected in future revisions. The process of updating the content of this chapter for FY09 began with a series of roundtable sessions convened in Washington, D.C. in September of 2008. The NGLIA members and other industry experts invited to these sessions presented short talks on current topics of interest for LED and OLED technologies and then discussed research tasks. The invited experts then formed technical committees for LEDs and OLEDs (the "LED Technical Committee" and the "OLED Technical Committee," respectively). During the fall of 2008, the Technical Committees further revised the research tasks and other aspects of the chapter during a series of teleconferences. In February of 2009, a workshop was convened in San Francisco, CA, where representatives of various sectors of the lighting industry gave their thoughts on SSL R&D task prioritization. After careful internal review, considering inputs received at the workshop, DOE defined the task priorities for 2009 as listed in section 4.5.

[45] 2006 Building Energy Data Book, U.S. Department of Energy, Office of Planning, Budget and Analysis, Energy Efficiency and Renewable Energy. Prepared by D&R International, Ltd., September 2006. Hereafter, BED.

The next section sets forth working definitions of the various components of a solid-state lighting luminaire in order to provide a common language for describing and reporting on the R&D progress.

4.1 Components of the SSL Luminaire[46]

Subsequent sections of this multiyear plan describe both LED and OLED white-light general-illumination luminaires. Understanding each component of a luminaire and its contribution to overall luminaire efficiency helps to highlight the opportunities for energy efficiency improvements and thereby to define priorities for DOE's SSL R&D Portfolio.

4.1.1 Components of LED Luminaires

As solid-state lighting has evolved, a number of product configurations have appeared in the market. Two essential levels of product can be identified based on whether or not the product includes a driver (defined in the list below), and a number of terms can be defined for each level. Please note that these definitions have been updated from prior editions of the MYPP to reflect the agreed definitions in IES Standard RP-16, Addendum a, as updated and released in 2008.

Component level (no power source or driver)

- LED Die refers to the small piece of semiconducting material ("chip") on which the light-emitting diode itself is constructed.

- LED Package (also known as an LED device) refers to an assembly of one or more LED dies including the mounting substrate, encapsulant, phosphor if applicable, electrical connections, and possibly optical components along with thermal and mechanical interfaces.

- LED Array. Several LED packages may be assembled on a common substrate or wiring board (possibly with additional optical components and mechanical, thermal, or electrical interfaces) in order to increase total light output or improve the spectrum.

- LED Module. This term refers to an LED package or array that is connected to the load side of an LED power source or driver. The module may include additional components such as optical components and thermal, mechanical, or electrical interfaces.[47]

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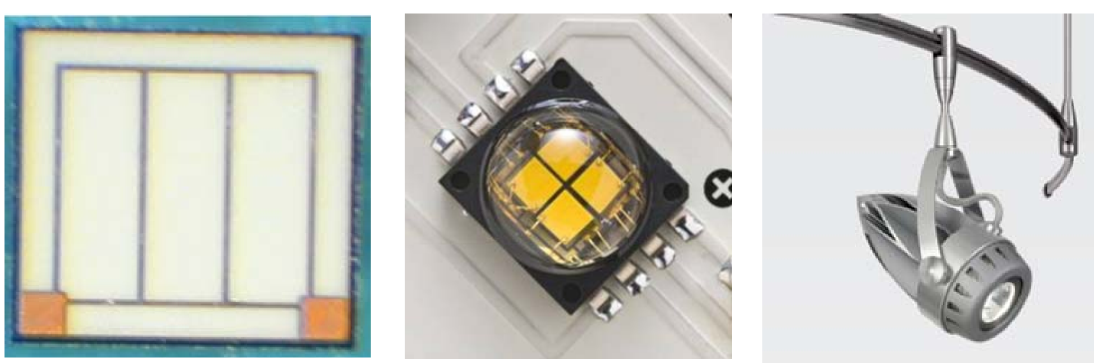
[46] To be consistent with terms used in the DOE Commercially Available LED Product Evaluation and Reporting (CALiPER) program and Addendum a of ANSI/IESNA RP-16-05, "luminaire" is used here to describe the entire solid state lighting product. CALiPER supports the testing of a wide, representative array of SSL products available for general illumination, using test procedures currently under development by standards organizations. More information is available at: http://www1.eere.energy.gov/buildings/ssl/caliper.html.
[47] The term "light engine" has come into usage in recent years; "light engine," however, is not defined by RP-16, and "module" is the preferred analogue.

Subassemblies and systems (including a driver)

- LED Lamp refers to an assembly with an ANSI standardized base designed for connection to an LED luminaire. There are two general categories of LED lamps:
    - Integrated LED Lamp refers to an assembly that is integrated with an LED driver and has an ANSI standardized base for connection directly to an electrical branch circuit.
    - Non-Integrated LED Lamp refers to an assembly with an ANSI standardized base but without a built-in LED driver. Non-integrated LED lamps are designed for connection to LED luminaires.
- LED Driver refers to a power source with integral control circuitry designed to meet the specific needs of an LED package, array, or module. The driver converts line voltage to appropriate power and current for the package and may also provide sensing of and corrections for shifts in color or intensity that occur over the life of the product or due to temperature variations. Other special features, such as dimming controls, may also be included.
- LED Luminaire refers to the complete lighting unit, intended to be directly connected to an electrical branch circuit. It consists of a light source and driver along with parts to distribute the light and to connect, position, and protect the light source.

Figure 4.1, below, illustrates a few of these definitions.



Die **Package** **Luminaire**

Figure 4.1: Photos of LED Components
Photo sources: Cree, Journée

4.1.2 Components of OLED Luminaires

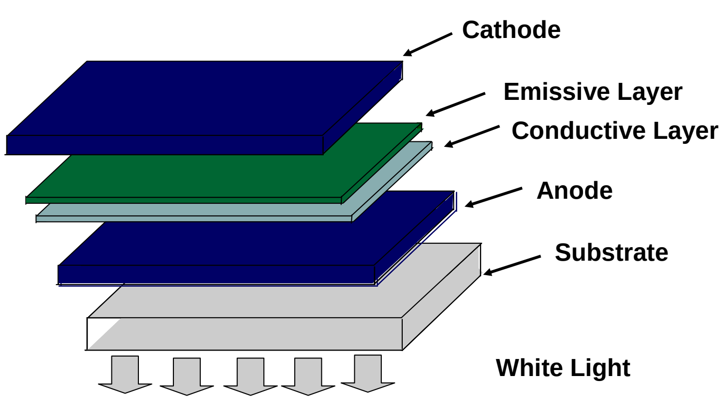
A structure parallel to LEDs can be used to define the components of an OLED luminaire. Formal definitions for OLED terminologies have not been standardized at this time, so the definitions below were crafted to parallel what is in RP-16 for LEDs.

- OLED Device is roughly analogous to an LED package. It refers to an assembly of layers of materials, including a set of charge-transporting and emissive layers (made of organic materials) that are analogous to those of the LED die. The device also includes other layers for encapsulation and electrical connection to the device.

- OLED Panel refers to one or more OLED devices that are assembled to create a unit with significant light output (at least 500 lumens). The OLED panel approximately corresponds to an LED array or module, depending on whether the panel is designed to be connected directly to the load side of an OLED driver. The OLED panel may also incorporate packaging, thermal management, and optical outcoupling components.

- OLED Luminaire refers to the complete lighting system, intended to be directly connected to an electrical branch circuit. It consists of an assembly of one or more interconnected OLED panels along with the OLED electrical driver and fixture. The OLED driver converts line voltage to appropriate power and current for the device. The OLED fixture provides for thermal management, if not included in the panels, as well as mounting and mechanical support, interconnection with the driver, and diffusion or direction of the light from the OLED device to the task.

Geometries that emit downward through a transparent substrate or upward from a reflective substrate are currently being considered for OLEDs. The simple planar structure shown in Figure 4.2 below displays an OLED which emits downward through a transparent substrate. These structures typically employ a reflective, metal cathode.



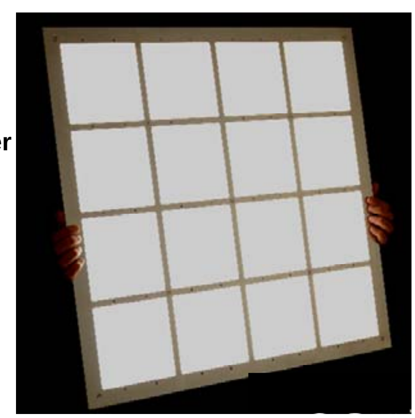


Figure 4.2: Diagram of OLED Device Structure and Photo of OLED Panel
Photo source: General Electric

It is also possible to manufacture an OLED with a highly transparent cathode (typically with up to 80% transmission across the visible spectral region). These structures can emit upward from a reflective substrate, such as a reflective metal foil, or can be entirely transparent devices. Figure 4.3 displays an entirely transparent OLED luminaire employing a transparent substrate and cathode.

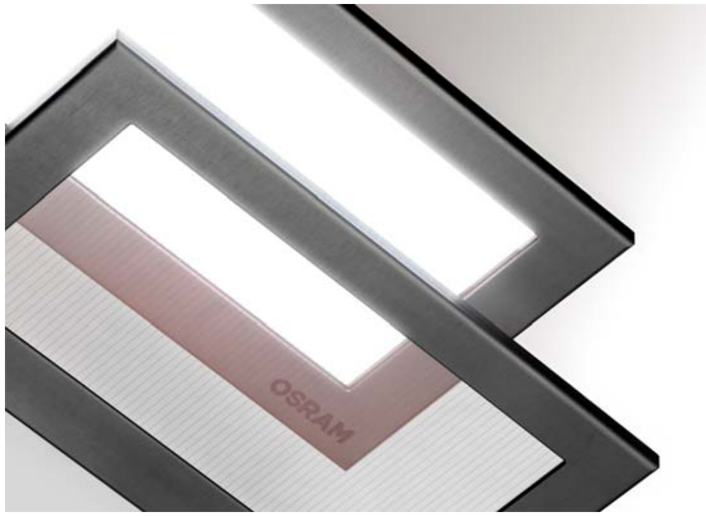


Figure 4.3: Photo of a Transparent OLED Lighting Tile
Photo source: OSRAM Opto-Semiconductor

4.2 Current Technology Status and Areas of Improvement

Significant progress has been made in LEDs over the past year, and several viable and efficient luminaire products have reached the market. More are expected in the coming year. LED package technology successfully met the first milestone set by DOE's multi-year plan and appears to be ahead of schedule for the next one. As a result, LED luminaires are now routinely more efficient than incandescent sources and are at or near parity with CFLs.[48] More work will be necessary to assure that luminaires and power conditioners do not excessively degrade the performance or lifetime of the packages. More work will also be necessary both to reach efficiencies that can compete with linear fluorescent lamps, and to achieve high-efficiency packages with a warmer light (i.e., lower correlated color temperature). OLED performance lags behind LEDs, as might be expected from this technology's later start. One niche product using OLEDs for general illumination has become available on the market at a high price and in very limited quantities. The niche product is a table lamp, shown in Figure 4.4, produced by the designer Ingo Maurer. This product appears to be more efficacious than incandescent sources, but it is not near the efficacy of a CFL. Although general market products for OLEDs have still not been introduced, the introduction of this niche product shows promise.

[48] *DOE Solid-State Lighting CALiPER Program: Summary of Results: Round 3 of Product Testing.* http://www1.eere.energy.gov/buildings/ssl/caliper.html

Figure 4.4: A Commercial OLED Table Lamp by Ingo Maurer
Photo source: OSRAM Opto-Semiconductor

To further define the relationship among the components of luminaires and to highlight relative opportunities for efficiency improvements, one can identify various elements of power efficiency, both electrical and optical, within the SSL device and for the luminaire as a whole. These losses and consequent opportunities for LED and OLED luminaires are apparent in the several figures that follow (Figure 4.5, Figure 4.6, and Figure 4.7). Generally, the losses identified result from the conversion of energy, either electrical or optical depending on the stage, into heat. However, the efficiency of converting optical radiated power into useful light (lumens) is derived from the optical responsiveness of the human eye. This source of inefficiency (the *spectral* or *optical* "efficacy" of the light) is essentially the human eye's spectral filtering of light that has already been radiated by the SSL luminaire.

The electrical *luminaire* efficacy, a key metric for the DOE SSL program, is the ratio of *useful* light power radiated (visible lumens) to the electrical power (watts) applied to the *luminaire*. The electrical *device* efficacy refers to the ratio of lumens out of the *device* to the power applied to the device at room temperature, so it does not include the driver, fixture, or thermal efficiencies. This technology plan forecasts both device efficacy and luminaire efficacy improvements. It is important to keep in mind that it is the luminaire efficacy that determines the actual energy savings.

Opportunities for improvement of the device include: reducing electrical and optical losses in the device; improving the efficiency of conversion of electrons into photons (IQE); maximizing the extraction of those photons from the material (extraction efficiency); and tailoring the spectrum of the radiated light to increase the eye response. Tailoring of the spectrum to the eye response is constrained by the need to provide light of appropriate color quality (correlated color temperature and color rendering index). Further improvements in phosphors and optimization of the spectrum of the LED are still needed to provide an appropriate color quality while increasing luminosity.

The following sections compare the current typical efficiency values for the individual luminaire elements to a set of suggested program goals for LED and OLED technologies.

These consensus numbers were developed in consultation with members of the LED and OLED Technical Committees as mentioned in the introduction to this chapter. It is important to realize there may be significantly different allocations of loss for any specific design, which may nevertheless result in an overall efficient luminaire. The allocation of typical current efficiency values and targets used in the sections to follow, however, serves as a guide for identifying the opportunities for improvement (*i.e.*, those components with the greatest differences between current and target values). It is *not*, however, the program's intention to impede novel developments that use a different allocation of losses that result in a better overall luminaire performance.

For consistency, OLED efficiencies throughout this chapter are reported assuming a pixel-sized OLED device, as defined in Section 4.1.2, at a fixed brightness (1,000 cd/m^2). Targets for OLED devices have been set with the goal of enabling the development of high quality OLED panels and luminaires. LED efficiencies are reported for a fixed drive current (350 mA) and area (1 mm^2). These values are simply used to compare efficiency levels and set targets to a common reference. It is not the DOE's intention to dictate the brightness, size, or current drive of devices used in practice.

4.2.1 Light-Emitting Diodes

As described in Section 2.3.4, white-light LED luminaires are typically based on one of three approaches:

a) phosphor-conversion LEDs (pc-LEDs)
b) discrete color-mixing LEDs
c) a hybrid consisting of phosphor (white) and monochromatic packages

Phosphor-Converting LED

Figure 4.5 presents a diagram of a phosphor-converting LED luminaire. On the left side of the figure is a simplified breakdown of the elements of luminaire efficiency that includes driver efficiency, thermal losses associated with steady state operation and thermal management design, and fixture and optical considerations. On the right hand side is a breakdown of package efficiencies. These efficiencies are independent of spectrum to first order, although the spectrum *will* determine the resulting efficacy. The table shows the efficiencies (both current and target) as typically reported for packages (e.g. pulsed measurements taken at 25°C). Target efficiencies represent the ultimate target of DOE's SSL program. Depending on the difficulty of the task, target efficiencies could be reached before or after the year 2015. Note that the targets for R&D research tasks are for the year 2015. For purposes of comparing various experimental results, this diagram and the next one for color-mixing LEDs assume a target correlated color temperature of 4100°K (the equivalent CCT of a cool-white fluorescent lamp), and a CRI of at least 80. Other combinations may provide acceptable light for particular market needs. Currently available 2008 products typically have color temperatures in the range of 4100-6500°K and often a lower CRI than 80, although more warm-white products are beginning to appear. The 2008 typical numbers reflect these less than optimal parameters, and therefore may overstate our current capability. The following definitions provide some clarification on the efficiency values presented in the figures and for the project objectives over time.

- Driver efficiency represents the efficiency of the electronics in converting input power from 120V alternating current to low-voltage direct current as well as any controls needed to adjust for changes in conditions (e.g. temperature or age) so as to maintain brightness and color.

- Package efficiency represents the total efficiency of the LED package (excluding the driver and luminaire) and consists of several components that are shown on the right in Figure 4.6 and also defined below. The output of the "LED package" in this figure is useful lumens; that is, the spectral effects are not included within the "package" box.

- Thermal efficiency is the ratio of the lumens emitted by the package in thermal equilibrium under continuous operation in a luminaire to the lumens emitted by the package as typically measured and reported in production at 25°C.[49] The thermal efficiency can be improved by minimizing temperature rise through innovative thermal management strategies.

- Fixture and optics efficiency, η_{fo}, is the ratio of the lumens emitted by the luminaire to the lumens emitted by the LED package in thermal equilibrium. Losses in this component of the luminaire include optical losses. (For purposes of this illustration, spectral effects in the fixture and optics are ignored, although this may not always be appropriate.)

Considering the package portion of the luminaire, the power efficiency is the ratio of electrical input from the driver (i.e., applied to the package) to the optical power out (irrespective of the spectrum of that output). As such, package power efficiency excludes driver losses. The package *efficacy* is the product of the power efficiency of the package and the spectral or optical efficacy due to the human eye response. Elements of the package power efficiency are:

- Electrical efficiency, η_V, accounts for the ohmic losses within the package and the loss of any charge carriers that do not arrive at the active region of the package. The forward voltage should be as low as possible in order to achieve the maximum number of charge carriers into the package active region. When resistive losses are low, the voltage is essentially the breakdown voltage which is approximately the bandgap energy divided by the electronic charge. Ohmic losses in the LED material and electrode injection barriers add to the forward

[49] Standard LED package measurements use relatively short pulses of current to eliminate thermal effects, keeping the device at 25°C (or other controlled point). In standard operation, however, the LED is driven under CW (continuous wave) conditions. Under these conditions, in thermal equilibrium the device operates at temperature higher than 25°C.

voltage. This efficiency also includes the injection efficiency, which reflects any loss of charge carriers that occurs away from the active region of the package.

- Internal quantum efficiency, IQE, is the ratio of the photons emitted from the active region of the semiconductor chip to the number of electrons *injected into* the active region.[50]

- Extraction efficiency, χ, is the ratio of photons emitted from the encapsulated chip into air to the photons generated in the active region. This includes the effect of power reflected back into the chip because of index of refraction difference, but excludes losses related to phosphor conversion.[51]

- External quantum efficiency, EQE, is the ratio of extracted photons to injected electrons.[52] It is the product of the IQE and the extraction efficiency χ.

- Color-mixing efficiency, η_{color}, refers to losses incurred while mixing the discrete colors in order to create white light (not the spectral efficacy, but just optical losses). Color-mixing could also occur in the fixture and optics, but for the purposes of Figure 4.6 is assumed to occur in the package.

- Phosphor efficiency, η_{phos}, refers to the efficiency with which current state of the art green-yellow phosphors create white light using a blue LED. The phosphor efficiency includes quantum efficiency and the Stokes loss of the phosphor. In order to improve the color quality of phosphor-converted white packages while maintaining high efficiency it will be necessary to improve the phosphor efficiency of phosphors that emit in the red wavelengths and, possibly, the efficiency of phosphors that emit in the green to blue-green region of the spectrum. Improvement in the efficiency of phosphors that emit in the red wavelengths will enable the development of more efficacious warm-white products.

- Scattering efficiency is the ratio of the photons emitted from the LED package to the number of photons emitted from the semiconductor chip. This efficiency, relevant only to the phosphor-converting LED in Figure 4.5, accounts for scattering losses in the phosphor and encapsulant of the package.

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[50] The internal quantum efficiency is difficult to measure, although it can be measured indirectly in various ways, for example using a methodology described by S. Saito, et al., Phys. Stat. Sol. (c) 5, 2195 (2008).
[51] The extraction efficiency may be calculated by several methods; one example is described in [R. Windisch et al. IEEE J.Sel. Top. Quantum Electron. 8, 248 (2002)] and in S. Riyopoulos, T. D. Moustakas and J. S. Cabalu, J. Appl. Phys. 102, 04311 (2007).
[52] The external quantum efficiency can be measured experimentally using the expression $\eta_{ex} = (P_{opt} / hv) / (I / q)$ where P_{opt} is the absolute optical output power, hv is the photon energy, I is the injection current and q is the electron charge.

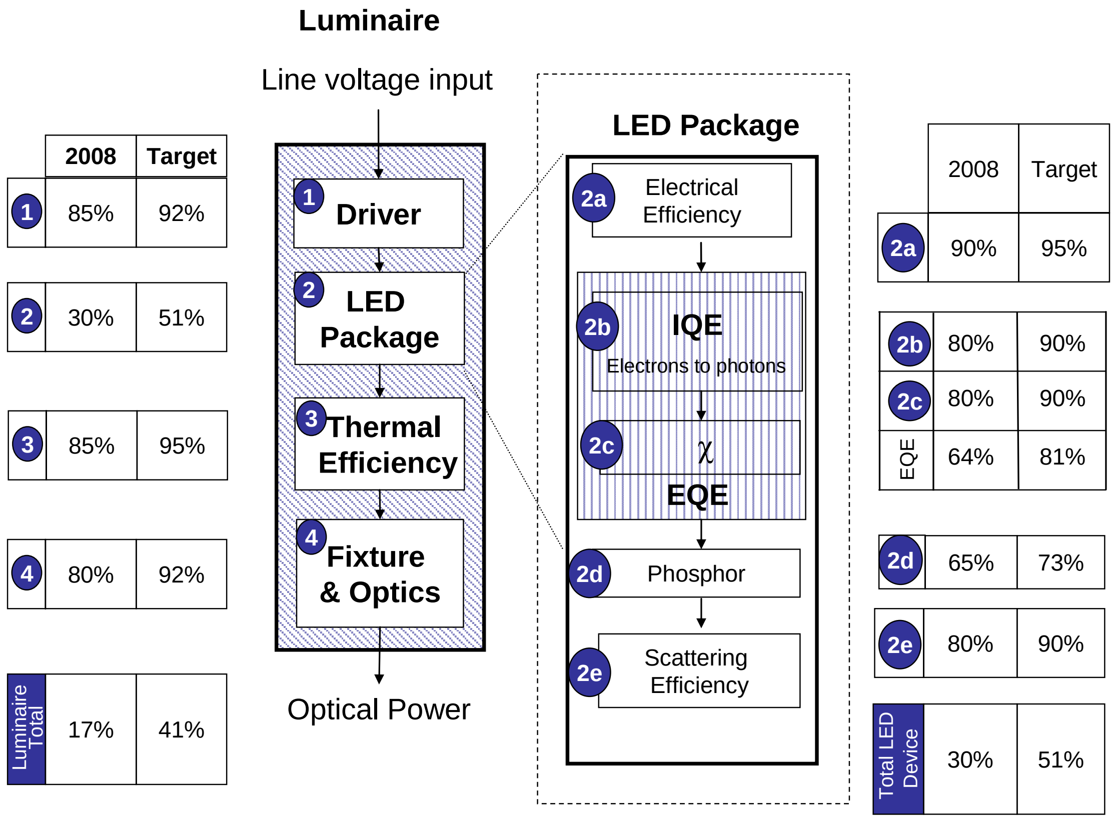

Figure 4.5: Phosphor-Converting LED - Current and Target Luminaire Efficiencies for Steady State Operation

Source: LED Technical Committee, Fall 2008

Note:

1. The target assumes a CCT of 4100K and CRI of 90. Current CCT: 4100-6500K, CRI: 75
2. The target for 2d includes the loss due to the Stokes shift (90% quantum yield times the ratio of the average pumped wavelength and the average wavelength emitted); the value here is typical of a blue diode/yellow phosphor system.
3. The shown efficiency allocation is only one method of achieving the 41% luminaire efficiency target.

In Figure 4.5, Component 2a (the LED package electrical efficiency) is estimated to have an efficiency of 90% for 2008 phosphor LED products (with available switching techniques). The ultimate target for this component is to improve the efficiency to 92%. In comparison, other components of the luminaire have more room for efficiency improvements. For example, the extraction efficiency of the mounted, encapsulated LED die is currently 80%. The ultimate goal of DOE's SSL program is to raise the extraction efficiency of the die to 90%.

Members of the LED Technical Committee estimated that today's driver efficiency is 85%, excluding possible additional losses for special control circuitry. The program target for the driver is to improve the efficiency to 92%. There is considerable room for improvement of the fixture and optics. Assuming a simple functional luminaire like a recessed downlight, fixture efficiencies for LEDs are currently around 80%. DOE expects the efficiency of the fixture can be ultimately increased to 92%. However, efficiencies for more decorative luminaires may not be able to reach this target because of losses due to color-altering diffusers or shades added for aesthetic purposes.

Currently, the phosphor-converting LED luminaire is approximately 16% efficient at converting electrical energy into visible white light. If all targets are reached, the LED package would have an efficiency of 51%, and the luminaire an efficiency of 41%. The package power efficiency (W_o/W_e), indicated in Figure 4.5 as the "Total White LED Package" efficiency, measures the power of light emitted by the package divided by the electrical power put into the package. This metric is independent of the spectrum of light emitted by the package. Electrical luminous efficacy (in lm/W_e),[53] on the other hand, measures the amount of useful visible light out of a package per unit of electrical energy. The electrical luminous efficacy of the phosphor-converting LED package can be calculated by multiplying the package power efficiency by the *optical* or *spectral* luminous efficacy of radiation (LER). For blended LEDs, the LER is approximately 360 lm/W_o (exact value varies with the CRI and CCT for the particular design and the available wavelengths[54]). Using this conversion, the target for a phosphor converting LED package would be close to 184 lm/W_e (51% power efficiency, above, multiplied by 360 lm/W_o). This would result in an overall luminaire efficacy, absent significant breakthroughs, of approximately 147 lm/W_e (360 lm/W_o multiplied by 41% luminaire efficiency). These additional luminaire losses are the reason that the program includes tasks directed at fixture and driver efficiency as well as those emphasizing the basic LED package, and also why the most energy-efficient installations of the future will have purpose-designed luminaires as opposed to retrofit lamps. These are "practical" figures based on the sources and technology that can be envisioned now. The electrical to optical power conversion efficiency could improve and the spectral luminous efficacy could also be higher, as much as 400 lm/W_o for a CRI of 80, if optimal wavelengths (or more colors) are available. This would yield a higher overall figure for lumens per watt.

Color-Mixing LED

Figure 4.6 presents a diagram of a color-mixing LED luminaire. For simplicity, three colors are used, although a fourth color, e.g. amber, or even more colors could be used to improve the spectrum. The definitions for the various efficiencies are the same as listed for Figure 4.5. The percentage efficiencies in the table next to each component indicate the typical performance in 2008 and targets that will satisfy the goals of the program. From this diagram one can infer the headroom for improvement for the various luminaire and package elements.

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[53] The subscript "e" denotes electrical power into the device and "o" denotes optical power within the device. Unless otherwise stated, "efficacy" means electrical luminous efficacy.

[54] NIST has simulated an LER of 361 lm/W_o at a CRI of 97 and CCT of 3300K. (Ohno, Y. "Color Rendering and Luminous Efficacy of White LED Spectra." Proc. SPIE 49th Annual Mtg., Conf. 5530 (2004).)

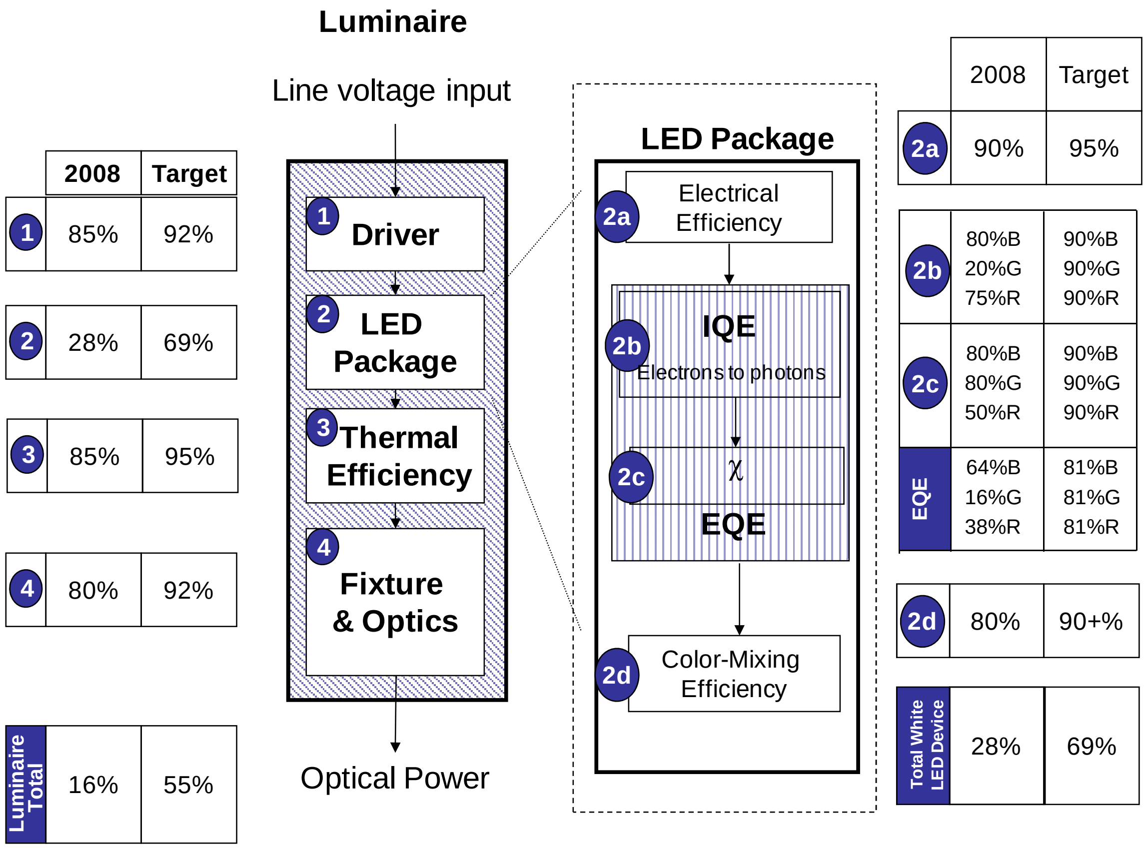

Figure 4.6: Color-Mixing LED - Current and Target Luminaire Efficiencies for Steady State Operation
Source: LED Technical Committee, Fall 2008
Note:
1. The target assumes a CCT of 4100K and CRI of 80. Current CCT: 4100-6500K, CRI: 75.
2. IQE statuses and targets assume wavelengths of 610 nm for red, 540 nm for green, and 450 nm for blue.
3. The efficiency allocation shown in this figure is only one example of how the 55% luminaire efficiency target can be met.

Because there is no Stokes loss, the color-mixing LED is theoretically capable of higher efficacies than the pc-LED. However, there are design issues of color-mixing packages that must be taken into account, such as additional driver complexity and cost, and the lower efficiency of green LEDs. Other options are possible for obtaining different color temperatures or color rendition indices using a hybrid approach. For example, a warm white color can be achieved by mixing phosphor-converted white LEDs with monochromatic red or amber LEDs. In fact, several very successful high efficacy warm-white luminaires employing this hybrid approach have recently appeared on the market.

Over the course of the program, performance improvements will make possible the manufacturing of packages with lower color temperature and better CRIs without seriously degrading the efficiency. Achieving the efficiency targets identified in Figure 4.6 will require more efficient emitters (particularly in the green area of the spectrum) and other improvements elsewhere in the luminaire. The package-related parameters of the luminaire have the greatest headroom for improvement in the short term. For example, the internal quantum efficiencies (2b) of the chips range from 20% to 80%, depending on color. The ultimate goal is to raise the IQE to 90% across the visible spectrum, bringing the total package efficiency to 69%. As the LEDs become more efficient, there will necessarily be more emphasis on the other luminaire losses in order to maximize overall efficiency.

Currently, the simple and functional color-mixing LED luminaire is approximately 16% efficient at converting electrical energy into visible white light. If all targets are achieved, the LED package would have an efficiency of 69%, with an overall luminaire efficiency of 55%. Similarly to the phosphor-converting package, the electrical luminous efficacy (in lm/W_e) of the color-mixing LED package can be calculated by multiplying the package power efficiency (W_o/W_e) by the *optical* luminous efficacy (useful light out (lm) divided by the optical power in (W_o)) of a phosphor. A practical target for a color-mixing LED luminaire is about 198 lm/W_e. Improving the color-mixing efficiency and temperature performance could improve the efficacy even more.

4.2.2 Organic Light-Emitting Diodes

Figure 4.7 presents a diagram for an OLED luminaire and compares the current typical efficiency values for the individual system elements to a set of suggested program targets. The definitions for the various efficiencies are the same as listed for Figure 4.5, with additional definitions for electrode efficiency and substrate optical losses. Additional clarification is also given for internal quantum efficiency and electrical efficiency.

- Electrode efficiency accounts for the losses that occur between the external electrical contacts of the device and the charge-injecting interfaces of the device.

- Internal quantum efficiency, IQE, is the ratio of the photons generated within the active region of the OLED to the number of electrons *injected into* the active region. IQE is the product of the fraction of all electrons and holes that eventually combine, the efficiency with which electrons and holes form an emissive state, and the quantum yield of the emissive state.

- Electrical efficiency is the ratio of photon electron volts to the electrical voltage input to the OLED. The electrical efficiency accounts for the internal device resistance and the barrier to charge injection at the electrode-organic interface.

- Substrate optical losses are losses incurred as photons exiting the device encounter the substrate and electrode materials. While such losses are small for glass and very thin electrodes such as those made from indium tin oxide, substrate optical losses may be substantial for different substrates (such as flexible substrates made from plastics) and non-ITO electrodes.

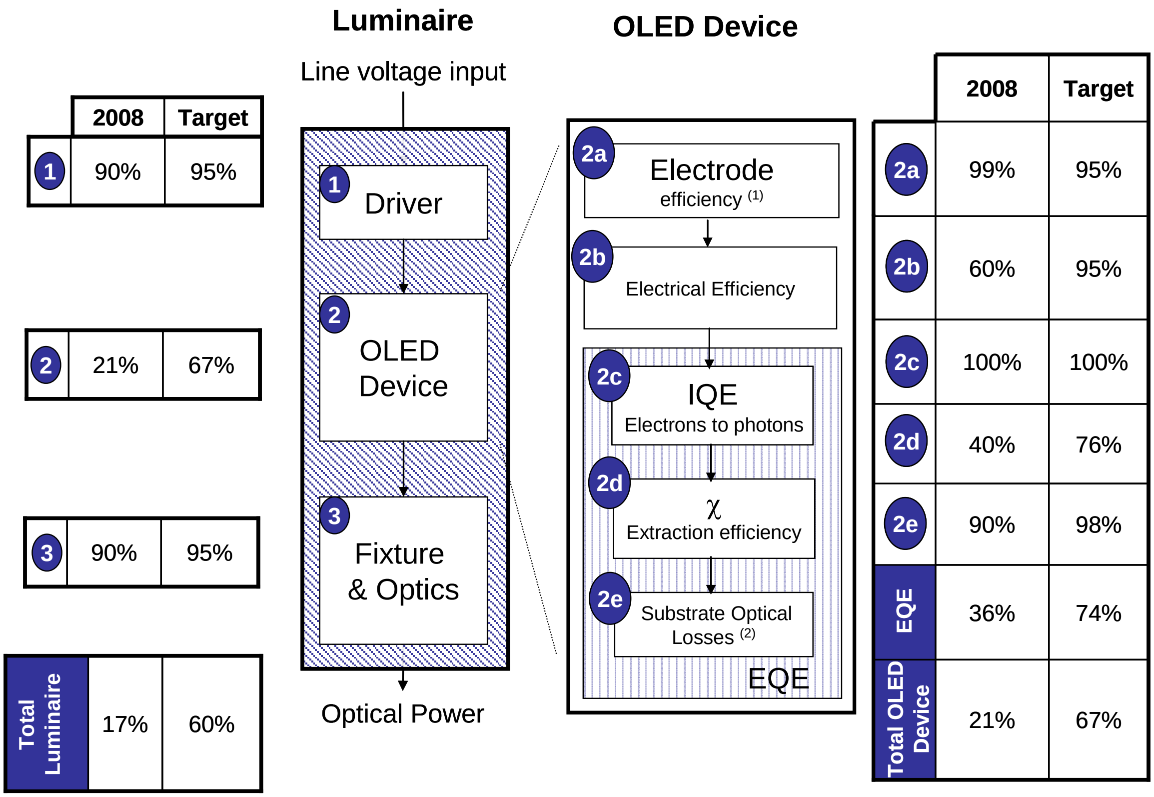

Figure 4.7: OLED Luminaire Efficiencies & Opportunities

(Assumptions for "Target" figures: CCT: 2700-4100K, CRI: 80, 1,000 cd/m2, total output ≥ 500 lm)

Note

1. Electrode loss is negligible for devices currently used for small displays but will be an issue for large area devices necessary for general illumination applications in the future.
2. Includes substrate and electrode optical loss – negligible for glass and very thin electrodes but may be important for plastic or thicker electrodes.
3. Note that the efficiency allocation shown here is only one example of how the 60% luminaire efficiency target can be met.

Source: OLED Technical Committee, Fall 2008

While there is significant room for improvement in the active layers which comprise the device, considerable attention will have to be paid to the practicalities of OLED manufacturing. Current assembly technologies for OLEDs, which are focused on display applications, usually employ glass substrates with virtually no scattering loss. Transitioning to a flexible polymer substrate may be necessary to realize low cost manufacturing, but that may also reduce the device efficiency. The figure above estimates a target of 95% electrode efficiency, but this may be optimistic. Similarly, electrode design techniques may reduce losses in the conductors but could also obstruct or impair portions of device emission, thus reducing overall device efficiency. Today, this is sometimes evidenced by dim regions on even a relatively small panel. There are electrode design techniques that can improve but not entirely eliminate electrode resistance, but it could become a significant issue as panel sizes increase. Thus, while this diagram shows very small source losses from these effects, as they can be in lab devices, a commercialized product with that level of loss may be difficult to achieve.

The external quantum efficiencies in OLED layers can be relatively good for green (in contrast to the situation for LEDs) but are lower for blue and red, thus depressing the overall performance of white light. Due to waveguiding, EQE in planar OLED designs is limited to around 20% if one does not include any outcoupling enhancement. Innovation is needed to enhance EQE, as the goal is to achieve EQE values in the 70% range (with outcoupling enhancement). The same discussion with regard to the overall efficacy as outlined in the LED section applies here as well; lumens per optical watt depends on available wavelengths and efficiencies while the power efficiency depends on the other loss mechanisms.

Fixture efficiencies for OLEDs may also be relatively high when compared to conventional fixtures, although this has yet to be shown. Because OLEDs can be large area emitters, fixtures (to the extent that they are used to reduce glare) could almost be eliminated if the total lumen output of the OLED is distributed over a large enough area. Although fixture efficiencies could increase, prices of these fixtures could rise as the area of the OLED increases. Also, it is important to note that because there are no commercial products on the market, estimates of luminaire efficiencies are based on laboratory prototypes.

Keys to efficiency improvements in OLEDs continue to revolve around finding suitable stable materials with which to realize white light, with blue colors being the most difficult. Progress on efficiencies for OLEDs has been relatively rapid, as discussed in the next section. However, achieving efficiency gains alone will not be sufficient to reach viable commercial lighting products. The films must also be producible in large areas at low cost, which highlights the importance of minimizing substrate and electrode losses, as noted above and in the figure, and may also limit materials choices.

4.3 SSL Performance Targets

The projections of the performance of SSL devices created in consultation with the Technical Committees assume adequate funding by both government and private industry for the duration of the program. Although the authorization level for the SSL program is $50M for 7 years, actual appropriations have never reached this level. Appropriated funding steadily increased until 2007 (see Figure 3.1). In 2008 and 2009, appropriated funding decreased slightly from 2007 levels. Meeting these performance targets assumes that there are no unforeseen resource availability problems.

In order to capture the ultimate objectives of the SSL program that relate to *luminaire* efficacy or cost, objectives for luminaire performance are also included along with device performance objectives. Although the graphs show large improvements in device performance, reaching the luminaire objectives will take longer, as shown by the luminaire efficacy values in Table 4.3.3 and Table 4.3.5. Innovative fixtures for LEDs can have a significant impact on overall efficacy. For example, package efficiencies (and operating lifetime) can be degraded by 30% or more when operating at full temperature at steady state in a luminaire. Despite this degradation, SSL will still help DOE meet its

ZEB goals by providing a luminaire that is more efficient than luminaires of other lighting technologies. The simultaneous accommodation of aesthetic and marketing considerations along with the preservation of the energy-saving advantages of solid state lighting is a challenge in commercializing this technology. Section 5.6 of the SSL MYPP discusses DOE's commercialization support plan.

4.3.1 Light-Emitting Diodes

The performance of white-light LED packages depends on both the correlated color temperature of the package and, to a lesser extent, the color rendering index. While every case cannot be examined, efficacy projections have been shown for two choices: one for cooler CCT (4100K to 6500K), and the other for warmer CCT (2700K to 3500K). Because the majority of commercial products sold today are cool-white products, forecasts for these products are more predictable. Therefore for the cool-white case, projections are shown both for laboratory prototype LEDs and for commercially available packaged LEDs. Experience suggests that a one and a half year lag between laboratory results and commercial product is fairly typical. Efficacy projections for warm-white commercial LEDs are also given.

Actual results through 2008 show that efficacy improvement continues to be faster than was expected in earlier forecasts. LEDs are beginning to approach what are perceived to be the practical limits of efficacy as shown in Table 4.3.1. Because of this, one can expect progress to begin to slow down. These limits depend on the choice of CCT and color quality demanded by the application. Apart from these more or less predictable limits, manufacturing and cost considerations may further reduce efficacies below their maxima. Based on expected rates of future improvements, these maximum efficacies should be achieved in products between the years 2016 and 2020.

Table 4.3.1: Practical Maximum Package Efficacy for LEDs

Maximum Efficacy (lm/W)		
CCT	75 CRI	90 CRI
3000K	182	162
4100K	220	193
6500K	228	186

Source: LED Technical Committee, Fall 2008

Figure 4.8 shows package efficacy improvement forecasts over time. The 2009 MYPP forecast does not differ greatly from the 2008 MYPP, except that a somewhat slower rate of improvement is now projected for warm white light. The asymptotes on the graph show the extremes of the above table: warm-white packages with high CRI at 162 lm/W and cool-white packages with a low CRI at 228 lm/W. The earlier diagrams (Figure 4.5 and Figure 4.6) showed efficiencies for targets in between, giving values for a neutral white (4100K) and a moderate-to-high CRI. By 2013 the efficacy for high power cool-white laboratory prototypes should reach 184 lm/W, near the limit in the table above. Cool-white commercial *products* should reach a level of approximately 172 lm/W by that time. By 2025, the projections approach the practical maximum efficacies for LEDs of 228 lm/W for cool-white LEDs and 162 lm/W of warm-white LEDs (with a CRI of 90). All projections assume a "reasonable" package life (i.e. tens of thousands of operating hours).

A number of actual reported results for high-power LED packages are plotted, although these specific examples may not meet all of the criteria specified in the footnotes. Low-power LED packages also exist, but examples of these are not plotted. Because many more low-power LED packages are required to make a useful light source, reported results between low- and high-power LED packages are not directly comparable. For example, although one can achieve a high-efficacy light source using these low-power packages, there may be issues of higher assembly cost that need attention. While claims of higher efficacy have been made, they cannot be compared unless all parameters are known.

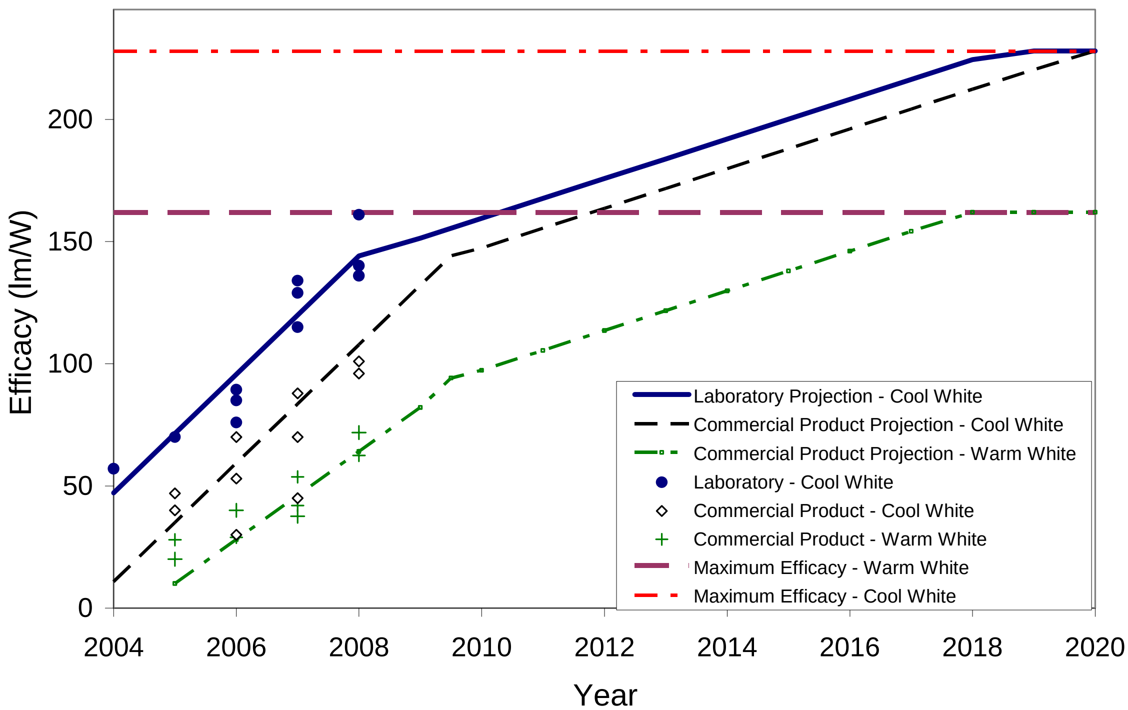

Figure 4.8: White-Light LED Package Efficacy Targets, Laboratory and Commercial

Note:

1. Cool-white efficacy projections assume CRI=70 → 80, CCT = 4100-6500°K,
2. Warm-white efficacy projections assume CRI>85, CCT =2800-3500°K
3. All projections are for high-power packages with a 350 ma drive current at 25°C, $1mm^2$ die size, package-level specification only (driver/luminaire not included), and reasonable package life.
4. The maximum efficacy values displayed in Table 4.3.1 for warm-white (3000K and 90 CRI) and cool-white (6500K and 75 CRI) packages are shown above as asymptotes. The target efficiency in Figure 4.5 assumes a CRI of 90 and a CCT of 4100K and would lie in between these two extremes.

Source: LED Technical Committee and the Department of Energy, Fall 2008; Press Releases

The price estimates represent the average purchase price of a white-light integrated LED lamp. The projected original equipment manufacturer (OEM) lamp price, assuming the purchase of "reasonable volumes" (i.e. several thousands) and good market acceptance, is shown in Figure 4.9. The price decreases exponentially from approximately $200/klm in 2007 to $2/klm in 2025. By way of rough comparison, a band representing a range of 2008 prices for conventional fluorescent technologies (with a self-ballasted 13 W compact fluorescent lamp at the bottom and a two-lamp 32 W T8 linear fluorescent lamp-and-ballast system at the top) are shown on the same chart. It is important to keep in mind that energy savings, replacement cost, and labor costs factor into a lamp's overall cost of ownership. LEDs are already cost-competitive on that basis with certain incandescent products.[55]

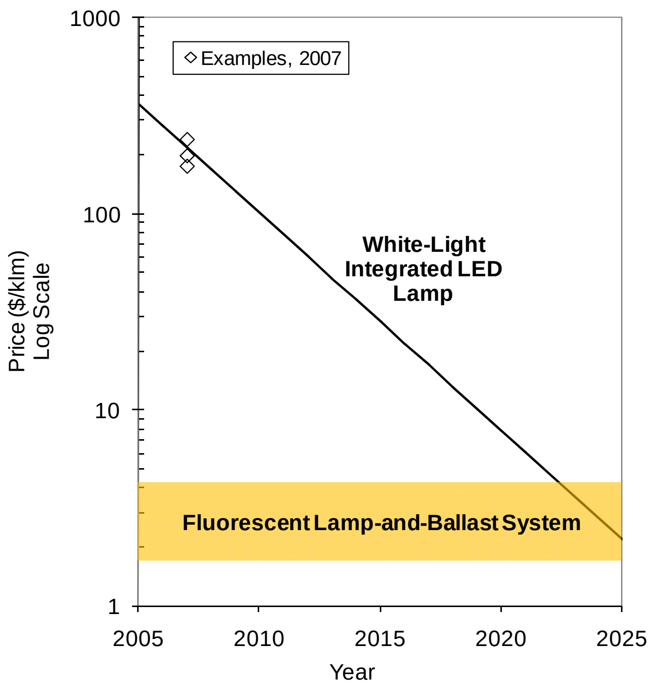

Figure 4.9: White-Light Integrated LED Lamp Price Projection (Logarithmic Scale)
Note: Assumes 2008 prices for fluorescent price range (13 W self-ballasted compact fluorescent lamp at bottom, and 2-lamp 32 W T8 linear fluorescent lamp-and-ballast system at top).
Source: LED Technical Committee, Fall 2008

The package life, measured to 70% lumen maintenance,[56] has increased steadily over the past few years and appears to be currently at its target of 50,000 hours. Although it appears that the majority of LEDs have reached the target of 50,000 hours, this has not been substantiated as yet by actual long-term operating data. Methods for characterizing lifetime, especially as changes in materials or processes are introduced, will likely require accelerated aging tests which so far have not been established for LED technologies. This is an important area of work, and there is an identified task for it described in Section 4.5.

An average package life of 50,000 hours allows LED packages to last more than twice as long as conventional linear fluorescent lighting products, five times longer than compact fluorescent lamps, and fifty times longer than incandescent lighting products. This long life makes LEDs very competitive with conventional technologies on a "Cost

[55] Typical 2008 lamp prices for conventional light sources listed in section 2.3.2 are also listed here for comparison: incandescent lamps (A19 60W), $0.30 per klm; self-ballasted compact fluorescent lamps (13W), $2 per klm; 2-lamp fluorescent lamp-and-ballast system (F32T8), $4 per klm.
[56] The package life stated above accounts for the lumen maintenance of the LED but does not account for other failure mechanisms.

of Light" basis (See Section 2.3.3). However, the total cost of ownership is not substantially affected by lifetimes greater than approximately 50,000 hours. LED products for niche/specialty applications could be developed with longer package life, upwards of 100,000 hours, by trading off with other performance parameters.

It is important to note that although the package lifetime may be 50,000 hours, the luminaire lifetime may be shorter. Bad luminaire design can shorten the life of an LED package dramatically through overheating. Drivers may also limit the lifetime of an LED luminaire. Therefore improving the lifetime of the driver to equal or exceed that of the LED package and improving heat management within an LED luminaire are goals of the SSL program.

Table 4.3.2 presents a summary of the LED performance projections in tabular form.

Table 4.3.2: Summary of LED Package Performance Projections

Metric	2008	2010	2012	2015
Efficacy- Lab (lm/W)	144	160	176	200
Efficacy- Commercial Cool White (lm/W)	108	147	164	188
Efficacy- Commercial Warm White (lm/W)	64	97	114	138
OEM Lamp ($/klm)	169	101	61	28

Note:

1. Efficacy projections for cool-white packages assume CRI=70 → 80 and a CCT = 4100-6500°K, while efficacy projections for warm-white packages assume CRI =>85 and a CCT of 2800-3500°K. All efficacy projections assume that packages are measured at 25°C.
2. All packages are assumed to have a 350 mA drive current, 1mm^2 die size, package-level specification only (driver/fixture not included), and lifetime as stated in table.
3. Price targets assume an integrated LED lamp, "reasonable volumes" (several 1000s), CRI=70 → 80, color temperature = 4100-6500K.
4. Package life is approximately 50,000 hrs assuming 70% lumen maintenance, "1 watt package," and 350 mA drive current.

Source: LED Technical Committee, Fall 2008

4.3.2 LED Luminaires

As stated in Section 4.2.1, the LED package is only one component of an LED luminaire. To understand the true performance metrics of a solid state lighting source, one must also take into account the efficiency of the driver and the efficiency of the fixture, and, importantly, the effects, primarily thermal, of the assembly on the performance of the packaged LED. Provided below in Table 4.3.3 are luminaire performance projections to complement the package and lamp performance projections given in Table 4.3.2. Table 4.3.3 assumes a linear progression over time from the current 2008 fixture and driver efficiency values to eventual fixture and driver efficiency 2015 program targets as given in Section 4.1.1. Estimating the factors that affect the performance of an LED luminaire, it appears that a cool-white luminaire in 2008 was capable of achieving 62 lm/W (although not all did so). By 2015 cool-white luminaire efficacies should reach a capability of 151 lm/W. A projected efficacy for a warm-white luminaire is not given here as it depends on the details of the light source design.

Table 4.3.3: Summary of LED Luminaire Performance Projections (at operating temperatures)

Metric	2008	2010	2012	2015
Package Efficacy-Commercial Cool White (lm/W, 25 degrees C)	108	147	164	188
Thermal Efficiency	85%	89%	91%	95%
Efficiency of Driver	85%	87%	89%	92%
Efficiency of Fixture	80%	83%	87%	92%
Resultant luminaire efficiency	58%	64%	70%	80%
Luminaire Efficacy-Commercial Cool White (lm/W)	62	94	115	151

Notes:
1. Efficacy projections for cool-white luminaires assume CRI=70 → 80 and a CCT = 4100-6500°K.
2. All projections assume a 350mA drive current, 1mm^2 die size, reasonable package life and operating temperature.
3. Luminaire efficacies are obtained by multiplying the resultant luminaire efficiency by the package efficacy values.

Source: LED Technical Committee, Fall 2008

4.3.3 Organic Light-Emitting Diodes

In consultation with the OLED Technical Committee, DOE developed price and performance projections for white light OLED devices operating in a CCT range from 2700-4100°K and a CRI of 80 or higher. Two projection estimates are shown: one for laboratory prototype OLEDs, and one for (future) commercially available OLEDs. Because it is difficult to obtain a highly-efficient blue OLED emitter, similar projections for cooler CCT values will have lower efficiencies than their warmer CCT counterparts shown below. This is unlike LEDs, where cooler CCT values are more efficient than their warmer CCT counterparts. Efficacy projections for OLEDs with a CRI of 90 or higher will also be slightly lower than projections shown.

Figure 4.10 (plotted on a logarithmic scale) predicts that the efficacy of laboratory prototypes will grow exponentially to reach 150 lm/W by 2012. As noted earlier, only one commercial OLED luminaire appears to have been produced for sale as of this writing, and in very limited quantities. Given such limited availability for commercial OLED lighting products, the estimated efficacies for commercial products are not very meaningful but have been assumed to lag approximately three years behind the laboratory products. Although the overall SSL program may be expected to continue until 2025 in order to achieve technologies capable of full market penetration, the commercial OLED efficacy forecast in this section only projects performance to 2015 due to a lack of knowledge about the ultimate limit of this technology. These projections assume the CRI and CCT mentioned above and a luminance of 1,000 cd/m^2 for a pixel-sized OLED device. These projections apply to a white light OLED device with a color point "near" the blackbody curve (Δc_{xy}<0.005),[57] which may be a necessary criterion to market the products for various general illumination applications. The figure indicates CRI and CCT values for devices with available CRI and CCT information. A number of actual reported results are plotted next to the performance projections, although these specific examples may not meet all of the specified criteria.

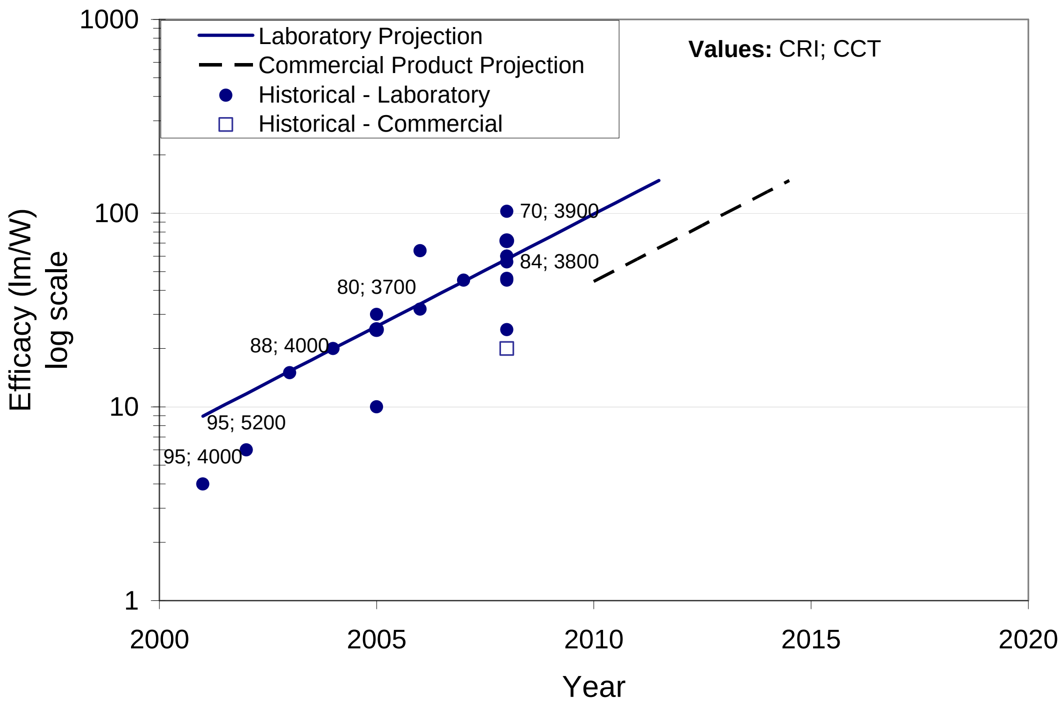

Figure 4.10: White-Light OLED Device Efficacy Targets, Laboratory and Commercial
(On a logarithmic scale)
Note: Efficacy projections assume CRI > 80, CCT = 2700-4100°K ("near" blackbody curve (Δc_{xy} <0.005), lifetime > 1000 hrs, luminance of 1,000 cd/m^2, and device-level specification only (driver/luminaire not included). CRI and CCT shown for those devices for which it is known.
Source: Projections: OLED Technical Committee, Fall 2008; Laboratory Points: Press Releases

[57] Δc_{xy} is the distance from the blackbody curve in C.I.E. color space.

Today, the efficacy of OLED devices lags behind LED packages. However, researchers are optimistic and when the projections of commercial LEDs and OLEDs are compared (see Figure 4.11) the efficacy of OLED products appears to approach that of the LED products in the latter part of the current forecast.

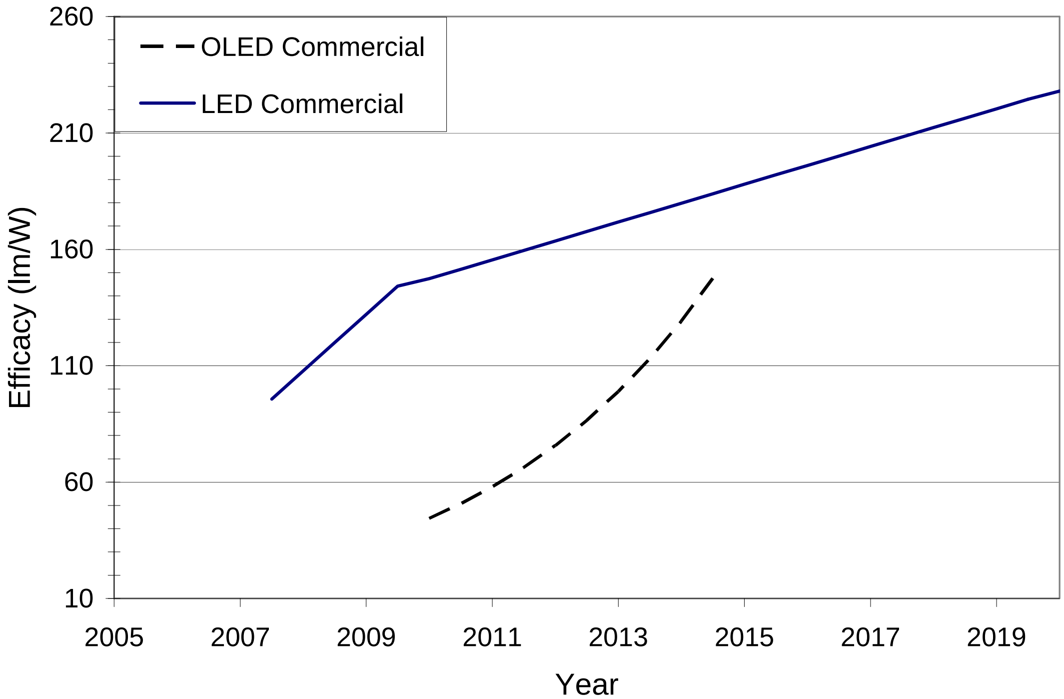

Figure 4.11: LED and OLED Device Efficacy Projections, Commercial
Source: LED and OLED Technical Committees and the Department of Energy, Fall 2008

Figure 4.12 presents the forecast targets for the OEM price of commercially available white-light pixel-sized OLED devices (driver and fixture not included) with a luminance of 1,000 cd/m^2. The price is expected to fall to \$10/klm by 2015, assuming reasonable volumes of OLED panels (approximately one square meter in size) are sold. Prices of OLEDs may remain around \$10/klm after 2015, although future price reductions are possible. The OEM device price, measured in \$/m^2, is approximately a factor of three greater than OLED device price when measured in \$/klm for the assumed luminance of 1,000 cd/m^2. It is important to note that the price projections below are for OLED devices and not luminaires. Because an OLED driver and fixture may be less costly than that of a conventional lighting source, however, an OLED luminaire with a more expensive device may still be cost competitive with a conventional luminaire.

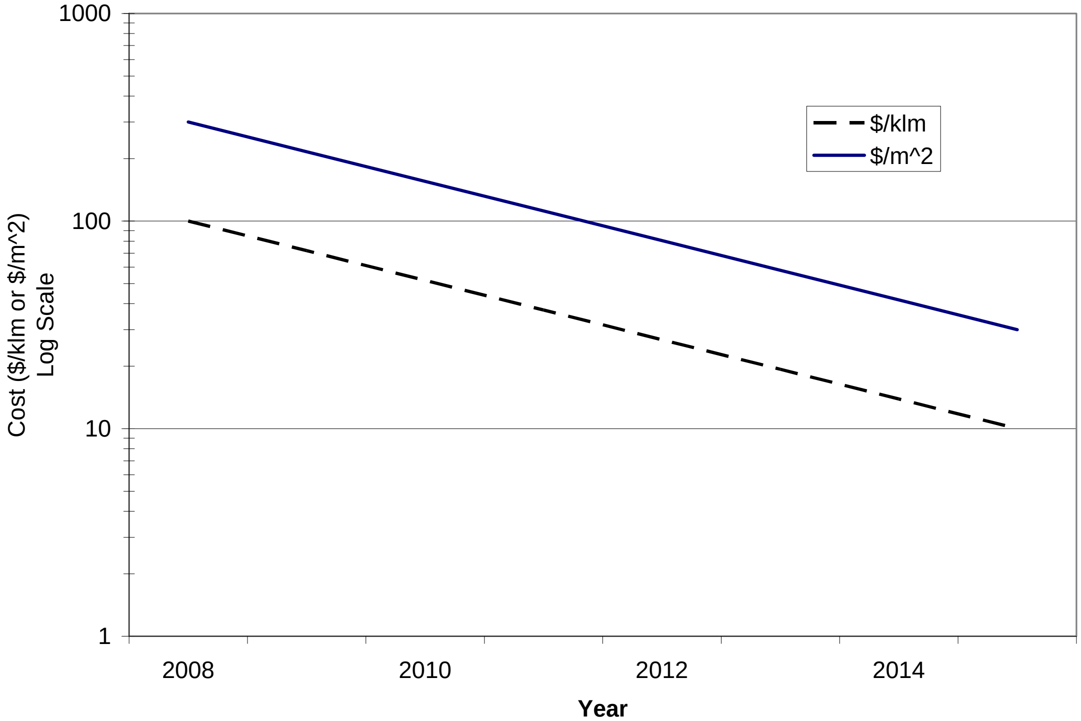

Figure 4.12: White-Light OLED Device Price Targets, $/klm and $/m^2
Note: Price targets are displayed on a logarithmic scale.
Source: OLED Technical Committee, Fall 2008

The device life for commercial products, defined as 70% lumen maintenance, is expected to increase linearly to a value of approximately 50,000 hours in 2015. Although 50% lumen maintenance is industry practice for evaluation of OLED displays, 70% lumen maintenance[58] is used in order to compare lifetimes with other lighting products.

Table 4.3.4 presents a summary of the OLED performance projections in tabular form. Projections below represent the lifetime of the device, not an entire OLED luminaire. Although the OLED device may reach long lifetimes, other components of the OLED luminaire like the driver may limit the luminaires lifetime. Therefore improving the lifetime of these additional components to at least equal that of the OLED device is a goal of the SSL program.

[58] Like LED package lifetimes shown in this section, OLED device lifetimes account for the lumen maintenance of the OLED but do not account for other failure mechanisms.

Table 4.3.4: Summary of OLED Device Performance Projections

Metric	2008	2010	2012	2015
Efficacy- Lab (lm/W)	58	99	150	150
Efficacy- Commercial (lm/W)	N/A	44	76	150
OEM Device Price- ($/klm)	N/A	72	27	10
OEM Device Price- ($/m^2)	N/A	216	80	30
Device Life- Commercial Product (1000 hours)	N/A	11	25	50

Notes:

1. Efficacy projections assume CRI = 80, CCT = 2700-4100°K ("near" blackbody curve (Δc_{xy}<0.005), luminance of 1,000 cd/m^2, and device-level specification only (driver/luminaire not included).
2. OEM price projections assume CRI = 80, luminance of 1,000 cd/m^2, and device-level specification only (driver/luminaire not included).
3. Device life projections assume CRI = 80, 70% lumen maintenance, and luminance of 1,000 cd/m^2.

Source: OLED Technical Committee, Fall 2008

4.3.4 OLEDs in Luminaires

The table below details a summary of the efficiency losses that occur when considering the entire OLED luminaire. Losses in the driver account for the majority of the efficiency degradation while losses in the fixture are assumed to be lower. In addition, OLEDs do not show significant thermal degradation loss, an effect that required the thermal efficiency component for LEDs shown in Table 4.3.3. Again, a linear improvement over time is assumed from current 2008 driver and fixture efficiency values to 2015 program targets as given in Figure 4.7. The 2010 OLED commercial luminaire efficacy projection is 36 lm/W and the 2015 OLED commercial luminaire efficacy projection is 122 lm/W, when all of the factors that affect the performance of an OLED luminaire are multiplied by the original device efficacy projections.

Table 4.3.5: Summary of OLED Luminaire Performance Projections beginning 2010

Metric	2008	2010	2012	2015
Commercial Device Efficacy (lm/W) (Table 4.3.4)	N/A	44	76	150
Efficiency of Fixture	90%	90%	92%	95%
Efficiency of Driver	90%	90%	92%	95%
Total Efficiency from Device to Luminaire	81%	81%	85%	90%
Resulting Luminaire Efficacy-Commercial Product (lm/W)	N/A	36	65	122

Notes:
Efficacy projections assume CRI = 80, CCT = 2700-4100°K ("near" blackbody curve (Δc_{xy} <0.005), luminance of 1,000 cd/m^2, and device-level specification only (driver/luminaire not included).
Source: OLED Technical Committee, Fall 2008

4.4 Barriers

The following lists some of the technical, cost, and market barriers to LEDs and OLEDs. Overcoming these barriers is essential to the success of the SSL program.

1. Cost: The initial cost of light from LEDs and OLEDs is too high, particularly in comparison with conventional lighting technologies such as incandescent and fluorescent (see Sections 2.3.2 - 2.3.3). Since the lighting market has been strongly focused on low first costs, lifetime benefits notwithstanding, lower-cost LED package and OLED device and luminaire materials are needed, as well as low-cost, high-volume, reliable manufacturing methods. For OLEDs, the cost and future availability of indium, often used in OLED electrodes, is of particular concern.

2. Luminous Efficacy: As the primary measure of DOE's goal of improved energy efficiency, the luminous efficacy (lumens/watt) of LED and OLED luminaires still need improvement. Although the luminous efficacy of LED luminaires has surpassed that of the incandescent lamps, improvement is still needed to compete with other conventional lighting solutions. For example, the industry must find ways to minimize the amount of "droop" in efficiency that occurs at high drive currents for LEDs. Improving red light emission in wavelengths specifically for color quality in efficacious lighting would also

benefit LED lighting products. While laboratory experiments demonstrate that OLED devices can be competitively efficacious as compared to conventional technologies, no products are yet available.

3. Lifetime: The lifetime of LEDs and OLEDs is defined as the number of hours for which the device maintains at least 70% of its initial lumen output. It is unclear what lifetimes LED luminaires are achieving. Furthermore, a definition of lifetime that focuses on lumen maintenance is inadequate for luminaires. Lumen maintenance is only one component of the lifetime of a complex system such as a luminaire that may be subject to other failure mechanisms like color shifts, reflector degradation, or even catastrophic failure. Premature failures due to excessive temperature are still relatively common. OLED lifetimes for both devices and luminaires still require improvement. The development of a long-lasting blue emitter for OLEDs is critical.

4. Testing: The reported lumen output and efficacies of LED and OLED products in the market do not always match laboratory tests of performance. Improved and standardized testing protocols for performance metrics need to be developed. An important barrier appears to be a lack of understanding of the meaning of device specifications versus continuous operation in a luminaire on the part of designers. Furthermore, accelerated reliability testing methods for systems and materials are absolutely necessary for market penetration. Such tests, capable of providing accurate projections of life, do not currently exist. Uncertainty in both device and luminaire lifetimes creates risk for manufacturers and consumers, potentially reducing adoption rates.

5. Lumen Output: LED luminaires are reaching reasonable total lumen output levels although many still perceive LEDs as offering only “dim” light, a significant market barrier. OLED packages with useful levels of output remain yet to be developed.

6. Manufacturing: While OLEDs have been built off of display manufacturing capabilities, there has been little investment by manufacturers in the infrastructure needed to develop commercial OLED lighting products. A breakthrough is necessary to produce low-cost OLEDs for general illumination. Lack of process uniformity is an important issue for LEDs and is a barrier to reduced costs as well as a problem for uniform quality of light.

7. Codes and Standards: New guidelines for installation and product safety certifications such as the UL provided by the Underwriters Laboratory must be developed. Common standards for fixture (or socket) sizes, electrical supplies and control interfaces may eventually be needed to allow for lamp interchangeability. Standard test methods are still lacking in some areas. In general, the development of appropriate codes and standards will enable consistency from brand to brand and year to year, reducing uncertainty for consumers.

For more information about individual research tasks that address these technical, cost and market barriers, refer to Section 4.5.

4.5 Critical R&D Priorities

In order to achieve these projections, progress must be achieved in several research areas. The original task structure and initial priorities were defined at a workshop in San Diego in February 2005. These priorities were updated in the March 2006, March 2007, and March 2008 editions of the Multi-Year Program Plan. Because of continuing progress in the technology and better understanding of critical issues, DOE engaged members of the lighting field, from industry representatives to academic researchers, to revisit and substantially revise the task structure for the 2009 MYPP. DOE first held solid-state lighting roundtable sessions Washington, D.C. in September of 2008. Further refinement occurred through a series of conference calls with members of DOE SSL technical committees in the fall of 2008. The tasks were further refined at the February 2009 "Transformations in Lighting" workshop in San Francisco, CA, where participants recommended tasks for prioritization. Using these recommendations, and after further internal review, the DOE defined the task priorities for 2009 as follows:

For LED Core Technology:

- This subtask A.1.2 (Emitter materials research) encourages the development of highly-efficient green and deep-red emitters to greatly improve the efficiency of color-mixing LED packages.

- Subtask A.1.3 (Down-converters) emphasizes improvements in phosphor lifetime, color control, and conversion efficiency, necessary to meet DOE's long-term LED milestones.

- The subtask A.5.1 (Optical component materials) is intended to lay the foundations of understanding necessary to reduce degradation over time of various optical component materials including diffusers, lenses, adhesives, or reflectors, to name a few.

- Subtask A.6.2 (Thermal components research) was prioritized because of the variety of thermal issues that exist across various components of the LED luminaire, all of which ultimately impact luminaire performance and lifetime.

- Subtask A.6.3 (System reliability methods) is intended to encourage the development of high-quality system reliability methods that could lead to improved efficiency and can also be used with a variety of LED luminaires.

For LED Product Development:

- Subtask B.1.2 (Semiconductor materials) was made a priority to further encourage the development and deployment of efficient green and deep-red emitters with an emphasis on the production of white light with improved droop and thermal sensitivity parameters.

- Subtask B.1.3 (Phosphors) was prioritized because advances in phosphors can improve LED efficiency as well as color quality, which will both encourage market adoption of LED products.

- Subtask B.3.4 (Emitter thermal control) supports the increase in LED thermal conductivity in order to increase LED efficacy, reliability, and current density.

- The subtask B.4.2 (Epitaxial growth) is meant to encourage the development of growth reactors and monitoring methods that can reproducibly grow advanced LEDs at low cost with high uniformity, substantially reducing the cost of LED luminaires and increasing the potential for market adoption.

- Subtask B.6.2 (Luminaire thermal management techniques) will support the improvement in thermal conductivity in order to substantially improve LED luminaire efficacy and reliability.

- Subtask B.6.3 (Optimizing system reliability) will encourage the development of consensus as to what methods should be used to assess and model system reliability.

For OLED Core Technology:

- Subtask C.1.1 (Novel device architectures) is intended to encourage the development of white-light OLED architectures with increased EQE, improved lifetime, and reduced voltage.

- Subtask C.1.2 (Novel materials) will support the development of stable white-light OLED emitter materials that have the potential for large-scale, low-cost production and processing.

- Subtask C.2.2 (Electrode research) is meant to encourage the development of non-ITO electrode types with the same performance as ITO or better. The prioritization of this subtask could encourage research into two-material electrodes, flexible electrodes, p-type and n-type degenerate electrodes, and other low-voltage electrodes.

- Subtask C.3.1 (Fabrication technology research) is intended to support the creation of practical, scalable techniques for organic material deposition, device fabrication, and encapsulation at low cost.

For OLED Product Development:

- Subtask D.2.1 (Substrate materials) will encourage the development of low-cost OLED substrate materials. These materials can be flexible or non-flexible.

- Subtask D.3.1 (Panel manufacturing technology) will help to address the capital and operational costs in manufacturing, which pose a large barrier to cost reduction of OLED devices.

- The subtask D.6.1 (Large-area OLED) will support efforts to tackle the significant challenges inherent in the creation of a large-area OLED.

The tables that follow provide a description of the task and defined metrics. There is also an estimate of the current status and a target for year 2015. Prioritized tasks for 2009 are listed first, and other tasks that were defined during the course of the updating progress are listed next.

Table 4.5.1: LED Priority Core Technology Tasks for 2009

	Task	Description	Metric	2008 Status	2015 Target
LED Priority Core Technology Tasks for 2009					
A.1.2	Emitter materials research	Focus on the development of efficient green and deep-red emitters with low droop and minimal thermal sensitivity and continue improvement in blue LEDs.	IQE across the visible spectrum at high current densities	20% green (540 nm), 75% red, 80% blue[59]	90% for all three colors
A.1.3	Down-converters	High-efficiency wavelength conversion materials for improved quantum yield, optical efficiency, and color stability. Explore novel approaches to conversion.	Quantum Yield;[60] Scattering Losses; Color Stability	Quantum Yield=80% warm, 95% cool; Scat 10%; Color Shift .012 over life	Quantum Yield=90% across visible spectrum warm, 95% across visible spectrum cool; Scat. 10%; cool 95%; 10% ; Color Shift < .007 over life
A.5.1	Optical component materials	Develop optical component materials that last at least as long as the LED source (50k hours) under lighting conditions which would include: elevated ambient and operating temperatures, UV- and blue-light exposure, and wet or moist environments.	Transmission Across Visible Spectrum; Lifetime		> 90% transmission; Lifetime=50 kHrs
A.6.2	Thermal components research	Research and develop novel thermal materials and devices that can be applied to solid-state LED products.	LED Source Junction Temperature Maintenance Improvement Relative to 2008	Baseline	25% improvement
A.6.3	System reliability methods	Develop models, methodology, and experimentation to determine the system lifetime of the integrated SSL luminaire and all of the components based on statistical assessment of component reliabilities and lifetimes. Includes investigation of accelerated testing.	Model Accuracy vs. Experiment	Some testing methods available for device lumen depreciation (LM-80)	99% at 6 kHrs, 90% at 50 kHrs

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[59] IQE status and projections assume pulsed measurements at 350 mA drive currents with a $1x1mm^2$ chip and $T_j = 25^oC$.

[60] Quantum Yield is measured at a pumped wavelength of 450 nm unless otherwise specified.

Table 4.5.2: LED Priority Product Development Tasks for 2009

	Task	Description	Metric	2008 Status	2015 Target
LED Priority Product Development Tasks for 2009					
B.1.2	Semiconductor materials	Improve IQE at optimal wavelengths for producing white light across the visible spectrum (red: 610nm; green: 540nm). Improve droop and thermal sensitivity.	IQE across the visible spectrum at high current densities	20% green (540 nm),75% red (610 nm), 80% blue	90% for all three colors
B.1.3	Phosphors	Optimize phosphors for LED white light applications, including color uniformity, color maintenance, thermal sensitivity and stability.	Quantum Yield; Scattering Losses; Color Stability; Temperature Stability	Quantum Yield=80% warm, 95% cool; Scat. 10%; Color Shift <.012	Quantum Yield=90% across visible spectrum (cool/warm); Scat. 10%; Color Shift <.007; <10% Temp drop at 150°C
B.3.4	Emitter thermal control	Demonstrate an LED or LED array that maximizes heat transfer to the package so as to improve chip lifetime and reliability.	Thermal Resistance (junction to case) for 1W $1mm^2$ single-chip package	10ºC/W general; some at 5ºC/W	<1ºC per Watt
B.4.2	Epitaxial growth	Develop and demonstrate growth reactors and monitoring tools or other methods capable of growing state of the art LED materials at low-cost and high reproducibility and uniformity with improved materials-use efficiency.			

Table 4.5.2: LED Priority Product Development Tasks for 2009 (Continued)

	Task	Description	Metric	2008 Status	2015 Target
LED Priority Product Development Tasks for 2009					
B.6.2	Luminaire thermal management techniques	Design low-cost integrated thermal management techniques to protect the LED source, maintain the luminaire efficiency and color quality.	Lumen Output of luminaire at steady state operating temperature relative to lumen output of luminaire at 25°C		Lumen Output relative difference <10%
B.6.3	Optimizing system reliability	Optimize and verify overall luminaire reliability. Includes system reliability analysis to determine failure mechanisms and improve.	Mean Time to Failure (either catastrophic or lumen depreciation below 70%)		40 kHrs

Table 4.5.3: Other Identified LED Core Technology Tasks

	Task	Description	Metric	2008 Status	2015 Target
Other Identified LED Core Technology Tasks					
A.1.1	Alternative substrates	Explore alternative practical substrate materials and growth for high-quality epitaxy so that device quality can be improved.	Performance Potential Improvement Over Conventional		
A.2.1	Light extraction approaches	Devise improved methods for raising chip-level extraction efficiency and LED system optical efficiency. Photonic crystal structures or resonant cavity approaches would be included.	Chip Extraction Efficiency (χ); Phosphor Conversion Efficiency	Chip Extraction Efficiency=80% green (540 nm), 50% red (610 nm), 80% blue; Phosphor Conversion Efficiency=65%	Chip Extraction Efficiency=90% for all colors; Phosphor Conversion Efficiency=73%
A.2.2	Novel emitter materials and architectures	Devise alternative emitter geometries and emission mechanisms in manufacturable configurations that show genuine improvement over existing approaches. (Possible examples: quantum dots, monolithic integrated RGB, 360 degree emitters, etc.)	EQE	64%	EQE=81%
A.3.4	Thermal control research	Simulation of solutions to thermal management issues at the package or array level. Innovative thermal management solutions.	Thermal Resistance (junction to case)		5ºC per Watt
A.4.4	Manufacturing simulation	Develop manufacturing simulation approaches that will help to improve yield and quality of LED products.			

Table 4.5.3: Other Identified LED Core Technology Tasks (Continued)

	Task	Description	Metric	2008 Status	2015 Target
Other Identified LED Core Technology Tasks					
A.7.4	Driver electronics	Develop advanced solid-state electronic materials and components that enable higher efficiency and longer lifetime for control and driving of LED light sources.	Driver Efficiency; Lifetime at Operating Temperature	Driver Efficiency=85%; Lifetime at Operating Temp=40 kHrs	Driver Efficiency=92%; 50 kHrs
A.7.5	Electronics reliability research	Develop designs that improve and methods to predict the lifetime of electronics components in the SSL luminaire.	Accuracy of Predictive Model vs. Long Term Actual Results or Potential Lifetime Improvement for a novel design approach		

Table 4.5.4: Other Identified LED Product Development Tasks

	Task	Description	Metric	2008 Status	2015 Target
Other Identified LED Product Development Tasks					
B.1.1	Substrate development	Develop low-cost, high-quality substrates that enable epitaxial growth of high-quality emitting material.	Cost of Substrate ($/klm); Defect Density		
B.2.3	Electrical	Reduce the operating voltage of LED chips or arrays by increasing lateral conductivity or architectural improvements or package design, etc.	Operating Voltage		
B.3.1	LED package optics	Beam-shaping or color-mixing at the LED package or array level.	Optical/Fixture Efficiency	80%	92%
B.3.2	Encapsulation	Develop a thermal/photo-resistant encapsulant that exhibits long life and has a high refractive index.[61]	% of Original Transmission Per mm at 150^{o}C and 10-15 kHrs	85-90%	95%
B.3.5	Environmental sensitivity	Develop and extensively characterize a packaged LED with significant improvements in lifetime associated with the design methods or materials.	Mean Time to Failure		50 kHrs

[61] The temperature reference in the metric may change to 185^{o}C as efficiency goals are met and cost becomes a higher priority.

Table 4.5.4: Other Identified LED Product Development Tasks (Continued)

	Task	Description	Metric	2008 Status	2015 Target
Other Identified LED Product Development Tasks					
B.3.6	Package architecture	Demonstrate a packaged chip or multi-chip product employing practical, low-cost designs, materials, or methods for improving light outcoupling and removing heat from the chip to produce a product with high total lumen output efficiently.			
B.4.1	Yield and manufacturability	Devise methods to improve epitaxial growth uniformity of wavelength and other parameters so as to reduce binning yield losses. Solutions may include in-situ monitoring and should be scalable to high volume manufacture.			
B.4.3	Manufacturing tools	Develop improved tools and methods for die separation, chip shaping, and wafer bonding, and testing equipment for manufacturability at lower cost.			
B.5.1	Light utilization	Maximize the ratio of useful light exiting the luminaire to total light from the LED source. This includes all optical losses in the luminaire; including luminaire housing as well as optical losses from diffusing, beam shaping, and color mixing optics. Minimize artifacts such as multishadowing or color rings.	Useful Light Output from Luminaire/Total Light Generated by LED Source	80%	92%
B.5.2	Color maintenance	Ensure luminaire optical components maintain the LED source color quality over the life of the luminaire.	Color maintenance within X-step MacAdam Ellipse over time		
B.5.3	Diffusion and beam shaping	Develop optical components that diffuse and/or shape the light output from the LED source(s) into a desirable beam pattern and develop optical components that mix the colored outputs from the LED sources evenly across the beam pattern.	Optical Loss measured as part of the luminaire optical system; Lifetime		

Table 4.5.4: Other Identified LED Product Development Tasks (Continued)

	Task	Description	Metric	2008 Status	2015 Target
Other Identified LED Product Development Tasks					
B.6.1	Luminaire mechanical design	Integrate all aspects of LED based luminaire design: thermal, mechanical, optical, and electrical. Design must be cost effective, energy efficient and reliable.			
B.7.1	Color maintenance	Develop LED driver electronics that maintain a color setpoint over the life of the luminaire by compensating for changes in LED output over time and temperature, and degradation of luminaire components.	Color Shift over the life of the luminaire; Efficiency of Control Electronics		
B.7.2	Color tuning	Develop efficient electronic controls that allow a user to set the color point of the luminaire.	Efficiency of Control Electronics; Off-State Power Consumption; Accuracy of Color-Setting		

Table 4.5.4: Other Identified LED Product Development Tasks (Continued)

	Task	Description	Metric	2008 Status	2015 Target
Other Identified LED Product Development Tasks					
B.7.3	Smart controls	Develop integrated lighting controls that save energy over the life of the luminaire. May include methods to maximize dimmer efficiency. May include sensing occupancy or daylight, or include communications to minimize energy use, for example.	Efficiency of Control Electronics; Off-State Power Consumption; Power Saved		
B.7.4	Electronics component research	Develop compact, long-life LED driver electronics and power converters that efficiently convert line power to acceptable input power of the LED source(s) while maintaining an acceptable power factor; encourage standardization in the long term.	Driver Efficiency @120V and 25W; Lifetime at Operating Temperature; Cost; Plug to Chip Efficiency @120V and 25W	Driver Efficiency=85%; Lifetime at Operating Temp=40 kHrs	Driver Efficiency=92%; 100 kHrs

Table 4.5.5: OLED Priority Core Technology Tasks for 2009

	Task	Description	Metric	2008 Status	2015 Target
OLED Priority Core Technology Tasks for 2009					
C.1.1	Novel device architectures	Device architectures to increase EQE, reduce voltage, and improve device lifetime that are compatible with the goal of stable white light. Explores novel structures like those that use multi-function components, cavities or other outcoupling strategies to optimize light extraction. Could include studying material interfaces.	EQE; Voltage; L_{70}	36% EQE including light extraction enhancements; L_{50}=20kHrs	EQE 74% for all colors including light extraction enhancements; V= close to the bandgap; 40 kHrs
C.1.2	Novel materials	Organic materials or contact materials to achieve white light: increase IQE, reduce voltage and improve device lifetime. Explores novel materials that can be used to emit light (especially blue) highly efficiently with the ultimate goal of generating highly-efficient white light. The materials should be inherently stable against moisture and temperature and should have the potential for large scale manufacture at low cost.	Voltage @ 1mA/cm^2; L_{70}; EQE without extraction enhancement; L_{70}; CCT;[62] CRI	L_{50}=20kHrs; 29% EQE; 3900K CCT; 70 CRI[63]	V= close to the bandgap ; 40 kHrs; EQE 20-30% across visible spectrum
C.2.2	Electrode research	Develop a novel transparent electrode with low resistivity to serve as a lower cost replacement for ITO with the same or better performance. This electrode should be inherently stable against moisture and temperature. Areas of research may include p-type and n-type degenerate electrodes, two-material electrodes, electrodes that reduce I*R loss, flexible electrodes, or other low-voltage electrodes.	Ohms/Square; Transparency and absorption over the visible spectrum	Non-ITO electrode: 40 Ohms/Square; 75-80% Transparency; ITO: <10 ohms/sq; 92% transparency	Non-ITO electrode: < 10 Ohms/Square; 92% Transparency (current performance of ITO)
C.3.1	Fabrication technology research	Develop new practical techniques for organic materials deposition, device fabrication, or encapsulation. Could also include developing a physical, chemical, or optical model for fabrication of OLED devices. Should show potential for scalability and low cost.	Material Use; Uniformity	<5% Material Utilization; Uniformity of <5% thickness variation over device area	>50% Material Utilization; <10% Variation over 6" square

[62] CRI and CCT metrics are useful only if color point is <0.005 distance away from black-body locus in CIE color space.
[63] Lack of standardized testing in OLEDs results in significant variation in the status of this task.

Table 4.5.6: OLED Priority Product Development Tasks for 2009

	Task	Description	Metric	2008 Status	2015 Target
OLED Priority Product Development Tasks for 2009					
D.2.1	Substrate materials	Demonstrate an OLED with reasonable performance and low degradation using a substrate material that is low-cost and shows reduced water and oxygen permeability. Other considerations may include processing and operational stability, weight, cost, optical and barrier properties, and flexibility.	$\$/m^2$ including substrate plus TCO or equivalent; Water Permeability; Oxygen Permeability; Lifetime as compared to existing technology	Glass: $\$50/m^2$ w/o TCO, no Water Permeability; Flexible: $\$100/m^2$, 10^{-6} g/m^2-day Water Permeability	< $4/m^2$ with substrate plus TCO or equivalent; 10^{-6} g/m^2-day Water Permeability including TCO or equivalent; No reduction in lifetime as compared to existing technology
D.3.1	Panel manufacturing technology	Develop and demonstrate methods to produce an OLED panel with performance consistent with the roadmap using integrated manufacturing technologies that can scale to large areas while enabling significant advances in yield, quality control, substrate size, process time, and materials usage using less expensive tools and materials than in the OLED display industry and can scale to large areas.	Capital Cost; Material Use; Deposition Rate; Uniformity; Total Actual Cycle (TAC) Time; $/klm, klm/time	Deposition Rate=5 min/m^2	Deposition Rate=1 min/m^2; $20/klm; 100 Mlm/month
D.6.1	Large-area OLED	Investigate barriers unique to the fabrication of OLED panels (assemblies of devices). Demonstrate a high-efficiency OLED panel with good thermal performance, employing low-cost designs and materials and with the potential for large-scale manufacturing. Demonstrate that the panel reduces conductive (I*R) losses, defect density, or shorting density and increases color and luminance uniformity of light. Areas of focus may include light extraction and encapsulation techniques suitable for large-area panels.	Lumen Output; Color; X-step MacAdam Ellipse away from Planckian locus		> 500 lumens;

Table 4.5.7: Other Identified OLED Core Technology Tasks

	Task	Description	Metric	2008 Status	2015 Target
Other Identified OLED Core Technology Tasks					
C.1.3	Material and device architecture modeling	Developing software simulation tools to model the performance of OLED devices using detailed material characteristics.			
C.1.4	Material degradation	Understand and evaluate the degradation of materials during device operation.	L_{70}	L_{50}=20 kHrs	L_{70}=50 kHrs
C.1.5	Thermal characterization of materials and devices	Involves modeling and/or optimizing the thermal characteristics of OLED materials and device architectures with the goal of developing less thermally sensitive and hydrolytically more stable materials and devices.			
C.4.3	Optimizing system reliability	Research techniques to optimize and verify overall luminaire reliability. Develop system reliability measurement methods and accelerated lifetime testing methods to determine the reliability and lifetime of an OLED device, panel, or luminaire through statistical assessment of luminaire component reliabilities and lifetimes.			
C.6.3	Light extraction approaches	Devise new optical and panel designs for improving OLED panel light extraction.	Light Extraction Efficiency	40%	76%

Table 4.5.8: Other Identified OLED Product Development Tasks

	Task	Description	Metric	2008 Status	2015 Target
Other Identified OLED Product Development Tasks					
D.1.1	Practical implementation of materials and device architectures	Develop materials and device architectures that can concurrently improve robustness, lifetime, efficiency, and color quality with the goal of stable white light over its lifetime. The device should be pixel-sized, demonstrate scalability, and have a lumen output of at least 50 lumens.	Efficacy; L_{70}; Lumen Output; CRI;[64] CCT	102 lm/W; L_{50}=20kHrs; 70 CRI	> 100 lm/W Efficacy; L_{70}=40 kHrs; 50 Lumens; 90 CRI; CCT=[blank]
D.1.5	Device failure	Understand the failure modes of an OLED at the device level.	L_{70}	L_{50}=20 kHrs	L_{70}=50 kHrs
D.2.2	Low-cost electrodes	Demonstrate a high-efficiency OLED employing a transparent electrode technology that is low-cost, low-voltage, and stable, with the potential for large-scale manufacturing. Design could include a conducting grid.	Effective Ohms/Square; Transparency over the visible spectrum; $/m^2 (material + deposition)	<10 Ohms/sq; 92% Transparency; Cost ~ $20/m^2	< 10 Ohms/Square; 92% Transparency; Cost < $6/m^2
D.3.2	Quality control	Develop characterization methods to help define material quality for different materials and explore the relationship between material quality and device performance. Develop improved methods for monitoring the deposition of materials in creating an OLED panel.			

[64] CRI and CCT metrics are useful only if color point is <0.005 distance away from black-body locus in CIE color space.

Table 4.5.8: Other Identified OLED Product Development Tasks (Continued)

	Task	Description	Metric	2008 Status	2015 Target
Other Identified OLED Product Development Tasks					
D.4.1	Light utilization	Maximize the ratio of useful light exiting the luminaire to total light from the OLED sources. This includes all optical losses in the luminaire; including optical losses from beam distribution and color mixing optics.	Useful light output from luminaire/total light generated by OLED panel	90%	95%
D.4.2	Luminaire mechanical design	Integrate one or more OLED panels into a luminaire, with thermal, mechanical, optical, and electrical design to achieve a cost-effective, long-life, energy-saving, and marketable luminaire suitable for general lighting applications. All components should be as robust as the OLED. This task is to include maximizing light output, thermal management to limit OLED source temperature, and electrical interconnections with driver and among OLED panels.	Luminaire Efficacy; Lifetime; Cost; Lumen Output	No product existing	Luminaire Efficacy >122 lm/W; L_{70} > 50kHrs; Competitively priced against other technologies; >500 lumens output
D.4.3	System reliability methods	Develop models, methodology, and experimentation to determine the lifetime of the integrated OLED luminaire and all of the components.			
D.4.4	Luminaire thermal management	Design integrated thermal management techniques to extract heat from the luminaire in a variety of environments and operating conditions. Thermal management should maintain the OLED source temperature as well as enhance the luminaire color and efficiency performance.	Lifetime; Case Temperature		
D.4.5	Electrical interconnects	Develop standard connections for integration of OLED panels into the luminaire.			

Table 4.5.8: Other Identified OLED Product Development Tasks (Continued)

	Task	Description	Metric	2008 Status	2015 Target
Other Identified OLED Product Development Tasks					
D.5.1	Color maintenance	Develop OLED driver electronics that maintain a color setpoint over the life of the luminaire by compensating for changes in OLED output over time and temperature, and degradation of luminaire components.	Color shift over luminaire lifetime; Efficiency of control electronics		
D.5.2	Smart controls	Develop integrated lighting controls and sensors that save energy over the life of the luminaire.	Efficiency of control electronics; Off-state power consumption; Power saved		
D.5.3	Driver electronics	Develop efficient, long-life OLED driver electronics and power converters that efficiently convert line power to acceptable input power of the OLED source(s) and maintain their performance over the life of the fixture. These can include energy-saving functionality such as daylight and occupancy sensors and communication protocols for external lighting control systems.	Conversion efficiency; component lifetime; Cost; Color maintenance at low light levels		

Table 4.5.8: Other Identified OLED Product Development Tasks (Continued)

	Task	Description	Metric	2008 Status	2015 Target
Other Identified OLED Product Development Tasks					
D.6.2	Panel packaging	Scale up practical, low-cost packaging designs that result in improved resistance to the environment (particularly water and oxygen impermeability) and thermal management. Encapsulation considerations should involve compatible materials, appropriate processes, etc. Edge fields should also be considered. Demonstrate a high-efficiency OLED panel that employs such a packaging design and exhibits improved lifetime.	Light Extraction Efficiency; Panel Operating Lifetime; Panel Shelf Life; $/m^2; Water and Oxygen Permeability		Panel Shelf Life >10yr ; <$4/m^2; Water and Oxygen Permeability=10^{-6} g/m^2-day
D.6.3	Panel outcoupling	Demonstrate manufacturable approaches to fabricate OLED panels with improved light extraction efficiency.	Light Extraction Efficiency		
D.6.4	Panel reliability	Analyze and understand failure mechanisms of OLED panels and demonstrate a packaged OLED panel with significant improvements in lifetime.			
D.6.5	Panel mechanical design	Integrate all aspects of OLED based luminaire design: thermal, mechanical, optical, and electrical. The design must be cost-effective, energy-efficient and reliable.			

4.6 Interim Product Goals

To provide some concrete measures of progress for the overall program, the committee identified several milestones that will mark progress over the next ten years. These milestones are not exclusive of the progress graphs shown earlier. Rather, they are "highlighted" targets that reflect significant gains in performance. Where only one metric is targeted in the milestone description, it is assumed that progress on the others is proceeding, but the task priorities are chosen to emphasize the identified milestone.

4.6.1 Light-Emitting Diodes

The FY08 LED milestone goal was to produce an LED product with an efficacy of 80 lm/W, an OEM price of $25/klm (device only), and a life of 50,000 hrs with a CRI greater than 80 and a CCT less than 5000K. These performance characteristics represent a "good" general illumination product that can achieve significant market penetration. These goals have been met individually. In fact, some commercial products have achieved device efficacies greater than 100 lm/W. However, all of the milestone targets have not been met concurrently in a single product. For example, a commercial LED that has an efficacy of 80 lm/W is currently priced much higher than $25/klm.

FY10 and FY15 milestones represent efficacy or price targets of LED packages with a lifetime of 70,000 hrs. Although all milestones in FY08 were not met concurrently, it is expected that the FY10 interim goals of 140 lm/W and a cost <$10/klm for a commercial device will be exceeded. Also, DOE expects to see a high efficiency luminaire on the market by 2012 that has the equivalent lumen output of a 75W incandescent bulb and an efficacy of 126 lm/W. Finally, by FY15, costs should be below $2/klm for LED packages while also meeting other performance goals.

Table 4.6.1: LED Package Milestones

Milestone	Year	Milestone Target
Milestone 1	FY08	80 lm/W, < $25/klm, 50,000 hrs package
Milestone 2	FY10	> 140 lm/W cool white package; >90 lm/W warm white package; < $10/klm
Milestone 3	FY12	126 lm/W luminaire that emits ~1000 lumens
Milestone 4	FY15	< $2/klm package

Assumption: CRI > 80, CCT < 5000°K, T_j = 125°C

LED subtasks are shown in four phases of development corresponding to the four milestones. The first phase, essentially complete, is to develop a reasonably efficient white LED package that is sufficient for the lighting market. Phase 2 is to further improve efficiency while further decreasing price in order to realize the best possible energy savings. This phase should be completed in about two years. Developing a more efficient luminaire is the thrust of Phase 3, expected to last until about 2012. Finally, the fourth phase is to significantly reduce the cost of LED lighting to the point where it is competitive across the board. This phase, currently underway, is expected to continue past 2015.

4.6.2 Organic Light-Emitting Diodes

The FY08 OLED milestone was to produce an OLED niche product with an efficacy of 25 lm/W, an OEM price of $100/klm (device only), and a life of 5,000 hrs, with a CRI greater than 80 and a CCT between 3,000-4,000K. A luminance of 1000 cd/m^2 and a lumen output greater than 500 lumens should be assumed as a reference level in order to compare the accomplishments of different researchers. That is *not* to say that lighting products may not be designed at higher luminance or higher light output levels.

Although current laboratory devices have reached efficacies between 25 and 102 lm/W (at reasonable life, luminance, and CCT), there appears to be just one niche OLED product available in the marketplace for general illumination applications. This is a table lamp produced by the designer Ingo Maurer and sold in limited quantities. The lamp is shown in Figure 4.4 at the beginning of this chapter. With an efficacy of 20 lm/W, it does not appear to meet the milestone precisely. The other parameters for this product are unknown at this time but the price point has undoubtedly also not been met.

According to industry experts, major manufacturers are likely to wait for OLED laboratory prototypes to achieve higher efficacies before investing in the manufacturing infrastructure to produce high efficacy, competitively priced OLED products for general illumination purposes. Milestone 2 targets an efficacy of greater than 45 lm/W by FY10. At this point the lifetime should be around 5,000 hours. Reaching a marketable price for an OLED lighting product is seen as one of the critical steps to getting this technology into general use because of the large area of OLED panels, so although the FY08 milestone may be late in coming, cost reduction remains the focus of the milestone for

FY12.[65] By FY15 the target is to get a 100 lm/W OLED panel. Cost and lifetime should show continuous improvement as well.

Table 4.6.2: OLED Panel Milestones

Milestone	Year	Milestone Target
Milestone 1	FY08	25 lm/W, < $100/klm, 5,000 hrs
Milestone 2	FY10	> 45 lm/W
Milestone 3	FY12	< $30/klm
Milestone 4	FY15	> 100 lm/W

Assumptions: CRI > 80, CCT < 2700-4100K and luminance = 1,000 cd/m^2, and total output ≥ 500 lumens for an OLED panel. All milestones assume continuing progress in the other overarching parameters - lifetime and cost.

4.7 Unaddressed Opportunities

Funding for the research tasks for LEDs and OLEDs is allocated, to the extent possible, according to the priorities agreed upon by the LED and OLED Technical Committees, DOE, and the annual SSL workshops. These priorities are updated annually based on actual progress, as described in this document. The task priorities represent estimates at the time of publication as to how best to achieve the program goals, recognizing that there are limits to how much can addressed in any year. This process may leave some critical tasks unfunded at any given time. These obviously represent unaddressed opportunities to accelerate the program or improve performance. This is simply one aspect of managing technology risk, which DOE believes is currently under control.

One area of potential development is to more strongly support improved manufacturing of the products. Though this area is outside the scope of the current program, a development in this area would represent a substantial opportunity for the industry and the country. Several potential benefits of such support are:

- Improved uniformity of processes would improve yields and lower costs as well as increase consumer confidence in the quality of SSL products by reducing variations of color and other parameters of manufactured SSL systems.

- Advanced automation methods could reduce labor content and potentially make domestic production - "made in the USA" - a more attractive option than it is today. Currently a considerable amount of LED die production and packaging occurs in Asia, although there are a few notable exceptions for white lighting. It would be beneficial to retain or grow this domestic capability.

- For OLEDs, the manufacturing issue is particularly acute since the needs for displays, the apparent synergistic technology, are actually quite different from

[65] Initially, cost reductions were targeted for FY10, however this was moved to FY12 for the 2009 report as products have just begun to enter the market.

what is needed for lighting. This makes the issue of cost reduction a barrier to this technology. In particular, fabrication technology breakthroughs are needed to produce large-area OLED panels uniformly with low cost.

While some manufacturing subtasks can be prioritized for core R&D, there is not sufficient funding at this time to support advanced manufacturing development to the extent contemplated above.

5.0 Solid-State Lighting Portfolio Management Plan

DOE's SSL R&D program is guided by the seven principles of Government – SSL Industry Partnership. Working through the competitive solicitation process, these seven guiding principles position DOE's research partners and projects for success:

1. Emphasis on competition
2. Cost- (and risk-) sharing – exceeding Energy Policy Act of 1992 cost-share requirements
3. SSL industry partners involved in planning and funding
4. Targeted research for focused R&D needs
5. Innovative intellectual property provisions
6. Open information and process
7. Success determined by milestones met and ultimately energy-efficient, long-life, and cost-competitive products developed

This chapter presents each of the aspects of the SSL Portfolio management plan, including: (1) Doe SSL Strategy, (2) the SSL Operational Plan, (3) the Portfolio Decision-Making Process, (4) the SSL Quality Control and Evaluation Plan, (5) the Stage-Gate Project Management plan, and the (6) Solid-State Lighting Commercialization Support Plan.

5.1 DOE Solid-State Lighting Strategy

The U.S. Department of Energy's SSL portfolio draws on DOE's long-term relationships with the SSL industry and research community to guide SSL technology from laboratory to marketplace. DOE's comprehensive approach includes Basic Energy Science, Core Technology Research, Product Development, Commercialization Support, Standards Development, and an SSL Partnership. Figure 5.1 shows the connections and interrelations ships between these elements of the program.

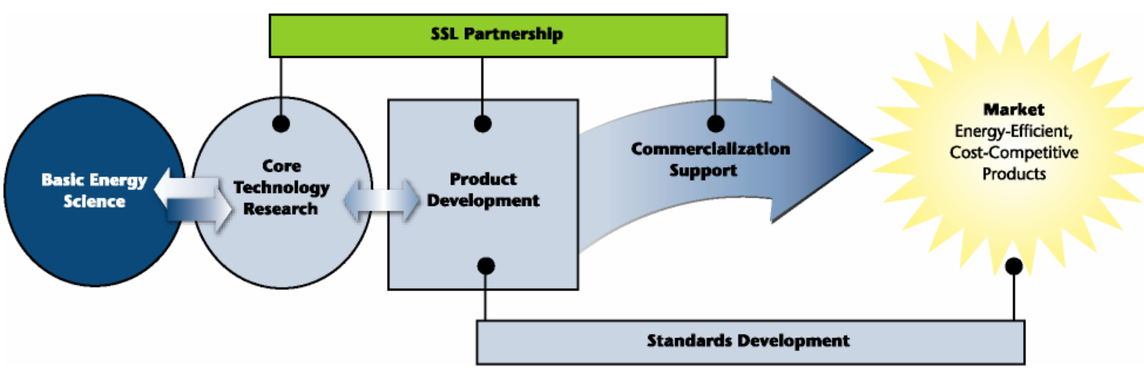

Figure 5.1: Interrelationships within DOE Solid-State Lighting Activities

Basic research advances fundamental understanding. Projects conducted by the Basic Energy Science Program focus on answering basic scientific questions that underlie DOE mission needs. These projects target principles of physics, chemistry, and the materials sciences, including knowledge of electronic and optical processes that enable development of new synthesis techniques and novel materials.

Core Technology research fills knowledge gaps. Conducted primarily by academia, national laboratories, and research institutions, Core Technology research involves scientific research efforts to seek more comprehensive knowledge or understanding about a subject. These projects fill technology gaps, provide enabling knowledge or data, and represent a significant advance in our knowledge base. They focus on applied research for technology development, with particular emphasis on meeting technical targets for performance and cost.

Product Development utilizes knowledge gains. Conducted primarily by industry, Product Development is the systematic use of knowledge gained from basic or applied research to develop or improve commercially viable materials, devices, or systems. Technical activities focus on a targeted market application with fully defined price, efficacy, and other performance parameters necessary for success of the proposed product. Project activities range from product concept modeling through development of test models and field-ready prototypes.

Commercialization support activities facilitate market readiness. To ensure that DOE investments in Core Technology and Product Development lead to SSL technology commercialization, DOE has also developed the federal government commercialization support strategy. Working with the SSL Partnership and other industry and energy organizations, DOE is implementing a full range of activities, including:

- ENERGY STAR® designation for SSL technologies and products
- Design competitions for lighting fixtures and systems using SSL
- Technical information resources on SSL technology issues, test procedures, and standards
- Testing of commercially available SSL products for general illumination
- Technology demonstrations to showcase high-performance SSL products in appropriate applications
- Technology procurement programs that encourage manufacturers to bring high-quality, energy-efficient SSL products to the market, and that link these products to volume buyers
- Coordination with utility, regional, and national market transformation programs.

SSL Partnership provides manufacturing and commercialization focus. Supporting the DOE SSL portfolio is the SSL Partnership between DOE and the NGLIA, an alliance of for-profit lighting manufacturers. DOE's Memorandum of Agreement with NGLIA, signed in 2005, details a strategy to enhance the manufacturing and commercialization focus of the DOE portfolio by utilizing the expertise of this organization of SSL manufacturers.

The SSL Partnership provides input to shape R&D priorities, and accelerates implementation of SSL technologies by:

- Communicating SSL program accomplishments
- Encouraging development of metrics, codes, and standards
- Promoting demonstration of SSL technologies for general lighting applications
- Supporting DOE voluntary market-oriented programs.

Standards Development Enables Meaningful Performance Measurement. LEDs differ significantly from traditional light sources, and new test procedures and industry standards are needed to measure their performance. DOE provides national leadership and support for this effort, working closely with IESNA, NEMA, NGLIA, ANSI, and other standards setting organizations to accelerate the standards development process, facilitate ongoing collaboration, and offer technical assistance. National standards and rating systems for new SSL products are expected to be issued in early 2008.

5.2 SSL Operational Plan

DOE has structured an operational plan for SSL R&D (see Figure 5.2) that features two concurrent, interactive pathways. **Core Technology** research is conducted primarily by academia, national laboratories, and research institutions. **Product Development** is conducted primarily by industry. Although the pathways and participants described here are typical, some cross-over does occur. For example, a product development project conducted by industry may include focused, short-term applied research, as long as its relevance to a specific product is clearly identified and the industry organization abides by the solicitation provisions. The operational structure also includes innovative intellectual property provisions and an **SSL Partnership** that provides significant input to shape the Core Technology priorities.

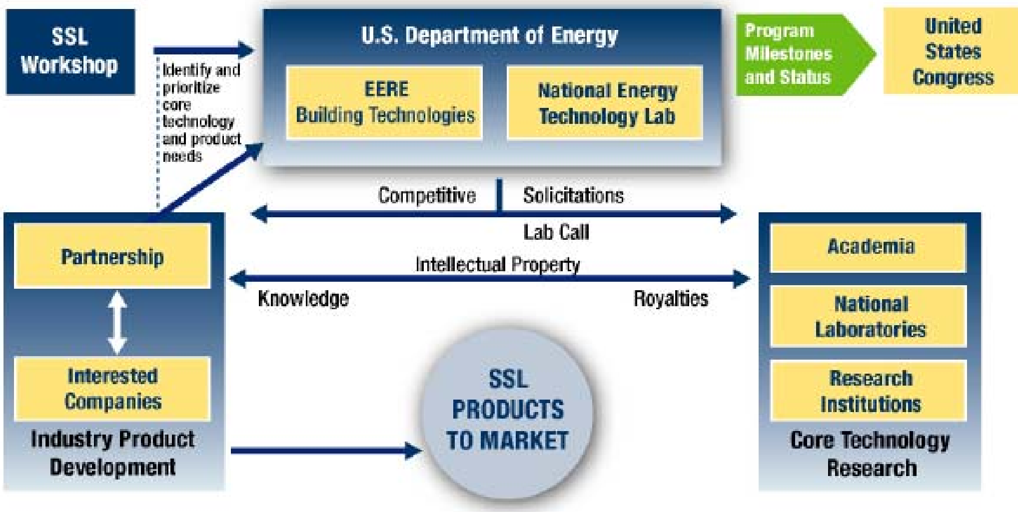

Figure 5.2: Structure of DOE SSL Operational Plan

SSL Partnership. In 2004, DOE competitively selected an SSL Partnership composed of manufacturers and allies that are individually or collaboratively capable of manufacturing and marketing the desired SSL products. Partnership members must comply with pertinent DOE guidelines on U.S.-based research and product development. A key function of the SSL Partnership related to R&D is to provide input to shape the R&D priorities. As SSL technologies mature, any research gaps identified are filled through Core Technology research—allowing the SSL industry to continue their development process, while much-needed breakthrough technologies are created in parallel. The Partnership members confer among themselves and communicate their R&D needs to DOE program managers, who in turn, shape these needs into the Core Technology solicitations.

Core Technology. Core Technology research provides the focused research needed to advance SSL technology—research that is typically longer-term in nature and not the focus of sustained industry investment. DOE funds these research efforts primarily at universities, national laboratories, and other research institutions through one or more competitive solicitations. Core Technology research supports the SSL program by providing problem-solving research to overcome barriers. Participants in the Core Technology program perform work subject to what is termed an "exceptional circumstance" to the Bayh-Dole Act, and any resultant intellectual property is open, with negotiated royalties, to all Partnership members with a non-exclusive license. At DOE's discretion, Core Technology projects are peer-reviewed by Government personnel, independent organizations, and consultants.

Product Development. DOE solicits proposals from interested companies (or teams of companies) for product development, demonstrations, and market conditioning. DOE expects these proposals to include comprehensive work plans to develop a specific SSL product or product family. Since the ultimate goal is to manufacture energy-efficient, high performance SSL products, each work plan should address the abilities of each participant or manufacturer throughout the development process. These participants must not only have all the technical requirements to develop the desired SSL technology, but also must have reasonable access to manufacturing capabilities and targeted markets to quickly move their SSL product from the industry laboratory to the marketplace.

High-Level Timeline. Figure 5.3 details the high-level timeline for the SSL R&D operational plan. Each year, DOE expects to issue at least three competitive solicitations: the Core Technology Solicitation, Core Technology to National Labs (Lab Call), and the SSL Product Development Solicitation. A number of annual meetings are held to provide regular DOE management and review checks, and to keep all interested parties adequately informed. More specifically, these meetings:

- Provide a general review of progress on the individual projects (open meeting)
- Review/update the R&D plan for upcoming "statement of needs" in future solicitations (open meeting)
- At DOE's discretion, provide a peer review of Core Technology and Product Development projects
- Provide individual project reviews by DOE

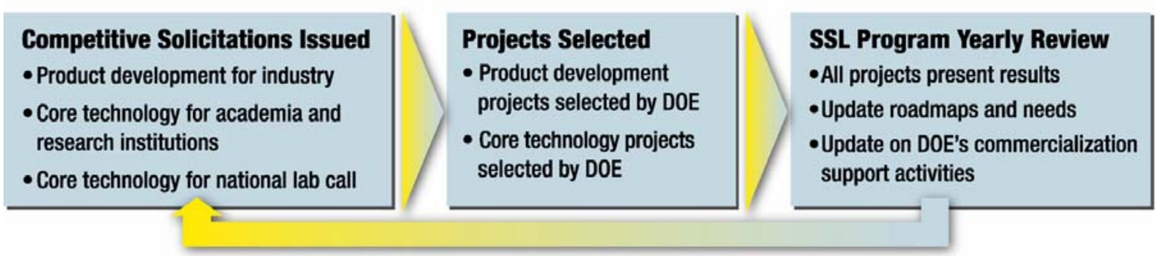

Figure 5.3: SSL Operational Plan Process

5.3 Portfolio Decision-Making Process

DOE establishes its SSL R&D priorities and projects through a consultative process with industry, expert technical reviewers and other interested parties. The portfolio decision-making process is based upon (1) the output of R&D planning workshops, (2) a competitive solicitation process based on the seven guiding principles of the SSL program (see Section 5.3.3), and (3) consultation with the SSL partnership. Each of these three components of the portfolio decision making process is discussed below.

5.3.1 Consultative Workshops

The SSL R&D program hosts consultative workshops every one to two years to solicit input from industry and researchers on the near-term priority R&D activities. Stakeholder consultation and participation are integral to the SSL R&D agenda planning process. Industry, national laboratories, and academia participated in the R&D agenda planning process to provide input to future SSL R&D Portfolio priorities DOE may pursue through several consultative workshops held by DOE:

- March 2009. Denver, CA. CALiPER roundtable to gather feedback from SSL representatives on CALiPER test results and procedures as well as additional testing needs for SSL.

- February 2009. San Francisco, CA. Planning workshop to further refine and reprioritize DOE's SSL R&D research portfolio.

- September 2008. Washington, DC. Roundtable session with SSL researchers and industry representatives to begin the reprioritization of DOE's SSL R&D research portfolio.

- July 2008. Portland, OR. Planning workshop for DOE and outside experts to address market introduction of solid-state lighting.

- May 2008. Washington, DC. Workshop for manufacturers to review the DOE ENERGY STAR criteria for SSL, the status of related test procedures, and the program launch and qualification process.

- March 2008. Chicago, IL. Workshop with the International Association of Lighting Designers to examine SSL market and technology issues and gather feedback on designers' experiences and recommendations for SSL.

- January 2008. Atlanta, GA. Planning workshop on LEDs and OLEDs to review and reprioritize DOE's SSL R&D portfolio.

- November 2007. Washington, DC. CALiPER roundtable to solicit feedback on CALiPER test results and procedures and additional testing needs for SSL.

- July 2007. Boston, MA. Workshop to explore how federal, state and private sectors can work together to guide the market introduction of SSL products.

- April 2007. Pasadena, CA. Workshop to explore how federal, state and private sectors can work together to guide the market introduction of SSL products.

- January 2007. Phoenix, AZ. Planning workshop on LEDs and OLEDs to review and reprioritize DOE's SSL R&D portfolio.

- May 2006. Bethesda, MD: Workshop to bring together SSL experts to address the Basic Energy Science Research needs for SSL.

- February 2006. Orlando, FL: Workshop to bring together SSL experts to address multi-disciplinary, multi-industry, science-to-market challenges facing SSL technology

- February 2005. San Diego CA: Planning workshop on LEDs and OLEDs to re-prioritize DOE's SSL R&D portfolio.

- November 2003. Crystal City, VA: Planning workshop on LEDs and OLEDs to review and prioritize DOE's SSL R&D portfolio.

- May 2002. Albuquerque, NM: LED technical workshop to refine targets, challenges and approaches.

- April 2002. Berkeley, CA: OLED technical workshop to refine targets, challenges and approaches.

- November 2000. Berkeley, CA: OLEDs for general illumination.

- October 2000. Albuquerque, NM: LEDs for general illumination.

The February 2005 workshop, held in San Diego, had four primary goals: (1) to convey DOE's vision for SSL technology to the R&D community, (2) to present the broad-based government funding opportunities related to SSL, (3) to communicate current successes and challenges for SSL from an industry perspective, and (4) to prioritize the SSL R&D tasks to ensure a focused, quality research agenda. One hundred seventy participants from industry, universities, trade associations, research institutions, and national laboratories reviewed, discussed, and prioritized more than sixty-five research and development tasks and subtasks within the DOE SSL R&D agenda. DOE considers input from these consultative workshops and other sources when developing its needs statements for future SSL solicitations. The results of the prioritization process from the 2005 workshop have been published in a DOE report.[66]

The February 2006 workshop, held in Orlando, Florida, focused on advancing SSL technologies from the laboratory to the marketplace. This workshop represented the third annual meeting of DOE's program to accelerate advances in SSL technology, and included for the first time a Basic Energy Sciences (BES) Contractors' Meeting. This format enabled BES and SSL researchers to exchange research highlights and results, identify needs, and foster new ideas and collaborations. Specifically, the workshop provided a forum for sharing updates on basic research underlying SSL technology, SSL core technology research, product development, commercialization support, and the ultimate goal of bringing energy-efficient, cost-competitive products to the market.

The January-February 2007 workshop, held in Phoenix, Arizona, was the fourth annual DOE SSL workshop. This workshop focused on "Getting SSL to Market" by providing a forum for building partnerships and strategies to accelerate technology advances and guide market introduction of high efficiency, high-performance SSL products. In addition, workshop participants were able to review and comment on proposed revisions

[66] "Solid-State Lighting Program Planning Workshop Report", April 2005, Navigant Consulting. Available at http://www.netl.doe.gov/ssl/PDFs/DOE_SSL_Workshop_Report_Feb2005.pdf.

to the DOE SSL R&D roadmap priorities. The results of the prioritization process from the 2006 workshop have been published in a DOE report.[67]

The February 2008 workshop, held in Atlanta, GA, also focused on advancing SSL technologies from the laboratory to the marketplace. The workshop, entitled "Transformations in Lighting," represented the fifth annual meeting of DOE's program to accelerate advances in SSL technology. This workshop provided a forum for lighting industry leaders, fixture manufacturers, researchers, academia, trade associations, lighting designers, energy efficiency organizations, and utilities to share perspectives on the rapidly evolving SSL market.

The February 2009 workshop represented DOE's sixth annual SSL R&D workshop. Lighting industry leaders, chip makers, fixture manufacturers, researchers, academics, lighting designers, architects, trade association representatives, energy efficiency organization representatives, and representatives of utilities gathered in San Francisco to share insights and updates on technology advances and market developments. Attendees also had an opportunity to provide input that will guide updates to the DOE SSL R&D Multi-Year Program Plan.

5.3.2 BES Workshop and Coordination

The U.S. Department of Energy's Office of Science, Basic Energy Sciences Program, and Office of Energy Efficiency and Renewable Energy, Building Technologies Program, hosted a workshop on May 22-24, 2006 in Bethesda, Maryland, focused on basic research needs for solid-state lighting (SSL). James Brodrick, DOE Lighting Program Manager, provided an overview of the EERE/BTP SSL portfolio strategy, a comprehensive approach that includes coordination with the BES Program as well as core technology research, product development, commercialization support, DOE ENERGY STAR® criteria for SSL, standards development, and an SSL partnership with industry. At the workshop, scientists from leading universities and national laboratories identified basic research needs and opportunities underlying light-emitting diode and related technologies, with a focus on challenges that impact on energy-efficient SSL. The research directions identified at this workshop will impact DOE program planning in the future.

5.3.3 Competitive Solicitations

The SSL R&D program has two separate funding mechanisms, one directed at core technology researchers, and the other at product developers. The Core Technology competitive solicitation works to ensure that the R&D portfolio addresses research in to technologies that can be readily and widely applied to existing and future lighting products. Applications are sought that are truly innovative and groundbreaking, fill technology gaps, provide enabling knowledge or data, and represent a significant advancement in the SSL technology base. The Product Development solicitation works

[67] "Solid-State Lighting Program Planning Workshop Report", April 2005, Navigant Consulting. Available at: http://www.netl.doe.gov/ssl/PDFs/07SSLWorkshop%20Report_3.pdf

to solicit applications from industrial organizations that examine high priority product development activities to move SSL beyond its present nascent state. These funding opportunities seek to advance and promote the collaborative atmosphere of the LR&D SSL program to identify product concepts and develop ideas that are novel, innovative and groundbreaking.

5.3.4 Cooperative Agreements

Because the purpose of the SSL Program is to develop advanced solid-state lighting technologies that are much more energy-efficient, longer-lasting and cost-competitive, the program uses financial assistance awards.[68] In addition, there are 2 types of financial assistance, specifically, cooperative agreements and grants. Cooperative agreements and grants are the same except cooperative agreements include "substantial involvement" by the government. Given the innovative structure of the SSL Program, it is imperative that the government be given the opportunity to assist the Recipients, the entity awarded the cooperative agreement, in managing the project to successful completion The role of the federal Project Manager is:

- Responsible for all technical aspects of project management of all SSL projects
- Primary interface with Recipients and Principal Investigators
- Provides technical direction when necessary by preparing modifications to the Recipient's statement of project objectives or schedule of deliverables. All technical direction is documented and officially approved by the Contracting Officer
- Provides technical input when necessary on field work plans, milestones or any other project aspect that does not require approval by the Contracting Officer.
- Receives, reviews and accepts all project deliverables.

5.3.5 Government-Industry Alliance

In February 2005, DOE signed a Memorandum of Agreement with the Next Generation Lighting Industry Alliance, creating and clarifying the expectations for the Partnership.

The NGLIA, administered by NEMA, is an alliance of for-profit corporations, established to accelerate SSL development and commercialization through government-industry partnership. As of June 2008, the NGLIA was made up of fifteen corporations —3M, Acuity Brands Lighting, Air Products & Chemicals, Inc., Applied Materials, Inc., CAO Group Inc., Corning, Inc., Cree Inc., Eastman Kodak Company, GE-Lumination, Lumination LLC, Light Prescriptions Innovators, LLC (LPI, LLC), LSI Industries, OSRAM Sylvania Inc., Philips Solid-State Lighting Solutions, QuNano, Inc., and Ruud

[68] Financial Assistance awards are used when the principal purpose of the relationship is to affect a public purpose of support or stimulation. In contrary, an acquisition contract is used when the principal purpose is to acquire goods and services for the direct benefit or use of the Federal Government

Lighting, Inc.[69] – though NEMA is actively seeking to extend membership to any firms active in SSL R&D.

In selecting the NGLIA to serve as its partner, DOE improved its access to the technical expertise of the organization's members. The Alliance provides input to shape DOE's SSL R&D program priorities, and as requested by DOE, provides technical expertise for proposal and project reviews. In addition, the Alliance will accelerate the implementation of SSL technologies by:

- Communicating SSL program accomplishments
- Encouraging the development of metrics, codes, and standards
- Promoting demonstrations of SSL technologies for general lighting applications
- Supporting DOE voluntary market-oriented programs

The NGLIA's mission involves public advocacy on issues related to SSL, promotion and support of SSL technology and DOE's research program in SSL, and facilitation of communications among members and other organizations with substantial interest in the NGLIA activities. For more information on NGLIA, see their website at: http://www.nglia.org. To see a complete version of the MOA, see Appendix B.

5.4 Quality Control and Evaluation Plan

The Solid-State Lighting Research & Development Portfolio uses a quality control and evaluation plan (QC&E) to judge both the merit of individual projects as well as the soundness of the overall portfolio. At key intervals, comprehensive reviews are conducted, supported by analysis and objective review and recommendations by panels of experts (merit review/peer review). Performance is a criterion in project selections and performance evaluation is used to reshape plans, reassess goals and objectives, and re-balance the overall portfolio.

This QC&E plan for the Lighting Research and Development program, of which the SSL portfolio is a part, has three objectives:

1. Improve the performance, cost-effectiveness and timeliness of individual contracts;
2. Improve the portfolio of projects in the LR&D program; and
3. Assure future quality by bringing new high quality researchers into the solicitation process.

The QC&E plan for the LR&D program is built around the four critical stages of the annual program cycle. At each stage, the objectives, questions, quality assurance tools and metrics, and performance schedules are discussed. The four stages are:

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[69] *Current NGLIA Members.* June 2, 2008. Next Generation Lighting Industry Alliance. Available at: http://www.nglia.org/membership.html

1. Planning the LR&D program direction;
2. Selection process for LR&D projects;
3. Concurrent monitoring and evaluation; and
4. Post project evaluation and review.

These four discrete stages occur sequentially throughout the fiscal year and feed directly into each other. However, there could be feedback mechanisms such as a project's final findings and recommendations resulting in a slight modification to the overall program direction or the selection of future projects.

The figure below illustrates the four critical stages and some of the most important interactions. Using this framework, this plan identifies all the QC&E tools and processes in place designed to keep the LR&D program in step with the current objectives of the DOE and the research and development interests of industry, academia and the National Laboratories.

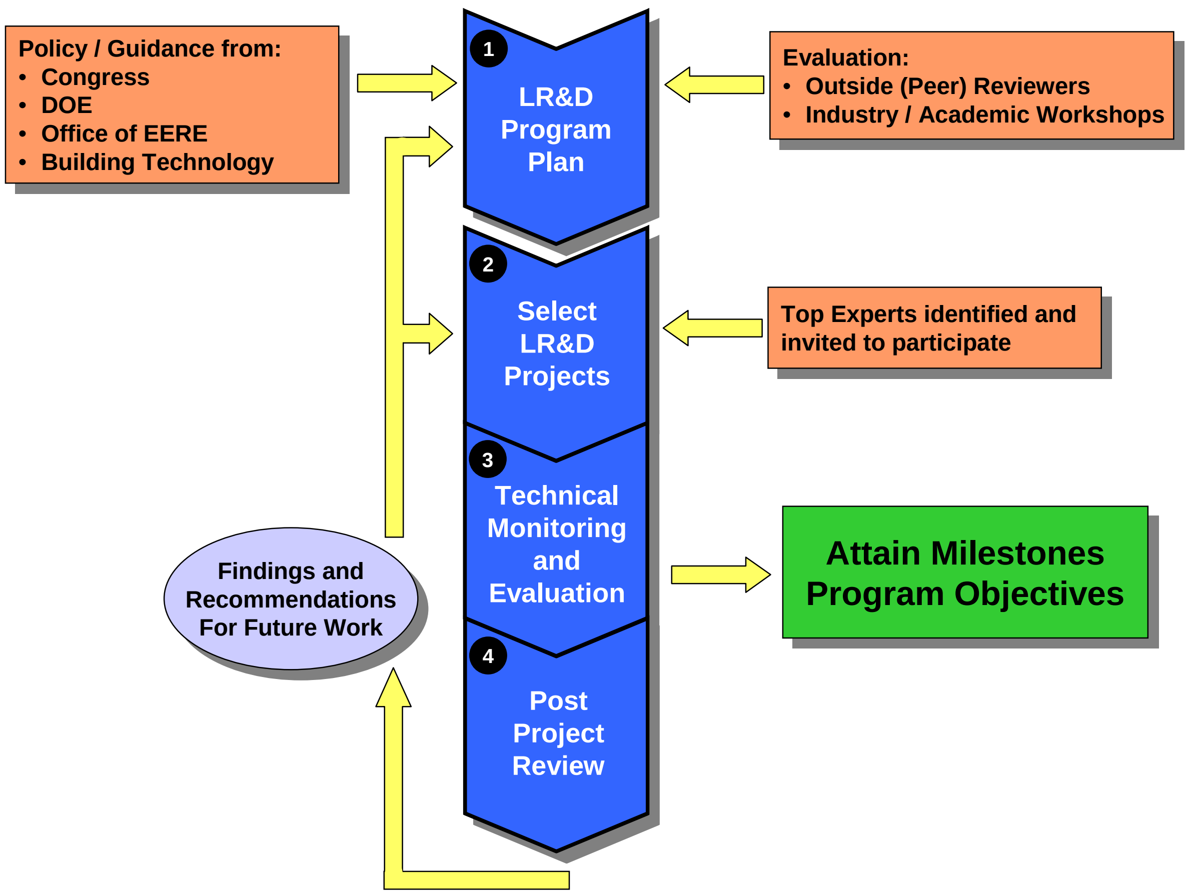
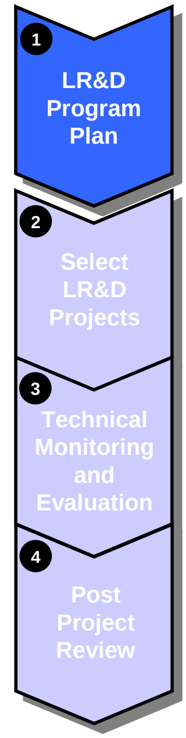


Figure 5.4: Four-Step Quality Control and Evaluation Plan for LR&D Program

5.4.1 Planning LR&D Program Direction



Objective of the Planning Stage:

- Review the LR&D Program Plan and determine if it conforms with the goals of Congress, the DOE, EERE, the Building Technologies Program, and key stakeholders and researchers.

Questions in the Planning Stage:

- Does this program plan solicit projects where there is a clear public benefit and result in energy conservation?
- Does this program plan identify and solicit research investment barriers perceived by private-sector researchers?
- What are the priority lighting-use areas and technologies that are consuming the most energy?
- Which technologies show the most promise of energy savings benefit?
- Is the plan structured to capture incremental improvements that could capture energy savings potential?
- How should the portfolio of projects be modified based on the review of the preceding year's projects?
- What are the research priorities and how should funding be appropriated, given all these inputs?

Analysis for the Planning Stage:

- The LR&D Program conducts analyses that provide input to the strategy and planning phase. Some examples include:
  - Lighting Market Characterization - Volume I: National Lighting Inventory and Energy Consumption Estimate: a national estimate of the number of lamps, operating and performance metrics, and energy consumption. Completed September 2002.[70]
  - Lighting Market Characterization - Volume II: Technology Options and Energy Savings Estimate: a review and prioritization of all the energy savings opportunities in lighting technology. Completed September 2005.[71]
  - Lighting Market Characterization - Volume III: Economic and Market Performance Targets. Analysis of lighting market milestones and targets that must be achieved in order to secure adoption and transformation. Ongoing assignment, as needed.
  - Solid-State Lighting Energy Savings Forecast – Specific to SSL, this study looks at a series of "what-if" scenarios of the energy savings potential if SSL achieves certain price and performance targets. Based on the national

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[70] This report is located at http://www.eere.energy.gov/buildings/info/documents/pdfs/lmc_vol1_final.pdf
[71] This report is located at http://www.eere.energy.gov/buildings/info/documents/pdfs/ee_lightingvolII.pdf

lighting inventory (Phase I) and a detailed market model based on paybacks. First edition completed April 2001. Second edition completed November 2003. Third edition completed December 2006.[72]

- The LR&D Program may sponsor periodic workshops to better understand research priorities and opportunities. The result of a previous example of a multi-year, private and public interactive activity is the Solid-State Lighting Roadmap.

Implementation of QC&E in the Planning Stage:

- Planning for the coming fiscal year starts in April / May by reviewing the present year's projects:
    - Review progress made in the context of the aforementioned planning tools
    - Assess any new or appropriate alternative technologies and/or approaches
- Determine new or revise existing milestones and performance targets for the next year's projects, based on the broad range of analysis tools available to the DOE for the Planning Stage
- Develop a needs statement to use in a competitive solicitation / evaluation / awards process which ensures applicants are cognizant of and specifically address the LR&D's focus on lighting performance and efficiency in their proposals. Applicants must demonstrate:
    - Technical research
    - Energy savings
    - Resources for research
    - Path to commercialization
- Identify opportunities for Intergovernmental Cooperation / Synergy (e.g., DOD, NIST, other DOE organizations including Basic Energy Science (BES)) – explore opportunities for cost share.
- Internal program reviews by Building Technology (BT) staff
    - FY spend plan review – project by project discussion of suggested funding level: contractors, funding, brief scope, milestones
    - BT Program Review– presentation of program: strategy, R&D preview, technology goals, overall funding, and major program elements in R&D
- Peer program review – DOE periodically organizes external experts to review the LR&D program and its portfolio of projects.
- DOE actively participates in industry workshops and professional conferences applicable to the technologies of interest to the LR&D program. Maintenance of a strong technical level of expertise and visible profile helps keep the LR&D program current and accessible to all interested parties, and it helps to attract new participants.

[72] This report is located at: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_energy_savings_potential_report_2006_final4.pdf

Table 5.1.1: LR&D Program – Outreach Meetings and Events

Company	Topic	Date
Fundamental Research Needs in Organic Electronic Materials – Salt Lake City, UT	SSL R&D – OLEDs	5/23/03
Society for Information Display – Phoenix, AZ	SSL R&D – OLEDs	9/16/03
Solid State Lighting Program Planning Workshop #1 – Washington, DC	SSL R&D	11/13/03 – 11/14/03
SPIE Fourth International Conference in SSL – Denver, CO	SSL R&D	8/3/04
Solid State Lighting Program Planning Workshop #2 – San Diego, CA	SSL R&D	02/03/05 – 02/04/05
Briefing to Staff of House Science Committee – Washington, DC	SSL R&D	5/9/05
SPIE Fifth International Conference in SSL – San Diego, CA	SSL R&D	8/1/05
Solid State Lighting Program Planning Workshop#3 – Orlando, FL	SSL R&D	02/01/06 – 02/03/06
Solid State Lighting Program Planning Workshop#4 – Phoenix, AZ	SSL R&D	1/31/07-2/02/07
Solid State Lighting Program Planning Workshop#5 – Atlanta, GA	SSL R&D	1/29/08-1/31/08
Solid State Lighting Program Planning Workshop#6 – San Francisco, CA	SSL R&D	2/3/09-2/5/09

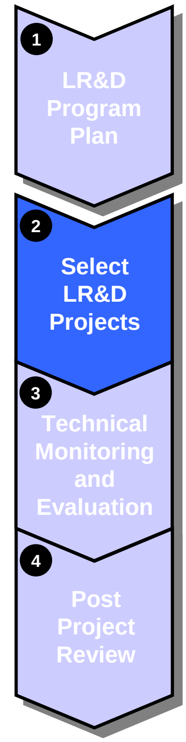
5.4.2 Selection Process for LR&D Projects

Objective of the Selection Stage:

- Strategically and competitively select projects that offer energy savings, incorporate milestones, and identify the path to market. Projects should be from contractors who have demonstrated technical leadership and have the resources to conduct the research. The resultant portfolio of projects should be balanced and reflect the overarching LR&D program plan and objectives.

Questions in the Selection Stage:

- Will this project help achieve the mission and goals of EERE and the LR&D program?
- Are the lighting energy conservation benefits reasonable?
- Is the project technically and economically feasible?
- How well does this project build on existing technology and is it complementary to related LR&D activities?
- How well does this project incorporate industry involvement? What is the level of industry cost-sharing of the program? Is there other Government investment in this area?
- Does the project offer sound, tangible performance indicators and/or milestones to facilitate monitoring?
- Does the project incorporate "off-ramps" and a clear end-point?
- How far from commercialization will the technology be when the project is complete? What is the commercialization time line (short, medium or long range)?
- What is the extent of technological risk inherent in the research? Is it cost-shared?
- For a project proposal, is there clear consensus among the internal and external reviewers?



Implementing QC&E in the Selection Stage:

- The sequence of technology maturation envisioned by the DOE is illustrated in Figure 5.5. It demonstrates how the overall SSL activity spans four technology maturation stages. The SSL program will conduct a series of actions to complete the levels of the continuum. DOE maintains a number of "open solicitations" that are released at various times during any given fiscal year. "Open" means that any and all stakeholders are invited to apply for cooperative research financial support via these established and well structured solicitations. The solicitations are publicized widely through the DOE's website, media press, industry trade organizations and at relevant technical conferences. As is shown in the figure below, each solicitation has a specific objective for participation (i.e., academic, small business, manufacturers, etc.) and level of technology maturity.

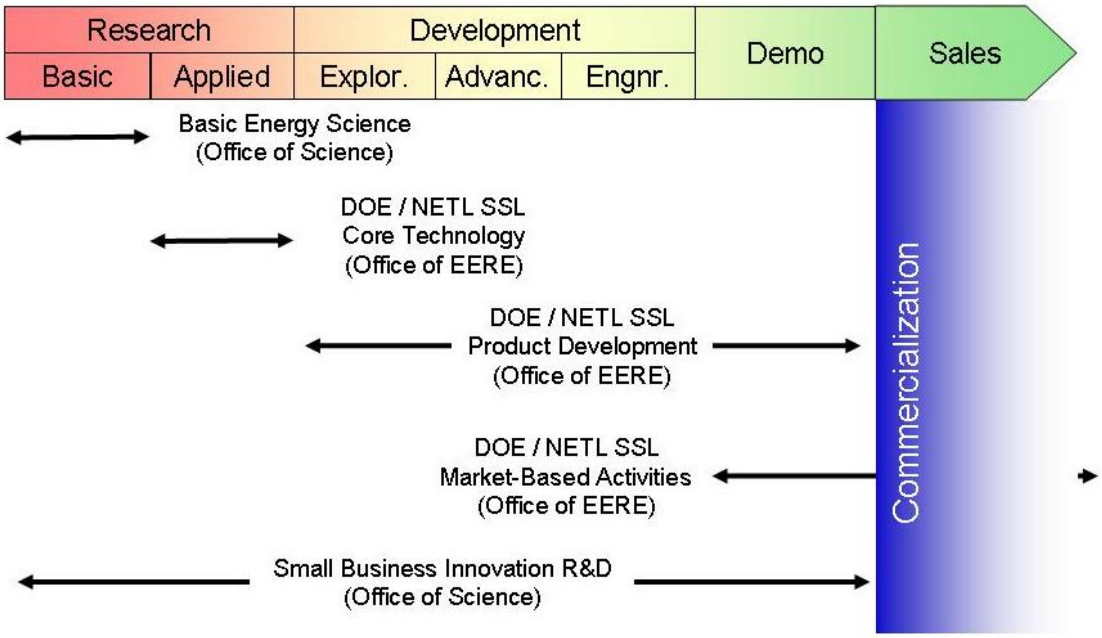


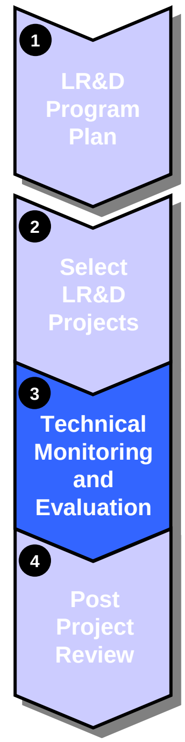
Figure 5.5: Approximate Technology Maturity Coverage of Selected DOE R&D Programs

- Develop new and utilize existing competitive solicitations:
  - Basic Science proposals are solicited throughout the year and are administered by BES according to their own Annual Operating Plan (AOP). However, there is considerable opportunity for technical collaboration between BES and the LR&D program in the nature of the basic research supported. Since BES does not support applied research, any successful basic research completed must be transitioned to more applied organizations such as BT and the LR&D program. BES also participates in the SBIR program, which tailors some solicitations to focus on lighting related issues.
  - The annual BT/NETL (National Energy Technology Laboratory) "Energy Efficient Building Equipment and Envelope Technologies" solicitation ensures competition among interested manufacturers, research institutions, and academia for projects that meet defined LR&D program goals and energy conservation requirements.
  - SBIR proposals are issued annually and represent an excellent opportunity to attract small business to the LR&D program. While of modest size, these projects have historically played pivotal roles in establishing the technical viability of novel approaches to overcoming key technology issues.
  - DOD and other Government agencies often solicit proposals for research specifically tailored to their own needs and AOPs. The LR&D program can enjoy a synergistic benefit of this research particularly that which is completed by the DOD. Often the DOD is an early adopter of emerging technology and can be very instrumental in establishing the technical

viability of a potential product whose military benefits offset constraints imposed by commercial markets. Many times, expensive technologies are first introduced into military applications and are subsequently reduced (in cost and sometimes technical complexity) to meet civilian applications.

- The LR&D program periodically organizes external technical and programmatic reviews to include internationally renowned expertise. This is utilized especially during the evaluation of proposals submitted to the "open" solicitations. The "evaluation criteria" includes technological risk, energy conservation potential, cost-sharing and other critical elements.
- To facilitate quantitative performance assessment, the LR&D program requires participants to explicitly state the performance targets they expect to achieve for their project during the period of performance along with justification.
- BT/NETL – projects are selected by votes from:
    - Expert (technical) reviewers – usually three
    - Technical managers at Building Technology
    - Merit Review Committee

5.4.3 Concurrent Monitoring and Evaluation



Objective of the Monitoring Stage:

- To manage current projects effectively through good communication and the monitoring of various project progress metrics. Determine appropriate remedial action for projects going off-track. Controls "scope-drift".

Questions in the Monitoring Stage:

- Ongoing Monitoring:
  - Are the projects meeting performance milestones on schedule and within budget?
  - Is reassessment of the project's objectives or milestones required?
  - Are the principal investigators providing sufficient updates on their progress?
  - Does the principal investigator present a logical R&D plan (with milestones) for next budget period?
  - Are required deliverables being satisfied? Are progress reports comprehensive and timely?
  - Should the NETL PMC Project Manager conduct a spot inspection or arrange an interim meeting to assess progress?
  - If the project is failing to achieve its milestones, should it be discontinued or redefined?
  - Are the objectives of the project still relevant to the LR&D goals and the EERE mission?
  - Is the project progressing against a reasonable cost plan?
- Project Completed:
  - Did the contractor complete the project to the satisfaction of DOE?
  - Was the project on time?
  - Was the project within budget?
  - Were the technical objectives met?
  - Do the results encourage further investigation / research into this particular project area? Or, another project area?
  - A "Close Out Questionnaire" is under development and may include some of the following draft suggestions (see Section 5.4.5):

Implementing QC&E in the Monitoring Stage:

- Conduct detailed technical and programmatic reviews of each individual project on a regular basis. Maintain good dialogue with all principal investigators and solicit feedback on progress in accordance with stated milestones and objectives.
- The NETL PMC Project Manager requires comprehensive periodic written progress reports (monthly, quarterly) from principal investigators pertaining to their progress.
    - Review these reports in relation to the stated milestones in the proposals
    - Consider remedial options if project is failing to meet deliverables or milestones (e.g., reprioritization, termination)
    - Re-assess the probability of success of the project
- Anytime spot check reviews – as needed, the NETL PMC Project Manager may select projects (or subtasks of a project) that are experiencing technical or programmatic difficulty. At his discretion, he may ask for a performance reviews at the contractor's facility or invite the contractor to some other location. This process allows the LR&D manager to keep a watchful eye on technical progress and helps ensure that problems are identified early and that deviations from the scope of work are identified quickly to get the project back on course.
- Annually, each project is critically reviewed sometimes with outside expertise. Each participant is expected to present the results of their research in progress and rationale for continued support. Previous milestones are reviewed and a determination of achievement is made. Future milestones are assessed and adjusted if necessary. In this way, research priorities are adjusted annually according to technical merit and relevance.

Milestone QC&E Meetings for FY'09:

The following schedule represents the project review meetings for FY'09 that cover the NETL, SBIR, and other project areas. At these meetings, DOE will be using the QC&E tools described above to assess technical and programmatic performance.

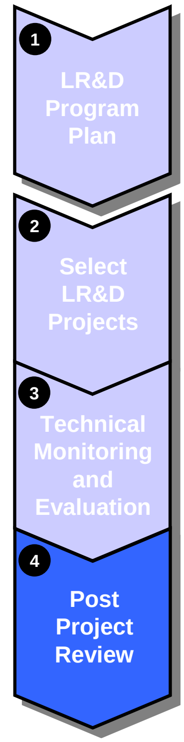
Table 5.1.2: LR&D Program Project Review Meetings for FY'09

PI and Contract Title	Funding Source	Objective	Date
DE-FC26-08NT01575 Add-Vision Inc.	LR&D Direct	Budget Period # 1 Progress Review	Sep-09
DE-FC26-08NT01576 Arkema, Inc.	LR&D Direct	Budget Period # 1 Progress Review	Sep-09
DE-FC26-08NT01577 Cree, Inc.	LR&D Direct	Budget Period # 1 Progress Review	Mar-09
DE-FC26-08NT01578 Crystal IS, Inc.	LR&D Direct	Budget Period # 1 Progress Review	Apr-09
DE-FC26-08NT01579 GE Global Research	LR&D Direct	Budget Period # 1 Progress Review	Apr-09
DE-FC26-08NT01580 Georgia Institute of Technology	LR&D Direct	Budget Period # 1 Progress Review	Aug-09
DE-FC26-08NT01581 Lehigh University, Office of Research and Sponsored Programs	LR&D Direct	Budget Period # 1 Progress Review	May-09
DE-FC26-08NT01582 Osram Sylvania Development Inc	LR&D Direct	Budget Period # 1 Progress Review	Jun-09
DE-FC26-08NT01583 Philips Lumileds Lighting, LLC	LR&D Direct	Budget Period # 1 Progress Review	Sep-09
DE-FC26-08NT01584 PhosphorTech Corporation	LR&D Direct	Budget Period # 1 Progress Review	May-09
DE-FC26-08NT01585 Universal Display Corporation	LR&D Direct	Budget Period # 1 Progress Review	Jul-09
DE-FC26-06NT42855 University of Florida	LR&D Direct	Final Briefing	Aug-09
DE-FC26-06NT42856 Georgia Tech Research Corporation	LR&D Direct	Final Briefing	Dec-09
DE-FC26-06NT42857 University of California, Santa Barbara	LR&D Direct	Final Briefing	Jul-09
DE-FC26-06NT42859 University of North Texas	LR&D Direct	Final Briefing	Feb-09
DE-FC26-06NT42860 Rensselaer Polytechnic Institute	LR&D Direct	Final Briefing	Aug-09
DE-FC26-06NT42861 Research Triangle Institute	LR&D Direct	Budget Period # 2 Progress Review	Mar-09
DE-FC26-06NT42862 Purdue University	LR&D Direct	Final Briefing	Apr-09
DE-FC26-06NT42932 Color Kinetics Incorporated	LR&D Direct	Final Briefing	Mar-09
DE-FC26-06NT42933 Eastman Kodak Company - 1999 Lake Ave.	LR&D Direct	Final Briefing	Mar-09
DE-FC26-06NT42934 GE Global Research	LR&D Direct	Final Briefing	Sep-09
DE-FC26-07NT43128 Consortium for Energy Efficiency, Inc.	LR&D Direct	Budget Period # 2 Progress Review	Jul-09

Table 5.1.2: LR&D Program Project Review Meetings for FY'09 (Continued)

PI and Contract Title	Funding Source	Objective	Date
DE-FC26-07NT43129 Northeast Energy Efficiency Partnership (NEEP)	LR&D Direct	Budget Period # 2 Progress Review	May-09
DE-FC26-07NT43225 Cree, Inc.	LR&D Direct	Final Briefing	Sep-09
DE-FC26-07NT43226 GE Global Research	LR&D Direct	Budget Period # 2 Progress Review	Dec-09
DE-FC26-07NT43227 Yale University	LR&D Direct	Budget Period # 2 Progress Review	Sep-09
DE-FC26-07NT43229 Carnegie Mellon University	LR&D Direct	Budget Period # 2 Progress Review	Sep-09
M6642865 Sandia National Laboratories (SNL) - NM	LR&D Direct	Final Briefing	Sep-09
M6642866 Pacific Northwest National Laboratory (PNNL)	LR&D Direct	Final Briefing	Sep-09
M6642869 Lawrence Berkeley National Laboratory (LBNL)	LR&D Direct	Final Briefing	Jun-09
M6642870 Los Alamos National Laboratory (LANL)	LR&D Direct	Final Briefing	Jul-09
M6743230 Sandia National Laboratories (SNL) - NM	LR&D Direct	Final Briefing	Aug-09
M6743231 Pacific Northwest National Laboratory (PNNL)	LR&D Direct	Budget Period # 2 Progress Review	Jul-09
M6743232 Lawrence Berkeley National Laboratory (LBNL)	LR&D Direct	Budget Period # 2 Progress Review	Sep-09
M68003934 Sandia National Laboratories (SNL) - NM	LR&D Direct	Budget Period # 1 Progress Review	Mar-09
M68004043 Pacific Northwest National Laboratory (PNNL)	LR&D Direct	Budget Period # 1 Progress Review	Mar-09
DE-FG02-06ER84567 Physical Optics Corporation	SBIR	Final Briefing	Aug-09
DE-FG02-06ER84582 Universal Display Corporation	SBIR	Final Briefing	Aug-09
DE-FG02-08ER84809 Universal Display Corporation	SBIR	Budget Period # 1 Progress Review	Aug-10
DE-FG02-08ER84810 Universal Display Corporation	SBIR	Budget Period # 1 Progress Review	Aug-10
DE-FG02-07ER86293 Add-Vision Inc.	SBIR	Budget Period # 1 Progress Review	Aug-09

5.4.4 Post Project Evaluation and Review



Objective of the Review Stage:

- Review the DOE objective and determine if further work in this area is warranted. Review the process and identify improvements.

Questions in the Review Stage:

- Questions from the draft Close-Out Quiz for Principle Investigators:
  - As a program participant, what are the important lessons you learned?
  - Has the project opportunity helped your organization achieve their strategic goals?
  - Do you have a commercialization plan for the technology you developed under this project?
  - Would you like the DOE to assist your organization to develop such a commercialization plan?
  - Looking back on the project, from solicitation to completion, can you make any specific recommendations to the DOE for improvement?
  - As a program participant, what, if anything, would you do differently?
  - Would you like to see the program continue in the future?

- Questions for DOE
  - What did we learn?
  - What did we accomplish?
  - Does the task completed in that area satisfy the original statement of needs?
  - Do the results encourage further evaluation of this project area? Or, have the target objectives of the DOE been met with the milestones achieved in this project?
  - How could we have improved the process – setting the plan, selecting the project and/or monitoring and evaluating the project?
    - Should there have been higher project goals?
    - Should there have been more interim reviews?
    - Should there have been more reporting (e.g., monthly instead of quarterly)?
  - Tie back to the Planning Stage, how do the results relate to the goals and objectives of the program and the interim milestone for DOE? Has the DOE achieved (completed) research in a particular area?

Implementing QC&E for the Review Stage:

- Recalibrate (if necessary) the LR&D objectives in a particular area based on findings from this research.
- Determine if milestones achieved will "close the chapter" in a particular area of research (e.g., evaluation of tungsten oxide research now determined to be complete).
- Review metrics of "success" for the project:
  - Number of Patents
  - Number of Conference Papers / Citations in Technical Literature
  - Product(s) delivered to market
  - Quantified energy savings impact
- Government Performance Results Act (GPRA) metrics?
- Publish results?

Unplanned Events

Occasionally, an event that is beyond the control of the DOE technical manager may occur which disrupts the normal project management framework. Some examples include:

- Delay in funding from Congress
- Increase or reduction in LR&D budget over planned
- Contractor actions, including: slow progress and funding spend rate; termination of contract; fast progress with need for additional funding; technical concept does not mature / can't meet project goals

These unplanned events will result in additional work by the program manager to alter contracts and/or funding levels for the LR&D program, to achieve original fiscal year goals.

5.4.5 QC&E Closeout Questionnaire

Draft EERE BT/NETL Energy Efficient Building Equipment and Envelope Technologies Competitive Solicitation
Contract Close Out Questionnaire

Overall, how would you rate your experience as a participant in the DOE's Building Envelope Technologies Program in the following categories:

		Good		Medium		Bad
1.	Contractual/Administration	☐	☐	☐	☐	☐
2.	Technical	☐	☐	☐	☐	☐
3.	Financial	☐	☐	☐	☐	☐
4.	Level of project success	☐	☐	☐	☐	☐

As a program participant, what are the important lessons you learned?

Has the project opportunity help your organization achieve their strategic goals?

Do you have a commercialization plan for the technology you developed under this project?

Would you like the DOE to assist your organization to develop such a commercialization plan?

Looking back on the project, from solicitation to completion, can you make any specific recommendations to the DOE for improvement?

As a program participant, what, if anything, you do differently?

Would you like to see the program continue in the future?

5.5 Stage-Gate Project Management Plan

The SSL Team developed a white paper to clearly elucidate the stages of Lighting Research and Development, which is intended to provide a management tool for the projects in the SSL portfolio.[73] A stage-gate system[74], tailored to the LR&D program, I applied to each project in the portfolio, and creates a lexicon for discussion, decisions, and planning which is mutually beneficial to the National Energy Technology Laboratory portfolio manager and contractors. This framework was developed as a tool to assist in guiding the research, technical and business actions and decisions that are necessary to move a concept from a scientific phenomenon to a marketable product. As a technical concept advances through the continuum of technology stages, it must demonstrate that it meets the criteria at each gate before it advances to the next stage. By constructing this type of framework, DOE and its contractors will be properly reviewing the R&D projects and asking the right questions to lead to successful commercialization of energy-saving products.

[73] Managing Research and Development: The Technology Continuum of the Lighting Research and Development Portfolio. James R. Brodrick. November 2005.
[74] Robert Cooper, "Winning at New Products, Accelerating the Process from Idea to Launch." 3rd Edition. 2001.

In addition, DOE will be cognizant of where its contractors are located in the overall process of new product development. The stage-gate system also offers management an opportunity to terminate poorly performing projects and allocate resources to better projects. A summary of this method, *The Technology Continuum of the Lighting Research and Development Portfolio* (November 2005*)* is described below.

Cooper's stage-gate system for Industry R&D portfolio management spans the complete spectrum from concept to product development. The stage-gate system divides the development process into discrete, multifunctional stages interspersed with gates that function as potential off-ramps. Gates are decision points where R&D managers review analytical data and make a decision whether to continue developing a project or to terminate it. Stages represent the analytical effort expended by the company to assess research and market analysis on a particular technology or project. Each stage involves a set of parallel activities conducted in different functional areas of a company.

Several of Cooper's stages, shown in the top portion of Figure 5.6, such as preliminary investigation and market launch, fall outside the scope of work supported by the LR&D program. The focus of the LR&D program is primarily on stages 2 through 4 of the industry model, as shown in Figure 5.6. The LR&D model adapts these three generic stages into more specific stages, providing finer differentiation and focus on the activities within each stage. The mapping of the generic industry stages to the more specific LR&D program stages is shown in Figure 5.6.

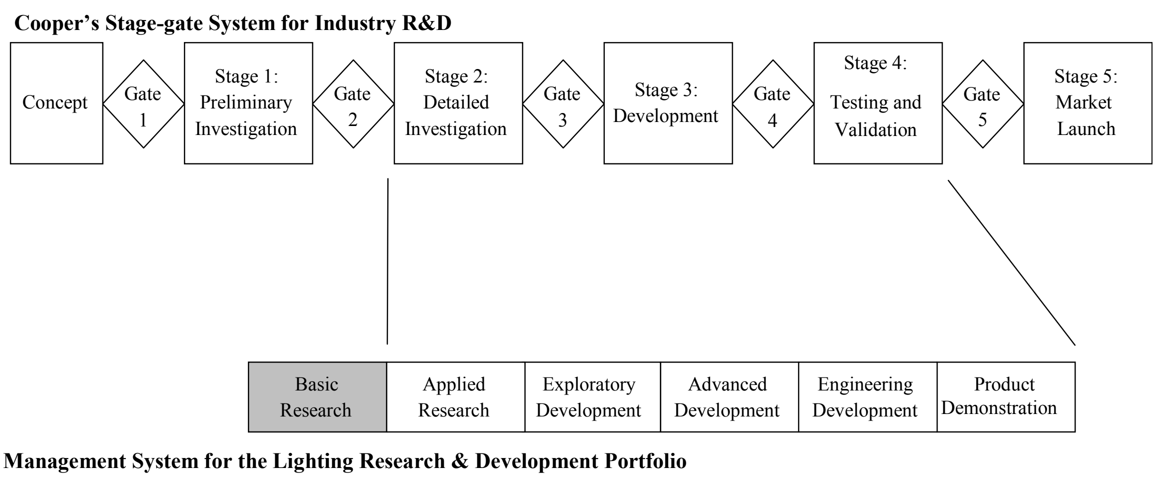


Figure 5.6: Mapping Cooper's Stage-Gate System to the LR&D Portfolio

On the following page, a diagram summarizes the LR&D technology development stages, providing the technical activities, gate expectations and deliverables required at each gate. This stage-gate system was developed primarily as a management system. In addition, it could assist in proposal targeting. For instance, if a solicitation intends to support applied research, a proposal centered on engineering development or product demonstration would be inappropriate. Proposals that are not matched to the solicitation objectives waste the time of stakeholders in their development as well as the DOE in their review.

Figure 5-7: LR&D Technology Development Stages and Gates

Technology Development Stages

	Basic Science Research* 1	Applied Research 2	Exploratory Development 3	Advanced Development 4	Engineering Development 5	Product Demonstration 6	Commercialization and Sales 7
Technical Activities	**Knowledge-Base Expansion** • Scientific principles formulated and proven • Empirical data and/or theoretical derivation	**Idea Generation** • Set performance milestones for Gate 2 • Fundamental lab testing • Create "hard" lab data to support physical principle • Math models of science • Scanning for match of science to application	**Proof of Technology- Product Definition** • Lab bread board of concept • Select technologies that have the best market entry potential • Identify and prioritize alternative approaches for performance/energy savings	**Proof of Technology- Working Model** • Fully functional lab prototypes • Specific application and approach • Testing of prototype on several performance parameters • Proof of "design concept" testing	**Engineering Prototype** • Testing of design features and performance limits, performance mapping • Field ready prototypes • Field testing with customer feedback • Preparation for manufacturing, marketing, certification/code compliance	**Production Prototype** • Validation of performance at owner / operator sites with third party data • Limited size demonstration in the field • Codes/standards certification • Finalize plans for manufacturing/ marketing	**Utilization by End User** • Commercialization • Deployment
Deliverables Required for Gate Decisions	Peer-reviewed paper or journal article Documentation of proof of concept	Correlation with building end use Analytical and/or empirical evidence of technology Performance viability, preferably lab data Written report of above Possible verification testing at another laboratory Set performance milestones for Gate 3	Performance status and expectation for market entry Comparison to available technology baseline Preliminary market assessment • Cost • Performance Estimate of national energy savings potential Attributes and benefits of approach Set performance & cost milestones for Gate 4	Product specifications defined Cost/Benefit analysis for owners/operators Detailed market assessment • Cost • Performance • Market penetration Estimates of national energy savings potential Identification of issues and technology status • Technical performance • Market barriers • Public acceptance • Legal – regulatory • Health and safety Set performance & cost milestones for Gate 5	Partnership agreements • Manufacturing • Licensing Resolution of issues from advanced development stage Field test results and adjustments in design Evaluation of national energy savings potential Update detailed market assessment Cost/Benefit analysis for market Set performance & cost milestones for Gate 6	Partnership agreements Final product specification Cost/Benefit analysis for market Update detailed market assessment Evaluation of national energy savings potential Report on demo performance at owner / operator sites	
Gate Expectations	**1** ✓ New concept or principle proven ✓ Theoretical or empirical proof ✓ Met performance milestones	**2** ✓ Address priority building end use ✓ Proof of technical performance ✓ Met performance milestones	**3** ✓ Prove clear advantage over available technology ✓ Met performance milestones	**4** ✓ Meet owner / operator cost/benefit requirements (1-5 yr. payback) ✓ Demonstrate significant end-user demand ✓ Technology status issues defined ✓ Met performance & cost milestones	**5** ✓ Ready for owner / operator on multi criteria (economics, safety, etc…)? ✓ Met performance & cost milestones	**6** ✓ Ready for production and/or application by owner/operator ✓ Met performance & cost milestones	

* Note: The Basic Science Research stage precedes the program mission of the Solid State Lighting Portfolio

Adapted from Robert Cooper, "Winning at New Products, Accelerating the Process from Idea to Launch." Perseus Books Group. 3rd Edition. 2001. ISBN: 0738204633

The LR&D technology development stages consist of seven stages, providing the technical activities, gate expectations and deliverables required at each gate. Each of the seven stages is discussed briefly below.

Technology Maturation Stage 1 – Basic Science Research
Fundamental science exploration is performed to expand the knowledge-base in a given field. Scientific principles (with data-empirical and/or theoretical derivation) are formulated and proven. The output from these projects would generally be peer-reviewed papers published in recognized scientific journals. Specific applications are not necessarily identified in Stage 1.

Technology Maturation Stage 2 - Applied Research
Scientific principles are demonstrated, an application is identified, and the technology shows potential advantages in performance over commercially available technologies. Lab testing and/or math modeling is performed to identify the application(s), or provide the options (technical pathways) to an application. Testing and modeling add to the knowledge base that supports an application and point to performance improvements.

Technology Maturation Stage 3 – Exploratory Development
A product concept addresses an energy efficiency priority. From lab performance testing, down select from alternative technology approaches for best potential performance, via selection of materials, components, processes, cycles, and so on. With lab performance testing data, down select from a number of market applications to the initial market entry ideas. This product concept must exhibit cost and/or performance advantages over commercially available technologies. Technical feasibility should be demonstrated through component bench-scale testing with at least a laboratory breadboard of the concept.

Technology Maturation Stage 4 – Advanced Development
Product concept testing is performed on a fully functional lab prototype – “proof of design concept” testing. Testing is performed on prototypes for a number of performance parameters to address issues of market, legal, health, safety, etc. Through iterative improvements of concept, specific applications and technology approaches are refocused and “down selected.” Product specification (for manufacturing or marketing) is defined. Technology should identify clear advantages over commercially available technologies, and alternative technologies, from detailed assessment.

Technology Maturation Stage 5 – Engineering Development
“Field ready prototype” system is developed to refine product design features and performance limits. Performance mapping is evaluated. Performer conducts testing of a field-ready prototype/system in a representative or actual application with a small number of units in the field. The number of units is a function of unit cost, market influences (such as climate), monitoring costs, owner/operator criteria, etc. Feedback from the owner/operator and technical data gathered from field trials are used to improve prototype design. Further design modifications and re-testing are performed as needed.

Technology Maturation Stage 6 – Product Demonstration
Operational evaluation of the demonstration units in the field is conducted to validate performance as installed. Third party monitoring of the performance data is required, although less data is recorded relative to the "field ready prototype" test in Stage 5. Pre-production units may be used. Size of demo is a function of unit cost, monitoring cost, etc., and involves relatively more visibility. Energy savings are measured, with careful analysis of economic viability and field durability for specific applications.

Technology Maturation Stage 7 – Commercialization and Sales
The final stage of the technology development continuum focuses on commercialization and sales. This stage involves the implementation of the marketing and manufacturing plans, culminating in the successful launch of a new energy saving product.

While the DOE is currently funding SSL projects in the early stages of the technology development spectrum, over the years as the technology evolves and improves, solicitations in the advanced development, engineering development and product demonstration are planned. The expectation is that future projects will build on the foundation of applied research and exploratory development, catalyzing innovations in lamp materials, systems, fixtures, electronics, and device infrastructure. Eventually, demonstration projects in various sectors may also be warranted, to measure and document the beneficial aspects of this revolutionary technology.

5.6 Solid-State Lighting Commercialization Support Plan

The U.S. Department of Energy has developed a comprehensive national strategy to guide solid state lighting technology from lab to market. To leverage DOE's $100 million investment in SSL technology research and development, and to increase the likelihood that this R&D investment pays off in commercial success, DOE has developed a commercialization support plan. The plan focuses DOE resources on strategic areas to move the SSL market toward the highest energy efficiency and the highest lighting quality.

DOE's plan draws on key partnerships with the SSL industry, research community, standards setting organizations, energy efficiency groups, utilities, and others, as well as lessons learned from the past. Commercialization support activities are closely coordinated with research progress to ensure appropriate application of SSL products, and avoid buyer dissatisfaction and delay of market development. DOE's role is to:

- Help consumers, businesses, and government agencies differentiate good products and applications
- Widely distribute objective technical information
- Coordinate SSL commercialization activities among federal, state, and local organizations
- Communicate performance targets to industry

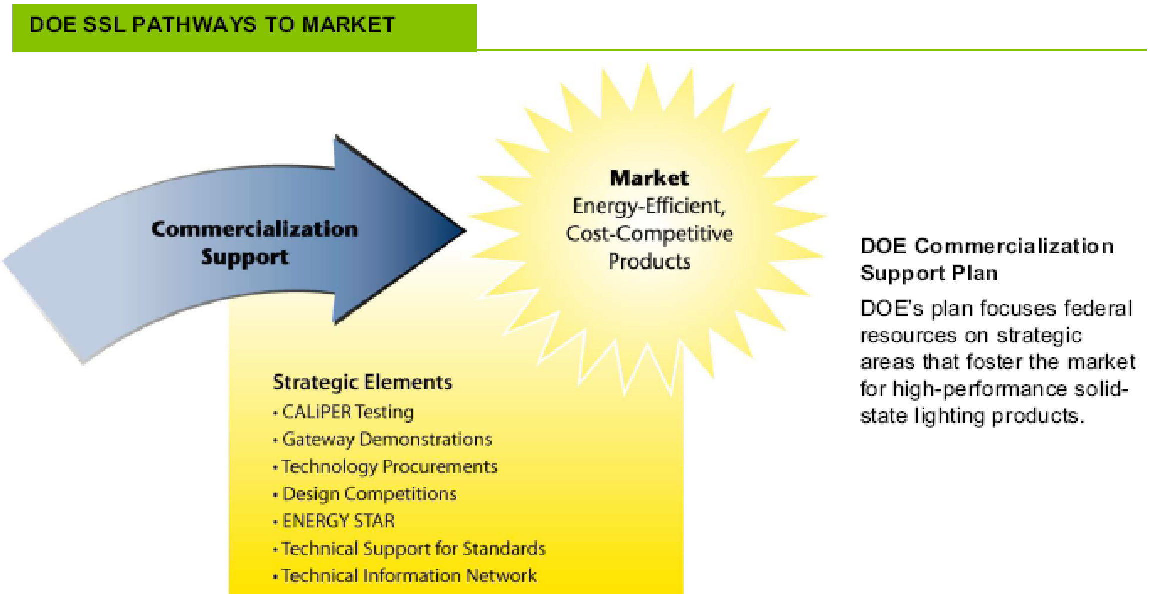


Figure 5.8: DOE SSL Commercialization Support Plan

DOE SSL Pathways to Market

CALiPER. Using test procedures currently under development by standards organizations, DOE's SSL testing program provides unbiased information on the performance of a widely representative array of commercially available SSL products for general illumination. Test results guide DOE planning for R&D, the Lighting for Tomorrow design competition, technology procurement activities, and ENERGY STAR®, in addition to furnishing objective product performance information to the public and informing the development and refinement of standards and test procedures for SSL products. http://www1.eere.energy.gov/buildings/ssl/caliper.html

GATEWAY Technology Demonstrations. Demonstrations showcase high performance LED products for general illumination in a variety of commercial and residential applications. Demonstration results provide real-world experience and data on state-of-the-art SSL product performance and cost effectiveness. Performance measurements include energy consumption, light output, color consistency, and interface/control issues. The results connect DOE technology procurement efforts with large-volume purchasers and provide buyers with reliable data on product performance.
http://www1.eere.energy.gov/buildings/ssl/gatewaydemos.html

Technology Procurement. Technology procurement is an established process for encouraging market introduction of new products meeting certain performance criteria. DOE has successfully used this approach with other lighting technologies, including sub-CFLs and reflector CFLs. Technology procurement will encourage adoption of new SSL systems and products that meet established energy efficiency and performance criteria, and link these products to volume buyers and market influencers.

Lighting for Tomorrow. In partnership with the American Lighting Association and the Consortium for Energy Efficiency (CEE), DOE sponsors Lighting for Tomorrow, a design competition that encourages and recognizes excellence in design of energy-efficient residential light fixtures. In the 2007 competition, 24 companies submitted 45 entries in the SSL category, with winning fixtures including a downlight, a desk lamp, an undercabinet fixture, and an outdoor wall lantern. In the 2008 competition, awards were given for an SSL undercabinet light, an SSL recessed can lamp, SSL task lights, an SSL spotlight luminaire, an SSL architectural lay-in, and an SSL module.
http://www.lightingfortomorrow.com

ENERGY STAR for SSL. ENERGY STAR is a voluntary energy efficiency labeling program identifying products that save energy, relative to standard technology. Final ENERGY STAR criteria for SSL luminaires were released in September 2007, with an effective date of September 2008, contingent on related standards and test procedure finalization. http://www1.eere.energy.gov/buildings/ssl/energy_star.html

Technical Support for Standards. LEDs differ significantly from traditional light sources, and new test procedures and industry standards are needed to measure their performance. DOE provides national leadership and support for this effort, working closely with the Illuminating Engineering Society of North America, the National Electrical Manufacturers Association, the Next Generation Lighting Industry Alliance, the American National Standards Institute, and other standards setting organizations to accelerate the standards development process, facilitate ongoing collaboration, and offer technical assistance. National standards and rating systems for new SSL products were ssued in early 2008. http://www1.eere.energy.gov/buildings/ssl/standards.html

TINSSL. DOE's Technical Information Network for SSL increases awareness of SSL technology, performance, and appropriate applications. Members include representatives from regional energy efficiency organizations and program sponsors, utilities, state and local energy offices, lighting trade groups, and other stakeholders. The Northeast Energy Efficiency Partnerships and the CEE support DOE in this effort, collaborating with DOE to produce SSL information and outreach materials, host meetings and events, and support other outreach activities. http://www.ssl.energy.gov/technetwork.html

SSL Quality Advocates. This program is jointly developed by the DOE and the NGLIA. It is a voluntary program where participants pledge to accurately represent the performance of SSL products in SSL marketing literature. This will encourage market acceptance of SSL lighting systems. Specifically, companies pledge to accurately report lumens, efficacy, watts, CCT, and CRI as measured by the industry standard IESNA LM-79-2008. http://www.lighting-facts.com/

L Prize. The Energy Independence and Security Act of 2007 directed DOE to establish the Bright Tomorrow Lighting Prizes (L Prize) competition to accelerate development and adoption of SSL products to replace the common light bulb. In May 2008, DOE launched the L Prize competition at LIGHTFAIR® International. The competition challenges industry to develop replacement technologies for two of today's most widely used and inefficient products: 60W incandescent lamps and PAR 38 halogen lamps. Winners will be eligible for cash prizes, opportunities for federal purchasing agreements, utility programs, and other incentives.

Four California utilities – Pacific Gas & Electric, Sacramento Municipal Utility District, San Diego Gas & Electric, and Southern California Edison – worked closely with DOE to establish rigorous technical requirements for the competition. These utilities also signed a Memorandum of Understanding with DOE (shown in Appendix C), agreeing to work cooperatively to promote high-efficiency SSL technologies. These L Prize partners will conduct field assessments of proposed products and play an important role in promoting and developing markets for the winning L Prize products. Since the competition's launch, a number of additional partners have signed on. http://www.lightingprize.org/.

Next Generation Luminaires Competition. In May 2008, DOE launched a parallel competition focused on commercial luminaires: the Next Generation Luminaires™ SSL Design Competition. DOE has partnered with IESNA and IALD to organize this new competition, which seeks to encourage technical innovation and recognize and promote excellence in the design of energy-efficient LED commercial lighting luminaires. Next Generation Luminaires encourages manufacturers to develop innovative commercial luminaires that are energy efficient and provide the high lighting quality and consistency, glare control, lumen maintenance, and luminaire appearance needed to meet specification lighting requirements. Entries were due in October 2008, and winners were announced at Strategies in Light in February 2009. http://www.ngldc.org/. The Memorandum of Understanding between DOE and IESNA is located in Appendix G, and the Memorandum of Understanding between DOE and the IALD is located in Appendix H.

Table 5.6.1 shows the DOE meetings related to SSL commercialization.

Table 5.6.1: DOE SSL Commercialization Support Meetings

Company	Topic	Date
CALiPER Roundtable	SSL Testing and Standards	March 2009
DOE SSL Market Introduction Workshop	SSL Commercialization	July 2008
Lighting Designer Roundtable	SSL Commercialization	March 2008
CALiPER Roundtable	SSL Testing	November 2007
DOE LED Industry Standards Workshop	SSL Standards	November 2007
DOE SSL Market Introduction Workshop	SSL Commercialization	July 2007
DOE SSL Market Introduction Workshop	SSL Commercialization	April 2007
DOE SSL Commercial Product Testing Program Workshop	SSL Testing	January 2007
DOE LED Industry Standards Workshop	SSL Standards	March 2006

Below are descriptions of a few of the most recent commercialization-related meetings listed in Table 5.6.1.

March 2009 – CALiPER Roundtable
Over 30 experts from organizations such as the Illuminating Engineering Society of North America (IESNA), International Association of Lighting Designers (IALD), National Institute of Standards and Technology (NIST), National Electrical Manufacturers Association (NEMA), American National Standards Institute (ANSI), independent photometric testing laboratories, SSL manufacturers, and research laboratories met in Denver, Colorado to discuss current issues related to SSL testing and related standards development. The roundtable focused on topics such as SSL luminaire photometry, subcomponent LED photometry, and market needs for SSL testing.

July 2008 - DOE SSL Market Introduction Workshop
More than 270 attendees gathered in Portland, Oregon, to attend the annual DOE SSL Market Introduction Workshop, sharing updates, market trends, lessons learned, and strategies to guide market introduction of SSL products.

May 2008 - ENERGY STAR® Manufacturer Stakeholder Meeting
DOE hosted a workshop in Washington, D.C., for manufacturers to review the DOE ENERGY STAR criteria for SSL, the status of related test procedures, and the program launch and qualification process, as well as to learn more about future plans for the DOE ENERGY STAR program for SSL.

March 2008 - Lighting Designer Roundtable
DOE, the International Association of Lighting Designers (IES), and the Illuminating Engineering Society of North America (IALD) hosted a Lighting Designer Roundtable in Chicago. Sixteen lighting designers, along with DOE representatives, gathered to discuss SSL market and technology issues and share experiences and recommendations regarding the SSL industry.

6.0 Solid-State Lighting Portfolio Evaluation Plan

6.1 Internal DOE Evaluation

6.1.1 Government Performance and Results Act (GPRA)

The plan must support the establishment of performance goals, measures, and expectations as required by GPRA. To develop this evaluative plan, the BT Program Manager performs a Situation Analysis (the context for planning), identifies and makes explicit all planning assumptions (constants), and identifies and assesses the impact of current and emerging market trends (variables).

PNNL estimates the fiscal year energy, environmental, and financial benefits (i.e., metrics) of the technologies and practices for the DOE's Office of Building Technologies. This effort is referred to as "GPRA Metrics" because the Government Performance and Results Act of 1993 mandates such estimates of benefits, which are submitted to EE's Office of Planning, Budget, and Management as part of EE's budget request. The metrics effort was initiated by EE in 1994 to develop quantitative measures of program benefits and costs.

The BTS GPRA estimates for solid-state lighting are calculated using the National Energy Modeling System (NEMS). NEMS can link the costs and benefit characteristics of a technology and its market penetration. The NEMS commercial and residential demand modules generate forecasts of energy demand (energy consumption) for those sectors. The commercial demand module generates fuel consumption forecasts for electricity, natural gas, and distillate fuel oil. These forecasts are based on energy prices and macroeconomic variables from the NEMS system, combined with external data sources. The residential model uses energy prices and macroeconomic indicators to generate energy consumption by fuel type and census division in the residential sector. NEMS selects specific technologies to meet the energy services demands by choosing among a discrete set of technologies that are exogenously characterized by commercial availability, capital costs, operating and maintenance costs, efficiencies, and lifetime. NEMS is coded to allow several possible assumptions to be used about consumer behavior to model this selection process. For the GPRA effort, the menu of equipment was changed to include relevant BTS program equipment, technological innovations, and standards.[75]

The most recent Government Performance Results Act benefit analysis based on DOE's FY2009 Budget Request estimates that the energy savings from SSL in 2030 will be approximately 79 TWh, which is 13% of all of the energy used to light commercial and residential buildings in 2001. Looking cumulatively across the analysis period of 2008 to 2030, SSL is projected to save 8.2 quadrillion British Thermal Units (Btu) of primary energy, valued at approximately $75 billion at today's energy prices. This is equivalent to approximately 759 terawatt-hours of cumulative site electricity savings in commercial

[75] Documentation for FY2003 BTS GPRA Metrics, Building Technology, State and Community Programs, Energy Efficiency and Renewable Energy, U.S. Department of Energy.

and residential buildings. These savings have the potential to eliminate the need for more than twelve new 1000 MW power plants in 2030. This analysis considers some – but not all – sectors and applications, so the energy savings could be higher as SSL displaces other incandescent and fluorescent light sources.

6.1.2 Peer Review

In November 2005, DOE conducted a formal peer review of 21 DOE-funded SSL projects completing their first year. A second formal peer review of 30 selected projects from the SSL portfolio was conducted in the summer of 2007. A third formal review of 12 projects from the SSL portfolio was conducted in the summer of 2008. These reviews were conducted by panels of highly qualified scientists, engineers, and independent technical consultants who evaluated each project based on technical approach, accomplishments, productivity, and relevance of the work to DOE goals. The panel identified areas of concern and areas to be commended, and the results of the peer review process were shared with the project team and DOE.

6.2 External Evaluation

6.2.1 National Academies of Science Review

EPACT 2005, passed in August 2005, requires the SSL program enter into an agreement with the National Academy of Sciences to conduct periodic reviews of the Solid-State Lighting Initiative. However, even before the passage of EPACT 2005, the National Research Council (NRC) was tasked by Congress to develop a methodology for the prospective assessment of DOE program impacts. Starting in December of 2003, the NRC developed a conceptual framework and applied it to a review of three DOE programs as the first step in developing a recommendation for a methodology for future program reviews. The committee appointed expert panels to apply the methodology to these programs as case studies.

One of these programs was the LR&D program, and in particular the solid state lighting program. Although the intent of the NRC study was not specifically to review these programs, some of the reported findings point to the benefits of investing in solid state lighting R&D. The NRC published a report, *Prospective Evaluation if Applied Research and Development at DOE (PHASE ONE): A First Look Forward* [76]

- The committee found that, if successful, the program would yield a projected national economic benefit of $84 billion through 2050, discounted to 2005 dollars. This is for annual DOE funding of $25 million for 20 years ($500 million, undiscounted). Even allowing for program risk, the projected risk-adjusted benefit is $50 billion (p. 151). This benefit is over and above that to be realized by the private and foreign R&D funding during these years, which is twice the assumed DOE funding.

- The NRC notes that the potential benefits associated with full funding are large,

[76] To download a PDF version of this report, please visit http://www.nap.edu/books/0309096049/html.

even if the stretch performance goals are not achieved.

- The panel notes that the large projected benefits were for a relatively conservative reference scenario, and the other scenarios not analyzed would have shown even larger benefits (p. 64). It notes that the projected benefits even under baseline conditions are high enough to justify the authorized $500 million SSL DOE program.

- The panel concluded that the achievement of DOE's technical goal depends on an increase in funding from $10 million per year at the time of the study to $50 million per year. Without DOE funding, the panel believes the technical goals will not be achieved.

- Even if the R&D results were to be considerably less than the stretch goal, the panel estimates that the benefits would substantially exceed the cost of the program.

The panel believes that DOE funding is an important catalyst to other R&D funding, and is a catalyst to spur such non-DOE funding. Huge environmental benefits would also flow from the program results, once implemented. Estimates of these benefits are given in the report, though they were not the focus of the study, and they are not included in the $50 billion economic benefits cited above.

Appendix A Approval of Exceptional Circumstances Determination for Inventions Arising Under the Solid State Lighting (SSL) Program

MEMORANDUM FOR: **DAVID K. GARMAN**
ASSISTANT SECRETARY FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY

DAVID N. HILL
DEPUTY GENERAL COUNSEL FOR ENERGY POLICY

FROM: **MICHAEL J. MCCABE**
BUILDING TECHNOLOGIES PROGRAM MANAGER

PAUL A. GOTTLIEB
ASSISTANT GENERAL COUNSEL FOR TECHNOLOGY TRANSFER AND INTELLECTUAL PROPERTY

SUBJECT: **Approval of Exceptional Circumstances Determination for Inventions Arising Under the Solid State Lighting (SSL) Program**

This Memorandum requests that you approve the attached Exceptional Circumstances (E-C) Determination for Inventions Arising Under the SSL Program. The E-C Determination, drafted by the National Energy Technology Laboratory (NETL) patent counsel in consultation with Headquarters patent counsel, finds that circumstances surrounding the SSL Program are exceptional and justify modified intellectual property arrangements as allowed by the Bayh-Dole Act (35 U.S.C. 202(a)(ii)). As the Manager of the Building Technologies Program, I ask that you approve the attached E-C Determination.

Background

The Department of Energy (DOE) is implementing the SSL Program through the Building Technologies Program. In partnership with NETL, the Building Technologies Program will, through the SSL Program, develop advanced solid state lighting technologies that, compared to conventional lighting technologies, are much more energy efficient, longer lasting, and cost-competitive, by targeting a product system efficiency of 50 percent with lighting that accurately reproduces sunlight spectrum. It is envisioned that SSL products of this quality will have substantial market penetration and with their improved performance would save significant energy.

The SSL Program has a multi-tier structure. One tier consists of a competitively selected SSL Partnership whose membership includes organizations that have or will have the capacity to manufacture SSL systems, i.e. the entire package from wall plug to illumination. This group includes a significant portion of the United States manufacturing base of SSL products for general lighting applications. Another tier is the Core Technology Program, which will enter into funding agreements with DOE to develop solutions to the more difficult shared technical barriers identified by the SSL Partnership.

A Memorandum of Agreement (MOA) was entered into between DOE and the SSL Partnership, under which no federal funding will be provided to the Partnership. The Partnership will provide a manufacturing and commercialization focus for the SSL Program and accelerate the commercialization of SSL technologies through DOE access to the technical expertise of the organization's members, communication of SSL Program accomplishments within the SSL community, and cooperative efforts of the Partnership to develop and promote demonstrations of SSL technologies. Some members of the Partnership may also be selected for the award of cost shared cooperative agreements under the SSL product development solicitations, the third tier of the SSL Program structure.

In order for the link between the SSL Partnership and the Core Technology Program to succeed, the members of the SSL Partnership will require a guaranteed right to license the technologies developed by Core Technology Program participants. However, most of the Core Technology Program participants are expected to be domestic small businesses or domestic nonprofit organizations, such as universities, including DOE laboratories and those laboratories subject to a class waiver. These entities are entitled under the Bayh-Dole Act, or their laboratory operating contracts, to retain title to any inventions they conceive or first actually reduce to practice under their government-funded awards. Fortunately, the Bayh-Dole Act also allows an agency to make a determination of exceptional circumstances when it finds that encumbering the right to retain title to any subject invention will better promote the policy and objectives of the Bayh-Dole Act.

Specifics of SSL Program Exceptional Circumstances Determination

The proposed intellectual property arrangement will allow members of the Core Technology Program to retain title to inventions made under their SSL Program awards, but will require them to offer to each member of the SSL Partnership the first option to enter into a non-exclusive license upon terms that are reasonable under the circumstances, including royalties, for these inventions. Field of use of the license could be limited to solid state lighting applications, although greater rights could be offered at the discretion of the invention owner. In addition, any entity having the right to use or sell any subject invention in the United States and/or any other country — including the Core Technology Program participant — must agree that any products embodying the subject invention or produced through the use of the subject invention will be substantially manufactured in the United States.

Participants in the Core Technology Program must hold open license offers to SSL Partnership members for at least 1 year after the U.S. patent has issued on a new invention made under the Core Technology Program. Up to and during this one year period, the invention owner can enter into licensing negotiations for solid state lighting applications only with members of the Partnership. The invention owner must agree to negotiate in good faith with any and all members of the Partnership that indicate a desire to obtain at least a non-exclusive license. Exclusive licensing may be considered if only one Partnership member expresses an interest in licensing the invention. If no agreement is reached after nine months of negotiations, the individual Partnership member can take action in a court of competent jurisdiction to force licensing on reasonable terms and conditions.

In developing the E-C Determination, the SSL Program strove to minimize the licensing obligations that the Core Technology Program participants would have to agree to. They would retain title to their inventions and would be free to enter into additional licenses in other fields of use (besides solid state lighting) at any time. Additionally, one year after the U.S. patent issues, they would be free to enter into licenses in any field of use with any interested party. The licensing of background patents owned by the invention owner is not required.

Separately, under the SSL Program, a number of product developers will receive cost shared cooperative agreements as a result of competitive Product Development solicitations. This E-C Determination also imposes a requirement that any entity having the right to use or sell any subject invention under one of these cooperative agreements in the United States and/or any other country — including the Product Developer — must agree that any products embodying the subject invention or produced through the use of the subject invention will be substantially manufactured in the United States.

The term of the E-C Determination will be 10 years from the date it is approved by the General Counsel or her designee. However, the Government reserves the unilateral right to cancel or revoke this Determination in the event that the SSL Partnership organization dissolves or becomes bankrupt or insolvent, or in the event that the MOA between DOE and the SSL Partnership is terminated by either party for any reason. In addition, if any of these events occurs and DOE subsequently enters into a similar agreement with another partnership, DOE reserves the unilateral right to continue the E-C Determination, with the benefits accruing to the successor partnership.

Justification for Approving the SSL Program Exceptional Circumstances Determination

Exceptional circumstances determinations are authorized by the Bayh-Dole Act when the agency determines that restricting of the right to retain title to an invention resulting from federally sponsored research and development will better promote the goals of the Act, e.g., to use the patent system to:

- Promote collaboration between commercial concerns, and nonprofit organizations and small businesses, universities, and non-profit laboratories;

- Ensure that inventions made by such organizations are used to promote free competition and enterprise; and
- Promote the commercialization and public availability of inventions made in the United States by United States industry and labor.

As discussed in the E-C Determination, the Building Technologies Program believes the proposed modification to the standard intellectual property allocation meets these goals.

Potential Concerns

- Some members of the SSL Partnership may prefer to submit a proposal to the Product Development solicitation and thus keep most development work in-house. However, the Building Technologies Program feels this is not necessarily the best technical approach or best use of public funds. Individual companies would typically not possess a concentration of the best talent; redundant equipment and facilities would have to be purchased; and redundant research and development efforts would have to be performed. This would negate the SSL Program goal of leveraging the most difficult problems to accelerate commercialization of this nationally important technology.

- Some small businesses may object to this E-C Determination because they want to reserve the right to practice their inventions themselves, rather than to license them to the SSL Partnership members. DOE has a large Small Business Innovative Research (SBIR) program to which this Determination does not apply. Small businesses have the option to apply for an award through the DOE SBIR program if they want to pursue a more entrepreneurial path towards commercialization.

- Some affected entities, especially universities, may object in principle to any restrictions of their intellectual property rights, no matter how compelling the logic is. Entities who believe that the Determination is contrary to the intent of Bayh-Dole may: (a) complain to Departmental officials and/or members of Congress; (b) pursue an administrative appeal to DOE; or (c) file a petition for review in the United States Court of Federal Claims. In addition, the Secretary of Commerce has the statutory authority to object to this Determination, but no right to disapprove, if he believes that the Determination is contrary to the policies of the Act. In that event, the Secretary of Commerce shall so advise the Secretary of Energy and the Administration of the Office of Procurement Policy and recommend corrective action. The Building Technologies Program feels that DOE can adequately justify its action in the face of such a challenge.

A similar Exceptional Circumstances Determination was approved in November 2000 under Fossil Energy's Solid State Energy Conversion Alliance (SECA) program. Neither the Secretary of Commerce nor the industry raised concerns regarding that E-C Determination.

Conclusion

The Building Technologies Program believes that approval of the Exceptional Circumstances Determination will benefit DOE program objectives, the SSL Partnership, and the Core Technology Program participants.

Approved ______________________ Date. 6-6.05
ASSISTANT SECRETARY FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY

Approved: ______________________ Date: 3-18-05
DEPUTY GENERAL COUNSEL FOR ENERGY POLICY

Attachment

cc: J. Brodrick
B. Marchick, GC-62
C. E. Christy, NETL
D. F. Gyorke, NETL
R. R. Jarr, NETL
L. A. Jarr, NETL

STATEMENT OF ANALYSIS OF DETERMINATION
OF EXCEPTIONAL CIRCUMSTANCES FOR WORK PROPOSED
UNDER THE SOLID STATE LIGHTING PROGRAM

For the reasons set forth below, the Department of Energy (DOE) has determined, pursuant to 35 U.S.C. § 202 (a)(ii), that the circumstances surrounding the DOE's Solid State Lighting (SSL) Program being implemented by DOE's Energy Efficiency and Renewable Energy's (EERE's) Office of Building Technologies and the National Energy Technology Laboratory (NETL), to develop improved lighting products described within various solicitations and National Laboratory funding calls implemented under the SSL program, are exceptional. Accordingly, a disposition of patent rights different from that generally available under Public Law 96-517 and Public Law 98-620 for funding agreements with small businesses, universities and other nonprofit organizations, and work done by DOE government-owned, contractor-operated (GOCO) National Laboratories, whether operated by nonprofit or for profit organizations, is warranted. These laws generally entitle such entities to retain title to inventions made under Government sponsorship, with minimal licensing obligations. The disposition of patent rights specified below will better promote the policies and objectives set out in 35 U.S.C. § 200, as described in detail below.

The goal of the SSL Program is to, by 2025, develop advanced solid state lighting technologies that, compared to conventional lighting technologies, are much more energy efficient, longer lasting, and cost-competitive, by targeting a product system efficiency of 50 percent with lighting that accurately reproduces sunlight spectrum. It is envisioned that SSL products of this quality would have substantial market penetration and with their improved performance would save significant energy.

The SSL Program has a multi-tier structure. One tier consists of a competitively selected SSL Partnership whose membership includes organizations that have or will have the capacity to manufacture SSL systems, *i.e.*, the entire package from wall plug to illumination. This group includes a significant portion of the United States manufacturing base of SSL products for general lighting applications. Another tier is the Core Technology Program, which will focus on finding solutions to the more difficult shared technical barriers identified by the SSL Partnership.

In order for the link between the SSL Partnership and the Core Technology Program to succeed, the SSL Partnership will require a guaranteed right to license the technologies developed by Core Technology Program participants. However, most of the Core Technology Program participants are expected to be domestic small businesses or domestic nonprofit organizations, such as universities, including DOE laboratories, and those laboratories subject to a class waiver. These entities are entitled under the Bayh-Dole Act (35 U.S.C. § 200 *et seq.*), or their laboratory operating contracts, to retain title to any inventions they conceive or first actually reduce to practice under their Government-funded awards.

It is anticipated that the Government share of the budget for this 20-year program will be over 200 million dollars. Except for the DOE GOCO National Laboratories, the organizations participating in the Core Technology Program will provide 20% cost-share. A Memorandum of Agreement (MOA) was entered into between DOE and the SSL Partnership, under which no federal funding will be provided to the Partnership. The Partnership will provide a manufacturing and commercialization focus for the SSL Program and accelerate the commercialization of SSL technologies through DOE access to the technical expertise of the organization's members, communication of SSL Program accomplishments within the SSL community, and cooperative efforts of the Partnership to develop and promote demonstrations of SSL technologies. Some members of the Partnership may also be selected for the award of cost shared cooperative agreements under the SSL product development solicitations.

Exceptional circumstances determinations are authorized by 35 U.S.C. § 202(a) when the agency determines that restriction of the right to retain title to an invention resulting from federally sponsored research and development "will better promote the policy and objectives of this chapter." This exceptional circumstances determination will better promote the following policy and objectives of the Congress as described in 35 U.S.C. § 200: to use the patent system to promote the utilization of inventions arising from federally supported research or development; to promote collaboration between commercial concerns and nonprofit organizations, including universities; to ensure that inventions made by nonprofit organizations and small business firms are used in a manner to promote free competition and enterprise; and to promote the commercialization and public availability of inventions made in the United States by United States industry and labor.

In addition, this determination is being made in accordance with 37 CFR 401.3(a)(2), 401.3(b), and 401.3(e). In particular, 37 CFR 401.3(b) requires that when an agency exercises an exception, it shall use a standard prescribed clause "with only such modifications as are necessary to address the exceptional circumstances or concerns which led to the use of the exception." Also, 37 CFR 401.3(e) specifies that "the agency shall prepare a written determination, including a statement of facts supporting the determination, that the conditions identified in the exception exist."

The exception to the disposition of patent rights from that generally available under Public Law 96-517 and Public Law 98-620 for funding agreements between small businesses, universities and other nonprofit organizations and for work done by DOE GOCO National Laboratories will have several components. First, it will involve requiring the participants in the SSL Core Technology Program to offer to each member of the SSL Partnership the first option to enter into a non-exclusive license upon terms that are reasonable under the circumstances, including royalties, for subject inventions developed under the Core Technology Program. The field of use of the license could be limited to solid state lighting applications, although greater rights could be offered at the discretion of the invention owner. In addition, any entity having the right to use or sell any subject invention in the United States and/or any other country — including the Core Technology Program participant — must agree that any products embodying the subject invention or produced through the use of the subject invention will be substantially manufactured in the United States. Any waiver of this requirement must be approved in writing by the Department of Energy in advance of foreign manufacture.

The Core Technology Program participant's licensing offer must be held open for at least one year after the U.S. patent issues and the invention owner must agree to negotiate in good faith with any and all SSL Partnership members that indicate a desire to obtain at least a non-exclusive license. During this one year period, the invention owner can enter into licensing negotiations for solid state lighting applications only with members of the Partnership.

Exclusive licensing may be considered if only one SSL Partnership member expresses an interest in licensing the invention. Partially exclusive licenses in a defined field of use may be granted to a Partnership member, as long as doing so would not preclude any other Partnership member that indicates a desire to license the invention from being granted at least a non-exclusive license. However, the Government will not require the patent owner to grant any exclusive or partially exclusive licenses. The Core Technology Program participant that owns or controls the invention must enter into good faith negotiations with each individual Partnership member that has indicated a desire to license the invention. Because the submission by a potential licensee of a satisfactory business plan is accepted licensing practice, DOE expects that good faith negotiations will include the invention owner requiring a satisfactory business plan from each individual Partnership member with which it is negotiating.

In the event the parties to the negotiation cannot reach agreement on the terms of the license, as set forth above, within nine months of initiating good faith negotiations, each individual SSL Partnership member shall have the right of a third party beneficiary to maintain an action in a court of competent jurisdiction to force licensing on reasonable terms and conditions. Any assignment of the invention must be made subject to these requirements.

The above described licensing option is believed to result in the minimum rights that the SSL Partnership members need to ensure that the technology developed by the Core Technology Program participants is available to promote commercialization of the solid state lighting technology. The Core Technology Program participants will retain title to the inventions and will be entirely free to negotiate and enter into additional licenses with entities other than the members of the SSL Partnership in other fields of use. This licensing for outfield uses could accelerate the SSL program because commercialization of outfield uses often benefits the commercialization of infield uses. In a similar manner, licensing leading to the commercialization of infield uses could benefit the commercialization of outfield uses. For example, SSL technology could be applied to non-lighting fields such as biological agent detection, power transistors, night vision systems, and photovoltaics. The DOE believes that this approach would ensure the most broad-based applications for the technology developed under the SSL program. To further demonstrate the fact that this licensing option minimizes the rights being extracted, the Core Technology Program participants will not be required to license their background patents. However, we would expect that a further positive outcome of this Determination will be the voluntary licensing of background technology to foster commercialization. Finally, in the event that an affected awardee may have an existing licensing arrangement or commitment that might conflict with this Determination, the DOE will seek to accommodate any such arrangement.

Based on discussions with a group of people associated with small businesses, DOE understands that some small businesses may object to this Determination because they want to reserve the right to practice their inventions themselves, rather than to license them to the SSL Partnership members. While DOE appreciates their concerns, DOE has a large Small Business Innovative Research (SBIR) program to which this Determination does not apply. Small businesses have the option to apply for an award through the DOE SBIR program if they want to pursue a more entrepreneurial path towards commercialization.

Because of the nature of this program, without this exceptional circumstances determination, the small businesses, universities, other nonprofits and DOE GOCO National Laboratories participating in the Core Technology Program would automatically be entitled, pursuant to Public Law 98-620 and Public Law 96-517 or advance patent waivers, to elect to retain title to their inventions. Should this occur, the Core Technology Program participants described above will be under no obligation to share the technology/innovations developed with the members of the SSL Partnership, or in the alternative, could choose to share the developed technology with only certain members. This would create a situation where some Partnership members would not have assurance of licensing rights to use the new technology developed. Such a situation, if allowed to occur, might stifle the ability of the Government to work with a broad base of participants in the SSL Program and would stifle the widest application of the developed technology, the very intent of the proposed Core Technology Program.

The SSL Program exceptional circumstances determination is justified for several additional reasons including the following:

- If Core Technology Program participants could exclusively license to anyone they choose, including non-members of the SSL Partnership, or could choose to not license anyone, then it would be unlikely that the SSL Partnership would be willing to, at no cost to the Government, support the SSL Program, including collaboratively defining the Core Technology Program objectives. This could seriously impede the SSL program goal of leveraging Government funds to address the most difficult problems in an effort to accelerate commercialization of this nationally important technology.

- A market for the intellectual property is being created. The Core Technology Program participants will have a ready set of potential licensees to which to license their invention(s), and, if the SSL Partnership members are successful in commercializing their lighting systems, reap income in the form of royalties.

- If the intellectual property was held by a small company, university, or DOE GOCO National Laboratory that is unwilling to negotiate in good faith, that technology could be unavailable for an extended period of time. This would be detrimental to U.S. national interests.

As further support for this Determination, the Conference Report for the FY 2005

Department of Interior and Related Agencies Appropriation Bill states in Note 8:

> The managers understand that the Department will soon issue an Exceptional Circumstances Determination with regard to solid state lighting core technology research, with the purpose of facilitating favorable access to the resulting intellectual property by members of the Next Generation Lighting Industry Alliance [the "SSL Partnership" in this Determination]. This access is in exchange for the active work for the Alliance in using its experience and expertise to bring a manufacturing and commercial focus to the solid state lighting project portfolio, as stipulated in the competitive solicitation by which the Alliance was selected. The managers support this arrangement and believe it will facilitate the deployment of solid state lighting technologies and accelerate reductions in electrical energy consumption.

The duration of this Determination will be 10 years from the date it is approved by the General Counsel or her designee. However, the Government reserves the unilateral right to cancel or revoke this determination in the event that the SSL Partnership organization dissolves or becomes bankrupt or insolvent, or in the event that the MOA between DOE and the SSL Partnership is terminated by either party for any reason. In addition, if any of these events occur and DOE subsequently enters into a similar agreement with another partnership, DOE reserves the unilateral right to continue the Determination, with the benefits accruing to the successor partnership.

The membership of the SSL Partnership may change as companies join and drop out. Individual companies will receive the benefits of this determination commencing on the date they become a member of the Partnership group. An individual company will be entitled to the licensing benefits described above for subject inventions made under Core Technology Program projects that have been selected for award after the time the company's membership in the Partnership becomes effective. A project is selected for award when the DOE source selection official has signed the selection statement for the core technology solicitation under which it is proposed. The DOE will maintain a log of Core Technology Program projects and their selection dates. The Partnership group shall maintain a log of membership, including the effective date of each company's membership. If an individual company elects to discontinue its membership in the Partnership, it will receive licensing benefits under this determination only for patent applications filed prior to the date when the company's membership ends.

Separately, under the SSL Program, a number of product developers will receive cost shared cooperative agreements from NETL as a result of competitive product development solicitations. This determination also imposes a requirement that any entity having the right to use or sell any subject invention under one of these cooperative agreements in the United States and/or any other country —including the product developer--must agree that any products embodying the subject invention or produced through the use of the subject invention will be substantially manufactured in the United States. Any waiver of this requirement must be approved in writing by the Department of Energy in advance of foreign manufacture.

For the foregoing reasons, the Department of Energy has determined that exceptional circumstances exist as provided in 35 U.S.C. § 202(a)(ii) in any agreement with a small business, university or other nonprofit organization, or GOCO National Laboratory selected as a Core Technology Program participant under SSL, such as to give rise to the need for the licensing provisions described herein.

Under 35 U.S.C. § 203(2), a contractor has a right to appeal any agency's determination of exceptional circumstances. Accordingly, each Core Technology Program and product developer participant to which this determination applies will be provided with notice of this determination and a right to appeal.

Appendix B Memorandum of Agreement between the U.S. Department of Energy and the Next Generation Lighting Industry Alliance

MEMORANDUM OF AGREEMENT
BETWEEN
THE UNITED STATES DEPARTMENT OF ENERGY (DOE)
AND
THE NEXT GENERATION LIGHTING INDUSTRY ALLIANCE (NGLIA)

ARTICLE I – PURPOSE

This Memorandum of Agreement (MOA) is entered into by and between the Next Generation Lighting Industry Alliance (NGLIA) and the U.S. Department of Energy (DOE) ("the Parties") for the purpose of establishing a mutual framework governing the respective responsibilities of the Parties. The Parties will conduct activities in support of research, development, demonstration and deployment of solid state lighting (SSL) technologies for general lighting applications.

ARTICLE II - AUTHORITY

DOE enters into this MOA under the authority of, among others, the Department of Energy Organization Act (Pub. L. 95-91) section 301, 42 U.S.C. § 7151; and the Energy Reorganization Act of 1974 (Pub. L. 93-438) section 103, 42 U.S.C. § 5813.

ARTICLE III - OBJECTIVE

The objective of this MOA is to provide a partnership to conduct various activities in support of core technology research, development, demonstration and deployment activities targeted to the application of SSL technologies in energy efficient general lighting applications. In particular, this collaboration will support and enhance the Solid State Lighting Program of the Building Technologies/Lighting R&D Program within DOE's Office of Energy Efficiency and Renewable Energy. The Parties believe that this cooperation will provide DOE with a manufacturing and commercialization focus in the development of research needs and goals for the DOE SSL Program. The quality of the SSL Program will be enhanced through the NGLIA's willingness, at DOE's discretion, to provide technical expertise for proposal and project reviews. The Parties further believe that the cooperation will accelerate the implementation of SSL technologies for the public benefit through communicating of SSL Program accomplishments within the SSL community, and through encouraging the development and dissemination of metrics, codes and standards. The partnership will stimulate the implementation of SSL technologies through the Parties' efforts to promote demonstrations of SSL technologies for general lighting applications.

ARTICLE IV – SCOPE OF COLLABORATIVE ACTIVITIES

Collaboration under this MOA includes, but is not limited to, SSL activities in support of:

- Core Technology Research;
- Product Development and Systems Integration;
- Demonstration; and
- Market Conditioning

The SSL technologies that are the subject of this MOA include light emitting diodes (LEDs), organic light emitting diodes (OLEDs), and other semiconductor white-light producing devices.

ARTICLE V – FORMS OF COLLABORATIVE ACTIVITIES

Collaboration under this MOA may include, but is not limited to, the following forms of joint activities:

- Conducting workshops related to SSL technology and annual program reviews for projects in DOE's SSL Program. These workshops and program reviews will be open to the public;
- At DOE's discretion, participating in proposal reviews and individual project reviews for research projects in DOE's SSL Core Technology Program;
- Encouraging the development of metrics, codes, standards for measurement and utilization of SSL products for general illumination, and criteria for voluntary DOE deployment programs; and
- Planning and promoting demonstrations by NGLIA members of SSL technologies used for general illumination applications.

The NGLIA may designate a third party (e.g., contractor or organization member) to act on its behalf to conduct these collaborative activities. Due to conflict of interest considerations, some members of the NGLIA and/or their employees may be unable to participate in certain activities of the MOA.

All representatives of the NGLIA and its members must agree to non-disclosure of all confidential or proprietary information prior to participation in partnership activities such as proposal or project reviews that may disclose confidential or proprietary information from DOE SSL Program participants. Government employees are bound by the provisions of the Trade Secrets Act (18 USC 1905) to not disclose confidential or proprietary information obtained during the course of their Government employment.

ARTICLE VI – RESPONSIBILITES OF THE PARTIES

A. Responsibilities of the Department of Energy:

- Identify a Federal employee as the point of contact (POC) to function as the interface between the SSL Program and the NGLIA to ensure that the collaborative activities conducted under this MOA are coordinated with the schedule and progress of the SSL Program, and are free of conflicts of interest.

- Maintain a log of Core Technology Program projects and their selection dates.
- Arrange to provide the NGLIA with SSL Program- and project-related releasable information in accordance with the purpose, terms, and conditions of this MOA and as available from DOE's SSL projects.
- As set forth in the document titled "Statement of Analysis of Determination of Exception Circumstances for Work Proposed Under the Solid State Lighting Program," provide the NGLIA with information regarding patents and other intellectual property available for licensing from SSL Core Technology Program participants, as that information becomes available to NETL.
- Notify the NGLIA when DOE announces funding opportunities available to its membership and the public for research, development, and demonstration of SSL technologies.
- Participate with the NGLIA in planning of SSL demonstrations by their members, and create criteria for voluntary market conditioning programs, such as Energy Star.

B. Responsibilities of the NGLIA:

- Identify an individual as the POC to function as the interface between the NGLIA, its membership, and DOE to ensure that the collaborative activities conducted under this MOA are coordinated with the SSL Program and are free of conflicts of interest.
- Maintain a log of membership, including the effective dates of each company's membership.
- Provide a membership including a significant portion of the United States manufacturing base of SSL products for general lighting applications that, together with the staff of the NGLIA, will:
  - Provide administrative expertise and staffing to organize and support technical meetings and workshops related to SSL technologies.
  - At DOE's discretion, provide technical expertise to review SSL Core Technology Program proposals, participate in SSL project review meetings, and provide recommendations from individual NGLIA members on the direction of research, development, and demonstration of SSL technologies for general illumination.
  - Encourage efforts to develop metrics and standards for the application of SSL products for general lighting.
  - Recommend, develop, and technically and financially support demonstrations of SSL technologies, emphasizing those technologies developed in the DOE SSL Program.

- Develop processes and/or procedures to safeguard any business, programmatically or technically sensitive information provided under the terms of this MOA.

C. NGLIA and DOE mutually agree to the following:

- Within statutory limits and DOE regulations, work to promote SSL technologies to the common benefit of the DOE program and NGLIA membership.
- At times and locations acceptable to the NGLIA and DOE POCs, meet to discuss and plan the activities of the partnership. At the discretion of the POCs, these meetings may also include representatives of the NGLIA members, SSL Core Technology Program participants, and other DOE contractors.

ARTICLE VII – PUBLICATIONS

Each Party agrees to seek pre-publication review and comment from the other Party prior to any planned publication under this MOA by the Parties to this MOA. The Parties agree that any such publications shall not include Confidential Information designated confidential by a third party. Failure to receive a written response within thirty (30) calendar days from the date the document is provided for review shall be considered as concurrence with the publication. The author of any such publication shall not be obligated to incorporate or address any comments received from the other Party. In case of failure to agree on the manner of publication or interpretation of results, either Party publishing the results will give due credit to the cooperation of the other Party, but will assume full responsibility for any statements in which a difference of opinion exists.

Any public information release concerning the activities related to this agreement shall describe the contribution of both Parties to the activity. This does not apply to reports or records released pursuant to the Freedom of Information Act.

Publication may be joint or separate, always giving due credit to the cooperation and recognizing, within proper limits, the rights of individuals, including employees of NGLIA members and employees of SSL Program participants, who performed the work.

ARTICLE VIII - INTELLECTUAL PROPERTY

DOE will use its best efforts to require each awardee under its SSL Core Technology Program to enter into negotiations with NGLIA members intended to lead to the non-exclusive licensing of any patented subject invention made under its DOE agreement. To accomplish this, DOE will seek to execute a determination of exceptional circumstances under the Bayh-Dole Act for domestic nonprofit and small business participants in the DOE Core Technology Program. In addition, in the Core Technology Program, DOE will seek to include comparable provisions in any patent waivers granted to entities such as large businesses that do not qualify for a statutory patent waiver under the Bayh-Dole

Act. DOE will use its best efforts to ensure that information is provided to the NGLIA concerning inventions and other intellectual property developed by SSL Core Technology Program participants.

The Parties understand that:

- Individual companies will receive rights under the determination of exceptional circumstances and/or any patent waivers granted commencing on the date they become a member of the NGLIA. The NGLIA shall maintain a log of membership, including the effective date of each company's membership.
- An individual company will be entitled to the licensing benefits described above for subject inventions made under SSL Core Technology Program projects that have been selected for award after the time the company's membership in the NGLIA becomes effective. A project is selected for award when the DOE source selection official has signed the selection statement for the core technology solicitation under which it is proposed. The DOE will maintain a log of Core Technology Program projects and their selection dates.
- If an individual company elects to discontinue its membership in the Partnership, it will receive licensing benefits only for patent applications filed at the time when the company's membership ends.

All representatives of the NGLIA and its members must agree to non-disclosure of any and all confidential or proprietary information prior to participation in partnership activities such as proposal or project reviews or any activity that may disclose confidential or proprietary information from DOE SSL Program participants. Government employees are bound by the provisions of the Trade Secrets Act (18 USC 1905) to not disclose confidential or proprietary information obtained during the course of their Government employment.

ARTICLE IX – FUNDING AND IMPLEMENTATION

The Parties shall each bear the costs they incur for performing, managing, and administering their activities under this MOA. These costs include salaries, travel, and per diem for personnel, as well as any contract costs. This MOA shall not be used to obligate or commit funds or as the basis for the transfer of funds.

ARTICLE X – MISCELLANEOUS

A. Other Relationships or Obligations

This MOA shall not affect any pre-existing or independent relationships or obligations between the DOE and the NGLIA.

B. Survival

The provisions of this MOA which require performance after the expiration or termination of this MOA shall remain in force notwithstanding the expiration or termination of this MOA.

C. Severability

Nothing in this MOA is intended to conflict with current law or regulation or the directives of the Department of Energy. If any provision of this MOA is determined to be invalid or unenforceable, the remaining provisions shall remain in force and unaffected to the fullest extent performed by law and regulation.

D. Compliance with Laws

The Parties shall each be responsible for their own compliance with applicable laws and regulations, including export control laws, in performing the work scope of this MOA. The construction, validity, performance, and effect of this MOA for all purposes shall be governed by the laws applicable to the Government of the United States.

E. Effect on Third Parties

This MOA does not direct or apply to any person outside DOE and the Next Generation Lighting Industry Alliance. It shall not be construed to provide a right, benefit, or cause of action for or by any person or entity not a party to this MOA, enforceable by law or equity against DOE or the Next Generation Lighting Industry Alliance, their officers, or employees.

ARTICLE XI – AMENDMENT, MODIFICATION, AND TERMINATION

This MOA shall remain in effect for the period of 5 years from its effective date, and, if agreed upon by the Parties, may be extended for three additional 2-year periods for a total of eleven years. This MOA may be modified or amended only by written agreement of the Parties. Either Party may terminate this MOA by providing written notice to the other Party. The termination shall be effective upon the sixtieth calendar day following notice, unless an earlier or later date is agreed to by the Parties.

ARTICLE XII – EFFECTIVE DATE

This MOA will become effective upon the latter date of signature of the Parties.

Executed in duplicate on the dates indicated below:

By: ______________________ Date: 2/2/2005

Michael J. McCabe
Building Technologies Program Manager
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy

By: ______________________ Date: 2 Feb 05

Dale Work
Chair
Next Generation Lighting Industry Alliance

for Susan Beard 1/28/05
Concurring for the Office of
General Counsel

Appendix C Memorandum of Understanding between the U.S. Department of Energy and L-Prize Partners

The following document contains a template Memorandum of Understanding that has been signed by all partners currently collaborating with the Department of Energy on the L-Prize. The list of partners as of March 2009 is below.

- Cape Light Compact
- Commonwealth Edison
- DTE Energy
- Efficiency Vermont
- Energy Trust of Oregon
- Eugene Water & Electric Board
- Midwest Energy Efficiency Alliance (covers 9 states)
- Northeast Energy Efficiency Partnerships (covers 8 states)
- NSTAR Electric
- NV Energy
- Pacific Gas & Electric
- Puget Sound Energy
- Sacramento Municipal Utility District
- San Diego Gas & Electric
- Seattle City Light
- Southern California Edison
- Wisconsin Energy Conservation Corporation

The United States Department of Energy
and
____

MEMORANDUM OF UNDERSTANDING
DOE Bright Tomorrow Lighting Prizes

By this Memorandum of Understanding (MOU), the U.S. Department of Energy (DOE) and ____________________ (company) agree to work cooperatively to improve the efficient use of energy and to minimize the impact of energy use on the environment.

DOE and ____________________ (company) intend to work together toward the following objectives:

1) Encourage the development of solid-state lighting (SSL) products to significantly decrease lighting energy use and maintain or improve lighting service, compared to traditional light sources through support of the Bright Tomorrow Lighting Prize.
2) Coordinate information-sharing regarding the evaluation of SSL products to the extent permissible.
3) Develop and implement cooperative programs to speed the market introduction, retail availability, and consumer acceptance of the selected SSL products. Such programs may include cooperative marketing, consumer education, distribution chain incentives, and/or field testing, among other possible strategies.

In conducting activities pursuant to this MOU, the parties understand and agree that DOE will not endorse any particular company or its products. The parties further understand and agree that the DOE logo shall not be used without the prior written authorization of DOE.

This MOU is neither a fiscal nor a funds obligation document. Nothing in this MOU authorizes or is intended to obligate the Parties to expend, exchange, or reimburse funds, services, or supplies, or transfer or receive anything of value.

All agreements herein are subject to, and will be carried out in compliance with, all applicable laws, regulations, and other legal requirements.

This MOU in no way restricts either of the parties from participating in any activity with other public or private agencies, organizations, or individuals.

This MOU is strictly for internal management purposes of the parties. It is not a contract for acquisition of supplies or services, is not legally enforceable, and shall not be construed to create any legal obligation on the part of either party, or any private right or cause of action for or by any person or entity.

This MOU will become effective upon signature by the Assistant Secretary of EERE, DOE and ____________________ (representative), ____________________ (company). It may be modified or amended by written agreement between both parties, and such amendments shall become part of, and shall be attached to this MOU.

This MOU shall terminate at the end of three (3) years from the later of the dates indicated below, unless revised or extended at that time by written agreement of the parties. It may be terminated at any time by either party, upon 90 days written notice to the other. Its provisions will be reviewed annually and amended/supplemented if mutually agreed upon in writing.

The Department of Energy enters into this MOU under the authority of section 646 of the Department of Energy Organization Act (Pub. L. No. 95-91, as amended; 42 U.S.C. 7256).

___________________________	__________	________________________	__________
John Mizroch	Date	Signature	Date
		________________________	
Acting Assistant Secretary Office of Energy Efficiency and Renewable Energy US Department of Energy		Name ________________________ Title ________________________ Company	

Appendix D Legislative Directive: EPACT 2005

Subtitle A – Energy Efficiency

Sec. 911. Energy Efficiency.

(c) Allocations. – From amounts authorized under subsection (a), the following sums are authorized:

(1) For activities under section 912, $50,000,000 for each of fiscal years 2007 through 2009.

(d) Extended Authorization. – They are authorized to be appropriated to the Secretary to carry out section 912 $50,000,000 for each of fiscal years 2010 through 2013.

Sec. 912. Next Generation Lighting Initiative.

(a) Definitions. – In this section:

(1) Advance Solid-State Lighting. – The term “advanced solid-state lighting” means a semiconducting device package and delivery system that produces white light using externally applied voltage.

(2) Industry Alliance. – The term “Industry Alliance” means an entity selected by the Secretary under subsection (d).

(3) Initiative. – The term “Initiative” means the Next Generation Lighting Initiative carried out under this section.

(4) Research. – The term “research” includes research on the technologies, materials, and manufacturing processes required for white light emitting diodes.

(5) White Light Emitting Diode. – The term “white light emitting diode” means a semiconducting package, using either organic or inorganic materials, that produces white light using externally applied voltage.

(b) Initiative. – The Secretary shall carry out a Next Generation Lighting Initiative in accordance with this section to support research, development, demonstration, and commercial application activities related to advanced solid-state lighting technologies based on white light emitting diodes.

(c) Objectives. – The objectives of the Initiative shall be to develop advanced solid-state organic and inorganic lighting technologies based on white light emitting diodes that, compared to incandescent and fluorescent lighting technologies, are longer lasting, are more energy-efficient and cost competitive, and have less environmental impact.

(d) Industry Alliance. – Not later than 90 days after the date of enactment of this Act, the Secretary shall competitively select an Industry Alliance to represent participants who are private, for-profit firms that, as a group, are broadly representative of the United States solid state lighting research, development, infrastructure, and manufacturing expertise as a whole.

(e) Research. –

(1) Grants. – The Secretary shall carry out the research activities of the Initiative through competitively awarded grants to –

(A) researchers, including Industry Alliance participants;

(B) National Laboratories; and
(C) institutions of higher education.

(2) Industry Alliance. – The Secretary shall annually solicit from the Industry Alliance –
(A) comments to identify solid-state lighting technology needs;
(B) an assessment of the progress of the research activities of the Initiative; and
(C) assistance in annually updating solid-state lighting technology roadmaps.

(3) Availability to Public. – The information and roadmaps under paragraph (2) shall be available to the public.

(f) Development, Demonstration, and Commercial Application. –
(1) In General. – The Secretary shall carry out a development, demonstration, and commercial application program for the Initiative through competitively selected awards.
(2) Preference. – In making the awards, the Secretary may give preference to participants in the Industry Alliance.

(g) Cost Sharing. – In carrying out this section the Secretary shall require cost sharing in accordance with section 988.

(h) Intellectual Property. – The Secretary may require (in accordance with section 202(a)(ii) of title 35, United States Code, section 152 of the Atomic Energy Act of 1954 (42 U.S.C. 2182), and section 9 of the Federal Nonnuclear Energy Research and Development Act of 1974 (42 U.S.C. 5908)) that for any new invention developed under subsection (e) –
(1) that the Industry Alliance participants who are active participants in research, development, and demonstration activities related to the advanced solid-state lighting technologies that are covered by this section shall be granted the first option to negotiate with the invention owner, at least in the field of solid-state lighting, nonexclusive licenses and royalties on terms that are reasonable under the circumstances;
(2) (A that, for 1 year after a United States patent is issued for the invention, the patent holder shall not negotiate any license or royalty with any entity that is not a participant in the Industry Alliance described in paragraph (1); and
(B) that, during the year described in clause (i), the patent holder shall negotiate nonexclusive licenses and royalties in good faith with any interested participants in the Industry Alliance described in paragraph (1); and
(3) such other terms as the Secretary determines are required to promote accelerated commercialization of inventions made under the Initiative.

(i) National Academy Review. – The Secretary shall enter into an arrangement with the National Academy of Sciences to conduct periodic reviews of the Initiative.

Appendix E List of Patents Awarded Through DOE-Funded Projects

As of December 2008, a total of twenty two solid-state lighting patents have been granted as a result of Department of Energy-funded research projects. This demonstrates the value of DOE SSL projects to private companies and notable progress toward commercialization. Since DOE began funding SSL research projects in 2000, a total of 90 patents applications have been applied for or awarded as follows: large businesses - 44, small businesses - 16, universities - 26, and national laboratories - 4.

Primary Research Organization	Title of Patent Application (Bolded titles indicates granted patents)
Agiltron, Inc.	Two patent applications filed.
Boston University	Formation of Textured III-Nitride Templates for the Fabrication of Efficient Optical Devices Formation of Textured III-Nitride Templates for the Fabrication of Efficient Optical Devices Nitride LEDs Based on Flat and Wrinkled Quantum Wells Optical Devices Featuring Textured Semiconductor Layers
Cree, Inc.	**Light Emitting Diode with Porous SiC Substrate and Method for Fabricating** Light Emitting Diode with High Aspect Ratio Sub-Micron Roughness for Light Extraction and Methods of Forming Light emitting diode with high aspect ratio submicron roughness for light extraction and methods of forming Light emitting diode package element with internal meniscus for bubble free lens placement One other patent application filed.
Dow Corning	Four patent applications filed
Eastman Kodak	**Ex-Situ Doped Semiconductor Transport Layer** Doped Nanoparticle-Based Semiconductor Junction Three other patent applications filed.
Fairfield Crystal Technology	Method and Apparatus for Aluminum Nitride Monocrystal Boule Growth
GE Global Research	**Light-Emitting Device with Organic Electroluminescent Material and Photoluminescent Materials** **Luminaire for Light Extraction from a Flat Light Source** **Mechanically Flexible Organic Electroluminescent Device with Directional Light Emission** **Organic Electroluminescent Devices and Method for Improving Energy Efficiency and Optical Stability Thereof** **Series Connected OLED Structure and Fabrication Method** **Organic Electroluminescent Devices having Improved Light Extraction** **Electrodes Mitigating Effects of Defects in Organic Electronic Devices** Hybrid Electroluminescent Devices OLED Area Illumination Source Eight other patent applications filed.
Georgia Tech Research Corporation	One patent application filed.

Primary Research Organization	**Title of Patent Application** (Bolded titles indicates granted patents)
International Technology Exchange	One patent application filed.
Light Prescriptions Innovators	**Optical Manifold for Light-Emitting Diodes** **Optical Manifold for Light-Emitting Diodes** Two other patent applications filed.
Maxdem Incorporated	Polymer Matrix Electroluminescent Materials and Devices
Nanosys	Nanocrystal Doped Matrices
OSRAM Opto Semiconductors, Inc.	**Integrated Fuses for OLED Lighting Device** Novel Method to Generate High Efficient Devices, which Emit High Quality Light for Illumination Novel Method to Generate High Efficient Devices, which Emit High Quality Light for Illumination OLED with Phosphors Polymer and Small Molecule Based Hybrid Light Source Polymer Small Molecule Based Hybrid Light Source
Pacific Northwest National Laboratory	Organic Materials with Phosphine Sulphide Moieties having Tunable Electric and Electroluminescent Properties Organic Materials with Tunable Electric and Electroluminescent Properties
Philips Electronics North America	High Color-Rendering-Index LED Lighting Source using LEDs from Multiple Wavelength Bins Three other patent applications filed.
PhosphorTech Corporation	**Light Emitting Device having Selenium-Based Fluorescent Phosphor** **Light Emitting Device having Silicate Fluorescent Phosphor** **Light Emitting Device having Sulfoselenide Fluorescent Phosphor** **Light Emitting Device having Thio-Selenide Fluorescent Phosphor**
Sandia National Laboratory	**Cantilever Epitaxial Process** One additional patent application filed.
Universal Display Corporation	**Binuclear Compounds** **Organic Light Emitting Device Structure for Obtaining Chromaticity Stability** **Organic Light Emitting Device Structure for Obtaining Chromaticity Stability** Stacked OLEDs with a Reflective Conductive Layer One other patent application filed.
University of California, San Diego	Rare-earth activated nitrides for solid state lighting applications Two additional patent applications filed.
University of California, Santa Barbara	**Plasmon Assisted Enhancement of Organic Optoelectronic Devices**

Primary Research Organization	Title of Patent Application (Bolded titles indicates granted patents)
	Silicone Resin Encapsulants for Light Emitting Diodes Five other patent applications filed.
University of North Texas	One patent application filed.
University of Southern California	Fluorescent Filtered Electrophosphorescence Fluorescent Filtered Electrophosphorescence OLEDs utilizing macrocyclic ligand systems Materials and architectures for efficient harvesting of singlet and triplet excitons for white light emitting OLEDs Organic vapor jet deposition using an exhaust Phenyl and fluorenyl substituted phenyl-pyrazole complexes of Ir Low Index Grids (LIG) To Increase Outcoupled Light From Top or Transparent OLED Three additional patent applications filed.

Appendix F Definition of Core Technology and Product Development

DOE defines Core Technology and Product Development as follows:

Core Technology - Core Technology research encompasses scientific efforts that focus on comprehensive knowledge or understanding of the subject under study, with possible multiple applications or fields of use in mind. Within Core Technology research areas, scientific principles are demonstrated, technical pathways to solid-state lighting (SSL) applications are identified, and price or performance advantages over previously available science/engineering are evaluated. Tasks in Core Technology are truly innovative and groundbreaking, fill technology gaps, provide enabling knowledge or data, and represent a significant advancement in the SSL knowledge base. Core Technology research focuses on gaining pre-competitive knowledge for future application to products by other organizations. Therefore, the findings are generally made available to the community at large to apply and benefit from as it works collectively towards attainment of DOE's SSL program goals.

Some examples of Core Technology research: molecular scale study of light generation and extraction; theory, fabrication and measurement of material properties of substrates, encapsulants, or polymers; software tools that capture scientific principles to expedite the design process; modeling of heat transfer principles to estimate temperature profiles within a semiconductor reactor; and mapping of scientific principles that explain the interactions of materials to create light of a specified spectrum.

Product Development - Product Development involves using basic and applied research (including Core Technology research) for the development of commercially viable SSL materials, devices, or luminaires. Product Development activities typically include evaluation of new products through market and fiscal studies, with a fully defined price, efficacy, and other performance parameters necessary for success of the proposed product. Product Development encompasses the technical activities of product concept modeling through to the development of test models and field ready prototypes. Product Development can also include "focused-short-term" applied research, but its relevance to a specific product must be clearly identified.

Product Development activities include laboratory performance testing on prototypes to evaluate product utility, market, legal, health, and safety issues. Feedback from the owner/operator and technical data gathered from testing are used to improve prototype designs.

Appendix G Memorandum of Understanding between the U.S. Department of Energy and the Illuminating Engineering Society of North America

The United States Department of Energy
and
The Illuminating Engineering Society
of North America

Final version: 6/5/06

MEMORANDUM OF UNDERSTANDING

By this Memorandum of Understanding (MOU), the U.S. Department of Energy (DOE) and the Illuminating Engineering Society of North America (IESNA) agree to work cooperatively to improve the efficient use of energy and to minimize the impact of energy use on the environment.

DOE and IESNA agree to work together toward the following goals:

1) Promoting and supporting the DOE Building Technologies Program and the DOE Efficiency Standards development by means of input from technical experts, and development of appropriate IESNA standards and procedures.

2) Developing and maintaining guides and procedures to assist the lighting measurement and application community in the photometric measurement of solid state lighting devices and other technologies to (i) support DOE programs, including development of ENERGY STAR® criteria for solid state lighting, and (ii) provide consistency and uniformity in photometric reports.

3) Developing and maintaining standards that include a focus on energy conservation strategies to benefit design professionals and users.

4) Encourage the participation of DOE personnel in IESNA technical committee activities and provide the opportunity for dissemination/publication of related research.

5) Develop and maintain appropriate educational modules for inclusion in IESNA course materials for use by the Society's Sections and other organizations.

This MOU in no way restricts either of the parties from participating in any activity with other public or private agencies, organizations or individuals.

This MOU is neither a fiscal nor a funds obligation document. Nothing in this MOU authorizes or is intended to obligate the parties to expend, exchange, or reimburse funds, services, or supplies, or transfer or receive anything of value.

This MOU is strictly for the internal purposes for each of the parties. It is not legally enforceable and shall not be construed to create any legal obligation on the part of either party. This MOU shall not be construed to provide a private right or cause of action for or by any person or entity.

This MOU will become effective upon signature by DAS of BCRB, DOE and the Executive Vice President of the Illuminating Engineering Society of North America. It may be modified or amended by written agreement between both parties, and such amendments shall become part of, and shall be attached to this MOU. This MOU shall terminate at the end of 5 years unless revised or extended at that time by written agreement of the parties. It may be terminated at any time by either party, upon 90 days written notice to the other. Its provisions will be reviewed annually and amended/supplemented if mutually agreed upon in writing.

7/17/06
Date

David E. Rodgers
Deputy Assistant Secretary (Acting)
Office of Technology Development
US Department of Energy

6/05/06
William Hanley
Executive Vice President
Illuminating Engineering
Society of North America
Date

Appendix H Memorandum of Understanding between the U.S. Department of Energy and the International Association of Lighting Designers

MEMORANDUM OF UNDERSTANDING
Between
The United States Department of Energy
and
The International Association of Lighting Designers

By this Memorandum of Understanding (MOU), the U.S. Department of Energy (DOE) and the International Association of Lighting Designers (IALD) agree to work cooperatively to improve the efficient use of energy by lighting equipment and systems, thereby minimizing the impact of energy use on the environment.

DOE and IALD agree to work together in the following areas:

1) Promoting lighting design principles and lighting technologies that improve lighting quality, energy efficiency, and environmental sustainability.

2) Developing and disseminating technical information to assist the lighting design community in the assessment and specification of solid state lighting (SSL) and other efficient lighting technologies, to support DOE programs on lighting quality such as ENERGY STAR and SSL Quality Advocates.

3) Jointly facilitating forums in which lighting designers can exchange ideas and information with DOE, and provide input to DOE lighting program planning.

4) Encouraging professional lighting designers to participate in DOE lighting projects, such as DOE's Gateway SSL Demonstrations, with particular attention to helping DOE assess lighting quality.

The Department of Energy enters into this agreement under the authority of Section 646 of the Department of Energy Organization Act (Pub. L. 95-91, as amended, 42 U.S.C. § 725 6).

This MOU in no way restricts either of the parties from participating in any activity with other public or private agencies, organizations or individuals.

This MOU is neither a fiscal nor a funds obligation document. Nothing in this MOU authorizes or is intended to obligate the parties to expend, exchange, or reimburse funds, services, or supplies, or transfer or receive anything of value.

This MOU is strictly for the internal purposes for each of the parties. It is not legally enforceable and shall not be construed to create any legal obligation on the part of either party. This MOU shall not be construed to provide a private right or cause of action for or by any person or entity.

This MOU will become effective upon signature by the Deputy Assistant Secretary for Energy Efficiency, DOE and the Executive Vice President of the International Association of Lighting Designers. It may be modified or amended by written agreement between both parties, and such amendments shall become part of, and shall be attached to this MOU. This MOU shall terminate at the end of five (5) years unless revised or extended at that time by written agreement of the parties. It may be terminated at any time by either party, upon 90 days written notice to the other. Its provisions will be reviewed annually and amended/supplemented if mutually agreed upon in writing.

10-28-08	10 November 08
David E. Rodgers — Date	Marsha L. Turner — Date
Deputy Assistant Secretary for Energy Efficiency	Executive Vice President
Office of Technology Development	International Association of
Energy Efficiency and Renewable Energy	Lighting Designers
U.S. Department of Energy	

Appendix I Legislative Directive: EISA 2007

Subtitle B--Lighting Energy Efficiency

Sec. 321. Efficient Light Bulbs.

(a) Energy Efficiency Standards for General Service Incandescent Lamps-

(1) DEFINITION OF GENERAL SERVICE INCANDESCENT LAMP- Section 321(30) of the Energy Policy and Conservation Act (42 U.S.C. 6291(30)) is amended--

(A) by striking subparagraph (D) and inserting the following:

`(D) GENERAL SERVICE INCANDESCENT LAMP-

`(i) IN GENERAL- The term `general service incandescent lamp' means a standard incandescent or halogen type lamp that--

`(I) is intended for general service applications;

`(II) has a medium screw base;

`(III) has a lumen range of not less than 310 lumens and not more than 2,600 lumens; and

`(IV) is capable of being operated at a voltage range at least partially within 110 and 130 volts.

`(ii) EXCLUSIONS- The term `general service incandescent lamp' does not include the following incandescent lamps:

`(I) An appliance lamp.

`(II) A black light lamp.

`(III) A bug lamp.

`(IV) A colored lamp.

`(V) An infrared lamp.

`(VI) A left-hand thread lamp.

`(VII) A marine lamp.

`(VIII) A marine signal service lamp.

`(IX) A mine service lamp.

`(X) A plant light lamp.

`(XI) A reflector lamp.

`(XII) A rough service lamp.

`(XIII) A shatter-resistant lamp (including a shatter-proof lamp and a shatter-protected lamp).

`(XIV) A sign service lamp.

`(XV) A silver bowl lamp.

`(XVI) A showcase lamp.

`(XVII) A 3-way incandescent lamp.

`(XVIII) A traffic signal lamp.

`(XIX) A vibration service lamp.

`(XX) A G shape lamp (as defined in ANSI C78.20-2003 and C79.1-2002 with a diameter of 5 inches or more.

`(XXI) A T shape lamp (as defined in ANSI C78.20-2003 and C79.1-2002) and that uses not more than 40 watts or has a length of more than 10 inches.

`(XXII) A B, BA, CA, F, G16-1/2, G-25, G30, S, or M-14 lamp (as defined in ANSI C79.1-2002 and ANSI C78.20-2003) of 40 watts or less.'; and

(B) by adding at the end the following:

`(T) APPLIANCE LAMP- The term `appliance lamp' means any lamp that--

`(i) is specifically designed to operate in a household appliance, has a maximum wattage of 40 watts, and is sold at retail, including an oven lamp, refrigerator lamp, and vacuum cleaner lamp; and

`(ii) is designated and marketed for the intended application, with--

`(I) the designation on the lamp packaging; and

`(II) marketing materials that identify the lamp as being for appliance use.

`(U) CANDELABRA BASE INCANDESCENT LAMP- The term `candelabra base incandescent lamp' means a lamp that uses candelabra screw base as described in ANSI C81.61-2006, Specifications for Electric Bases, common designations E11 and E12.

`(V) INTERMEDIATE BASE INCANDESCENT LAMP- The term `intermediate base incandescent lamp' means a lamp that uses an intermediate screw base as described in ANSI C81.61-2006, Specifications for Electric Bases, common designation E17.

`(W) MODIFIED SPECTRUM- The term `modified spectrum' means, with respect to an incandescent lamp, an incandescent lamp that--

`(i) is not a colored incandescent lamp; and

`(ii) when operated at the rated voltage and wattage of the incandescent lamp--

`(I) has a color point with (x,y) chromaticity coordinates on the Commission Internationale de l'Eclairage (C.I.E.) 1931 chromaticity diagram that lies below the black-body locus; and

`(II) has a color point with (x,y) chromaticity coordinates on the C.I.E. 1931 chromaticity diagram that lies at least 4 MacAdam steps (as referenced in IESNA LM16) distant from the color point of a clear lamp with the same filament and bulb shape, operated at the same rated voltage and wattage.

`(X) ROUGH SERVICE LAMP- The term `rough service lamp' means a lamp that--

`(i) has a minimum of 5 supports with filament configurations that are C-7A, C-11, C-17, and C-22 as listed in Figure 6-12 of the 9th edition of the IESNA Lighting handbook, or similar configurations where lead wires are not counted as supports; and

`(ii) is designated and marketed specifically for `rough service' applications, with--

`(I) the designation appearing on the lamp packaging; and

`(II) marketing materials that identify the lamp as being for rough service.

`(Y) 3-way incandescent lamp- The term `3-way incandescent lamp' includes an incandescent lamp that--

`(i) employs 2 filaments, operated separately and in combination, to provide 3 light levels; and

`(ii) is designated on the lamp packaging and marketing materials as being a 3-way incandescent lamp.

`(Z) SHATTER-RESISTANT LAMP, SHATTER-PROOF LAMP, OR SHATTER-PROTECTED LAMP- The terms `shatter-resistant lamp', `shatter-proof lamp', and `shatter-protected lamp' mean a lamp that--

`(i) has a coating or equivalent technology that is compliant with NSF/ANSI 51 and is designed to contain the glass if the glass envelope of the lamp is broken; and

`(ii) is designated and marketed for the intended application, with--

`(I) the designation on the lamp packaging; and

`(II) marketing materials that identify the lamp as being shatter-resistant, shatter-proof, or shatter-protected.

`(AA) VIBRATION SERVICE LAMP- The term `vibration service lamp' means a lamp that--

`(i) has filament configurations that are C-5, C-7A, or C-9, as listed in Figure 6-12 of the 9th Edition of the IESNA Lighting Handbook or similar configurations;

`(ii) has a maximum wattage of 60 watts;

`(iii) is sold at retail in packages of 2 lamps or less; and

`(iv) is designated and marketed specifically for vibration service or vibration-resistant applications, with--

`(I) the designation appearing on the lamp packaging; and

`(II) marketing materials that identify the lamp as being vibration service only.

`(BB) GENERAL SERVICE LAMP-

`(i) IN GENERAL- The term `general service lamp' includes--

`(I) general service incandescent lamps;

`(II) compact fluorescent lamps;

`(III) general service light-emitting diode (LED or OLED) lamps; and

`(IV) any other lamps that the Secretary determines are used to satisfy lighting applications traditionally served by general service incandescent lamps.

`(ii) EXCLUSIONS- The term `general service lamp' does not include--

`(I) any lighting application or bulb shape described in any of subclauses (I) through (XXII) of subparagraph (D)(ii); or

`(II) any general service fluorescent lamp or incandescent reflector lamp.

`(CC) LIGHT-EMITTING DIODE; LED-

`(i) IN GENERAL- The terms `light-emitting diode' and `LED' means a p-n junction solid state device the radiated output of which is a function of the physical construction, material used, and exciting current of the device.

`(ii) OUTPUT- The output of a light-emitting diode may be in--

`(I) the infrared region;

`(II) the visible region; or

`(III) the ultraviolet region.

`(DD) ORGANIC LIGHT-EMITTING DIODE; OLED- The terms `organic light-emitting diode' and `OLED' mean a thin-film light-emitting device that typically consists of a series of organic layers between 2 electrical contacts (electrodes).

`(EE) COLORED INCANDESCENT LAMP- The term `colored incandescent lamp' means an incandescent lamp designated and marketed as a colored lamp that has--

`(i) a color rendering index of less than 50, as determined according to the test method given in C.I.E. publication 13.3-1995; or

`(ii) a correlated color temperature of less than 2,500K, or greater than 4,600K, where correlated temperature is computed according to the Journal of Optical Society of America, Vol. 58, pages 1528-1595 (1986).'.

(2) COVERAGE- Section 322(a)(14) of the Energy Policy and Conservation Act (42 U.S.C. 6292(a)(14)) is amended by inserting `, general service incandescent lamps,' after `fluorescent lamps'.

(3) ENERGY CONSERVATION STANDARDS- Section 325 of the Energy Policy and Conservation Act (42 U.S.C. 6295) is amended--

(A) in subsection (i)--

(i) in the section heading, by inserting `, General Service Incandescent Lamps, Intermediate Base Incandescent Lamps, Candelabra Base Incandescent Lamps,' after `Fluorescent Lamps';

(ii) in paragraph (1)--

(I) in subparagraph (A)--

(aa) by inserting `, general service incandescent lamps, intermediate base incandescent lamps, candelabra base incandescent lamps,' after `fluorescent lamps';

(bb) by inserting `, new maximum wattage,' after `lamp efficacy'; and

(cc) by inserting after the table entitled `INCANDESCENT REFLECTOR LAMPS' the following:

`GENERAL SERVICE INCANDESCENT LAMPS

Rated Lumen Ranges	Maximum Rate Wattage	Minimum Rate Lifetime	Effective Date
1490-2600	72	1,000 hrs	1/1/2012
1050-1489	53	1,000 hrs	1/1/2013
750-1049	43	1,000 hrs	1/1/2014
310-749	29	1,000 hrs	1/1/2014

`MODIFIED SPECTRUM GENERAL SERVICE INCANDESCENT LAMPS

Rated Lumen Ranges	Maximum Rate Wattage	Minimum Rate Lifetime	Effective Date
1118-1950	72	1,000 hrs	1/1/2012
788-1117	53	1,000 hrs	1/1/2013
563-787	43	1,000 hrs	1/1/2014
232-562	29	1,000 hrs	1/1/2014';

and

(II) by striking subparagraph (B) and inserting the following:

`(B) APPLICATION-

`(i) APPLICATION CRITERIA- This subparagraph applies to each lamp that--

`(I) is intended for a general service or general illumination application (whether incandescent or not);

`(II) has a medium screw base or any other screw base not defined in ANSI C81.61-2006;

`(III) is capable of being operated at a voltage at least partially within the range of 110 to 130 volts; and

`(IV) is manufactured or imported after December 31, 2011.

`(ii) REQUIREMENT- For purposes of this paragraph, each lamp described in clause (i) shall have a color rendering index that is greater than or equal to--

`(I) 80 for nonmodified spectrum lamps; or

`(II) 75 for modified spectrum lamps.

`(C) CANDELABRA INCANDESCENT LAMPS AND INTERMEDIATE BASE INCANDESCENT LAMPS-

`(i) CANDELABRA BASE INCANDESCENT LAMPS- A candelabra base incandescent lamp shall not exceed 60 rated watts.

`(ii) INTERMEDIATE BASE INCANDESCENT LAMPS- An intermediate base incandescent lamp shall not exceed 40 rated watts.

`(D) EXEMPTIONS-

`(i) PETITION- Any person may petition the Secretary for an exemption for a type of general service lamp from the requirements of this subsection.

`(ii) CRITERIA- The Secretary may grant an exemption under clause (i) only to the extent that the Secretary finds, after a hearing and opportunity for public comment, that it is not technically feasible to serve a specialized lighting application (such as a military, medical, public safety, or certified historic lighting application) using a lamp that meets the requirements of this subsection.

`(iii) ADDITIONAL CRITERION- To grant an exemption for a product under this subparagraph, the Secretary shall include, as an additional criterion, that the exempted product is unlikely to be used in a general service lighting application.

`(E) EXTENSION OF COVERAGE-

`(i) PETITION- Any person may petition the Secretary to establish standards for lamp shapes or bases that are excluded from the definition of general service lamps.

`(ii) INCREASED SALES OF EXEMPTED LAMPS- The petition shall include evidence that the availability or sales of exempted incandescent lamps have increased significantly since the date on which the standards on general service incandescent lamps were established.

`(iii) CRITERIA- The Secretary shall grant a petition under clause (i) if the Secretary finds that--

`(I) the petition presents evidence that demonstrates that commercial availability or sales of exempted incandescent lamp types have increased significantly since the standards on general service lamps were established and likely are being widely used in general lighting applications; and

`(II) significant energy savings could be achieved by covering exempted products, as determined by the Secretary based on sales data provided to the Secretary from manufacturers and importers.

`(iv) NO PRESUMPTION- The grant of a petition under this subparagraph shall create no presumption with respect to the determination of the Secretary with respect to any criteria under a rulemaking conducted under this section.

`(v) EXPEDITED PROCEEDING- If the Secretary grants a petition for a lamp shape or base under this subparagraph, the Secretary shall--

`(I) conduct a rulemaking to determine standards for the exempted lamp shape or base; and

`(II) complete the rulemaking not later than 18 months after the date on which notice is provided granting the petition.

`(F) DEFINITION OF EFFECTIVE DATE- In this paragraph, except as otherwise provided in a table contained in subparagraph (A), the term `effective date' means the last day of the month specified in the table that follows October 24, 1992.';

(iii) in paragraph (5), in the first sentence, by striking `and general service incandescent lamps';

(iv) by redesignating paragraphs (6) and (7) as paragraphs (7) and (8), respectively; and

(v) by inserting after paragraph (5) the following:

`(6) STANDARDS FOR GENERAL SERVICE LAMPS-

`(A) RULEMAKING BEFORE JANUARY 1, 2014-

`(i) IN GENERAL- Not later than January 1, 2014, the Secretary shall initiate a rulemaking procedure to determine whether--

`(I) standards in effect for general service lamps should be amended to establish more stringent standards than the standards specified in paragraph (1)(A); and

`(II) the exemptions for certain incandescent lamps should be maintained or discontinued based, in part, on exempted lamp sales collected by the Secretary from manufacturers.

`(ii) SCOPE- The rulemaking--

`(I) shall not be limited to incandescent lamp technologies; and

`(II) shall include consideration of a minimum standard of 45 lumens per watt for general service lamps.

`(iii) AMENDED STANDARDS- If the Secretary determines that the standards in effect for general service incandescent lamps should be amended, the Secretary shall publish a final rule not later than January 1, 2017, with an effective date that is not earlier than 3 years after the date on which the final rule is published.

`(iv) PHASED-IN EFFECTIVE DATES- The Secretary shall consider phased-in effective dates under this subparagraph after considering--

`(I) the impact of any amendment on manufacturers, retiring and repurposing existing equipment, stranded investments, labor contracts, workers, and raw materials; and

`(II) the time needed to work with retailers and lighting designers to revise sales and marketing strategies.

`(v) BACKSTOP REQUIREMENT- If the Secretary fails to complete a rulemaking in accordance with clauses (i) through (iv) or if the final rule does not produce savings that are greater than or equal to the savings from a minimum efficacy standard of 45 lumens per watt, effective beginning January 1, 2020, the Secretary shall prohibit the sale of any general service lamp that does not meet a minimum efficacy standard of 45 lumens per watt.

`(vi) STATE PREEMPTION- Neither section 327(b) nor any other provision of law shall preclude California or Nevada from adopting, effective beginning on or after January 1, 2018--

`(I) a final rule adopted by the Secretary in accordance with clauses (i) through (iv);

`(II) if a final rule described in subclause (I) has not been adopted, the backstop requirement under clause (v); or

`(III) in the case of California, if a final rule described in subclause (I) has not been adopted, any California regulations relating to these covered products adopted pursuant to State statute in effect as of the date of enactment of the Energy Independence and Security Act of 2007.

`(B) RULEMAKING BEFORE JANUARY 1, 2020-

`(i) IN GENERAL- Not later than January 1, 2020, the Secretary shall initiate a rulemaking procedure to determine whether--

`(I) standards in effect for general service incandescent lamps should be amended to reflect lumen ranges with more stringent maximum wattage than the standards specified in paragraph (1)(A); and

`(II) the exemptions for certain incandescent lamps should be maintained or discontinued based, in part, on exempted lamp sales data collected by the Secretary from manufacturers.

`(ii) SCOPE- The rulemaking shall not be limited to incandescent lamp technologies.

`(iii) AMENDED STANDARDS- If the Secretary determines that the standards in effect for general service incandescent lamps should be amended, the Secretary shall publish a final rule not later than January 1, 2022, with an effective date that is not earlier than 3 years after the date on which the final rule is published.

`(iv) PHASED-IN EFFECTIVE DATES- The Secretary shall consider phased-in effective dates under this subparagraph after considering--

`(I) the impact of any amendment on manufacturers, retiring and repurposing existing equipment, stranded investments, labor contracts, workers, and raw materials; and

`(II) the time needed to work with retailers and lighting designers to revise sales and marketing strategies.'; and(B) in subsection (l), by adding at the end the following:

`(4) ENERGY EFFICIENCY STANDARDS FOR CERTAIN LAMPS-

`(A) IN GENERAL- The Secretary shall prescribe an energy efficiency standard for rough service lamps, vibration service lamps, 3-way incandescent lamps, 2,601-3,300 lumen general service incandescent lamps, and shatter-resistant lamps only in accordance with this paragraph.

`(B) BENCHMARKS- Not later than 1 year after the date of enactment of this paragraph, the Secretary, in consultation with the National Electrical Manufacturers Association, shall-

`(i) collect actual data for United States unit sales for each of calendar years 1990 through 2006 for each of the 5 types of lamps described in subparagraph (A) to determine the historical growth rate of the type of lamp; and

`(ii) construct a model for each type of lamp based on coincident economic indicators that closely match the historical annual growth rate of the type of lamp to provide a neutral comparison benchmark to model future unit sales after calendar year 2006.

`(C) ACTUAL SALES DATA-

`(i) IN GENERAL- Effective for each of calendar years 2010 through 2025, the Secretary, in consultation with the National Electrical Manufacturers Association, shall--

`(I) collect actual United States unit sales data for each of 5 types of lamps described in subparagraph (A); and

`(II) not later than 90 days after the end of each calendar year, compare the lamp sales in that year with the sales predicted by the comparison benchmark for each of the 5 types of lamps described in subparagraph (A).

`(ii) CONTINUATION OF TRACKING-

`(I) DETERMINATION- Not later than January 1, 2023, the Secretary shall determine if actual sales data should be tracked for the lamp types described in subparagraph (A) after calendar year 2025.

`(II) CONTINUATION- If the Secretary finds that the market share of a lamp type described in subparagraph (A) could significantly erode the market share for general service lamps, the Secretary shall continue to track the actual sales data for the lamp type.

`(D) ROUGH SERVICE LAMPS-

`(i) IN GENERAL- Effective beginning with the first year that the reported annual sales rate for rough service lamps demonstrates actual unit sales of rough service lamps that achieve levels that are at least 100 percent higher than modeled unit sales for that same year, the Secretary shall--

`(I) not later than 90 days after the end of the previous calendar year, issue a finding that the index has been exceeded; and

`(II) not later than the date that is 1 year after the end of the previous calendar year, complete an accelerated rulemaking to establish an energy conservation standard for rough service lamps.

`(ii) BACKSTOP REQUIREMENT- If the Secretary fails to complete an accelerated rulemaking in accordance with clause (i)(II), effective beginning 1 year after the date of the issuance of the finding under clause (i)(I), the Secretary shall require rough service lamps to--

`(I) have a shatter-proof coating or equivalent technology that is compliant with NSF/ANSI 51 and is designed to contain the glass if the glass envelope of the lamp is broken and to provide effective containment over the life of the lamp;

`(II) have a maximum 40-watt limitation; and

`(III) be sold at retail only in a package containing 1 lamp.

`(E) VIBRATION SERVICE LAMPS-

`(i) IN GENERAL- Effective beginning with the first year that the reported annual sales rate for vibration service lamps demonstrates actual unit sales of vibration service lamps that achieve levels that are at least 100 percent higher than modeled unit sales for that same year, the Secretary shall--

`(I) not later than 90 days after the end of the previous calendar year, issue a finding that the index has been exceeded; and

`(II) not later than the date that is 1 year after the end of the previous calendar year, complete an accelerated rulemaking to establish an energy conservation standard for vibration service lamps.

`(ii) BACKSTOP REQUIREMENT- If the Secretary fails to complete an accelerated rulemaking in accordance with clause (i)(II), effective beginning 1 year after the date of the issuance of the finding under clause (i)(I), the Secretary shall require vibration service lamps to--

`(I) have a maximum 40-watt limitation; and

`(II) be sold at retail only in a package containing 1 lamp.

`(F) 3-way incandescent lamps-

`(i) IN GENERAL- Effective beginning with the first year that the reported annual sales rate for 3-way incandescent lamps demonstrates actual unit sales of 3-

way incandescent lamps that achieve levels that are at least 100 percent higher than modeled unit sales for that same year, the Secretary shall--

`(I) not later than 90 days after the end of the previous calendar year, issue a finding that the index has been exceeded; and

`(II) not later than the date that is 1 year after the end of the previous calendar year, complete an accelerated rulemaking to establish an energy conservation standard for 3-way incandescent lamps.

`(ii) BACKSTOP REQUIREMENT- If the Secretary fails to complete an accelerated rulemaking in accordance with clause (i)(II), effective beginning 1 year after the date of issuance of the finding under clause (i)(I), the Secretary shall require that--

`(I) each filament in a 3-way incandescent lamp meet the new maximum wattage requirements for the respective lumen range established under subsection (i)(1)(A); and

`(II) 3-way lamps be sold at retail only in a package containing 1 lamp.

`(G) 2,601-3,300 lumen general service incandescent lamps- Effective beginning with the first year that the reported annual sales rate demonstrates actual unit sales of 2,601-3,300 lumen general service incandescent lamps in the lumen range of 2,601 through 3,300 lumens (or, in the case of a modified spectrum, in the lumen range of 1,951 through 2,475 lumens) that achieve levels that are at least 100 percent higher than modeled unit sales for that same year, the Secretary shall impose--

`(i) a maximum 95-watt limitation on general service incandescent lamps in the lumen range of 2,601 through 3,300 lumens; and

`(ii) a requirement that those lamps be sold at retail only in a package containing 1 lamp.

`(H) SHATTER-RESISTANT LAMPS-

`(i) IN GENERAL- Effective beginning with the first year that the reported annual sales rate for shatter-resistant lamps demonstrates actual unit sales of shatter-resistant lamps that achieve levels that are at least 100 percent higher than modeled unit sales for that same year, the Secretary shall--

`(I) not later than 90 days after the end of the previous calendar year, issue a finding that the index has been exceeded; and

`(II) not later than the date that is 1 year after the end of the previous calendar year, complete an accelerated rulemaking to establish an energy conservation standard for shatter-resistant lamps.

`(ii) BACKSTOP REQUIREMENT- If the Secretary fails to complete an accelerated rulemaking in accordance with clause (i)(II), effective beginning 1 year after the date of issuance of the finding under clause (i)(I), the Secretary shall impose--

`(I) a maximum wattage limitation of 40 watts on shatter resistant lamps; and

`(II) a requirement that those lamps be sold at retail only in a package containing 1 lamp.

`(I) RULEMAKINGS BEFORE JANUARY 1, 2025-

`(i) IN GENERAL- Except as provided in clause (ii), if the Secretary issues a final rule prior to January 1, 2025, establishing an energy conservation standard for any of the 5 types of lamps for which data collection is required under any of subparagraphs (D) through (G), the requirement to collect and model data for that type of lamp shall terminate unless, as part of the rulemaking, the Secretary determines that continued tracking is necessary.

`(ii) BACKSTOP REQUIREMENT- If the Secretary imposes a backstop requirement as a result of a failure to complete an accelerated rulemaking in accordance with clause (i)(II) of any of subparagraphs (D) through (G), the requirement to collect and model data for the applicable type of lamp shall continue for an additional 2 years after the effective date of the backstop requirement.'.

(b) Consumer Education and Lamp Labeling- Section 324(a)(2)(C) of the Energy Policy and Conservation Act (42 U.S.C. 6294(a)(2)(C)) is amended by adding at the end the following:

`(iii) RULEMAKING TO CONSIDER EFFECTIVENESS OF LAMP LABELING-

`(I) IN GENERAL- Not later than 1 year after the date of enactment of this clause, the Commission shall initiate a rulemaking to consider--

`(aa) the effectiveness of current lamp labeling for power levels or watts, light output or lumens, and lamp lifetime; and

`(bb) alternative labeling approaches that will help consumers to understand new high-efficiency lamp products and to base the purchase decisions of the consumers on the most appropriate source that meets the requirements of the consumers for lighting level, light quality, lamp lifetime, and total lifecycle cost.

(II) COMPLETION- The Commission shall--

`(aa) complete the rulemaking not later than the date that is 30 months after the date of enactment of this clause; and

`(bb) consider reopening the rulemaking not later than 180 days before the effective dates of the standards for general service incandescent lamps established under section 325(i)(1)(A), if the Commission determines that further labeling changes are needed to help consumers understand lamp alternatives.'.

(c) Market Assessments and Consumer Awareness Program-

(1) IN GENERAL- In cooperation with the Administrator of the Environmental Protection Agency, the Secretary of Commerce, the Federal Trade Commission, lighting and retail industry associations, energy efficiency organizations, and any other entities that the Secretary of Energy determines to be appropriate, the Secretary of Energy shall--

(A) conduct an annual assessment of the market for general service lamps and compact fluorescent lamps--

(i) to identify trends in the market shares of lamp types, efficiencies, and light output levels purchased by residential and nonresidential consumers; and

(ii) to better understand the degree to which consumer decisionmaking is based on lamp power levels or watts, light output or lumens, lamp lifetime, and other factors, including information required on labels mandated by the Federal Trade Commission;

(B) provide the results of the market assessment to the Federal Trade Commission for consideration in the rulemaking described in section 324(a)(2)(C)(iii) of the Energy Policy and Conservation Act (42 U.S.C. 6294(a)(2)(C)(iii)); and

(C) in cooperation with industry trade associations, lighting industry members, utilities, and other interested parties, carry out a proactive national program of consumer awareness, information, and education that broadly uses the media and other effective communication techniques over an extended period of time to help consumers understand the lamp labels and make energy-efficient lighting choices that meet the needs of consumers.

(2) AUTHORIZATION OF APPROPRIATIONS- There is authorized to be appropriated to carry out this subsection $10,000,000 for each of fiscal years 2009 through 2012.

(d) General Rule of Preemption for Energy Conservation Standards Before

Federal Standard Becomes Effective for a Product- Section 327(b)(1) of the Energy Policy and Conservation Act (42 U.S.C. 6297(b)(1)) is amended--

(1) by inserting `(A)' after `(1)';

(2) by inserting `or' after the semicolon at the end; and

(3) by adding at the end the following:

`(B) in the case of any portion of any regulation that establishes requirements for general service incandescent lamps, intermediate base incandescent lamps, or candelabra base lamps, was enacted or adopted by the State of California or Nevada before December 4, 2007, except that--

`(i) the regulation adopted by the California Energy Commission with an effective date of January 1, 2008, shall only be effective until the effective date of the Federal standard for the applicable lamp category under subparagraphs (A), (B), and (C) of section 325(i)(1);

`(ii) the States of California and Nevada may, at any time, modify or adopt a State standard for general service lamps to conform with Federal standards with effective dates no earlier than 12 months prior to the Federal effective dates prescribed under subparagraphs (A), (B), and (C) of section 325(i)(1), at which time any prior regulations adopted by the State of California or Nevada shall no longer be effective; and

`(iii) all other States may, at any time, modify or adopt a State standard for general service lamps to conform with Federal standards and effective dates.'.

(e) Prohibited Acts- Section 332(a) of the Energy Policy and Conservation Act (42 U.S.C. 6302(a)) is amended--

(1) in paragraph (4), by striking `or' at the end;

(2) in paragraph (5), by striking the period at the end and inserting `; or'; and

(3) by adding at the end the following:

`(6) for any manufacturer, distributor, retailer, or private labeler to distribute in commerce an adapter that--

`(A) is designed to allow an incandescent lamp that does not have a medium screw base to be installed into a fixture or lampholder with a medium screw base socket; and

`(B) is capable of being operated at a voltage range at least partially within 110 and 130 volts.'.

(f) Enforcement- Section 334 of the Energy Policy and Conservation Act (42 U.S.C. 6304) is amended by inserting after the second sentence the following: `Any such action to restrain any person from distributing in commerce a general service incandescent lamp that does not comply with the applicable standard established under section 325(i) or an adapter prohibited under section 332(a)(6) may also be brought by the attorney general of a State in the name of the State.'.

(g) Research and Development Program-

(1) IN GENERAL- The Secretary may carry out a lighting technology research and development program--

(A) to support the research, development, demonstration, and commercial application of lamps and related technologies sold, offered for sale, or otherwise made available in the United States; and

(B) to assist manufacturers of general service lamps in the manufacturing of general service lamps that, at a minimum, achieve the wattage requirements imposed as a result of the amendments made by subsection (a).

(2) AUTHORIZATION OF APPROPRIATIONS- There are authorized to be appropriated to carry out this subsection $10,000,000 for each of fiscal years 2008 through 2013.

(3) TERMINATION OF AUTHORITY- The program under this subsection shall terminate on September 30, 2015.

(h) Reports to Congress-

(1) REPORT ON MERCURY USE AND RELEASE- Not later than 1 year after the date of enactment of this Act, the Secretary, in cooperation with the Administrator of the Environmental Protection Agency, shall submit to Congress a report describing recommendations relating to the means by which the Federal Government may reduce or prevent the release of mercury during the manufacture, transportation, storage, or disposal of light bulbs.

(2) REPORT ON RULEMAKING SCHEDULE- Beginning on July 1, 2013, and semiannually through July 1, 2016, the Secretary shall submit to the Committee on Energy and Commerce of the House of Representatives and the Committee on Energy and Natural Resources of the Senate a report on--

(A) whether the Secretary will meet the deadlines for the rulemakings required under this section;

(B) a description of any impediments to meeting the deadlines; and

(C) a specific plan to remedy any failures, including recommendations for additional legislation or resources.

(3) NATIONAL ACADEMY REVIEW-

(A) IN GENERAL- Not later than December 31, 2009, the Secretary shall enter into an arrangement with the National Academy of Sciences to provide a report by December 31, 2013, and an updated report by July 31, 2015. The report should include-

(i) the status of advanced solid state lighting research, development, demonstration and commercialization;

(ii) the impact on the types of lighting available to consumers of an energy conservation standard requiring a minimum of 45 lumens per watt for general service lighting effective in 2020; and

(iii) the time frame for the commercialization of lighting that could replace current incandescent and halogen incandescent lamp technology and any other new technologies developed to meet the minimum standards required under subsection (a)(3) of this section.

(B) REPORTS- The reports shall be transmitted to the Committee on Energy and Commerce of the House of Representatives and the Committee on Energy and Natural Resources of the Senate.

Subtitle E: Miscellaneous Provisions

Sec. 655. Bright Tomorrow Lighting Prizes

(a) Establishment- Not later than 1 year after the date of enactment of this Act, as part of the program carried out under section 1008 of the Energy Policy Act of 2005 (42 U.S.C. 16396), the Secretary shall establish and award Bright Tomorrow Lighting Prizes for solid state lighting in accordance with this section.

(b) Prize Specifications-

(1) 60-WATT INCANDESCENT REPLACEMENT LAMP PRIZE - The Secretary shall award a 60-Watt Incandescent Replacement Lamp Prize to an entrant that produces a solid-state-light package simultaneously capable of--

(A) producing a luminous flux greater than 900 lumens;
(B) consuming less than or equal to 10 watts;
(C) having an efficiency greater than 90 lumens per watt;
(D) having a color rendering index greater than 90;
(E) having a correlated color temperature of not less than 2,750, and not more than 3,000, degrees Kelvin;
(F) having 70 percent of the lumen value under subparagraph (A) exceeding 25,000 hours under typical conditions expected in residential use;
(G) having a light distribution pattern similar to a soft 60-watt incandescent A19 bulb;
(H) having a size and shape that fits within the maximum dimensions of an A19 bulb in accordance with American National Standards Institute standard C78.20-2003, figure C78.20-211;
(I) using a single contact medium screw socket; and
(J) mass production for a competitive sales commercial market satisfied by producing commercially accepted quality control lots of such units equal to or exceeding the criteria described in subparagraphs (A) through (I).

(2) PAR TYPE 38 HALOGEN REPLACEMENT LAMP PRIZE- The Secretary shall award a Parabolic Aluminized Reflector Type 38 Halogen Replacement Lamp Prize (referred to in this section as the `PAR Type 38 Halogen Replacement Lamp Prize') to an entrant that produces a solid-state-light package simultaneously capable of--

(A) producing a luminous flux greater than or equal to 1,350

lumens;
(B) consuming less than or equal to 11 watts;
(C) having an efficiency greater than 123 lumens per watt;
(D) having a color rendering index greater than or equal to 90;
(E) having a correlated color coordinate temperature of not less than 2,750, and not more than 3,000, degrees Kelvin;
(F) having 70 percent of the lumen value under subparagraph (A) exceeding 25,000 hours under typical conditions expected in residential use;
(G) having a light distribution pattern similar to a PAR 38 halogen lamp;
(H) having a size and shape that fits within the maximum dimensions of a PAR 38 halogen lamp in accordance with American National Standards Institute standard C78-21-2003, figure C78.21-238;
(I) using a single contact medium screw socket; and
(J) mass production for a competitive sales commercial market satisfied by producing commercially accepted quality control lots of such units equal to or exceeding the criteria described in subparagraphs (A) through (I).

(3) TWENTY-FIRST CENTURY LAMP PRIZE- The Secretary shall award a Twenty-First Century Lamp Prize to an entrant that produces a solid-state-light-light capable of--
(A) producing a light output greater than 1,200 lumens;
(B) having an efficiency greater than 150 lumens per watt;
(C) having a color rendering index greater than 90;
(D) having a color coordinate temperature between 2,800 and 3,000 degrees Kelvin; and
(E) having a lifetime exceeding 25,000 hours.

(c) Private Funds-
(1) IN GENERAL- Subject to paragraph (2), and notwithstanding section 3302 of title 31, United States Code, the Secretary may accept, retain, and use funds contributed by any person, government entity, or organization for purposes of carrying out this subsection--
(A) without further appropriation; and
(B) without fiscal year limitation.
(2) PRIZE COMPETITION- A private source of funding may not participate in the competition for prizes awarded under this section.

(d) Technical Review- The Secretary shall establish a technical review committee composed of non-Federal officers to review entrant data submitted under this section to determine whether the data meets the prize specifications described in subsection (b).

(e) Third Party Administration- The Secretary may competitively select a third party to administer awards under this section.

(f) Eligibility for Prizes- To be eligible to be awarded a prize under this section--
(1) in the case of a private entity, the entity shall be incorporated in and

maintain a primary place of business in the United States; and

(2) in the case of an individual (whether participating as a single individual or in a group), the individual shall be a citizen or lawful permanent resident of the United States.

(g) Award Amounts- Subject to the availability of funds to carry out this section, the amount of--

(1) the 60-Watt Incandescent Replacement Lamp Prize described in subsection (b)(1) shall be $10,000,000;

(2) the PAR Type 38 Halogen Replacement Lamp Prize described in subsection (b)(2) shall be $5,000,000; and

(3) the Twenty-First Century Lamp Prize described in subsection (b)(3) shall be $5,000,000.

(h) Federal Procurement of Solid-State-Lights-

(1) 60-watt incandescent replacement- Subject to paragraph (3), as soon as practicable after the successful award of the 60-Watt Incandescent Replacement Lamp Prize under subsection (b)(1), the Secretary (in consultation with the Administrator of General Services) shall develop government wide Federal purchase guidelines with a goal of replacing the use of 60-watt incandescent lamps in Federal Government buildings with a solid-state-light package described in subsection (b)(1) by not later than the date that is 5 years after the date the award is made.

(2) PAR 38 HALOGEN REPLACEMENT LAMP REPLACEMENT- Subject to paragraph (3), as soon as practicable after the successful award of the PAR Type 38 Halogen Replacement Lamp Prize under subsection (b)(2), the Secretary (in consultation with the Administrator of General Services) shall develop governmentwide Federal purchase guidelines with the goal of replacing the use of PAR 38 halogen lamps in Federal Government buildings with a solid-state-light package described in subsection (b)(2) by not later than the date that is 5 years after the date the award is made.

(3) WAIVERS-

(A) IN GENERAL- The Secretary or the Administrator of General Services may waive the application of paragraph (1) or (2) if the Secretary or Administrator determines that the return on investment from the purchase of a solid-state-light package described in paragraph (1) or (2) of subsection (b), respectively, is cost prohibitive.

(B) REPORT OF WAIVER- If the Secretary or Administrator waives the application of paragraph (1) or (2), the Secretary or Administrator, respectively, shall submit to Congress an annual report that describes the waiver and provides a detailed justification for the waiver.

(i) Report- Not later than 2 years after the date of enactment of this Act, and annually thereafter, the Administrator of General Services shall submit to the Energy Information Agency a report describing the quantity, type, and cost of each lighting product purchased by the Federal Government.

(j) Bright Tomorrow Lighting Award Fund-

(1) ESTABLISHMENT- There is established in the United States Treasury a Bright Tomorrow Lighting permanent fund without fiscal year limitation to award prizes under paragraphs (1), (2), and (3) of subsection (b).

(2) SOURCES OF FUNDING- The fund established under paragraph (1) shall accept--

(A) fiscal year appropriations; and

(B) private contributions authorized under subsection (c).

(k) Authorization of Appropriations- There are authorized to be appropriated such sums as are necessary to carry out this section.