Multi-Year Program Plan FY'08-FY'13

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.
and
Radcliffe Advisors

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DISCLAIMER

ACKNOWLEDGEMENTS

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Mark McClear	Cree, Inc.
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COMMENTS

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The March 2007 edition of the Multi-Year Program Plan updates the March 2006 edition. Updates were primarily made to Section 3.0, 4.0, and 5.0.

1.0 Introduction

President Bush's National Energy Policy (NEP) calls for "reliable, affordable, and environmentally sound energy for America's future." In order to achieve this vision, the President's plan has defined several objectives including increasing energy conservation, relieving congestion on the Nation's electricity transmission and distribution systems, and establishing a national priority for improving energy efficiency and protecting our environment.[1]

> ***"America must have an energy policy that plans for the future, but meets the needs of today. I believe we can develop our natural resources and protect our environment."***
>
> George W. Bush
> President

The implementation of the President's NEP is a top priority for the Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE). Because the NEP specifically calls for improvements in the energy efficiency of residential and commercial buildings and of energy-using equipment in these buildings, the EERE's Building Technologies Program plays a critical role in achieving this mission.

> ***"We believe a set of revolutionary new technologies called solid-state lighting offer excellent prospects for meeting our future lighting needs in a less costly, more efficient way than today's incandescent and even fluorescent fixtures. We at the Department of Energy want to see it fully developed as quickly as possible."***
>
> Dr. Samuel Bodman
> Secretary of Energy

While announcing the selection of Sandia National Laboratories as the new home for the National Laboratory Center for Solid State Lighting R&D, Dr. Samuel Bodman, Secretary of Energy, noted that eighteen percent of all US energy generated, goes to lighting homes, offices, and factories. According to Secretary Bodman, supporting solid state lighting will help the nation meet its lighting needs in a more energy efficient manner.[2]

No other lighting technology offers the Department and our nation so much potential to save energy and enhance the quality of our building environments. The Department 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.*

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[1] National Energy Policy, May 2001. Available at: http://www.whitehouse.gov/energy/National-Energy-Policy.pdf.

[2] "DOE Selects Sandia as National Laboratory Center for SSL R&D." LED Journal: The Magazine of Solid-State Lighting. Jan.-Feb. 2007:4.

1.1. Significant SSL Program Accomplishments to Date

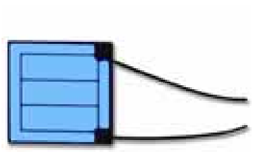
The U.S. Department of Energy (DOE) initiated its work in solid-state lighting (SSL) research and development in 2000. In this short time frame, DOE researchers have made considerable progress. In the course of their research, performers supported by the DOE SSL portfolio have won several prestigious 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:

- November 2003. Two research partners, Dr. George Craford of Lumileds Lighting and Professor Russell Dupuis of the Georgia Institute of Technology, were awarded the National Medal of Technology by the President.
- 2004. Lumileds Lighting teamed with Sandia National Laboratories to develop semiconductor nanoparticles ("quantum dots") with a quantum efficiency of 76 percent.
- March 2004. General Electric Global Research teamed with Cambridge Display Technologies to develop an OLED light panel that produces 1200 lumens of white light at 15 lumens per Watt at a color rendering index greater than 94.
- May 2004. Universal Display Corporation teamed with Princeton University and the University of Southern California to develop low-voltage, high-efficiency white phosphorescent OLEDs that achieved a record 20 lumens per Watt.
- July 2004. Sandia National Laboratories received an R&D 100 Award from R&D magazine for development of a new process for growing gallium nitride on an etched sapphire substrate.
- August 2005. Universal Display Corporation reported a prototype OLED panel with a power efficiency of 30 lm/W, a color temperature of 4000K and a color rendering index greater than 80. Emitting white-light at 3700K, the panel emits 150 lumens at 15 lm/W.
- September 2005. CREE Inc. announced achieving 70 lumens per Watt with their XLamp 7090 white LED at 350 mA on September 2, 2005. This represents a 43 percent increase in brightness compared with the maximum luminous flux of white XLamp 7090 power LEDs currently in production.
- November 2005. OSRAM Opto-Semiconductors, Inc. demonstrated a polymer-based white OLED with a record efficiency of 25 lm/W. The white light emission was produced by applying a standard orange inorganic phosphor to a blue light device.
- July 2006. CREE Inc. fabricated a cool white LED array prototype with luminous efficacy of 79 lm/W, exceeding the DOE FY06 Joule target. Cree's prototype uses an array of several high-power, large-area chips to produce sufficient light for practical application in the general illumination market.
- August 2006. UDC achieved a record 30% external quantum efficiency for a white organic light emitting diode (OLED). The device operates at 850 nits with

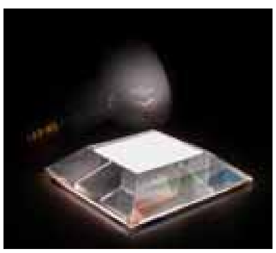
an efficacy value of 30 lm/W, and color rendering index (CRI) of 70.

- November 2006. PNNL achieved a record of 11% external quantum efficiency for a blue OLED at 800 nits. This value exceeds the previous 5% record.
- August 2006. UCSB achieved a record brightness of 25,000 nits in a solution fabricated blue-green OLED. This achievement is the highest ever reported for this approach to producing a blue emitting device.

Research highlights from FY'06 are described below.



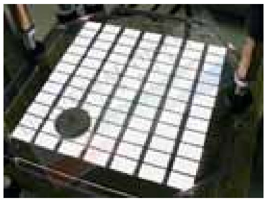
Cree LED Array Prototype Exceeds DOE FY06 Joule Target. In July, researchers at Cree Inc. fabricated a cool white LED array prototype with luminous efficacy of 79 lm/W, exceeding the DOE FY06 Joule target. Cree's prototype uses an array of several high-power, large-area chips to produce sufficient light for practical application in the general illumination market. The goal of this research program is to develop a luminaire suitable for low-cost use in existing commercial and residential lighting fixtures. Further improvements to the prototype efficacy and performance are under way.



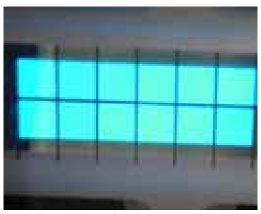
Cree releases new EZBright™ power chip for general lighting applications. Another Cree project resulted in a new high performance LED chip on the market. Cree's new EZBright1000 LED power chip, released in September 2006, delivers high efficiency, low emission losses, and twice the brightness of Cree's current power chips. Measured as a bare die, the new blue power chip delivers up to 370mW at 350mA drive current, and up to 800mW at 1A. The chips are designed for general lighting applications such as home and office lighting, streetlights, and garage and warehouse low-bay lighting.

UDC achieves record quantum efficiency in a white OLED. Universal Display Corporation (UDC) achieved a new record external quantum efficiency (EQE) of 30% for a white OLED device operating at 850 nits (roughly equivalent to an incandescent light). The UDC team employed various novel design strategies, including microlens arrays and aperiodic gratings, to improve the light extraction for white phosphorescent OLEDs. As a result, UDC was able to obtain efficacy values of 30 lm/W, with a color rendering index (CRI) of 70.

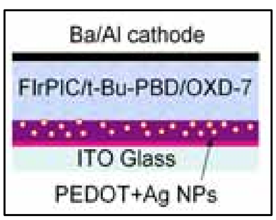
UDC team explores another pathway to produce high-brightness, low-voltage OLED devices. Researchers at UDC have also successfully demonstrated a white OLED light panel that achieved 25 lm/W at 850 cd/m2, with a CRI of 70. The device efficacy obtained corresponds to an external quantum efficiency of 27%, exceeding the project target of 25%. This achievement was accomplished by combining novel low-voltage dopants, highly efficient phosphorescent OLED emission layers, and a stacked phosphorescent OLED architecture.



USC team develops novel approach to increase OLED device efficiency. Researchers from the University of Southern California, University of Michigan, and Universal Display Corporation are exploring another innovative approach to increase OLED device efficiency. This team has created a white OLED device that employs a novel combination of blue fluorescent and red and green phosphorescent dopants, overcoming many of the shortcomings of standard OLEDs such as short lifetime and poor color stability. The device has demonstrated an efficiency of 24 lm/W, which is 50% more efficient than a standard incandescent light bulb and 20% more efficient than the team's previous record OLED. Further developments will lead to additional improvements in efficiency and device lifetime.



PNNL researchers achieve record efficiency in a blue OLED device. Scientists at Pacific Northwest National Laboratory (PNNL) have created a blue OLED device with an external quantum efficiency (EQE) of 11% at 800 cd/m^2, exceeding their previous record EQE of 5%. This achievement is particularly notable since it was achieved at much lower operating voltage than previous demonstrations, revealing the potential for much higher power efficiencies. The PNNL team has designed a new way to build molecular structures from small fragments, which successfully combines the optical properties of small, blue emitting molecules with the thin film properties of larger molecules. This breakthrough will enable an entire new class of improved efficiency OLED devices appropriate for SSL.



UCSB demonstrate high-brightness OLED device. Researchers at the University of California, Santa Barbara (UCSB), achieved a record brightness of 25,000 cd/m^2 in a solution fabricated blue-green organic light emitting diode (OLED) device capable of operation at increased current densities. This achievement is the highest ever reported for this approach to producing a blue emitting device, and underscores the significant potential for this approach to enhancing the performance of phosphorescent OLEDs.

During FY06, several significant events also occurred that will impact future planning and direction for DOE's SSL portfolio.

February 2006 – DOE SSL Program Planning Workshop

In February 2006, more than 180 experts from industry, academia, research organizations, and national laboratories gathered in Orlando for the DOE SSL Program Planning Workshop. This annual workshop provides an open forum for sharing information and updates, forging partnerships, and seeking stakeholder input to guide DOE planning. The workshop included:

- Reports on fundamental research projects related to SSL, conducted by the DOE Basic Energy Sciences (BES) Program
- Progress updates on DOE-funded SSL projects

- Discussion of DOE commercialization support activities under way, including an overview of the proposed approach and schedule for DOE's SSL ENERGY STAR program.

May 2006 – BES Workshop Identifies Key Areas of Focus for Basic Research- DOE hosted another workshop to focus specifically on basic research needs for solid-state lighting (SSL). Scientists from leading universities and national laboratories gathered to identify 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 provided additional guidance for DOE program planning.

July 2006- DOE signed a Memorandum of Understanding (MOU) with the Illuminating Engineering Society of North America (IESNA), designed to strengthen their ongoing partnership and commitment to improve the efficient use of energy and develop standards with a strong energy efficiency focus. In the MOU, DOE and IESNA agree to collaborate on development of appropriate IESNA standards that support DOE programs related to building energy codes, standards, and SSL. The MOU also outlines goals to develop guides and procedures to assist the lighting measurement and application community in the photometric measurement of SSL devices and other technologies, and to develop and maintain standards that include energy-conservation strategies.

A full version of the MOU with the IESNA can be found in Appendix F.

DOE Issues Eight Competitive Solicitations Related to SSL
During FY06, DOE issued eight competitive solicitations related to SSL:

- Core Technology Research, Round II
- Product Development, Round II
- Core Technology Research, Round III
- Product Development, Round III (this solicitation also included funding for the establishment of a technical information network among energy efficiency program sponsors and organizations, designed to share technology updates)
- National Laboratory Call for the National Laboratory Center for Solid-State Lighting R&D
- National Laboratory Call for Core Technology Research in Nanotechnology
- Small Business Innovation Research, Phase I
- Small Business Innovation Research, Phase II

In total, the Department reviewed 211 proposals, and selected and initiated 36 projects in FY06. Selections for Round III solicitations will be made in FY07.

DOE Selects National Center and Nanotechnology Research Projects
The Center for Integrated Nanotechnologies, jointly operated by Sandia National Laboratories and Los Alamos National Laboratory, has been selected by DOE as the National Laboratory Center for SSL R&D. The purpose of the National Laboratory Center is to stimulate and enable the rapid transition of fundamental nanoscience discoveries into energy-efficient SSL technologies, augmenting DOE Core Technology Research. DOE also selected seven projects for Core Technology Research in Nanotechnology; these projects will initiate in FY07.

Patents for Future Products – Additional SSL portfolio highlights from FY06 include a record number of 20 patents submitted as a result of DOE-funded SSL research projects. This brings the total number to 64 patents submitted since DOE began focused funding of SSL research projects in 2000. These patents highlight the value of DOE SSL projects to private companies and notable progress toward commercialization.

For the list of patents awarded for DOE funded SSL research, see Appendix D.

1.2. Legislative Directive

The Energy Policy Act of 2005 (EPACT 2005) (Pub. L. 109-58), enacted on August 8th 2005, issued a directive to the Secretary of Energy to carry out a "Next Generation Lighting Initiative" to support the research and development of solid-state lighting:[3]

> ***"(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 new 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.

[3] Section 911 of Energy Policy Act of 2005, Pub. L. 109-58, enacted on August 8, 2005, allocates $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 is proposing $350 million for R&D investment in SSL.

- 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. 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 C.

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 A.

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 Research program area, which creates technology breakthroughs that can be widely applicable to future products. To see a full version of the Exceptional Circumstances Determination, please see Appendix B.

1.3. International Competition and US Industrial Positioning

Today, lighting product sales in the U.S. are worth approximately $13.0 billion annually. Of this, approximately $2.45 billion is associated with lamps while the remaining sales are divided between fixtures, components (including ballasts and controls) and associated services such as design and maintenance.[4] High-brightness (HB) LEDs, a popular product thought by many to be the nearest general illumination solution to SSL, is a $3.7 billion business globally with a compound annual growth rate of over 46% since 1995.[5] Of these HB LED revenues, approximately 6%, or $271 million is attributable to illumination applications.[6,7]

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[4] *Statistics for Industry Groups and Industries: 2006.* M05(AS)-1 (RV). Economics and Statistics Administration. U.S. Census Bureau. November, 2006.

[5] Strategies in Light, 2005. *High-Brightness LED Market Review and Forecast — 2005.* July 2005. Table of Contents available at: http://downloads.pennnet.com/pnet/research/66/hbled2005.pdf

[6] Doe not include signage, mobile appliances, signals, automotive, or electrical equipment.

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 surpass present U.S. technical know-how, and coupled with their advantage in mass production, will position themselves as the future suppliers of lighting sources and systems. Losing this emerging industry will mean lost jobs, lost industry, and more imports. Companies are already produce low grade, inefficient SSL products, which they are marketing in the U.S. as an innovative light source. DOE continues to monitor this practice carefully, as it may need to enact minimum efficiency or performance standards to better inform consumers about their available choices.

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 the Department. Through a proactive, collaborative approach, the Department 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.

1.4. Federal Role in Supporting the SSL Initiative

The Department of Energy's overarching mission is to advance the national, economic, and energy security of the United States; to promote scientific and technological innovation in support of that mission; and to ensure the environmental cleanup of the national nuclear weapons complex. The Department has four strategic goals toward achieving the mission, one of which, 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 cost share, although perhaps not overall cost, will diminish. The government's role 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

[7] *Worldwide Optoelectronics Markets*, 2004. Optoelectronics Industry Development Association. June, 2005.

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 (EERE). 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 (EERE) 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 (BT) 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, which DOE also hopes to achieve by 2025. 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. At the 2005 Workshop, Michael J. McCabe, Chief Engineer in BT, commented in his keynote address that "solid-state lighting fits perfectly into the goal statement of the Building Technologies Program." The commercialized efficacy goal of SSL is to reach an order of magnitude increase in efficacy over incandescent lamps and a two-fold improvement over fluorescent lamps. Mr. McCabe noted that 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'08 through FY'13 to implement this mission.[8] This plan is expected to be a living document, updated periodically to incorporate new analyses and progress, and new research priorities, as science evolves.

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[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 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 (HID) lighting, but the first high-pressure mercury vapor (MV) 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 is highly dependent on lamp type and wattage.

Each of these three light sources – incandescent, fluorescent and HID – has 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, on the other hand, has potential to not only reach the performance levels of some of today's most efficacious white-light sources, but experts project it can achieve a two-fold improvement over these sources. This projection is illustrated for light-emitting diodes (LEDs) below, in

[9] *Lighting a Revolution*. National Museum of American History. Smithsonian Institute.

Figure 2-1: .

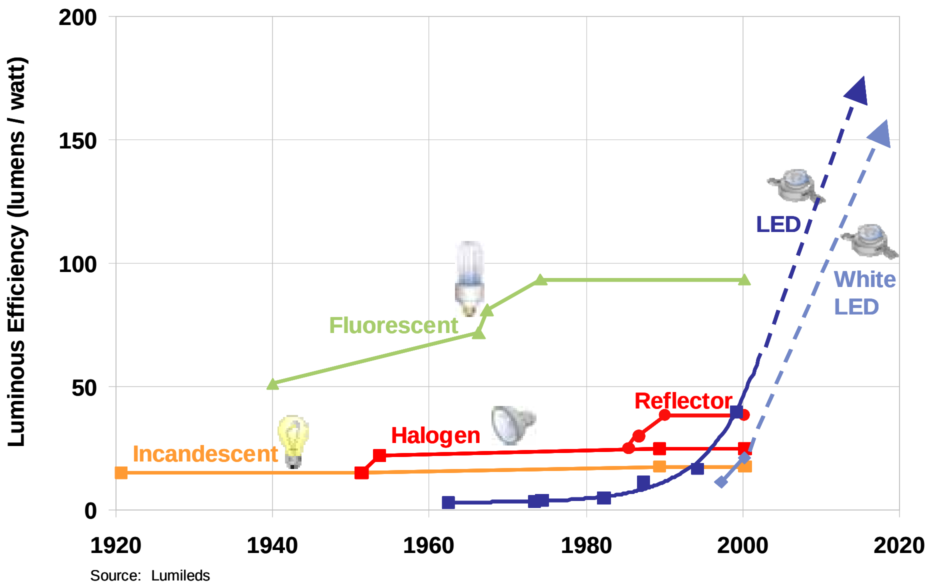


Figure 2-1: Historical and Predicted Efficacy of Light Sources

Source: Lumileds.

2.2. Current National Lighting Needs

Lighting is the second largest end-use of energy in buildings.[10] 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

Energy consumption for all lighting in the U.S. is estimated to be 8.2 quads, or about 22% of the total electricity generated in the U.S.[11] 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.

[10] Building Energy Databook 2006. Available at http://buildingsdatabook.eren.doe.gov/?id=view_book

[11] In the United States, total energy consumption in 2006 was 100.8 quadrillion BTU's, of which slightly more than a third – 40 quads – is for electricity production (Annual Energy Outlook, 2006; Table 2 Energy Consumption by Sector and Source).

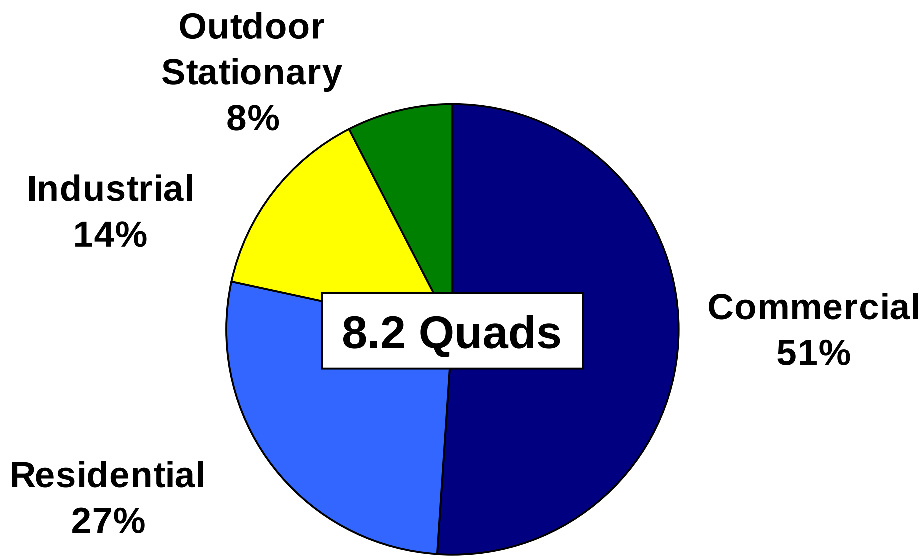


Figure 2-2: Total U.S. Primary Energy Consumption for Lighting by Sector 2001

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 are consumed in the commercial sector, the largest energy user for lighting. This is one of the principle markets the DOE has targeted to develop more efficient technologies, as lighting also contributes to a building's internal heat generation and subsequent air-conditioning loads. Looking at just the commercial and residential sectors, total energy use for lighting was approximately 6.4 quads. Nationally, total energy use in commercial and residential buildings was approximately 36.4 quads, of which electricity use was approximately 21.3 quads (BTS, 2002). Thus, in the residential and commercial sectors, lighting constituted approximately 17.6% of total building energy consumption, or approximately 30.3% of 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.

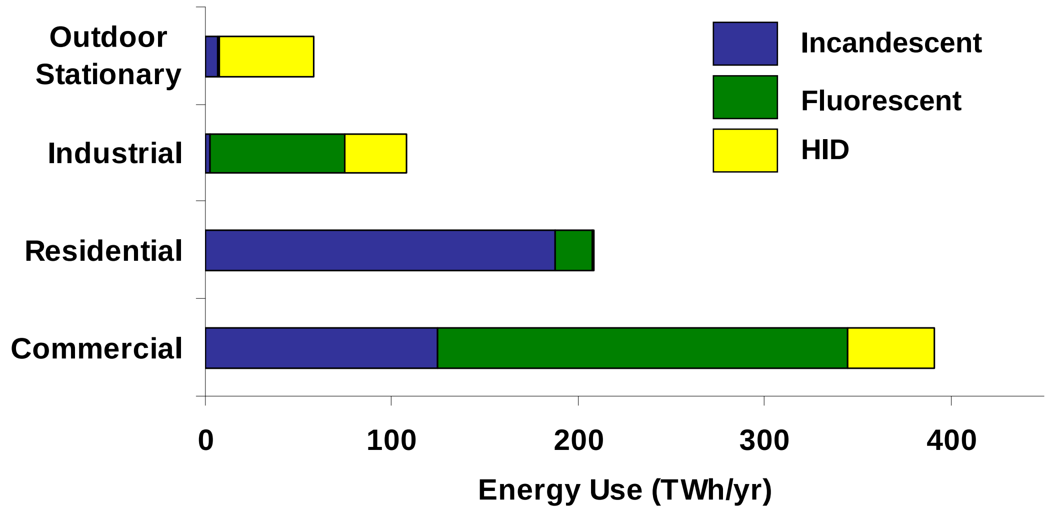


Figure 2-3: Lighting Energy Consumption by Sector & Source

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.

Figure 2-3, a lighting end-use energy consumption chart, shows that fluorescent sources in the commercial sector are the single largest energy-consuming segment in the U.S., slightly greater than incandescent sources in the residential sector. However, across all sectors, incandescent is the leading energy consumer in the U.S. consuming 321 terawatt-hours per year (TWh/yr). Fluorescent lighting is second with about 313 TWh/yr and HID is third with approximately 130 TWh/yr.

Figure 2-3 shows that outdoor stationary energy consumption is from primarily HID sources, which account for 87% of its 58 TWh/year of electricity use. The industrial sector has sizable energy shares of both fluorescent and HID sources, 67% and 31% respectively, of this sector's 108 TWh/year consumption. The commercial sector is the largest energy user overall, having large quantities of energy used by all three light sources. Fluorescent and incandescent are the two largest commercial lighting energy users, accounting for 56% and 32% of its annual 391 TWh/year of electricity use. In the residential sector, energy use is primarily driven by incandescent technologies, where 90% of the energy is consumed by this light source.

In September 2005, the DOE published U.S. Lighting Market Characterization Volume II: Energy Efficient Lighting Technology Options.[12] 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,

[12] *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

fluorescent, and HID, as well as SSL.

2.3. Current Technology Status

2.3.1. Performance of Light Sources

Table 2-1 presents the typical performance of 2006 LED device products on the market[13] in comparison to conventional technologies.

Table 2-1: Typical Performance of LED Devices and Conventional Technologies

Color	Luminous Output	Wattage	Luminous Efficacy	CCT (Typical)/ Dominant Wavelength	CRI	Lifetime
White	45 lm	1W	71 lm/W	5500°K	70	50k hours
Warm White	20 lm	1W	30 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 devices - drive current = 350ma, 1W device, T_j=25°C, batwing distribution, lifetime measured at 70% lumen maintenance. Lumen output is measure in mean lumens.
Source: Seoul Semiconductor, 2006. CREE, 2006. GE, 2006. Philips Lighting, 2006. OSRAM Sylvania, 2006. Product Catalogs.

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 in your specific application. As LED technology advances, costs decrease, and efficiency improves, LEDs will build market share in general illumination market.

2.3.2. First Cost of Light Sources

The cost of light sources in 2006 is typically compared on a cost per kilolumen basis. A kilolumen is 1000 lumens of light, approximately the amount emitted by a 75W incandescent light-bulb. The first-costs for today's principal light sources indicate the degree of the challenge facing SSL in the marketplace:

Incandescent Lamps (A19 60W)	$0.30 per kilolumen
Compact fluorescent lamp (13W)	$3.50 per kilolumen
Fluorescent Lamps (F32T8)	$0.60 per kilolumen
High-Intensity Discharge (250W MH)	$2.00 per kilolumen

[13] It should be noted that LED laboratory prototypes reach much higher efficacies than those listed above.

Light Emitting Diode (1W Cool White)	$40.00 per kilolumen[14]

Although the first cost of LED light sources has dropped dramatically in the past few years it is still far greater than for traditional light sources. On a normalized light output basis, LEDs are more than 50 times the cost of the incandescent light bulb and about 7 times the cost of a CFL. 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. 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.

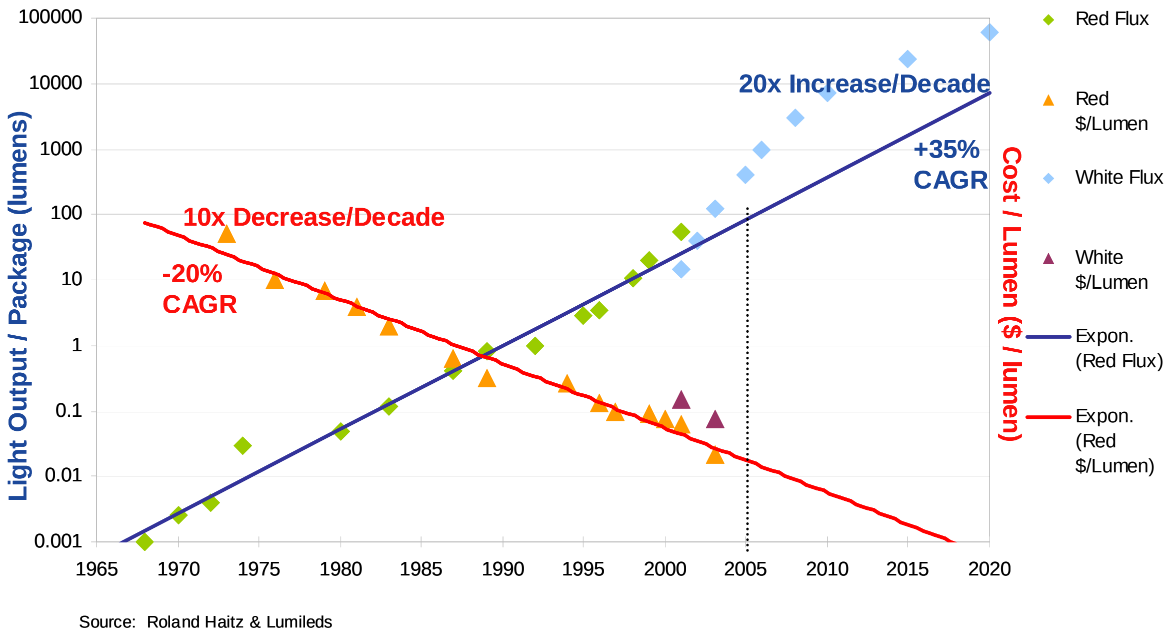


Figure 2-4: Haitz's Law: LED Light Output Increasing / Cost Decreasing

Source: Roland Haitz and Lumileds.
Note: CAGR = compound annual growth rate. Both lines are on the same numerical scale (however, different units)

2.3.3. The Cost of Light[15]

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 or ($/klm-hr): [16]

[14] This price assumes reasonable volumes, CCT: 5-6000°K, CRI: 75. See Section 4.3.1
[15] "Cost of Light – When does Solid-state Lighting make Cents?" by Kevin Dowling, Color Kinetics, September 12, 2003.
[16] IES Lighting Handbook, 8th Edition. Lighting Economics, p501-2.

$$CostOfLight = \left(\frac{10}{LampLumens} \right) x \left(\frac{LampCost + LaborCost}{Lifetime} + EnergyUse \times EnergyCost \right)$$ [15]

Where:

LampLumens = the light output of the lamp measured in lumens

LampCost = the initial or 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.

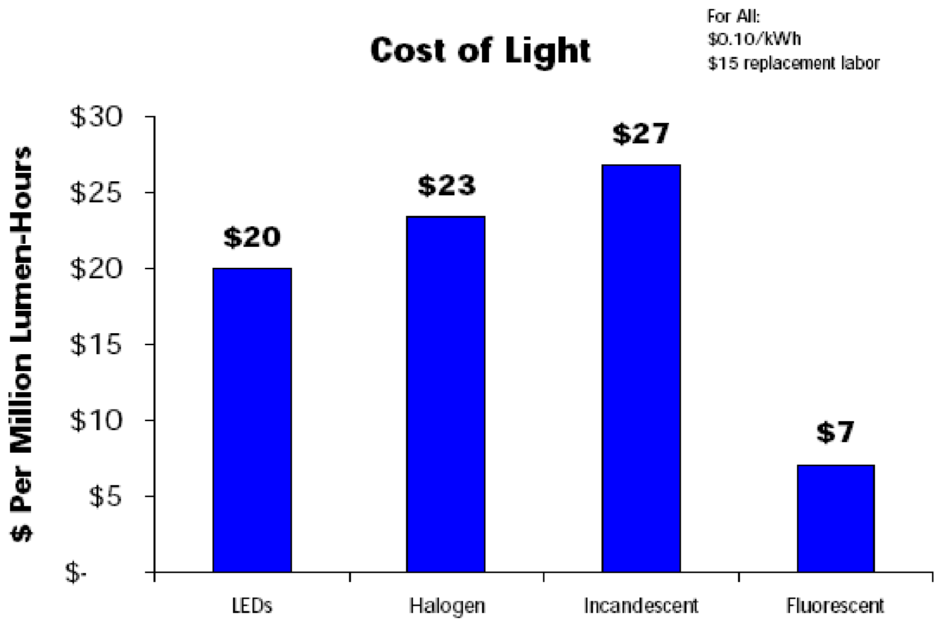


Figure 2-5: Cost of Light

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.

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.

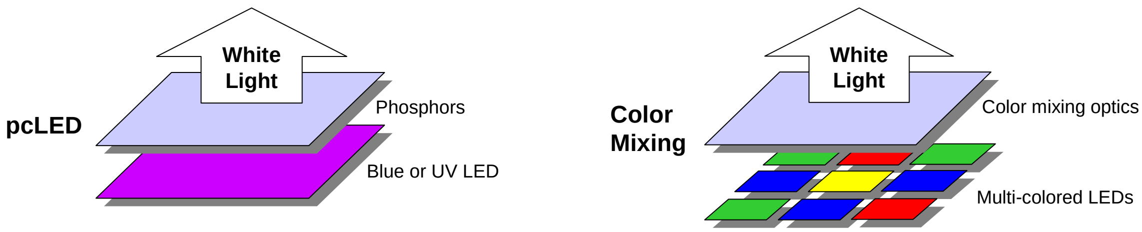
In addition, all of the comparisons in this study deal with economics and not the technical features of the light sources. For example, LEDs are ideal for use in extreme environments (e.g., high vibration, extreme cold) or in applications where the light emission must not include UV. The properties of 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 light-emitting diode (LED) was invented at General Electric's Advanced Semiconductor Laboratory.[17] 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.

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

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. Alone, these LED chips or “die” 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 LEDs (pc-LEDs) and (b) discrete color-mixing. Figure 2-6 shows these two approaches to white-light production.



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

Figure 2-6: General Types of White-Light LED Devices

From a research perspective, pc-LEDs are often subdivided into two groups – one based on blue LEDs and one on UV LEDs. The blue LED approach creates white-light by blending a portion of the blue light emitted directly from the chip with light emission down-converted by a phosphor. The UV LED approach starts with a UV-emitting LED chip that energizes phosphors designed to emit light in the visible spectrum. All the UV energy is adsorbed and converted into the visible spectrum by the phosphors. The color-mixing approach starts with discrete colored sources and uses color mixing optics to blend together the light output from these sources to create white-light emission.

For the phosphor converting blue LED approach, an LED chip 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 devices on a commercial scale in 1997. It has since been adopted by numerous other manufacturers as the method for white-light LEDs used in display and conspicuity applications. Some manufacturers have successfully lowered color correlated temperature[18] (CCT) and increased the color rendering index[19] (CRI) by adding a second phosphor to the device, but at a cost to device efficacy. These “warm-white” devices are currently available in high power packages with an efficacy of 30 lm/W and a CRI of 90.

[18] The CCT is the temperature of a blackbody that best matches the color of a given light source. It describes the color appearance of the source, measured on the Kelvin (K) scale. Lamps with a CCT below 3500 K are "warm", and appear more reddish in color. Lamps above 4000 K are "cool" sources, and appear whiter or bluer in color.

[19] CRI is the measure of the effect of a light source on the color appearance of objects in comparison to a reference case with the same CCT.

A pc-LED using a UV LED chip is similar to the blue LED system, but has some important differences. In this type of pc-LED, the LED radiates energy in the UV (340-380nm) or near-UV (<430nm) that excites phosphors, which down-convert the UV radiation into the visible wavelengths. The discrete emissions from the phosphors combine to produce white light. However, like the hybrid approach, non-recoverable losses that occur during wavelength conversion (phosphor conversion loss also called Stoke's loss) currently limit the maximum efficacy achievable through this method.

One of the problems confronting manufacturers of pc-LED devices is their ability to maintain consistent quality white-light across a production line due to natural variations in LED (blue or UV) wavelength. 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. And, as LED devices migrate toward general illumination applications, this variation could become more problematic than it is for simple conspicuity applications like indicator lamps.

Breakthroughs in phosphor technology aside, discrete color-mixing is thought by many to promise the highest efficacy device. In color-mixing, LED devices mix discrete emissions from two or more LED chips 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 efficacy of approximately 200 lm/W, assuming a device efficiency of 66% (See section 4.2.1). The principal advantage of the color-mixing method is that it does not involve phosphors, thereby minimizing phosphor conversion losses in the production of white-light. The largest challenge is the absence of efficient emitters of green light, which reduces the ability to change the spectrum to produce warmer light or to give better color quality. Another drawback is increased complexity. It would require multi-chip mounting and potentially sophisticated optics for blending the discrete colors. It may also require color control feedback circuitry that could address the different degradation and thermal characteristics of the discrete LED chips.

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.[20] For a diagram of an OLED, see Figure 4-2.

At least one of the electrodes must be transparent to light. 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

[20] Organic Light Emitting Diodes (OLEDs) for General Illumination: An OIDA Technology Roadmap Update 2002. Optoelectronics Industry Development Association. November 2002. Available at: http://www.netl.doe.gov/ssl/workshop/Report%20OLED%20August%202002_1.pdf.

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 is in a nascent, yet critical, stage of development and experts agree that without a substantial infusion of capital, the technology may not be commercialized until 2015. In that time, companies overseas, with support from their governments, may have developed an insurmountable technological lead, making it difficult for U.S. manufacturers to compete. However, as the U.S. government invests in this technology, bringing together our best experts from academia and industry, OLED commercialization may be accelerated. [21]

Much of the work for this technology is exploratory and far from commercialization. Therefore, most of the research is concentrated in research institutions and academia, both domestically and abroad. Although general illumination applications are still years away, the 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.[22] Currently, the best laboratory OLED devices have efficacies of approximately 31 lm/W.

2.4. Current 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 faster on-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.

A 2003 study[23] analyzed the energy savings potential of LEDs in twelve niche markets. Figure 2-7 summarizes the on-site electricity savings from the six niche markets that represent the greatest savings potential with 100 percent LED penetration.

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

[22] 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 January 2007, Sony released a 27" OLED TV which may start production in 2008.

[23] 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://www.netl.doe.gov/ssl/PDFs/Niche%20Final%20Report.pdf

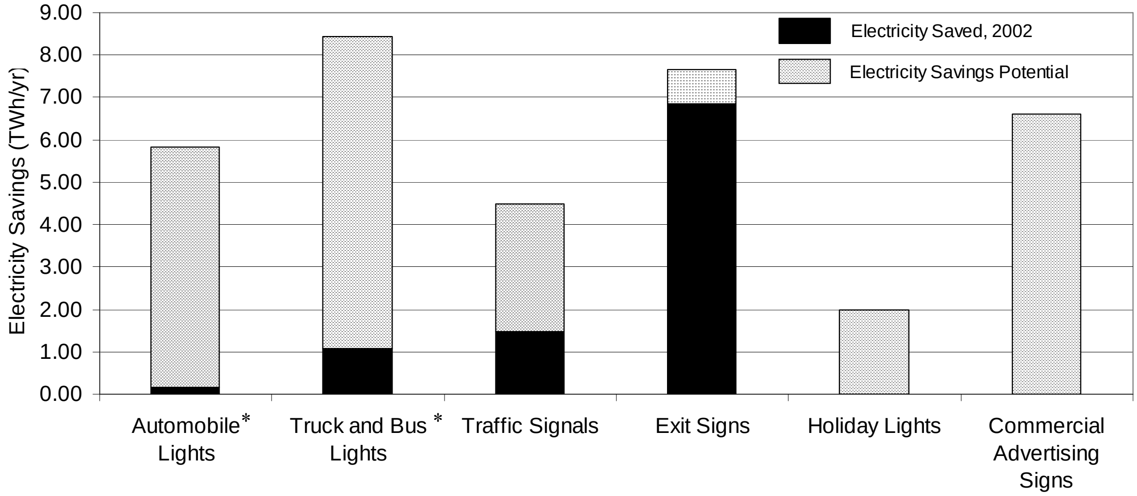

Figure 2-7: Electricity Saved and Potential Savings of Selected Niche Applications

*On-board electricity savings on mobile vehicle
Source: *Energy Savings Potential of Solid-State Lighting in General Illumination Applications*. Prepared by Navigant Consulting, Inc. for the Department of Energy. Washington D.C. November 2003.

Considering only those applications that are grid-connected, approximately 8.3 TWh of electricity consumption was saved in 2002, more than the equivalent output of one large (1,000 MW) electric power station.

Buildings Applications

Exit Signs. In 2002, LED exit signs dominated national electricity savings attributable to LEDs, comprising 71% of the total energy savings from LEDs. Due to favorable economics, better performance, enhanced safety capabilities, and marketing programs such as ENERGY STAR® Exit Signs, LED exit signs already captured a significant share of the inventory of exit signs in the U.S., with an estimated 80% of the installed-base being LED. The number of installed LED exit signs is already more than 26 million and only about 1.6 million incandescent exit signs remain in the market. In terms of primary energy consumption, the energy savings in 2002 translates into 75.2 TBtu/yr with a further 8.8 TBtu of annual savings potential.

Holiday Lights. Over the last several years, LEDs have started to carve a small niche in the holiday minilight market. While LEDs have significant benefits, such as operating lifetimes more than 30 times longer than traditional miniature lights and energy consumption 90% lower for each lamp, the LED penetration in this market is still in its nascent stages due to a high first cost ($9-$15 per string).

For 37.1 billion lamps operating 150 hours per year each consuming 0.4 watts equates to 2.22 TWh of electricity consumption annually, or 24.3 TBtu of primary energy consumption. An LED mini-lamp consumes only 0.04 watts, which is 90% less than its incandescent counterpart. Therefore, the potential annual energy savings from a total market shift to LED holiday lights are approximately 2.0 TWh, or 21.9 TBtu of primary energy consumption.

Commercial Signage. In terms of the magnitude of potential on-grid energy savings, this niche application has the largest near-term savings potential. The market penetration of LEDs into channel letter signs is relatively low, as the technology was only introduced in 2001. Converting the installed-base of neon commercial signs to LED would save approximately 72.5 TBtu per year. There are several benefits in addition to energy savings that are driving the adoption of LEDs to illuminate commercial advertising signs, including: minimal light loss, longer life, lower operating voltages, ease of installation and maintenance, and design flexibility.

Other applications for white-light LED products include LED reading/task lights, night lights, under cabinet lighting, and solar garden lights. At the 2005 Solar Decathlon[24], many of the University's solar homes featured these products. Figure 2-8 shows photographs from this event of integrated LED lighting products that the University teams chose to incorporate into their designs.

Night Light

Solar Garden Light

Reading Task Light

Under Counter Light

Figure 2-8: LED Technologies Employed during 2005 Solar Decathlon

In recent years, LEDs have entered the lighting market, offering consumers performance and features exceeding those of traditional lighting technologies. LEDs can be found in a

[24] For more information on this event, see http://www.eere.energy.gov/solar_decathlon/

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

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 November 2006). 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, the Department'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 the Current Portfolio (November 2006)

Figure 3-1 presents the congressional appropriation for the SSL portfolio from FY2003 to FY2006. The funding request for FY2007, totaling $19.3 million, is also represented. The program's funding level increased from $3 million in FY2003 to $12.7 million in FY 2005. For the current fiscal year (FY2006, which began in October 2005), the final funded amount was $13 million. A Congressional Directive in FY2006 also added an additional $5 million in funding for solid-state lighting R&D.

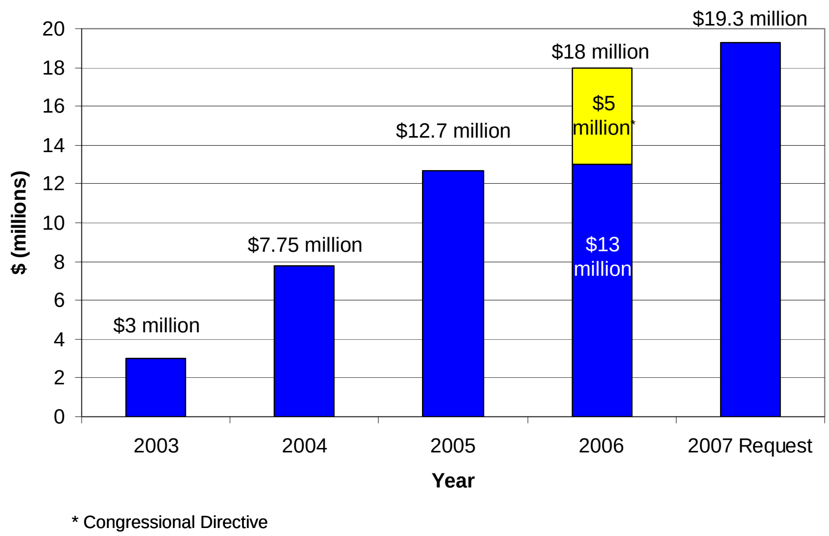

Figure 3-1: Congressional Appropriation for SSL Portfolio, 2003-2006

The current SSL DOE research portfolio[25] (not including completed projects) includes sixty projects, which address LEDs, OLEDs, and additional SSL technologies. Projects balance long-term and short-term activities, as well as large and small business and university participation. The portfolio totals more than $91.8 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. The Department is currently providing $71.9 million in funding for the projects, and the remaining $20.0 million is cost-shared by project awardees. Of the sixty-four projects active in the SSL R&D portfolio through 2006, thirty-six were associated with LEDs and twenty-eight were focused on OLEDs. The LED project partners had a slightly higher cost-share contribution ($11.8 million) than the OLED project partners ($8.1 million).

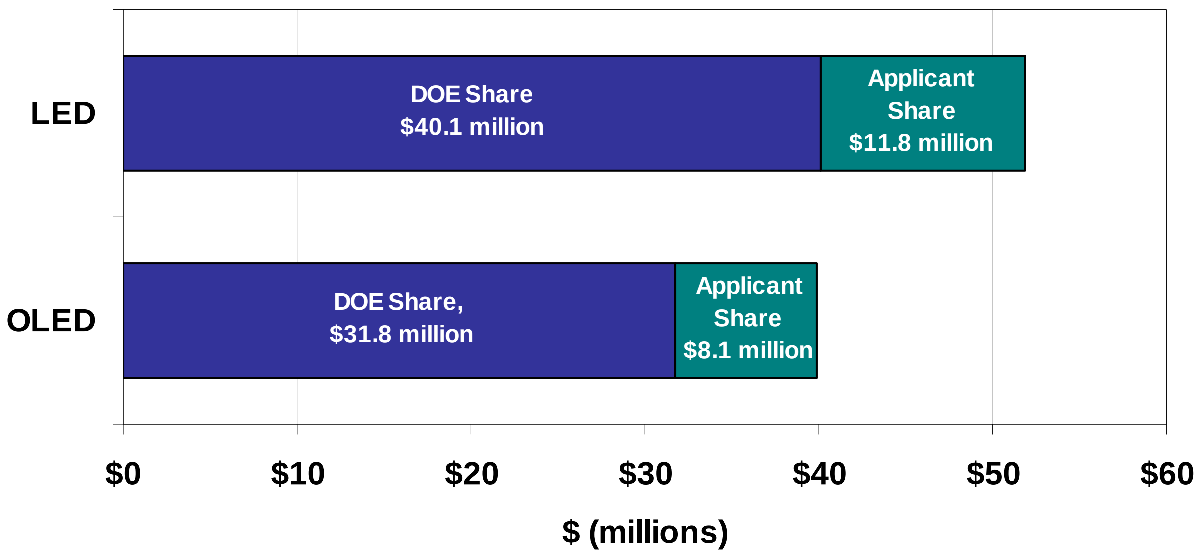

Figure 3-2: Cumulative Funding of SSL R&D Project Portfolio, November 2006

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[25] As of November 2006.

Figure 3-3 shows the DOE funding sources and level of support contributing to the SSL project portfolio, for projects active in July in 2006. The Building Technologies Program in the Office of Energy Efficiency and Renewable Energy (EERE) provided the majority of the funding; forty-one projects receive $83.2 million in funding from this source. Approximately 66 percent ($55.0 million) is directed to fund Core Technology Research projects and with the balance 34 percent ($28.1 million) supporting Product Development projects. The Small Business Innovation Research (SBIR) program in the Office of Science funded fifteen projects for a total of $8.0 million. The EE Science program in the Office of EERE provided $0.6 million in funding for one project.

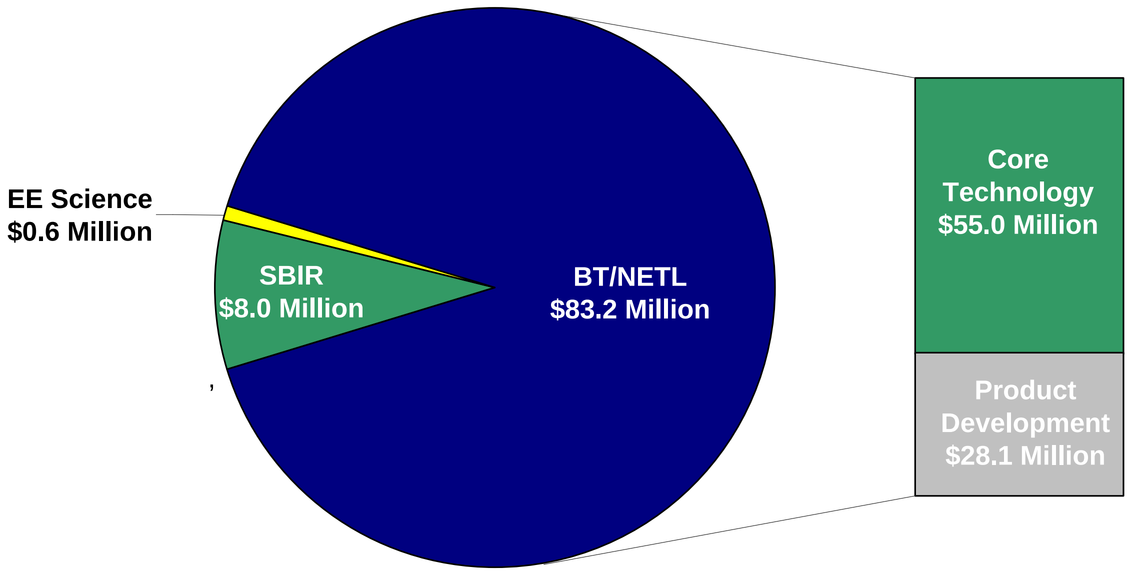


Figure 3-3: Cumulative SSL R&D Portfolio: Funding Sources, November 2006

The Department 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. Industry participants receive approximately 31% of portfolio funding, with $27.9 million in R&D activities. Small business comprises the next largest category receiving 29%, or $26.9 million, in research funds. Finally, universities and national laboratories comprise 21% and 19% of the R&D portfolio, respectively.

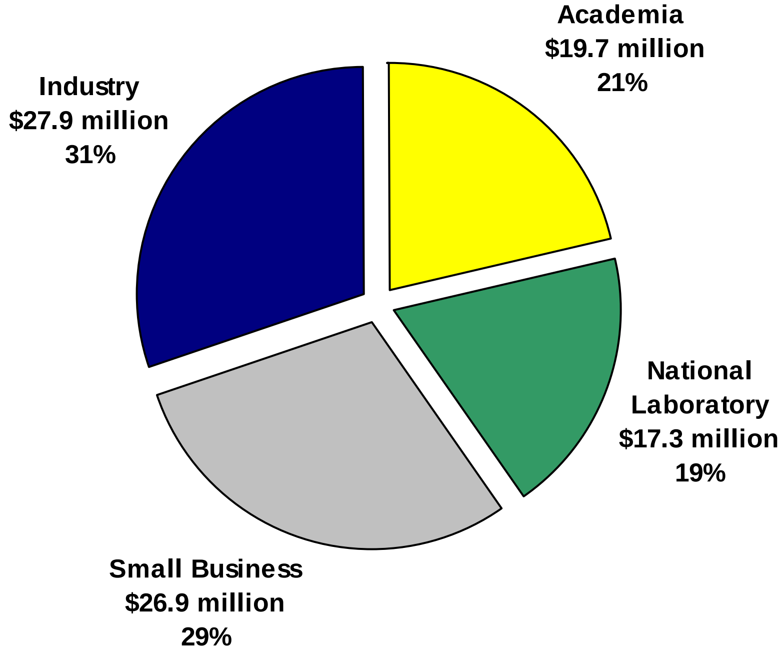


Figure 3-4: SSL R&D Project Portfolio: Recipients of DOE Funding, November 2006

Table 3-1 and Table 3-2 show the total number of projects and total-project funding in the SSL portfolio by subtask (as of November 2006). 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. Table 3-1shows the projects that DOE chose to fund, in keeping with these priorities, under the *Core Technology Research* solicitations.

Table 3-1: SSL R&D Portfolio: Core Technology, November 2006

	Number of Projects	**Funding ($)**
Light-Emitting Diode		
Large-area substrates, buffer layers, and wafer research	2	$1.4 million
High-efficiency semiconductor materials	15	$22.0 million
Device approaches, structures, and systems	2	$3.7 million
Strategies for improved light extraction and manipulation	1	$0.8 million
High-efficiency Phosphors and conversion materials	5	$7.4 million
Encapsulants and packaging materials	1	$0.1 million
Design and development of in-situ diagnostic tools for the substrate and epitaxial process	2	$1.0 million
Research into low-cost, high efficiency reactor designs and manufacturing methods	1	$0.8 million
Total LED	*29*	*$37.1 million*
Organic Light-Emitting Diodes		
Substrate materials for electro-active organic devices	2	$0.9 million
High-efficiency, low voltage, stable OLED materials	12	$13.2 million
Improved contact materials and surface modification techniques to improve charge injection	1	$0.7 million
Strategies for improved light extraction and manipulation	2	$1.8 million
Approaches to OLED structures between the electrodes for improved-performance low-cost white-light devices	1	$0.8 million
Research on low-cost transparent electrodes	4	$4.4 million
Investigation (theoretical and experimental) of low-cost fabrication and patterning techniques and tools	1	$4.0 million
Total OLED	*23*	*$25.8 million*
TOTAL	**52**	**$62.9 million**

Table 3-2 shows the projects that are currently funded in *Product Development* (as of November 2006).

Table 3-2: SSL R&D Portfolio: Product Development, November 2006

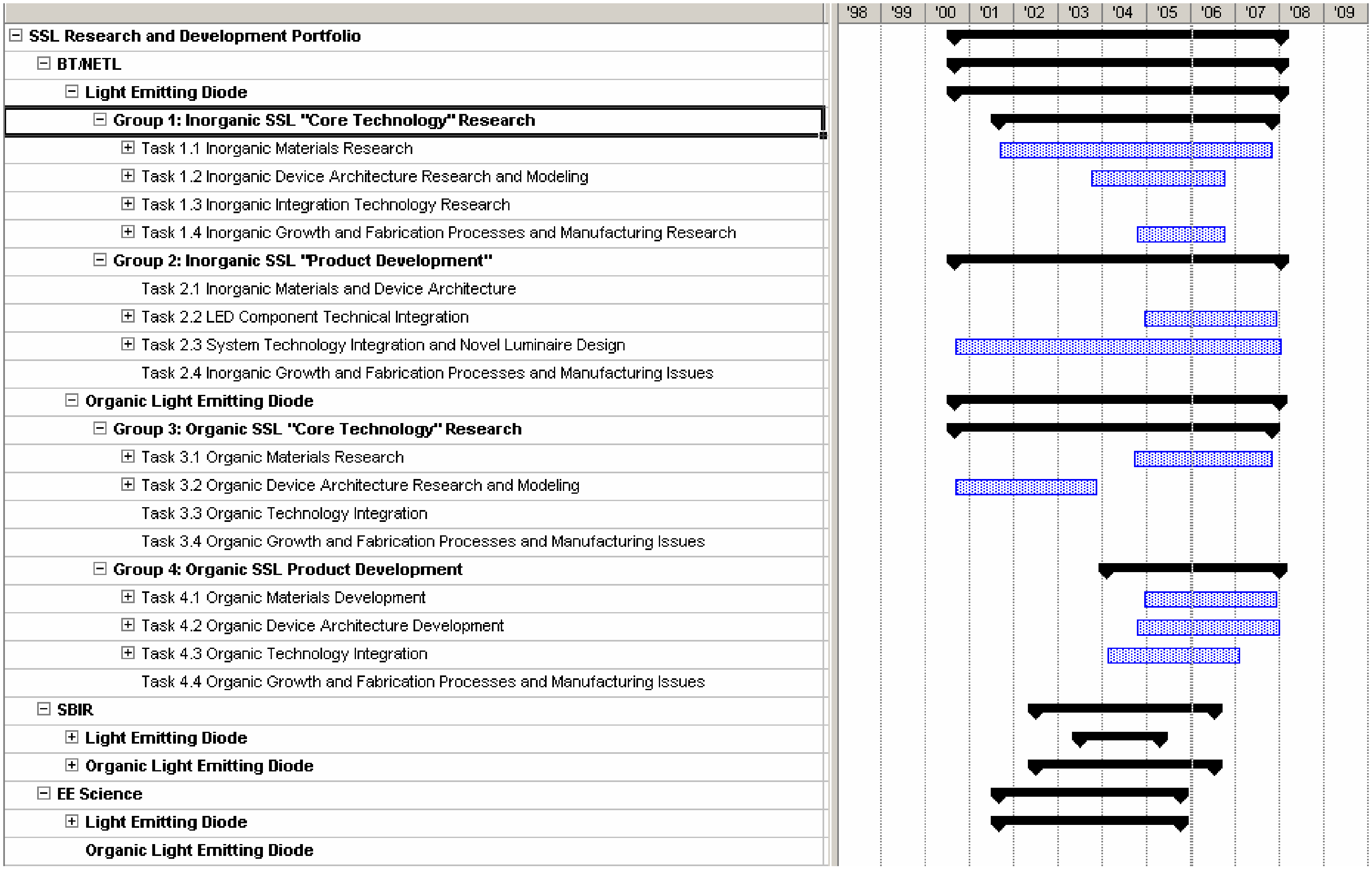
	Number of Projects	Funding ($)
Light-Emitting Diode		
High-efficiency semiconductor materials	1	$1.9 million
Implementing strategies for improved light extraction and manipulation	2	$3.7 million
Optical coupling and modeling	3	$6.5 million
Electronics development	1	$2.6 million
Total LED	***7***	***$14.7 million***
Organic Light-Emitting Diodes		
Develop architectures that improve device robustness, increase lifetime and increase efficiency	5	$14.2 million
Total OLED	***5***	*$14.2 million*
TOTAL	**12**	**$28.9 million**

3.2.1. Summary of Current Research Tasks and Timeline

The following Gantt chart, shown in Table 3-3 provides a high level summary of the current research and development tasks the Department is funding.[26] This chart presents the timeline of projects, past and current, grouped by funding source and categorized by task.

[26] The information is derived from the *2005 Project Portfolio: Solid State Lighting*, available at http://www.netl.doe.gov/ssl/PDFs/SSL%20Portfolio%202005_2-03.pdf

Table 3-3: Timeline of Current (FY06) and Completed Projects



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 below. 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.

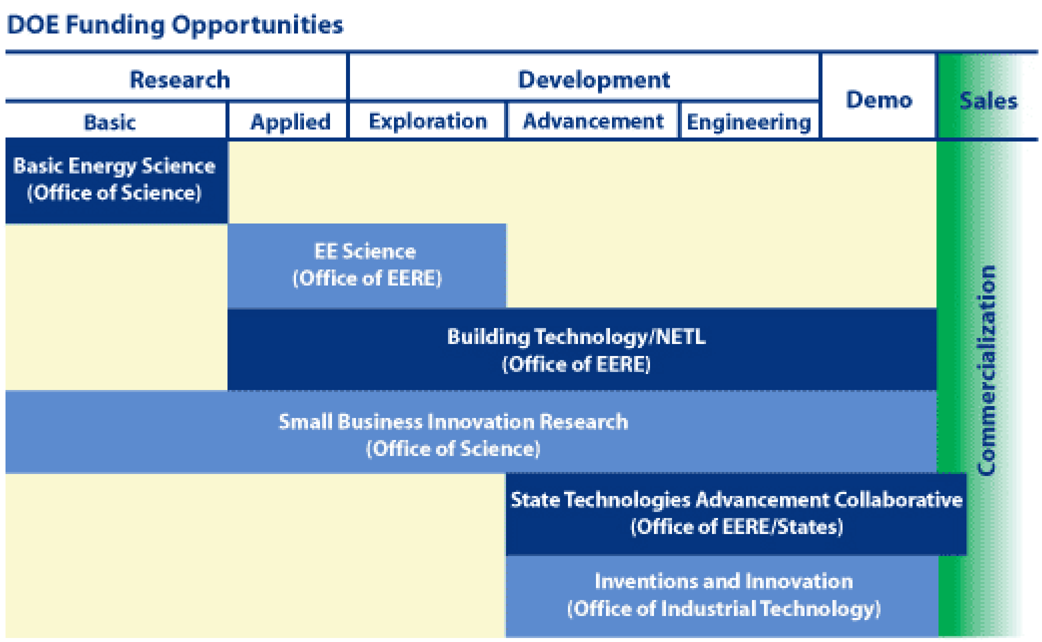


Figure 3-5: DOE Funding Opportunities

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.

- **EE Science Initiative** — Provided funding for materials science research on semiconductors, electro-optical materials, and other materials for applications that include solid-state lighting – Several current SSL projects are funded through this solicitation

- **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 (NETL)

- **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

- **State Technologies Advancement Collaborative (STAC)** — Seeks to strengthen collaboration between DOE and States to advance energy research, development, demonstration, and deployment projects. Solicits and awards projects co-funded by DOE and States

- **Inventions & Innovation (I&I)** — Seeks to assist inventors, entrepreneurs, and small businesses in bringing energy-saving ideas to the marketplace. Solicitations are open to all program areas within DOE's Office of Energy Efficiency and Renewable Energy, including building and lighting technologies

- **Solid-State Lighting Competitive Solicitations** — Seeks 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.

4.0 Technology Research and Development Plan

This March 2007 edition of the Multi-Year Program Plan includes updates to research task priorities, status, metrics and targets, summarized in section 4.4. Due to significant progress in SSL technology, projections of future LED and OLED efficacies were also updated.

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. The Department'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.

A part of the Department'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. The Department'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 five to ten years. Actual accomplishments will result in changes to the plan over this time period which will be reflected in future revisions. 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[27]

The following 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 inefficiencies helps to highlight the opportunities for energy-efficiency improvements and thereby to define priorities for the Department's SSL R&D Portfolio.

4.1.1. Components of LED Luminaires

At their most basic level, LED luminaires are comprised of three components, the *driver*, the *LED device* and the *fixture and optics* of the luminaire. These are illustrated by example photos in Figure 4-1 below.

[27] In the March 2006 edition of the SSL MYP, the term "system" was used to describe the combined source, driver, and fixture. However, to be consistent with terms used in the SSL Testing and Energy Star Programs, "luminaire" is used here to describe the entire solid state lighting product

- The driver consists of the power supply and electronic controls that manage the LED device. It converts line power to appropriate voltage and current, and may also provide sensing of and corrections for shifts in color or intensity that occur due to age or temperature effects over the life of the product.

- The LED device includes the chip and its associated packaging. The device includes the semiconductor die itself, the mounting substrate, the encapsulant which in some cases forms a lens, and the phosphor (if applicable). The encapsulant surrounds the chip for protection, and affects light extraction from the chip (through index of refraction and loss).

- The fixture houses these components and provides optical management of the light emission. "Optical management" may include color mixing optics, reflectors, and diffusers, or any other light-modifying structure.

a) Driver **b) Chip** **c) Device** **d) Fixture and Optics**

Figure 4-1: Photos of LED Luminaire Components

Sources: Lumileds, Color Kinetics.

4.1.2. Components of OLED Luminaires

The OLED may be described in similar terms, although the "device" and "fixture" are difficult to distinguish in some panel configurations that are currently being explored. The OLED device consists of layers of materials, including an emissive layer that corresponds to the basic LED chip and other layers that provide encapsulation, electrical connection and packaging. The existence of the electrode and the substrate in the light path is an important distinction between an OLED and an LED. The OLED's substrate adds scattering losses, which is not a significant issue with glass, the typical material in today's OLEDs, but may become an issue with flexible polymers that may be used in the future. For large area OLEDs, electrode sheet resistance may also become significant; however, this can be minimized with certain electrical designs. As the complexity of the electrodes or the segmentation increases, a diffuser may become necessary to obscure blocked areas (visible in the panel shown in Figure 4-2). In some OLEDs, the emissive layers (there may be more than the one shown in the simplified diagram below) emit light in both directions, but the metal cathode reflects the light so that it, too, passes through the substrate. Therefore, the reflective properties of the cathode may also introduce losses into the luminaire. The simple planar structure shown in this diagram would trap much of the light within the OLED device due to internal reflections. Therefore, modification of the substrate surface could be employed to improve the efficiency. It is also possible to manufacture an OLED with a highly transparent cathode (typically with up to 80% transmission across the visible spectral region). This creates the potential for either entirely transparent devices or "top emitting" structures built on opaque or reflective substrate and anode combinations. By engineering the thickness and refractive index of the transparent cathode, an additional degree of control over optical out-coupling is accomplished which might lead to higher extraction efficiency. Furthermore, these architectures enable the use of opaque metal foil substrates and perhaps cheaper, large area materials yet to be invented. Components of an OLED luminaire are shown in Figure 4-2.

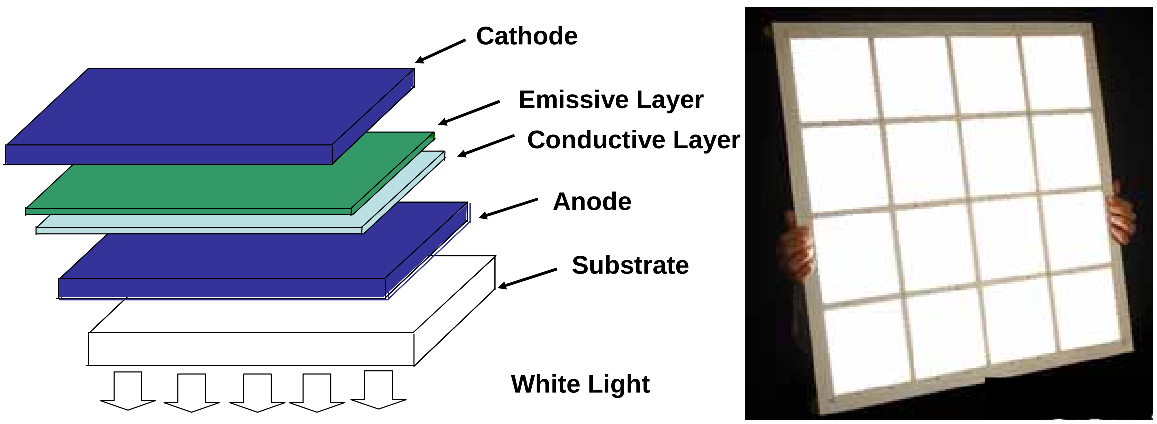


Figure 4-2: Diagram/Photo of OLED Panel

Photo source: General Electric.

4.2. Current Technology Status and Areas of Improvement

To further define the relationship among these components 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 opportunities for LED and OLED luminaires are shown in several figures that follow (Figure 4-3, Figure 4-4, and Figure 4-5). 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 spectral filtering of light by the eye 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; so it does not include the driver or fixture efficiencies. This technology plan provides both device efficacy and luminaire efficacy values. 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 (heat generation) in the device; improving the efficiency of conversion of electrons into photons and the extraction of those photons from the material (quantum efficiency); and tailoring the spectrum of the radiated light to increase the eye response. Tailoring of the spectrum is constrained by the need to provide light of a particular color quality (correlated color temperature and color rendering index).

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 are consensus numbers, developed over a series of weekly consultations with members of the NGLIA. It is important to realize there may be significantly different allocations of loss for any specific design, which may also result in an efficient luminaire. So, while this allocation of typical current efficiency values and targets serves as a useful guide for identifying the opportunities for improvement (i.e., those components with the greatest differences between current and target values), it is *not* the program's intention, by stating these intermediate efficiencies, to impede novel developments using a different allocation of losses that may result in a better overall luminaire performance.

All efficiencies throughout this chapter are reported at a fixed brightness (1,000 cd/m^2) for OLEDs or a fixed drive current (350mA) for LEDs. These values are simply used to compare efficiency levels and set targets. They are not necessarily ideal drive currents or brightness levels.

4.2.1. Light Emitting Diodes

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

(a) discrete color-mixing and

(b) phosphor-conversion LEDs (pc-LEDs).

Color-mixing LED

Figure 4-3 presents a diagram of a color-mixing LED luminaire. The percentage efficiencies in the diagram next to each component indicate the typical performance in 2006 and targets that will satisfy the goals of the program. Therefore, this diagram depicts the present inefficiencies of the various luminaire components and the headroom for improvement. For purposes of comparing various experimental results, this diagram, as well as the next one, assumes 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, but may then be inappropriate for the targets indicated. Currently available 2006 products typically have color temperatures in the range of 4100-6500°K, and usually a lower CRI. The 2006 typical numbers reflect these less than optimal parameters, and therefore may overstate our current capability.

Over the course of the program, performance improvements will make possible the manufacturing of lamps with lower color temperature and better CRIs without seriously degrading the efficiency. Achieving the program goals will require more efficient emitters (particularly in the green area of the spectrum), and improvements elsewhere in the luminaire greater than those indicated in Figure 4-3.

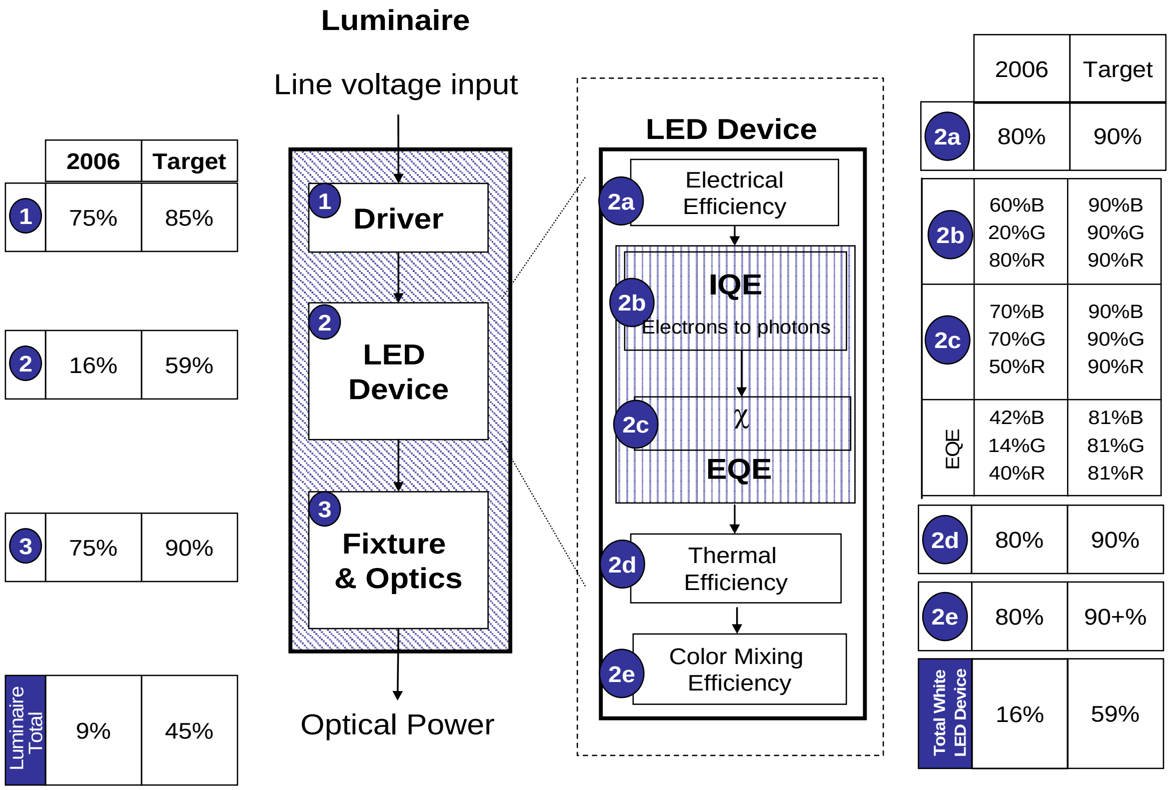


Figure 4-3: Current and Target Luminaire Efficiencies – Color-Mixing LED

(The target assumes a CCT of 4100K and CRI of 80; Current CCT: 4100-6500K, CRI: 75)
Source: NGLIA LED Technical Committee, Fall 2006

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. The losses in the driver are electrical.

Device efficiency, There are several components of the device electrical efficacy that are shown on the right in Figure 4-3 and also defined below. The output of the "LED device" in this figure is useful lumens; that is, the spectral effects are not included within the "device" box. Losses in the device are both electrical and optical.

Fixture and optics efficiency, η_{fo}, is the ratio of the lumens emitted by the luminaire to the lumens emitted by the LED lamp, or device 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 device portion of the luminaire, the power efficiency ("wall plug efficiency") is the ratio of electrical input from the driver (i.e., applied to the device) to the optical power out, irrespective of the spectrum of that output. As such, wall plug efficiency excludes driver losses. The device electrical *efficacy* is the product of the wall plug efficiency and the spectral or optical efficacy due to the human eye response. Elements of the power efficiency are:

Electrical efficiency, η_v, accounts for the conversion to photon energy from electrical energy (photon energy divided by the product of the applied voltage and electron charge). The forward voltage applied is determined by the diode characteristics, and should be as low as possible in order to get the maximum current (hence maximum number of electrons eligible to convert to photons) for a given input power. When resistive losses are low, it is essentially the breakdown voltage which is approximately the bandgap energy divided by the electronic charge. Resistive losses and electrode injection barriers add to the forward voltage.

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 LED.

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

External quantum efficiency, EQE, is the ratio of extracted photons to injected electrons. It is the product of the internal quantum efficiency, IQE, and the extraction efficiency χ.[28]

[28] In practice, it is very difficult to separate the relative contributions of internal quantum efficiency and extraction efficiency to the overall external quantum efficiency. At the same time, it is useful to make the distinction when discussing the objectives of different research projects. At present, it is common for individual laboratories to compare measurements of different device configurations in order to estimate relative improvements. This makes it difficult to compare and use results from different labs, and so it

Thermal Efficiency, is the ratio of a device lumens emitted by the device in thermal equilibrium under continuous operation to the lumens emitted by the device at 25°C. [29]

Color-mixing efficiency, η_{color} , here 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 4-3 is assumed to occur in the lamp/device.

The device-related parameters of the luminaire have the greatest headroom for improvement in the short term. For example, the external quantum efficiencies (2c) of the chips range from 14% to 42%, depending on color. The ultimate goal is to raise the EQE of the chip blend to 81%. However, as the diodes become more efficient, there will necessarily be more emphasis on the other luminaire losses in order to maximize overall efficiency.

In this figure, the driver (1) has an efficiency of 75% in today's products. This driver efficiency is somewhat lower than that for a phosphor converting LED (see Figure 4-4) because the driver needs to produce different colors with different (and controllable) colors. The ultimate target for this component is to improve the efficiency to greater than 85%. Likewise, there is considerable room for improvement of the fixture and optics. Currently, the color-mixing LED luminaire is approximately 9% efficient at converting electrical energy into visible white-light. If all targets are achieved, the LED device (lamp) would have an efficiency of 59%, with an overall luminaire efficiency of 45%.

The losses estimated above are with respect to power and independent of spectrum. However, the electrical luminous efficacy (in lm/W_e)[30] of the color-mixing LED device can be calculated by multiplying the wall plug efficiency (W_o/W_e) by the *optical* or *spectral* luminous efficacy of radiation (LER). For blended LEDs, the LER is approximately 360[31] lm/W_o (exact value varies with the CRI and CCT for the particular design and the available wavelengths). Using this conversion, the target for a color mixing LED device would be close to 212 lm/W_e (59% efficiency, above, multiplied by 360 lm/W_o). This would result in an overall luminaire efficacy, absent significant breakthroughs, of approximately 160 lm/W_e. These additional luminaire losses are the

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would be worthwhile to try to develop some measurement standards for these parameters, perhaps a role for NIST.

[29] Standard LED device measurements use single pulses of current to eliminate thermal affects, keeping the device at 25°C. In standard operation, however, the LED is driven under CW (continuous wave) conditions. Under these conditions, the device operates a temperature higher than 25°C at thermal equilibrium.

[30] The subscript "e" denotes electrical Watts into the lamp and "o" denotes optical Watts within the lamp. Unless otherwise stated, "efficacy" means electrical luminous efficacy.

[31]NIST has simulated an LER of 361 lm/W_o at a CRI of 97 and CCT of 3300K. The committee chose 360 lm/ W_o as a realistic number for a CCT of 4100K and a CRI of 80, the parameters for these projections. (Ono, Y. "Color Rendering and Luminous Efficacy of White LED Spectra." Proc. SPIE 49th Annual Mtg., Conf. 5530 (2004).)

reason that the program includes tasks directed at fixture and driver efficiency as well as those emphasizing the basic LED device, and also why the most energy-efficient installations of the future will have purpose-designed luminaires as opposed to simply retrofittable 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 are available. This would yield a higher overall figure for lumens per watt.

Phosphor Converting LED

Figure 4-4, below, presents a diagram of a phosphor converting LED luminaire. The definitions for the various efficiencies are the same as listed for Figure 4-3, with additional definitions for phosphor efficiency and scattering efficiency:

> Phosphor efficiency, η_{phos}, accounts for the conversion efficiency, Stokes loss, of the phosphor. This is a fundamental property of phosphor-converting LEDs.
>
> Scattering efficiency is the ratio of the photons emitted from the LED lamp to the number of photons emitted from the semiconductor chip. This efficiency, relevant only to the phosphor converting LED in Figure 4-4, accounts for scattering losses in the encapsulant of the lamp.

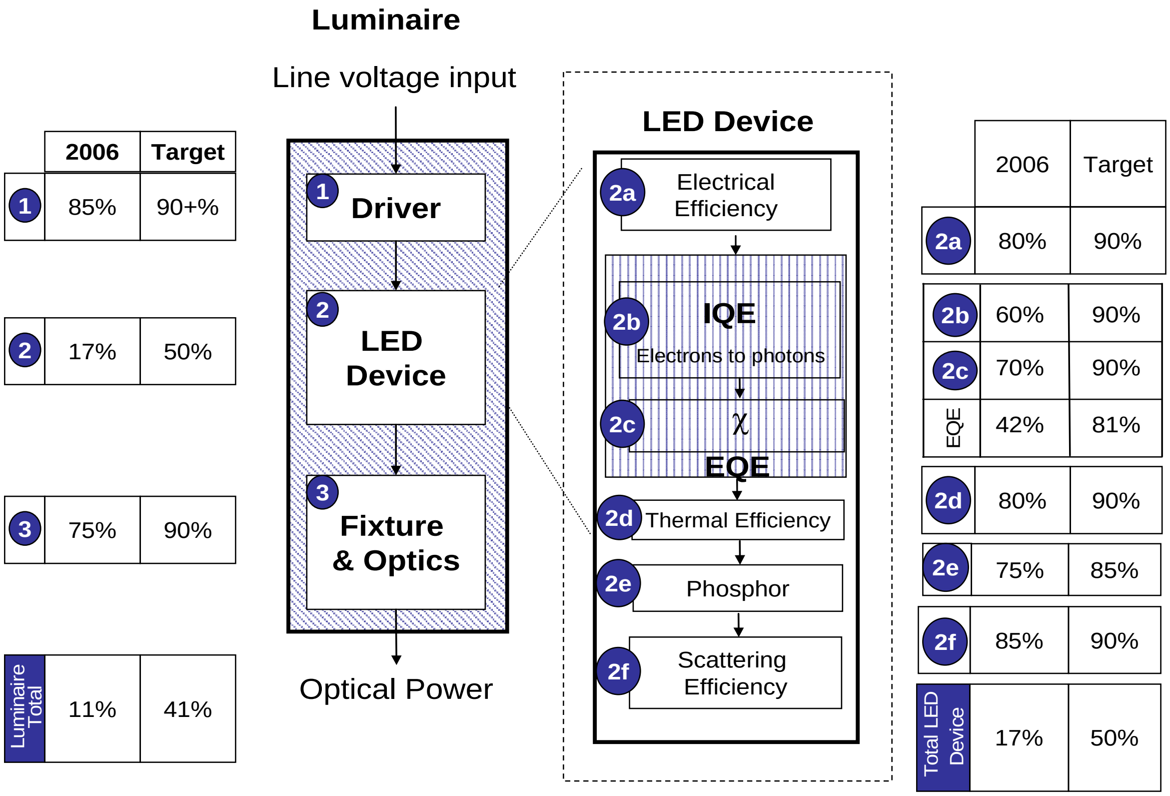

Figure 4-4: Current and Target Luminaire Efficiencies - Phosphor Converting LED

(The target assumes a CCT of 4100K and CRI of 80; Current CCT: 4100-6500K, CRI: 75)
Source: NGLIA LED Technical Committee, Fall 2006

In the above figure, Component 1, the driver, has an efficiency of 85% for 2006 products (with available switching techniques). The ultimate target for this component is to improve the efficiency to greater than 90%. In comparison, other components of the luminaire have more room for efficiency improvements. For example, the extraction efficiency of the LED chip is currently only 70%. The ultimate goal is to raise the extraction efficiency of the mounted, encapsulated chip to 90%.

The areas with the greatest headroom for improvement are the internal quantum efficiency (2b) and extraction efficiency (2c) of the LED chip, and the fixture and optics (3). Currently, the phosphor-converting LED luminaire is approximately 11% efficient at converting electrical energy into visible white-light. If all targets are reached, the LED device (lamp) would have an efficiency of 50%, with a luminaire efficiency of 41%. Similarly to the color-mixing device, the electrical luminous efficacy (in lm/W_e) of the phosphor converting LED device can be calculated by multiplying the wall plug 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. Similar to color-mixing LEDs, a practical target for a phosphor-converting LED luminaire is about 147 lm/W_e. Improving the phosphor efficiency and temperature performance could improve the efficacy even more.

4.2.2. Organic Light Emitting Diodes

Similarly, Figure 4-5 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.

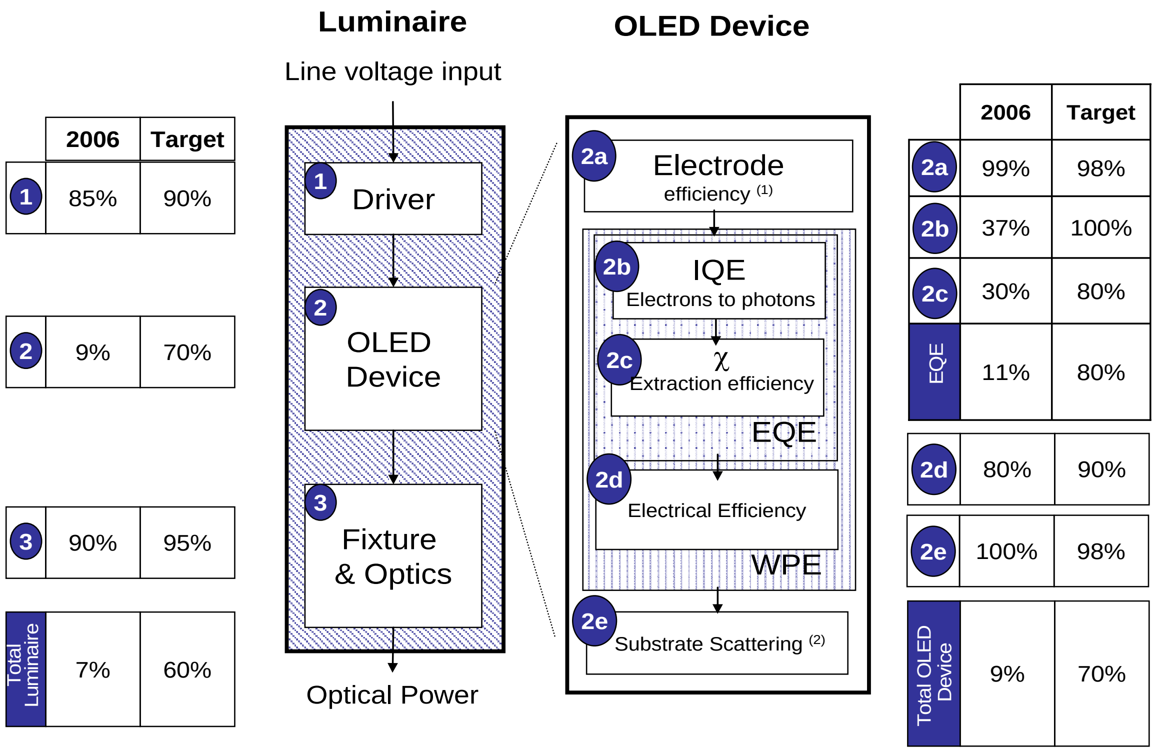

Figure 4-5: OLED Luminaire Efficiencies & Opportunities

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

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.

Note 2: Includes substrate and electrode optical loss – negligible for glass and very thin electrodes but may be important for plastic or thicker electrodes

Source: NGLIA OLED Technical Committee, Fall 2006

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 98% 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 tricks 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 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. The goal is to achieve EQE values in the 80% range within the time period of this forecast. Only a short while ago it was thought that efficiencies of OLEDs would be limited to 25%, but the realization that triplet states could be harvested has raised the projections. The same discussion with regards 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. Because OLEDs are area emitters, fixtures, to the extent that they are used to reduce glare, could almost be eliminated if the brightness of the OLED lamp itself could be kept below 800 cd/m^2, distributing the total lumen output over a large area.

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. It is also somewhat difficult to achieve low forward voltages primarily because of barriers at the electrodes, but also due to series resistance. Progress on efficiencies for OLEDs is nonetheless expected to be 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

With these improvement goals in mind, a projection of the performance of SSL devices was created in consultation with the NGLIA Technical Committee, a team of solid-state lighting experts, assuming a “reasonable” level of funding by both government and private industry. A figure that has been quoted for the SSL program is $25M for 20 years. This is probably a good overall figure, albeit over-simplified. For instance, the profile of spending may be lower in the early years as fundamental issues are explored, but higher in the later years as practical problems of achieving high efficiency are encountered. Meeting these goals assumes that there are no unforeseen resource availability problems. Although the overall SSL program may be expected to continue until 2025 in order to achieve technologies capable of full market penetration, forecasts in this section only project performance to 2015.

Note that these performance goals are *exclusive* of the driver and fixture as discussed above. Thus, the goals do not entirely capture the objectives of the SSL program which relate to *luminaire* efficiency or cost. Reaching these ultimate objectives will take longer than may be inferred from these graphs of device performance as shown by the luminaire efficiency values in Table 4-2. It is not anticipated that it will be difficult to achieve good driver performance (although there are some challenges). On the other hand, innovative fixtures for LEDs can have a significant impact on overall efficiency, and the challenge in this area is to accommodate aesthetic and marketing considerations while preserving the energy-saving advantages.

4.3.1. Light Emitting Diodes

The price and performance of white LED devices are projected assuming that they are operating at a correlated color temperature (CCT) of approximately 4100-6500°K[32] and a color rendering index (CRI) of 70-80 or higher. The choice of the rather cool light provides a reference point based on commercial product today. The goal is to have future improvements that will allow warmer light at similar efficiencies, but such improvements may occur later in the SSL program, beyond the forecast period of this report. Two projection estimates are shown, one for laboratory prototype LEDs, and one for commercially available LEDs. In the March 2006 edition of the SSL MYP, the commercial efficacy projection assumed a three year lag between laboratory demonstrations and commercialization. However, new data, shown in Figure 4-6, suggests a one and a half year lag is more appropriate. Because new data also suggests that progress could be advancing more rapidly than previously projected, the slope of the laboratory and commercial projections was increased from the March 2006 projections.

Figure 4-6 shows *device* efficacy improving linearly through 2015 (driver/fixture efficacies are excluded). The dotted lines indicate a continuation of this linear projection though it is unclear whether devices will eventually reach those efficacies. The efficacy for high power laboratory prototypes reaches 162 lm/W in 2013. Commercial products should reach a level of about 145 lm/W by that time. These projections assume the CRI and CCT mentioned above and a prototype with a "reasonable" lamp life. A number of actual reported results for both high power and low power diodes are plotted on the curve as well, although these specific examples may not meet all of the criteria specified. Because many more low power diodes are required to make a useful light source, the two reported results are not directly comparable. However, there is a possibility one could achieve a high efficiency light source using these low-power devices. While higher efficacy claims have been made, they cannot be compared unless all these parameters are known. By stating the assumptions, it should be easier in the future to track progress against the Department's goals.

Although the program is planned to continue past 2015, it is difficult to make meaningful projections further into the future. Additional improvements are anticipated for future

[32] The cooler color temperature has been chosen to reflect the current and near-term state of the art. Warmer color temperatures will result in lower efficacies, primarily because of the eye response. Notwithstanding, the expectation is that devices near these operating goals will be achieved in the future with lower color temperatures and higher efficacies so as to make them useful for a wider space of applications.

years, for example, warmer light at similar energy performance. For comparison to the projected performance, a rough estimate of progress towards a higher future CRI of 85, lower CCT of approximately 2800-3500°K lamps (still excluding other luminaire components) is also indicated in the figure. Plans and goals will be revisited as the program progresses.

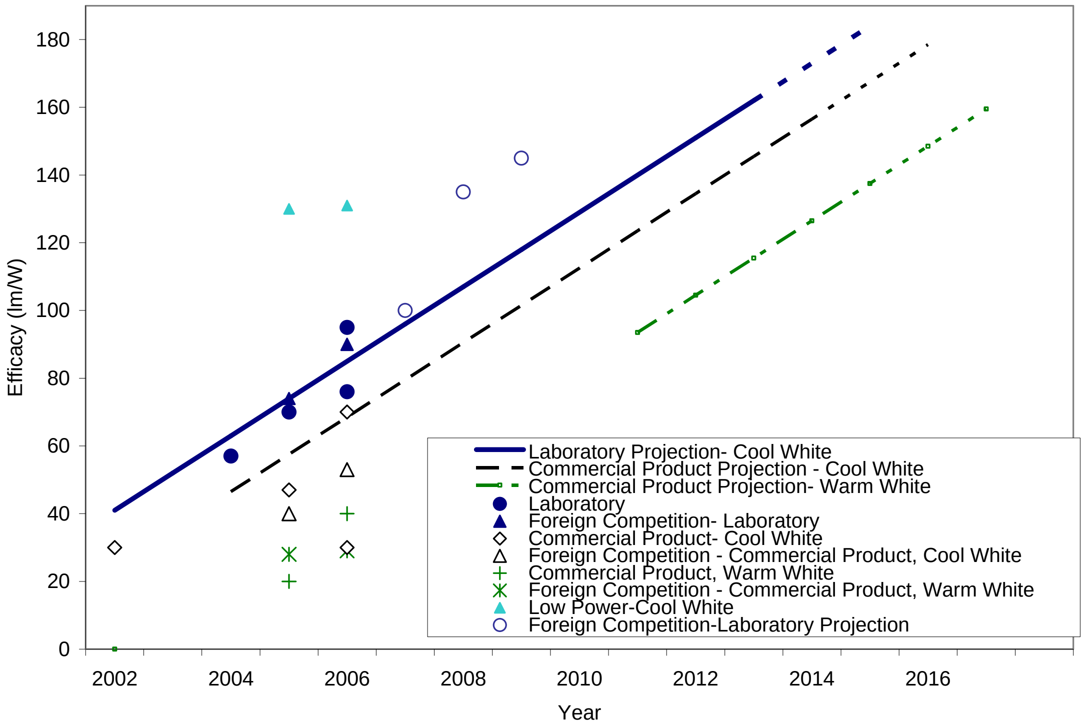

Figure 4-6: White Light LED Device Efficacy Targets, Laboratory and Commercial

Note:
1. Cool white efficacy projections assume CRI=70 → 80, Color temperature = 4100-6500°K,
2. Warm white efficacy projections assume CRI>85, Color temperature=2800-3500°K
3. All projections are for high-power diodes with a 350 ma drive current at 25°C, lamp-level specification only (driver/luminaire not included), and reasonable lamp life.
4. Low power diodes shown have a 20 mA drive current.
5. The dotted line indicates a continuation of the projection though it is uncertain whether devices will eventually reach those efficacies.

Source: Projections: NGLIA LED Technical Committee and the Department of Energy, Fall 2006, Points: Press Releases

The cost estimates were also developed in consultation with the NGLIA Technical Committee, and represent the average performance of 1-3 watt white-light LED devices driven at 350 mA (excluding driver or fixture costs). 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 4-7. The price decreases exponentially from approximately $35/klm in 2006 to $2/klm in 2015. Recent price reduction announcements seem to confirm the trend, at least in the near term.[33]

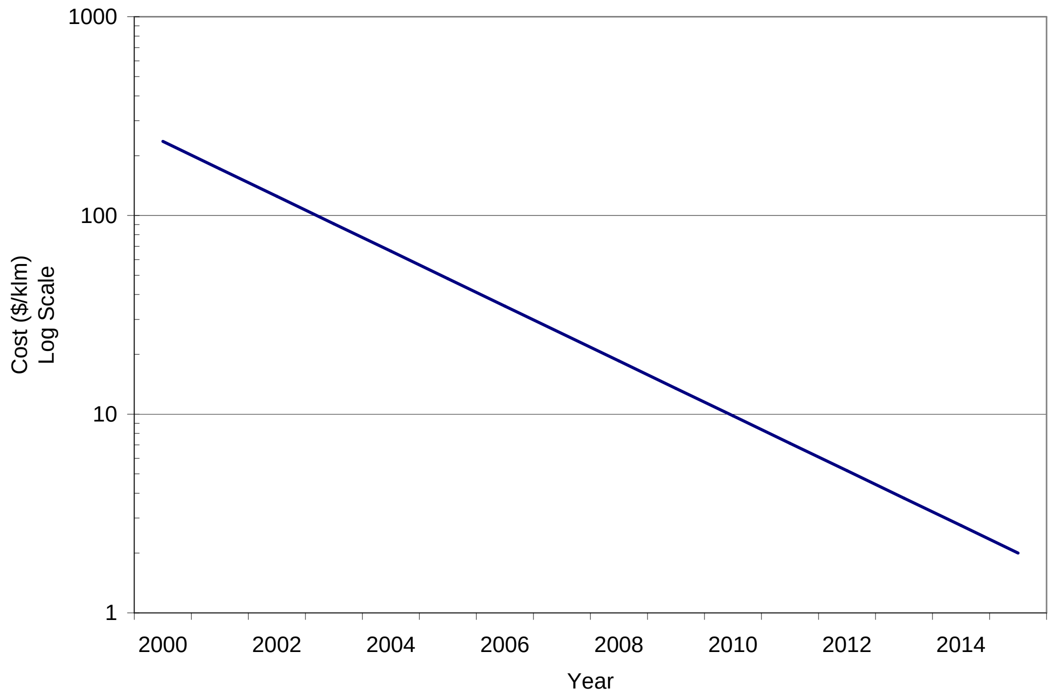

Figure 4-7: White Light LED Device Price Targets, Commercial

(On a logarithmic scale)

Note: Price targets assume "reasonable volumes" (several 1000s), CRI=70 → 80,
Color temperature = 4100-6500K, and lamp-level specification only (driver/fixture not included)
Source: NGLIA LED Technical Committee, Fall 2006

[33] The first cost of light sources listed in section 2.3.2 is also listed here for comparison: Incandescent Lamps (A19 60W), $0.30 per klm; Compact fluorescent lamp (13W), $3.50 per klm; Fluorescent Lamps (F32T8), $0.60 per klm; High-Intensity Discharge (250W MH), .$2.00 per klm. By 2015, LEDs will be able to compete with both High-Intensity Discharge lamps and Compact Fluorescents based solely on first cost. It is important to keep in mind that energy savings, replacement cost, and labor costs also factor into a lamps overall price. Because of these factors, LEDs are already competing with niche incandescent products.

Figure 4-8 presents the projection for LED device lifetime. The device life, measured to 70% lumen maintenance, is projected to increase linearly until it reaches 50,000 hours in 2008. An average lamp life of 50,000 hours would allow LED devices 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. It is important to note that projections below represent the lifetime of the device, not the luminaire. Because drivers may limit the lifetime of the LED luminaire, improving the lifetime of the driver to equal or exceed that of the LED device is a goal of the SSL program.

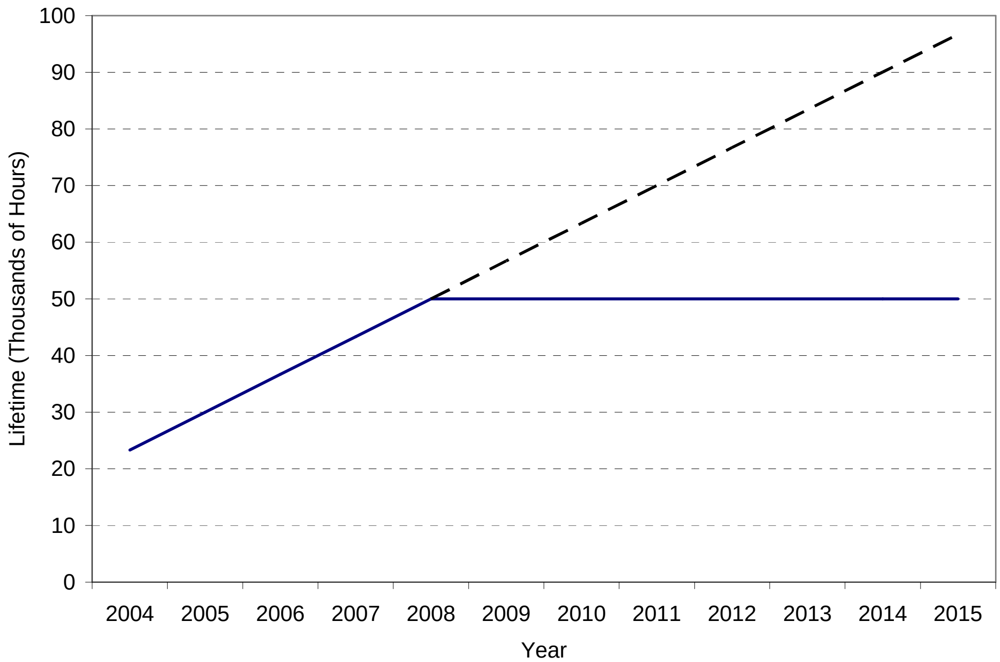

Figure 4-8: White Light LED Device Lifetime Targets, Commercial

Note: Lamp life projections assume 70% lumen maintenance, "1 Watt device," 350mA drive current.
Source: NGLIA LED Technical Committee, Fall 2006

This long life makes LEDs very competitive with conventional technologies on a "Cost of Light" basis (See Section 2.3.3). However, the total cost of ownership flattens out at approximately 50,000 hours. Yet, LED products for niche/specialty applications could be developed with longer lamp life, upwards of 100,000 hours, by trading off with other performance parameters. A lifetime projection for these specialty products is shown as a dashed line in Figure 4-8.

A lifetime of 50,000 hours is not easy to measure or substantiate. There are some who argue that lifetime is already not an issue for LEDs, but it is not proven. 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 4.4. Table 4-1 presents a summary of the LED performance projections in tabular form.

Table 4-1: Summary of LED Device Performance Projections

Metric	2006	2010	2012	2015
Efficacy- Lab (lm/W)	85	129	151	184
Efficacy- Commercial Cool White (lm/W)	68	113	135	168
Efficacy- Commercial Warm White (lm/W)	38	83	105	138
OEM Lamp Price- Product ($/klm)	35	10	5	2
Lamp Life- (1000 hours)	37	50	50	50

Note:
1. Efficacy projections for cool white lamps assume CRI=70 → 80 and a Color temperature = 4100-6500°K, while efficacy projections for warm white lamps assume CRI= >85 and a Color temperature of 2800-3500°K. All efficacy projections assume that devices are measured at 25°C.
2. All lamps are assumed to have a 350 mA drive current, lamp-level specification only (driver/fixture not included), and lifetime as stated in table.
3. Price targets assume "reasonable volumes" (several 1000s), CRI=70 → 80, Color temperature = 4100-6500K, and lamp-level specification only (driver/luminaire not included)
4. Lamp life projections assume 70% lumen maintenance, "1 Watt device," 350 mA drive current.
Source: NGLIA LED Technical Committee, Fall 2006

4.3.2. LEDs in Luminaires

As stated in section 4.2.1, the LED device 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. Provided below in Table 4-2 are luminaire performance projections to complement the device performance projections given in Table 4-1.

Values in Table 4-2 assume a linear progression over time from the current 2006 fixture and driver efficiency values to eventual fixture and driver efficiency 2015 program targets as given in section 4.1.1. After taking into account all of the factors that affect the performance of an LED luminaire and multiplying them by the original device efficacy projections, it was found that the cool white luminaire efficacy 2006 status is 35 lm/W while the 2015 cool white luminaire efficacy projection is 123 lm/W.

Table 4-2: Summary of LED Luminaire Performance Projections (at operating temperature)

Metric	2006	2010	2012	2015
Device Efficacy- Commercial Cool White (lm/W, 25 degrees C)	68	113	135	168
Device Efficacy Commercial Warm White (lm/W, 25 degrees C))	38	83	105	138
Thermal Efficiency	80%	84%	87%	90%
Efficiency of Driver	85%	87%	88%	90%
Efficiency of Fixture	75%	82%	85%	90%
Resultant luminaire efficiency	51%	60%	65%	73%
Luminaire Efficacy- Commercial Cool White (lm/W)	35	59	88	123
Luminaire Efficacy- Commercial Warm White (lm/W)	20	44	68	101

Notes:
1. Efficacy projections for cool white luminaires assume CRI=70 → 80 and a Color temperature = 4100-6500°K, while efficacy projections for warm white luminaires assume CRI= >85 and a Color temperature of 2800-3500°K. All projections assume a 350ma drive current, reasonable lamp life and operating temperature.
2. Efficacies are obtained by multiplying the efficiency degradation by the device efficacy values shown in Table 4-1.
Source: NGLIA LED Technical Committee, Fall 2006

4.3.3. Organic Light Emitting Diodes

In consultation with the NGLIA Technical Committee for general illumination, 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 were prepared, 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 4-9 (plotted on a logarithmic scale) shows the efficacy for laboratory prototypes growing exponentially to exceed 150 lm/W by 2014. Unlike the LED device projection which is based off a product that has had time to mature, the efficacy projection for commercial products does not begin until 2008 (the target date for the first niche OLED products) and lags approximately three years behind the laboratory products. Efficacy for commercial products is projected to reach approximately 100 lm/W by 2015.

These projections assume the CRI and CCT mentioned above and a luminance of 1,000 cd/m^2. These projections apply to a white-light OLED device "near" the blackbody curve (Δc_{xy}<.01), which may be a necessary criterion to market the products for various general illumination applications. 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.

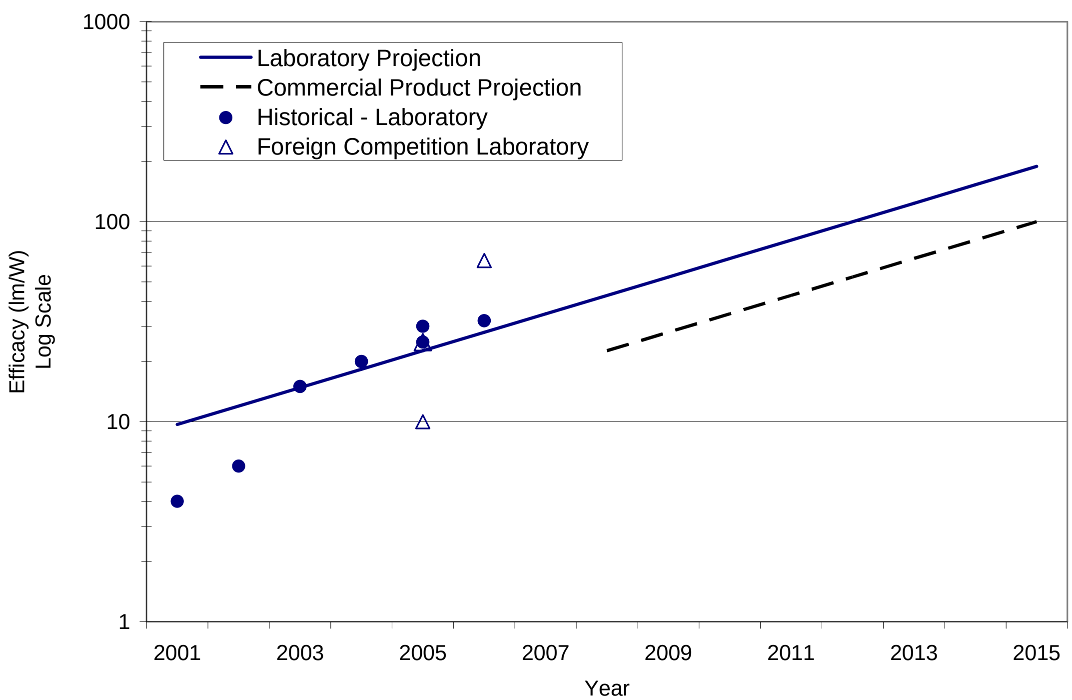

Figure 4-9: White Light OLED Device Efficacy Targets, Laboratory and Commercial (On a logarithmic scale)

Note: Efficacy projections assume CRI = 80, Color temperature = 2700-4100°K ("near" blackbody curve (Δc<.01xy), luminance of 1,000 cd/m^2, and lamp level specification only (driver/luminaire not included).
Source: Projections: NGLIA OLED Technical Committee, Fall 2006, Laboratory Points: Press Releases

Today, the efficacy of OLED devices lags behind LED devices, both in the laboratory and in the market. However, when the projections of commercial LEDs and OLEDs are compared (see Figure 4-10), the efficacy of OLED products should approach that of the LED products in the latter part of the current forecast. This figure reflects the anticipated exponential efficacy improvements of OLED devices as compared to the projected linear improvement in the commercial efficacy of LED devices.

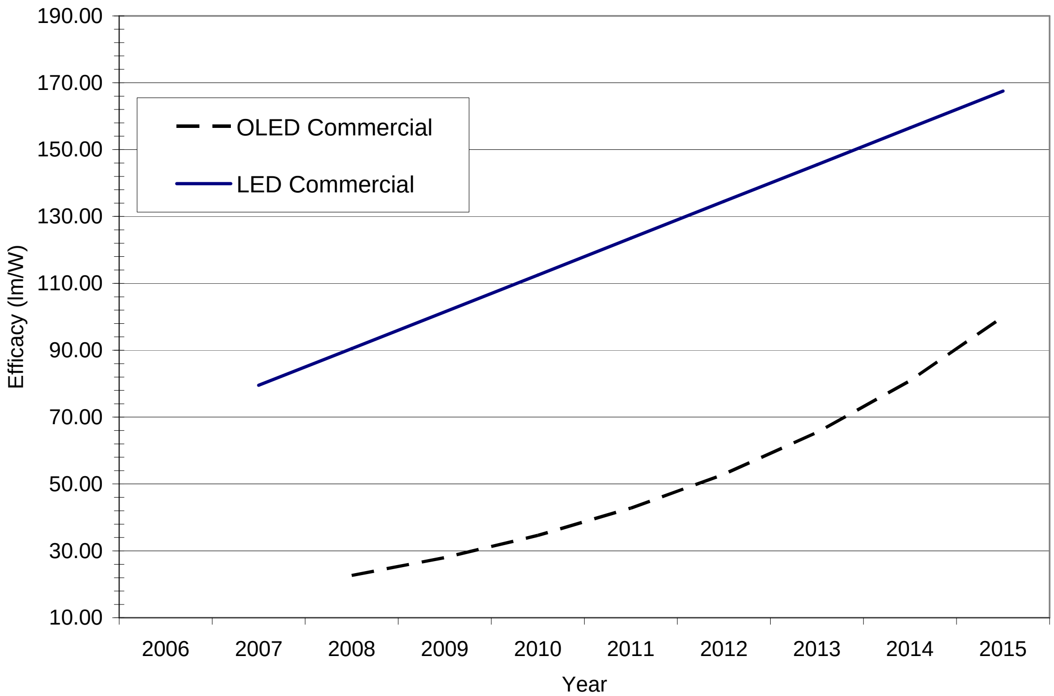

Figure 4-10: LED and OLED Device Efficacy Projections, Commercial

Source: NGLIA OLED Technical Committee and the Department of Energy, Fall 2006

Figure 4-11 presents the projected OEM price of commercially available white-light OLED devices (driver and fixture not included) for a luminance of 1,000 cd/m^2. The OEM lamp price decreases exponentially from an estimated \$100/klm in 2008 to \$10/klm by 2015, assuming reasonable volumes of tens of thousands. The OEM lamp price, measured in \$/m^2 is approximately a factor of three greater than OLED device price when measured in \$/klm for the assumed luminance. 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, an OLED luminaire with a more expensive "lamp/device" may still be cost competitive with a conventional luminaire.

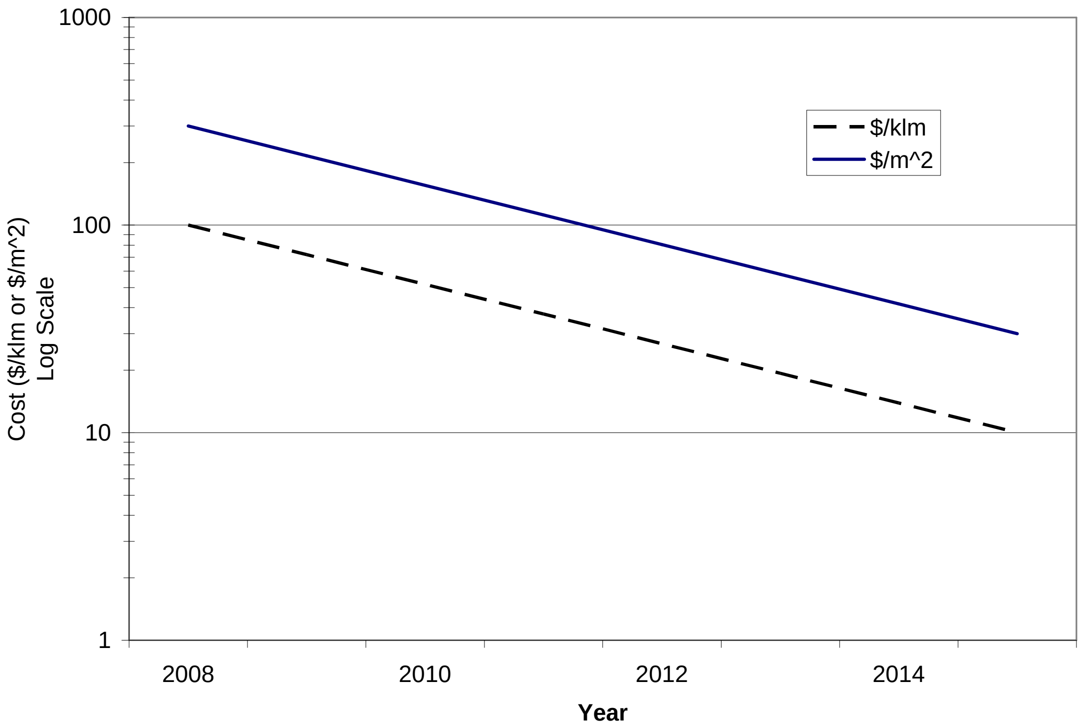

Figure 4-11: White Light OLED Device Price Targets, \$/klm and \$/m^2

(On a logarithmic scale)

Source: NGLIA OLED Technical Committee, Fall 2006

The lamp life for commercial products, measured to 70% lumen maintenance or its "half-life," increases linearly to a value of approximately 40,000 hours in 2015. In the March 2006 version of the SSL MYP, projections were made using 50% lumen maintenance which is industry practice for evaluation of displays. However, in this version we use 70% lumen maintenance in order to compare lifetimes with other lighting products.

Table 4-3 presents a summary of the OLED performance projections in tabular form. Lifetime projections below represent the lifetime of the device, not the entire luminaire. Because the driver may limit the lifetime of the OLED luminaire, improving the lifetime of the driver to at least equal that of the OLED device is a goal of the SSL program.

Table 4-3: Summary of OLED Device Performance Projections

Metric	2006	2007	2010	2012	2015
Efficacy- Lab (lm/W)	28	35	65	100	189
Efficacy- Commercial (lm/W)	N/A	18	35	53	100
OEM Lamp Price- ($/klm)	N/A	139	52	27	10
OEM Lamp Price- ($/m2)	N/A	417	155	80	30
Lamp Life- Commercial Product (1000 hours)	N/A	2	16	25	40

Notes:
1. Efficacy projections assume CRI = 80, Color temperature = 2700-4100°K ("near" blackbody curve (Δc<.01xy), luminance of 1,000 cd/m^2, and lamp level specification only (driver/luminaire not included)
2. OEM Price projections assume CRI = 80, luminance of 1,000 cd/m^2 and lamp level specification only (driver/luminaire not included)
3. Lamp life projections assume CRI = 80, 70% lumen maintenance, luminance of 1,000 cd/m2
Source: NGLIA OLED Technical Committee, Fall 2006

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 4-2. Again, a linear improvement over time is assumed from current 2006 driver and fixture efficiency values to 2015 efficiency program targets as given in Figure 4-5. After taking into account all of the factors that affect the performance of an OLED luminaire and multiplying them by our original device efficacy projections, the 2007 OLED commercial luminaire efficacy status becomes 14 lm/W while the 2015 OLED commercial luminaire efficacy projection becomes 86 lm/W.

Table 4-4: Summary of OLED Luminaire Performance Projections

Metric	2006	2007	2010	2012	2015
Commercial Device Efficacy (lm/W) (Table 4-3)	N/A	18	35	53	100
Efficiency of Fixture	90%	91%	92%	93%	95%
Efficiency of Driver	85%	86%	87%	88%	90%
Total Efficiency from Device to Luminaire	77%	77%	80%	82%	86%
Resulting Luminaire Efficacy-Commercial Product (lm/W)	N/A	14	28	44	86

Notes:
1. Efficacy projections assume CRI = 80, Color temperature = 2700-4100°K ("near" blackbody curve ($\Delta c<.01xy$), luminance of 1,000 cd/m^2, and lamp level specification only
Source: NGLIA OLED Technical Committee, Fall 2006

4.4. 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 edition of the Multi-year program plan, and, because of continuing progress in the technology and better understanding of critical issues are again revised in this edition of the plan. DOE received considerable assistance and public comment in developing the current task priority listing. The NGLIA Technical Committee provided an initial draft of the revised list for consideration by participants at the annual DOE SSL Program Planning workshop held from January 31 to February 2, 2007.

With respect to the March 2006 MYPP the following changes in the highest priority tasks have been made:

For LED Core Technology:

1. Subtask 1.1.3, "Reliability and defect physics for improved emitter lifetime and efficiency", has been added to the priority list. Both the NGLIA team and many workshop participants recognized that as product technology matures the issues of reliability will become increasingly important. A better understanding of many failure mechanisms in LEDs is needed in order to make progress.

2. Subtask 1.2.1, "Device approaches, structures and systems", was moved to a lower priority. In part this change reflects the great strides that have been made in the design of LEDs for general illumination. While this will always be an important aspect of LED development, and many participants at the workshop felt this change should not be made, DOE currently believes other issues are more pressing.

3. There was considerable discussion about subtask 1.1.1, “Large-area substrates, buffer layers, and wafer research.” Like 1.2.1, many participants believed this area of research is at a sufficient state of development that it no longer needs to be among the top priorities. However, after consideration of all of the inputs and reviewing the state of the art, DOE decided to leave this task as a top priority. It is thought that there still may be room for improvements that will lead to lower costs, better chip yields and improved reliability through further work on substrates.

For LED Product Development:

1. Subtask 2.3.6, “Evaluate luminaire lifetime and performance characteristics”, has been added in recognition of the importance of luminaire reliability and performance in realizing a successful SSL product. This addition was well-supported both by the NGLIA team and the workshop participants.

2. Subtask 2.2.3, “Electronics Development” was removed from the priority list. In addition, it was combined with subtask 2.3.3 as the objectives were related and overlapping. While DOE recognizes the importance of this task to successful product development, there is some question as to how effective funding of these efforts will be at this time. There are still a number of underlying performance issues that need to be solved before a “final” electronics approach can be defined. The importance of electronics in determining the lifetime of the luminaire is recognized (as primarily an electronic component lifetime issue) and is called out in other reliability-related tasks.

3. There was consideration and some support for removing subtask 2.2.2, “LED packages and packaging materials”, from the high- priority list. After reviewing all the inputs, however, DOE decided to keep the task as a high priority because serious thermal issues must still be resolved.

For OLED Core Research:

1. Subtask 3.2.1, “Strategies for improved light extraction” has been moved up to the high priority list in recognition of both the difficulty of extracting light out of a planar OLED structure and of promising innovations that may greatly improve this situation. This change was proposed by the NGLIA and supported at the workshop.

2. Subtask 3.1.3, “Improved contact materials and surface modification techniques to improve charge injection” was also added. Although this task did not receive a lot of discussion, DOE felt that there is still considerable room for improvement in charge injection which can directly contribute to better efficiencies and device performance.

3. 3.1.2 and 3.2.2 have been combined as they are nearly identical tasks. Subtask 3.4.3 is now numbered 3.4.2 as there were redundancies on the original list.

For OLED Product Development:

1. Subtask 4.4.1, “Module and process optimization and manufacturing” has been added to the priorities. Much OLED development is directed at displays and there is a need to consider how the manufacturing will need to be adapted to best serve the needs of general illumination. This addition was widely supported by both the NGLIA and workshop participants.

2. Subtasks 4.1.2 and 4.2.2 have been combined as the objectives were clearly overlapping.

Along with the priority changes noted above, there was considerable discussion both with the NGLIA team and with workshop participants regarding some areas where the task titles or descriptions were not clear or else were overlapping. Changes made to Table 4-5 to Table 4-16 are intended to clarify these areas of confusion and also to better delineate the objectives of the various tasks. Also, metrics to measure each task have been provided, together with the perceived status of that metric and a target for the program for the year 2015. There are a few cases, particularly where a task has been added, for which the status or targets are not well-defined at this time. As progress is made in these areas, DOE will provide more specific guidance as to expectations.

As in the last edition of the MYP, the following continuation tables list some additional “later priority” and “long term priority” tasks which may ultimately need attention to achieve the overall goals of the program. All of the tasks below were not discussed at the 2007 Solid State Light Program Workshop Breakout Sessions. For a summary of the discussion in each Session, see the 2007 *Solid-State Lighting Program Planning Workshop Report*, available at: http://www.netl.doe.gov/ssl/publications.html.

Table 4-5: LED Core Technology Research Tasks and Descriptors (2007-Priority Tasks)

Subtask		Short Descriptor	Metric	2006	Program Target (2015)
Core Technology					
1.1.2	High-efficiency semiconductor materials	Improve IQE across the visible spectrum and in the near UV (down to 360 nm)	IQE[34]	20% green, 80% red, 60% blue	90%
1.3.1	Phosphors and conversion materials	High-efficiency wavelength conversion materials for improved quantum yield, optical efficiency, and color stability	Quantum Yield Scattering losses Color stability	80% (green-yellow)	90% across the visible spectrum
1.1.3	Reliability and defect physics for improved emitter lifetime and efficiency	- Dopant and defect physics - Device characterization and modeling - Investigation of droop (reduced efficiency at high temperature and current density)	Lifetime Efficiency at high current density		$_{70}$[35] = 50 khrs 150 lm/W at 150 A/cm^2
1.1.1	Large-area substrates, buffer layers, and wafer research	Develop low cost, high quality substrates that enable epitaxial growth of high quality emitting material	Defect Density		$10^5/cm^2$
1.2.2	Strategies for improved light extraction and manipulation	Improved chip level extraction efficiency and LED system optical efficiency, including phosphor scattering and encapsulation.	Chip extraction efficiency (χ)	L 70%	90%

[34] IQE and EQE status and projections assume pulsed measurements.
[35] Time for light output to fall to 70% of initial value (following burn-in).

Table 4-6: LED Core Technology Research Tasks and Descriptors (Later Priority Tasks)

Subtask		Short Descriptor	Metric	2006	Program Target (2015)
Core Technology					
1.2.1	Device approaches, structures and systems	Alternative emitter geometries and emission mechanisms, i.e. lasing, surface plasmon enhanced emission	EQE	50%	80%
1.3.2	Encapsulants and packaging materials	Create high temperature (~185C), long-life encapsulants and packaging materials. Also includes work to develop thermal management strategies and modeling of encapsulants.			
1.3.4	Measurement metrics and color perception	Standardizing metrics to measure electrical and photometric characteristics of LED devices.			
1.4.x[36]	Inorganic growth and fabrication processes and manufacturing research.	Physical, chemical, optical modeling, measurement, and experimentation for substrate and epitaxial process; design and development of in-situ diagnostics tools for the substrate and epitaxial process; low cost, high-efficiency reactor designs and manufacturing methods; and investigation of die separation, chip shaping, and wafer bonding techniques.			

Table 4-7: LED Core Technology Research Tasks and Descriptors (Long Term Priority Tasks)

Subtask		Short Descriptor
Core Technology		
1.3.3	Electrodes and interconnects	Low resistance electrodes

[36] There are several subtasks to 1.4, designated “x”; all need attention.

Table 4-8: LED Product Development Tasks and Descriptors (2007-Priority Tasks)

Subtask		Short Descriptor	Metric	2006	Program Target (2015)
Product Development					
2.3.1	Optical coupling and modeling	Solving problem of extracting LED photons and getting them to the task. This includes issues such as coupling to multiple sources and the multi-shadowing problem.	Optical/Fixture Efficiency	70%	90%
2.2.1	Manufactured materials	Includes phosphors and luminescent materials and high temperature encapsulants and mounting materials.[37]	% of original transmission per mm	85-90% (@150C and 10-15 kHrs)	95% (@150C Junction Temp. and 50 kHrs)[38]
2.2.2	LED packages and packaging materials	Solving problem of removing heat from the chip, delivering high-lumen output chips with low resistance contacts.			
2.3.4	Thermal design	Solving problem of removing heat away from the emitter chip and reducing thermal resistance to keep LED device at a low operating temperature while integrating the packaged LED device into a luminaire.	Thermal resistance (Junction to case)	8-9ºC per Watt	5ºC per Watt
2.3.6	Evaluate luminaire lifetime and performance characteristics	Develop reliability information on luminaire performance characteristics	Mean time to failure	May be limited by driver lifetime	As good as source lifetimes – >40K hours

[37] NGLIA Technical Committee suggested breaking out this subtask as it represents several different types of materials efforts.
[38] This target may change to 185C as efficiency goals are met and cost becomes a higher priority

Table 4-9: LED Product Development Tasks and Descriptors (Later Priority Tasks)

Subtask		Short Descriptor	Metric	2006	Program Target (2015)
Product Development					
2.1.2	High-efficiency semiconductor materials	Improve IQE across the visible spectrum and in the near UV (down to 360 nm)	IQE	20% green, 80% red, 60% blue	90%
2.1.3	Implementing strategies for improved light extraction and manipulation	Develop high refractive index encapsulants for improved light extraction and large-area light extraction and current injection			
2.2.3, 2.3.3	Electronics Development	-Develop lower cost, more compact, reliable, and efficient drivers with longer lifetime -Control electronics for RGB color stability	%Energy Conversion $/Watt X-step Macadam Ellipse Lifetime	85% $0.50 /Watt 7-step Macadam Ellipse 20-50 kHrs[39]	90+% $0.10 /Watt 4-step Macadam Ellipse 50 kHrs
2.4.x[40]	Inorganic growth and fabrication processes and manufacturing issues.	Incorporate proven in-situ diagnostics into existing equipment; develop low-cost, high efficiency reactor designs; and develop techniques of die separation, chip shaping, and wafer bonding techniques.			

[39] Some 50 kHr devices exist today, but these are presently military specification and are too costly for general illumination applications.
[40] There are several subtasks to 2.4, designated "x"; all need attention.

Table 4-10: LED Product Development Tasks and Descriptors (Long Term Priority Tasks)

Subtask		Short Descriptor
Product Development		
2.1.1	Substrate, buffer layer and wafer engineering and development	
2.1.4	Device architectures with high power-conversion efficiencies	Chip scaling and micro-arrays; Multi-color chips, arrays on a single substrate
2.2.4	Evaluate component lifetime and performance characteristics	
2.3.2	Mechanical design	
2.3.5	Evaluate human factors and metrics	

Table 4-11: OLED Core Technology Research Tasks and Descriptors (2007-Priority Tasks)

Subtask		Short Descriptor	Metric	2006	Program Target (2015)
Core Technology					
3.1.2, 3.2.2	Novel materials and device architectures.	Single and multi-layered device structures to increase IQE, reduce voltage, and improve device lifetime.	IQE[41] Voltage L_{70}	B>20%, G 100%, R 60% 4-5 V 	100% IQE over the visible spectrum 2.8 V 40,000 hrs
3.2.1	Novel strategies for improved light extraction	Optical and device design for improving light extraction.	Extraction Efficiency	30%-40%	80%
3.1.3	Improved contact materials and surface modification techniques to improve charge injection	n- and p- doped polymers and molecular dopants with emphasis on new systems and approaches for balanced charge injection, low voltage, and long lifetime.	Operating voltage	4-5 V	2.8 V
3.2.3	Research on low-cost transparent electrodes	Better transparent electrode technology that offers an improvement over ITO cost and deposition rate and allows for roll-to-roll manufacturing	Ohms/□ Transparency over the visible spectrum $\$/m^2$	40 Ohms/□ (flexible) 75-80% 	<10 Ohms/□ (flexible) 92% $<\$1/m^2$
3.4.2	Investigation of low-cost fabrication and patterning techniques and tools	Development of low cost deposition techniques	Deposition Speed Material utilization Cost/area		

41 As noted in Section 4.5.2, these metrics should be measured at a reference brightness of $1000 cd/m^2$.

Table 4-12: OLED Core Technology Research Tasks and Descriptors (Later Priority Tasks)

Subtask		Short Descriptor	Metric	2006	Program Target (2015)
Core Technology					
3.1.4	Applied Research in OLED devices	Understand the underlying issues limiting performance in organic light emitting devices.			
3.3.2	Low-cost encapsulation and packaging technology	Low-cost ways to seal the device to protect the luminaire from its environment to ensure a long device lifetime.			

Table 4-13: OLED Core Technology Research Tasks and Descriptors (Long Term Priority Tasks)

Subtask		Short Descriptor
Core Technology		
3.1.1	Substrate materials for electro-active organic devices	
3.3.1	Down conversion materials	
3.3.3	Electrodes and interconnects	
3.3.4	Measurement metrics and human factors	Productivity, preference, and demonstrations; Standards for electrical and photometric measurement
3.4.1	Physical, chemical and optical modeling for fabrication of OLED devices	

Table 4-14: OLED Product Development Research Tasks (2007-Priority Tasks)

Subtask		Short Descriptor	Metric	2006	Program Target (2015)
Product Development					
4.1.2, 4.2.2	Practical implementation of materials and device architectures.	Developing architectures and materials that concurrently improve robustness, lifetime and efficiency and the optimization of materials that show mass production potential.	Efficacy[42,43] CRI Voltage L_{70}	32 lm/W	>100 lm/W 90 2.8 V L_{70} = 40 khrs
4.2.1	Practical application of light extraction technology.	Improving on known approaches for extracting light.	Extraction Efficiency	25-30%	80%
4.1.1	Low-cost substrates	Developing low cost, readily available substrates that enable robust device operation	Cost		< $\$3/m^2$
4.4.1	Module and process optimization and manufacturing	Inventing and adapting OLED manufacturing technologies to the needs of lighting.	Luminaire cost/m^2		< $\$30/m^2$
4.3.1	OLED encapsulation packaging for lighting applications	Research in heat management, encapsulants, and encapsulants with reduced water permeability.	$\$/m^2$ %dark spot area Loss penalty (compared to glass)	$\$4/m^2$	< $\$3/m^2$ <10% dark spots at 5 year shelf life 0%

[42] This efficacy refers to an OLED device absent of any effort to improve light extraction efficiency.
[43] As noted in Section 4.5.2, these metrics should be measured at a reference brightness of 1000cd/m^2.

Table 4-15: OLED Product Development Research Tasks (Later Priority Tasks)

Subtask		Short Descriptor	Metric	2006	Program Target (2015)
Product Development					
4.1.3	Improved contact materials and surface modification techniques to improve charge injection	Research into n- and p- doped polymers and molecular dopants with emphasis on new systems and approaches for balanced charge injection, low voltage, and long lifetime.			
4.2.3	Demonstrate device architectures: e.g., white-light engines (multi-color versus single emission)	Includes demonstrating a device that scalable.			

Table 4-16: OLED Product Development Research Tasks (Long Term Priority Tasks)

Subtask		Short Descriptor
Product Development		
4.3.2	Simulation tools for modeling OLED devices	
4.3.3	Voltage conversion, current density and power distribution and driver electronics	
4.3.4	Luminaire design, engineered applications, field tests and demonstrations	
4.4.2	Synthesis manufacturing scale-up of active OLED materials	
4.4.3	Tools for manufacturing the lighting module	

4.5. 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 a milestone description, it is assumed that progress on the others is proceeding, but the task priorities are chosen to emphasize the identified milestone.

4.5.1. Light Emitting Diodes

The interim (FY08) LED milestone reflects a goal of producing an LED product with an efficacy of 80 lm/W, an OEM price of $25/klm (lamp only), and a life of 50,000 hrs with a CRI greater than 80 and a CCT less than 5000°K. With this performance it would be a "good" general illumination product that could achieve significant market penetration. Current laboratory devices have reached an efficacy of approximately 95 lm/W; so it is expected that this target will be reached in commercial products in 2008 (a one and a half year lag). The 2008 price and life targets represent a 70% improvement over current products, and therefore pose a significantly larger challenge. By FY10, it is expected that the interim goal of 100 lm/W will be exceeded. Other parameters will also progress, but the task priorities are set by the goal of reaching this particular mark. Finally, by FY15, the end of the current forecast period, costs should be below $2/klm for LED devices while also meeting other performance goals, as outlined above.

Table 4-17: LED Product Milestones

Milestone	Year	Milestone Target
Milestone 1	FY08	80 lm/W, < $25/klm, 50,000 hrs
Milestone 2	FY10	> 100 lm/W
Milestone 3	FY15	< $2/klm

Assumption: CRI > 80, CCT < 5000°K

Using the subtask descriptions in the tables in the previous section, it is possible to associate those that must show significant early progress with the individual milestones. This linkage is graphically shown in the Gantt charts that follow. On these charts, the "2006-priority" subtasks, as defined in the Fall of 2006 by NGLIA are bold. The additional "later-priority" subtasks are not bolded.
The key to these charts is described below:

Key:
- Milestone (Occur at end of fiscal year, so blocks are placed in following year)
- Priority Tasks for M1 (FY08)
- Priority Tasks for M2 (FY10)
- Priority Tasks for M3 (FY15)

For example, to reach Milestone 1, a commercial LED product for general illumination in FY08, progress is necessary in several subtasks in core technology and product development. The duration of these activities are shown in yellow with crosshatching. To reach Milestone 2, an efficacy target of >100 lm/W, additional research is necessary on the subtasks shown in green with diagonal lines. To reach Milestone 3, a price target of <$2/klm, additional research is necessary on the subtasks shown in blue with vertical lines.

There is not enough detail in the subtasks as defined to identify strict linkages and required "predecessor" tasks that would define a critical path to the various milestones. Nonetheless, the chart identifies, at least to some extent, those tasks that must see significant progress in order to meet the objectives and thus provides a basis for deciding work priorities. But additional work on the early tasks will also be needed *after* meeting the early milestones in order to continue progress towards the overall program goals. Thus, on the Gantt charts, an individual task may show two or even all three colors or patterns over the time period from now to 2015.

Table 4-18: Planned Research Tasks – LEDs

Task	Description[44]	FY'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16
1.1.2	High efficiency semic. materials											
1.2.1	Device approaches, structures, systems											
1.2.2	Strategies for improved light extraction.											
2.2.2	LED packages & packaging materials											
2.3.4	Thermal design											
2.2.1	Manufactured materials											
M1	***Niche lighting product by 2008***											
1.3.1	High efficiency phosphors…											
1.3.4	Measurement metrics…											
1.3.2	Encapsulants & packaging mtls.											
2.1.3	Implementing strategies for light extrac.											
2.3.6	Eval luminaires lifetime & performance											
2.4.x	…manufacturing issues											
M2	***>100 lumens/watt by 2010***											
1.1.1	Large area substrates, …											
1.1.3	Reliability & defect physics…											
1.4.x	…manufacturing research											
2.3.1	Optical coupling & modeling											
2.2.3, 2.3.3	Electronics development											
2.1.2	High efficiency semic. materials											
M3	***<$2/klm by 2015***											

Source: NGLIA LED Technical Committee Date: March 2007.

[44] For a short description of these subtasks, see Table 4-5 to Table 4-10.

4.5.2. Organic Light Emitting Diodes

The interim (FY08) OLED milestone is to produce an OLED niche product with an efficacy of 25 lm/W, an OEM price of $100/klm (lamp only), and a life of 5,000 hrs. CRI should be greater than 80 and the CCT should be between 3,000-4,000°K. Importantly, the NGLIA team also thought that a luminance of 1000 cd/m^2 could be used to compare the accomplishments of different researchers. That is *not* to say that lighting products may not be designed at higher luminance levels.

Current laboratory devices have reached an efficacy of approximately 31 lm/W (at reasonable life, luminance, and CCT). Because it normally takes three years to develop a laboratory device into an equally efficient commercial product, the SSL OLED program will be able to meet the FY08 (Milestone 1) efficacy target. The FY08 price and life targets, however, represent a 70% improvement over current laboratory devices, which still pose a large challenge. As there are currently no general illumination products for OLEDs, this milestone is an ambitious goal, but one the group thought was necessary to maintain a healthy program.

Milestone 2 targets a price of less than $52/klm by FY10. Inasmuch as there are no "prices" today, this is a difficult target to set at this point. Nonetheless, reaching a marketable price for an OLED lighting product, with their large areas is seen as one of the critical steps to getting this technology into general use.

Despite the considerable challenges the first two milestones offer, industry representatives agreed that reaching the 100 lm/W target by FY15 in Milestone 3 is one of the largest challenges because there are so many different performance parameters that will need to be improved.

Table 4-19: OLED Product Milestones

Milestone	Year	Milestone Target
Milestone 1	FY08	25 lm/W, < $100/klm, 5,000 hrs
Milestone 2	FY10	<$52/klm
Milestone 3	FY15	40,000 hrs., > 100 lm/W

Assumptions: CRI > 80, CCT < 2700-4100°K, luminance = 1,000 cd/m^2

The key for the OLED Gantt chart is the same as for the LED chart.

Table 4-20: Planned Research Tasks - OLEDs

Task	Description[45]	FY'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16
3.3.2	Low cost encapsulation…technology											
3.1.2, 3.2.2	High-efficiency..materials..architectures…											
3.2.1	Strategies for improved light extraction…											
4.1.2, 4.2.2	High-efficiency..materials..architectures …for robustness…increased lifetime.											
4.3.1	OLED encapsulation…											
4.2.1	Implementing..improved light extraction											
4.1.1	Substrates…											
M1	***Niche product by FY08***											
3.2.3	...low-cost transparent electrodes											
3.4.2	…low-cost fabrication ..and tools											
3.1.3	Improved contact materials…											
4.4.1	Module and process optimization..											
4.1.3	Improved contact materials…											
M2	***<$52/klm by FY10***											
3.1.4	Applied Research in OLED devices											
4.2.3	Demonstrate device architectures…											
M3	***40 khrs, 100 lm/w by FY15***											

Source: NGLIA OLED Technical Committee Date: March 2007.

[45] For a short description of these subtasks, see Table 4-11 and Table 4-16 .

5.0 Solid-State Lighting Portfolio Management Plan

The Department'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 the Department'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 the Department'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.

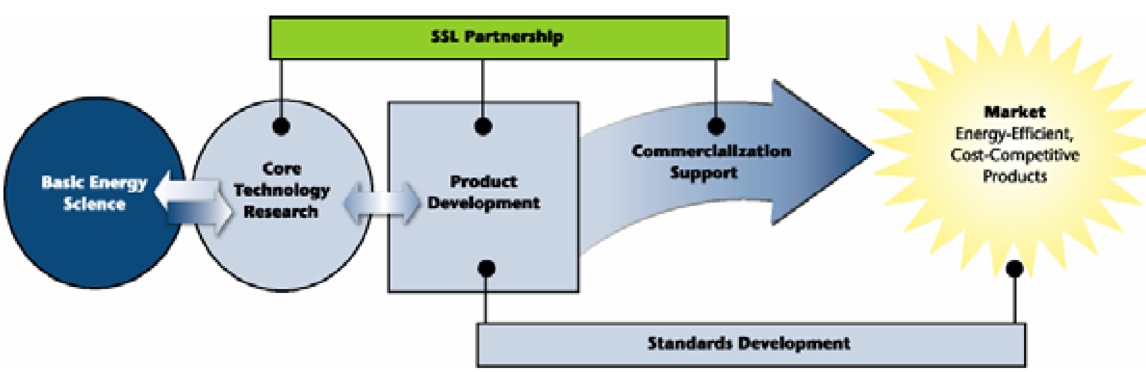

Figure 5-1: Interrelationships within DOE Solid-State Lighting Activities

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 luminaires. 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.

For definitions of Core Technology Research and Product Development, see Appendix E.

Commercialization Support Activities Facilitate Market Readiness. To ensure that DOE investments in Core Technology Research 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 planning a full range of activities, including:

- ENERGY STAR® designation for SSL technologies and products
- Design competitions for lighting fixtures and luminaires using SSL
- Coordination with utility promotions and regional energy efficiency programs
- 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
- Consumer and business awareness programs
- Information resources for lighting design professionals and students

SSL Partnership Provides Manufacturing and Commercialization Focus. Supporting the DOE SSL portfolio is the SSL Partnership between DOE and the Next Generation Lighting Industry Alliance (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 will provide input to shape Core Technology Research priorities, and will accelerate 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 Product Comparisons. The development of national standards and rating systems for new products enables consumers to compare products made by different manufacturers, since all companies must test their products and apply the rating in the same way. No ratings or standards have been set yet for SSL products, but DOE is working with the National Electrical Manufacturers Association (NEMA), NGLIA, and other industry and research organizations to begin development of needed metrics, codes, and standards.

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 a **SSL Partnership** that provides significant input to shape the Core Technology Research priorities.

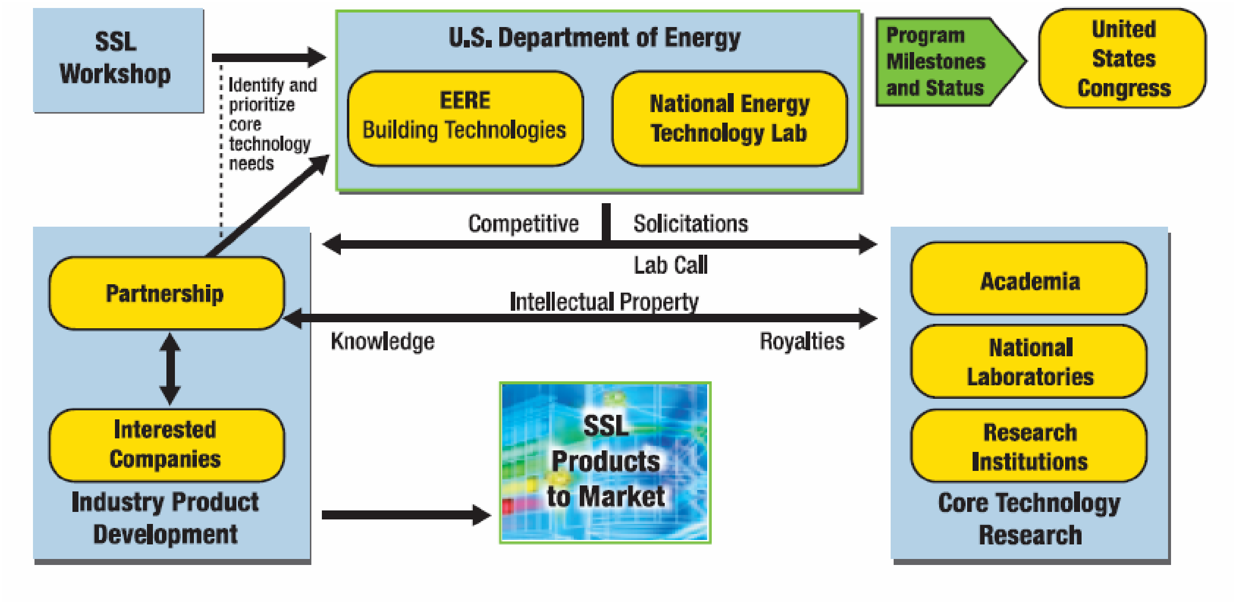

Figure 5-2: Structure of DOE SSL Operational Plan

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 Core Technology Research 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 individual research needs to DOE program managers, who in turn, shape these needs into the Core Technology Research solicitations.

Core Technology Research. 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 identified by the Partnership. Participants in the Core Technology Research 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 Research projects are peer-reviewed by Government personnel, independent organizations, and the SSL Partnership.

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 offerors 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.

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 Research 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 Research projects
- Provide individual project reviews by DOE

Figure 5-3: SSL Operational Plan Process

5.3. Portfolio Decision-Making Process

The Department 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 the Department may pursue through several consultative workshops held by the Department:

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

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

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

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

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

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

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

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

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

During 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[46].

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 the Department'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

[46] "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.

ultimate goal of bringing energy-efficient, cost-competitive products to the market.

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 in Bethesda, Maryland, focused on basic research needs for solid-state lighting (SSL). James Brodrick, DOE Lighting R&D 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 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.[47] 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:

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[47] 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

- 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 (MOA) with the Next Generation Lighting Industry Alliance (NGLIA) creating and clarifying the expectations for the Partnership.

The NGLIA, administered by the National Electrical Manufacturers Association (NEMA), is an alliance of for-profit corporations, established to accelerate SSL development and commercialization through government-industry partnership. As of February 2006, the NGLIA was made up of sixteen corporations —3M, Acuity Brands Lighting, Air Products & Chemicals, Inc., CAO Group Inc., Color Kinetics Inc., Corning, Inc., Cree Inc., Dow Corning Corporation, Eastman Kodak Company, General Electric Company, Lumination LLC, Light Prescriptions Innovators, LLC (LPI, LLC), OSRAM Sylvania Inc., Philips Electronics North America Corporation, Ruud Lighting, Inc. — though they are 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 the Department'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 F.

5.4. Quality Control and Evaluation Plan

The Solid State Lighting (SSL) Research & Development (R&D) 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 (LR&D) 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:

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.

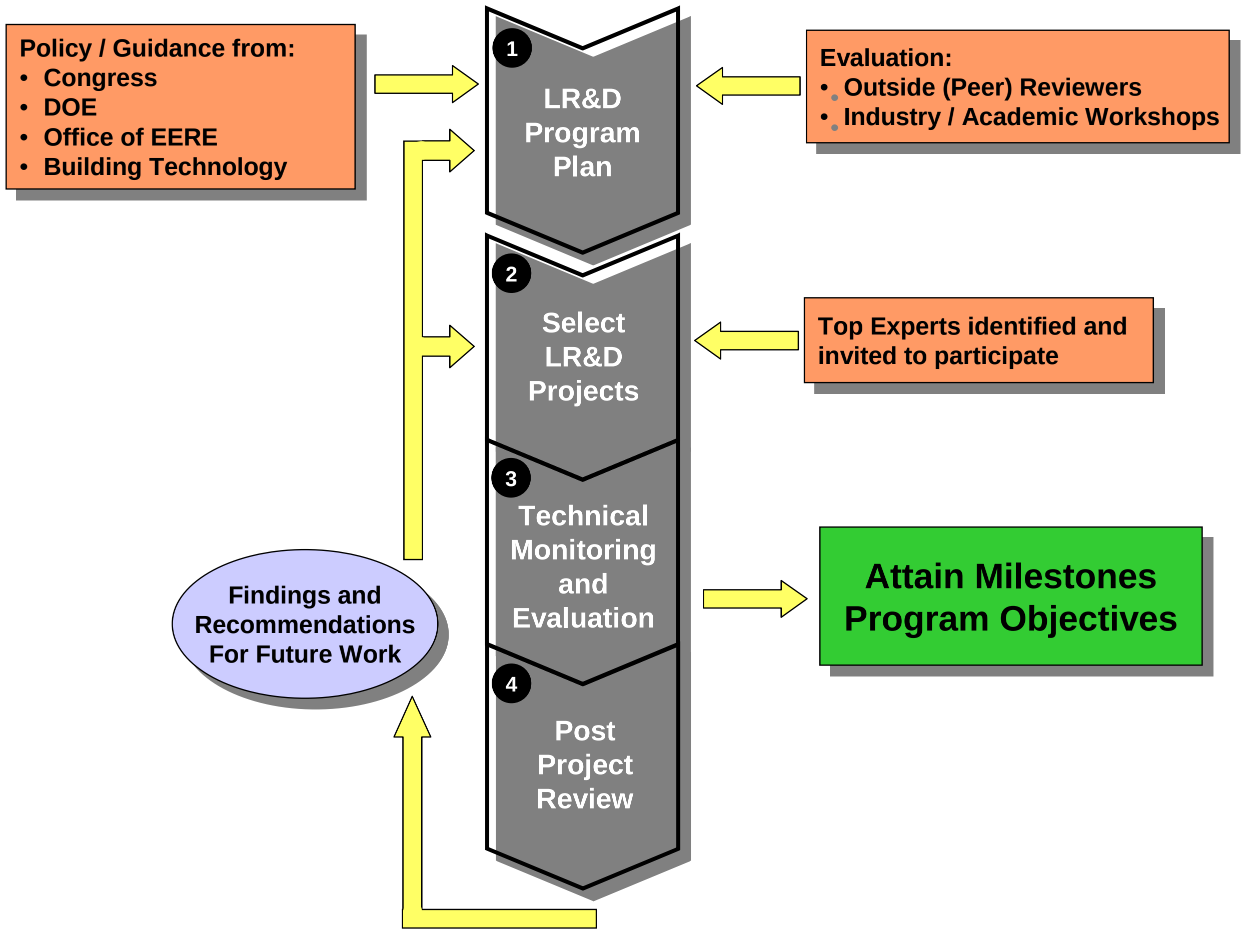
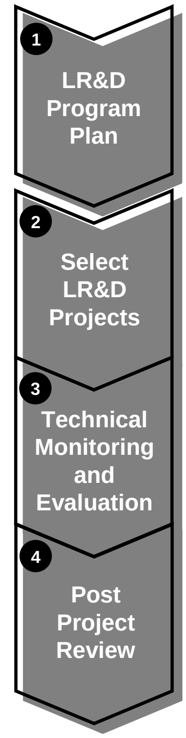


Figure 5-4: Four Step Quality Control and Evaluation Plan for LR&D Program

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.[48]
    - 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.[49]
    - 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 (SSL) 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

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

the national lighting inventory (Phase I) and a detailed market model based on paybacks. First edition completed April 2001. Second edition completed November 2003.[50]

- 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:

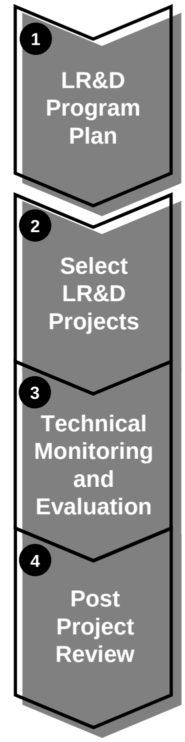
- Planning for the coming fiscal year starts in April / May by reviewing the present year's projects:
    - Review progress made in the context of the aforementioned planning tools
    - Assess any new or appropriate alternative technologies and/or approaches
- Determine new or revise existing milestones 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.

[50] This report is located at: http://www.netl.doe.gov/ssl/PDFs/SSL%20Energy%20Savi_ntial%20Final.pdf

Table 5-1: LR&D Program – Recent and Upcoming 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
High Intensity Discharge (HID) Lighting Technology Workshop	HID	11/15/05
Solid State Lighting Program Planning Workshop#3Orlando, FL	SSL R&D	02/01/06 – 02/03/06
Commercial Product Testing Program Workshop – Washington, DC	SSL R&D	10/27/06
Solid State Lighting Program Planning Workshop#4 – Phoenix, AZ	SSL R&D	1/31/07-2/02/07
Market Introduction Workshop - "Voices for SSL Efficiency: Opportunities to Partner and Participate" – Pasadena, CA	SSL R&D	4/23/07-4/24/07

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 the subsequent Figure. 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. The Department 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.

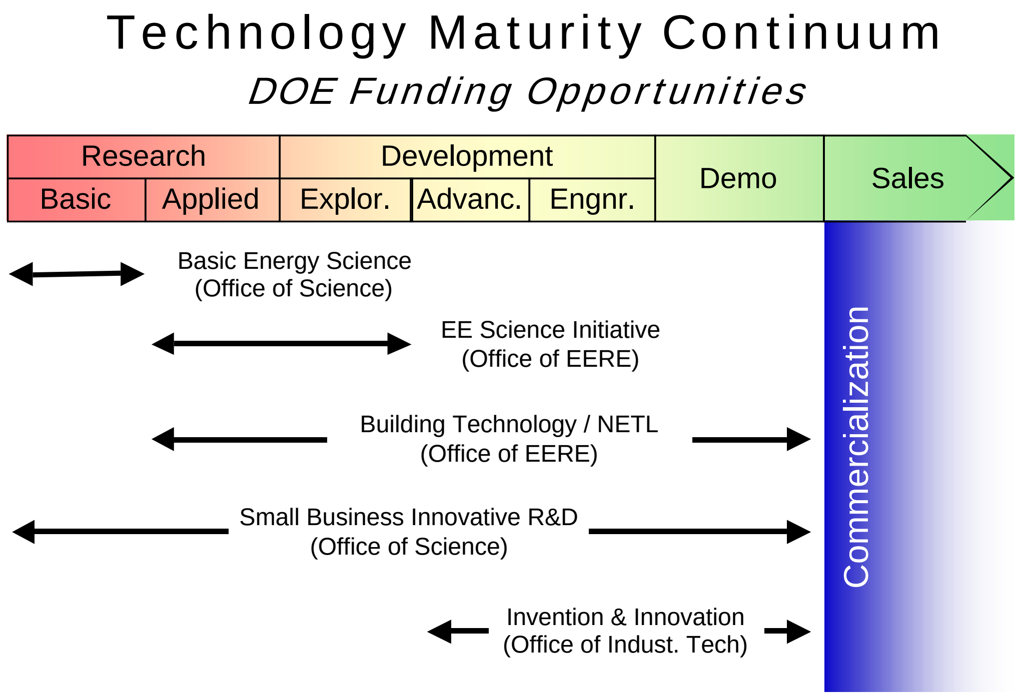
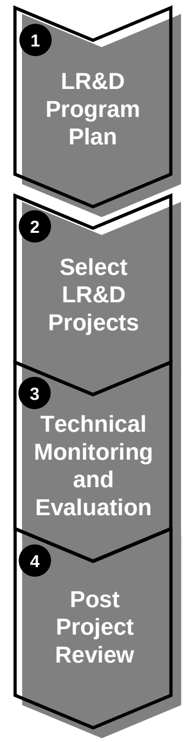


Figure 5-5: Approximate technology maturity coverage of selected DOE R&D programs

- Develop new and utilize existing competitive solicitations:
  - 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.
  - EESI proposals have been issued only twice before but were immensely successful in attracting the attention of academia and organizations wishing to become more engaged in basic research supporting advanced lighting technologies. It is anticipated that these EE-level solicitations will continue in the future and will remain restricted to academic institutions as the primary participants.
  - 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.
    - 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'06:

The following schedule represents the project review meetings for FY'06 and FY'07 that cover the NETL, SBIR, EESI, States R&D and other project areas. At these meetings, the Department will be using the QC&E tools described above to assess technical and programmatic performance.

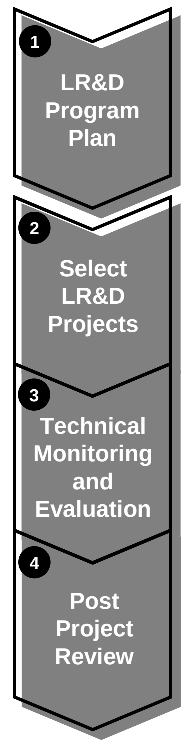
Table 5-2:.LR&D Program Project Review Meetings for FY'06 and FY'07

PI and Contract Title	Funding Source	Objective	Date
DE-FC26-03NT41942 Cermet, Inc.	LR&D Direct	Final Briefing	Nov 06
DE-FC26-05NT42340 Cree, Inc.	LR&D Direct	Budget Period #2 Progress Review	Nov 06
DE-FC26-05NT42344 Dow Corning Corporation - MI	LR&D Direct	Budget Period #2 Progress Review	Nov 06
M6442285 Sandia National Laboratories (SNL)	LR&D Direct	Final Briefing	Nov 06
DE-FC26-03NT41943 Cree, Inc.	LR&D Direct	Final Briefing	Dec 06
M6442286 Sandia National Laboratories (SNL)	LR&D Direct	Final Briefing	Dec 06
DE-FC26-03NT41941 Brown University	LR&D Direct	Final Briefing	Mar 07
DE-FC26-03NT41946 Georgia Tech Research Corporation	LR&D Direct	Final Briefing	Mar 07
DE-FC26-05NT42341 Light Prescriptions Innovators	LR&D Direct	Final Briefing	Mar 07
DE-FC26-06NT42863 Technologies and Devices International, Inc.	LR&D Direct	Final Briefing	Jun 07
DE-FG02-04ER84113 Universal Display Corporation	SBIR	Final Briefing	Jul 07
DE-FC26-04NT42271 University of Florida	LR&D Direct	Final Briefing	Sep 07
DE-FC26-04NT42272 University of Southern California	LR&D Direct	Final Briefing	Sep 07
DE-FC26-04NT42274 University of California, San Diego	LR&D Direct	Final Briefing	Sep 07
DE-FC26-04NT42275 Boston University	LR&D Direct	Final Briefing	Sep 07

PI and Contract Title	Funding Source	Objective	Date
M6442287 Los Alamos National Laboratory (LANL)	LR&D Direct	Final Briefing	Sep 07
M6442288 Pacific Northwest National Laboratory (PNNL)	LR&D Direct	Final Briefing	Sep 07
M6643036 Oak Ridge National Laboratory (ORNL)	LR&D Direct	Final Briefing	Nov 07
DE-FC26-05NT42340 Cree, Inc.	LR&D Direct	Budget Period #2 Progress Review	Jan 07
DE-FC26-04NT42277 Regents of the Univ. of Calif., Santa Barbara Dept., Div. or Unit:	LR&D Direct	Budget Period #2 Progress Review	Jan 07
DE-FC26-06NT42862 Purdue University	LR&D Direct	Budget Period #1 Progress Review	Apr 07
DE-FC26-06NT42855 University of Florida	LR&D Direct	Budget Period #1 Progress Review	May 07
M6642868 Sandia National Laboratories (SNL) - NM	LR&D Direct	Budget Period #1 Progress Review	Jun 07
M6642869 Lawrence Berkeley National Laboratory (LBNL)	LR&D Direct	Budget Period #1 Progress Review	Jun 07
DE-FC26-06NT42857 University of California, Santa Barbara	LR&D Direct	Budget Period #1 Progress Review	Jul 07
DE-FC26-06NT42858 Agiltron, Inc.	LR&D Direct	Budget Period #1 Progress Review	Jul 07
DE-FC26-06NT42864 Eastman Kodak Company - State Street	LR&D Direct	Budget Period #1 Progress Review	Jul 07
M6642870 Los Alamos National Laboratory (LANL)	LR&D Direct	Budget Period #1 Progress Review	Jul 07
DE-FC26-06NT42860 Rensselaer Polytechnic Institute	LR&D Direct	Budget Period #1 Progress Review	Aug 07

PI and Contract Title	Funding Source	Objective	Date
DE-FC26-06NT42861 Research Triangle Institute	LR&D Direct	Budget Period #1 Progress Review	Aug 07
DE-FC26-05NT42342 Philips Lighting	LR&D Direct	Budget Period #1 Progress Review	Sep 07
DE-FC26-05NT42343 GE Global Research	LR&D Direct	Budget Period #1 Progress Review	Sep 07
DE-FC26-06NT42856 Georgia Tech Research Corporation	LR&D Direct	Budget Period #2 Progress Review	Sep 07
DE-FC26-06NT42859 University of North Texas	LR&D Direct	Budget Period #2 Progress Review	Sep 07
DE-FC26-06NT42932 Color Kinetics Incorporated	LR&D Direct	Budget Period #1 Progress Review	Sep 07
DE-FC26-06NT42933 Eastman Kodak Company	LR&D Direct	Budget Period #1 Progress Review	Sep 07
DE-FC26-06NT42934 GE Global Research	LR&D Direct	Budget Period #1 Progress Review	Sep 07
DE-FC26-06NT42935 Osram Sylvania	LR&D Direct	Budget Period #1 Progress Review	Sep 07
DE-FC26-06NT42936 SRI International	LR&D Direct	Budget Period #1 Progress Review	Sep 07
DE-FG02-05ER84232 Fairfield Crystal Technology, LLC	SBIR	Budget Period #1 Progress Review	Sep 07
M6642866 Pacific Northwest National Laboratory (PNNL)	LR&D Direct	Budget Period #1 Progress Review	Sep 07
M6643035 Los Alamos National Laboratory (LANL)	LR&D Direct	Budget Period #1 Progress Review	Sep 07

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 (LR&D), which is intended to provide a management tool for the projects in the SSL portfolio.[51] A stage-gate system[52], 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 (NETL) 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

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

constructing this type of framework, the Department 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.

In addition, the Department 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.

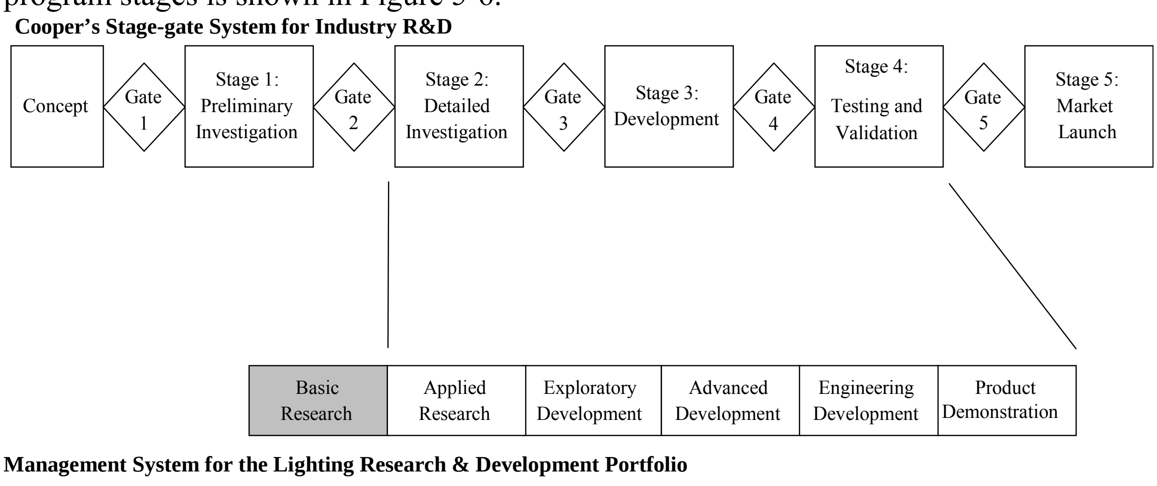


Figure 5-6: Mapping Cooper's Stage-Gate System to the LR&D Portfolio

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	**Gate 1** ✓ New concept or principle proven ✓ Theoretical or empirical proof ✓ Met performance milestones	**Gate 2** ✓ Address priority building end use ✓ Proof of technical performance ✓ Met performance milestones	**Gate 3** ✓ Prove clear advantage over available technology ✓ Met performance milestones	**Gate 4** ✓ Meet owner / operator cost/benefit requirements (1-5 yr. payback) ✓ Demonstrate significant end-user demand ✓ Technology status issues defined ✓ Met performance & cost milestones	**Gate 5** ✓ Ready for owner / operator on multi criteria (economics, safety, etc…)? ✓ Met performance & cost milestones	**Gate 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

DOE is actively engaged in activities that support the commercialization of SSL technologies for use as general illumination sources. As a public agency DOE is able to provide support and guidance in several areas that move the SSL market toward the highest energy efficiency and highest lighting quality. DOE’s on-going partnership with the LED industry helps to connect R&D and product development activities to the market. DOE has organized its commercialization support activities in terms of pathways to the market, and supporting tasks needed to facilitate those pathways. Figure 5-8 expands the Commercialization Support area, showing the relationship of the activities to the luminous efficacy goals over time.

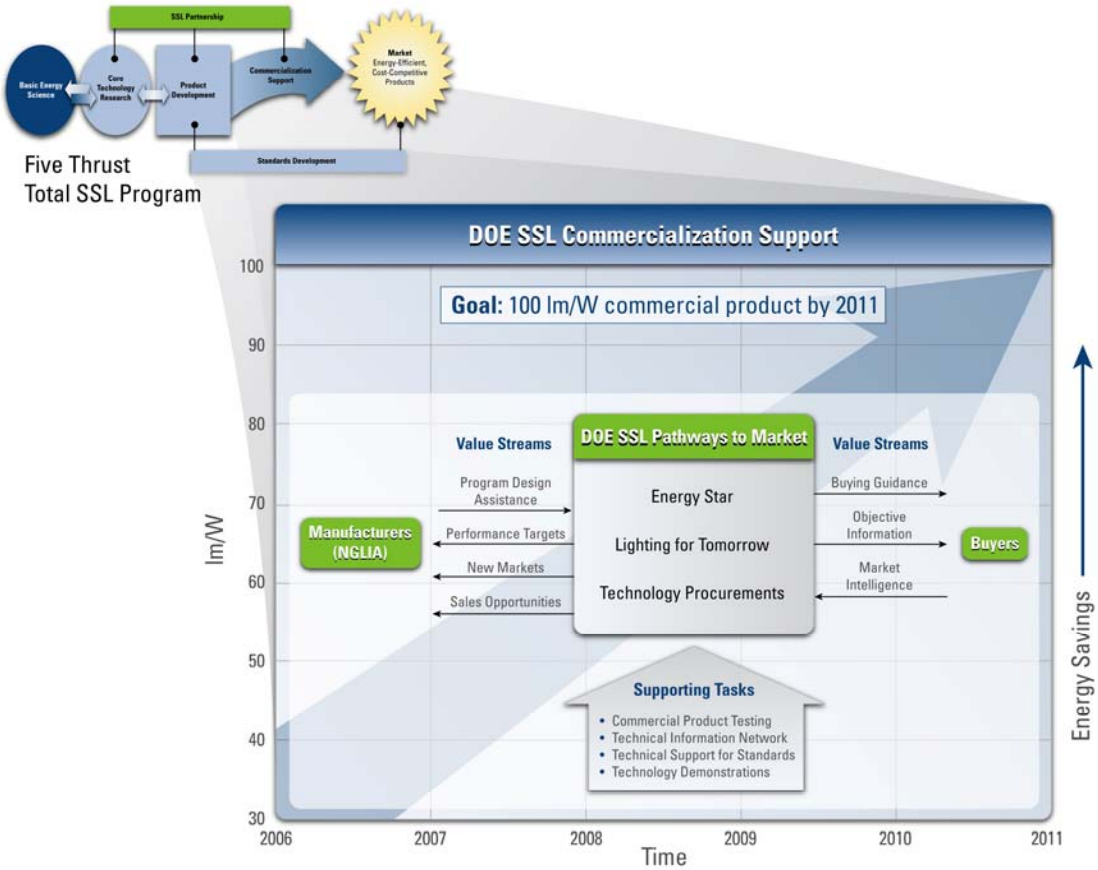


Figure 5-8: DOE SSL Commercialization Support Plan

<u>Activities in Progress</u>

SSL Industry Partnership

EPACT 2005 directed DOE to partner, through a competitive selection process, with an industry alliance representing US-based SSL research, development, infrastructure, and manufacturing expertise. The legislation further directed DOE to seek industry input in identifying SSL technology needs, assessing the progress of research activities, and updating SSL technology roadmaps. In fulfillment of this directive, DOE signed a Memorandum of Agreement with the Next Generation Lighting Industry Alliance (NGLIA) in 2005. Alliance members include the major US-based manufacturers of LEDs, OLEDs, components, materials, and systems. Membership continued to grow in 2006, including increased participation by lighting fixture manufacturers. The Alliance provides regular feedback to DOE the program areas through bimonthly meetings.

A. Pathways to Market

The pathways to market speed introduction and adoption of energy-efficient technologies by providing a competitive advantage to products that are more efficient compared to standard technology. DOE is engaged in three activities that serve as pathways to market for energy-efficient SSL technologies, as described below.

ENERGY STAR for SSL
ENERGY STAR is a voluntary energy efficiency labeling program that helps consumers to identify products that save energy, relative to standard technology. DOE issued draft ENERGY STAR criteria for solid-state lighting (SSL) luminaires in December 2006. The proposed criteria include two categories: Category A covers a limited number of general illumination niche applications for which white LED systems are appropriate in the near-term, and Category B, which is intended to cover a wide range of LED systems for general illumination. Category B will serve as the longer term target for the industry. Initial applications eligible under Category A include those with the following characteristics: 1) appropriate for a light source with a directional beam, as opposed to a diffuse source; 2) low to moderate illuminance requirement; 3) illuminated task or surface relatively close to the light source; and 4) potential for cost-effective use of LED-based products in the near term. Initial Category A applications are: undercabinet lighting, portable desk/task lights, outdoor porch, pathway, and step lighting, and recessed downlights.

Lighting for Tomorrow DOE is one of the organizing sponsors of Lighting for Tomorrow (LFT), along with the American Lighting Association and the Consortium for Energy Efficiency. Lighting for Tomorrow is a design competition that encourages and recognizes excellence in design of energy-efficient residential light fixtures. In 2006, an SSL competition was added to the existing program for CFL-based lighting fixtures. Winners of the initial SSL competition were announced in December, including kitchen undercabinet light fixtures, portable desk/task lights, and outdoor lighting, all using white LEDs as the light source. Winning companies included Progress Lighting, American Fluorescent, Lucesco, and Lucere Lighting. Lighting for Tomorrow will continue in 2007, again with separate categories for CFL-based fixture families and LED-based fixtures. Information is available at www.lightingfortomorrow.com.

Technology Procurement
Technology procurement is an established process for encouraging market introduction of new products that meet certain performance criteria. DOE has employed this approach successfully with other lighting technologies, including sub-CFLs and reflector CFLs. DOE plans to employ technology procurement to encourage new SSL systems and products that meet established energy efficiency and performance criteria, and link these products to volume buyers and market influencers. Volume buyers may include the federal government (FEMP, DLA, GSA), utilities, or various sub-sectors including hospitals, lodging, or retail. This activity is linked closely to the technology demonstrations described below.

B. Supporting Tasks

The pathways to market described above are underpinned by several supporting tasks. The results of these tasks feed directly into the pathway activities.

Commercial Product Testing Program

SSL technologies today are undergoing rapid change and improvements, and products arriving on the market exhibit a wide range of performance. There is a need for reliable, unbiased product performance data to allow potential users to compare SSL products to traditional technologies, to reveal technical and design problems, and to inform the performance expectations of the pathway activities, as well as the standards processes. DOE initiated the Commercial Product Testing Program with a pilot round in which four commercially-available LED-based lighting fixtures were tested for total luminous flux, luminous intensity, wattage, and color characteristics. The program was officially kicked off during a half-day workshop on October 27, 2006 and is testing 8 to 10 products per quarter. DOE allows test results to be distributed in the public interest for noncommercial, educational purposes only. Detailed test reports are provided to users who provide their name, affiliation, and confirmation of agreement to abide by DOE's "No Commercial Use Policy." See the DOE SSL website www.netl.doe.gov/ssl for more information.

Technical Information Network

SSL is a rapidly changing technology and is new to many in the lighting and energy efficiency professions. To facilitate learning and promote ongoing emphasis on energy efficiency and quality in the deployment of SSL, DOE is establishing a technical information network. The network will involve energy efficiency program sponsors, utilities, lighting researchers and designers, and others with interest in lighting energy efficiency. The network will meet regularly to receive technical information about SSL, and to provide feedback from the market, including retailers, builders, and consumers, on market needs and barriers. DOE has already developed a series of fact sheets addressing technical and applications issues related to use of white LEDs as a general illumination source. These fact sheets and web-based materials are updated regularly to reflect the rapid development of the technology, and new topics are under development. Members of the Network will adapt and disseminate these technical materials to their local constituencies.

Technical Support for Standards

Because LEDs differ significantly from traditional light sources, new test procedures and industry standards are needed to measure their performance. To help coordinate and accelerate the standards development process, DOE hosted workshops in March and October 2006 bringing together all of the relevant standard-setting organizations. New or revised procedures and standards are currently under development to measure luminous flux, luminous intensity, lumen depreciation, and color characteristics of white-light LEDs. The new standards are expected to be published in mid-2007.

Technology Demonstrations

DOE is planning SSL technology demonstrations in both the residential and commercial building sectors. Currently in the product and host site identification phase, the demonstrations are expected to be implemented later in 2007. These demonstrations will provide real-life experience and data involving SSL installations in various applications. DOE will verify performance of the selected SSL-based products, including measurement of energy consumption, light output, color consistency, and interface/control issues. The technology demonstrations will also play a critical role in the technology procurement process, providing the performance verification needed to secure large volume purchases of SSL-based products.

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 the Government Performance and Results Act (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 (GPRA) 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) method. 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.[53]

The full set of GPRA metrics are calculated just for the Building Technologies Program as a whole, and not at the sub-program level.

6.1.2. Peer Review

In November 2005, the Department conducted a formal peer review of 21 DOE-funded SSL projects completing their first year. The review was conducted by a panel of highly qualified scientists and engineers, who evaluated each project based on technical

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

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. The next peer review process will take place in the Summer of 2007.

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* [54]

- 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, 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 $500 million SSL DOE program.

- The panel concluded that the achievement of DOE's technical goal depends on an increase in funding from today's $10 million per year 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

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

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.

Table 6-1 presents the benefits that were published by the National Academy of Sciences in April 2005 for a 20 year $25 million dollar R&D program in solid-state lighting. Benefits extend beyond this time period, but these levels show the gains up through the year 2025.

Table 6-1: Estimated Benefits of Full Funding, $25 Million over 20 Years, FY'06

Benefit	**2010**	**2015**	**2020**	**2025**
Energy Displaced				
Nonrenewable Energy Savings (quadrillion Btu/yr)	-	0.02	0.20	0.83
Economic				
Energy-Expenditure Savings (billion 2001$/yr)	-	0.4	4.4	12.2
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	-	0.4	3.5	16.5
Security				
Oil Savings (million barrels per day)	-	-	0.01	0.03
Natural Gas Savings (quadrillion Btu/yr)	-	-	0.12	0.40
Avoided Additions to Central Conventional Power (gigawatts)	-	-	2	16

Source: GPRA, 2005. NAS, 2005.

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: Dale E. Work 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– Legislative Directive

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 D - List of Patents Awarded through DOE Funded Projects

Organization	Title of Patent
Agiltron, Inc.	Light Emitting Diodes with Porous SiC Substrate and Method for Fabricating
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
	Two additional patents pending
GE Global Research	A Mechanically Flexible OLED Light Source with Increased External Quantum Efficiency
	Thin Electrodes with a Collection Grid for Organic Light Emitting Diodes
	Luminaire for Light Extraction from a Flat Light Source
	Organic Light-Emitting Devices with Integrated Series Connection
	Efficient and Stable Operation of Organic Light Emitting Diodes
	Hybrid Electroluminescent Devices
	Organic Electroluminescent Devices Having Improved Light Extraction
	Array for Area Illumination by Organic Light Emitting Diodes
	Light-Emitting Device with Organic Electroluminescent Material and Photoluminescent Material
	Eight additional patents pending
Georgia Tech Research Corporation	*One patent pending.*
International Technology Exchange	*One patent pending.*
Light Prescriptions Innovators	Optical Manifold for Light-Emitting Diodes
	Two additional patents pending
Lumileds Lighting U.S., LLC	Cantilever Epitaxial Process
Maxdem Incorporated	Polymer Matrix Electroluminescent Materials and Devices

Organization	Title of Patent
Nanosys	Nanocrystal Doped Matrices
OSRAM Opto Semiconductors, Inc.	Integrated Fuses for Organic Light Emitting Diode Lighting Device
	Organic Light Emitting Diodes with Phosphors
	Novel Method to Generate High Efficient Devices
	Hybrid Light Source
Philips Electronics North America	*Four patents pending*
Pacific Northwest National Laboratory	Thin Films Based on Organic Phosphine Oxide Compounds for Electronic Applications
	One additional patent pending
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
University of California, Santa Barbara	Silicone Resin Encapsulants for Light Emitting Diodes
	Plasmon Assisted Enhancement of Organic Optoelectronic Devices
	Four additional patents pending
Universal Display Corporation	Organic Light Emitting Device Structure for Obtaining Chromaticity Stability
	Organic Light Emitting Devices for Illumination
	Stacked OLEDs Electrically Connected by A Reflective Electrode
	Binuclear Compounds
	One additional patent pending
University of California, San Diego	*One patent pending*
University of Southern California	Fluorescent Filtered Electrophosphorescence

Source: D&R, International

Appendix E – Definition of Core Technology and Product Development

The Department 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 F – 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 EERE, 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	______ 6/05/06 Date
David E. Rodgers Deputy Assistant Secretary (Acting) Office of Technology Development US Department of Energy	William Hanley Executive Vice President Illuminating Engineering Society of North America