Multi-Year Program Plan FY'09-FY'14

Solid-State Lighting Research and Development

Prepared for:

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

Prepared by:

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

March 2008

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DISCLAIMER

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NGLIA LED Technical Committee

Srinath Aanegola	GE Lumination
George Craford	Philips Lumileds
Kevin Dowling	Philips Solid-State Lighting Solutions
Angela Hohl-AbiChedid	Osram Sylvania
Jianzhong Jiao	Osram Opto Semiconductor
Ann Norris	Dow Corning Corporation
Paul Phillips	LSI Industries
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NGLIA OLED Technical Committee

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Joseph Shiang	General Electric
Steffan Zahn	Air Products and Chemicals

COMMENTS

The Department of Energy is interested in feedback or comments on the materials presented in this document. Please write to James Brodrick, Lighting R&D Manager:

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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

> ***"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

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.

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:

- September 2007. Cree, Inc. developed an LED array prototype that delivers of 95 lm/W at 350 mA.
- September 2007. GE Global Research set a new record for solution-processed white OLED devices, demonstrating a performance greater than 14% peak W/W (overall power conversion efficiency). Further improvements will enable the demonstration of a 45 lm/W illumination-quality OLED that proves near-term technology viability as an incandescent replacement for certain applications.
- September 2007. Universal Display Corporation (UDC) fabricated a 6-square-inch OLED panel that produces 100 lumens of light at an efficacy of 31 lm/W and a brightness of 3,000 nits, relatively brighter than todays fluorescent lamps.
- June 2007. Eastman Kodak developed a new device architecture for white OLED devices that demonstrates an extraction efficiency of 46%, a tremendous improvement over previous devices.
- 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 units in a solution fabricated blue-green OLED. This achievement is the highest ever reported for this approach to producing a blue emitting device.
- 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.
- July 2006. CREE Inc. fabricated a cool white LED array prototype with luminous efficacy of 79 lm/W. 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.
- 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.
- 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.

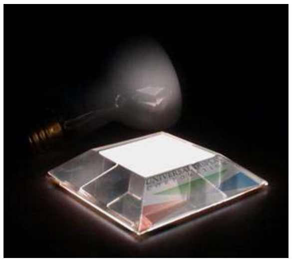
- August 2005. Universal Display Corporation reported a prototype OLED panel with a power efficiency of 30 lm/W, a color temperature of 4000K and a color rendering index greater than 80. Emitting white-light at 3700K, the panel emits 150 lumens at 15 lm/W.
- July 2004. Sandia National Laboratories received an R&D 100 Award from R&D magazine for development of a new process for growing gallium nitride on an etched sapphire substrate.
- 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.
- 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.
- 2004. Lumileds Lighting teamed with Sandia National Laboratories to develop semiconductor nanoparticles (“quantum dots”) with a quantum efficiency of 76 percent.
- 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.

Recent research highlights are described below.

<u>Cree, Inc. Demonstrates Cool White Multi-Chip Prototype</u>

In September 2007, Cree, Inc. successfully fabricated a new cool white multi-chip LED component prototype with efficacies of 88-95 lm/W at 350 mA, exceeding the DOE FY07 annual Joule milestone. The component prototype consumes approximately 8 watts. This demonstration is based on Cree’s EZBright™ chip technology platform combined with prototype packaging technology developed with funding support form DOE.

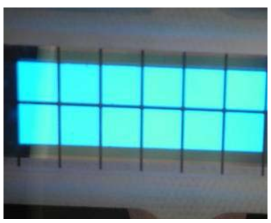
Universal Display Corporation Achieves Record OLED Efficacy



In June 2007, Universal Display Corporation (UDC) successfully demonstrated an all phosphorescent white organic light emitting diode (WOLED^{TM}) with a record luminous efficacy of 45 lm/W at 1,000 cd/m^2. UDC's high-efficacy device was enabled by lowering the operating voltage, increasing the outcoupling efficiency, and incorporating highly efficient phosphorescent emitters that are capable of converting all current passing through a WOLED into light. Warm white emission from the device has a color rendering index of 78.

PNNL Achieves Record Efficiency in a Blue OLED Device, Exceeds Milestones

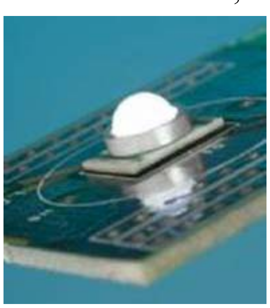
In November 2006, Scientists at Pacific Northwest National Laboratory (PNNL) created a blue OLED device with an external quantum efficiency (EQE) of 11% at 800 cd/m^2.



This achievement is particularly notable since it was achieved at much lower operating voltage (6.2V) than previous demonstrations using similar structures, 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, wide bandgap molecules with the charge transporting and thin-film properties of larger molecules, enabling the use of blue organic phosphors at low operating voltage. This breakthrough will enable an entire new class of improved efficiency OLED devices appropriate for SSL.

DOE SSL Research Contributes to World Record Setting Efficiency in Cree's New LED XLamp

In October 2006, Cree, Inc. released the new XLamp® 7090 power LED in white, setting



world records for LED brightness and efficacy. Designed for general lighting applications such as street, industrial, and parking garage lighting, the XLamp delivers 80 lumens at 350 mA, yielding 70 lumens per watt. Cree is also offering quantities of XLamp LEDs that deliver 95 lumens at 350 mA, or 85 lumens per watt. The new XLamp is the first device based on Cree's performance breakthrough EZBright™ LED chip; both products were developed with R&D funding support from DOE.

DOE SSL Research Contributes to GE Lumination's Vio™ LED Lamp

Unique phosphor compositions coupled with robust design and high-power 405 nm chips enable GE Lumination's Vio™ LED lamp to deliver an efficacy of 38 to 45 lm/W, with flexible color temperature (3500K/4100K) and color rendering (70/85). This efficacy achievement is particularly notable for warm color light. Designed for general illumination applications, Vio LEDs exhibit minimal part-to-part color temperature variation and a color shift of <100K over life. The underlying research to identify factors that influence the efficiency of phosphor down conversion in LED packages was conducted by GE Global Research and the University of Georgia, with R&D funding support from DOE. (July 2007)

DOE R&D Improves Semiconductor Components for LED White Lighting

Technology advances achieved with DOE R&D support enabled development of novel, low-defect GaN template substrates and InN epitaxial wafers by Technologies and Devices International (TDI). TDI manufactures and supplies a variety of semiconductor substrate templates for GaN and AlGaN epitaxial growth. These templates are excellent materials for fundamental research, product development, and production of high efficiency, high-brightness LEDs. Development of improved, cost-effective substrates and epitaxial technology for highly efficient white LEDs will enhance LED performance and speed up penetration of solid-state lighting products into the illumination market. (November 2006).

GE Global Research Sets New Efficiency Record for Solution-Processed White OLED Devices

GE Global Research set a new record for solution-processed white OLED devices, demonstrating a performance greater than 14% peak W/W (overall device efficiency). This achievement represents a very significant increase in the conversion of electron to photon efficiency, relative to GE's 2003 8% peak W/W, 15 lm/W baseline device. The new high performance device was achieved by optimizing layer thicknesses, materials choices, and a phosphor conversion layer. The solution-processed approach will allow for extremely fast, continuous roll-to-roll OLED manufacturing and low-cost deposition on flexible substrates. The GE team is working on further improvements that will enable demonstration of a 45 lm/W illumination-quality OLED that proves near-term technology viability as an incandescent replacement for certain applications. (September 2007)

Universal Display Corporation Scales Up OLED Panel

Universal Display Corporation (UDC) fabricated a 6-square-inch OLED panel that produces 100 lumens of light at an efficacy of 31 lm/W. At 100 lumens, the output of the device is approximately 3,000 candelas per square meter, comparable to UDC's previous laboratory scale 2-square-millimeter device and relatively brighter than today's fluorescent lights. This accomplishment is significant because it allows for more total lumens emitted per device, with fewer processing issues compared to multiple single pixels. (September 2007)

Eastman Kodak Achieves Breakthrough Extraction Efficiency in White OLED Device
Eastman Kodak developed a new device architecture for white OLED devices that demonstrates tremendous improvement in extraction efficiency, achieving an estimated 46 percent. Their new Internal Extraction Layer (IEL) offers a promising new approach to improving the power efficiency and lifetime of white OLEDs, demonstrating a power efficiency of 23.6 lm/W. Eastman Kodak also reduced forward voltage, which further impacts on power efficiency, achieving a drive voltage below 3.0 volts at $5mA/cm^2$. The team will continue their work in multiple parallel areas to further improve the power efficiency and lifetime of OLED devices. (June 2007)

Sandia National Laboratories (SNL) Project to Improve Yield of Green LEDs
Technology advances achieved with DOE R&D support will reduce high brightness LED costs and accelerate the commercial manufacture of inexpensive, white light LEDs with very high color quality. In April, SNL concluded a two-year effort to improve the yield of green Indium Gallium Nitride (InGaN) LEDs. Green is currently the least efficient primary color of the color-mixing approach to white light LEDs. SNL has advanced the "state-of-the-art" for mid-infrared and ultraviolet-violet pyrometry (temperature measurement). The project extended previous research (funded by DOE) that developed emissivity correcting pyrometers. SNL looks to license the technology to equipment vendors, thereby speeding market penetration of solid-state lighting products. (April 2007)

Recent SSL Program Highlights

February 2007 – DOE SSL Program Planning Workshop
More than 250 experts from industry, academia, research organizations, trade associations, utilities, and energy efficiency organizations gathered in Phoenix for the DOE SSL Program Planning Workshop on January 31-February 2, 2007. This annual workshop provides a forum for building partnerships and strategies to accelerate technology advances and guide market introduction of high efficiency, high-performance SSL products. In Phoenix, industry experts in lighting design, manufacturing, and venture capital shared perspectives on the rapidly evolving SSL market. DOE-funded researchers discussed technology advances and evaluated DOE SSL R&D roadmap priorities, providing input to guide future DOE planning for R&D funding. Government, utility, and energy efficiency programs shared insights, lessons learned, and ways to move SSL to market. A PDF copy of the workshop report is available on the DOE web site at:.http://www.netl.doe.gov/ssl/PDFs/07SSLWorkshop%20Report_3.pdf

"Voices for SSL Efficiency" Gather in Pasadena and Boston for DOE Workshops
In April and July, DOE hosted two market introduction workshops – each with over 100 attendees – to initiate a dialogue on how Federal, State, and private-sector organizations can work together to guide market introduction of high efficiency, high-performance SSL products. The first was held April 23-24 in Pasadena and was co-hosted by Southern

California Edison. The second, co-hosted by Northeast Energy Efficiency Partnerships, took place in Boston on July 16-17. Participants from energy efficiency organizations, utilities, government, and industry shared insights, ideas, and updates on the emerging SSL market, and explored ways to partner and participate in DOE SSL market introduction activities. The two gatherings on opposite coasts also allowed for regional perspectives on SSL market issues. A PDF copy of the Pasadena workshop report is available at: http://www.netl.doe.gov/ssl/PDFs/Pasadena_2007/Pasadena%20 SSL%20Workshop%20Report_FNL.pdf. The Boston workshop report is available at: http://www.netl.doe.gov/ssl/PDFs/Boston_2007/SSL_Boston_Report_d4final.pdf.

DOE Report Forecasts Energy Savings Potential of SSL in General Illumination Applications

At the Phoenix Workshop, DOE released the report *Energy Savings Potential of Solid-State Lighting in General Illumination Applications.* The report forecasts the energy savings potential of SSL sources compared to conventional light sources. Using an econometric model of the U.S. lighting market, two scenarios are evaluated: one considering light emitting diodes (LEDs) and one considering organic light emitting diodes (OLEDs). Under the LED scenario, total electricity consumption for lighting would decrease by roughly 33 percent relative to a scenario with no SSL on the market – a savings greater than the energy consumed to illuminate all the homes in the U.S. today. Over the 20-year analysis period, spanning 2007-2027, the cumulative energy savings are estimated to total approximately 3,019 terawatt-hours, representing approximately $280 billion at today's energy prices. A PDF copy of the report is available on the DOE SSL website at: http://www.netl.doe.gov/ssl/publications/publications-ssltechreports.htm.

DOE Issues Five Competitive Solicitations Related to SSL

During FY07, DOE issued five competitive solicitations related to SSL:

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

In total, the Department reviewed 111 proposals, and selected and initiated 15 projects in FY07. Selections for Round IV solicitations will be made in FY08.

Results from DOE-Funded Projects: Patents and Publications

As of January 2007, 14 SSL patents related to DOE-funded research have been granted. This demonstrates the value of DOE SSL projects to private companies and notable progress toward commercialization. Since DOE began funding SSL research projects in 2000, a total of 64 patent applications have been applied for or awarded as follows: large businesses – 27, small businesses – 21, universities – 13, and national laboratories – 3. For the list of patents awarded for DOE funded SSL research, see Appendix D.

1.2. Legislative Directive

On December 19, 2007, the President signed the Energy Independence and Security Act (EISA), Pub. L 110-140 which builds on the directives issued in the Energy Policy Act of 2005 (EPACT 2005), Pub. L. 109-58. EISA instituted the "Bright Tomorrow Lighting Prizes." The "Bright Tomorrow Lighting Prizes" establishes prizes for a solid-state lighting product with an efficacy of 90 lm/W to replace an incandescent 60W lamp, a solid-state lighting product with an efficacy of 123 lm/W to replace halogen PAR38 lamps, and a solid-state lighting product with an efficacy of 150 lm/W. After the prizes are awarded, the Federal Government may purchase the lamps for its own facilities. Excerpts of EISA 2007, describing all lighting prizes, new energy efficiency standards for lighting, and authorization for a lighting research and development program can be found in Appendix G. More information on the "Bright Tomorrow" Lighting Prizes will be available on DOE's Solid-State Lighting website (http://www.netl.doe.gov/ssl/) by the summer of 2008.

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

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

EPACT 2005, enacted on August 8th 2005, issued a directive to the Secretary of Energy to carry out a "Next Generation Lighting Initiative" 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 legislation directs the Secretary of Energy to support research, development, demonstration, and commercial application activities related to advanced solid-state lighting technologies. This law specifically directs the Secretary to:
Develop SSL technologies based on white LEDs that are longer lasting, more energy-efficient, and cost-competitive compared to traditional lighting technologies.

- Competitively select an Industry Alliance to represent participants that are private, for-profit firms that, as a group, are broadly representative of United States solid-state lighting research, development, infrastructure, and manufacturing expertise.

- Carry out the research activities of the Next Generation Lighting Initiative through competitively awarded grants to researchers, including Industry Alliance participants, National Laboratories, and research institutions.
- Solicit comments to identify SSL research, needs, and progress. Develop roadmaps in consultation with the industry alliance.

Manage an on-going development, demonstration, and commercial application program for the Next Generation Lighting Initiative through competitively selected awards.
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

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

and commercialization focus of the DOE portfolio by utilizing the expertise of this organization of SSL manufacturers in February 2005. This document can be found in Appendix B.

In addition to signing an MOA with NGLIA, DOE also issued an Exceptional Circumstances Determination to the Bayh-Dole Act to facilitate more rapid commercialization of SSL technologies in June 2005. The determination places guidance on intellectual property generated under the Core Technology 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 A.

1.3. International Competition and US Industrial Positioning

In 2005, 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] Sales of high-brightness (HB) LEDs, the technology associated with LEDs for lighting applications were $4.7 billion in 2007,.[5] Of these HB LED revenues, approximately 7%, or $330 million is attributable to illumination applications. [6]

DOE support of SSL R&D is essential. There is a window of opportunity to establish the United States as a global leader in this technology, retaining intellectual property rights, high tech value-added jobs, and economic growth for the nation. As time passes, foreign companies will try to surpass present U.S. technical know-how and compete with the U.S. to become future suppliers of LED and OLED lighting sources and systems. Losing this emerging industry would mean lost jobs, lost industry, and more imports. Foreign companies already produce SSL products, which they are marketing in the U.S.. For example, the Japanese industry had about 70 percent of the market share of solid-state lighting components in 2002. Foreign companies are also establishing intellectual property rights to LEDs. Almost 10 times as many solid-state lighting patents have been applied for by Japanese companies than either U.S. or German companies.[7]

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.

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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] *High Brightness LED Market Review and Forecast*, R.V. Steele, Strategies Unlimited, Feb. 2008.
[6] Doe not include signage, mobile appliances, signals, automotive, or electrical equipment.
[7] *Partnership for Solid-State Lighting: Report of a Workshop.* National Research Council. Washington, DC. 2002. http://www.nap.edu/catalog.php?record_id=10473

1.4. Federal Role in Supporting the SSL Initiative

A part of the Department of Energy's overarching mission is to advance the national, economic, and energy security of the United States and to promote scientific and technological innovation in support of that mission. 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 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.. 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 luminaires and a two-fold improvement over fluorescent luminaires. 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'09 through FY'14 to implement this mission.[8] This plan is a living document, updated periodically to incorporate new analyses and progress, and new research priorities, as science evolves.

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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.

In the 1950s, British scientists conducted experiments on the semiconductor Gallium Arsenide (GaAs), which exhibited electroluminescence or the emission of a low-level of infrared light, leading to the creation of the first "modern" light emitting diode (LED). In 1962, the first practical visible-spectrum light-emitting diode (LED) was invented at General Electric's Advanced Semiconductor Laboratory.[10] After subsequent improvements in this technology, the first commercial visible (red) light LEDs were fabricated in the late 1960s using Gallium Arsenide Phosphide (GaAsP). In the mid 1970s, green LEDs were produced using Gallium Phosphide (GaP). The first blue LEDs emerged in the 1990s using Gallium Nitride (GaN). Combining the red, green, and blue

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

LEDs or coating the blue LEDs with a yellow phosphor led to the creation of white LEDs, a promising, high-efficiency technology for general illumination. Parallel to efforts to create white LEDs, researchers have been working to improve the efficacy of the technology. Present day LED commercial devices have reached efficacies of 88 lm/W, comparable to the efficacies of fluorescent and certain HID lamps.[11]

In the late 1970's, after green LEDs were discovered, Dr. Ching Tang at Eastman Kodak discovered that sending an electrical impulse through a carbon compound caused these materials to glow. Continuing research in this vein, Dr. Ching Tang developed the first organic light emitting diode (OLED). A paper on his research was published in 1987[12]. Since then OLED researchers have developed white OLEDs that have reached efficacies of up to 64 lm/W in the laboratory. Although currently only OLEDs used for display purposes are sold commercially, companies are conducting research in white OLEDs so that commercial products can be sold in the future for general illumination purposes.

The traditional three light sources – incandescent, fluorescent and HID – have evolved to their present performance levels over the last 60 to 120 years of research and development. Industry researchers have studied all aspects of improving the efficiency of these sources, and while marginal incremental improvements are possible, there is little room for significant, paradigm-shifting, efficacy improvements. SSL technology, such as LEDs and OLEDs, on the other hand, has potential to 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 Figure 2-1.

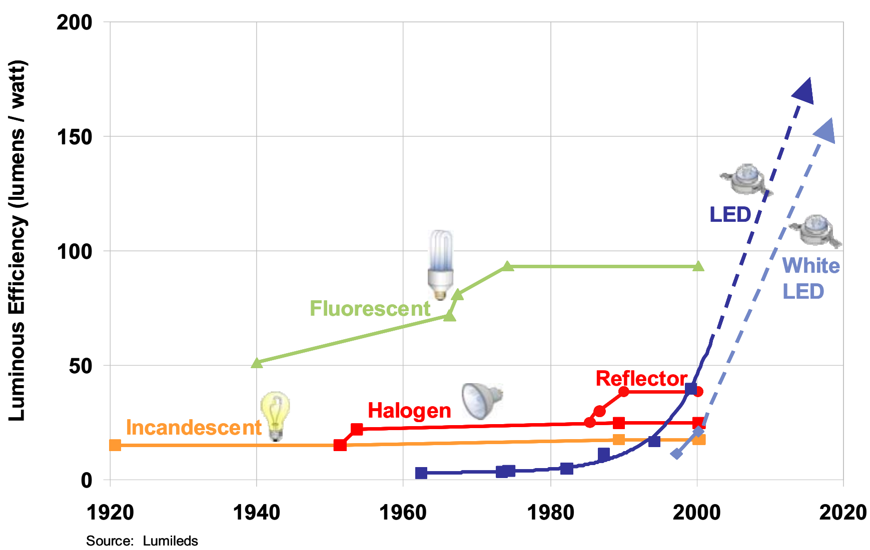

Figure 2-1: Historical and Predicted Efficacy of Light Sources
Source: Lumileds.

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

2.2. Current National Lighting Needs

Lighting is the second largest end-use of energy in buildings.[13] New lighting technologies offer one of the greatest opportunities for energy savings potential within the building sector.

2.2.1. Lighting Energy Use in Buildings

In 2001, energy consumption for all lighting in the U.S. was estimated to be 8.2 quads, or about 22% of the total electricity generated in the U.S.[14] Figure 2-2 provides a break-down by end-use sector of the energy consumption for lighting our homes, offices and other metered applications around the country.

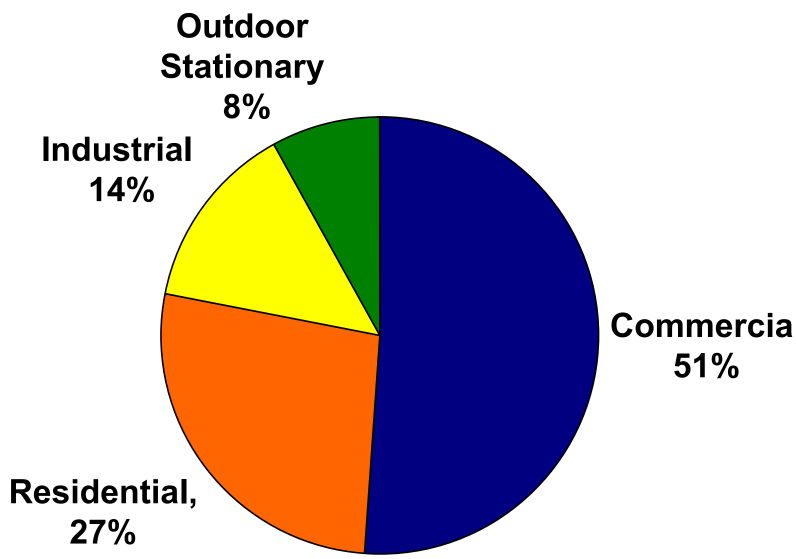

Figure 2-2: Total U.S. Primary Energy Consumption for Lighting by Sector 2001
Source: *U.S. Lighting Market Characterization Volume I: National Lighting Inventory and Energy Consumption Estimate.* Prepared by Navigant Consulting, Inc. for the Department of Energy. Washington D.C. September 2002.

Figure 2-2 shows that more than half of these 8.2 quads are consumed in 2001 were for

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[13] Building Energy Databook 2007. Available at http://buildingsdatabook.eren.doe.gov/

[14] In 2001, total energy consumption was 98.3 quads of which about a third – 37 quads is used for electricity production. (Annual Energy Outlook, 2002; Table 2 Energy Consumption by Sector and Source) In 2007 total energy consumption was 101.26 quadrillion BTU's, of which 40 quads is for electricity production (Annual Energy Outlook, 2007; Table 2 Energy Consumption by Sector and Source). If the percentage of electricity used for lighting is the same as in 2001, energy consumption for all lighting could be as high as 8.8 quads.

the commercial sector, the largest energy user for lighting. This is one of the principal markets the DOE has targeted to develop more efficient technologies. Lighting also contributes to a building's internal heat generation and subsequent air-conditioning loads. Excluding outdoor applications, total energy use for lighting was approximately 6.4 quads. Looking at just commercial and residential sectors, lighting consumed 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.

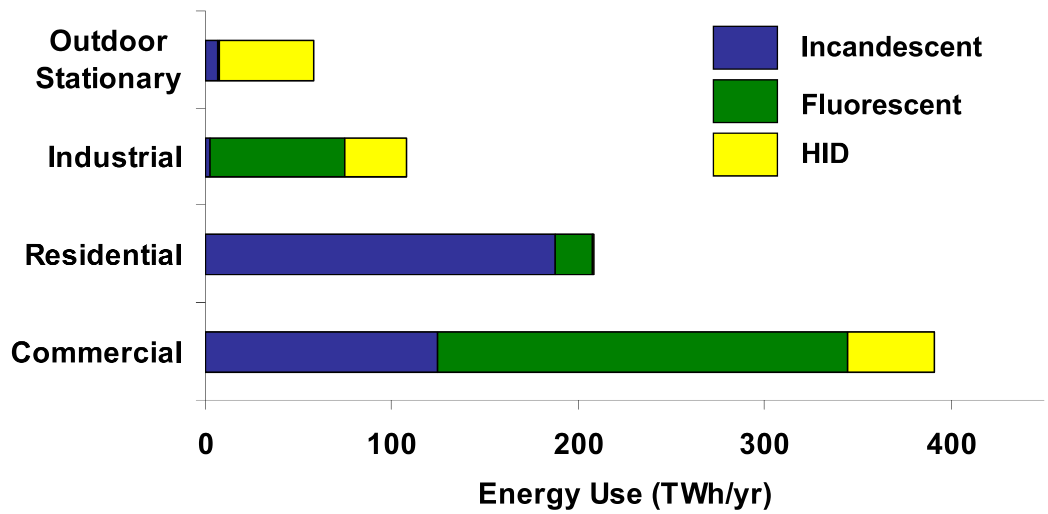


Figure 2-3: Lighting Energy Consumption by Sector & Source

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. As noted in Section 2.4.3, this may change as a result of current legislation.

Figure 2-3 shows that outdoor stationary energy consumption 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 for lighting 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.[15] This report looks broadly at energy-efficient options in lighting and identifies leading opportunities. Volume II presents fifty-two technology options that promise to save energy or demonstrate energy savings potential. The options encompass both conventional technologies such as incandescent, fluorescent, and HID, as well as SSL.

2.3. Current Technology Status

2.3.1. Performance of Light Sources

Table 2-1 presents the typical performance of 2007 LED device products on the market[16] 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	88 lm/W	5500°K	70	50k hours
Warm White	20 lm	1W	54 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, 2007. CREE, 2007. GE, 2007. Philips Lighting, 2007. OSRAM Sylvania, 2007. Product Catalogs.

[15] *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
[16] It should be noted that LED laboratory prototypes reach much higher efficacies than those listed above.

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

2.3.2. First Cost of Light Sources

The cost of light sources in 2007 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
Light Emitting Diode (1W Cool White)	\$25.00 per kilolumen[17]

Although, 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,[18] the price of the LED has significantly dropped over the years and will continue to drop. However, over the next several years, as performance improves and price drops, LED light sources are projected to become competitive on a first cost basis. 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.

[17] This price assumes reasonable volumes, CCT: 5-6000°K, CRI: 75. See Section 4.3.1.

[18] Because LEDs can be more directional than conventional technologies, comparing them on a lumen per lumen basis based on the lamp may not be entirely accurate. For example, if a CFL and LED lamp emitted the same lumens, the lumens emitted by the LED luminaire would be higher than that of the CFL luminaire. Therefore, on a normalized luminaire light output basis, the LED luminaire may cost less than 7 times the cost of a CFL luminaire.

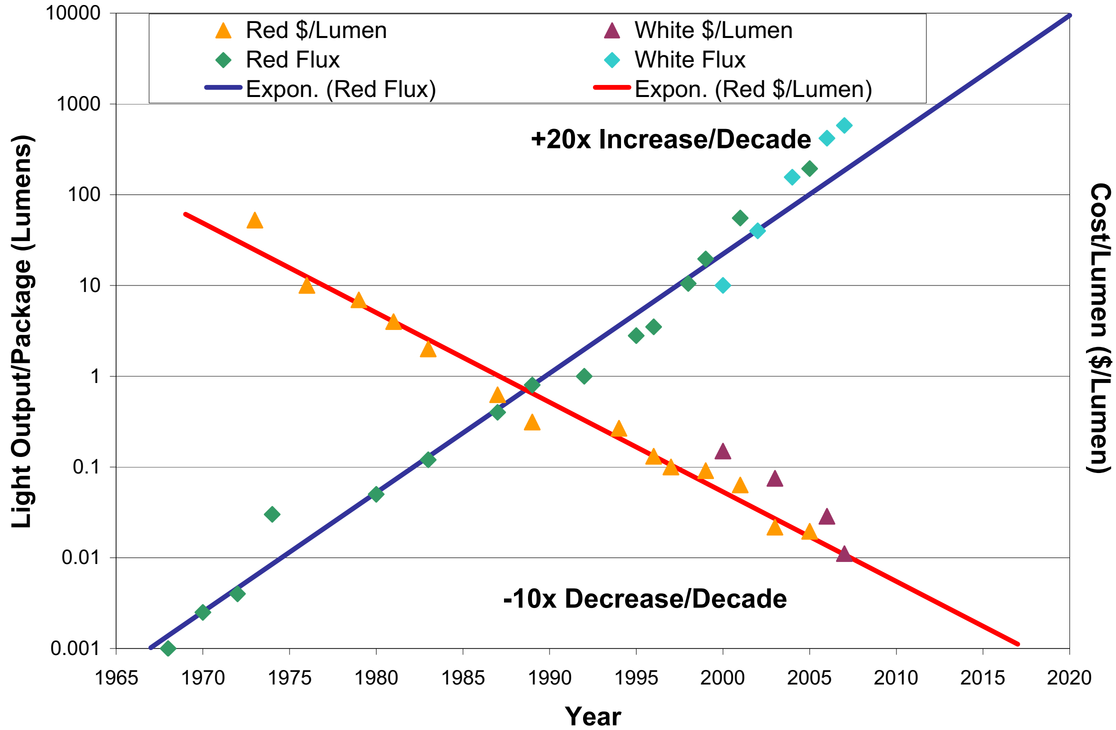


Figure 2-4: Haitz's Law: LED Light Output Increasing / Cost Decreasing
Source: Roland Haitz and Lumileds.

Note: Both lines are on the same numerical scale (with different units)

2.3.3. The Cost of Light[19]

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): [20]

$$CostOfLight = \left(\frac{10}{LampLumens}\right) x \left(\frac{LampCost + LaborCost}{Lifetime} + EnergyUse \times EnergyCost\right)^{19}$$

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

[19] "Cost of Light – When does Solid-state Lighting make Cents?" by Kevin Dowling, Color Kinetics, September 12, 2003.

[20] IES Lighting Handbook, 8th Edition. Lighting Economics, p501-2.

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

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

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

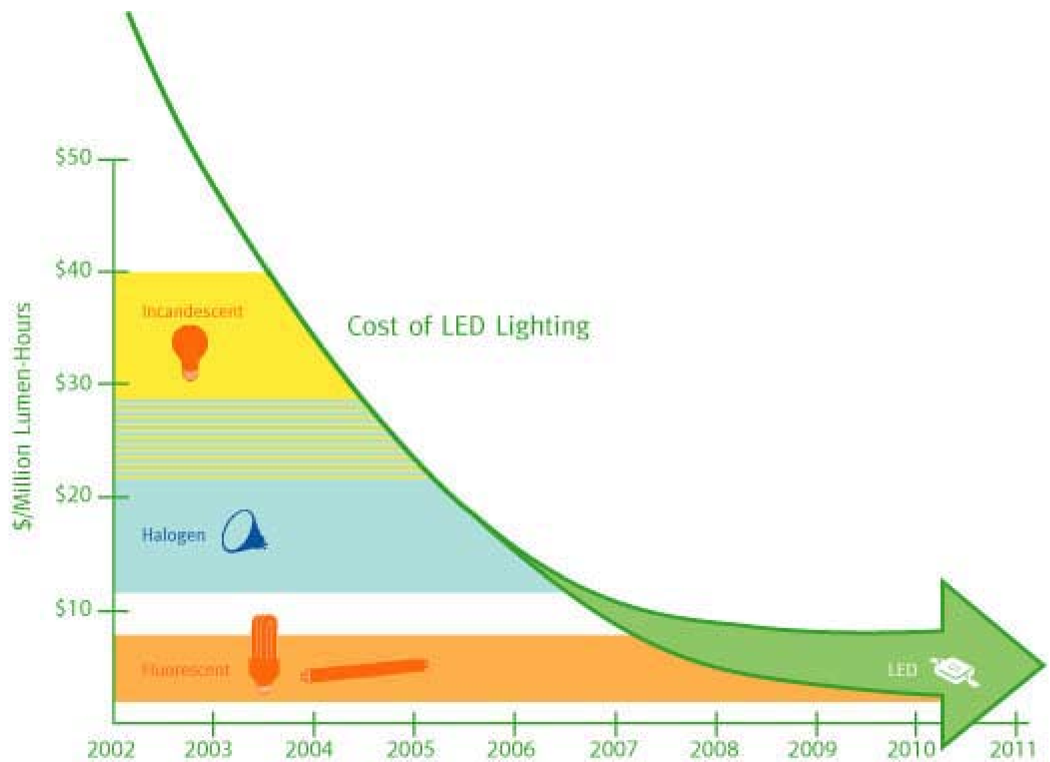


Figure 2-5: Cost of Light

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

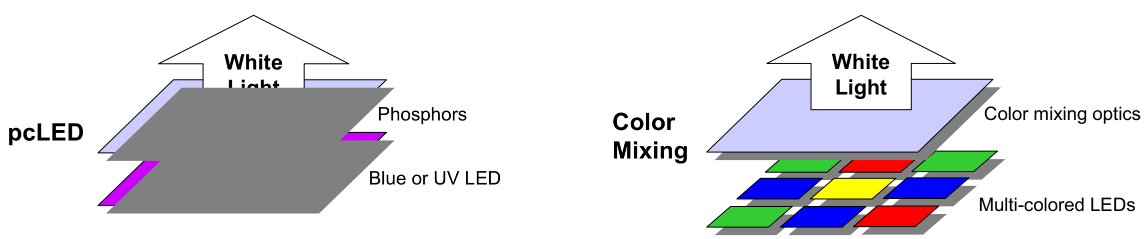
In the case of conventional technologies, the price and performance are not projected to change drastically, and the cost of light will remain relatively constant. However, as LED efficacy improves and the first-cost decreases, the "cost of light" for LED lighting will decrease, and eventually reach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

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

2.3.4. Technology Status: Inorganic Light Emitting Diodes

In 1962, the first practical visible-spectrum light-emitting diode (LED) was invented at General Electric's Advanced Semiconductor Laboratory.[21] This LED consisted of a GaAsP alloy with a p-n homojunction. The performance of this technology improved over the next few years, culminating in the commercial release of red LEDs in the late 1960s. While the efficacy of these first LEDs was extremely low (~ 0.1 lm/W), researchers continued to improve the technology over the next three decades, achieving higher efficiencies and expanding the range of emission wavelengths through the engineering of new III-V alloy systems, thus providing the wide array of high-brightness LEDs on today's market.

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

The phosphor conversion LEDs primarily create white-light by blending a portion of the blue light emitted directly from the chip with light emission down-converted by a phosphor. Discrete color-mixing, on the other hand, start with discrete colored sources and use 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

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

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 a method for generating white-light. Some manufacturers have successfully lowered color correlated temperature[22] (CCT) and increased the color rendering index[23] (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 54 lm/W and a CCT of 3000K.

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

Although improvements in phosphor technology will help, the Stoke's loss is an inevitable limitation to the efficiency. Discrete color-mixing is thought by many, for this reason, 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 eliminating phosphor conversion losses in the production of white-light. The largest challenge is the absence of efficient emitters of green light, which significantly limits achievable efficacy. Another drawback is increased complexity. 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

[22] 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.
[23] 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.

layer.[24] 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 emission peak of the device. Therefore, getting good quality white light from OLEDs is easier and it is anticipated that the quality of the white light will improve with the science.

OLED technology for general illumination applications is in a nascent, yet critical, stage of development. Although currently OLEDs used for display applications are being commercialized, experts agree that without a substantial infusion of capital, OLED technologies developed for general illumination applications may not be commercialized until 2015. Companies overseas, with support from their governments, may develop an insurmountable technological lead, making it difficult for U.S. manufacturers to compete. However, as the U.S. government invests in this technology OLED commercialization may be accelerated in the U.S. [25]

Although much of the work for this technology is exploratory and far from commercialization, research is being conducted in industry as well as research institutions and academia. For example, SSL divisions of General Electric, Osram Sylvania, and Philips Electronics are participating in the research, positioning themselves to participate in this market when white-light OLEDs become a reality.[26] Currently, the best laboratory OLED devices have efficacies of approximately 64 lm/W.

2.3.6. Technology Trends

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

Current incandescent light sources range in efficacy from 3 to 20 lm/W.[27] Currently research being conducted on higher temperature incandescent light sources has the

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[24] *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.

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

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

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

potential to raise these efficacies to 26.5 lm/W. Basic and applied research is also being conducted on selective radiators that tailor the spectrum of incandescent emissions to maximize emission in the visible spectrum. Some researchers claim that this technology may allow incandescent sources to achieve efficacies of 80lm/W.[28]

Fluorescents are typically more efficient than incandescent sources. Efficacies for this technology ranges from 25 to 103 lm/W.[27]. Linear and compact fluorescent lamp technology can improve in efficacy through a variety of research efforts. For example, researchers estimate that basic and applied research on multi-photon phosphors has the potential to raise efficacies of this light source to 200 lm/W.[28]

High intensity discharge lamps are the most efficacious lamp currently on the market with efficacies ranging from 25 to 150 lm/W.[27] Efforts are underway to improve the energy efficiency of high intensity discharge lamps (which includes mercury vapor, metal halide and high-pressure sodium lamps).

Commercial LED devices have the potential to surpass the efficacy of conventional light sources. Although the range in efficacy for commercial LEDs is currently 20 to 88 lm/W,[29] research in a variety of areas as outlined in this report may raise the efficacy of LEDs to 230 lm/W. Laboratory efficacies for OLEDs are beginning to surpass efficacies of conventional technologies. The best laboratory efficacy for an OLED devices is around 64 lm/W. More research needs to be done to realize the potential of this technology for creating efficient white light.

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

[29] Seoul Semiconductor, 2007. CREE, 2007. GE, 2007. Philips Lighting, 2007. OSRAM Sylvania, 2007. Product Catalogs.

2.4. Current Market Status

2.4.1. Market Status

Presently, BT's SSL R&D portfolio is investing in activities to improve efficiency, performance, lifetime, and quality of light. While SSL sources are just starting to compete for market share in general illumination applications, recent technical advances have made LEDs cost-effective in many colored-light niche applications. LED technology is capturing these new applications because it offers a better quality, cost-effective lighting service compared to less efficient conventional light sources such as incandescent or neon. In addition to energy savings, LEDs offer longer operating life (>50,000 hours), lower operating costs, improved durability, compact size and 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.

Applications for white-light LED products include LED task lights, down lights, under cabinet lighting, and outdoor lights. At the 2007 Solar Decathlon[30], many of the University's solar homes featured these products. Figure 2-7 shows photographs from this event of integrated LED lighting products that the University teams chose to incorporate into their designs.

Figure 2-7: LED Technologies Employed during 2007 Solar Decathlon

In addition to the applications listed above, LEDs currently are beginning to compete with HID lamps in street lighting applications. Several cities including Raleigh, NC,

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

Austin, TX, and Ann Arbor, MI have begun installing LED street and area lights to save both on energy and maintenance costs.[31] LEDs also have the potential to compete in many other applications. DOE sponsors a design competition called "Lighting for Tomorrow" to encourage the use of LEDs in a variety of applications. In the 2007 competition, winning fixtures included a downlight, a desk lamp, an undercabinet fixture, and an outdoor wall lantern.[32]

A 2003 study[33] analyzed the energy savings potential of LEDs in twelve niche markets. Figure 2-8 summarizes the on-site electricity savings from the six niche markets that represent the greatest savings potential. As shown, LEDs are achieving high levels of market penetration for some niche applications.

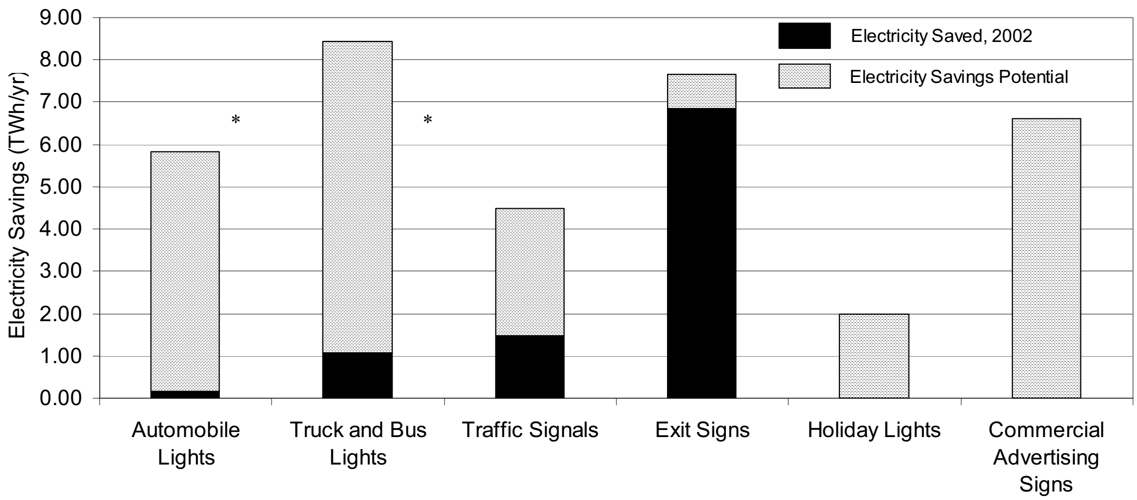

Figure 2-8: Electricity Saved and Potential Savings of Selected Niche Applications
*On-board electricity savings on mobile vehicle
Source: *Energy Savings Potential of Solid-State Lighting in General Illumination Applications*. Prepared by Navigant Consulting, Inc. for the Department of Energy. Washington 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. The following summarizes the findings for three of those niche 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

[31] Details about the LED city program is available at: http://www.ledcity.org/
[32] Details about "Lighting for Tomorrow" is available at: http://www.lightingfortomorrow.com/
[33] 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

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.

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

2.4.2. Market Share

The market share of lighting technologies such as incandescent lamps, compact and linear fluorescent lamps, high-intensity discharge lamps, and solid-state lamps varies by market sector. Table 2-2 illustrates the average number of lamps in residential, commercial, and industrial buildings, disaggregated by technology type. Close to sixty-three percent of all lamps in the market are incandescent lamps while almost thirty-five percent of these lamps are fluorescent. .

Table 2-2: Average Number of Lamps per Building and Total Lamps, 2001

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

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

Although incandescents account for the largest number of installations, they provide only 12% of the total amount of light delivered in the United States. Fluorescent lamps, on the other hand, provide the majority of light at 62% while HID sources provide around 26% of light delivered in the country.[34]

2.4.3. Market Views

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

After more than a century of dominance, incandescent lamps are facing serious competition in the form of energy-efficient linear and compact fluorescent lamps. The UNDP-UNEP-GEF[35] has a global initiative to support the phaseout of incandescent lamps in non-OECD[36] countries.[37] On April 25, 2007, the Canadian Government

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

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

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

[37] International Energy Agency―Energy Efficiency and Environment Division. *European Policy*

announced its commitment to phase out the use of inefficient incandescent lamps.[38] In addition, lamp manufacturers have made voluntary commitments to improve the efficacy of incandescent lamps. For example, in June 2007, European lighting manufacturers proposed standards for incandescent lamps. In addition, EISA 2007 established efficiency standards for incandescent lamps in the U.S. These standards would increase the average efficacy of incandescent lamps to at least 18 lm/W by 2014. In 2020, the efficacies of general service lamps must be at least 45 lm/W. This standard may phase out the use of incandescent lamps entirely.

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

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

LEDs form a small but rapidly growing segment of the $40 billion a year global lighting market.[39] High-brightness (HB) LEDs, a popular product is a $4.7 billion business globally.[5] LEDs are expanding from use as indicator lights in traffic signals and exit signs to being used for general illumination purposes. Of the HB LED revenues, approximately 7%, or $330 million is attributable to general illumination applications.[5]

OLEDs are still being improved in the lab, with a best reported efficacy for a white LED at 64 lm/W.[40] Manufacturers are waiting for OLED efficacies to improve before investing in the capital-intensive manufacturing infrastructure needed to produce commercial products at high volumes.

Developments Concerning Incandescent Lighting. 2007. <ftp://ftp.nrcan.gc.ca/pub/outgoing/lighting/Europe%20-%20%20Paul%20Waide.ppt#355,1,European policy developments concerning incandescent lighting>

[38] Natural Resources Canada. *Lighting the Way to a Greener Future: Canada's New Government to Ban Inefficient Light Bulbs*. 2007. <http://www.nrcan.gc.ca/media/newsreleases/2007/200735_e.htm>

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

[40] *OLED focus for Osram Opto, efficacy reaches 64 lm/W*. LEDs Magazine August 2006. Available at: http://www.ledsmagazine.com/news/3/8/8/1.

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 January 2008). 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 (January 2008)

Figure 3-1 presents the congressional appropriation for the SSL portfolio from FY2003 to FY2007. The funding request for FY 2009, totaling $19.1 million, is also represented. The program's funding level increased from $3 million in FY2003 to $30.0 million in FY 2007. For the current fiscal year (FY2008, which began in October 2007), the final funded amount was $24.3 million, including $5 million of additional funding provided by Congress over the Administration request.

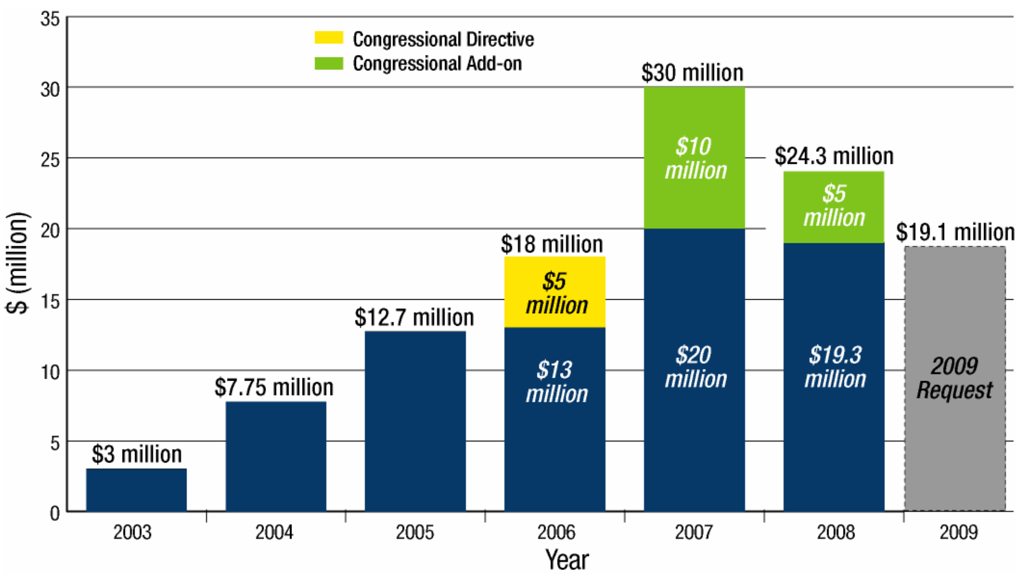


Figure 3-1: Congressional Appropriation for SSL Portfolio, 2003-2008

The current SSL DOE research portfolio[41] (not including completed projects) includes fifty-one 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 $74.8 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 $56.8 million in funding for the projects, and the remaining $17.9 million is cost-shared by project awardees. Of the fifty-one projects active in the SSL R&D portfolio through 2007, twenty-six were associated with LEDs and twenty-five were focused on OLEDs. The OLED project partners had a slightly higher cost-share contribution ($9.0 million) than the LED project partners ($8.9 million).

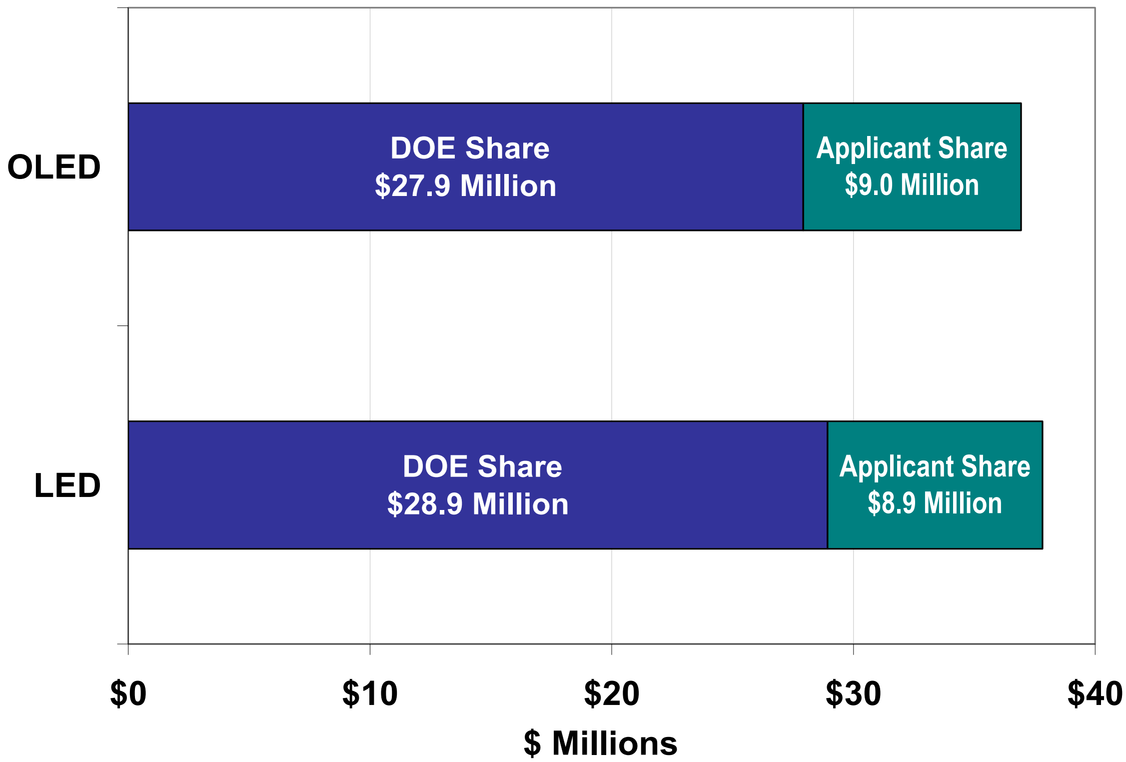


Figure 3-2: Cumulative Funding of SSL R&D Project Portfolio, January 2008

[41] As of November 2007.

Figure 3-3 shows the DOE funding sources and level of support contributing to the SSL project portfolio, for projects active in January 2008. The Building Technologies Program in the Office of Energy Efficiency and Renewable Energy (EERE) provided the majority of the funding; fifty-one projects receive $70.2 million in funding from this source. Approximately 58 percent ($40.8 million) is directed to fund Core Technology Research projects and with the balance 42 percent ($29.3 million) supporting Product Development projects. The Small Business Innovation Research (SBIR) program in the Office of Science funded ten projects for a total of $4.6 million.

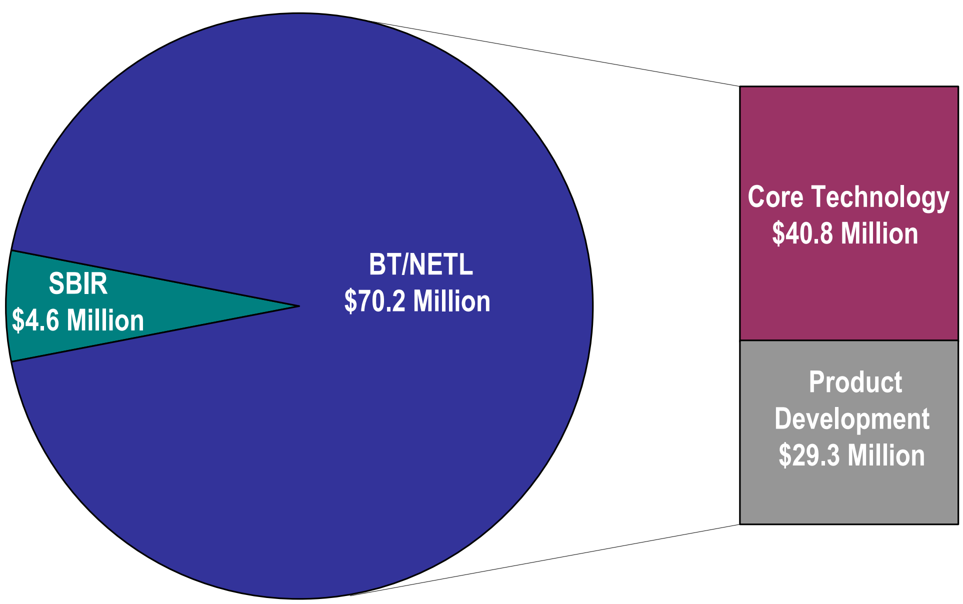


Figure 3-3: Cumulative SSL R&D Portfolio: Funding Sources, January 2008

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 39% of portfolio funding, with $29.0 million in R&D activities. Universities comprise the next largest category receiving 23%, or $16.9 million, in research funds. Finally, small businesses and national laboratories each comprise 19% of the R&D portfolio, receiving $14.5 million and $14.3 million respectively.

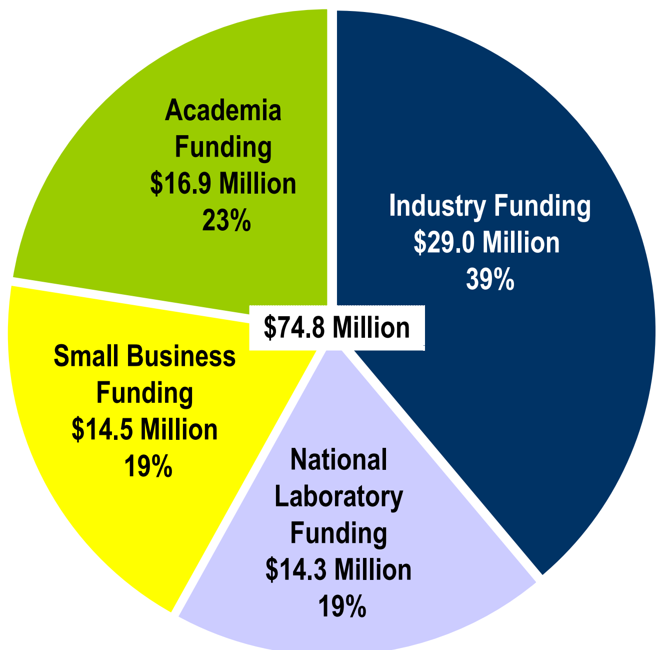


Figure 3-4: Total Funding of Projects in DOE's SSL R&D Project Portfolio, January 2008

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 January 2008). During the SSL workshop held in November 2003, participants suggested research areas that required emphasis at that time in order to advance SSL technology toward the goal of general illumination. These priorities have been continuously updated since that time. Table 3-1 shows the projects that DOE has chosen to fund, in keeping with the evolving priorities, under the *Core Technology Research* solicitations. Table 3-2 shows the projects that are currently funded in *Product Development* (as of January 2008).

Table 3-1: SSL R&D Portfolio: Core Technology, January 2008

	Number of Projects	$ Funding (Million)
Light-Emitting Diode		
Large-area substrates, buffer layers, and wafer research	3	$2.5
High-efficiency semiconductor materials	12	$15.6
Strategies for improved light extraction and manipulation	1	$2.5
Phosphors and conversion materials	2	$2.5
Total LED	*18*	*$23.1*
Organic Light-Emitting Diodes		
Novel materials and device architectures	7	$8.6
Improved contact materials and surface modification techniques to improve charge injection	1	$1.7
Applied Research in OLED devices	1	$0.8
Research on low-cost transparent electrodes	5	$5.2
Investigation (theoretical and experimental) of low-cost fabrication and patterning techniques and tools	1	$4.0
Total OLED	*15*	*$20.3*
TOTAL	**33**	**$43.4**

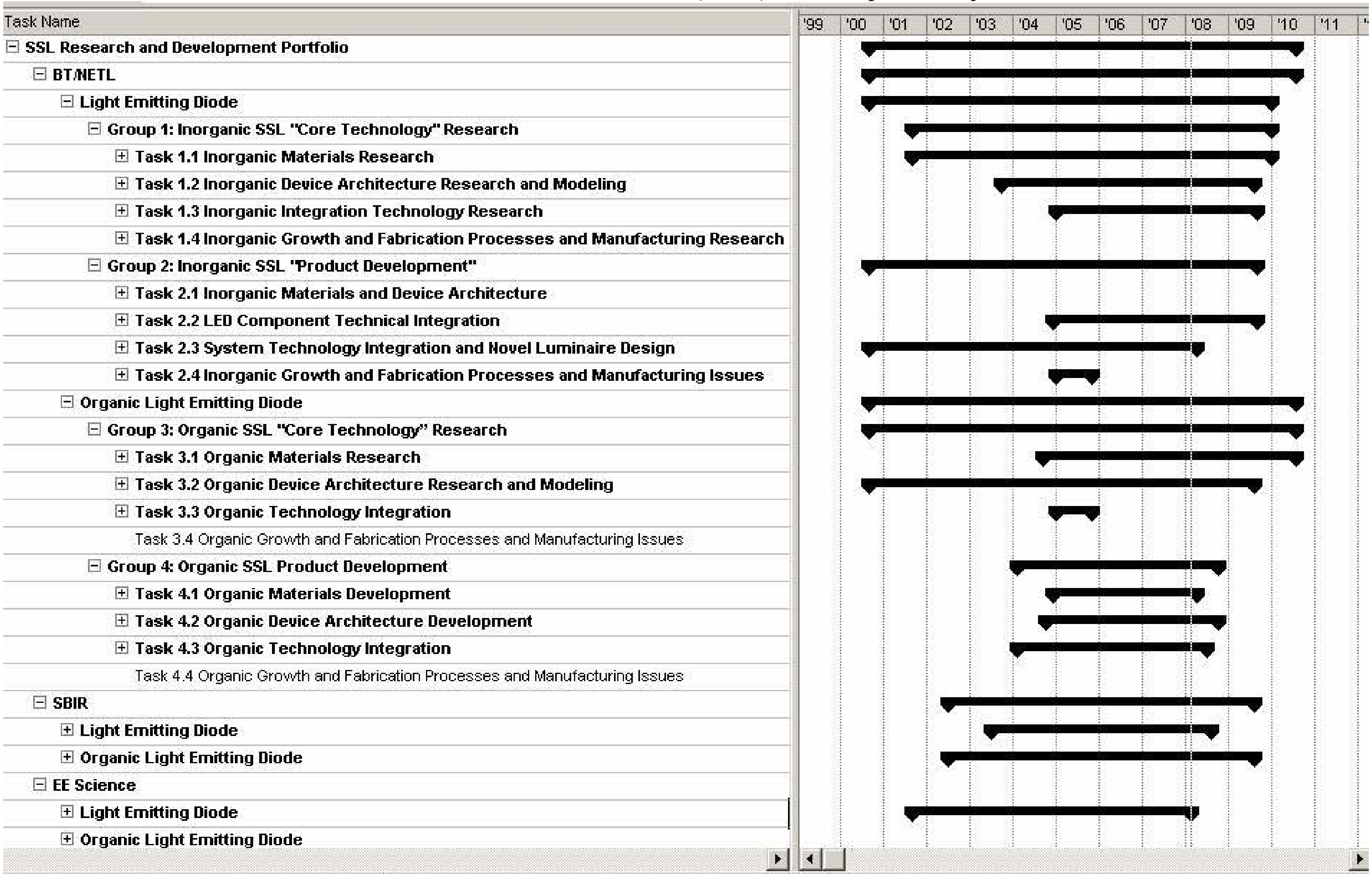
Table 3-2: SSL R&D Portfolio: Product Development, January 2008

	Number of Projects	$ Funding (Million)
Light-Emitting Diode		
Manufactured Materials	2	$3.9
LED packages and packaging materials	3	$4.5
Electronic Development	1	$2.6
Optical coupling and modeling	2	$3.7
Total LED	*8*	*$14.7*
Organic Light-Emitting Diodes		
Practical Implementation of materials and device architectures	3	$5.0
Practical Application of Light Extraction Technology.	3	$6.6
OLED encapsulation packaging for lighting applications	3	$5.0
Module and process optimization and manufacturing	1	$0.1
Total OLED	*10*	*$16.6*
TOTAL	**18**	**$31.3**

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. This chart presents the timeline of current and completed projects grouped by funding source and categorized by task. To complete the program targets for each task, more funding may be required.

Table 3-3: Timeline of Current (FY08) 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.

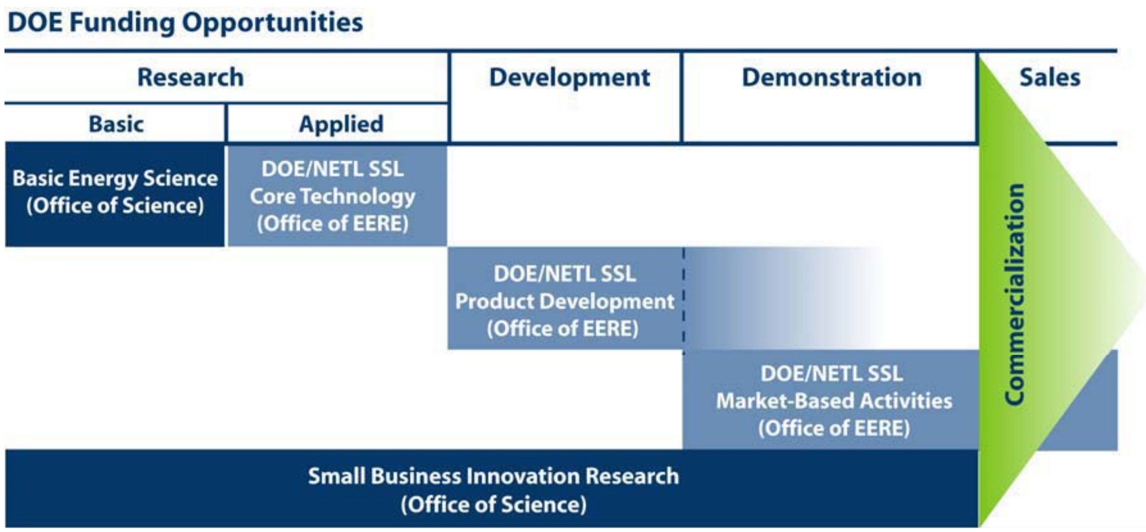


Figure 3-5: DOE Funding Opportunities

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.

- **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

- **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.

3.4. Procurement Strategy

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

3.4.1. Performers

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

3.4.2. Gaps

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

3.5. Cross Area Coordination

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

In November 2003, representatives from the DOE Building Technologies Program and Basic Energy Sciences Program, National Science Foundation (NSF), National Institutes of Standards and Technologies's (NIST) Advanced Technologies Program (ATP), and the Defense Advanced Research Projects Agency (DARPA) met with representatives from the solid-state lighting industry in a workshop to coordinate and prioritize public-private research on solid-state lighting technologies.[42] Since then, these offices have continued to share results of research projects and coordinate topics for competitive

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

solicitations for solid-state lighting research, typically released once a year.

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

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

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

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

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

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

4.0 Technology Research and Development Plan

The U.S. Department of Energy supports domestic research, development, demonstration, and commercialization activities related to SSL to fulfill its objective of advancing energy-efficient technologies. 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.

Improving the efficiency and decreasing the cost of SSL will have a large contribution towards DOE's goal of a net-zero energy building (ZEB). Lighting constitutes approximately 12 percent of residential building energy consumption and 25 percent of commercial building energy consumption. This electricity consumption figure does not include the additional loads due to the heat generated by lighting, which is estimated to be up to 40 percent in a typical "stock" building. Further technology and cost improvements and market acceptance of SSL technologies will dramatically reduce lighting energy consumption, and thereby the total energy consumption, of residential and commercial buildings by 2025.[43]

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 7 years, with some general observations to 2025. Actual accomplishments will result in changes to the plan over this time period which will be reflected in future revisions. The 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[44]

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

[43] 2006 Building Energy Data Book, U.S. Department of Energy, Office of Planning, Budget and Analysis, Energy Efficiency and Renewable Energy. Prepared by D&R International, Ltd., September 2006. Hereafter, BED.
[44] 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

4.1.1. Components of LED Luminaires

As solid state lighting has evolved, a number of product configurations have appeared in the market. While definitions are still in flux, they are beginning to solidify[45] so that we can identify two essential levels of product based on whether or not they include a driver and a number of terms in each level:

Component level (no power source or driver)

- LED Device refers to the packaged light-emitting semiconductor chip or die including the mounting substrate, encapsulant, phosphor if applicable, and electrical connections.

- LED Array. Several LED chips may be packaged together on a common substrate or wiring board in order to increase total light output or improve the spectrum.

- LED Module. This term is new and refers to an LED packaged with additional components such as thermal, mechanical, or electrical interfaces

Subassemblies and Systems (including a driver)

- LED Lamp refers to an assembly with a standardized base consisting of an LED device integrated with an LED Driver. Such assemblies are generally intended as replacement products for conventional light bulbs, although this situation may evolve over time should standardized bases specific to LEDs come into being.

- LED Light Engine is a term in fairly wide use now, and refers to a subsystem of a luminaire that includes one or more LED Devices, arrays or modules, an LED Driver, an integral heat sink, and appropriate mechanical interfaces. It is intended to be a building block for an LED Luminaire, below.

- LED Luminaire refers to the complete lighting unit, intended to be directly connected to an electrical branch circuit. It consists of a light source, as above, and driver along with parts to distribute the light and to connect, position, and protect the light source.

In the above definitions, the term LED Driver means a power source with integral control circuitry designed to meet the specific needs of an LED Device, Array, or Module. The driver converts line voltage to appropriate power and current for the device and may also provide sensing of and corrections for shifts in color or intensity that occur over the life of the product or due to temperature variations. Other special features, such as dimming controls, may also be included. Figure 4-1, below, illustrates a few of these definitions.

[45] The IES draft document RP-16, nearing completion, provides an extended list of definitions of which this list is a paraphrased subset. These definitions are slightly different from those in earlier versions of the MYPP.

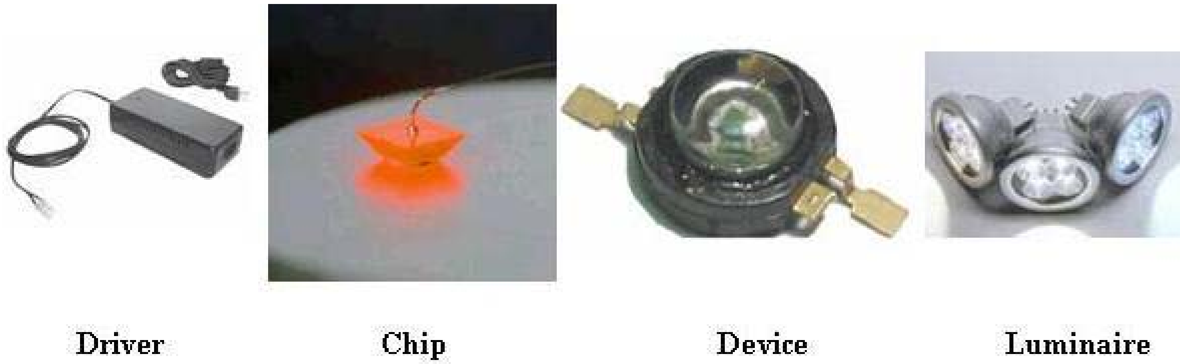


Figure 4-1: Photos of LED Luminaire Components
Sources: Lumileds, Color Kinetics.

4.1.2. Components of OLED Luminaires

Because of the nature of the OLEDs, as well as the state of the technology, the number of product configurations can be described below in simpler terms, at least for now. At the component level, there is the OLED device and at the system level, there is the OLED luminaire.

- OLED Device refers to the layers of materials, including a set of charge transporting and emissive layers (made of organic materials) that correspond to those of the basic LED chip. Other layers provide encapsulation, electrical connection and packaging. Because OLEDs are a diffuse light sources, large areas are needed for general illumination applications. Therefore the electrodes of an OLED must be relatively complex in order to spread current out over a large area efficiently. A number of specific OLED device structures are possible, and a few are mentioned below.

- OLED Luminaire refers to the complete lighting unit, intended to be directly connected to an electrical branch circuit. It consists of the OLED device, driver, and fixture. The OLED driver converts line voltage to appropriate power and current for the device. The OLED fixture provides for mounting and mechanical support for the device, interconnection with the driver, and diffusion or direction of the light from the OLED device to the task. Because OLEDs are more diffuse light sources, less complicated fixtures may be possible relative to LEDs or conventional light sources.

Geometries that emit downwards through a transparent substrate or upward from a reflective substrate are currently being considered for OLEDs. The simple planar structure shown in Figure 4-2 below displays an OLED which emits downward through a transparent substrate. These structures typically employ a reflective, metal cathode.

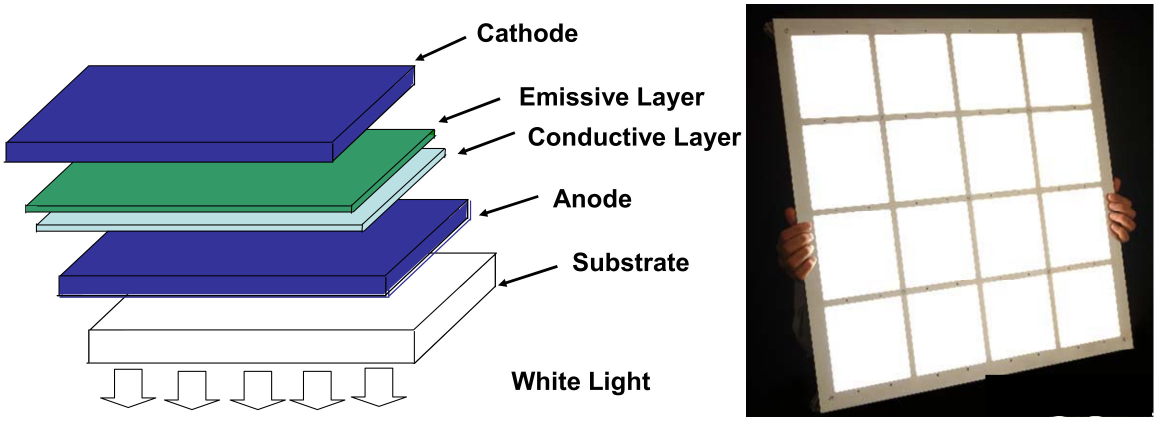


Figure 4-2: Diagram/Photo of OLED Panel
Photo source: General Electric.

It is also possible to manufacture an OLED with a highly transparent cathode (typically with up to 80% transmission across the visible spectral region). These structures can emit upward from a reflective substrate, such as a reflective metal foil, or can be entirely transparent devices. Figure 4-3 displays an entirely transparent OLED employing a transparent substrate and cathode.

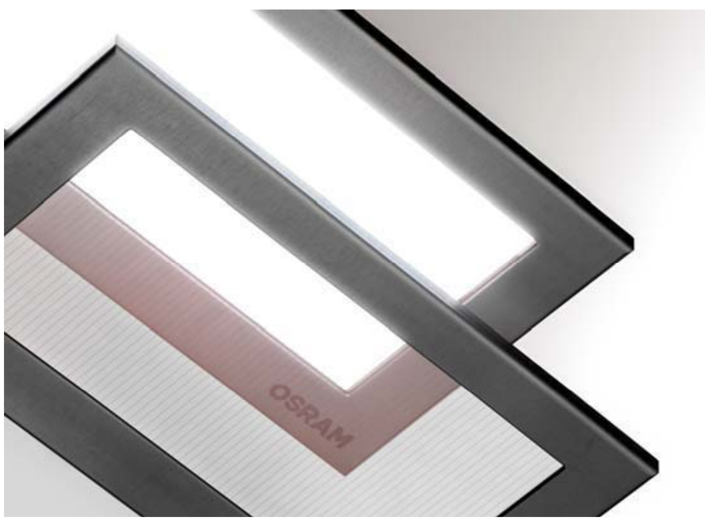


Figure 4-3: Photo of a Transparent OLED Lighting Tile
Photo source: OSRAM Opto

4.2. Current Technology Status and Areas of Improvement

Significant progress has been made in LEDs over the past year and several viable and efficient luminaire products have reached the market. More are expected in the coming year. LED device technology successfully met the first milestone set by DOE's multi-year plan and appears to be ahead of schedule for the next one. As a result, some LEDs are now more efficient than incandescent sources and are approaching parity with CFLs. More work will be necessary to assure that luminaires and power conditioners do not excessively degrade the performance of the devices. More work will also be necessary to reach efficiencies that can compete with linear fluorescent lamps. OLED performance lags behind LEDs, as might be expected from that technology's later start. There are essentially no viable OLED products for general illumination available today; however, there is reason to believe that they are not too far off.

To further define the relationship among the components of luminaires and to highlight relative opportunities for efficiency improvements, one can identify various elements of power efficiency, both electrical and optical, within the SSL device and for the luminaire as a whole. These losses and consequent opportunities for LED and OLED luminaires are apparent in the several figures that follow (Figure 4-4, Figure 4-5, and Figure 4-6). 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 forecasts both device efficacy and luminaire efficacy improvements. It is important to keep in mind that it is the luminaire efficacy that determines the actual energy savings.

Opportunities for improvement of the device include: reducing electrical and optical losses in the device; improving the efficiency of conversion of electrons into photons (IQE); the extraction of those photons from the material (extraction efficiency); and tailoring the spectrum of the radiated light to increase the eye response. Tailoring of the spectrum to the eye response is constrained by the need to provide light of appropriate color quality (correlated color temperature (CCT) and color rendering index (CRI)).

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. 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,* however*,* the program's intention to impede novel developments which use a different allocation of losses that result in a better overall luminaire performance.

For consistency, OLED efficiencies throughout this chapter are reported at a fixed brightness (1,000 cd/m^2) and output (>500 lm). LEDs are reported for a fixed drive current (350 mA) and area (1mm^2). These values are simply used to compare efficiency levels and set targets. Using these reference values is not intended to imply that they are ideal or even the most desirable drive current densities 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 4-4 presents a diagram of a color-mixing LED luminaire. Because there is no Stoke's loss, the color-mixing LED, is capable of higher efficacies than the pc-LED. On the left side of the figure is a simplified breakdown of the elements of luminaire efficiency that includes thermal losses associated with steady state operation. On the right hand side is a breakdown of device efficiencies. These efficiencies are independent of spectrum to first order, and shows the results as typically reported for devices (e.g. pulsed measurements taken at 25°C).

The percentage efficiencies in the diagram next to each component indicate the typical performance in 2007 and targets that will satisfy the goals of the program. From this diagram and one can infer the headroom for improvement for the various luminaire and device elements. For purposes of comparing various experimental results, this diagram and the next one for pc-LEDs, assume a target correlated color temperature of 4100°K (the equivalent CCT of a cool white fluorescent lamp), and a CRI of at least 80. Other combinations may provide acceptable light for particular market needs, but may then be inappropriate for the targets indicated. Currently available 2007 products typically have color temperatures in the range of 4100-6500°K, and often a lower CRI, although more warm white products are beginning to appear.[46] The 2007 typical numbers reflect these less than optimal parameters, and therefore may overstate our current capability. For simplicity, Figure 4-4 depicts only RGB color-mixing using LEDs. However, other options are possible for obtaining different color temperatures or color rendition indices using a hybrid approach. For example, a warm white color can be achieved by mixing phosphor converted white LEDs with monochromatic red or amber LEDs.
Over the course of the program, performance improvements will make possible the manufacturing of devices with lower color temperature and better CRIs without seriously degrading the efficiency. Achieving the efficiency targets identified in Figure 4-4 will require more efficient emitters (particularly in the green area of the spectrum) and other improvements elsewhere in the luminaire.

[46] The DOE Commercially Available LED Product Evaluation and Reporting (CALiPER) supports the testing of a wide, representative array of SSL products available for general illumination, using test procedures currently under development by standards organizations. More information is available at: http://www.netl.doe.gov/ssl/comm_testing.htm

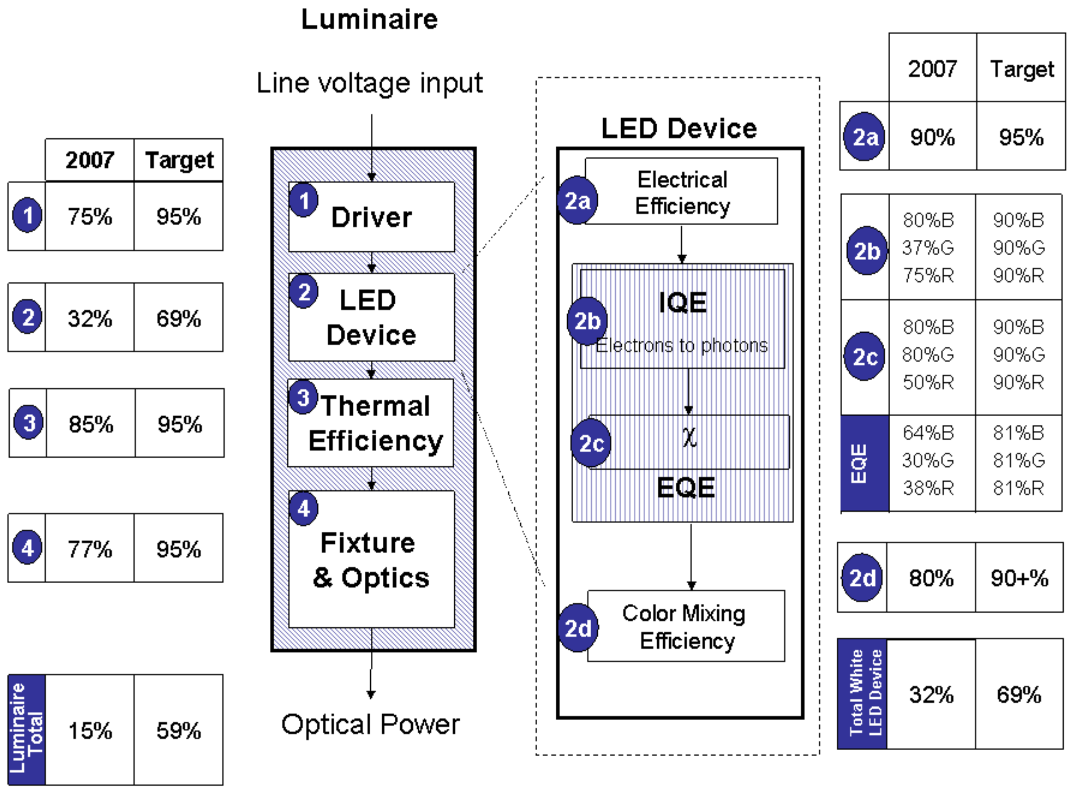


Figure 4-4: Color-Mixing LED- Current and Target Luminaire Efficiencies for Steady State Operation

Source: NGLIA LED Technical Committee, Fall 2007

Note: The target assumes a CCT of 4100K and CRI of 80; Current CCT: 4100-6500K, CRI: 75

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.

Device efficiency, There are several components of the device electrical efficacy that are shown on the right in Figure 4-4 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.

Thermal Efficiency is the ratio of the lumens emitted by the device in thermal equilibrium under continuous operation in a luminaire to the lumens emitted by the device as typically measured in production at 25°C.[47]

Fixture and optics efficiency, η_{fo}, is the ratio of the lumens emitted by the luminaire to the lumens emitted by the LED 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 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, device power efficiency excludes driver losses. The device *efficacy* is the product of the power efficiency of the device and the spectral or optical efficacy due to the human eye response. Elements of the device power efficiency are:

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

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

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

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.[48]

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

[48] 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

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 4-4 is assumed to occur in the device.

The device-related parameters of the luminaire have the greatest headroom for improvement in the short term. For example, the internal quantum efficiencies (2b) of the chips range from 37% to 80%, depending on color. The ultimate goal is to raise the IQE to 90% across the visible spectrum, bringing the total device efficiency to 69%. As the LEDs become more efficient, there will necessarily be more emphasis on the other luminaire losses in order to maximize overall efficiency.

The driver (1) efficiency of 75% indicated for today's products is somewhat lower than that for a phosphor converting LED (see Figure 4-5) because the driver needs to produce different colors at different drive voltages with controllable intensities. The ultimate target for this component is to improve the efficiency to be greater than 95%. Likewise, there is considerable room for improvement of the fixture and optics. Currently, the color-mixing LED luminaire is approximately 15% efficient at converting electrical energy into visible white-light. If all targets are achieved, the LED device would have an efficiency of 69%, with an overall luminaire efficiency of 59%.

The device power efficiency (W_o/W_e), indicated in the above figure, measures the energy of light emitted by the device divided by the electrical energy put into the device. This metric is independent of the spectrum of light emitted by the device. Electrical luminous efficacy (in lm/W_e)[49], on the other hand, measures of the amount of useful visible light out of a device per unit of electrical energy. The electrical luminous efficacy of the color-mixing LED device can be calculated by multiplying the device power efficiency by the *optical* or *spectral* luminous efficacy of radiation (LER). For blended LEDs, the LER is approximately 360 lm/W_o (exact value varies with the CRI and CCT for the particular design and the available wavelengths[50]). Using this conversion, the target for a color mixing LED device would be close to 248 lm/W_e (69% power efficiency, above, multiplied by 360 lm/W_o). This would result in an overall luminaire efficacy, absent significant breakthroughs, of approximately 213 lm/W_e (360 lm/W_o x 59% luminaire efficiency)These additional luminaire losses are the reason that the program includes tasks directed at fixture and driver efficiency as well as those emphasizing the basic LED device, and also why the most energy-efficient installations of the future will have

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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 would be worthwhile to try to develop some measurement standards for these parameters.

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

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

purpose-designed luminaires as opposed to simply retrofit lamps. These are “practical” figures based on the sources and technology that can be envisioned now. The electrical to optical power conversion efficiency could improve and the spectral luminous efficacy could also be higher, as much as 400 lm/W_o for a CRI of 80, if optimal wavelengths (or more colors) are available. This would yield a higher overall figure for lumens per watt.

Phosphor Converting LED

Figure 4-5 below, presents a diagram of a phosphor converting LED luminaire. The definitions for the various efficiencies are the same as listed for Figure 4-4, with additional definitions for phosphor efficiency and scattering efficiency:

> Phosphor efficiency, η_{phos} , the value given in 2d is given for current state of the art green-yellow phosphors necessary to create a simple white emitting device using a blue emitting LED. In order to improve the color quality of phosphor converted white devices while maintaining high efficiency it will be necessary to improve the phosphor efficiency of phosphors that emit in the red wavelengths and, possibly, the efficiency of phosphors that emit in the green to blue-green region of the spectrum. The phosphor efficiency includes quantum efficiency and the Stokes loss of the phosphor.
>
> Scattering efficiency is the ratio of the photons emitted from the LED device to the number of photons emitted from the semiconductor chip. This efficiency, relevant only to the phosphor converting LED in Figure 4-5, accounts for scattering losses in the phosphor and encapsulant of the device.

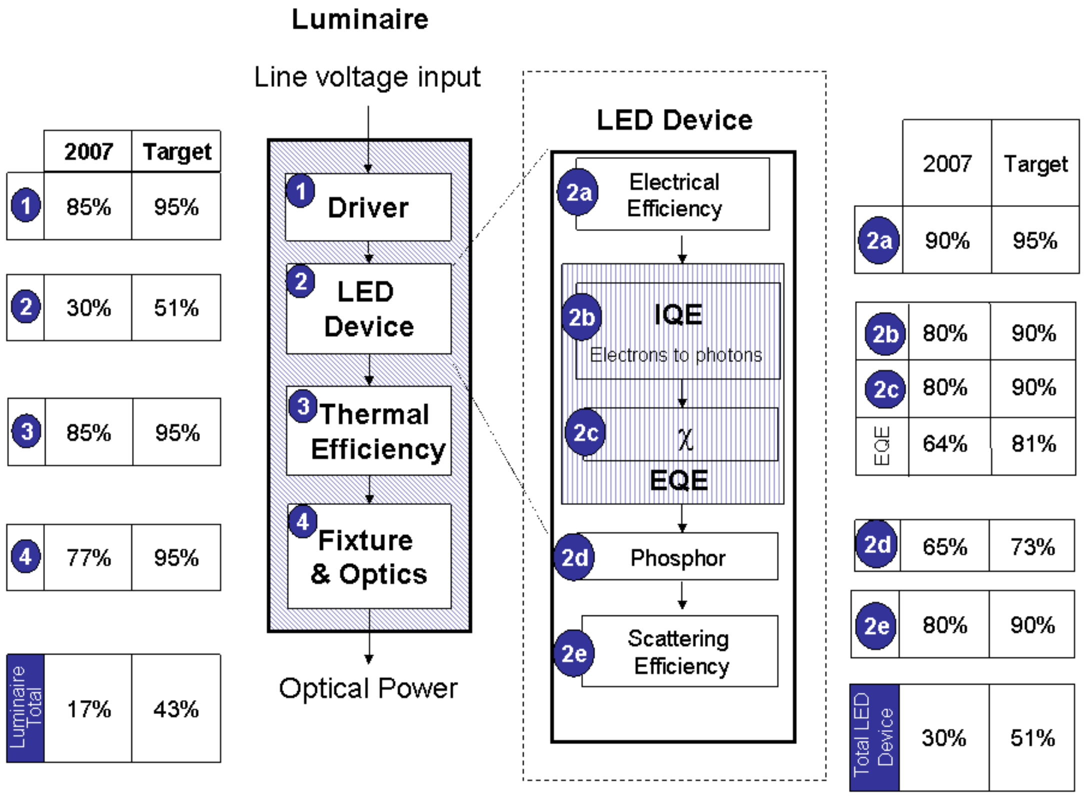

Figure 4-5: Phosphor Converting LED- Current and Target Luminaire Efficiencies for Steady State Operation

Source: NGLIA LED Technical Committee, Fall 2007

Note: The target assumes a CCT of 4100K and CRI of 90; Current CCT: 4100-6500K, CRI: 75

Note: The target for 2e includes the loss due to the Stokes shift (90% quantum yield times the ratio of the the average pumped wavelength and the average wavelength emitted); the value here is typical of a blue diode/yellow phosphor system.

In the above figure, Component 2a, the LED device electrical efficiency, is estimated to have an efficiency of 90% for 2007 products (with available switching techniques). The ultimate target for this component is to improve the efficiency to greater than 95%. In comparison, other components of the luminaire have more room for efficiency improvements. For example, the extraction efficiency of the LED chip is currently 80%. 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 17% efficient at converting electrical energy into visible white-light. If all targets are reached, the LED device would have an efficiency of 51%, and the luminaire an efficiency of 43%. 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 device power efficiency (W_o/W_e) by the *optical* luminous efficacy (useful light out (lm) divided by the optical power in (W_o)) of a phosphor. Similar to color-mixing LEDs, a practical target for a phosphor-converting LED luminaire is about 171 lm/W_e. Improving the phosphor efficiency and temperature performance could improve the efficacy even more.

4.2.2. Organic Light Emitting Diodes

Figure 4-6 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.

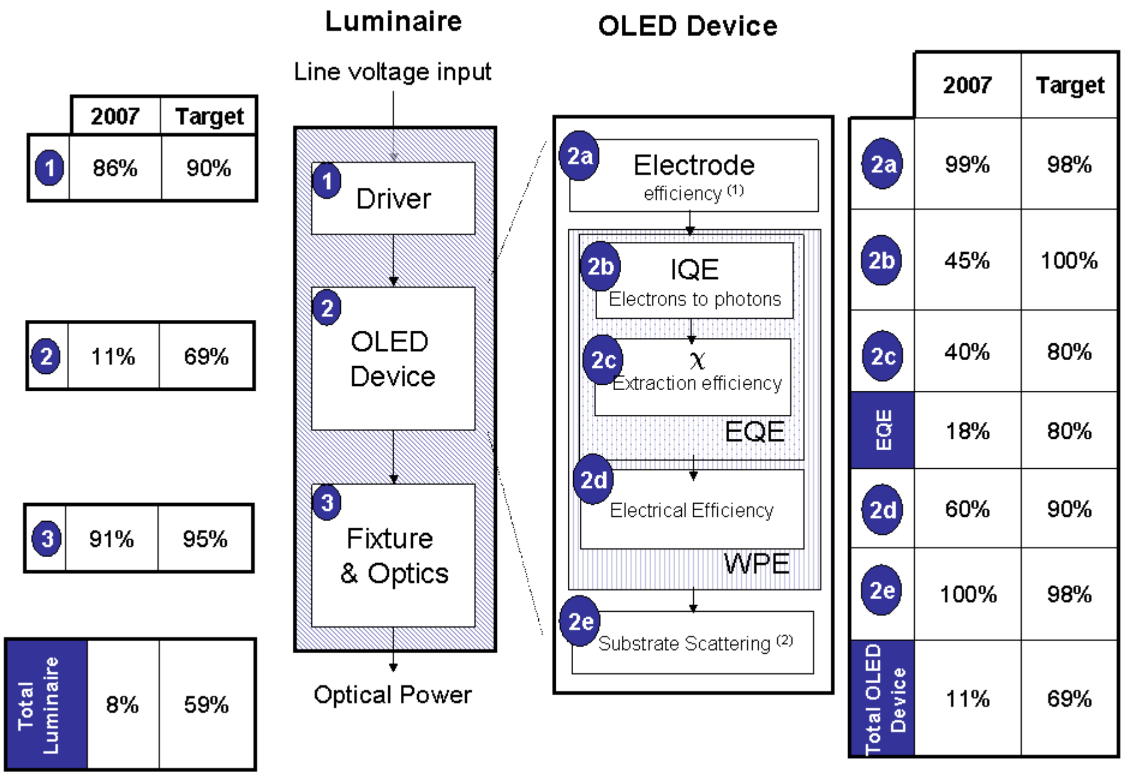

Figure 4-6: OLED Luminaire Efficiencies & Opportunities

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

Note 1: Electrode loss is negligible for devices currently used for small displays but will be an issue for large area devices necessary for general illumination applications in the future.

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 2007

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. Early 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 techniques that can improve but not entirely eliminate electrode resistance, but it could become a significant issue as panel sizes increase. Thus, while this diagram shows very small source losses from these effects, as they can be in lab devices, a commercialized product with that level of loss may be difficult to achieve. The external quantum efficiencies 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. 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 can be large area emitters, fixtures, to the extent that they are used to reduce glare, could almost be eliminated if the total lumen output of the OLED is distributed over a large enough area. Although fixture efficiencies could increase, prices may also rise as the area of the OLED increases. Also, it is important to note that because there are no commercial products on the market, estimates of luminaire efficiencies are based on laboratory estimates.

Keys to efficiency improvements in OLEDs continue to revolve around finding suitable stable materials with which to realize white light, with blue colors being the most difficult. Progress on efficiencies for OLEDs 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 adequate funding by both government and private industry. Although the authorization level for the SSL program is $50M for 7 years, actual appropriations have not reached this level. Appropriated funding has steadily increased over the life of the program (see Figure 3-1) although recently appears to be declining. 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, the OLED efficacy forecast in this section only projects performance to 2012 due to a lack of knowledge about the ultimate limit of this technology.

In order to capture the ultimate objectives of the SSL program which relate to *luminaire* efficacy or cost, objectives for luminaire performance are also included along with device performance objectives. It is important to note that the graphs are of device performance. Reaching the luminaire objectives will take longer, as shown by the luminaire efficacy values in Table 4-2. Innovative fixtures for LEDs can have a significant impact on overall efficacy. For example, device efficiencies (and operating lifetime) can be degraded by 30% or more when operating at full temperature at steady state in a luminaire. Although device efficiencies can be degraded in luminaires, SSL will still help DOE meet its Zero Energy Building (ZEB) goals by providing a luminaire that is more efficient than other lighting technologies. Accommodating both aesthetic and marketing considerations, while preserving the energy-saving advantages of solid state lighting, is a challenge in commercializing this technology. Section 5.6 of the SSL MYPP discusses DOE's commercialization support plan.

4.3.1. Light Emitting Diodes

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

Figure 4-7 shows device efficacy improvement over time. Actual results through 2008 show that progress has been faster than was expected in the March 2007 projection. However, progress is not expected to continue at this rate over the next few years.

We are beginning to approach what are perceived to be the practical limits of efficacy as shown in Table 4-1. These limits depend on the choice of CCT and color quality demanded by the application. Apart from these more or less predictable limits, manufacturing and cost considerations may further reduce efficacies below their maxima. Based on our expected rates of improvements going forward, these maximum efficacies should be achieved in products between the years 2016 and 2020.

Table 4-1: Practical Maximum Device Efficacy for LEDs

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

Source: NGLIA LED Technical Committee, Fall 2007

The asymptotes on the graph show the extremes of the above figure, warm white with high CRI at 162 lm/W and cool white with a low CRI at 228 lm/W. The earlier diagrams (Figures 4-4 and 4-5) showed efficiencies for targets in between, giving values for a neutral white (4100K) and a moderate-to-high CRI. By 2013 the efficacy for high power cool white laboratory prototypes should reach 184 lm/W, near the limit in the table above. Cool white commercial *products* should reach a level of approximately 172 lm/W by that time. By 2025, the projections approach the practical maximum efficacies for LEDs of 228 lm/W for cool white LEDs and 162 lm/W of warm white LEDs (with a CRI of 90). All projections assume a prototype with a "reasonable" device life.

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

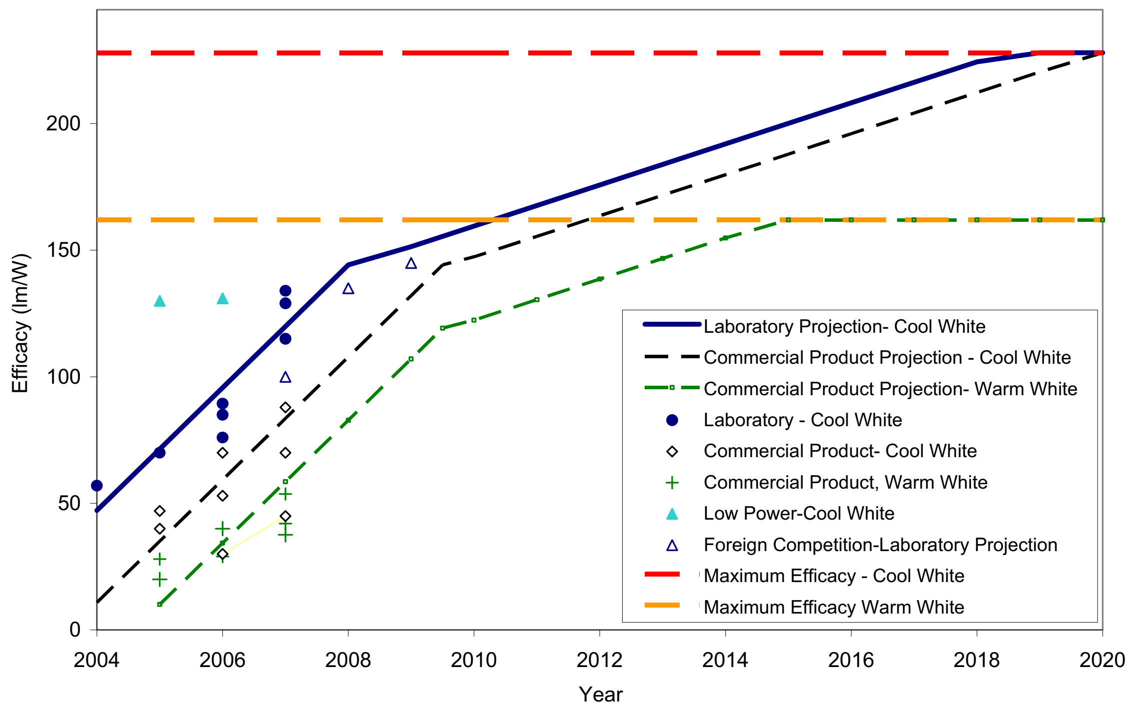

Figure 4-7: White Light LED Device Efficacy Targets, Laboratory and Commercial

Note:

1. Cool white efficacy projections assume CRI=70 → 80, CCT = 4100-6500°K,
2. Warm white efficacy projections assume CRI>85, CCT =2800-3500°K
3. All projections are for high-power diodes with a 350 ma drive current at 25°C, 1mm^2 chip size, device-level specification only (driver/luminaire not included), and reasonable device life.
4. Low power diodes shown have a 20 mA drive current.
5. The maximum efficacy values displayed in Table 4-1 for warm white (3000K and 90 CRI) and cool white (6500K and 75 CRI) are shown above as asymptotes. The target efficiency in Figure 4-4 assumes a CRI of 90 and a CCT of 4100K and would lie in between these two extremes.

Source: NGLIA LED Technical Committee and the Department of Energy, Fall 2007 and Press Releases

The cost estimates were also developed in consultation with the NGLIA Technical Committee, and represent the average purchase cost of a 3 watt white-light LED device driven at 350 mA (excluding driver or fixture costs). The projected original equipment manufacturer (OEM) device price, assuming the purchase of "reasonable volumes" (i.e. several thousands) and good market acceptance, is shown in Figure 4-8. By way of rough comparison, *lamp* prices for conventional technologies are shown on the same chart. 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.[51] Beyond 2015, price projections for LEDs will remain at or near $2/klm.

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[51] Typical lamp costs for conventional light sources listed in section 2.3.2 are 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. It is important to note that to operate an LED device, a heat sink, fixture, and driver are required. Therefore the full price of an LED luminaire (~$100/klm in2008) is greater than that of the device ($25/klm in 2008).

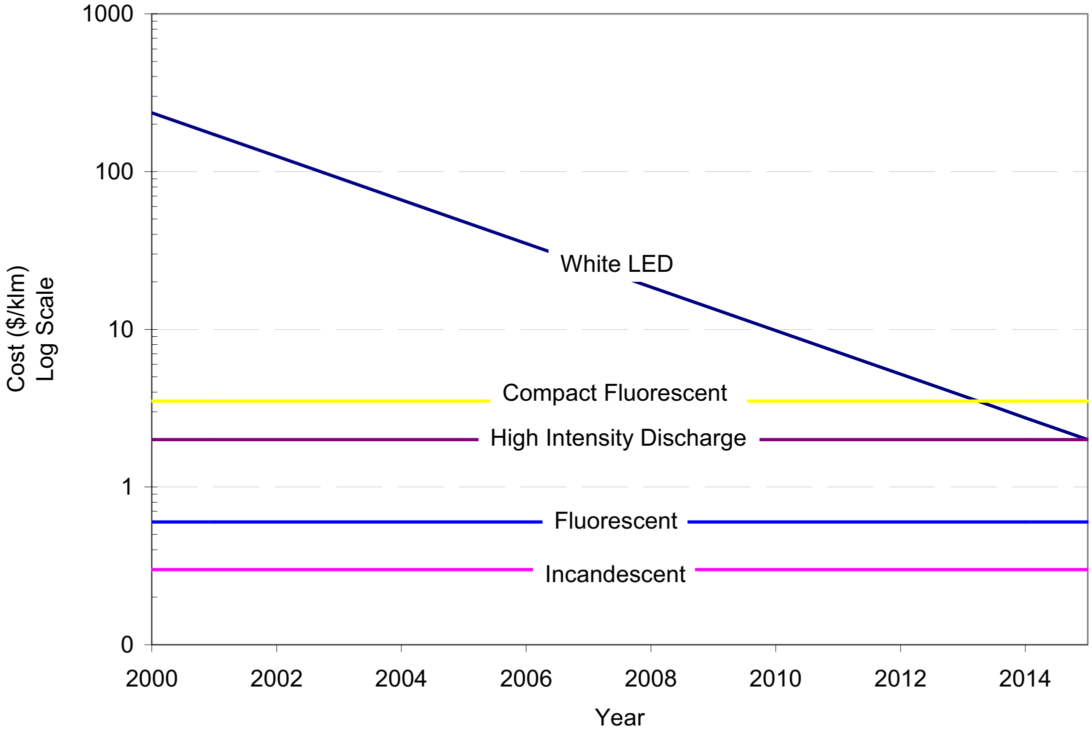

Figure 4-8: White Light LED Device Cost Projection (logarithmic scale)

Note: Price targets assume "reasonable volumes" (several 1000s), CRI=70 → 80,
CCT = 4100-6500K, and device-level specification only (i.e., driver/fixture not included)
Assumes 1-3 W white LED device, 13 W compact fluorescent lamp, 250 W metal halide lamp, 32 W T-8 linear fluorescent lamp, and 60 W A19 incandescent lamp with 2008 prices.
Source: NGLIA LED Technical Committee, Fall 2007

The device life, measured to 70% lumen maintenance[52], has increased steadily over the past few years and appears to be currently at its target of 50,000 hours. Although it appears that the majority of LEDs have reached the target of 50,000 hours, this has not been substantiated as yet by actual long term operating data. Methods for characterizing lifetime, especially as changes in materials or processes are introduced, will likely require accelerated aging tests which so far have not been established for LED technologies. This is an important area of work (and there is an identified task for it described in Section 4.5).

An average device life of 50,000 hours allows 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. This long

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Furthermore, costs among light sources shown in Figure 4-8 are not directly comparable as these light sources may not need a driver, or heat sink to operate. It is also important to keep in mind that energy savings, replacement cost, and labor costs factor into a lamp's overall cost of ownership. LEDs are already cost competitive on that basis with certain incandescent products.

[52] The device life stated above accounts for the lumen maintenance of the LED but does not account for other failure mechanisms.

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 is not substantially affected by lifetimes greater than approximately 50,000 hours. LED products for niche/specialty applications could be developed with longer device life, upwards of 100,000 hours, by trading off with other performance parameters.

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

Table 4-2 presents a summary of the LED performance projections in tabular form.

Table 4-2: Summary of LED Device Performance Projections

Metric	2007	2010	2012	2015
Efficacy- Lab (lm/W)	120	160	176	200
Efficacy- Commercial Cool White (lm/W)	84	147	164	188
Efficacy- Commercial Warm White (lm/W)	59	122	139	163
OEM Device Price- Product ($/klm)	25	10	5	2

Note: 1. Efficacy projections for cool white devices assume CRI=70 → 80 and a CCT = 4100-6500°K, while efficacy projections for warm white devices assume CRI= >85 and a CCT of 2800-3500°K. All efficacy projections assume that devices are measured at 25°C.
2. All devices are assumed to have a 350 mA drive current, 1mm^2 chip size, device-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 device-level specification only (driver/luminaire not included)
4. Device life is approximately 50,000 hrs, assuming 70% lumen maintenance, "1 Watt device," 350 mA drive current.
Source: NGLIA LED Technical Committee, Fall 2007

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 4-3 is luminaire performance projections to complement the device performance projections given in Table 4-2.

Table 4-3 assumes a linear progression over time from the current 2007 fixture and driver efficiency values to eventual fixture and driver efficiency 2015 program targets as given in section 4.1.1. Estimating the factors that affect the performance of an LED luminaire, it appears that a cool white luminaire in 2007 was capable of achieving 50 lm/W (although not all did so). By 2015 cool white luminaire efficacies should reach a capability of 161 lm/W. A projected efficacy for a warm white luminaire is not given here as it depends on the details of the light source design.

Table 4-3: Summary of LED Luminaire Performance Projections (at operating temperatures)

Metric	2007	2010	2012	2015
Device Efficacy-Commercial Cool White (lm/W, 25 degrees C)	84	147	164	188
Thermal Efficiency	85%	89%	91%	95%
Efficiency of Driver	85%	89%	91%	95%
Efficiency of Fixture	77%	84%	88%	95%
Resultant luminaire efficiency	56%	66%	73%	86%
Luminaire Efficacy-Commercial Cool White (lm/W)	47	97	121	161

Notes:
1. Efficacy projections for cool white luminaires assume CRI=70 → 80 and a CCT = 4100-6500°K. All projections assume a 350mA drive current, 1mm^2 chip size, reasonable device life and operating temperature.
2. Luminaire efficacies are obtained by multiplying the resultant luminaire efficiency by the device efficacy values.
Source: NGLIA LED Technical Committee, Fall 2007

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 are shown: one for laboratory prototype OLEDs, and one for (future) commercially available OLEDs. Because it is difficult to obtain a highly efficient blue OLED emitter, similar projections for cooler CCT values will have lower efficiencies than their warmer CCT counterparts shown below. This is unlike LEDs where cooler CCT values are more efficient than their warmer CCT counterparts. Efficacy projections for OLEDs with a

CRI of 90 or higher will also be slightly lower than projections shown.

Figure 4-9 (plotted on a logarithmic scale) predicts that the efficacy of laboratory prototypes will grow exponentially to exceed 150 lm/W by 2012. Based on new data, the NGLIA OLED technical committee has changed the efficacy projection to be more aggressive than in the 2007 Multi-Year Program Plan. As there are not yet any commercial OLED lighting products, the estimated efficacies for commercial products are not meaningful until 2009 and lag approximately three years behind the laboratory products. Projections above 150 lm/W would be speculative given our current understanding of the technology. Therefore, these projections are not shown.
These projections assume the CRI and CCT mentioned above and a luminance of 1,000 cd/m^2 and total output of at least 500 lumens. These projections apply to a white-light OLED device "near" the blackbody curve (Δc_{xy}<0.01)[53], 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.

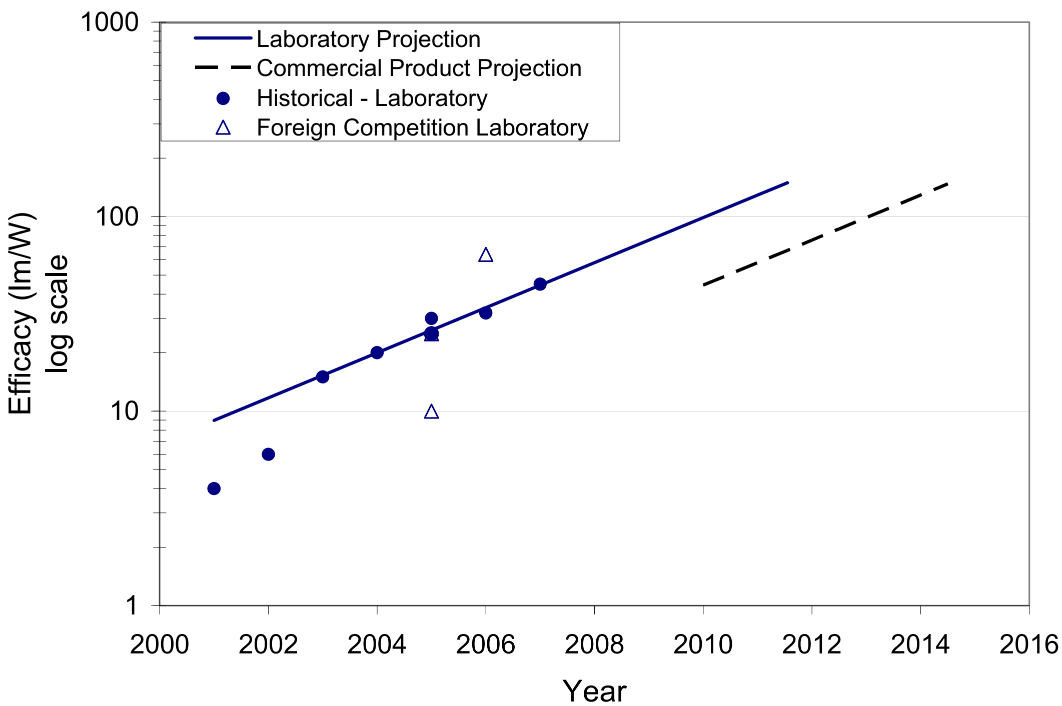

Figure 4-9: White Light OLED Device Efficacy Targets, Laboratory and Commercial
(On a logarithmic scale)
Note: Efficacy projections assume CRI > 80, CCT = 2700-4100°K ("near" blackbody curve (Δc_{xy} <0.01), lifetime > 1000 hrs, luminance of 1,000 cd/m^2, total output ≥ 500 lm, and device level specification only (driver/luminaire not included).
Source: Projections: NGLIA OLED Technical Committee, Fall 2007, Laboratory Points: Press Releases

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

Today, the efficacy of OLED devices lags behind LED devices, and there are no products on the market. However, researchers are optimistic and when the projections of commercial LEDs and OLEDs are compared (see Figure 4-10), the efficacy of OLED products approaches that of the LED products in the latter part of the current forecast.

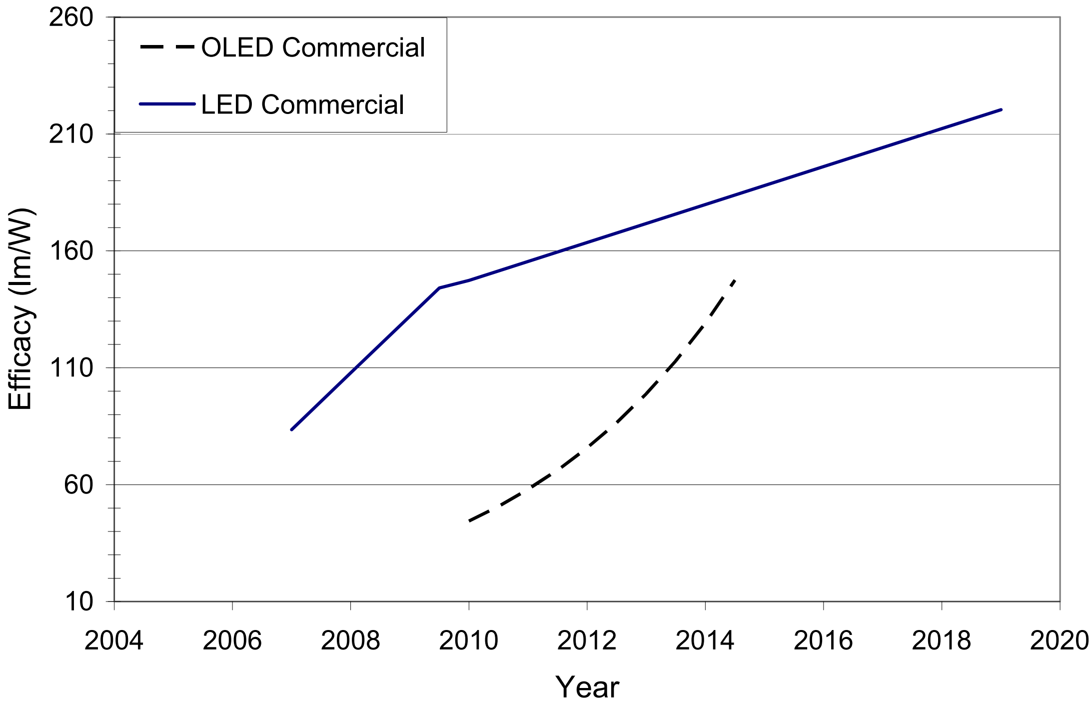

Figure 4-10: LED and OLED Device Efficacy Projections, Commercial
Source: NGLIA OLED Technical Committee and the Department of Energy, Fall 2007

Figure 4-11 presents the anticipated OEM price of commercially available white-light OLED devices (driver and fixture not included) for a luminance of 1,000 cd/m^2 and a total output of at least 500 lumens. Based on current costs of fabrication, we estimate that the 2009 OEM device price would be about $72/klm. The price is expected to fall to $10/klm by 2015, assuming reasonable volumes OLEDs (approximately one square meter in size) sold. Prices of OLEDs may remain around $10/klm after 2015, although future price reductions are possible. The OEM device price, measured in \$/m^2 is approximately a factor of three greater than OLED device price when measured in $/klm for the assumed luminance of 1,000 nits. It is important to note that the price projections below are for OLED devices and not luminaires. Because an OLED driver and fixture may be less costly than that of a conventional lighting source, however, an OLED luminaire with a more expensive "device" may still be cost competitive with a conventional luminaire.

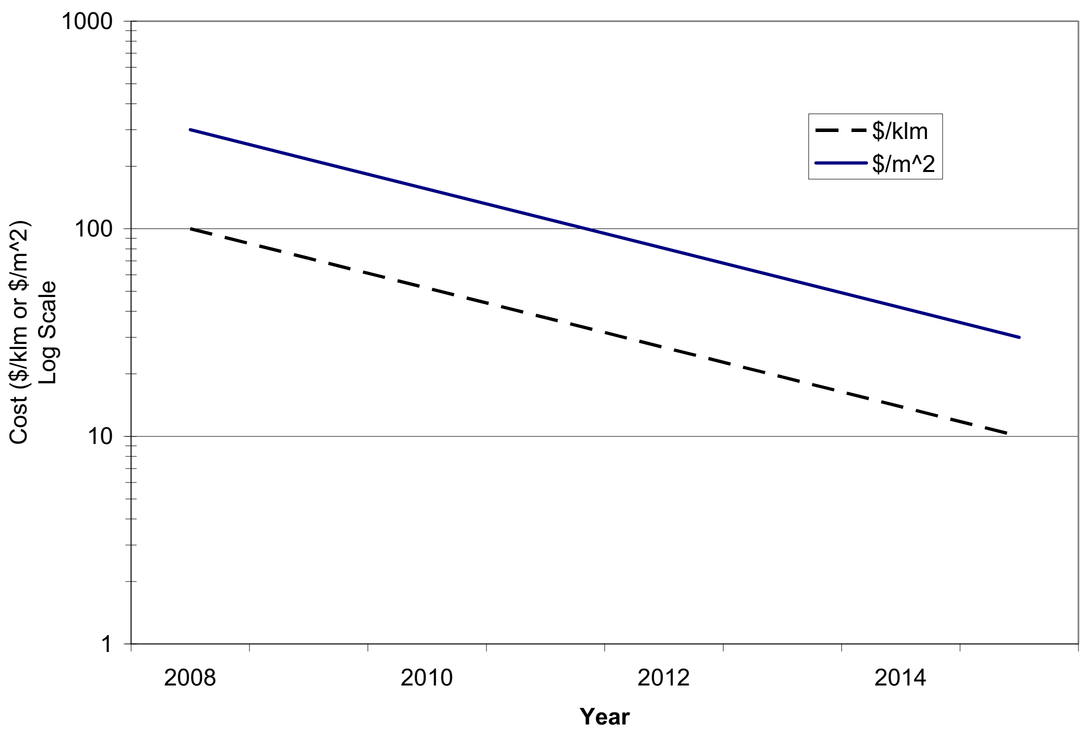

Figure 4-11: White Light OLED Device Price Targets, $/klm and $/m2
Note: Price targets are displayed on a logarithmic scale
Source: NGLIA OLED Technical Committee, Fall 2007

The device life for commercial products, defined as 70% lumen maintenance, is expected to increase linearly to a value of approximately 40,000 hours in 2015. Although 50% lumen maintenance is industry practice for evaluation of OLED displays, we use 70% lumen maintenance[54] in order to compare lifetimes with other lighting products. Table 4-4 presents a summary of the OLED performance projections in tabular form.

[54] Like LEDs, device lifetimes account for the lumen maintenance of the OLED but do not account for other failure mechanisms.

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 4-4: Summary of OLED Device Performance Projections

Metric	2007	2009	2012	2015
Efficacy- Lab (lm/W)	44	76	150	150
Efficacy- Commercial (lm/W)	N/A	34	76	150
OEM Device Price- ($/klm)	N/A	72	27	10
OEM Device Price- ($/m^2)	N/A	216	80	30
Device Life- Commercial Product (1000 hours)	N/A	11	25	40

Notes:
1. Efficacy projections assume CRI = 80, CCT = 2700-4100°K ("near" blackbody curve (Δc_{xy}<0.01), luminance of 1,000 cd/m^2, total output ≥ 500 lm, and device level specification only (driver/luminaire not included)
2. OEM Price projections assume CRI = 80, luminance of 1,000 cd/m^2, total output ≥ 500 lm, and device level specification only (driver/luminaire not included)
3. Device life projections assume CRI = 80, 70% lumen maintenance, luminance of 1,000 cd/m^2, and total output ≥ 500 lm.
Source: NGLIA OLED Technical Committee, Fall 2007

4.3.4. OLEDs in Luminaires

The table below details a summary of the efficiency losses that occur when considering the entire OLED luminaire. Losses in the driver account for the majority of the efficiency degradation while losses in the fixture are assumed to be lower. In addition, OLEDs do not show significant thermal degradation loss, an effect that required the thermal efficiency component for LEDs shown in Table 4-3. Again, a linear improvement over time is assumed from current 2007 driver and fixture efficiency values to 2015 program targets as given in Figure 4-6. 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 2009 OLED commercial luminaire efficacy status becomes 16 lm/W while the 2015 OLED commercial luminaire efficacy projection becomes 129 lm/W.

Table 4-5: Summary of OLED Luminaire Performance Projections beginning 2009

Metric	2009	2012	2015
Commercial Device Efficacy (lm/W) (Table 4-4)	34	76	150
Efficiency of Fixture	92%	93%	95%
Efficiency of Driver	87%	88%	90%
Total Efficiency from Device to Luminaire	80%	82%	86%
Resulting Luminaire Efficacy-Commercial Product (lm/W)	27	62	129

Notes:
1. Efficacy projections assume CRI = 80, CCT = 2700-4100°K ("near" blackbody curve ($\Delta c<0.01xy$), luminance of 1,000 cd/m^2, total output ≥ 500 lm, and device level specification only
Source: NGLIA OLED Technical Committee, Fall 2007.

4.4. Barriers

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

1. Cost: The initial cost of light from LEDs and OLEDs is too high, particularly in comparison with conventional lighting technologies such as incandescent and fluorescent (see section 2.3.2 – 2.3.3). Since the lighting market has been strongly focused on low first costs, lifetime benefits notwithstanding, lower cost LED and OLED device and luminaire materials are needed, as well as low-cost, high-volume, reliable manufacturing methods.
2. Luminous Efficacy: As the primary measure of DOE's goal of improved energy efficiency, the luminous efficacy (lumens/watt) of LED and OLED luminaires still need improvement. Although the luminous efficacy of LED luminaires has surpassed that of the incandescent lamps, improvement is still needed to compete with other conventional lighting solutions. While laboratory experiments demonstrate that OLED devices can be competitively efficacious as compared to conventional technologies, no products are yet available.

3. Lifetime: The lifetime of LEDs and OLEDs is defined as the number of hours for which the luminaire maintains 70% of its initial lumen output. The

lifetime target for the LED device has apparently been achieved. However, it is unclear whether this same lifetime target has been achieved by the LED luminaire. Potential premature failure due to high temperature operation remains a barrier to general deployment. OLED lifetimes for both devices and luminaires still require improvement.

4. Testing: The reported lumen output and efficacies of LED products in the market do not always match laboratory tests of performance. Improved and standardized testing protocols for performance metrics need to be developed. An important barrier appears to be a lack of understanding of the meaning of device specifications versus continuous operation in a luminaire on the part of designers.
5. Lumen Output: LED luminaires are reaching reasonable total lumen output levels although many still perceive LEDs as offering only "dim" light, a significant market barrier. OLED packages with useful levels of output remain yet to be developed.
6. Manufacturing: While OLEDs have been built off of display manufacturing capabilities, there has been little investment by manufacturers in the infrastructure needed to develop commercial OLED lighting products. Lack of process uniformity is an important issue for LEDs and is a barrier to reduced costs as well as a problem for uniform quality of light.
7. Codes and Standards: New guidelines for installation, product safety certifications such as the UL provided by the Underwriters Laboratory must be developed. Common standards for fixture (or socket) sizes, electrical supplies and control interfaces may eventually be needed to allow for lamp interchangeability. Standard test methods are still lacking in some areas.

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

4.5. Critical R&D Priorities

In order to achieve these projections, progress must be achieved in several research areas. The original task structure and initial priorities were defined at a workshop in San Diego in February 2005. These priorities were updated in the March 2006 and March 2007 editions 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.

With respect to the March 2007 MYPP the following changes in the highest priority tasks have been made for 2008:

For LED Core Technology:

1. Subtask 1.1.3, "Reliability and defect physics for improved emitter lifetime and efficiency," was removed from the priority list. Significant progress has been reported on chip lifetime, so this is no longer a high priority for investment.

2. Subtask 1.1.1, "Large-area substrates, buffer layers, and wafer research," was moved to a lower priority. Again, this area of research is at a sufficient state of development that it no longer needs to be among the top core priorities although there is some development work to be done.

3. Subtask 1.2.2 "Strategies for improved light extraction and manipulation" was moved to a lower priority. This task is now largely covered by product development.

4. Subtask 1.3.2 "Encapsulants and Packaging Materials" was moved to the priority list. This task has been somewhat modified to emphasize lower loss and more stable encapsulants and to improve long term reliability of LEDs.

5. Subtask 1.4.x "Inorganic growth, fabrication processes, and manufacturing research" was moved to the priority list. Novel ideas to improve the consistency and uniformity of epitaxial growth and other processes, including improved measurement methods, could reduce the need for binning product and significantly reduce cost. This goes beyond refining existing methods.

For LED Product Development:

1. Subtask 2.3.3, "Power Electronics Development" was moved to the high priority list, but with a more focused scope of work. The lack of small, efficient, high power electronics suitable for converting A.C. line voltage to a suitable current for LED operation limits penetration of LED based products into the direct lamp replacement market and may limit the luminaire lifetime because of the premature failure of some electronic components.

For OLED Core Technology:

1. Subtask 3.1.3, "Improved contact materials and surface modification techniques to improve charge injection" was removed from the priority list. This task is currently at a sufficient state of development to be moved to a lower priority task.

2. Subtask 3.3.2, "Low-cost encapsulation and packaging technology", was moved to a high priority. An important aspect to improving the performance of an OLED over time is to reduce the sensitivity of organic materials to ambient conditions.

The following tables list the priority tasks for LEDs and for OLEDs for each of Core Technology and Product Development. As in the last edition of the MYPP, there are additional tables listing "later priority" tasks which may ultimately need attention to achieve the overall goals of the program as well as some "long term" research tasks that do not appear to need funding at this time, either because they have reached sufficient advancement, or because they are not immediately necessary to enable progress in the next few years towards SSL goals.

Table 4-6 LED Core Technology Research Tasks and Descriptors (2008-Priority Tasks)

Subtask		Short Descriptor	Metric	2007	2015 Target
Core Technology					
1.1.2	High-efficiency semiconductor materials	Improve IQE across the visible spectrum and in the near UV (down to 360 nm) at high current densities	IQE[55]	20% green (540 nm),75% red, 80% 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	95%[56]	90% across the visible spectrum
			Scattering losses	10%	
			Color stability		
1.3.2	Encapsulants and packaging materials	Develop a thermal/photo resistant encapsulant that exhibits long life and has a high refractive index.	Retention of original transmittance[57]		>97%
			Lifetime[58]	50 khrs	
			Refractive Index	1.4-1.57	1.7
1.4.x[59]	Inorganic growth and fabrication processes and manufacturing research.	Novel approaches to improving uniformity and yield for epitaxial growth and other manufacturing processes. Research on diagnostic tools and efficient reactor designs and methods.	Wavelength spread across the wafer	20 nm	5 nm

[55] IQE and EQE status and projections assume pulsed measurements at 350 mA drive currents with a 1x1mm^2 chip and Tj = 25^{o}C.
[56] Quantum Yield is measured at a pumped wavelength of 450 nm.
[57] Retention should be measured at wavelengths of 450 nm, a flux of 300mW/mm^2, and Temperature of 185 ^{o}C.
[58] Lifetime status and projections are for an encapsulant measured at 185 ^{o}C.
[59] There are several subtasks to 1.4, designated "x"; all need attention.

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

Subtask		Short Descriptor	Metric	2007	2015 Target
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%
1.2.2	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)	80%[60]	90%
			Phosphor conversion efficiency	80%	90%
1.3.4	Measurement metrics and color perception	Standardizing metrics to measure electrical and photometric characteristics of LED devices.			

Table 4-8: LED Core Technology Research Tasks and Descriptors (Long Term Tasks)

Subtask		Short Descriptor
Core Technology		
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
1.1.3	Reliability and defect physics for improved emitter lifetime and efficiency	- Dopant and defect physics - Device characterization and modeling
1.3.3	Electrodes and interconnects	Low resistance electrodes

[60] M. R. Krames, O. B. Shchekin, R. Mueller-Mach, G. O. Mueller, L. Zhou, G. Harbers, and M. G. Craford, " Status and Future of High-Power Light-Emitting Diodes for Solid-State Lighting," J. Display Technol. 3, 160-175 (2007)

Table 4-9: LED Product Development Tasks and Descriptors (2008-Priority Tasks)

Subtask		Short Descriptor	Metric	2007	2015 Target
Product Development					
2.2.1	Manufactured materials	**[Phosphor or Encapsulant product]** Develop high efficiency phosphors, luminescent materials, encapsulants, or materials suitable for high-volume, low-cost manufacture, and improved lifetime. Demonstrate improvements in a high-quality packaged prototype chip.	% of original transmission per mm	85-90% (@150C and 10-15kHrs)	95% (@150C Junction Temp. and 50 kHrs)[61]
2.2.2	LED packages and packaging materials	**[Packaged chip or material]** Design and demonstrate a high-quality packaged chip product employing practical, low-cost, designs, materials, or methods for improving light out-coupling and removing heat from the chip to produce a product with high total lumen output efficiently.	Thermal resistance (junction to case)		5ºC per Watt
2.3.1	Optical coupling and modeling	**[Luminaire]** Develop and demonstrate an application-specific luminaire product that solves the problem of extracting useful task-oriented photons from an LED. This task includes addressing issues such as coupling to multiple sources and the multi-shadowing problem.	Optical/Fixture Efficiency	90%	95%
2.3.4	Thermal design	**[Luminaire]** Demonstrate a luminaire or array of LEDs that solves the problem of removing heat from the chip so as to improve luminaire and chip lifetime and reliability.			
2.3.6	Evaluate luminaire lifetime and performance characteristics	**[Luminaire]** Develop and demonstrate a luminaire with significant improvements in lifetime associated with the design methods or materials. Provide extensive characterization to prove the effectiveness of the approach.	Mean time to failure	May be limited by driver lifetime	As good as source lifetimes – >40K hours

[61] This target may change to 185ºC as efficiency goals are met and cost becomes a higher priority.

Table 4-9: LED Product Development Tasks and Descriptors (2008-Priority Tasks) (continued)

Subtask		Short Descriptor	Metric	2007	2015 Target
Product Development					
2.3.3	Power Electronics Development	**[Modular driver]** Develop a high power modular LED driver capable of converting A.C. line voltage to suitable LED operating currents with low cost, compact size, good power factor, efficient operation, and long lifetime at high operating temperatures.	%Energy Conversion	85%	90+%
			$/Watt	$0.20 /Watt	$0.03 /Watt
			Power factor		0.9
			Lifetime at high operating temperature (125C)	20-50 kHrs[62]	50 kHrs

[62] Some 50 kHr devices exist today, but these are presently for military specifications and are too costly for general illumination applications.

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

Subtask		Short Descriptor	Metric	2007	2015 Target
Product Development					
2.1.2	High-efficiency semiconductor materials	**[Unpackaged Chip or epitaxial material]** Demonstrate a chip using materials that promote high efficiency across the visible spectrum.	IQE	20% green, 80% red, 60% blue	90%
2.1.3	Implementing strategies for improved light extraction and manipulation	**[Unpackaged Chip, or material]** Apply manufacturable techniques or material products to state-of-the art LEDs to improve light extraction under lighting conditions at low cost.			
2.2.3	Modeling, distribution, and coupling issues	**[Software tool or Luminaire]** Develop models to understand the coupling of the light between the chip and phosphor to optimize the efficiency of the interaction between chip light extraction, phosphor absorption and re-emission, and phosphor scattering. Develop practical techniques to optimize the chip-phosphor coupling and control the resulting optical distribution for various lighting applications			
2.4.1	Incorporate proven in-situ diagnostic tools into existing equipment.	**[Integrated manufacturing measurement tool]** Develop and demonstrate in-situ diagnostic tools into existing equipment to improve manufacturability of LEDs used for lighting.			
2.4.2	Develop low-cost, high-efficiency reactor designs	**[Reactor for low cost manufacture]** Develop and demonstrate growth reactors capable of growing state of the art LED materials at low-cost and high reproducibility with improved materials use efficiency.			
2.4.3	Develop techniques for die separation, chip shaping, and wafer bonding	**[Manufacturing tools]** Develop and demonstrate improved tools and methods for die separation, chip shaping, and wafer bonding for manufacturability.			

Table 4-11: 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	**[Substrate product for chip manufacture]** Develop and demonstrate high quality substrates suitable for improved device efficiency, manufacturing uniformity, and yield.
2.1.4	Device architectures with high power-conversion efficiencies	**[Array of chips]** Demonstrate an array employing large chips, multi-color chips on a single submount suitable for use in a luminaire design.
2.2.4	Evaluate component lifetime and performance characteristics	
2.3.2	Mechanical design	**[Luminaire]** Develop a luminaire mechanical design that contributes to improving energy efficiency through improved optics, thermal management, or any other efficiency factor.
2.3.5	Evaluate human factors and metrics	

Table 4-12: OLED Core Technology Research Tasks and Descriptors (2008-Priority Tasks)

Subtask		Short Descriptor	Metric	2007	2015 Target
Core Technology					
3.1.2, 3.2.2	Novel materials and device architectures.	Single and multi-layered device structures, materials, and contact materials to increase IQE, reduce voltage, and improve device lifetime.	IQE[63]	B>20%, G 100%, R 60%	100% IQE over the visible spectrum
			Voltage	4-5 V	2.8 V
			L_{70}		40,000 hrs
3.2.1	Novel strategies for improved light extraction	Optical and device design for improving light extraction.	Extraction Efficiency	40%	80%
3.2.3	Research on low-cost transparent electrodes	Better transparent electrode technology that offers an improvement over ITO materials cost and deposition rate and shows the potential for low-cost manufacturing.	Ohms/□	40 Ohms/□	<10 Ohms/□
			Transparency over the visible spectrum	75-80%	92%
3.4.2	Investigation of low-cost fabrication and patterning techniques and tools	Development of potentially low cost deposition techniques	Deposition Speed		
			Material utilization		
			Cost/area		
3.3.2	Encapsulation and packaging technology	Demonstrate a high-efficiency OLED luminaire with intrinsically stable OLED materials resilient to the ambient environment or encapsulated or packaged so as to reduce water permeability, improve lifetime, and exhibit the potential for low-cost.	Operating lifetime		40,000 hrs

[63] As noted in Section 4.5.2, these metrics should be measured at a reference brightness of 1000 cd/m^2 and total output ≥ 500 lm.

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

Subtask		Short Descriptor
Core Technology		
3.1.1	Substrate materials for electro-active organic devices	
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.
3.1.4	Applied Research in OLED devices	Understand the underlying issues limiting performance in organic light emitting 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 (2008- Priority Tasks)

Subtask		Short Descriptor	Metric	2007	2015 Target
Product Development					
4.1.1	Low-cost substrates	**[Substrate Material]** Demonstrate a substrate material that is low cost, shows reduced water permeability, and enables robust device operation.	Cost	~$100/m	< $3/m^2
			Water permeability	10^{-6} g/m^2-day	10^{-6} g/m^2-day
4.1.2, 4.2.2	Practical implementation of materials and device architectures.	**[Device]** Demonstrate an OLED device employing architectures and materials that provide concurrently improve robustness, lifetime, efficiency, and color quality. The device should show potential for mass production.	Efficacy[64]	64 lm/W	>100 lm/W
			CRI	78	90
			Lumen Output	500	5,000
			L_{70}	L_{50}>10 khrs[65]	L_{70}=40 khrs
4.2.1	Practical application of light extraction technology.	**[Device]** Demonstrate an OLED device employing a light extraction technology that features high total extraction efficiency and the potential for large scale manufacturing at low added cost.	Extraction Efficiency	40%	80%
			Cost		
			Lumen Output[66]	500	5,000
4.4.1	Module and process optimization and manufacturing	**[Luminaire]** Produce an OLED luminaire using integrated manufacturing technologies that have a short TAC time and the ability to scale to large areas.	Total Actual Cycle (TAC) time	5 min/m^2	1 min/m^2
4.3.1	OLED encapsulation packaging for lighting applications	**[Luminaire]** Demonstrate a high-efficiency OLED luminaire packaged or encapsulated so as to reduce water permeability and improve lifetime.	$/m^2	$4/m^2	< $3/m^2
			%dark spot area adder		<10% dark spot area adder at 5 year shelf life
			Loss penalty (as compared to glass)		
			L_{70}	L_{50}>10 khrs[65]	L_{70}=40 khrs

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

0%

[64] As noted in Section 4.5.2, efficacy and lumen output should be measured at a reference brightness of 1000cd/m^2 and total output of ≥ 500 lm.
[65] The metric L_{50} is used here because data on L_{70} lifetimes is unavailable.
[66] As noted in Section 4.5.2, lumen output should be measured at a reference brightness of 1000cd/m^2

Subtask		Short Descriptor	Metric	2007	2015 Target
Product Development					
4.1.3	Improved contact materials and surface modification techniques to improve charge injection	**[Device]** Develop and demonstrate an OLED device with improved contact materials and surface modification techniques involving 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)	**[Luminaire]** Demonstrate an OLED luminaire employing multi-color chips on a single substrate for use in a luminaire design.			

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

Subtask		Short Descriptor
Product Development		
4.3.2	Simulation tools for modeling OLED devices	**[Software Tool]** Develop software simulation tools for modeling performance characteristics of OLED devices.
4.3.3	Voltage conversion, current density and power distribution and driver electronics	**[Driver]** Demonstrate improved drivers for OLED devices with optimized voltage conversion, current density, power distribution, and electronics.
4.3.4	Luminaire design, engineered applications, field tests and demonstrations	**[Luminaire]** Demonstrate in the lab and field-test an OLED luminaire design engineered for a specific application.
4.4.2	Synthesis manufacturing scale-up of active OLED materials	**[Device]** Develop and demonstrate an OLED device using improved materials capable of being scaled-up while maintaining material purity.
4.4.3	Tools for manufacturing the lighting module	**[Manufacturing Tool or Machine]** Demonstrate an improved OLED manufacturing tool or machine.

4.6. Interim Product Goals

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

4.6.1. Light Emitting Diodes

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

FY10 and FY15 milestones represent efficacy or price targets of LEDs devices with a lifetime of 70,000 hrs. Although all milestones in FY08 were not met concurrently, it is expected that the FY10, interim goal of 140 lm/W for a commercial device will be exceeded. Other parameters will also progress, but the task priorities are set by the goal of reaching this particular mark. A new luminaire milestone has also been included in this update: By FY12, DOE expects to see a high efficiency luminaire on the market that has the equivalent lumen output of a 75W incandescent bulb and an efficiency of 126 lm/W. Finally, by FY15, costs should be below $2/klm for LED devices while also meeting other performance goals.

Table 4-17: LED Product Milestones

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

Assumption: CRI > 80, CCT < 5000°K, $T_j = 125^oC$

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

This phase, currently underway, is expected to continue past 2015.

The bars on the Gantt chart indicate an estimated time period for execution of the task in question, while the connecting lines show the interdependence of tasks. The duration of the task depends to some extent on the amount of resources applied. As a deeper understanding of each task is developed, duration estimates can be refined and varied according to the applied resources. Currently, these estimates, based on past experience with funded projects in the DOE program, are approximate. The letters next to the task numbers (a,b,c) identify phases of the tasks. These phases are not to be confused with the overall program phases (1,2,3). Further task phases and program phases will be identified as the program moves past 2015 so that the full potential of solid state lighting can be realized.

Using these estimates of duration and task dependencies, one can identify critical paths to success. Those tasks on the critical path are shown with hashed bars. Tasks identified by the NGLIA/DOE team as high priority have shaded task names. For reasons noted above, the two do not necessarily coincide.

ID	Name	Start	Duration	Finish
Phase1	**Develop efficient white device**	9/12/2001	1,853	10/20/2008
113a	Reliability and defect physics	9/12/2001	110	2/12/2002
112a	High-efficiency emitters	2/13/2002	330	5/20/2003
111a	Substrate Research	9/27/2002	218	7/29/2003
122a	Improved light extraction	6/9/2003	407	12/28/2004
131a	Phosphors and conversion	8/29/2003	342	12/20/2004
133a	Electrodes and interconnects	6/28/2004	525	6/30/2006
132a	Encapsulants and packaging	8/23/2004	221	6/27/2005
211a	Substrate, buffer, wafer devel	10/4/2004	220	8/5/2005
121a	Device structures and systems	12/29/2004	393	6/30/2006
212a	Hi-eff semic materials development	3/3/2005	543	4/2/2007
221a	Manufactured materials	6/28/2005	440	3/5/2007
144a	Die separation, shaping, bonding	11/9/2005	218	9/8/2006
134a	Measurement metrics and color	12/13/2005	220	10/16/2006
141a	Substrate and epitaxial processes	1/24/2006	525	1/28/2008
142a	In-situ diagnostic tools	1/27/2006	522	1/28/2008
214a	Implement Device architectures	7/3/2006	270	7/13/2007
243a	Develop chip fabrication methods	9/11/2006	220	7/13/2007
234a	Pkgd chip thermal design	10/19/2006	522	10/17/2008
222a	Device packages and materials	7/16/2007	330	10/17/2008
241a	Incorporate diagnostic tools	10/8/2007	113	3/12/2008
143a	Reactor designs and mfg methods	1/29/2008	189	10/17/2008
M1	Milestone #1 (> 80 lpw)	10/20/2008	0	10/20/2008
Phase2	**Improved Device Efficacy**	5/16/2002	2,186	9/30/2010
113b	Reliability and defect physics	5/16/2002	264	5/20/2003
112b	High-efficiency emitters	5/21/2003	434	1/17/2005
111b	Substrate Research	7/30/2003	528	8/5/2005
131b	Phosphors and conversion	12/21/2004	520	12/18/2006
122b	Improved light extraction	1/18/2005	500	12/18/2006
132b	Encapsulants and packaging	6/28/2005	440	3/5/2007
211b	Substrate, buffer, wafer devel	8/8/2005	527	8/14/2007
133b	Electrodes and interconnects	11/1/2006	356	3/12/2008
121b	Device structures and systems	12/19/2006	322	3/12/2008
221b	Manufactured materials	3/6/2007	522	3/4/2009
212b	Hi-eff semic materials development	4/3/2007	584	6/26/2009
214b	Implement Device architectures	3/13/2008	339	6/30/2009
144b	Die separation, shaping, bonding	5/20/2008	289	6/26/2009
243b	Develop chip fabrication methods	6/29/2009	329	9/30/2010
222b	Device packages and materials	7/1/2009	327	9/30/2010
M2	Milestone #2 (>140 lpw)	9/30/2010	0	9/30/2010
Phs 2a	**Efficient Luminaire**	10/17/2006	1,628	1/11/2013
134b	Measurement metrics and color	10/17/2006	524	10/17/2008
224a	Component lifetime & performance	10/20/2008	549	11/25/2010
231b	Luminaire optical coupling and modeling	11/27/2008	263	11/30/2009
234b	Luminaire thermal design	4/23/2009	158	11/30/2009
232b	Luminaire mechanical design	12/1/2009	258	11/25/2010
223a	Electronics Development	3/4/2010	191	11/25/2010
236a	Eval luminaire life and performance	11/26/2010	555	1/10/2013
M2a	Milestone #2a (luminaire efficiency)	1/11/2013	0	1/11/2013
Phase3	**Lower device costs**	8/15/2007	2,311	6/22/2016
211c	Substrate, buffer, wafer devel	8/15/2007	527	8/20/2009
221c	Manufactured materials	3/5/2009	522	3/4/2011
212c	Hi-eff semic materials development	8/21/2009	401	3/4/2011
143b	Reactor designs and mfg methods	11/30/2010	588	2/28/2013
141b	Substrate and epitaxial processes	2/24/2011	526	2/28/2013
142b	In-situ diagnostic tools	2/28/2011	524	2/28/2013
214c	Implement Device architectures	3/7/2011	484	1/10/2013
231c	Luminaire optical coupling and modeling	1/11/2013	257	1/6/2014
242b	Develop reactor designs	3/1/2013	520	2/26/2015
234c	Luminaire thermal design	4/8/2013	196	1/6/2014
232c	Luminaire mechanical design	1/7/2014	227	11/19/2014
236c	Eval luminaire life and performance	11/20/2014	415	6/22/2016
222c	Device packages and materials	12/25/2014	390	6/22/2016
241b	Incorporate diagnostic tools	2/27/2015	344	6/22/2016
243c	Develop chip fabrication methods	3/11/2015	336	6/22/2016
223b	Electronics Development	3/26/2015	325	6/22/2016
M3	Low cost light (<$2/klm)	6/22/2016	0	6/22/2016

Figure 4-12: White LED Program Gantt Chart

4.6.2. Organic Light Emitting Diodes

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

Although current laboratory devices have reached efficacies between 25 and 64 lm/W (at reasonable life, luminance, and CCT), there are currently no niche OLED products available in the marketplace for general illumination applications. According to industry experts, major manufacturers will wait for OLED laboratory prototypes to achieve higher efficacies before investing in the manufacturing infrastructure to produce OLEDs for general illumination purposes. Therefore, unless a smaller manufacturer, less averse to risk, develops a niche product, the FY08 milestone will not be met. Milestone 2 targets a commercial price of $70/klm by FY10. At this point the lifetime should be around 5,000 hours. Reaching a marketable price for an OLED lighting product, is seen as one of the critical steps to getting this technology into general use because of their large area, so although the FY08 milestone may be late in coming, cost reduction remains the focus. By FY15 the target is to get a high efficacy, 100 lm/W OLED. Cost and lifetime should show continuous improvement as well.

Table 4-18: OLED Product Milestones

Milestone	Year	Milestone Target
Milestone 1	FY08	25 lm/W, < $100/klm, 5,000 hrs
Milestone 2	FY10	<$70/klm
Milestone 3	FY15	>100 lm/W

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

ID	Name	Start	Duration	Finish
Phase 0	**Technical Feasibility**	**5/30/2001**	**878**	**10/11/2004**
314a	**Applied Research in OLED devices**	**5/30/2001**	**358**	**10/11/2002**
341a	Physical, chemical and optical modeling for f	10/15/2001	390	4/11/2003
432a	Simulation tools for modeling OLED devices	10/26/2001	170	6/20/2002
321a	Novel strategies for improved light extraction	6/21/2002	336	10/3/2003
331a	**Down conversion materials**	**10/14/2002**	**260**	**10/10/2003**
312a	Novel materials and device architectures.	2/13/2003	416	9/16/2004
311a	Substrate materials for electro-active organic	3/21/2003	260	3/18/2004
342a	Investigation of low-cost fabrication and patt	4/14/2003	390	10/8/2004
431a	OLED encapsulation packaging for lighting a	9/15/2003	280	10/8/2004
421a	Practical application of light extraction techn	10/6/2003	265	10/8/2004
M0	**Demonstrate OLED technical feasibility**	**10/11/2004**	**0**	**10/11/2004**
Phase 1	**Niche Product**	**10/13/2003**	**1,558**	**9/30/2009**
331b	**Down conversion materials**	**10/13/2003**	**260**	**10/8/2004**
323b	Research on low-cost transparent electrodes	2/25/2004	390	8/23/2005
313a	Improved contact materials and surface mod	3/19/2004	260	3/17/2005
411b	Low-cost substrates	3/19/2004	390	9/15/2005
312b	Novel materials and device architectures.	9/17/2004	390	3/16/2006
321b	Novel strategies for improved light extraction	9/17/2004	390	3/16/2006
412a	**Practical implementation of materials and**	**10/11/2004**	**520**	**10/6/2006**
443a	Tools for manufacturing the lighting module	10/11/2004	520	10/6/2006
313b	Improved contact materials and surface mod	3/18/2005	260	3/16/2006
332a	Low-cost encapsulation and packaging techn	7/1/2005	260	6/29/2006
323c	Research on low-cost transparent electrodes	8/24/2005	537	9/13/2007
413b	Improved contact materials and surface mod	3/17/2006	390	9/13/2007
421b	Practical application of light extraction techn	3/17/2006	390	9/13/2007
332b	Low-cost encapsulation and packaging techn	6/30/2006	591	10/3/2008
412b	**Practical implementation of materials and**	**10/9/2006**	**520**	**10/3/2008**
443b	Tools for manufacturing the lighting module	10/9/2006	520	10/3/2008
433b	Voltage conversion, current density and pow	10/8/2007	260	10/3/2008
434a	Luminaire design, engineered applications, fi	4/3/2008	390	9/30/2009
M1	Niche Product (25 lpw)	9/30/2009	0	9/30/2009
Phase 2	**Reduce costs**	**9/16/2005**	**1,836**	**9/30/2012**
411c	Low-cost substrates	9/16/2005	520	9/13/2007
413c	Improved contact materials and surface mod	9/14/2007	390	3/12/2009
421c	Practical application of light extraction techn	9/14/2007	390	3/12/2009
431b	**OLED encapsulation packaging for lightin**	**10/6/2008**	**520**	**10/1/2010**
332c	Low-cost encapsulation and packaging techn	11/26/2008	597	3/10/2011
412c	Practical implementation of materials and de	3/13/2009	520	3/10/2011
341b	Physical, chemical and optical modeling for f	10/5/2009	260	10/1/2010
342b	Investigation of low-cost fabrication and patt	10/5/2009	260	10/1/2010
334b	Measurement metrics and human factors	4/5/2010	260	4/1/2011
441b	**Module and process optimization and ma**	**10/4/2010**	**520**	**9/28/2012**
434b	Luminaire design, engineered applications, fi	4/4/2011	390	9/28/2012
442b	Synthesis manufacturing scale-up of active	4/4/2011	390	9/28/2012
M2	**Meet <$70 cost target**	**10/1/2012**	**0**	**9/30/2012**
Phase 3	**Increase Efficacy**	**11/12/2009**	**1,476**	**7/9/2015**
432b	Simulation tools for modeling OLED devices	11/12/2009	260	11/10/2010
433c	Voltage conversion, current density and pow	3/12/2010	260	3/10/2011
314b	Applied Research in OLED devices	11/11/2010	606	3/7/2013
431c	OLED encapsulation packaging for lighting a	3/11/2011	520	3/7/2013
443c	Tools for manufacturing the lighting module	3/11/2011	520	3/7/2013
333b	Electrodes and interconnects	1/11/2013	260	1/9/2014
441c	Module and process optimization and manuf	3/8/2013	610	7/9/2015
423c	Demonstrate device architectures: e.g., whit	1/10/2014	390	7/9/2015
434c	Luminaire design, engineered applications, fi	5/15/2014	301	7/9/2015
M3	Increase efficacy to >100 lpw	7/9/2015	0	7/9/2015

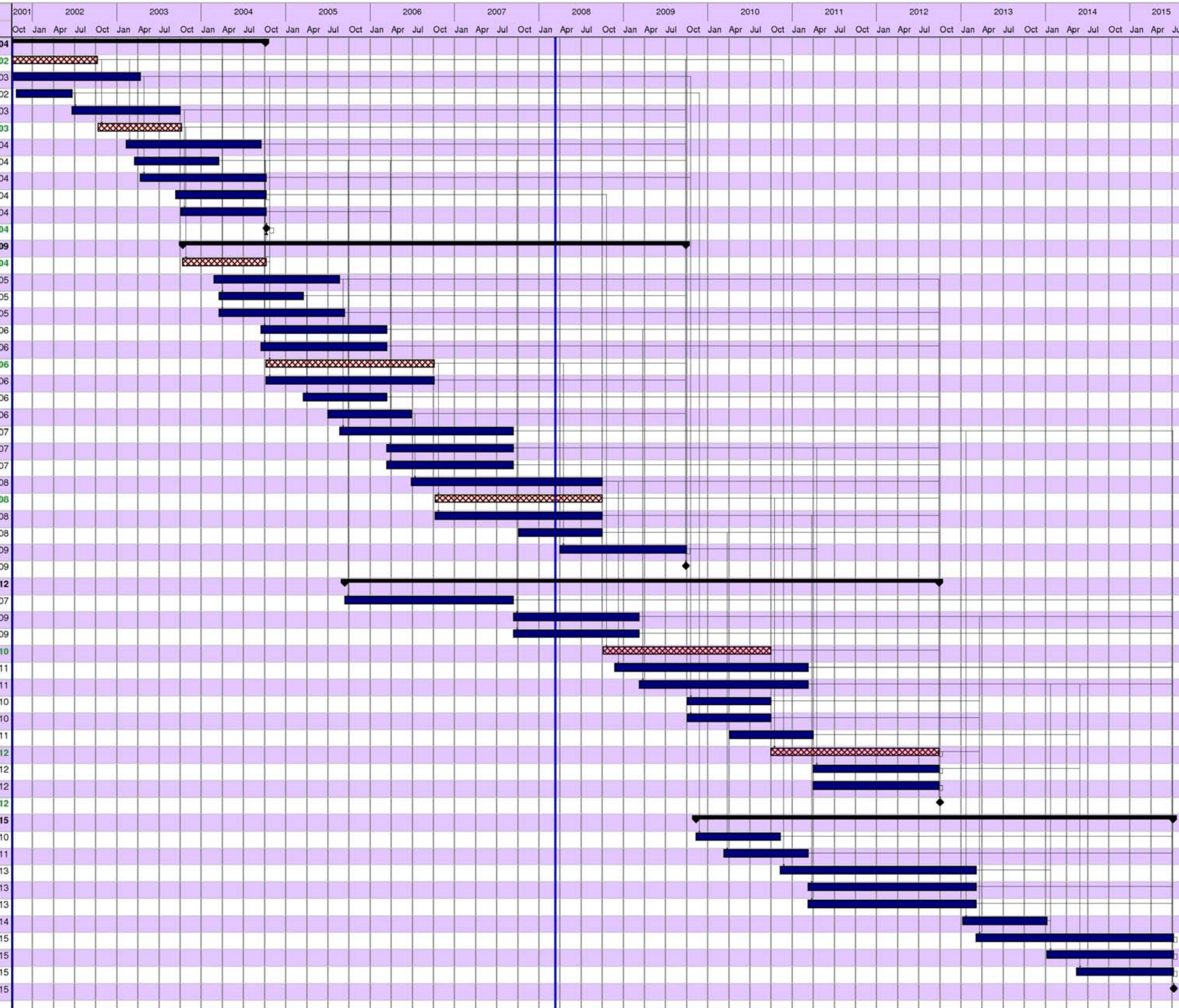

Figure 4-13: White OLED Program Gantt Chart

4.7. Unaddressed Opportunities

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

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

- Improved uniformity of processes would improve yields and lower costs.
- Improved control over manufacture would reduce color variation, an impediment to deployment.
- Advanced automation methods could reduce labor content and potentially make domestic production-"made in the USA"- a more attractive option than it is today. Currently most LED chip production has moved to Asia.
- For OLEDs, the manufacturing issue is particularly acute since the needs for displays, the apparent synergistic technology, are actually quite different from what is needed for lighting. This makes the issue of cost reduction a barrier to this technology.

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

5.0 Solid-State Lighting Portfolio Management Plan

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.

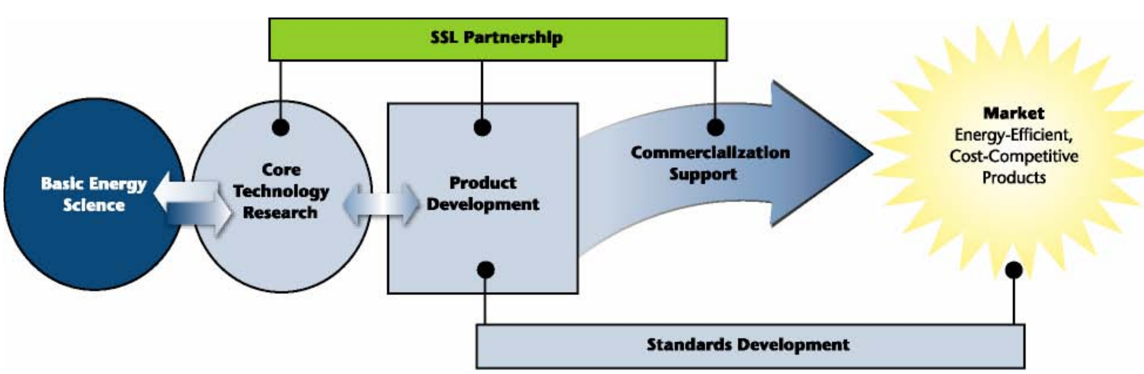

Figure 5-1: Interrelationships within DOE Solid-State Lighting Activities

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 systems. Technical activities focus on a targeted market application with fully defined price, efficacy, and other performance parameters necessary for success of the proposed product. Project activities range from product concept modeling through development of test models and field-ready prototypes.

Commercialization support activities facilitate market readiness. To ensure that DOE investments in Core Technology 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 implementing a full range of activities, including:

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

SSL Partnership provides manufacturing and commercialization focus. Supporting the DOE SSL portfolio is the SSL Partnership between DOE and the 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 provides input to shape R&D priorities, and accelerates implementation of SSL technologies by:

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

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

5.2. SSL Operational Plan

DOE has structured an operational plan for SSL R&D (see Figure 5-2) that features two concurrent, interactive pathways. **Core Technology Research** is conducted primarily by academia, national laboratories, and research institutions. **Product Development** is conducted primarily by industry. Although the pathways and participants described here are typical, some cross-over does occur. For example, a product development project conducted by industry may include focused, short-term applied research, as long as its relevance to a specific product is clearly identified and the industry organization abides by the solicitation provisions. The operational structure also includes innovative intellectual property provisions and a **SSL Partnership** that provides significant input to shape the Core Technology Research priorities.

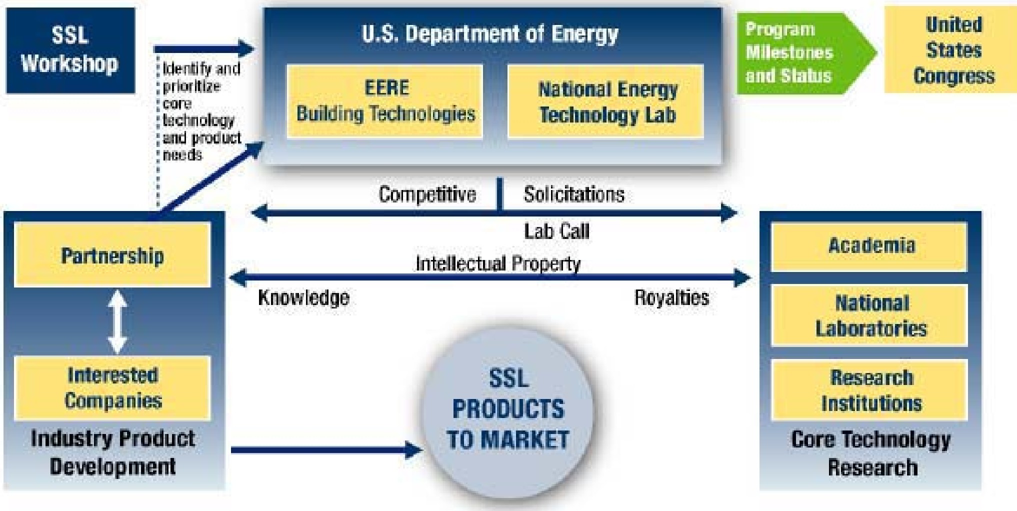

Figure 5-2: Structure of DOE SSL Operational Plan

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 R&D priorities. As SSL technologies mature, any research gaps identified are filled through Core Technology Research—allowing the SSL industry to continue their development process, while much-needed breakthrough technologies are created in parallel. The Partnership members confer among themselves and communicate their R&D needs to DOE program managers, who in turn, shape these needs into the Core Technology 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. 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 consultants.

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

High-Level Timeline. Figure 5-3 details the high-level timeline for the SSL R&D operational plan. Each year, DOE expects to issue at least three competitive solicitations: the Core Technology 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 and Product Development projects
- Provide individual project reviews by DOE

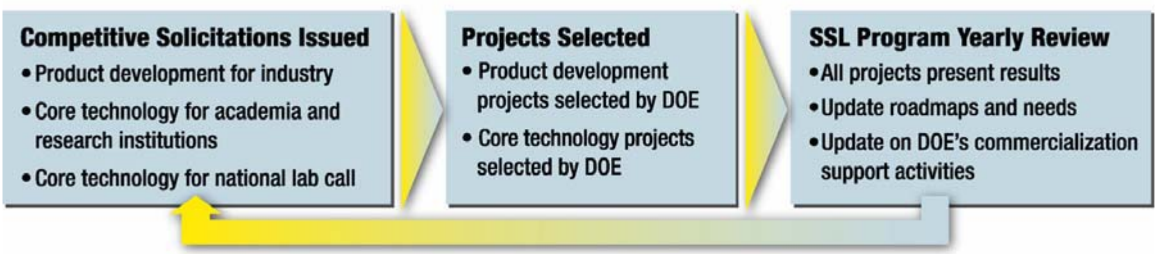

Figure 5-3: SSL Operational Plan Process

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.
- April 2007. Pasadena, CA. Workshop to explore how federal, state and private sectors can work together to guide the market introduction of SSL products.
- July 2007. Boston, MA. Workshop to explore how federal, state and private sectors can work together to guide the market introduction of SSL products.
- January 2008. Atlanta, GA. Planning workshop on LEDs and OLEDs to review and reprioritize DOE's SSL R&D portfolio.
- July 2008. Portland, OR. Planning workshop for DOE and outside experts to address market introduction of solid-state lighting.

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[67].

The February 2006 workshop, held in Orlando, Florida, focused on advancing SSL technologies from the laboratory to the marketplace. This workshop represented the third

[67] "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.

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

The February 2007 workshop, held in Phoenix, Arizona, was the fourth annual DOE SSL workshop. This workshop focused on "Getting SSL to Market" by providing a forum for building partnerships and strategies to accelerate technology advances and guide market introduction of high efficiency, high-performance SSL products. In addition, workshop participants were able to review and comment on proposed revisions to the DOE SSL R&D roadmap priorities. The results of the prioritization process from the 2006 workshop have been published in a DOE report.[68]

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

5.3.2. BES Workshop and Coordination

The U.S. Department of Energy's Office of Science, Basic Energy Sciences Program, and Office of Energy Efficiency and Renewable Energy, Building Technologies Program, hosted a workshop on May 22-24, 2006 in Bethesda, Maryland, focused on basic research needs for solid-state lighting (SSL). James Brodrick, DOE Lighting 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

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

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.[69] In addition, there are 2 types of financial assistance, specifically, cooperative agreements and grants. Cooperative agreements and grants are the same except cooperative agreements include "substantial involvement" by the government. Given the innovative structure of the SSL Program, it is imperative that the government be given the opportunity to assist the Recipients, the entity awarded the cooperative agreement, in managing the project to successful completion The role of the federal Project Manager is:

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

5.3.5. Government-Industry Alliance

In February 2005, DOE signed a Memorandum of Agreement (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

[69] 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

development and commercialization through government-industry partnership. As of February 2008, the NGLIA was made up of fifteen corporations ―3M, Acuity Brands Lighting, Air Products & Chemicals, Inc., CAO Group Inc., Corning, Inc., Cree Inc., Dow Corning Corporation, Eastman Kodak Company, GE-Lumination, Lumination LLC, Light Prescriptions Innovators, LLC (LPI, LLC), LSI Industries, OSRAM Sylvania Inc., Philips Solid-State Lighting Solutions, QuNano, Inc., 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 B.

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.

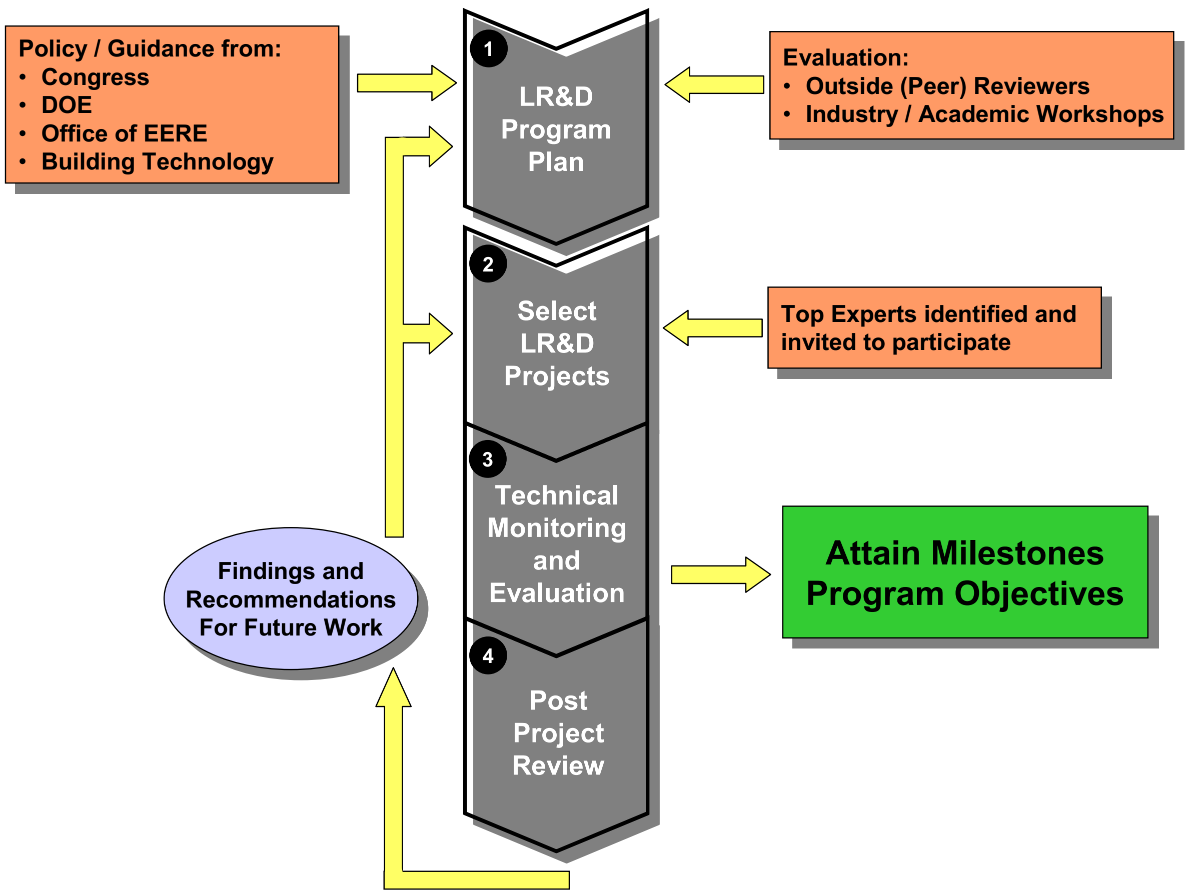
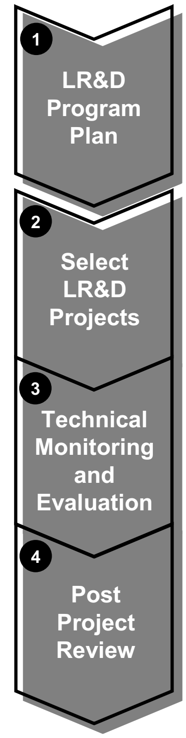


Figure 5-4: Four Step Quality Control and Evaluation Plan for LR&D Program

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.[70]
    - Lighting Market Characterization - Volume II: Technology Options and Energy Savings Estimate: a review and prioritization of all the energy savings opportunities in lighting technology. Completed September 2005.[71]
    - Lighting Market Characterization - Volume III: Economic and Market Performance Targets. Analysis of lighting market milestones and targets that must be achieved in order to secure adoption and transformation. Ongoing assignment, as needed.
    - Solid State Lighting (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

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

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

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

Implementation of QC&E in the Planning Stage:

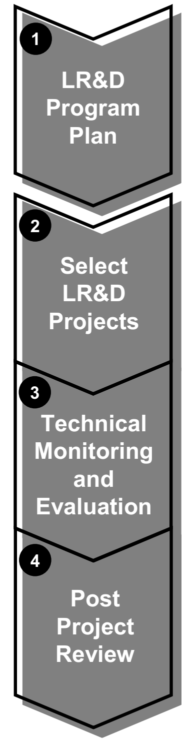
- Planning for the coming fiscal year starts in April / May by reviewing the present year's projects:
    - Review progress made in the context of the aforementioned planning tools
    - Assess any new or appropriate alternative technologies and/or approaches
- Determine new or revise existing milestones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

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

Table 5-1: LR&D Program – Outreach Meetings and Events

Company	Topic	Date
Fundamental Research Needs in Organic Electronic Materials – Salt Lake City, UT	SSL R&D – OLEDs	5/23/03
Society for Information Display – Phoenix, AZ	SSL R&D – OLEDs	9/16/03
Solid State Lighting Program Planning Workshop #1 – Washington, DC	SSL R&D	11/13/03 – 11/14/03
SPIE Fourth International Conference in SSL – Denver, CO	SSL R&D	8/3/04
Solid State Lighting Program Planning Workshop #2 – San Diego, CA	SSL R&D	02/03/05 – 02/04/05
Briefing to Staff of House Science Committee – Washington, DC	SSL R&D	5/9/05
SPIE Fifth International Conference in SSL – San Diego, CA	SSL R&D	8/1/05
High Intensity Discharge (HID) Lighting Technology Workshop	HID	11/15/05
Solid State Lighting Program Planning Workshop#3 – Orlando, 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
Market Introduction Workshop- "Voices for SSL Efficiency" – Boston, MA	SSL R&D	6/16/07 – 6/17/07
Solid State Lighting Program Planning Workshop#5, "Transformations in Lighting" – Atlanta, GA	SSL R&D	1/29/08-1/31/08
Market Introduction Workshop – Portland, OR	SSL R&D	7/08

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.

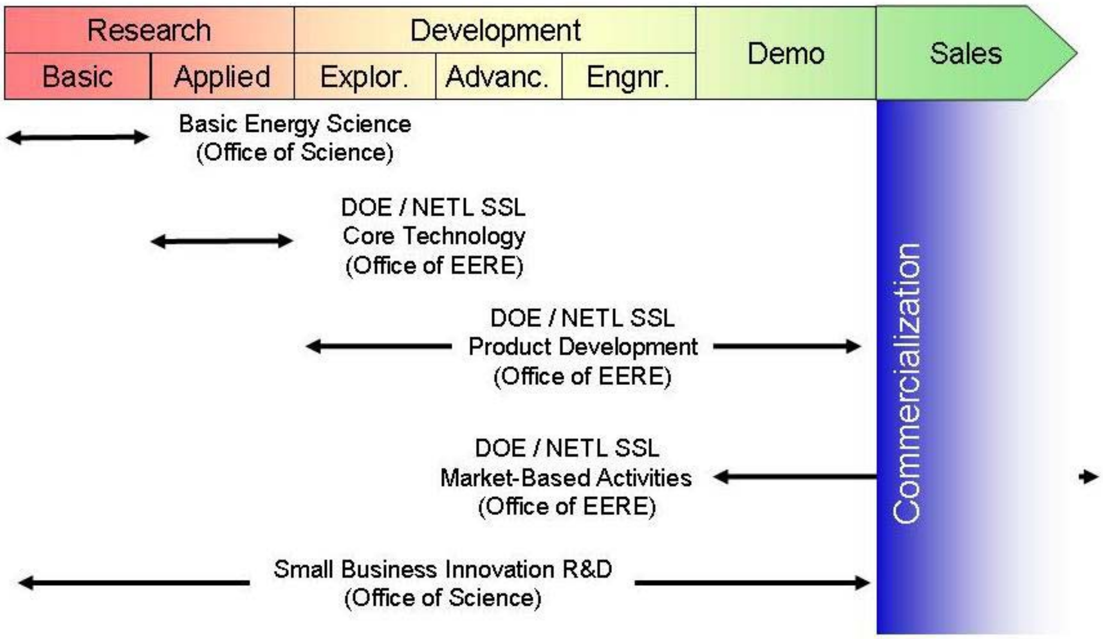


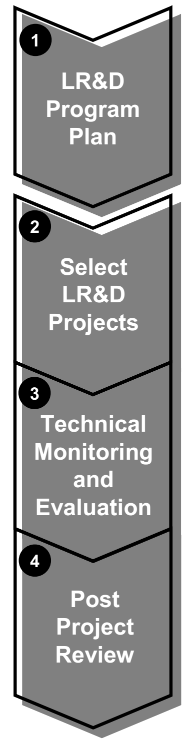
Figure 5-5: Approximate technology maturity coverage of selected DOE R&D programs

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

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

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

5.4.3. Concurrent Monitoring and Evaluation



Objective of the Monitoring Stage:

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

Questions in the Monitoring Stage:

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

Implementing QC&E in the Monitoring Stage:

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

Milestone QC&E Meetings for FY'08:

The following schedule represents the project review meetings for FY'08 that cover the NETL, SBIR, and other project areas. At these meetings, the Department will be using the QC&E tools described above to assess technical and programmatic performance.

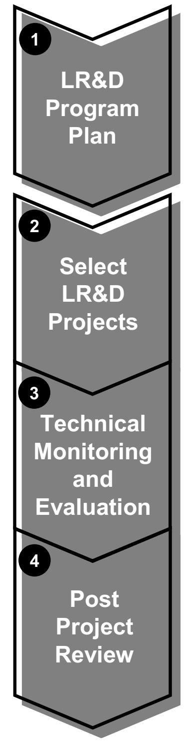
Table 5-2:.LR&D Program Project Review Meetings for FY'08

PI and Contract Title	Funding Source	Objective	Date
DE-FC26-04NT42274 University of California, San Diego	LR&D Direct	Final Briefing	Dec 07
DE-FC26-05NT42340 Cree, Inc.	LR&D Direct	Final Briefing	Jan 08
DE-FC26-06NT42859 University of North Texas	LR&D Direct	Budget Period # 1 Progress Review	Jan 08
DE-FG02-04ER83996 Materials Modification Inc	SBIR	Final Briefing	Jan 08
M6642795 Lawrence Berkeley National Laboratory (LBNL)	LR&D Direct	Final Briefing	Jan 08
DE-FC26-06NT42856 Georgia Tech Research Corporation	LR&D Direct	Budget Period # 1 Progress Review	Feb 08
DE-FC26-06NT42864 Eastman Kodak Company - State Street	LR&D Direct	Budget Period # 1 Progress Review	Feb 08
M6643032 Sandia National Laboratories (SNL) - NM	LR&D Direct	Final Briefing	Mar 08
M6643037 Argonne National Laboratory-IL (ANL)	LR&D Direct	Final Briefing	Mar 08
M6643031 Sandia National Laboratories (SNL) - NM	LR&D Direct	Final Briefing	Mar 08
M6643033 Sandia National Laboratories (SNL) - NM	LR&D Direct	Final Briefing	Mar 08
M6643034 Sandia National Laboratories (SNL) - NM	LR&D Direct	Final Briefing	Mar 08
DE-FC26-04NT42272 University of Southern California	LR&D Direct	Final Briefing	Mar 08
DE-FC26-05NT42343 GE Global Research	LR&D Direct	Final Briefing	Mar 08
DE-FC26-06NT42932 Color Kinetics Incorporated	LR&D Direct	Final Briefing	Mar 08
M6642867 Sandia National Laboratories (SNL) - NM	LR&D Direct	Budget Period # 1 Progress Review	Apr 08
DE-FC26-06NT42862 Purdue University	LR&D Direct	Budget Period # 2 Progress Review	Apr 08
DE-FC26-07NT43129 Northeast Energy Efficiency Partnership (NEEP)	LR&D Direct	Budget Period # 1 Progress Review	May 08
DE-FC26-05NT42341 Light Prescriptions Innovators	LR&D Direct	Final Briefing	May 08
M6642868 Sandia National Laboratories (SNL) - NM	LR&D Direct	Final Briefing	May 08

PI and Contract Title	Funding Source	Objective	Date
M6642869 Lawrence Berkeley National Laboratory (LBNL)	LR&D Direct	Budget Period # 2 Progress Review	Jun 08
M6643036 Oak Ridge National Laboratory (ORNL)	LR&D Direct	Final Briefing	Jun 08
DE-FC26-04NT42273 Universal Display Corporation	LR&D Direct	Final Briefing	Jun 08
DE-FC26-05NT42344 Dow Corning Corporation - MI	LR&D Direct	Final Briefing	Jun 08
DE-FC26-07NT43128 Consortium for Energy Efficiency, Inc.	LR&D Direct	Budget Period # 1 Progress Review	Jul 08
M6743231 Pacific Northwest National Laboratory (PNNL)	LR&D Direct	Budget Period # 1 Progress Review	Jul 08
M6642870 Los Alamos National Laboratory (LANL)	LR&D Direct	Budget Period # 2 Progress Review	Jul 08
M6743230 Sandia National Laboratories (SNL) - NM	LR&D Direct	Budget Period # 1 Progress Review	Jul 08
M6743232 Lawrence Berkeley National Laboratory (LBNL)	LR&D Direct	Budget Period # 1 Progress Review	Jul 08
DE-FC26-06NT42857 University of California, Santa Barbara	LR&D Direct	Budget Period # 2 Progress Review	Jul 08
DE-FC26-04NT42277 Regents of the Univ. of Calif., Santa Barbara Dept., Div. or Unit:	LR&D Direct	Final Briefing	Aug 08
DE-FC26-06NT42855 University of Florida	LR&D Direct	Budget Period # 2 Progress Review	Aug 08
DE-FG02-05ER84263 Universal Display Corporation	SBIR	Final Briefing	Aug 08
DE-FG02-06ER84567 Physical Optics Corporation	SBIR	Budget Period # 1 Progress Review	Aug 08
DE-FC26-06NT42860 Rensselaer Polytechnic Institute	LR&D Direct	Budget Period # 2 Progress Review	Aug 08
DE-FC26-06NT42861 Research Triangle Institute	LR&D Direct	Budget Period # 2 Progress Review	Aug 08
DE-FC26-05NT42342 Philips Lighting	LR&D Direct	Final Briefing	Sep 08
M6642865 Sandia National Laboratories (SNL) - NM	LR&D Direct	Budget Period # 2 Progress Review	Sep 08
M6642866 Pacific Northwest National Laboratory (PNNL)	LR&D Direct	Budget Period # 2 Progress Review	Sep 08
DE-FC26-06NT42934 GE Global Research	LR&D Direct	Budget Period # 2 Progress Review	Sep 08

PI and Contract Title	Funding Source	Objective	Date
DE-FC26-07NT43225 Cree, Inc.	LR&D Direct	Budget Period # 1 Progress Review	Sep 08
DE-FC26-07NT43226 GE Global Research	LR&D Direct	Budget Period # 1 Progress Review	Sep 08
DE-FC26-07NT43227 Yale University	LR&D Direct	Budget Period # 1 Progress Review	Sep 08
DE-FC26-07NT43228 Inlustra Technologies, LLC	LR&D Direct	Budget Period # 1 Progress Review	Sep 08
DE-FC26-07NT43229 Carnegie Mellon University	LR&D Direct	Budget Period # 1 Progress Review	Sep 08
DE-FG02-05ER84232 Fairfield Crystal Technology, LLC	SBIR	Final Briefing	Sep 08
DE-FC26-06NT42933 Eastman Kodak Company	LR&D Direct	Final Briefing	Sep 08
DE-FC26-06NT42935 Osram Sylvania	LR&D Direct	Final Briefing	Sep 08

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.[73] A stage-gate system[74], tailored to the LR&D program, I applied to each project in the portfolio, and creates a lexicon for discussion, decisions, and planning which is mutually beneficial to the National Energy Technology Laboratory (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 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.

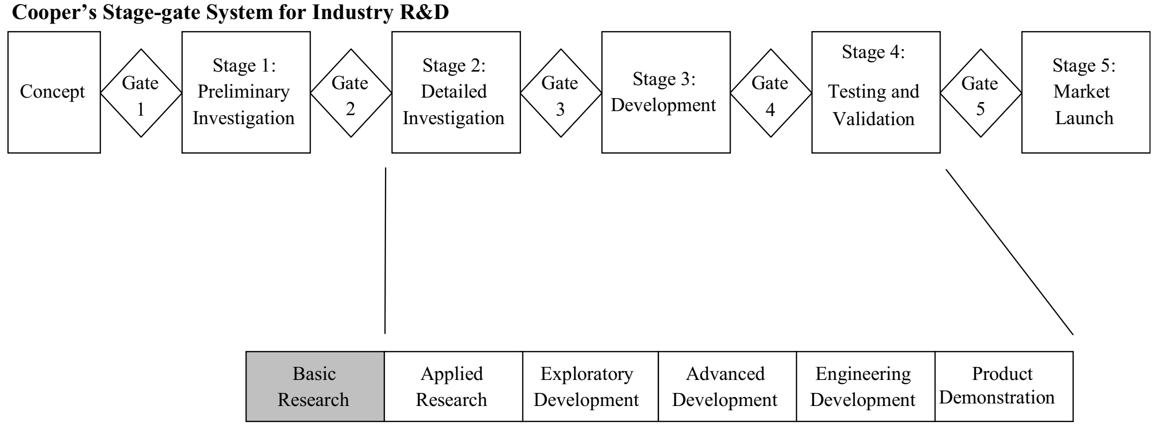
[73] Managing Research and Development: The Technology Continuum of the Lighting Research and Development Portfolio. James R. Brodrick. November 2005.
[74] Robert Cooper, "Winning at New Products, Accelerating the Process from Idea to Launch." 3rd Edition. 2001.

In addition, 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.

Cooper's Stage-gate System for Industry R&D



Management System for the Lighting Research & Development Portfolio

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 5-2: LR&D Technology Development Stages and Gates

Technology Development Stages

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

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

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

Lighting Research and Development, Building Technologies Program, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy. 11-07-05

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

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

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

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

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

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

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

Technology Maturation Stage 7 – Commercialization and Sales
The final stage of the technology development continuum focuses on commercialization and sales. This stage involves the implementation of the marketing and manufacturing plans, culminating in the successful launch of a new energy saving product.
While the DOE is currently funding SSL projects in the early stages of the technology development spectrum, over the years as the technology evolves and improves, solicitations in the advanced development, engineering development and product demonstration are planned. The expectation is that future projects will build on the foundation of applied research and exploratory development, catalyzing innovations in lamp materials, systems, fixtures, electronics, and device infrastructure. Eventually, demonstration projects in various sectors may also be warranted, to measure and document the beneficial aspects of this revolutionary technology.

5.6. Solid-State Lighting Commercialization Support Plan

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

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

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

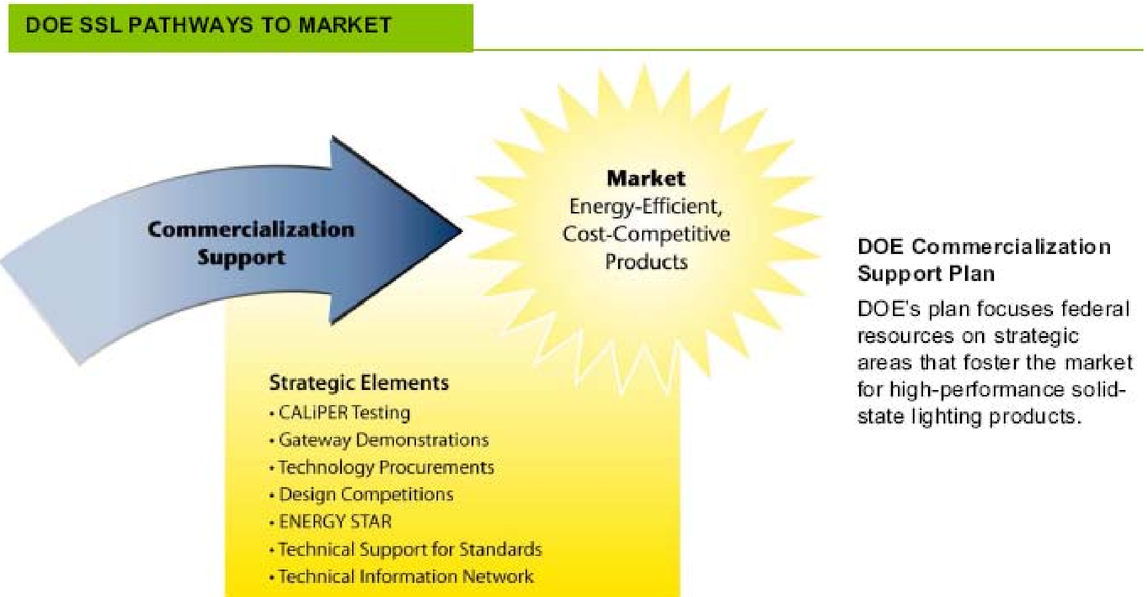


Figure 5-8: DOE SSL Commercialization Support Plan

DOE SSL Pathways to Market

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

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

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

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

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

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

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

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.[75]

The Government Performance Results Act (GPRA) benefit analysis based on DOE's Fiscal Year 2008 Budget Request estimates that the energy savings from SSL in 2030 will be approximately equivalent to the energy used to illuminate 28 million homes today. Looking cumulatively across the analysis period of 2008 to 2030, SSL is projected to save 6.4 quadrillion British Thermal Units (Btu) of primary energy, valued at approximately $55 billion at today's energy prices. This is equivalent to approximately 589 terawatt-hours of cumulative site electricity savings in commercial and residential

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

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

6.1.2. Peer Review

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

6.2. External Evaluation

6.2.1. National Academies of Science Review

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

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

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

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

- 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 authorized $500 million SSL DOE program.

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

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

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

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

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

DAVID N. HILL
DEPUTY GENERAL COUNSEL FOR ENERGY POLICY

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

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

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

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

Background

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

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

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

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

Specifics of SSL Program Exceptional Circumstances Determination

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

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

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

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

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

Justification for Approving the SSL Program Exceptional Circumstances Determination

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

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

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

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

Potential Concerns

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

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

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

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

Conclusion

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

Approved ______________________ Date. 6-6-05
ASSISTANT SECRETARY FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY

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

Attachment

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

ARTICLE I – PURPOSE

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

ARTICLE II - AUTHORITY

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

ARTICLE III - OBJECTIVE

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

ARTICLE IV – SCOPE OF COLLABORATIVE ACTIVITIES

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

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

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

ARTICLE V – FORMS OF COLLABORATIVE ACTIVITIES

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

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

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

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

ARTICLE VI – RESPONSIBILITES OF THE PARTIES

A. Responsibilities of the Department of Energy:

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

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

B. Responsibilities of the NGLIA:

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

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

C. NGLIA and DOE mutually agree to the following:

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

ARTICLE VII – PUBLICATIONS

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

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

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

ARTICLE VIII - INTELLECTUAL PROPERTY

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

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

The Parties understand that:

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

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

ARTICLE IX – FUNDING AND IMPLEMENTATION

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

ARTICLE X – MISCELLANEOUS

A. Other Relationships or Obligations

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

B. Survival

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

C. Severability

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

D. Compliance with Laws

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

E. Effect on Third Parties

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

ARTICLE XI – AMENDMENT, MODIFICATION, AND TERMINATION

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

ARTICLE XII – EFFECTIVE DATE

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

Executed in duplicate on the dates indicated below:

By: ______________________ Date: 2/2/2005

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

By: 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: EPACT 2005

Subtitle A – Energy Efficiency

Sec. 911. Energy Efficiency.

(c) Allocations. – From amounts authorized under subsection (a), the following sums are authorized:
   (1) For activities under section 912, $50,000,000 for each of fiscal years 2007 through 2009.

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

Sec. 912. Next Generation Lighting Initiative.

(a) Definitions. – In this section:
   (1) Advance Solid-State Lighting. – The term “advanced solid-state lighting” means a semiconducting device package and delivery system that produces white light using externally applied voltage.
   (2) Industry Alliance. – The term “Industry Alliance” means an entity selected by the Secretary under subsection (d).
   (3) Initiative. – The term “Initiative” means the Next Generation Lighting Initiative carried out under this section.
   (4) Research. – The term “research” includes research on the technologies, materials, and manufacturing processes required for white light emitting diodes.
   (5) White Light Emitting Diode. – The term “white light emitting diode” means a semiconducting package, using either organic or inorganic materials, that produces white light using externally applied voltage.

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

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

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

(e) Research. –
   (1) Grants. – The Secretary shall carry out the research activities of the Initiative through competitively awarded grants to –
      (A) researchers, including Industry Alliance participants;

(B) National Laboratories; and
(C) institutions of higher education.
(2) Industry Alliance. – The Secretary shall annually solicit from the Industry Alliance –
(A) comments to identify solid-state lighting technology needs;
(B) an assessment of the progress of the research activities of the Initiative; and
(C) assistance in annually updating solid-state lighting technology roadmaps.
(3) Availability to Public. – The information and roadmaps under paragraph (2) shall be available to the public.
(f) Development, Demonstration, and Commercial Application. –
(1) In General. – The Secretary shall carry out a development, demonstration, and commercial application program for the Initiative through competitively selected awards.
(2) Preference. – In making the awards, the Secretary may give preference to participants in the Industry Alliance.
(g) Cost Sharing. – In carrying out this section the Secretary shall require cost sharing in accordance with section 988.
(h) Intellectual Property. – The Secretary may require (in accordance with section 202(a)(ii) of title 35, United States Code, section 152 of the Atomic Energy Act of 1954 (42 U.S.C. 2182), and section 9 of the Federal Nonnuclear Energy Research and Development Act of 1974 (42 U.S.C. 5908)) that for any new invention developed under subsection (e) –
(1) that the Industry Alliance participants who are active participants in research, development, and demonstration activities related to the advanced solid-state lighting technologies that are covered by this section shall be granted the first option to negotiate with the invention owner, at least in the field of solid-state lighting, nonexclusive licenses and royalties on terms that are reasonable under the circumstances;
(2) (A that, for 1 year after a United States patent is issued for the invention, the patent holder shall not negotiate any license or royalty with any entity that is not a participant in the Industry Alliance described in paragraph (1); and
(B) that, during the year described in clause (i), the patent holder shall negotiate nonexclusive licenses and royalties in good faith with any interested participants in the Industry Alliance described in paragraph (1); and
(3) such other terms as the Secretary determines are required to promote accelerated commercialization of inventions made under the Initiative.
(i) National Academy Review. – The Secretary shall enter into an arrangement with the National Academy of Sciences to conduct periodic reviews of the Initiative.

Appendix D – List of Patents Awarded Through DOE-Funded Projects

As of January 2008, a total of eighteen solid-state lighting (SSL) patents have been granted as a result of Department of Energy-funded research projects. This demonstrates the value of DOE SSL projects to private companies and notable progress toward commercialization. Since DOE began funding SSL research projects in 2000, a total of 71 patent applications have been applied for or awarded as follows: large businesses – 40; small businesses – 15; universities – 13; and national laboratories – 3.

Organization	**Title of Patent Application** (Bolded titles indicates granted patents**)**
Agiltron, Inc.	Two patent applications filed.
Boston University	Formation of Textured III-Nitride Templates for the Fabrication of Efficient Optical Devices Formation of Textured III-Nitride Templates for the Fabrication of Efficient Optical Devices Nitride LEDs Based on Flat and Wrinkled Quantum Wells Optical Devices Featuring Textured Semiconductor Layers
Cree, Inc.	**Light Emitting Diode with Porous SiC Substrate and Method for Fabricating** Light Emitting Diode with High Aspect Ratio Sub-Micron Roughness for Light Extraction and Methods of Forming Two other patent applications filed.
Eastman Kodak	Five patent applications filed.
Fairfield Crystal Technology	Method and Apparatus for Aluminum Nitride Monocrystal Boule Growth
GE Global Research	**Light-Emitting Device with Organic Electroluminescent Material and Photoluminescent Materials** **Luminaire for Light Extraction from a Flat Light Source** **Mechanically Flexible Organic Electroluminescent Device with Directional Light Emission** **Organic Electroluminescent Devices and Method for Improving Energy Efficiency and Optical Stability Thereof** **Series Connected OLED Structure and Fabrication Method** **Organic Electroluminescent Devices having Improved Light Extraction** Electrodes Mitigating Effects of Defects in Organic Electronic Devices Hybrid Electroluminescent Devices OLED Area Illumination Source Eight other patent applications filed.

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

Organization	**Title of Patent Application** (Bolded titles indicates granted patents**)**
	One other patent application filed.
University of California, San Diego	One patent application filed.
University of California, Santa Barbara	**Plasmon Assisted Enhancement of Organic Optoelectronic Devices** Silicone Resin Encapsulants for Light Emitting Diodes Four other patent applications filed.
University of Southern California	Fluorescent Filtered Electrophosphorescence

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

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

6/05/06
Date

William Hanley
Executive Vice President
Illuminating Engineering
Society of North America

Appendix G – Legislative Directive: EISA 2007

Subtitle B--Lighting Energy Efficiency

Sec. 321. Efficient Light Bulbs.

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

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

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

`(D) GENERAL SERVICE INCANDESCENT LAMP-

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

`(I) is intended for general service applications;
`(II) has a medium screw base;
`(III) has a lumen range of not less than 310 lumens and not more than 2,600 lumens; and
`(IV) is capable of being operated at a voltage range at least partially within 110 and 130 volts.

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

`(I) An appliance lamp.
`(II) A black light lamp.
`(III) A bug lamp.
`(IV) A colored lamp.
`(V) An infrared lamp.
`(VI) A left-hand thread lamp.
`(VII) A marine lamp.
`(VIII) A marine signal service lamp.
`(IX) A mine service lamp.
`(X) A plant light lamp.
`(XI) A reflector lamp.
`(XII) A rough service lamp.
`(XIII) A shatter-resistant lamp (including a shatter-proof lamp and a shatter-protected lamp).
`(XIV) A sign service lamp.
`(XV) A silver bowl lamp.
`(XVI) A showcase lamp.
`(XVII) A 3-way incandescent lamp.
`(XVIII) A traffic signal lamp.
`(XIX) A vibration service lamp.
`(XX) A G shape lamp (as defined in ANSI C78.20-2003 and C79.1-2002 with a diameter of 5

inches or more.

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

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

(B) by adding at the end the following:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

`(BB) GENERAL SERVICE LAMP-

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

`(I) general service incandescent lamps;

`(II) compact fluorescent lamps;

`(III) general service light-emitting diode (LED or OLED) lamps; and

`(IV) any other lamps that the Secretary determines are used to satisfy lighting applications traditionally served by general service incandescent lamps.

`(ii) EXCLUSIONS- The term `general service lamp' does not include--

`(I) any lighting application or bulb shape described in any of subclauses (I) through (XXII) of subparagraph (D)(ii); or

`(II) any general service fluorescent lamp or incandescent reflector lamp.

`(CC) LIGHT-EMITTING DIODE; LED-

`(i) IN GENERAL- The terms `light-emitting diode' and `LED' means a p-n junction solid state device the radiated output of which is a function of the physical construction, material used, and exciting current of the device.

`(ii) OUTPUT- The output of a light-emitting diode may be in--

`(I) the infrared region;

`(II) the visible region; or

`(III) the ultraviolet region.

`(DD) ORGANIC LIGHT-EMITTING DIODE; OLED- The terms `organic light-emitting diode' and `OLED' mean a thin-film light-emitting device that typically consists of a series of organic layers between 2 electrical contacts (electrodes).

`(EE) COLORED INCANDESCENT LAMP- The term `colored incandescent lamp' means an incandescent lamp designated and marketed as a colored lamp that has--

`(i) a color rendering index of less than 50, as determined according to the test method given in C.I.E. publication 13.3-1995; or

`(ii) a correlated color temperature of less than 2,500K, or greater than 4,600K, where correlated temperature is computed according to the Journal of Optical Society of America, Vol. 58, pages 1528-1595 (1986).'.

(2) COVERAGE- Section 322(a)(14) of the Energy Policy and Conservation Act (42 U.S.C. 6292(a)(14)) is amended by inserting `,

general service incandescent lamps,' after `fluorescent lamps'.

(3) ENERGY CONSERVATION STANDARDS- Section 325 of the Energy Policy and Conservation Act (42 U.S.C. 6295) is amended--

(A) in subsection (i)--

(i) in the section heading, by inserting `, General Service Incandescent Lamps, Intermediate Base Incandescent Lamps, Candelabra Base Incandescent Lamps,' after `Fluorescent Lamps';

(ii) in paragraph (1)--

(I) in subparagraph (A)--

(aa) by inserting `, general service incandescent lamps, intermediate base incandescent lamps, candelabra base incandescent lamps,' after `fluorescent lamps';

(bb) by inserting `, new maximum wattage,' after `lamp efficacy'; and

(cc) by inserting after the table entitled `INCANDESCENT REFLECTOR LAMPS' the following:

`GENERAL SERVICE INCANDESCENT LAMPS

Rated Lumen Ranges	Maximum Rate Wattage	Minimum Rate Lifetime	Effective Date
1490-2600	72	1,000 hrs	1/1/2012
1050-1489	53	1,000 hrs	1/1/2013
750-1049	43	1,000 hrs	1/1/2014
310-749	29	1,000 hrs	1/1/2014

`MODIFIED SPECTRUM GENERAL SERVICE INCANDESCENT LAMPS

Rated Lumen Ranges	Maximum Rate Wattage	Minimum Rate Lifetime	Effective Date
1118-1950	72	1,000 hrs	1/1/2012
788-1117	53	1,000 hrs	1/1/2013
563-787	43	1,000 hrs	1/1/2014
232-562	29	1,000 hrs	1/1/2014';

and

(II) by striking subparagraph (B) and inserting the following:

`(B) APPLICATION-

`(i) APPLICATION CRITERIA- This subparagraph applies to each lamp that--

`(I) is intended for a general service or general illumination application (whether incandescent or not);

`(II) has a medium screw base or any other screw base not defined in ANSI C81.61-2006;

`(III) is capable of being operated at a voltage at least partially within the range of 110 to 130 volts; and

`(IV) is manufactured or imported after December 31, 2011.

`(ii) REQUIREMENT- For purposes of this paragraph, each lamp described in clause (i) shall have a color rendering index that is greater than or equal to--

`(I) 80 for nonmodified spectrum lamps; or

`(II) 75 for modified spectrum lamps.

`(C) CANDELABRA INCANDESCENT LAMPS AND INTERMEDIATE BASE INCANDESCENT LAMPS-

`(i) CANDELABRA BASE INCANDESCENT LAMPS- A candelabra base incandescent lamp shall not exceed 60 rated watts.

`(ii) INTERMEDIATE BASE INCANDESCENT LAMPS- An intermediate base incandescent lamp shall not exceed 40 rated watts.

`(D) EXEMPTIONS-

`(i) PETITION- Any person may petition the Secretary for an exemption for a type of general service lamp from the requirements of this subsection.

`(ii) CRITERIA- The Secretary may grant an exemption under clause (i) only to the extent that the Secretary finds, after a hearing and opportunity for public comment, that it is not technically feasible to serve a specialized lighting application (such as a military, medical, public safety, or certified historic lighting application) using a lamp that meets the requirements of this subsection.

`(iii) ADDITIONAL CRITERION- To grant an exemption for a product under this subparagraph, the Secretary shall include, as an additional criterion, that the exempted product is unlikely to be used in a general service lighting application.

`(E) EXTENSION OF COVERAGE-

`(i) PETITION- Any person may petition the Secretary to establish standards for lamp shapes or bases that are excluded from the definition of general service lamps.

`(ii) INCREASED SALES OF EXEMPTED LAMPS- The petition shall include evidence that the availability or sales of exempted incandescent lamps have increased significantly since the date on which the standards on general service incandescent lamps were established.

`(iii) CRITERIA- The Secretary shall grant a petition under clause (i) if the Secretary finds that--

`(I) the petition presents evidence that demonstrates that commercial availability or sales of exempted incandescent lamp types have increased significantly since the standards on general service lamps were established and likely are being widely used in general lighting applications; and

`(II) significant energy savings could be achieved by covering exempted products, as determined by the Secretary based on sales data provided to the Secretary from manufacturers and importers.

`(iv) NO PRESUMPTION- The grant of a petition under this subparagraph shall create no presumption with respect to the determination of the Secretary with respect to any criteria under a rulemaking conducted under this section.

`(v) EXPEDITED PROCEEDING- If the Secretary grants a petition for a lamp shape or base under this subparagraph, the Secretary shall--

`(I) conduct a rulemaking to determine standards for the exempted lamp shape or base; and

`(II) complete the rulemaking not later than 18 months after the date on which notice is provided granting the petition.

`(F) DEFINITION OF EFFECTIVE DATE- In this paragraph, except as otherwise provided in a table contained in subparagraph (A), the term `effective date' means the last day of the month specified in the table that follows October 24, 1992.';

(iii) in paragraph (5), in the first sentence, by striking `and general service incandescent lamps';

(iv) by redesignating paragraphs (6) and (7) as paragraphs (7) and (8), respectively; and

(v) by inserting after paragraph (5) the following:

`(6) STANDARDS FOR GENERAL SERVICE LAMPS-

`(A) RULEMAKING BEFORE JANUARY 1, 2014-

`(i) IN GENERAL- Not later than January 1, 2014, the Secretary shall initiate a rulemaking procedure to determine whether--

`(I) standards in effect for general service lamps should be amended to establish more stringent standards than the standards specified in paragraph (1)(A); and

`(II) the exemptions for certain incandescent lamps should be maintained or discontinued based, in part, on exempted lamp sales collected by the Secretary from manufacturers.

`(ii) SCOPE- The rulemaking--

`(I) shall not be limited to incandescent lamp technologies; and

`(II) shall include consideration of a minimum standard of 45 lumens per watt for general service lamps.

`(iii) AMENDED STANDARDS- If the Secretary determines that the standards in effect for general service incandescent lamps should be amended, the Secretary shall publish a final rule not later than January 1, 2017, with an effective date that is not earlier than 3 years after the date on which the final rule is published.

`(iv) PHASED-IN EFFECTIVE DATES- The Secretary shall consider phased-in effective dates under this subparagraph after considering--

`(I) the impact of any amendment on manufacturers, retiring and repurposing existing equipment, stranded investments, labor contracts, workers, and raw materials; and

`(II) the time needed to work with retailers and lighting designers to revise sales and marketing strategies.

`(v) BACKSTOP REQUIREMENT- If the Secretary fails to complete a rulemaking in accordance with clauses (i) through (iv) or if the final rule does not produce savings that are greater than or equal to the savings from a minimum efficacy standard of 45 lumens per watt, effective beginning January 1, 2020, the Secretary shall prohibit the sale of any general service lamp that does not meet a minimum efficacy standard of 45 lumens per watt.

`(vi) STATE PREEMPTION- Neither section 327(b) nor any other provision of law shall preclude California or Nevada from adopting, effective beginning on or after January 1, 2018--

`(I) a final rule adopted by the Secretary in accordance with clauses (i) through (iv);

`(II) if a final rule described in subclause (I) has not been adopted, the backstop requirement under clause (v); or

`(III) in the case of California, if a final rule described in subclause (I) has not been adopted, any California regulations relating to these covered products adopted pursuant to State statute in effect as of the date of enactment of the Energy Independence and Security Act of 2007.

`(B) RULEMAKING BEFORE JANUARY 1, 2020-

`(i) IN GENERAL- Not later than January 1, 2020, the Secretary shall initiate a rulemaking procedure to determine whether--

`(I) standards in effect for general service incandescent lamps should be amended to reflect lumen ranges with more stringent maximum wattage than the standards specified in paragraph (1)(A); and

`(II) the exemptions for certain incandescent lamps should be maintained or discontinued based, in part, on exempted lamp sales data collected by the Secretary from manufacturers.

`(ii) SCOPE- The rulemaking shall not be limited to incandescent lamp technologies.

`(iii) AMENDED STANDARDS- If the Secretary determines that the standards in effect for general service incandescent lamps should be amended, the Secretary shall publish a final rule not later than January 1, 2022, with an effective date that is not earlier than 3 years after the date on which the final rule is published.

`(iv) PHASED-IN EFFECTIVE DATES- The Secretary shall consider phased-in effective dates under this subparagraph after considering--

`(I) the impact of any amendment on manufacturers, retiring and repurposing existing equipment, stranded investments, labor contracts, workers, and raw materials; and

`(II) the time needed to work with retailers and lighting designers to revise sales and marketing strategies.'; and(B) in subsection (l), by adding at the end the following:

`(4) ENERGY EFFICIENCY STANDARDS FOR CERTAIN LAMPS-

`(A) IN GENERAL- The Secretary shall prescribe an energy efficiency standard for rough service lamps, vibration service lamps, 3-way incandescent lamps, 2,601-3,300 lumen general service incandescent lamps, and shatter-resistant lamps only in accordance with this paragraph.

`(B) BENCHMARKS- Not later than 1 year after the date of enactment of this paragraph, the Secretary, in consultation with the National Electrical Manufacturers Association, shall-

`(i) collect actual data for United States unit sales for each of calendar years 1990 through 2006 for each of the 5 types of lamps described in subparagraph (A) to determine the historical growth rate of the type of lamp; and

`(ii) construct a model for each type of lamp based on coincident economic indicators that closely match the historical annual growth rate of the type of lamp to provide a neutral comparison benchmark to model future unit sales after calendar year 2006.

`(C) ACTUAL SALES DATA-

`(i) IN GENERAL- Effective for each of calendar years 2010 through 2025, the Secretary, in consultation with the National Electrical Manufacturers Association, shall--

`(I) collect actual United States unit sales data for each of 5 types of lamps described in subparagraph (A); and

`(II) not later than 90 days after the end of each calendar year, compare the lamp sales in that year with the sales predicted by the comparison benchmark for each of the 5 types of lamps described in subparagraph (A).

`(ii) CONTINUATION OF TRACKING-

`(I) DETERMINATION- Not later than January 1, 2023, the Secretary shall determine if actual sales data should be tracked for the lamp types described in subparagraph (A) after calendar year 2025.

`(II) CONTINUATION- If the Secretary finds that the market share of a lamp type described in subparagraph (A) could significantly erode the market share for general service lamps, the Secretary shall continue to track the actual sales data for the lamp type.

`(D) ROUGH SERVICE LAMPS-

`(i) IN GENERAL- Effective beginning with the first year that the reported annual sales rate for rough service lamps demonstrates actual unit sales of rough service lamps that achieve levels that are at least 100 percent higher than modeled unit sales for that same year, the

Secretary shall--

`(I) not later than 90 days after the end of the previous calendar year, issue a finding that the index has been exceeded; and

`(II) not later than the date that is 1 year after the end of the previous calendar year, complete an accelerated rulemaking to establish an energy conservation standard for rough service lamps.

`(ii) BACKSTOP REQUIREMENT- If the Secretary fails to complete an accelerated rulemaking in accordance with clause (i)(II), effective beginning 1 year after the date of the issuance of the finding under clause (i)(I), the Secretary shall require rough service lamps to--

`(I) have a shatter-proof coating or equivalent technology that is compliant with NSF/ANSI 51 and is designed to contain the glass if the glass envelope of the lamp is broken and to provide effective containment over the life of the lamp;

`(II) have a maximum 40-watt limitation; and

`(III) be sold at retail only in a package containing 1 lamp.

`(E) VIBRATION SERVICE LAMPS-

`(i) IN GENERAL- Effective beginning with the first year that the reported annual sales rate for vibration service lamps demonstrates actual unit sales of vibration service lamps that achieve levels that are at least 100 percent higher than modeled unit sales for that same year, the Secretary shall--

`(I) not later than 90 days after the end of the previous calendar year, issue a finding that the index has been exceeded; and

`(II) not later than the date that is 1 year after the end of the previous calendar year, complete an accelerated rulemaking to establish an energy conservation standard for vibration service lamps.

`(ii) BACKSTOP REQUIREMENT- If the Secretary fails to complete an accelerated rulemaking in accordance with clause (i)(II), effective beginning 1 year after the date of the issuance of the finding under clause (i)(I), the Secretary shall require vibration service lamps to--

`(I) have a maximum 40-watt limitation; and

`(II) be sold at retail only in a package containing 1 lamp.

`(F) 3-way incandescent lamps-

`(i) IN GENERAL- Effective beginning with the first year that the reported annual sales rate for 3-way incandescent lamps demonstrates actual unit sales of 3-way incandescent lamps that achieve levels that are at least 100 percent higher than modeled unit sales for that same year, the Secretary shall--

`(I) not later than 90 days after the end of the previous calendar year, issue a finding that the index has been exceeded; and

`(II) not later than the date that is 1 year after the end of the previous calendar year, complete an accelerated rulemaking to establish an energy conservation standard for 3-way incandescent lamps.

`(ii) BACKSTOP REQUIREMENT- If the Secretary fails to complete an accelerated rulemaking in accordance with clause (i)(II), effective beginning 1 year after the date of issuance of the finding under clause (i)(I), the Secretary shall require that--

`(I) each filament in a 3-way incandescent lamp meet the new maximum wattage requirements for the respective lumen range established under subsection (i)(1)(A); and

`(II) 3-way lamps be sold at retail only in a package containing 1 lamp.

`(G) 2,601-3,300 lumen general service incandescent lamps- Effective beginning with the first year that the reported annual sales rate demonstrates actual unit sales of 2,601-3,300 lumen general service incandescent lamps in the lumen range of 2,601 through 3,300 lumens (or, in the case of a modified spectrum, in the lumen range of 1,951 through 2,475 lumens) that achieve levels that are at least 100 percent higher than modeled unit sales for that same year, the Secretary shall impose--

`(i) a maximum 95-watt limitation on general service incandescent lamps in the lumen range of 2,601 through 3,300 lumens; and

`(ii) a requirement that those lamps be sold at retail only in a package containing 1 lamp.

`(H) SHATTER-RESISTANT LAMPS-

`(i) IN GENERAL- Effective beginning with the first year that the reported annual sales rate for shatter-resistant lamps demonstrates actual unit sales of shatter-resistant lamps that achieve levels that are at least 100 percent higher than modeled unit sales for that same year, the Secretary shall--

`(I) not later than 90 days after the end of the previous calendar year, issue a finding that the index has been exceeded; and

`(II) not later than the date that is 1 year after the end of the previous calendar year, complete an accelerated rulemaking to establish an energy conservation standard for shatter-resistant lamps.

`(ii) BACKSTOP REQUIREMENT- If the Secretary fails to complete an accelerated rulemaking in accordance with clause (i)(II), effective beginning 1 year after the date of issuance of the finding under clause (i)(I), the Secretary shall impose--

`(I) a maximum wattage limitation of 40 watts on shatter resistant lamps; and

`(II) a requirement that those lamps be sold at retail only in a package containing 1 lamp.

`(I) RULEMAKINGS BEFORE JANUARY 1, 2025-

`(i) IN GENERAL- Except as provided in clause (ii), if the Secretary issues a final rule prior to January 1, 2025, establishing an energy conservation standard for any of the 5 types of lamps for which data collection is required under any of subparagraphs (D) through (G), the requirement to collect and model data for that type of lamp shall terminate unless, as part of the rulemaking, the Secretary determines that continued tracking is necessary.

`(ii) BACKSTOP REQUIREMENT- If the Secretary imposes a backstop requirement as a result of a failure to complete an accelerated rulemaking in accordance with clause (i)(II) of any of subparagraphs (D) through (G), the requirement to collect and model data for the applicable type of lamp shall continue for an additional 2 years after the effective date of the backstop requirement.'.

(b) Consumer Education and Lamp Labeling- Section 324(a)(2)(C) of the Energy Policy and Conservation Act (42 U.S.C. 6294(a)(2)(C)) is amended by adding at the end the following:

`(iii) RULEMAKING TO CONSIDER EFFECTIVENESS OF LAMP LABELING-

`(I) IN GENERAL- Not later than 1 year after the date of enactment of this clause, the Commission shall initiate a rulemaking to consider--

`(aa) the effectiveness of current lamp labeling for power levels or watts, light output or lumens, and lamp lifetime; and `(bb) alternative labeling approaches that will help consumers to understand new high-efficiency lamp products and to base the purchase decisions of the consumers on the most appropriate source that meets the requirements of the consumers for lighting level, light quality, lamp lifetime, and total lifecycle cost.

(II) COMPLETION- The Commission shall--

`(aa) complete the rulemaking not later than the date that is 30 months after the date of enactment of this clause; and

`(bb) consider reopening the rulemaking not later than 180 days before the effective dates of the standards for general service incandescent lamps established under section 325(i)(1)(A), if the Commission determines that further labeling changes are needed to help consumers understand lamp alternatives.'.

(c) Market Assessments and Consumer Awareness Program-

(1) IN GENERAL- In cooperation with the Administrator of the Environmental Protection Agency, the Secretary of Commerce, the Federal Trade Commission, lighting and retail industry associations, energy efficiency organizations, and any other entities that the Secretary of Energy determines to be appropriate, the Secretary of Energy shall--

(A) conduct an annual assessment of the market for general service lamps and compact fluorescent lamps--

(i) to identify trends in the market shares of lamp types, efficiencies, and light output levels purchased by residential and nonresidential consumers; and

(ii) to better understand the degree to which consumer decisionmaking is based on lamp power levels or watts, light output or lumens, lamp lifetime, and other factors, including information required on labels mandated by the Federal Trade Commission;

(B) provide the results of the market assessment to the Federal Trade Commission for consideration in the rulemaking described in section 324(a)(2)(C)(iii) of the Energy Policy and Conservation Act (42 U.S.C. 6294(a)(2)(C)(iii)); and

(C) in cooperation with industry trade associations, lighting industry members, utilities, and other interested parties, carry out a proactive national program of consumer awareness, information, and education that broadly uses the media and other effective communication techniques over an extended period of time to help consumers understand the lamp labels and make energy-efficient lighting choices that meet the needs of consumers.

(2) AUTHORIZATION OF APPROPRIATIONS- There is authorized to

be appropriated to carry out this subsection $10,000,000 for each of fiscal years 2009 through 2012.

(d) General Rule of Preemption for Energy Conservation Standards Before Federal Standard Becomes Effective for a Product- Section 327(b)(1) of the Energy Policy and Conservation Act (42 U.S.C. 6297(b)(1)) is amended--

(1) by inserting `(A)' after `(1)';

(2) by inserting `or' after the semicolon at the end; and

(3) by adding at the end the following:

`(B) in the case of any portion of any regulation that establishes requirements for general service incandescent lamps, intermediate base incandescent lamps, or candelabra base lamps, was enacted or adopted by the State of California or Nevada before December 4, 2007, except that--

`(i) the regulation adopted by the California Energy Commission with an effective date of January 1, 2008, shall only be effective until the effective date of the Federal standard for the applicable lamp category under subparagraphs (A), (B), and (C) of section 325(i)(1);

`(ii) the States of California and Nevada may, at any time, modify or adopt a State standard for general service lamps to conform with Federal standards with effective dates no earlier than 12 months prior to the Federal effective dates prescribed under subparagraphs (A), (B), and (C) of section 325(i)(1), at which time any prior regulations adopted by the State of California or Nevada shall no longer be effective; and

`(iii) all other States may, at any time, modify or adopt a State standard for general service lamps to conform with Federal standards and effective dates.'.

(e) Prohibited Acts- Section 332(a) of the Energy Policy and Conservation Act (42 U.S.C. 6302(a)) is amended--

(1) in paragraph (4), by striking `or' at the end;

(2) in paragraph (5), by striking the period at the end and inserting `; or'; and

(3) by adding at the end the following:

`(6) for any manufacturer, distributor, retailer, or private labeler to distribute in commerce an adapter that--

`(A) is designed to allow an incandescent lamp that does not have a medium screw base to be installed into a fixture or lampholder with a medium screw base socket; and

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

(f) Enforcement- Section 334 of the Energy Policy and Conservation Act (42 U.S.C. 6304) is amended by inserting after the second sentence the following: `Any such action to restrain any person from distributing in commerce a general service incandescent lamp that does not comply with the applicable standard established under section 325(i) or an adapter prohibited under section 332(a)(6) may also be brought by the attorney general of a State in the name of the State.'.

(g) Research and Development Program-

(1) IN GENERAL- The Secretary may carry out a lighting technology research and development program--

(A) to support the research, development, demonstration, and commercial application of lamps and related technologies sold, offered for sale, or otherwise made available in the United States; and

(B) to assist manufacturers of general service lamps in the manufacturing of general service lamps that, at a minimum, achieve the wattage requirements imposed as a result of the amendments made by subsection (a).

(2) AUTHORIZATION OF APPROPRIATIONS- There are authorized to be appropriated to carry out this subsection $10,000,000 for each of fiscal years 2008 through 2013.

(3) TERMINATION OF AUTHORITY- The program under this subsection shall terminate on September 30, 2015.

(h) Reports to Congress-

(1) REPORT ON MERCURY USE AND RELEASE- Not later than 1 year after the date of enactment of this Act, the Secretary, in cooperation with the Administrator of the Environmental Protection Agency, shall submit to Congress a report describing recommendations relating to the means by which the Federal Government may reduce or prevent the release of mercury during the manufacture, transportation, storage, or disposal of light bulbs.

(2) REPORT ON RULEMAKING SCHEDULE- Beginning on July 1, 2013, and semiannually through July 1, 2016, the Secretary shall submit to the Committee on Energy and Commerce of the House of Representatives and the Committee on Energy and Natural Resources of the Senate a report on--

(A) whether the Secretary will meet the deadlines for the rulemakings required under this section;

(B) a description of any impediments to meeting the deadlines; and

(C) a specific plan to remedy any failures, including recommendations for additional legislation or resources.

(3) NATIONAL ACADEMY REVIEW-

(A) IN GENERAL- Not later than December 31, 2009, the Secretary shall enter into an arrangement with the National Academy of Sciences to provide a report by December 31, 2013, and an updated report by July 31, 2015. The report should include-

(i) the status of advanced solid state lighting research, development, demonstration and commercialization;

(ii) the impact on the types of lighting available to consumers of an energy conservation standard requiring a minimum of 45 lumens per watt for general service lighting effective in 2020; and

(iii) the time frame for the commercialization of lighting that could replace current incandescent and halogen incandescent lamp technology and any other new technologies developed to meet the minimum standards required under subsection (a)(3) of this section.

(B) REPORTS- The reports shall be transmitted to the Committee on Energy and Commerce of the House of Representatives and the Committee on Energy and Natural Resources of the Senate.

Subtitle E: Miscellaneous Provisions

Sec. 655. Bright Tomorrow Lighting Prizes

(a) Establishment- Not later than 1 year after the date of enactment of this Act, as part of the program carried out under section 1008 of the Energy Policy Act of 2005 (42 U.S.C. 16396), the Secretary shall establish and award Bright Tomorrow Lighting Prizes for solid state lighting in accordance with this section.

(b) Prize Specifications-

(1) 60-WATT INCANDESCENT REPLACEMENT LAMP PRIZE - The Secretary shall award a 60-Watt Incandescent Replacement Lamp Prize to an entrant that produces a solid-state-light package simultaneously capable of--

(A) producing a luminous flux greater than 900 lumens;

(B) consuming less than or equal to 10 watts;

(C) having an efficiency greater than 90 lumens per watt;

(D) having a color rendering index greater than 90;

(E) having a correlated color temperature of not less than 2,750, and not more than 3,000, degrees Kelvin;

(F) having 70 percent of the lumen value under subparagraph (A) exceeding 25,000 hours under typical conditions expected in residential use;

(G) having a light distribution pattern similar to a soft 60-watt incandescent A19 bulb;

(H) having a size and shape that fits within the maximum dimensions of an A19 bulb in accordance with American National Standards Institute standard C78.20-2003, figure C78.20-211;

(I) using a single contact medium screw socket; and

(J) mass production for a competitive sales commercial market satisfied by producing commercially accepted quality control lots of such units equal to or exceeding the criteria described in subparagraphs (A) through (I).

(2) PAR TYPE 38 HALOGEN REPLACEMENT LAMP PRIZE- The Secretary shall award a Parabolic Aluminized Reflector Type 38 Halogen

Replacement Lamp Prize (referred to in this section as the `PAR Type 38 Halogen Replacement Lamp Prize') to an entrant that produces a solid-state-light package simultaneously capable of--

(A) producing a luminous flux greater than or equal to 1,350 lumens;
(B) consuming less than or equal to 11 watts;
(C) having an efficiency greater than 123 lumens per watt;
(D) having a color rendering index greater than or equal to 90;
(E) having a correlated color coordinate temperature of not less than 2,750, and not more than 3,000, degrees Kelvin;
(F) having 70 percent of the lumen value under subparagraph (A) exceeding 25,000 hours under typical conditions expected in residential use;
(G) having a light distribution pattern similar to a PAR 38 halogen lamp;
(H) having a size and shape that fits within the maximum dimensions of a PAR 38 halogen lamp in accordance with American National Standards Institute standard C78-21-2003, figure C78.21-238;
(I) using a single contact medium screw socket; and
(J) mass production for a competitive sales commercial market satisfied by producing commercially accepted quality control lots of such units equal to or exceeding the criteria described in subparagraphs (A) through (I).

(3) TWENTY-FIRST CENTURY LAMP PRIZE- The Secretary shall award a Twenty-First Century Lamp Prize to an entrant that produces a solid-state-light-light capable of--

(A) producing a light output greater than 1,200 lumens;
(B) having an efficiency greater than 150 lumens per watt;
(C) having a color rendering index greater than 90;
(D) having a color coordinate temperature between 2,800 and 3,000 degrees Kelvin; and
(E) having a lifetime exceeding 25,000 hours.

(c) Private Funds-

(1) IN GENERAL- Subject to paragraph (2), and notwithstanding section 3302 of title 31, United States Code, the Secretary may accept, retain, and use funds contributed by any person, government entity, or organization for purposes of carrying out this subsection--

(A) without further appropriation; and
(B) without fiscal year limitation.

(2) PRIZE COMPETITION- A private source of funding may not participate in the competition for prizes awarded under this section.

(d) Technical Review- The Secretary shall establish a technical review committee composed of non-Federal officers to review entrant data submitted under this section to determine whether the data meets the prize specifications described in subsection (b).

(e) Third Party Administration- The Secretary may competitively select a third party to administer awards under this section.

(f) Eligibility for Prizes- To be eligible to be awarded a prize under this section--

(1) in the case of a private entity, the entity shall be incorporated in and maintain a primary place of business in the United States; and

(2) in the case of an individual (whether participating as a single individual or in a group), the individual shall be a citizen or lawful permanent resident of the United States.

(g) Award Amounts- Subject to the availability of funds to carry out this section, the amount of--

(1) the 60-Watt Incandescent Replacement Lamp Prize described in subsection (b)(1) shall be $10,000,000;

(2) the PAR Type 38 Halogen Replacement Lamp Prize described in subsection (b)(2) shall be $5,000,000; and

(3) the Twenty-First Century Lamp Prize described in subsection (b)(3) shall be $5,000,000.

(h) Federal Procurement of Solid-State-Lights-

(1) 60-watt incandescent replacement- Subject to paragraph (3), as soon as practicable after the successful award of the 60-Watt Incandescent Replacement Lamp Prize under subsection (b)(1), the Secretary (in consultation with the Administrator of General Services) shall develop government wide Federal purchase guidelines with a goal of replacing the use of 60-watt incandescent lamps in Federal Government buildings with a solid-state-light package described in subsection (b)(1) by not later than the date that is 5 years after the date the award is made.

(2) PAR 38 HALOGEN REPLACEMENT LAMP REPLACEMENT- Subject to paragraph (3), as soon as practicable after the successful award of the PAR Type 38 Halogen Replacement Lamp Prize under subsection (b)(2), the Secretary (in consultation with the Administrator of General Services) shall develop governmentwide Federal purchase guidelines with the goal of replacing the use of PAR 38 halogen lamps in Federal Government buildings with a solid-state-light package described in subsection (b)(2) by not later than the date that is 5 years after the date the award is made.

(3) WAIVERS-

(A) IN GENERAL- The Secretary or the Administrator of General Services may waive the application of paragraph (1) or (2) if the Secretary or Administrator determines that the return on investment from the purchase of a solid-state-light package described in paragraph (1) or (2) of subsection (b), respectively, is cost prohibitive.

(B) REPORT OF WAIVER- If the Secretary or Administrator waives the application of paragraph (1) or (2), the Secretary or Administrator, respectively, shall submit to Congress an annual report that describes the waiver and provides a detailed justification for the waiver.

(i) Report- Not later than 2 years after the date of enactment of this Act, and annually thereafter, the Administrator of General Services shall submit to the Energy Information Agency a report describing the quantity, type, and cost of each lighting product purchased by the Federal Government.

(j) Bright Tomorrow Lighting Award Fund-

(1) ESTABLISHMENT- There is established in the United States Treasury a Bright Tomorrow Lighting permanent fund without fiscal year limitation to award prizes under paragraphs (1), (2), and (3) of subsection (b).

(2) SOURCES OF FUNDING- The fund established under paragraph (1) shall accept--

(A) fiscal year appropriations; and

(B) private contributions authorized under subsection (c).

(k) Authorization of Appropriations- There are authorized to be appropriated such sums as are necessary to carry out this section.