Accelerating the Development of Next-Generation Solid-State Lighting Sources

DOE's Solid-State Lighting R&D Program

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ABSTRACT

Solid-state lighting (SSL) is a pivotal emerging technology that promises to fundamentally alter and improve lighting systems of the future. Successful development and commercialization of SSL technology will require coordinated efforts that leverage the strengths and capabilities of industry, research and academic organizations, national laboratories, and government. This paper discusses the U.S. Department of Energy's role as a catalyst in accelerating SSL technology advances. Through DOE's SSL R&D program, the collaborative efforts of our nation's best and brightest lighting experts are moving this promising technology from the laboratory to the marketplace.

Keywords: Solid-state lighting, light emitting diodes, organic light emitting diodes, energy savings, energy efficient lighting, efficacy, efficient white light, Department of Energy, research and development

1. INTRODUCTION

In November 2003, the U.S. Department of Energy launched a national research and development program to accelerate technological advances in solid-state lighting (SSL). This technology has the potential to save a significant amount of energy while improving the quality of our illuminated building environments. The Department's program is focused on developing highly efficacious white-light SSL devices with good color rendering, stable correlated color temperature, and long operating life, all at an affordable retail price.

Breakthroughs in light emitting diode (LED) and organic light emitting diode (OLED) technology are catalyzing advances in SSL devices. Once used only for indicator lights, SSL technology is now replacing conventional technologies in traffic lights, exit signs, airplane taxiway edge-lights, and other niche applications. Research to achieve additional technology advances is well under way, driving toward development of white-light sources that are expected to replace less efficacious conventional technologies such as incandescent and eventually fluorescent lighting.

Solid-state lighting R&D investments can help secure our nation's energy future and technological leadership. According to a recent study[1], potential benefits are enormous if SSL achieves projected price and performance characteristics anticipated under an accelerated research investment scenario:

- By 2025, SSL could displace general illumination light sources such as incandescent and fluorescent lamps, decreasing national energy consumption for lighting by 29 percent and saving 3.5 quadrillion BTUs of primary energy.

[1] *Energy Savings Potential of Solid State Lighting in General Illumination Applications*, Building Technologies Program, Office of Energy Efficiency and Renewable Energy, US DOE, prepared by Navigant Consulting, Washington DC, November 2003. Available on-line at: www.netl.doe.gov/ssl

- The cumulative electricity savings from 2005 to 2025 could save more than $125 billion dollars on consumer electric bills.

- More than forty 1000 MW power plants would be deferred, contributing to a cleaner environment and a more reliable electrical transmission and distribution system.

- The SSL market revenues in 2025 are projected to be about $10 billion per year nationally.

Major research challenges must be addressed before these and other benefits of solid-state lighting can be realized. To help tackle these challenges, DOE is funding targeted R&D projects that will improve the technology and expedite the commercialization of high quality, efficacious white-light SSL technologies. Projects in the Department's portfolio are selected to align with an overall R&D plan developed in partnership with industry, research and academic organizations, and national laboratories.

The Department's support of SSL R&D is essential. While the projected energy savings are significant, white-light sources represent a high-risk investment that industry is unlikely to fund in the near term. If our nation is to maintain its leadership position in SSL technology development, the U.S. must concentrate more resources on the development of white-light SSL devices. The results of DOE's collaborative, cost-shared projects will ultimately deliver substantial energy savings and position U.S. companies as global leaders in new products, systems, and service markets.

2. SOLID STATE LIGHTING R&D PLAN

Through structured workshops with industry partners, DOE has defined a comprehensive R&D agenda that targets solid-state lighting (SSL) technology improvements in six critical areas: quantum efficiency, longevity, sustainability and control, packaging, infrastructure, and cost reduction. DOE held a Solid-State Lighting Workshop on November 13-14, 2003, to refine and prioritize its SSL R&D activities in these areas. More than 160 participants - including scientists and business leaders from industry, universities, research institutions, trade associations, and national laboratories - gathered in Washington, D.C., to participate in this interactive forum. Hosted by DOE's Office of Energy Efficiency and Renewable Energy, this workshop represented the first annual meeting of the Department's newly established program to accelerate SSL technology. Representatives from DOE's Office of Science, the National Science Foundation, the National Institute of Standards and Technology, and the Defense Advanced Research Projects Agency outlined their research programs in SSL and related materials and device technologies. Industry representatives and select associations described their efforts to foster SSL technology development and meet some of the key challenges ahead. Successful commercialization of SSL technology will require coordinated efforts that leverage the strengths and capabilities of industry, research and academic organizations, national laboratories, and government.

Figure 1. Technical advances in six critical areas are essential to achieve the price and performance necessary to accelerate market adoption of SSL.

The current portfolio includes about 30 applied research projects, addressing LEDs and OLEDs, and other SSL technologies. Projects balance long-term and short-term activities, as well as large and small business and university participation.

DOE partners with leading researchers from industry, academia, and national laboratories to accelerate advances in solid-state lighting (SSL). These researchers have made significant progress, achieving several world records. Here are a few examples of successful research projects from our portfolio:

- Lumileds Lighting teamed with Sandia National laboratories to investigate critical materials issues, including the use of semiconductor nanoparticles ("quantum dots") as luminescent down-converting materials for white LEDs. The nanoparticles produced quantum efficiencies up to 76 percent, a world record. Figure 2 depicts one of their prototypes during testing.

- General Electric Global Research teamed with Cambridge Display Technologies to develop a practical-sized OLED light panel that produces 1200 lumens of quality white light with an efficacy of 15 lumens per watt - on par with today's incandescent bulb technology. This achievement broke two world records. Figure 3 shows the prototype illuminating a colorful selection of candles, demonstrating the quality of the white light emission.

- Cree Lighting Company is working to improve LED package efficiency and brightness through the development of new structures and materials. Cree achieved what we believe is another world record, producing the most efficacious white-light LED laboratory device at 74 lumens per watt - on par with some fluorescent lighting systems and more than four times more efficient than incandescent sources. Figure 4 depicts the record-setting prototype from Cree.

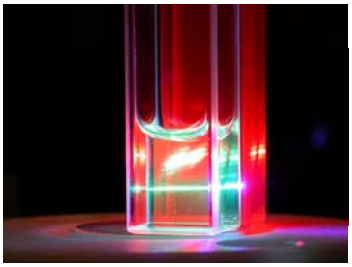

Figure 2. Lumileds and Sandia conduct experiments

Figure 3. General Electric and CDT's OLED panel

Figure 4. Cree's highly efficacious prototype

Collaborative, cost-shared projects like these combine the technical resources of premier research institutions and national laboratories with the product development, manufacturing, and commercialization expertise of industry leaders. DOE invests in research projects that target the needed improvements in price, performance, and manufacturability to speed SSL technologies to market.

3. FUNDING OPPORTUNITIES

DOE supports research, development, and demonstration of promising solid-state lighting (SSL) technologies. As a technology matures, different funding mechanisms are available to support its development, as detailed below. SSL 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.

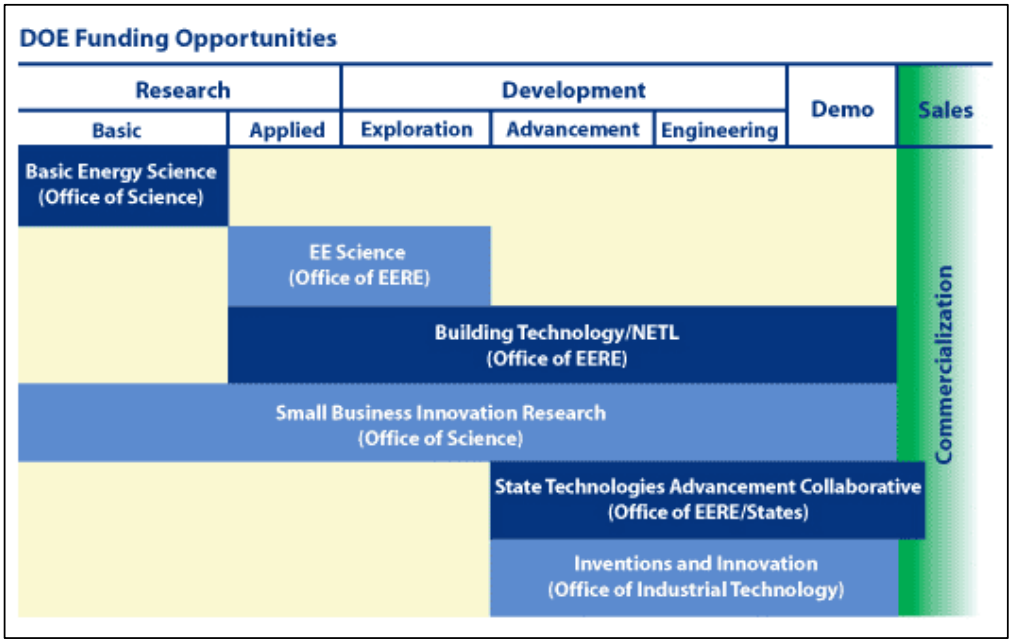

Figure 5. DOE Funding Mechanisms Used in the SSL R&D Program

Brief descriptions of each of these six funding mechanisms currently used in the SSL R&D Program follow. More information on each of these can be found on the Department's SSL website, http://www.netl.doe.gov/ssl.

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

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

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

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

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

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

4. SOLID STATE LIGHTING OPERATING PLAN

The Department has tasked the National Energy Technology Laboratory in the implementation of the SSL R&D program. The operational plan proposed for the program at the November 2003 workshop included the following key ingredients:

- Emphasis on competition for research funds
- Cost (and risk) sharing between Government and research partners
- Partners involved in planning and funding
- Targeted research for a focused need
- Innovative Intellectual Property (IP) provisions
- Open information and process
- Success determined by milestones met, and products developed

A flow diagram sketches out the relationships, roles and responsibilities in the draft organizational structure (see Figure 6). Congress appropriates funding through the Department, which in turn works with NETL to manage the program and solicitations. All R&D project awards are made through competitive solicitations, by which proposing investigators demonstrate their ability to conduct results-oriented SSL research. Most R&D project awards are also cost-shared, such as the three example projects mentioned earlier in this paper.

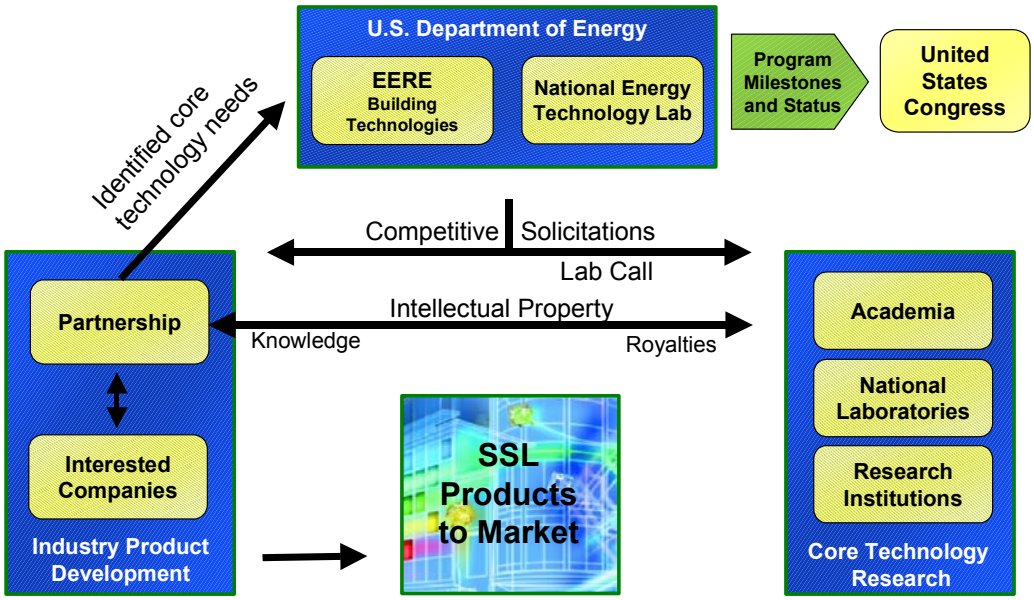

Figure 6. Organizational Structure of SSL R&D Program

The organizational structure of the program essentially encompasses two main solicitation areas. On the right is the Core Technology Research activity where most of the technical barriers to highly efficacious white-light SSL sources will be investigated. On the left of the figure is the Industry Product Development activity, which looks more at commercialization opportunities and bringing products to market. Further, the Department is interested in developing an active partnership around SSL technology, in order to sustain high levels of interest and involvement in the program and the competitive solicitations.

5. CONCLUDING REMARKS

Nationwide, lighting consumes more than eight quadrillion BTUs in a given year - that is more than twenty percent of all electricity consumed in the United States and more than eight percent of total national energy consumption. If SSL achieves its price and performance targets, it will penetrate the lighting market, offering more efficacious and better performing sources of light. The market penetration of this highly efficacious light source will contribute to significant national energy savings, including a reduction in the peak electricity demand on the national grid and lower life-cycle costs for consumers.

The Department is looking to advance solid state lighting technology from the laboratory to the marketplace, working in partnership with industry, national laboratories and academia, and devoting resources to the development of next-generation SSL sources. The Department is always looking for new experts and interested parties to participate in the competitive solicitation process. Many challenges lay ahead, and ideas from the best and brightest of the research community are needed to achieve our goals and secure national benefits. Your participation is encouraged. Please monitor our website, where the solicitations are posted - http://www.netl.doe.gov/ssl.