

Solid-State Lighting

Brilliant Solutions for America's Energy Future





Today, our nation is facing the urgent challenges of revitalizing our economy, strengthening our energy security, and reducing greenhouse gas emissions. Solid-state lighting is an emerging technology with the potential to address all three of these challenges.

Solid-state lighting will mean “greener” homes and businesses that use substantially less electricity, making them less dependent on fossil fuels. In the coming decade, they will become a key to affordable net-zero energy buildings—buildings that produce at least as much energy annually as they use from the grid.

The U.S. Department of Energy (DOE) is committed to realizing the full potential of energy-efficient technologies such as solid-state lighting in meeting our nation’s challenges. With the cooperation of the Next Generation Lighting Industry Alliance (NGLIA) and the support of the U.S. Congress, DOE is the lead federal agency for all research, development, and commercialization efforts to systematically accelerate this groundbreaking technology.

There is a window of opportunity to establish the United States as a global leader in solid-state lighting technology, retaining intellectual property rights, high-tech value-added jobs, and **economic growth for the nation.**

The Lighting Revolution

Solid-state lighting has the potential to reduce lighting energy use in the United States by one-third.

With the promise of being **ten times more efficient than incandescent lighting**, light-emitting diodes (LEDs) and organic light-emitting diodes (OLEDs) will change the way we light our homes and businesses.

Consumers will benefit from the superior features of solid-state lighting (SSL) products:

- Low power consumption
- Ultra-long source life
- Low maintenance
- No UV or IR radiation
- Cool beam of light
- Digitally controllable
- Very durable
- No mercury content

The benefits to our nation will be even more dramatic. By 2030, solid-state lighting could potentially reduce national lighting electricity use by one-third—the annual equivalent to saving:

- 348 billion kilowatt hours
- \$30 billion (in today's dollars)
- Output of forty-four 1,000-megawatt power plants
- Greenhouse gas emissions equivalent to 47 million cars

Energy-efficient solid-state lighting is a smart strategy for reducing our nation's carbon footprint. It will save money for homeowners and businesses and deliver superior performance while reducing consumption of fossil fuels.

How can our nation realize the full benefits of solid-state lighting?

Despite rapid advancements in solid-state lighting, the technology remains in its infancy.

- How can the remaining technical and design barriers be overcome?
- How can we ensure that solid-state lighting products live up to their potential for quality and energy efficiency?

Together with a wide array of industry partners, DOE is tackling these issues in its research, development, and commercialization program—charting a pathway for successfully moving solid-state lighting from the laboratory to the marketplace. The program also addresses strategies for enabling globally competitive manufacturing of solid-state lighting here in the United States, creating new “green” job opportunities.

DOE's Pathway to Success with Industry



“LEDs are an obvious area that we can achieve energy savings and we can also achieve **economic benefits—job creation.**”

U.S. Senator Jeff Bingaman (D-NM), Chair, Senate Energy Committee

DOE's Role: A Wise Federal Investment

A key goal of DOE's involvement in solid-state lighting is to support and accelerate the industry's move to **higher levels of efficiency and quality.** The early days of another energy-saving technology, compact fluorescent light bulbs (CFLs), provide a cautionary tale: quality and technical problems delayed full market acceptance for decades. Capitalizing on lessons learned from the introduction of CFLs, DOE has established a number of strategies designed to ensure consumer satisfaction with emerging solid-state lighting products and to accelerate market adoption of this important technology.

From laboratory to market, DOE identifies and assists in the early adoption of promising solid-state lighting products that offer users significant improvements over the current best-competing products. DOE's program addresses two overarching objectives:

1. Overcoming technical and design barriers to high-quality solid-state lighting; and
2. Establishing the foundations for successful market introduction.

Partnership is a hallmark of every element of DOE's solid-state lighting program. DOE works with over 200 researchers on more than 200 projects to accelerate development of technology advancements through an extensive Research and Development (R&D) program designed to successfully move solid-state lighting into

the market. On the market side, DOE works closely with energy efficiency program partners, lighting professionals, manufacturers, and others to improve technical understanding and proper application of this advanced technology. DOE also works closely with industry partners to lay the groundwork for cost-competitive U.S.-based manufacturing.

Overcoming technical and design barriers to high-quality solid-state lighting

Since 2000, researchers and product developers have made extraordinary strides in improving the efficacy of solid-state lighting, particularly in LED devices and luminaires (see “Improving at the Speed of Light” below).

Many solid-state lighting products are beginning to appear on the market, but even as they do, DOE-supported R&D continues to attack many issues that limit performance. Much of the research, for both OLEDs and LEDs, is focused on materials research—for example, how to get an efficient deep-green LED emitter, or a more efficient blue-emitting OLED. Efficiently extracting light from an LED chip or a film of OLED material, or improving the performance of a phosphor, continue to be areas of interest. As understanding of luminaire design issues improves, additional work is directed at providing environmentally robust devices with consistent and uniform performance and longer lifetimes. Thermal control and efficient electrical control are also R&D areas of interest.

Improving at the Speed of Light

The Monochrome Era Early 1960s to late 1990s

LEDs first appeared on the lighting scene in the early 1960s, in the form of red diodes. Pale yellows and greens followed. As red LEDs improved, they began appearing in products as indicator lights and in some of the first pocket calculators. The appearance of blue LEDs in the 1990s led to the first white LEDs, which were made by coating blue LEDs with phosphor. Shortly thereafter, green, blue, and red LEDs were combined to produce white light. With the availability of white light, LEDs could now be designed for general lighting, but to realize the full potential of LEDs, vast efficiency improvements had to be made.

LED General Illumination 2000–2009

In 2000, DOE and private industry partnered to push white LED technology forward with the intention to develop a high-efficiency LED packaged device. At the start, white LED devices were no more efficient than the incandescent bulb. By 2009, a comparable warm white LED replacement lamp with good color rendering showed a steady-state efficacy of about 58 lumens per watt (lm/W) compared to about 13 lm/W for incandescents—about three to four times more efficient, with similar quality warm light. In terms of packaged LED components, lab efficacies of 160 lm/W were demonstrated in 2008, with commercially available devices producing 108 lm/W.



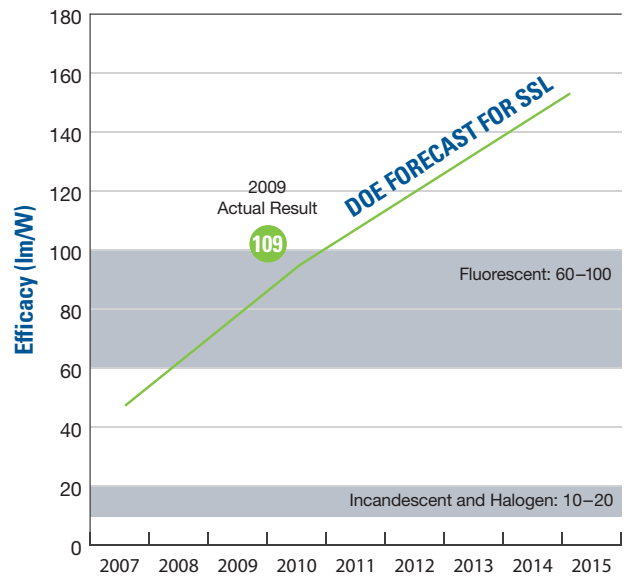
The I-35W Bridge in Minneapolis, Minnesota,

features LED roadway lighting on the main span, offering DOE the opportunity to study the use of LED lighting in a highly challenging environment over the course of three years.

Today, the quality of available LED products varies widely, primarily because traditional manufacturers have much to learn about incorporating LEDs into their fixtures. The combination of factors that make LED lighting unique, such as source size, controllability, and color quality, presents engineering challenges that require advances in applied research and design. Quality LED luminaires require precise design of several components—LED array, electronic driver, heat sink, and optics. LEDs must be carefully integrated into lighting fixtures because they are sensitive to thermal and electrical design. Given the design challenges, DOE works with both fixture and LED manufacturers to assist in performance improvements.

Solid-State Lighting Luminaire (Fixture) Performance Curve

In the next few years, LED light sources will surpass the performance capability of incandescent and fluorescent lighting, and last at least 25 times longer than incandescents. By 2015, LED luminaires (fixtures) will be capable of producing a luminaire efficacy of over 150 lm/W, about two to three times the typical fluorescent fixture efficacy. While research into high-performance fluorescent technologies has potential, their upside is not anywhere close to LED potential.



Source: DOE SSL R&D Multi-Year Program Plan

The Future of LED General Lighting 2010–2015

Researchers believe the maximum achievable light output for packaged LED devices is 160–230 lm/W, depending on the color temperature. Rapid progress will continue as the DOE and industry partnership pushes this technology to its efficiency limit, expected to be reached by about 2015. Properly designed LED luminaires will achieve efficacies of about 138–188 lm/W, or 10 to 14 times that of incandescent lighting. Reported LED lamp efficacies today are 20–40% higher than when the lamp is installed in a luminaire, since other components in the luminaire add to loss of light. LEDs, although expensive now, will continue to fall in price as new and better ways to package and manufacture them are perfected.

The Promise of OLED General Lighting 2013–2018

While LEDs act as concentrated sources of bright light, OLEDs can be configured as larger-area, more diffuse light sources. These may be more suited to general ambient lighting or, if on a flexible base material, can conform to various shapes and be integrated more tightly into architectural designs. Researchers have made rapid progress in improving OLED light output, reaching over 100 lm/W for small prototype devices in 2008. But while OLED efficiencies are on track to catch up with LEDs over the next several years, many other challenges remain, including environmental stability, lifetime, and above all, cost and manufacturability. As these challenges are overcome, OLED products will begin to appear on the market in the next few years.

Establishing the foundations for successful market introduction

The number of market-ready LED products grows daily. Some perform very well, but the quality and energy efficiency of today's LED products vary widely. One reason for the variation is the blistering pace of technology advancement, with new generations of LED devices becoming available approximately every four to six months. To lay the groundwork for consumer satisfaction and successful product introductions in the rapidly evolving solid-state lighting marketplace, DOE's program incorporates robust demonstration, testing and quality control, standards development, and consumer education elements. DOE is also working with partners to identify conditions needed for successful U.S.-based manufacturing of solid-state lighting.

DOE's **GATEWAY Demonstration Program** showcases high-performance LEDs. Outdoor lighting is the first area to gain a major market foothold. One of the best examples of these demonstrations is the I-35W Project in Minneapolis, Minnesota. The bridge, which became notable when it collapsed in 2007, reopened to traffic in September 2008. The roadbed is lit by 20 LED luminaires, rather than more traditional technologies such as high-pressure sodium lamps. The luminaires are expected to save 13 percent on energy costs over the lifetime of the bridge. Maintenance costs, which typically outstrip installation and energy costs for roadway lighting, are also expected to drop significantly, because LED products have the potential to last 10 to 15 years (or more) before relamping, compared with four years (or less) for high-pressure sodium lighting.

Product testing—conducted through DOE's **CALiPER Program** (Commercially Available LED Product Evaluation and Reporting)—is an essential element in the emergence of a high-quality LED product market. CALiPER tests LED

products and compares their performance to both the manufacturer's claims and other conventional products. Of 300 LED products tested by CALiPER to date, more than half are considered poor performers. Thanks to these tests, companies are motivated to improve their products. CALiPER testing results guide DOE planning for solid-state lighting R&D and market introduction activities. CALiPER also supports DOE GATEWAY demonstrations and technology procurement activities, and guides the development of credible, standardized testing procedures and measurements. Buyers and specifiers benefit from objective product performance information, building confidence that solid-state lighting products will perform as claimed.

Standards setting is another key to successful market introduction. Important differences between LED technology and conventional lighting have created a gap in the industry standards and test procedures that complicates typical product comparisons and ratings. DOE is collaborating with many standards-setting organizations—including the Illuminating Engineering Society of North America (IES), the National Electrical Manufacturers Association (NEMA), Underwriters Laboratories (UL), and the American National Standards Institute (ANSI)—to accelerate the adoption of standards for LEDs. Two new nationally recognized industry testing standards from IES—LM-79 and LM-80—have already been developed to measure key properties of LED lighting, including light output, light intensity distribution, maintenance of light output over time, energy performance, light color, and color rendering.

DOE also is paying significant attention to **consumer education**, in partnership with industry stakeholders such as retail and wholesale chains, energy efficiency sponsors, and state and local governments.



Next Generation Luminaires Winners (left to right):

Winona Lighting
STEP03 indoor/outdoor
step lighting

GE Lighting
Immersion™ jewelry case
lighting

Journée Lighting
AZARA track mounted
luminaires



The Lighting Facts label—part of DOE’s SSL Quality Advocates program—provides a quick summary of the key performance results from products tested according to industry standards.

- DOE has established the Lighting Facts^{CM} label for LED lighting that is similar to a nutrition label. This voluntary labeling effort, part of DOE’s **SSL Quality Advocates**, requires participating manufacturers to test their products to prescribed standards and to label them accordingly.
- DOE co-sponsors two annual competitions that recognize milestone achievements in LED product design. The **Next Generation LuminairesTM** competition, which concentrates specifically on LED products designed to meet lighting demands in commercial spaces, is jointly sponsored by DOE, IES, and the International Association of Lighting Designers (IALD). The **Lighting for Tomorrow** competition, jointly supported by DOE, the American Lighting Association, and the Consortium for Energy Efficiency, showcases some of the best residential LED products available on the market today.
- To spur manufacturers to develop high-quality, high-efficiency SSL products that replace the common bulb, DOE is sponsoring the **L PrizeSM** competition. Prizes will be awarded to companies whose products meet prescribed efficiency and performance levels, and L Prize partners stand ready to promote the winning products. With this challenge to industry, DOE aims to substantially accelerate America’s shift from inefficient general lighting products to innovative, high-performance lighting. In September 2009, the competition welcomed its first entry.

Through a comprehensive commercialization support strategy, ranging from demonstrations to consumer education, DOE and its partners are ensuring that solid-state lighting will make the greatest possible inroads in the marketplace and the greatest possible contributions to a greener American energy future.

While DOE continues to work with industry to drive technology forward, these are still the early days of market development for solid-state lighting. Only application in a host of real-world operating conditions will reveal the extent of this technology’s potential. With continued collaboration, America’s lighting future promises to be brilliant and efficient.

Definitions

Solid-state lighting (SSL) technology uses semi-conducting materials to convert electricity into light. SSL is an umbrella term encompassing both light-emitting diodes (LEDs) and organic light-emitting diodes (OLEDs).

Light-emitting diodes (LEDs) are based on inorganic (non-carbon-based) materials. An LED is a semi-conducting device that produces light when an electrical current flows through it.

Organic light-emitting diodes (OLEDs) are based on organic (carbon-based) materials. In contrast to LEDs, which are small point sources, OLEDs are made in sheets that provide a diffuse area light source. OLED technology is developing rapidly, but is still some years away from becoming a practical general illumination source.

Luminaire efficacy measures the efficacy of the complete luminaire, or fixture, taking into account the optics, thermal design, and other design factors that impact efficacy. It is calculated by measuring the total light output of a luminaire, divided by the amount of power drawn by that luminaire. It is expressed in lumens per watt (lm/W).

Source efficacy measures the efficacy of the light source, separate from the fixture. It is calculated by measuring the total light output of a lamp/power supply system, divided by the power drawn by that system. (It does not account for losses caused when that system is installed in a fixture.) It is expressed in lumens per watt (lm/W).

For partner information, visit:

DOE Solid-State Lighting: www.ssl.energy.gov

L Prize: www.lightingprize.org

Next Generation Luminaires: www.ngldc.org

Lighting for Tomorrow: www.lightingfortomorrow.com

SSL Quality Advocates: www.lightingfacts.com

GATEWAY Demonstrations: www.ssl.energy.gov/gatewaydemos.html

Next Generation Lighting Industry Alliance: www.nglia.org



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