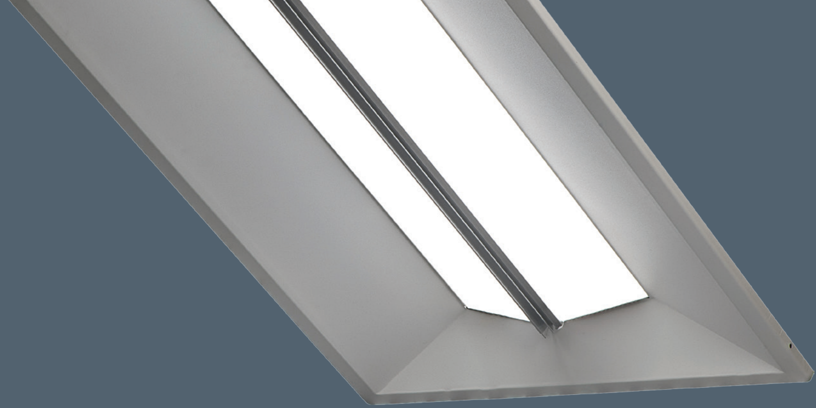
Solid-State Lighting

Brilliant Solutions for America's Energy Future

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
BUILDING TECHNOLOGIES OFFICE



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 (SSL) will mean greener homes and businesses that use substantially less electricity, making them less dependent on fossil fuels. In the coming decade, SSL will become a key to affordable high-performance buildings—buildings that consume less energy and produce fewer greenhouse gas emissions than their counterparts.

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 as directed by the Energy Policy Act of 2005, DOE is the lead federal agency for all research, development, and market support 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 nearly one half.

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

Users 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
- Digitally controllable
- Able to withstand strong vibrations
- 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 nearly one half—the annual equivalent to saving:

- 300 terawatt-hours
- $30 billion (in today's dollars)
- Output of fifty 1,000-megawatt power plants
- Greenhouse gas emissions equivalent to 40 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 technology, the SSL market 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?
- How can the U.S. establish a distinct global lead in the production of quality SSL products?

Together with a wide array of industry partners, DOE is tackling these issues in its research, development, and market support 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 job opportunities.

DOE's Pathway to Success with Industry

"LEDs are an obvious area where we can achieve energy savings and we can also achieve **economic benefits—job creation.**"
—U.S. Senator Jeff Bingaman, Chair, Senate Committee on Energy and Natural Resources

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 increase the likelihood of 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 has worked with hundreds of 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 "From Indicator Lights to LED General Illumination" below). Today, a wide variety of LED products are available for most lighting applications, and many can compete with conventional technologies in terms of performance.

Yet despite the rapid pace of technology developments, solid-state lighting has not yet come close to achieving its full potential. DOE-supported R&D continues to attack many issues that limit performance. The goal now is to maximize efficacy—not in comparison to what *was*, but what *is* and what *can be*. Today's LED research focuses on improving phosphors, simplifying package design, tuning the spectrum, and addressing stability for both light output and color.

The combination of factors that make LED lighting unique, such as source size, controllability, and color quality, presents engineering challenges that require continued advances in applied research and design. Quality LED luminaires require precise design of several components—LED arrays, electronic drivers, heat sinks, and optics. LEDs must be carefully integrated into lighting fixtures because they are sensitive

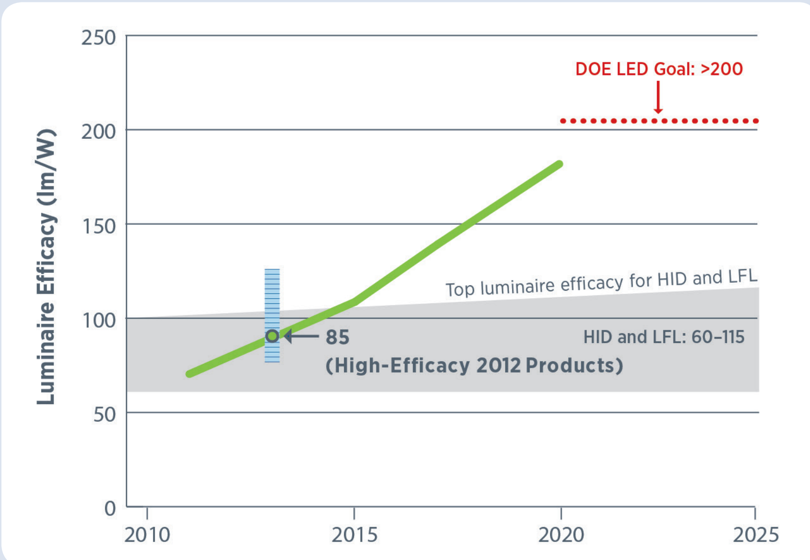
From Indicator Lights to LED General Illumination

Early 1960s to late 1990s • The Monochrome Era

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 development of blue LEDs in the 1990s led to the first white LEDs, which were made by coating blue LEDs with phosphor. White light made using red, green, and blue LEDs was demonstrated shortly thereafter. With the availability of white light, LEDs could be designed for general lighting, but to realize the full potential of LEDs, vast efficiency improvements had to be made.

2000–2012 • LED General Lighting

In 2000, DOE and private industry partnered to push white LED technology forward with the intention to develop a high-efficiency, packaged LED device. At the start, white LED devices were no more efficient than the incandescent bulb, but rapid technology advances have led to market introduction of LED products in just about every application. By 2012, the L Prize-winning LED replacement bulb delivered 90 lm/W, while a number of other similar LED bulbs approached that performance. In terms of packaged LEDs, commercial LED packages delivered 144 lm/W for cool white and about 100 lm/W for warm white at standard drive currents. Product designers realized that LEDs can reach significantly higher efficacies if driven at low current, and falling prices make the use of more devices in a product an acceptable tradeoff.

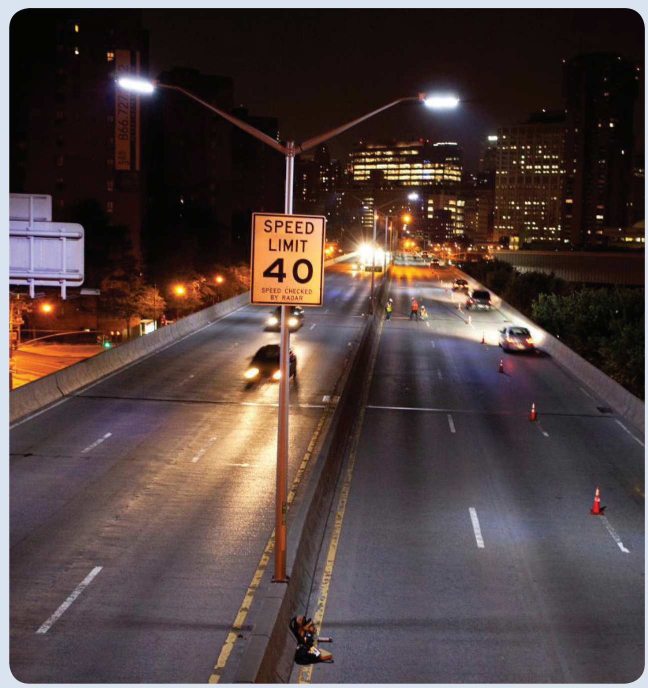


Solid-State Lighting Luminaire (Fixture) Performance Curve

The efficacy of LED light sources has already surpassed that of incandescent, halogen, high intensity discharge, and linear fluorescent lamps, and will continue to improve. By 2020, LED luminaires will be capable of luminaire efficacies approaching 170 lm/W, more than twice that of a typical fluorescent fixture. The sampling of high-efficiency LED products shown in the blue bar on the graph achieve an average of 85 lm/W, with a range of 70–120 lm/W. *Source: DOE LED Lighting Facts product database, as of October 2012; Solid-State Lighting Research and Development Multi-Year Program Plan analysis, April 2012.*

to thermal, optical, and electrical design. And as controls come into greater use, new issues are emerging, and R&D is needed to learn how best to match electronics and LEDs.

OLED technology is less mature than LED technology, and innovations are needed on multiple fronts to increase the efficiency, lifetime, and output of OLED devices. Manufacturing infrastructure investments will be essential to transitioning OLED products from the prototype stage to commercial viability. Price is one of the biggest hurdles to widespread adoption, for both LED and OLED technology, and DOE works with manufacturers to reduce costs through improvements in manufacturing equipment and processes.



LED street and roadway lighting has proven capable of matching or surpassing the performance of incumbent products and is attracting interest from many quarters. Its potential advantages include energy efficiency, durability, long life, and compatibility with controls, all of which can help cut down on energy consumption and reduce maintenance costs. *Photo courtesy of Ryan Pyle.*

2013–2025 • The Future of LED General Lighting

Researchers believe that phosphor-converted LED packages will peak at around 200 lm/W at standard drive (and low current drive will produce LED products with similar efficacies in the near term). However, using hybrids of white and red LEDs or other combinations in LED packages offers more headroom, and over 250 lm/W is possible if researchers are able to successfully color mix four or more monochromatic diodes. Luminaire efficacies should be able to achieve 75–80% of these device efficacies, but the real focus will shift to product design features that add value —better color consistency and rendition, easier installation and maintenance, integrated controls and more—to drive significant market adoption.

2013–2025 • The Promise of OLED General Lighting

While LEDs act as concentrated sources of bright light, OLEDs are more diffuse light sources. These may be more practical for general ambient lighting or, if on a flexible base material, can be shaped and integrated more tightly into architectural designs. Improvements in OLED light output continue, with reports of up to 68 lm/W for small "panel" devices that can be combined into luminaire products. While OLED efficiencies are on track to catch up with LEDs over the next several years, other challenges remain, including making larger panels of about 200 cm^2, and addressing environmental stability, lifetime, and above all, cost and manufacturability. As soon as these challenges are overcome, OLED products will appear on the market, to compete with incumbent lighting.

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 buyer satisfaction and successful product introductions in the rapidly evolving solid-state lighting marketplace, DOE's program incorporates field demonstrations, third-party testing and reporting, technical support for standards development, education elements, and design and technology competitions. 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 LED products in general illumination applications—ranging from streets and roadways, to parking lots and garages, to private homes, to grocery freezer cases, to museums and hotels. Results are shared to provide real-world experience and data on product performance and cost effectiveness, which enable users to evaluate and refine their lighting requirements before making large-scale purchasing decisions. Demonstrations are also conducted through the **Municipal Solid-State Street Lighting Consortium**, established by DOE to help cities and other LED street lighting buyers make better, more informed purchase and installation decisions. The Consortium collects, analyzes, and shares technical information and experiences related to LED street and area lighting demonstrations, enabling participants to tap into a vast body of field data and knowledge.

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 publicly tests LED products and compares their performance to both the manufacturer's claims and conventional products,

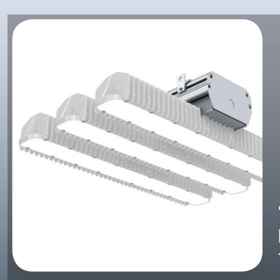
The LED Lighting Facts product list is a web-based, searchable tool that summarizes verified data, equipping buyers to make informed decisions about the best products for their applications.

with nearly 600 products tested to date. Thanks to these tests, companies are motivated to improve their products. CALiPER testing often detects issues that require further scrutiny, and that might hinder market acceptance. CALiPER analysis guides DOE planning for R&D and market support activities, GATEWAY demonstrations, and 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.

DOE is also paying significant attention to **educating** industry stakeholders such as retail and wholesale chains, utilities, energy efficiency programs, and lighting specifiers. DOE's **LED Lighting Facts**® program requires participating manufacturers to test and report their LED lighting product performance using prescribed standards, to facilitate accurate product comparison. LED Lighting Facts partners pledge to look for and use products that are registered with the program, and they also benefit from a host of related tools on the LED Lighting Facts website.

Next Generation Luminaires 2012 Indoor Competition Winners

'ST Series' by Lithonia Lighting



'H-Series' by Albeo Technologies Inc.

'MBW2 LED' by Intense Lighting

Photos courtesy of the manufacturers.

The first L Prize was awarded to Philips Lighting North America for their 60W LED replacement bulb.
Photos courtesy of Midwest Energy Efficiency Alliance and Philips.

Standards development 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 Institute of Electrical and Electronics Engineers (IEEE), the National Electrical Manufacturers Association (NEMA), Underwriters Laboratories (UL), and the American National Standards Institute (ANSI)—to accelerate the adoption of standards for LEDs.

DOE also co-sponsors **design and technology competitions** to heighten awareness and speed market adoption of high-performance SSL products. The **Next Generation Luminaires**™ competition, which concentrates specifically on recognizing LED products designed to meet lighting demands in commercial spaces, is jointly sponsored by DOE, IES, and the International Association of Lighting Designers (IALD).

To spur manufacturers to develop high-quality, high-efficiency SSL products that replace common light bulbs, reflector lamps, and other lighting products, DOE sponsors the **L Prize**® competition. The competition challenges companies to develop products that set leading-edge performance benchmarks for the industry. Unlike other technology competitions, L Prize adds practical elements beyond production of a product prototype—to deliver energy savings and American jobs, entrants are required to demonstrate the capacity for mass production, and a substantial amount of the manufacturing must be done in the U.S. L Prize partners (utilities and energy efficiency programs) stand ready to promote the winning products, which will represent a significant technology leap forward. With this challenge to industry, DOE aims to substantially accelerate America's shift from inefficient general lighting products to innovative, high-performance lighting.

Through a comprehensive market development 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 advances forward, these are still the early days of market development for solid-state lighting. Continued R&D and application in a host of real-world operating conditions will reveal the extent of this technology's potential. With ongoing 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 for lamps and luminaires that use either light-emitting diodes (LEDs) or 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.

LED package refers to an assembly of one or more LEDs, including electrical connections and possibly an optical element. The power source and base are not incorporated into the device.

LED luminaire is a complete lighting unit or fixture consisting of LEDs (often LED packages), driver, and parts to distribute, position, and protect the light emitting elements.

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 more information, visit:

DOE Solid-State Lighting: www.ssl.energy.gov
CALiPER: www.ssl.energy.gov/caliper.html
GATEWAY Demonstrations: www.ssl.energy.gov/gatewaydemos.html
Municipal Solid-State Street Lighting Consortium: www.ssl.energy.gov/consortium.html
L Prize: www.lightingprize.org
LED Lighting Facts: www.lightingfacts.com
Next Generation Lighting Industry Alliance: www.nglia.org
Next Generation Luminaires: www.ngldc.org

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