



# 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 (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 gases 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 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-fourth.

With the promise of being **more than ten times as efficient as 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
- 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-fourth—the annual equivalent to saving:

- 190 terawatt-hours
- \$15 billion (in today's dollars)
- Output of twenty-four 1,000-megawatt power plants
- Greenhouse gas emissions equivalent to 21 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 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 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 management and efficient electrical control are also R&D areas of interest.

Today, the quality of available LED products varies widely, partly because traditional lighting manufacturers have much to learn about incorporating LEDs into their fixtures

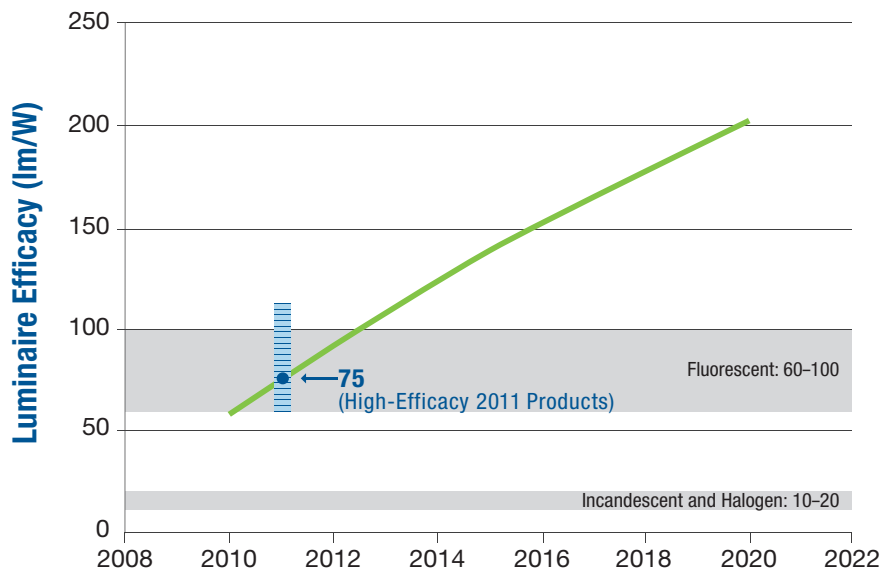
## From Indicator Lights to LED General Illumination

### 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 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.

### 2000–2010 • The Beginning of LED General Illumination

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 2010, a comparable warm white LED replacement lamp with good color rendering showed a steady-state efficacy of about 62 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 200 lm/W were demonstrated in 2010, with commercially available cool white devices producing efficacies as high as 132 lm/W.

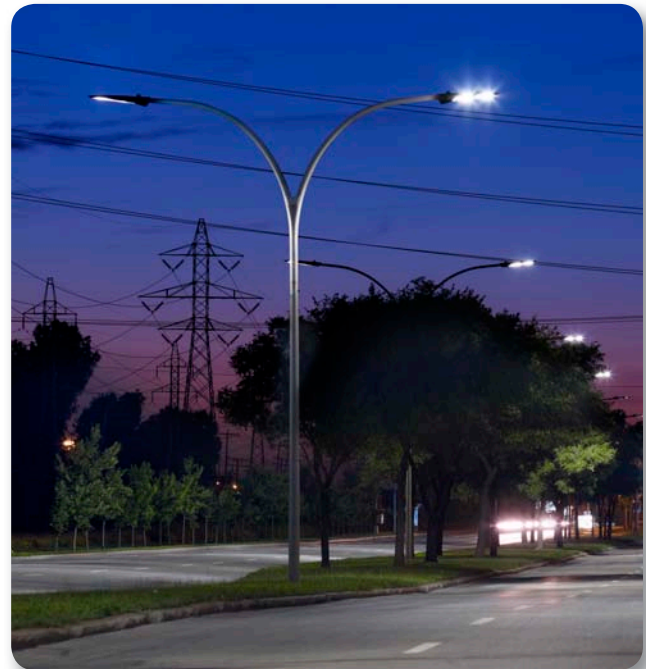


### Solid-State Lighting Luminaire (Fixture) Performance Curve

The efficacy of LED light sources has already surpassed that of incandescent lighting and will continue to improve. By 2015, LED luminaires (fixtures) will be capable of luminaire efficacies exceeding 150 lm/W, more than twice that of a typical fluorescent fixture. Lowering the drive current applied to the LEDs can increase efficacy. The high-efficacy 2011 products shown on the graph achieve 75 lm/W using a standard drive current, but there are other high-efficacy products on the market that range from 60 lm/W to 110 lm/W, depending on the drive current. *Source: 2011 DOE SSL R&D Multi-Year Program Plan*

and partly because SSL, like so many previous fast-growth markets created by new technologies, has spawned the development of a large number of inexperienced companies. 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 arrays, electronic drivers, heat sinks, and optics. LEDs must be carefully integrated into lighting fixtures because they are sensitive to thermal, optical, and electrical design. Given the design challenges, DOE works with both fixture and LED manufacturers to assist in performance improvements.

**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 Philips Roadway Lighting.*



### 2011–2015 • The Future of LED General Lighting

Researchers believe the maximum achievable efficacy for packaged LED devices is around 250 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 2020. Properly designed LED luminaires could achieve efficacies over 200 lm/W, or up to 15 times that of incandescent lighting. Reported LED package efficacies today are 20–40% higher than when the package is installed in a luminaire, since other components in the luminaire cause light and electrical losses. LEDs, although expensive now, will continue to fall in price as new and better ways to package and manufacture them are perfected.

### 2013–2018 • The Promise of OLED General Lighting

While LEDs act as concentrated sources of bright light, OLEDs can be configured as larger-area, 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<sup>2</sup>, 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 consumer 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, consumer 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 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 leverage the efforts of the many cities that are pursuing evaluations of LED street lighting products. The Consortium collects, analyzes, and shares technical information and experience 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 tests LED products and compares their performance to both the manufacturer's claims and conventional products. Of more than 350 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 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 National Electrical Manufacturers Association (NEMA), Underwriters Laboratories (UL), and the American National Standards Institute (ANSI)—to accelerate the adoption of standards for LEDs.

DOE is also paying significant attention to **educating** industry stakeholders such as retail and wholesale chains, utilities, energy efficiency sponsors, and lighting specifiers. DOE has established the **Lighting Facts®** program, which requires participating manufacturers to test their LED lighting products to prescribed standards, and offers a standardized label that facilitates accurate product comparison. Lighting Facts partners pledge to look for and use products that bear this label, and they also benefit from a host of related tools on the Lighting Facts website.

## Next Generation Luminaires Winners



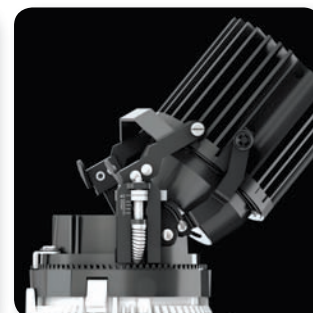
**The Lighting Quotient:** Fraqtir™ linear concealed LED cove luminaire.



**Philips Color Kinetics:** eW Burst® Powercore facade lighting.

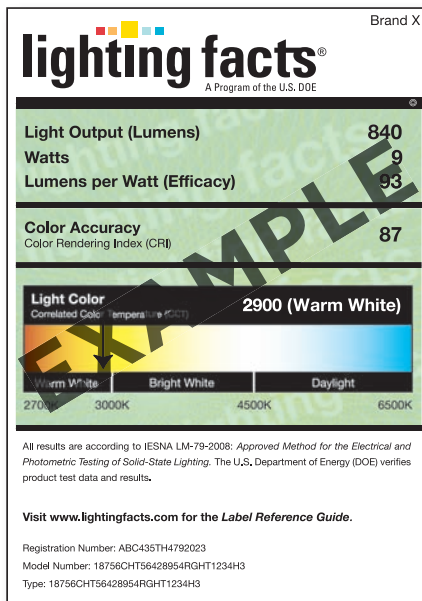


**Koncept Technologies:** Equo™ LED desk lamp.



**USAI:** NanoLED™ recessed accent lighting.

*Photos courtesy of (left to right): The Lighting Quotient, Philips Color Kinetics, Koncept Technologies, and USAI.*



The **Lighting Facts** label provides a quick summary of key performance results from products tested according to industry standards.

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<sup>SM</sup>** competition. Prizes will be awarded to companies whose products meet prescribed efficiency and performance levels, and 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 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 more information, visit:

DOE Solid-State Lighting: [www.ssl.energy.gov](http://www.ssl.energy.gov)

CALiPER: [www.ssl.energy.gov/caliper.html](http://www.ssl.energy.gov/caliper.html)

GATEWAY Demonstrations: [www.ssl.energy.gov/gatewaydemos.html](http://www.ssl.energy.gov/gatewaydemos.html)

L Prize: [www.lightingprize.org](http://www.lightingprize.org)

Lighting Facts: [www.lightingfacts.com](http://www.lightingfacts.com)

Next Generation Lighting Industry Alliance: [www.nglia.org](http://www.nglia.org)

Next Generation Luminaires: [www.ngldc.org](http://www.ngldc.org)