



DOE's 5-Year SSL Commercialization Support Plan

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Voices for SSL Efficiency,

DOE Solid-State Lighting Workshop

Pasadena, CA



Key Take Away from CFL Experience

- Early consumer experience with fluorescent lamps and CFLs still defines attitudes towards CFLs, even though the technology has greatly improved since its introduction





Plan Purpose

1. *Affect the types* of products adopted by the market
2. *Accelerate commercial adoption* of products
3. Support applications that *maximize energy savings*

Plan Scope

FY08 to FY12 ♦ general Illumination SSL luminaires



Goals: By FY12

1. **Products Brought to Market:**

Warm White Products

1. 68 lm/W luminaire efficacy
2. 85 CRI (or similar for revised metric)
3. 3500 CCT or less

Cool White Products

1. 88 lm/W luminaire efficacy
2. 70 CRI (or similar for revised metric)
3. 6500 CCT or less

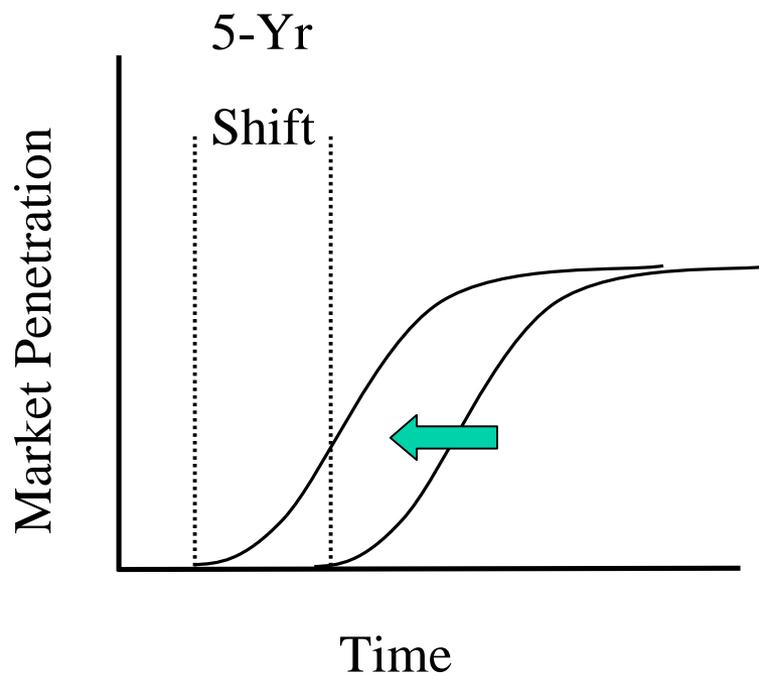
2. **Market Adoption:** 5 million units/year (ENERGY STAR)

3. **Energy Savings:** 19 TWh per year (includes savings from R&D)



Energy Savings Goal Methodology

- For complete DOE SSL program (includes R&D, and contributions from program partners)
- Based on savings estimates prepared by Navigant Consulting
- Assumes market adoption curve is advanced 5 years
- Consistent with findings of NRC 2001 evaluation of DOE BT investment in electronic ballasts and low-e windows





Desired End State (Point at Which DOE Ceases Effort)

- **Products Brought to Market:**
 - *Warm White*: at least ten 100+ lm/W luminaire efficacy
 - *Cool White*: at least ten 120+ lm/W luminaire efficacy
 - Offered for sale by major fixture manufacturers in each of following categories:
 - *Warm White*: residential recessed downlights, commercial recessed downlights, commercial office overhead ambient
 - *Cool White*: pole-mounted roadway luminaires, high bay luminaires
- **Market Adoption:** High performance (ENERGY STAR) comprise 10% of annual sales in above product categories
- **Energy Savings:** 50 TWh/year electricity



Primary Market Barriers

- High costs
- Lack of industry standards and test procedures
- Lack of information

Note: *Barriers do not address technical barriers, which are being addressed in R&D program.*



Market Needs (to address Barriers)

- Effective product purchasing and architectural design guidance
- State of the art products and lighting designs
- Highly visible examples of model SSL general illum. applications
- Independent performance test results on commercial products
- Objective technical information from a credible, source
- Industry standards and test procedures for SSL general illumination products
- Coordination of local, regional, and federal SSL commercialization activities



DOE SSL Commercialization Support Strategy Elements

1. Buyer Guidance
 - ENERGY STAR
 - Design Guidance
2. Design Competitions
 - Lighting for Tomorrow (Residential Fixtures)
 - Commercial Fixture Design Competition
 - Architectural Lighting Design Competition
3. Technology Demonstrations/Procurements
 - Demonstrations of Market Readiness
 - Demonstrations to Test Field Performance



DOE SSL Commercialization Support Strategy Elements (cont.)

4. Commercial Product Testing Program
5. Technical Information
 - Technical Information Development & Dissemination
 - Technical Information Network
6. Standards and Test Procedures Support
7. Coordination and Leadership
 - Facilitating & Coordinating Local and Regional Efforts
 - Federal Government Leadership



1) Buyer Guidance

- Developed draft ENERGY STAR criteria for SSL luminaires for general illumination
- General illumination only
- Residential and commercial products
- Intended to provide early market presence
- 1st draft issued in Dec. 06
- Stakeholder workshop on February 8, 2007 in DC
- 2nd draft issue in April 07





Why ENERGY STAR SSL? Why Now?

- Many new products entering market
- Many appear to have greatly exaggerated performance
- DOE SSL commercial product testing is showing actual performance is much less than claimed



Example: Downlight claimed 40 lm/W; measured luminaire efficacy of 13 lm/W and 193 lumens; less than 1/2 the efficacy of typical CFL downlight, and ~1/3 the lumens.



Why ENERGY STAR SSL? Why Now?

- Meanwhile, LED technology is rapidly improving
- Manufacturers are announcing new performance records almost every month
 - Nichia announced 150 lm/W @ 20 mA in December (lab)
 - Seoul Semiconductor announced 100 lm/W @ 350 mA in December (commercial)
 - Lumileds announced 115 lm/W @ 350 mA in January (commercial)

Note: the above performance levels are typically done at 25°C for 25 ms with non-standard test; they are not meant to represent actual performance in a luminaire



Why ENERGY STAR SSL? Why Now?

- DOE expects market introduction in 07 and 08 of high performance products

Example: 2700K CCT, 90+ CRI downlight, 60 lm/W (luminaire efficacy); twice the efficacy of a CFL downlight expected 2nd Q 07.



Design Guidance

- Develop SSL design guidance in cooperation with IESNA
- Purpose: provide lighting designers with key information on SSL technology & characteristics to be considered in designs
- Project in development





2) Design Competitions

- Lighting for Tomorrow
 - Partnership with ALA and CEE approved through 2008
 - Niche applications
 - Cutting edge design
 - Residential products only
 - Recently expanded to include SSL
 - Expert judges
 - Publicity, visibility for winners





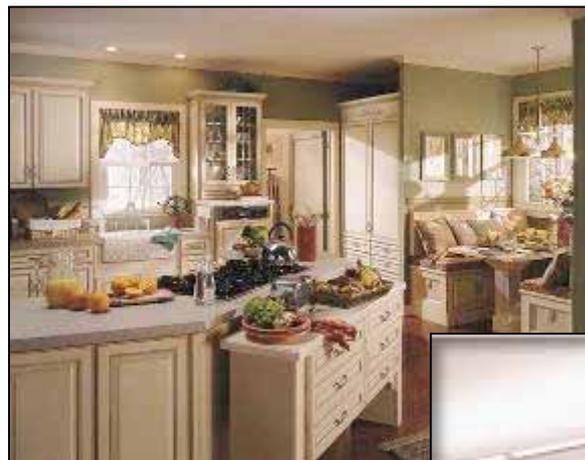
Design Competitions (cont.)

- Two new design competitions being considered
 - Commercial luminaires
 - Architectural lighting designs
- New competitions being discussed with IES and NEMA



3) Technology Demonstrations/ Procurements

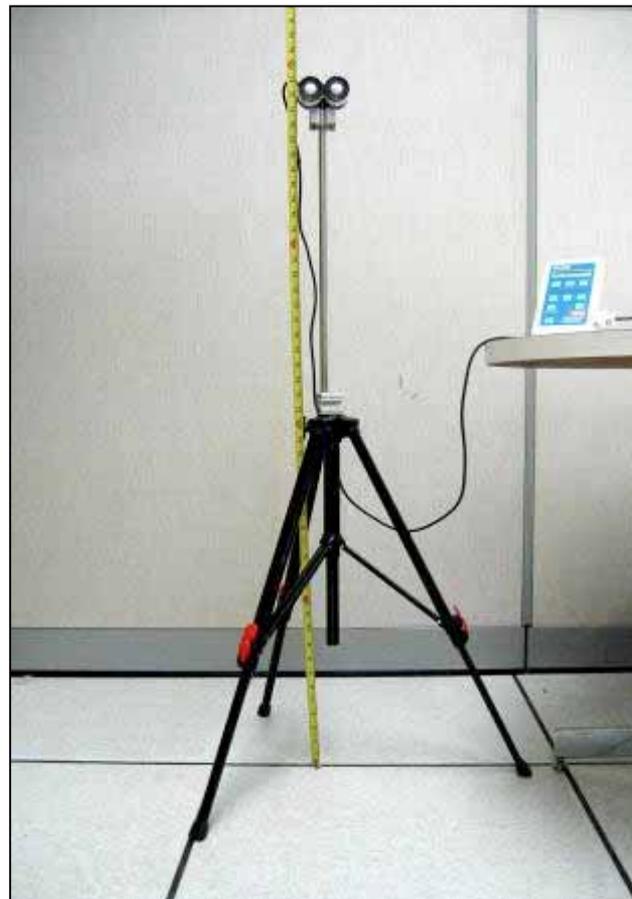
- **Purpose:** Demonstrate advanced technology in general illumination applications for visibility & improved understanding
- Leverage demos with closely linked promotional/procurement effort
- Two types of demos:
 - Market readiness
 - Field test





Technology Demonstrations

- 1st Round started
- Invitation issued to manufacturers in March
- DOE finds partners & host sites, conducts testing, publicizes results and helps promote follow-up sales
- Evaluations to focus on light quality, occupant responses
- Next round likely before FY end





Other Technology Demonstrations

- Solar Decathlon
- DOE SSL Showcase





4) Commercial Product Testing Program

Purposes:

- Provide objective, high quality performance information
- Know performance of market available products
 - To support R & D planning
 - To support ENERGY STAR
- Inform industry test procedures and standards development
- Discourage low quality products
- Reduce SSL market risks to buyers

True 2700K
Color

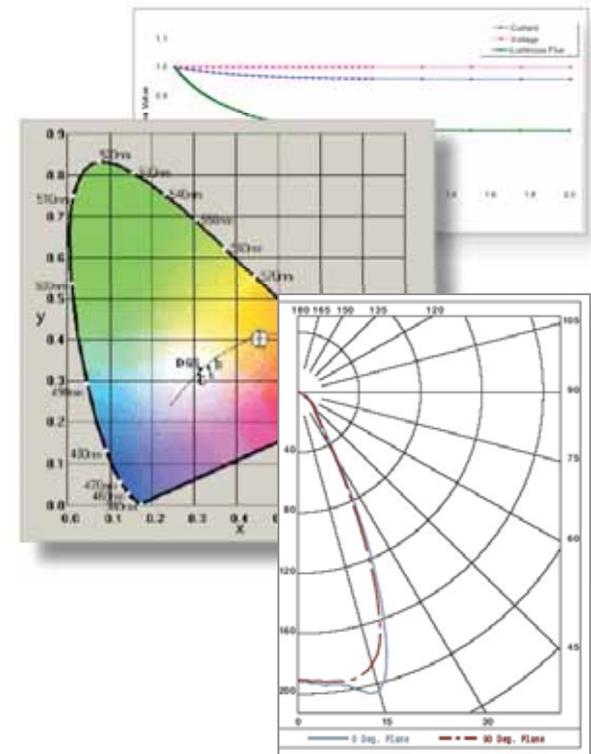
YOU MAY NEVER CHANGE
ANOTHER LIGHT BULB

- ✓ *Long life*
- ✓ *Energy efficient*
- ✓ *Easy to install (standard socket)*
- ✓ *Natural white, superb color rendering*



Testing Program Scope

- Commercially-available SSL products for the general illumination market
 - Luminaires (white light)
 - Indoor and outdoor
 - Residential and commercial
- Testing for
 - Luminaire light output, efficacy
 - Power, thermal characteristics
 - Beam and intensity
 - Lumen depreciation
 - Spectral power distribution, CCT, CRI
 - Benchmarking (other light sources)





5) Technical Information

Building Technologies Program

Thermal Management of White LEDs

LEDs won't burn your hand the same light sources, but they do produce heat. In fact, thermal management is arguably the most important aspect of successful LED system design. This fact sheet reviews the risks of heat in LED performance and methods for managing it.

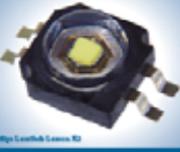


Photo Courtesy: Cree, Inc.

All light sources convert electric power into radiant energy and heat in various proportions. Incandescent lamps emit primarily infrared (IR), with a small amount of visible light. Fluorescent and metal halide sources convert a higher proportion of the energy into visible light, but also emit IR, ultraviolet (UV), and heat. LEDs generate less heat than IR or UV, but convert only 15% to 25% of the power into visible light; the remainder is converted to heat that must be conducted from the LED die to the underlying circuit board and heat sink, housing, or laminate frame assembly. The table below shows the proportions in which each watt of input power is converted to heat and radiant energy (including visible light) for various white light sources.

Power Conversion for "White" Light Sources					
Incandescent*	Fluorescent*	Phosphor-coated metal halide*	LED†	LED†	
Visible Light	7.5%	21%	27%	15-25%	
IR	73.5%	37%	17%	0%	
UV	0%	0%	1%	0%	
Total Radiant Energy	81.0%	58%	25%	15-25%	
Heat	19.0%	42.0%	75.0%	75-85%	
Total	100%	100%	100%	100%	

* DOE Handbook † Cree, Inc.
 *Values depending on LED efficacy. The lowest DOE LED has the highest heat sink.

Why does thermal management matter?

Excess heat does not only affect lumen (brightness) output, but also causes lumen depreciation and color shifts.

The light output of different colored LEDs responds differently to temperature changes, with warmer and the more sensitive, and blue the least. (See graph at right.) These unique temperature response rates can result in noticeably color shifts in RGB-based white light manufacturers test and use (up to 1 millionth power pulse, at 100 temperatures and with significant thermal stress). Therefore, white LEDs will provide reduction in light output for you.

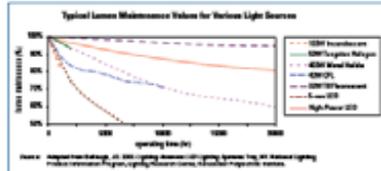
Lifetime of White LEDs

One of the main "selling points" of LEDs is their potentially very long life. Do they really last 50,000 hours or even 100,000 hours? This fact sheet discusses lumen depreciation, measurement of LED useful life, and the features to look for in evaluating LED products.

Lumen Depreciation

All electric light sources experience a decrease in the amount of light they emit over time, a process known as lumen depreciation. Incandescent filaments evaporate over time and the tungsten particles collect on the bulb wall. This typically results in 10-15% depreciation compared to initial lumen output over the 1,000-hour life of an incandescent lamp.

In fluorescent lamps, photochemical degradation of the phosphor coating and accumulation of light-absorbing deposits cause lumen depreciation. Compact fluorescent lamps (CFLs) generally lose no more than 20% of initial lumen over their 10,000-hour life. High-quality linear fluorescent lamps (T8 and T5) using rare earth phosphors will lose only about 5% of initial lumen at 20,000 hours of operation.



The primary cause of LED lumen depreciation is heat generated at the LED junction. LEDs do not emit heat as infrared radiation (IR), so the heat must be removed from the device by conduction or convection. Without adequate heat sinking or convection, the device temperature will rise, resulting in lower light output. While the effects of short-term exposure to high temperature can be reversed, continuous high temperature operation will cause permanent reduction in light output. LEDs continue to operate even after their light output has decreased to very low levels. This becomes the important factor in determining the effective useful life of the LED.

Defining LED Useful Life

To provide an appropriate measure of useful life of an LED, a level of acceptable lumen depreciation must be chosen. At what point is the light level no longer meeting the needs of the application? The answer may differ depending on the application of the product. For a common application such as general lighting in an office environment, research has shown that the majority of occupants in a space will accept high level reductions of up to 10% with little notice, particularly if the reduction is gradual. Therefore a level of 70% of initial light level could be considered an appropriate threshold of useful life for general lighting. Based on this research, the Alliance for Solid State Illumination Systems and Technologies (ASIST), a group led by the Lighting Research Center (LRC),

ASIST, 2010. LED Light Level and Lumen and Depreciation. ASIST. <http://www.asist.org>.
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Building Technologies Program



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Building Technologies Program

Energy Efficiency of White LEDs

The energy efficiency of light-emitting diodes (LEDs) is expected to rival the most efficient white light sources by 2015. But how energy efficient are LEDs right now? This fact sheet discusses various aspects of lighting energy efficiency and the rapidly evolving status of white LEDs.



Photo Courtesy: Cree, Inc.

Luminous Efficacy

Energy efficiency of light sources is typically measured in lumens per watt (lm/W), meaning the amount of light produced for each watt of electricity consumed. This is known as luminous efficacy. DOE's long-term research and development goal calls for white light LEDs producing 100 lm/W in cost-effective, market-ready systems by 2025. In the meantime, how does the luminous efficacy of today's white LEDs compare to traditional light sources? Currently, the best white LED approach the efficacy of compact fluorescent lamps (CFL). However, there are several important caveats, as explained below.

Color Quality

The data LED luminous efficacy similar to that of CFLs has been achievable only with higher color temperature products, which produce a "cool" or bluish-tinted light and relatively low color rendering index (CRI). In the 70s, LEDs with warmer color appearance and higher CRI are only marginally more efficacious than incandescent sources. However, this is changing rapidly, with new performance improvements being announced regularly by the industry. For more detail, see DOE fact sheet "Color Quality of White LEDs."

Driver Losses

Fluorescent and high-intensity discharge (HID) light sources convert function without a ballast, which provides a starting voltage and limits electrical supplementary electronics, usually called drivers. The voltage (typically between 2 and 4 volts DC for high-bay 1000 milliwatt or mA), and may also include dimming

Currently available LED drivers are typically about 85% efficient by 100% to account for the driver. For a rough efficiency for traditional and LED sources, including the driver below:

Light Source	Typical Efficiency
Incandescent	10-15%
Halogen Incandescent	15-20%
Compact Fluorescent Lamp (CFL)	20-30%
Fluorescent	25-35%
Metal Halide	25-35%
Good white LED (5000K)	30-40%
Warm white LED (3000K)	25-35%

Thermal Effects

The luminous flux figures cited by LED manufacturers (75 of 20°C) are used during manufacturing actual operation in a fixture or system. In general, lamp operation (perhaps a 20 milliwatt pulse) to open, at 1 meter distance causes in a fixture or system. LEDs in a fixture will produce 10% to 15% less light than indicated



Color Quality of White LEDs

Color quality is one of the key challenges facing light-emitting diodes (LEDs) as a general lighting source. This fact sheet reviews the basics regarding light color and summarizes the most important color issues related to white LED lighting.

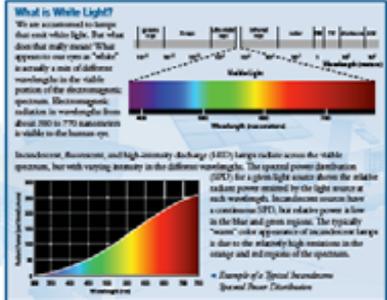
Unlike incandescent and fluorescent lamps, LEDs are not inherently white light sources. Instead, LEDs emit light in a very narrow range of wavelengths in the visible spectrum, resulting in nearly monochromatic light. This is why LEDs are not efficient for colored light applications such as traffic lights and exit signs. However, to be used as a general lighting source, white light is needed. The potential of LED technology to produce high-quality white light with unprecedented energy efficiency is the impetus for the intense level of research and development currently being supported by the U.S. Department of Energy.

White Light from LEDs

White light can be achieved with LEDs in two main ways: 1) phosphor conversion, in which a blue or ultraviolet (UV) chip is coated with phosphor to emit white light; and 2) RGB systems, in which light from multiple monochromatic LEDs (red, green, and blue) is mixed, resulting in white light.

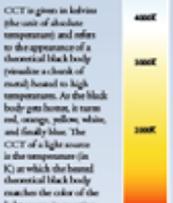
The phosphor conversion approach is most commonly based on a blue LED. When combined with a yellow phosphor (usually yttrium-doped gadolinium garnet or YAG:Gd), the light will appear white to the human eye. A more recently developed approach uses an LED emitting in the near-UV region of the spectrum to excite multiple chromatic phosphors to generate white light.

The RGB approach produces white light by mixing the three primary colors red, green, and blue. Color quality of the resulting light can be enhanced by the addition of either a "fill" or the "refill" region of the spectrum. Status, benefits and trade-offs of each approach are outlined on page 2.



Building Technologies Program

Correlated Color Temperature (CCT) describes the relative color appearance of a white light source, indicating whether it appears more yellowish or more blue, in terms of the range of visible shades of white.



CCT is given in kelvins (the unit of absolute temperature) and refers to the appearance of a theoretical black body (imagine a chunk of metal heated to high temperature). At the black body's glow (red, orange, yellow, white, and finally blue), the CCT of a light source is the temperature (in K) at which the heated theoretical black body matches the color of the light source in question. Incandescent light sources with a higher CCT are said to be "cooler" in appearance, while those with lower CCT are characterized as "warmer."

Color Rendering Index (CRI)

CRI indicates how well a light source renders colors, on a scale of 0 - 100, compared to a reference light source. The test procedure established by the International Commission on Illumination (CIE) involves measuring the extent to which a series of eight standardized color samples differ in appearance when illuminated under a given light source, relative to the reference source. The average "shift" in those eight color samples is reported as R_a or CRI.

In addition to the eight color samples used by convention, some lighting manufacturers report an "R₉" score, which indicates how well the light source renders a saturated deep red color.





Building Technologies Program

LED Application Series:

Recessed Downlights

Recessed downlights are very common in both residential and commercial buildings. Is this a good application for LEDs? This fact sheet explores issues unique to this type of luminaire, and the potential for use of LEDs in downlights.

Recessed downlights are the most common installed luminaire type in residential new construction. Downlights are used for general ambient lighting in kitchens, hallways, bathrooms, and other areas of the home. Downlights with small apertures and more directional lensing and baffling are also used for wall-washing and accent lighting. In commercial settings, a wide variety of downlight types, sizes, and finishes are used in lobbies, perimeter areas, hallways, and restrooms.



The light output of a recessed downlight is a function of the lumens produced by the lamp and the luminaire efficiency. Reflector-style lamps are specially shaped and coated to emit light in a defined cone, while "A" style incandescent lamps and CFLs emit light in all directions, leading to significant light loss within the luminaire. Downlights using non-reflector lamps are typically only 50% efficient, meaning about half the light produced by the lamp is wasted inside the fixture. LEDs are more directional, but can they provide enough light? For comparison, the table below shows typical light output and efficiency of residential-style fluorescent and incandescent recessed downlights and an LED downlight.

Examples of Recessed Downlight Performance Using Different Light Sources

		Fluorescent*		Incandescent*		LED**
		26W pin-based CFL	15W R-30 CFL Edison base	65W R-30	100W A-19	LED 15W Downlight
LAMP	Rated lamp lumens	1800	750	755	1700	unknown
	Lamp wattage (nominal W)	26	15	65	100	9 x 1W LEDs
	Lamp efficacy (lm/W)	70	50	12	17	45
LUMINAIRE	Luminaire efficiency	50%	90%	90%	50%	unknown
	Delivered light output (lumens), initial	900	675	680	850	300
	Luminaire wattage (nominal W)	27	15	65	100	15
	Luminaire efficacy (lm/W)	33	45	10	9	20

*Based on photometric data for commonly available products. Actual product performance depends on reflection, trim, lamp positioning, and other factors. Assumptions available from FPNL.

**Based on one commercially-available product tested. Other LED-based downlights may differ. Lamp efficacy for the LED product refers to the manufacturer listed "typical luminous flux" of the LEDs used. Luminaire flux of the 9-LED array is not known.

Even though the 26W CFL is the most efficacious light source listed, the 15W reflector CFL provides higher luminaire efficacy, i.e., total lumens out of the fixture per watt consumed. The 15W LED downlight provides less than half the delivered light output of the 15W reflector CFL. As LED technology matures, this performance is expected to improve.



Terms

Luminaire – a complete lighting unit including lamp(s), ballast(s) (when applicable), and the parts designed to distribute the light, position and protect the lamps, and connect to the power supply.

Luminaire (fixture) efficiency – the ratio of luminous flux (lumens) emitted by a luminaire to that emitted by the lamp or lamps used therein; expressed as a percentage.

Luminaire efficacy – total lumens provided by the luminaire divided by the total wattage drawn by the fixture, expressed in lumens per watt (lm/W).

ICAT – stands for "insulated ceiling (or "insulation contact"), air tight" and refers to ratings on recessed downlight luminaires used in residential construction.

Downlights installed on the top floor of a house are immersed in insulation, creating a high-temperature operating environment that is difficult for CFLs and potentially similarly challenging for LEDs. Further, energy codes in most states require downlights installed in the building shell to be rated "air tight" to minimize loss of heating and cooling energy.

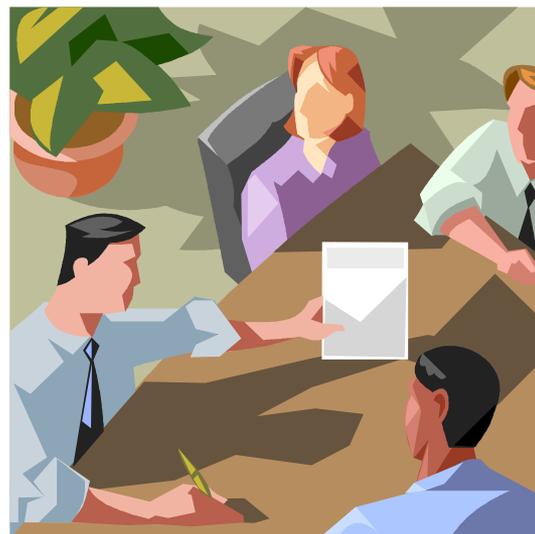


- Application series:
 - Recessed downlights
 - Undercabinet
 - Portable desk/task
- Others coming:
 - Compare/contrast LED and traditional light sources
 - Cost/economics
 - Many more
- Measurement series:
 - Luminaire efficacy



Technical Information Network

- Cooperative agreements to be awarded soon to selected partners: (CEE and NEEP)
- Outreach to efficiency orgs, utilities, and their contractors
- Leverage existing programs & contacts
- Quarterly meetings
- Disseminate information to:
 - Retailers, builders
 - Consumers, others

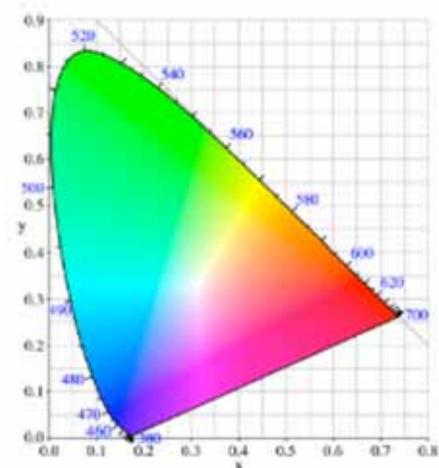




6) Standards & Test Procedures Support

Key Measurement Issues:

- Measurement of luminous flux
 - Luminous efficacy
 - Luminaire efficacy
- Chromaticity and color rendering
- Electrical characteristics
- Drivers
- Life rating (lumen maintenance)
- Definitions and nomenclature





Standards and Test Procedures Support

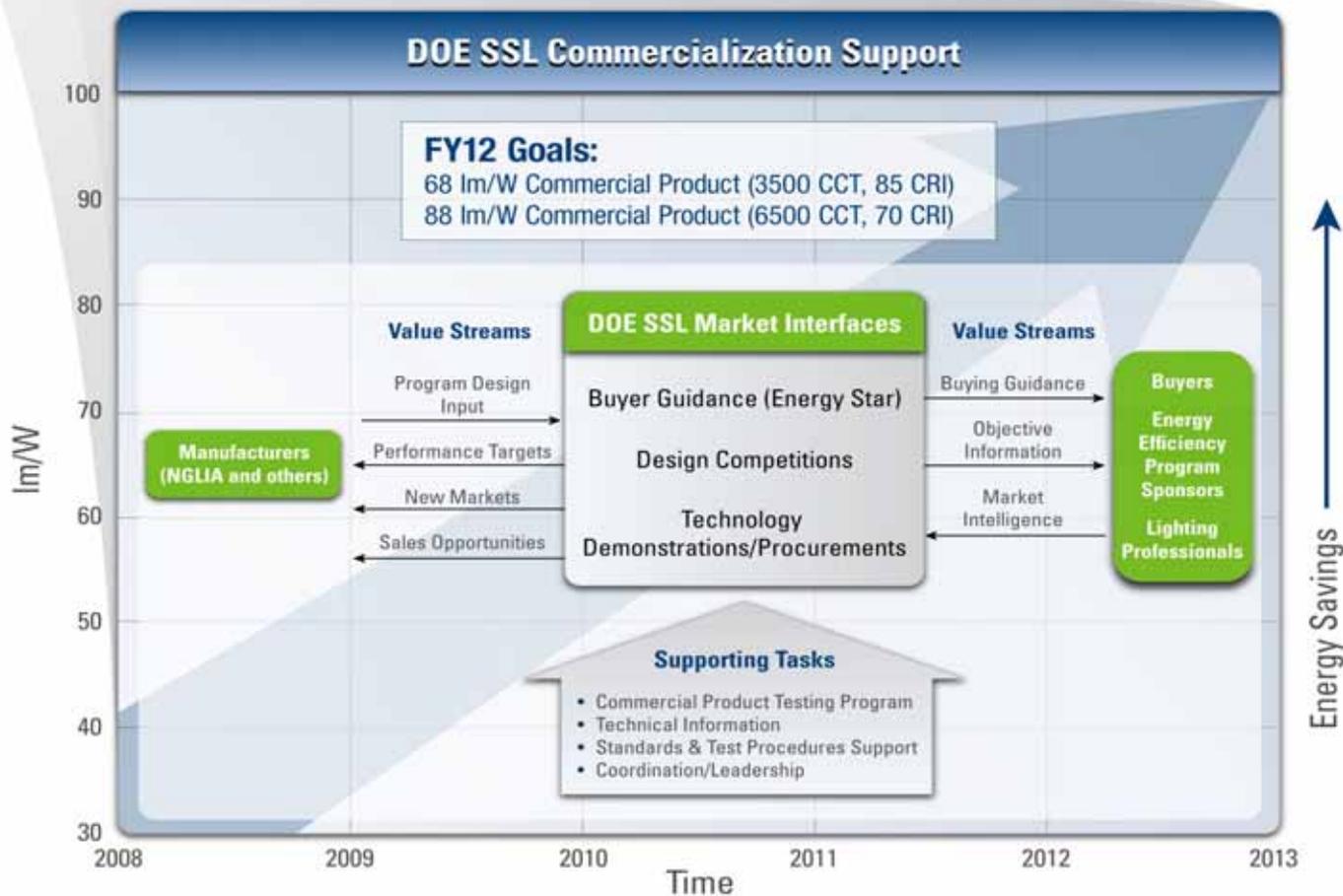


- DOE workshops in Mar & Oct 2006
- In process:
 - Photometric Measurement (LM-79)
 - Lumen Depreciation (LM-80)
 - Chromaticity (ANSI C78.377A)
 - Electrical performance (ANSI C78.XX3)
 - SSL-LED power supply (ANSI C82.XX1)
 - Definitions/nomenclature (IESNA RP-16)
- New standards before end of 2007



7) Coordination & Leadership

- Federal government is largest U.S. energy consumer
 - Working with FEMP to identify opportunities for early SSL applications
- Organize workshops, joint projects for key partners, including
 - Efficiency organizations, utilities
 - Lighting industry professionals
 - Fixture manufacturers





Key Issues to be Considered in Project Development

1. Early, low-performing products can cause long-term market damage
2. High costs
3. Low color quality, high CCT
4. Incomplete standards & test procedures
5. Lead to profligate use of lighting
6. Quick obsolescence
7. Retrofit products
8. Commercial vs. residential emphasis
9. Appropriate near-term lighting applications



DOE SSL Communications Plan

- Objective: Build awareness of SSL technology, advantages, limitations, and appropriate applications
 - Continue core communications activities and tools (website, SSL UPDATES, workshops, reports, fact sheets)
 - Broaden to engage market transformation partner audiences, support commercialization plan elements
 - Input from this meeting will shape future communications planning



DOE Solid-State Lighting Website

- Current information on SSL program, progress, and events
- SSL publications: roadmaps, reports, technical fact sheets
- Solicitations
- Register for ongoing SSL UPDATES at:

www.netl.doe.gov/ssl





Support for Commercialization Plan Elements

- Support and leverage partner channels to disseminate information
 - ENERGY STAR criteria, testing program results, demonstrations, design competitions, fact sheets
- Expand media relations
 - Press releases, press events, conferences, articles

