Northwest Power and Conservation Council

September 4, 2013

MEMORANDUM

TO: Power Committee

FROM: Charlie Grist

SUBJECT: Update on the State of Solid-State Lighting

Solid-state lighting first appeared in the Council's Fifth Power Plan, in the form of light-emitting diode (LED) traffic lights. In the Sixth Power Plan, LED street lighting and outdoor area lighting expanded solid-state lighting energy efficiency potential significantly. Since that time, the pace of technological and market advancement of solid-state lighting has been remarkably fast. At the September Council meeting, staff will present an update about what has been going on in solid-state lighting since the Sixth Power Plan, and provide a glimpse into the future.

Solid-state lighting is beginning to penetrate the general illumination market in significant ways. Over the past four years, there have been ten-fold improvements in cost and performance in some classes of equipment. Advanced capabilities of LED systems have spawned innovative product design and have made new realms of adaptive lighting control possible. Several organizations are forecasting continued large improvements in cost, performance and industry size. In the meantime, performance metrics, testing standards, and application guidelines are just barely keeping up with the innovations.

This presentation will provide a brief background on key solid-state technology and industry trends that will have influence on the Council's Seventh Power Plan lighting load forecasts and remaining conservation potential assessment. Supply curves for achievable conservation will be developed for the Seventh Plan later, as data on cost and performance are collected.

851 S.W. Sixth Avenue, Suite 1100
Portland, Oregon 97204-1348
www.nwcouncil.org

Steve Crow
Executive Director

503-222-5161
800-452-5161
Fax: 503-820-2370

The State of Solid State Lighting

September 2013 Council Meeting
Coeur d'Alene, Idaho

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Outline

- Physics
- What Has Happened Since Sixth Plan
- Emerging Technology and Markets
- Initiatives: USDOE, Market, Utilities
- Issues for Seventh Plan
- Modern Applications & Innovations

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This is an Update

- Update on emerging new lighting technology
- Background for Seventh Plan
- Conservation potential will be developed later

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Special Thanks

- USDOE
- Pacific Northwest Labs (PNL)
- Dr. John Curran
- NEEA
- Design Lights Consortium

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Some Key Terms & Concepts

- Solid State Lighting: Semi-conductor based diodes that produce light (LED and OLED)
- Lumen: A measure of light output
- Efficacy: Light output per electric input
  - lumens per Watt or lm/Watt
  - Source Efficacy versus Luminaire Efficacy
- Key Components: diodes, LED package, optics, thermal management, driver, fixture, controls
- Color Metrics: CRI, CCT, R9, whites
- Lifetime Metrics:
  - LM-80: Test procedure to determine lumen depreciation
  - TM-21: Method to determine useful life

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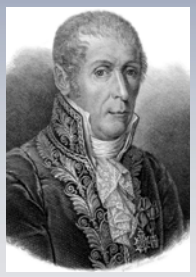
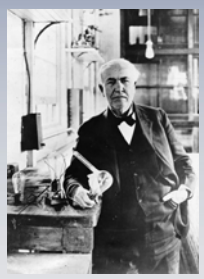
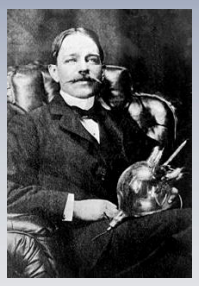
Electric Light Luminaries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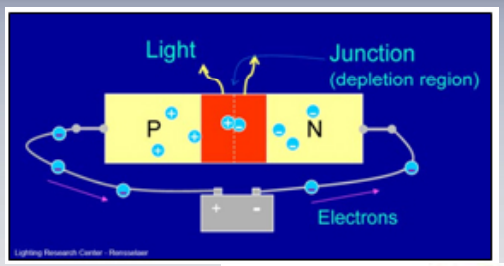
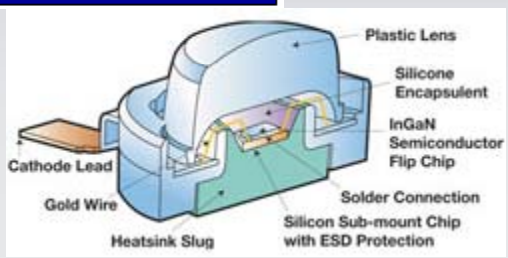
How It Works: Electricity to Photons & Heat





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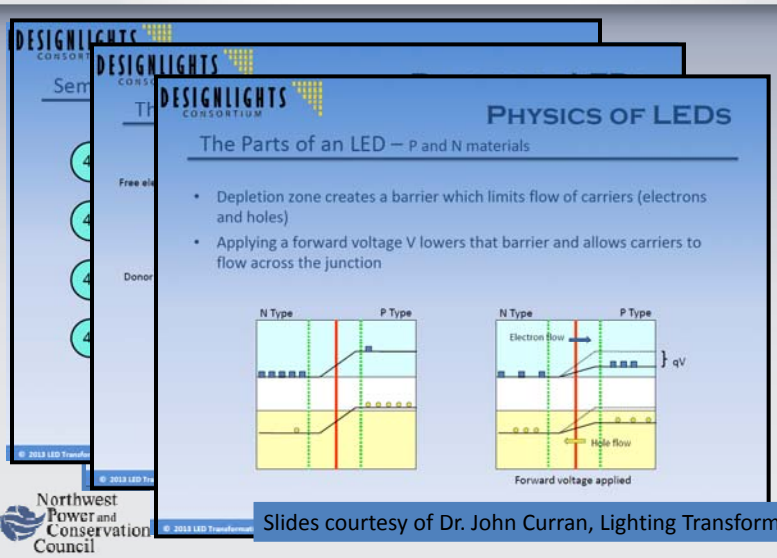
Detail of Electricity to Light in LED



Slides courtesy of Dr. John Curran, Lighting Transformations

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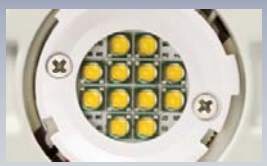
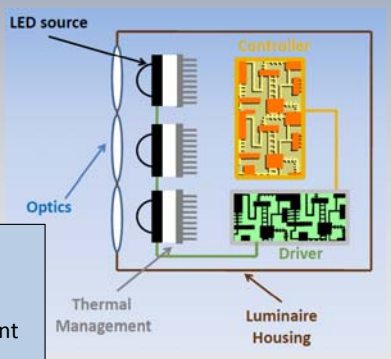
LED Modules combined to Arrays Modules to Products





- LED Modules are combined into LED Arrays
- LED Arrays plus optics produce useful light
- Thermal management removes heat
- Drivers convert power to proper voltage & current
- Controller for switching, dimming, color
- Luminaire puts it all together in a fixture

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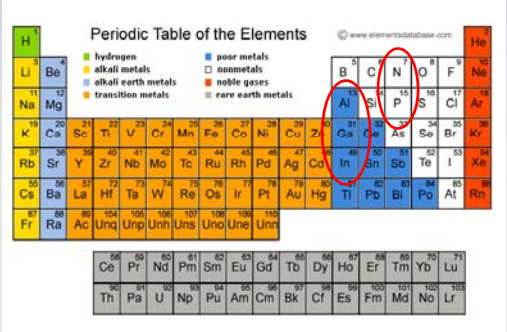
LED: All the colors of the rainbow - Except White

DOPING AGENTS FOR COLOR
Indium gallium nitride (InGaN) = Blue & Green
Gallium arsenide phosphide (GaAsP) = Red & Amber
Aluminium gallium phosphide (AlInGaP) = Red
Gallium phosphide (GaP)= Green



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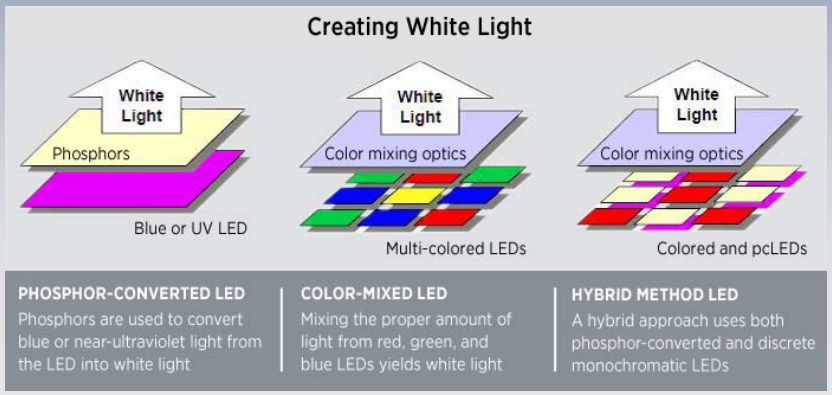
How to Get White Light



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Source: USDOE
http://www1.eere.energy.gov/buildings/ssl/sslbasics_ledbasics.html

How Are LED's Different?

- Physical & chemical properties
- Durability
- Size form factor
- Controllability
- Industry players
- Market dynamics

These differences have impact on energy efficiency potential.

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US Lighting Inventory

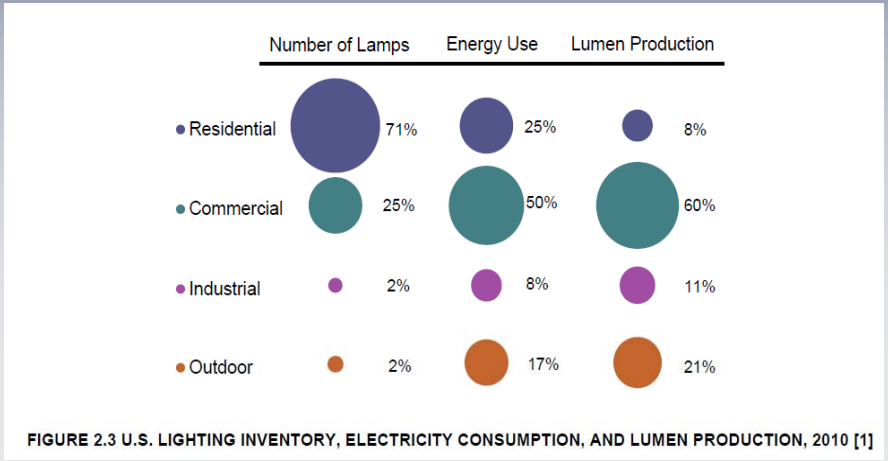

FIGURE 2.3 U.S. LIGHTING INVENTORY, ELECTRICITY CONSUMPTION, AND LUMEN PRODUCTION, 2010 [1]

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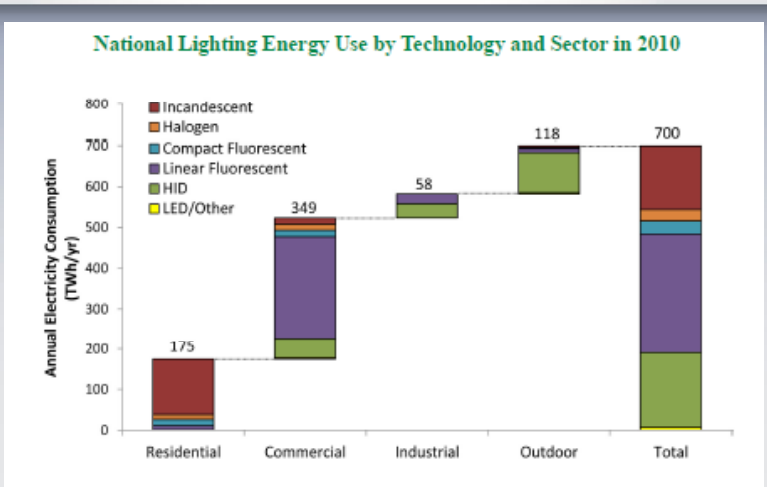
Source: Navigant Consulting, Inc., "2010 U.S. Lighting Market Characterization," U.S. Department of Energy, Washington, DC, 2012.

US Lighting Energy by Equipment Type



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Source: Navigant Consulting, Inc., "2010 U.S. Lighting Market Characterization," U.S. Department of Energy, Washington, DC, 2012.

Low LED Saturation 2012

Source: Multi-Year Program Plan, Solid-State Lighting Research and Development (USDOE April 2013)

TABLE 2.1 U.S. PREVALENCE OF LED SOURCES IN SELECT LIGHTING APPLICATIONS [20, 1

Application	Estimated LED Penetration of Installed Stock (%)[1]	
	2010	2012
A-Type	–	<1
Directional	<1	5
MR16	3	10
Decorative	–	<1
Downlight	<1	<1
Troffer	–	–
High-Bay	–	<1
Parking[2]	<1	1
Streetlight[2]	1	2

Notes:
1. Values less than 0.1% are considered negligible.
2. These estimates have been updated using data from the 2010 U.S. Lighting Market Characterization report.

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Pace of Change

Logarithmic Scale

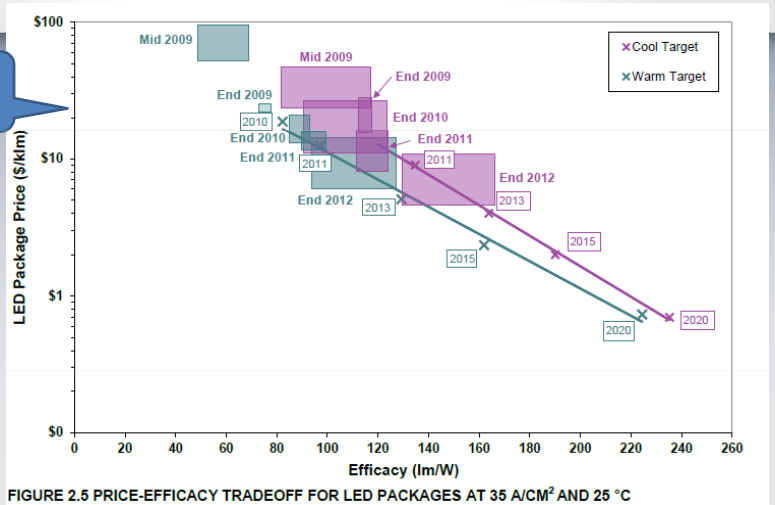

FIGURE 2.5 PRICE-EFFICACY TRADEOFF FOR LED PACKAGES AT 35 A/CM^2 AND 25 °C

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Source: Multi-Year Program Plan, Solid-State Lighting Research and Development (USDOE April 2013)

Relative Cost of Equipment - 2012

TABLE 2.2 COMPARISON OF TYPICAL MARKET PRICES FOR VARIOUS LIGHTING SOURCES

Lighting Source	Price ($/klm)
Halogen Lamp (A19 43W; 750 lumens)	$2.5
CFL (13W; 800 lumens)	$2
CFL (13W; 800 lumens dimmable)	$10
Fluorescent Lamp and Ballast System (F32T8)	$4
LED Lamp (A19 12W; 800 lumens dimmable)	$19
CFL 6" Downlight (13 W; T4; ~500 lumens)	$10
LED 6" Downlight (10.5 W; 575 lumens)	$50
OLED Panel	$800
OLED Luminaire	$2,400

Fixture/bulb cost only.

Does not include energy cost.

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Source: Multi-Year Program Plan, Solid-State Lighting Research and Development (USDOE April 2013)

Ten-fold Cost Decrease LED Module Next 8 Years?

TABLE 2.4 SUMMARY OF LED PACKAGE PRICE AND PERFORMANCE PROJECTIONS

Metric	2012	2013	2015	2020	Goal
Cool-White Efficacy (lm/W)	150	164	190	235	266
Cool-White Price ($/klm)	6	4	2	0.7	0.5
Warm-White Efficacy (lm/W)	113	129	162	224	266
Warm-White Price ($/klm)	7.9	5.1	2.3	0.7	0.5

Note: Projections for cool-white packages assume CCT=4746-7040 K and CRI >70, while projections for warm-white packages assume CCT=2580-3710 K and CRI >80. All efficacy projections assume that packages are measured at 25 °C with a drive current density of 35 A/cm^2.

Source: Multi-Year Program Plan, Solid-State Lighting Research and Development (USDOE April 2013)

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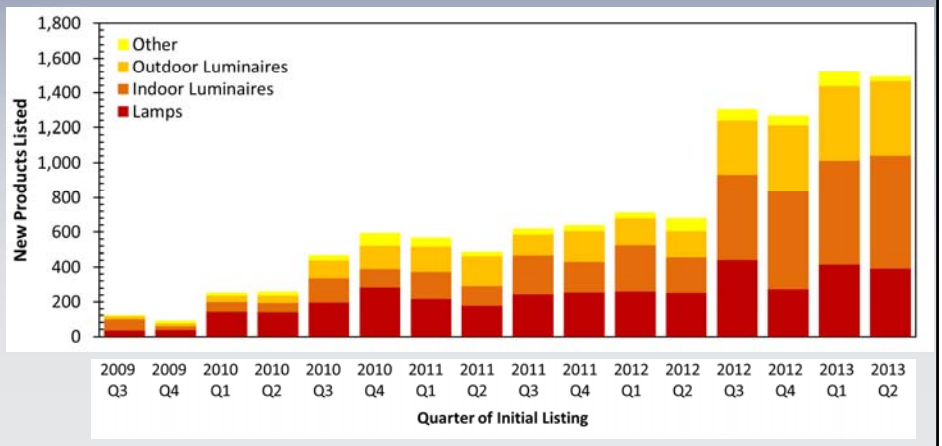
LED Product Count On the Rise



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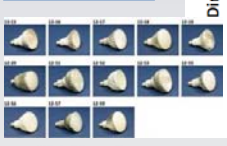
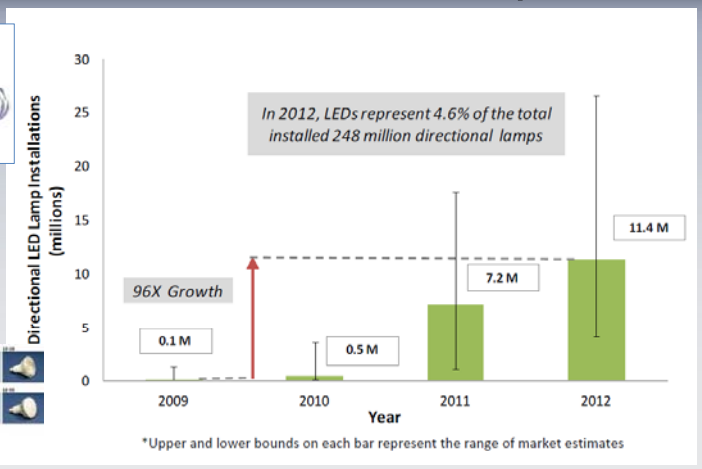
Source: DOE Lighting Facts Snap Shot July 2013

Higher US Saturation for LED Reflector Lamps





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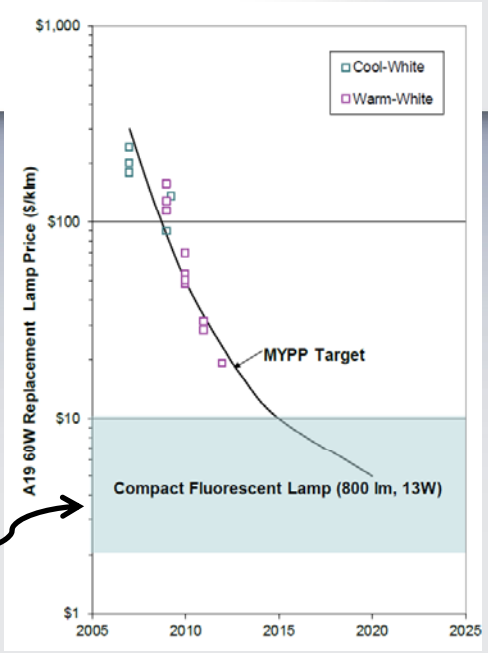
Source: DOE/EERE Adoption of Light-Emitting Diodes in Common Lighting Applications, April 2013, Revised May 2013

Bulb Cost Trends

FIGURE 2.6 A19 REPLACEMENT LAMP PRICE PROJECTION (60W EQUIVALENT)

Note: The shaded region illustrates the price range for a typical equivalent performance CFL (13W self-ballasted CFL, non-dimmable at bottom, and dimmable at top).

A halogen incandescent costs about $2.50/klm today.



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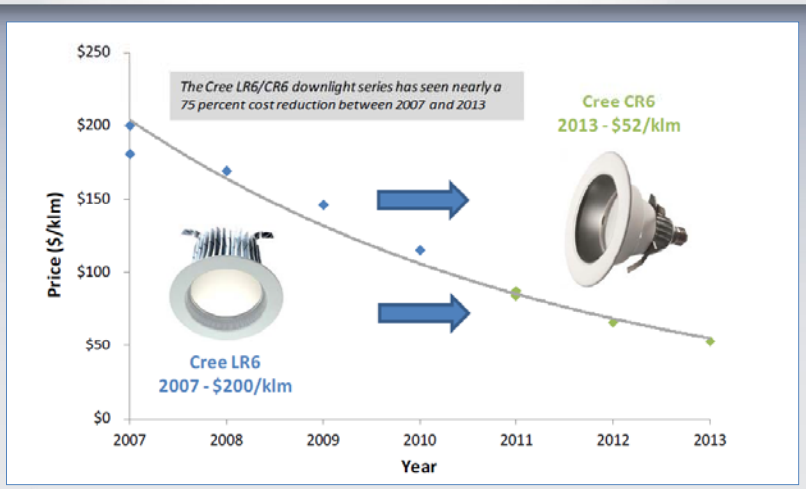
Downlight Cost Trends



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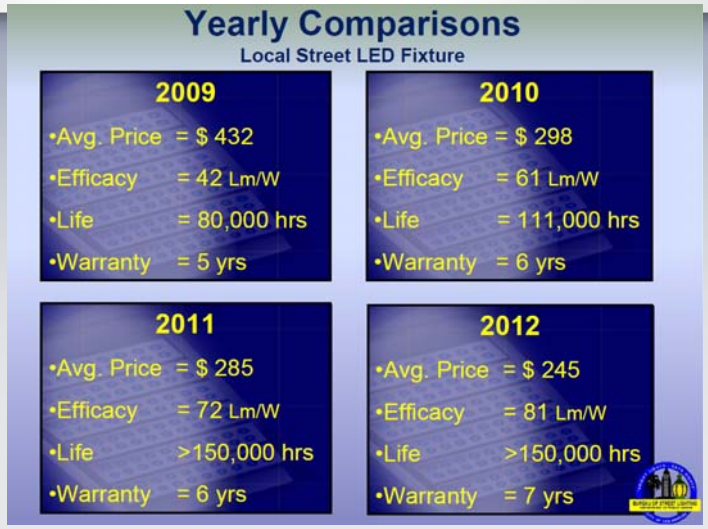
Streetlight Fixture Cost Trends

Source: City of Los Angeles, Bureau of Lighting



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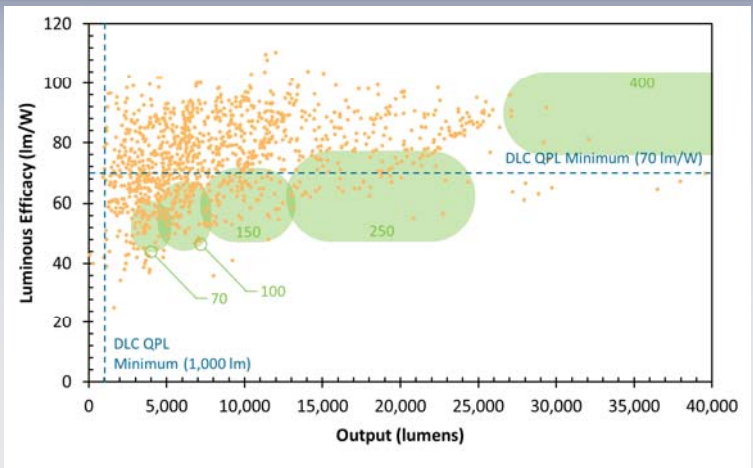
Most Outdoor LED Products in Lower Output Categories



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Source: DOE Lighting Facts Snap Shot July 2013

Pace of Change: Global

- US: Now at 1 to 3% of stock depending of application
- US: By 2020, USDOE expects LED market share to hit 38 percent of U.S. lumen-hour sales (or 28 percent of unit sales)
- China: Goal 30% LED by 2015
- Japan: High elec prices & Fukushima increasing LED sales from 9% in 2010 to forecast 30% of non HID at 2020

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New Industry Players: From Hi-Tech

Slides courtesy of Dr. John Curran, Lighting Transformations

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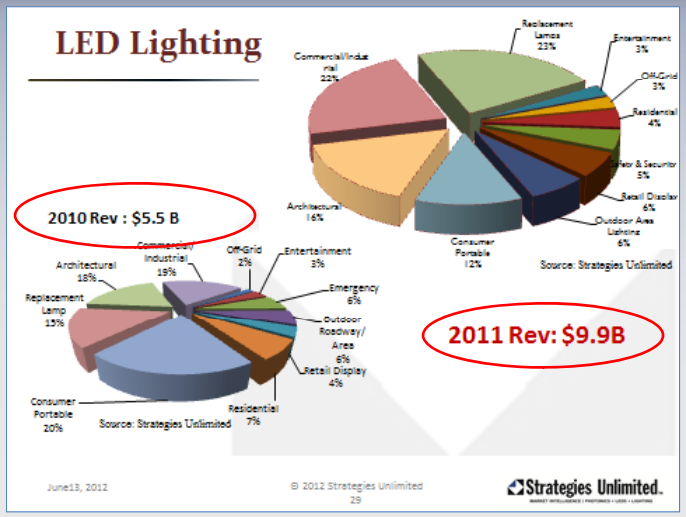
Industry Revenues Growing

Strategies Unlimited forecast industry revenue of $22 Billion by 2016



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Solid State Lighting Challenges

- Color Quality: CRI, CCT, R9
- Application performance:
  - Interchangeability, dimming functionality, form factor, output
- Lifetime:
  - Source life can be long, but luminaire life can vary
  - Failure modes not well understood: color shift, power supply, optics, solder joints
- Short Product Cycle
- Cost

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Congress to USDOE: Tremendous Potential in LED Technology

DOE: Let's avoid pitfall of CFL roll-out and market adoption. Work on all aspects of R&D, testing, product development & market development

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USDOE-Supported Initiatives

- Research & Development
- Testing (CALiPER)
- LED Lighting Facts (online product list)
- Technical Information Network
- Standards
- Design Competition (LPrize, Next Generation)
- Demonstrations (GATEWAY)
- Municipal Street Lighting Consortium

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Today's Research

- Improving phosphors
- Simplifying package design
  - Careful integration into fixtures: LEDs sensitive to thermal, optical & electrical design
- Tuning the color spectrum
- Addressing stability in output & color

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USDOE Research Money

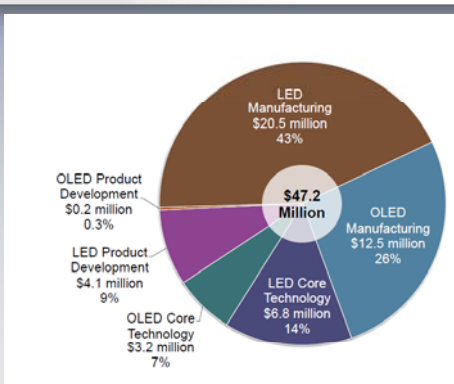

FIGURE 4.3 DOE SSL TOTAL PORTFOLIO SUMMARY, APRIL 2013

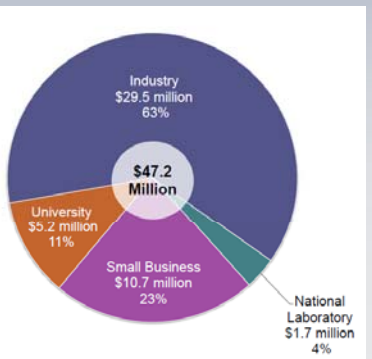

FIGURE 4.5 DOE SSL TOTAL PORTFOLIO SUMMARY BY RECIPIENT GROUP, APRIL 2013

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LED Testing Standards

- LM-79-08
  - test procedure for evaluating light distribution
- LM-80-08
  - test procedure for measuring lumen depreciation
- TM-21-11
  - method for determining "useful lifetime"
- ANSI C78.377-2008
  - binning structure to specify LED device colors

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Solid State Lighting Supply Curves

- How much savings available?
- At what cost?
- How soon?
- What will happen on its own?

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Sixth Power Plan Supply Curves

Measure Category	Total Potential 2030 (MWa)	Levelized Cost ($/MWh)
Traffic Signals	0 *	
Street & Roadway	44	$30-$250
Parking Lot & Garages	54	$40-$90
Outdoor Area Lighting	88	$30-$100
Signage	7	$30-$40
Grocery Cases	8	$50-$60
Commercial Downlights	tiny	$50-$600
Residential	0	

*Traffic signals was 8 MWa potential in 5th Plan. Assumed completed for Sixth Plan– Remaining potential in forecast

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What will be in Seventh Plan Supply Curves?

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Seventh Plan Starting Assumptions

- Baseline
  - Federal lamp & fixture standards OR Better
  - Example: In 2011, about 30% CFL in residential (CFLs are more efficient than federal standard)
- Stock Turn-Over
  - When lamps/fixtures burn out or are remodeled out, replacement lamps & fixtures are federal standard efficiency or better
- Frozen Efficiency Baseline
  - Replaced lamps/fixtures at today's efficiency levels

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Some Best-In-Class Efficacy Mid-2013

In Efficacy: LED products are challenging some Best-In-Class incumbent technologies. Some potential gains are big, others small.

But it's not all about efficacy:
- Cost
- Life
- Output
- Color
- Maintenance

Form Factor	Incumbent Technology	Best New Incumbent Efficacy (lm/Watt)	Best LED Efficacy (lm/Watt)
A-19 bulb	Halogen IR	30	94
A-19 bulb	CFL	70	94
PAR-38 bulb	Halogen IR	26	89
MR-16 Bulb	Halogen IR	20	77
Candelabra	Incandescent	10	80
Downlight	CFL	40	88
4-Foot Linear Pendant	Linear Fluor	90	119
2x2 Recessed Troffer	U-Bent Fluor	50	90
High Bay	Metal Halide	100	110
Streetlight	HPS	75	110

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Studies Forecast Significant Penetration of SSL

Table 7.10 Comparison of LED Forecast Model Results

Study	Units	Region	Market Share			
			2010	2011	2015	2020
DOE, 2011	Lumen-hours	U.S.	-	0.6%	10%	36%
Morgan Stanley, 2011	Lumen-hours	World	1%	-	15%	-
McKinsey, 2011	Units	World	1%	-	19%	46%
Stern Agee, 2010	Units	World	0.45%	-	13%	-
IMS Research, 2011	USD	World	10%	-	46%	50%
Cree, 2010	USD	World	5%	-	33%	75%
Philips, 2010	EUR	World	-	8%	50%	-

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USDOE: Forecast Big Savings

Source: *Energy Savings Potential of Solid-State Lighting in General Illumination Applications*, USDOE/EERE January 2012

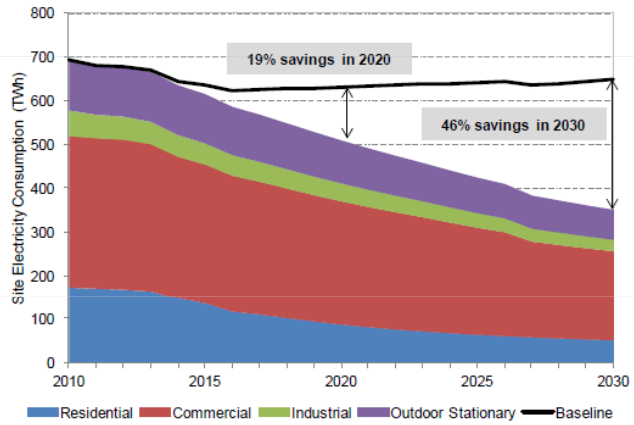

Figure 7.1 Total U.S. Lighting Energy Consumption Forecast, 2010 to 2030

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USDOE: Forecast Lumens by Source

Source: *Energy Savings Potential of Solid-State Lighting in General Illumination Applications*, USDOE/EERE January 2012

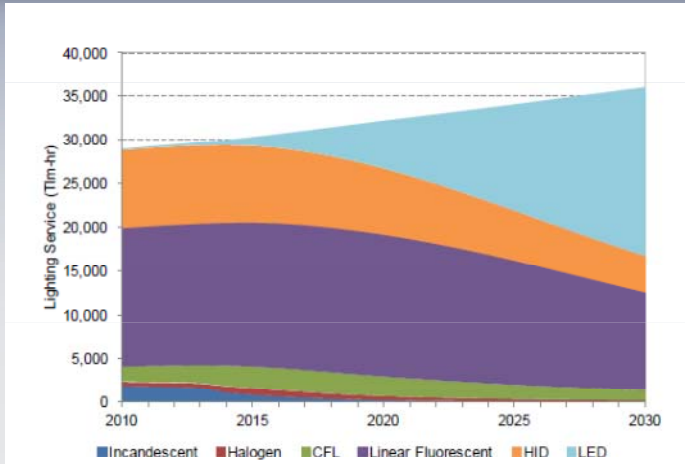

Figure 7.2 Total U.S. Lighting Service Forecast, 2010 to 2030

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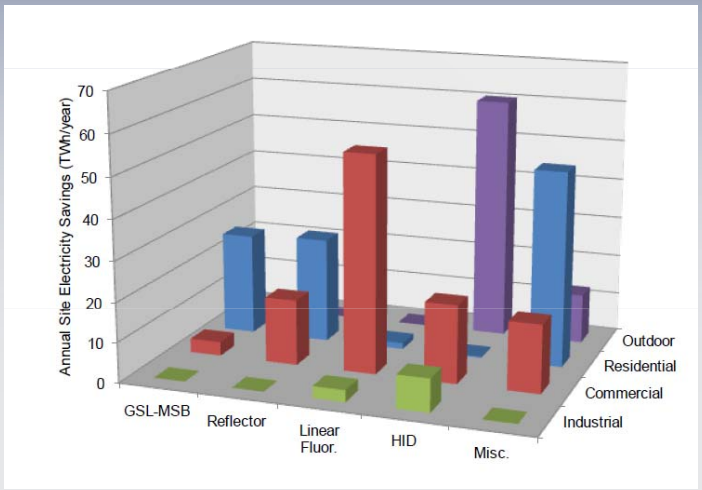
USDOE Forecast Inroads for SSL

Source: *Energy Savings Potential of Solid-State Lighting in General Illumination Applications*, USDOE/EERE January 2012



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USDOE Forecast Outdoor Lighting

Table 7.9 Outdoor Stationary HID Energy Savings Results

	2010	2015	2020	2025	2030	Cumulative (2010-2030)
Baseline site electricity consumption (TWh)	98	101	109	115	121	2,274
LED market share (% of lm-hr)	-	29.3%	65.3%	82.7%	87.8%	-
Site electricity savings (TWh)	-	5	23	44	60	532
Site electricity savings (%)	-	4.8%	20.8%	37.9%	50.0%	23.4%

Source: *Energy Savings Potential of Solid-State Lighting in General Illumination Applications*, USDOE/EERE January 2012

6P estimates of max penetration:
30% by 2015
85% by 2026

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PNW Utility Programs

- Traffic light conversion largely complete
- Niche applications moving from pilots to programs (grocery cases, directional)
- Outdoor lighting programs on the uptick
- Moving into general illumination as new products emerge (downlights, A-19, LF)
- Need for product selection/specification guidance

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Some Images of New LED Systems

- From USDOE Next Generation Luminaire

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Innovative Applications

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Innovative Applications

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Innovative Applications

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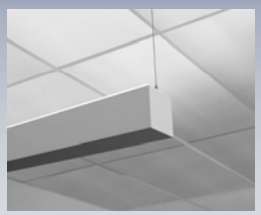
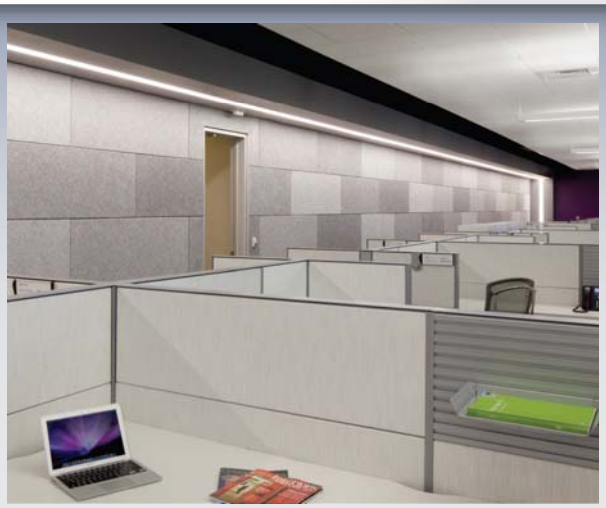
Innovative Applications





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Innovative Applications

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Innovative Optics

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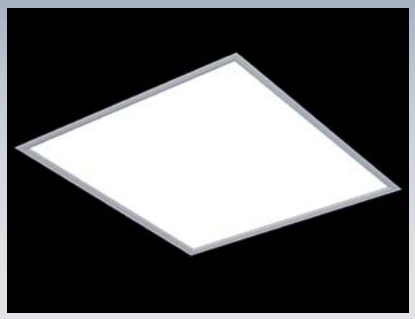
Slides courtesy of Dr. John Curran, Lighting Transformations

Innovative Applications



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Summary of Major Shifts

- Lighting used to be predictable well-understood technologies & markets & players
- Introduction of SSL has rocked the boat
  - Both technology & how we see artificial light
- Vast & speedy improvements in cost & efficacy
- Unprecedented cooperation between government, manufacturers, specifiers & business-sector users
- There is still a lot to learn
- Test methods and standards catching up

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Seventh Plan Issues

- Include forecast cost trends beyond 2015?
- Estimating pace of market uptake
- Near-term technology innovation
- Estimating old system turnover rates in face of new technology

Take these issues up at Conservation Resource Advisory Committee (CRAC)

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The End

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