



U.S. Department of Energy
Energy Efficiency and Renewable Energy

SSL Luminaire Performance in the Lab: Just How Well Do They Perform?



Mia Paget

Pacific Northwest National Laboratory

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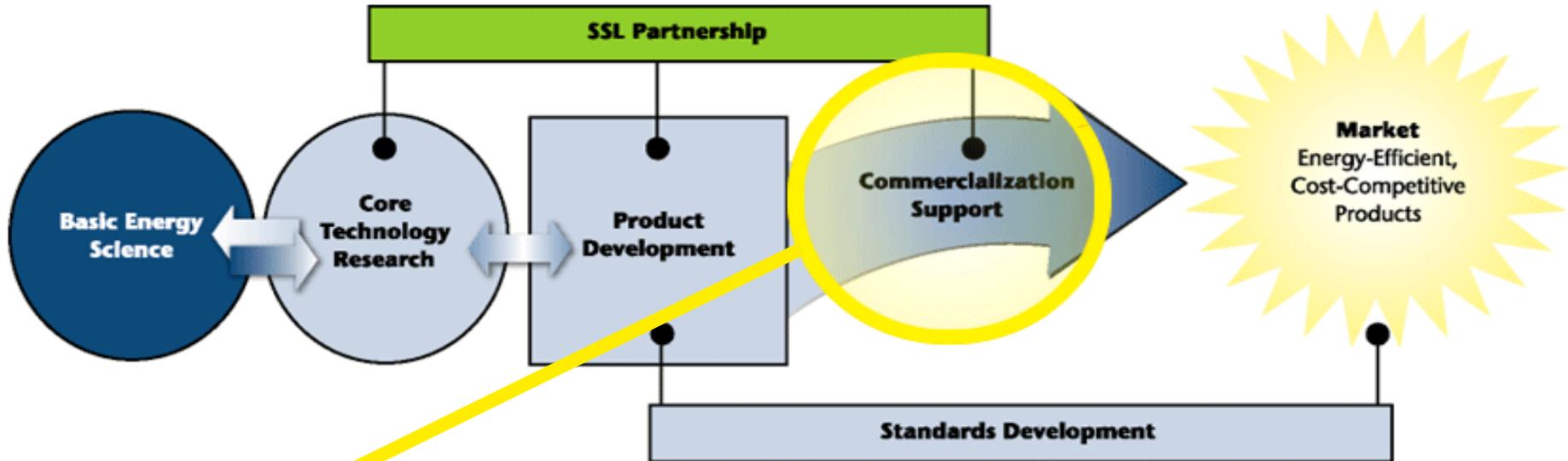


Today's Talk: CALiPER Program

- Context and purposes of CALiPER
- Testing program scope
- Testing methods & CALiPER process
- Progress to date
- Rounds 1-3 results
- Where to go for more info



DOE SOLID-STATE LIGHTING PORTFOLIO

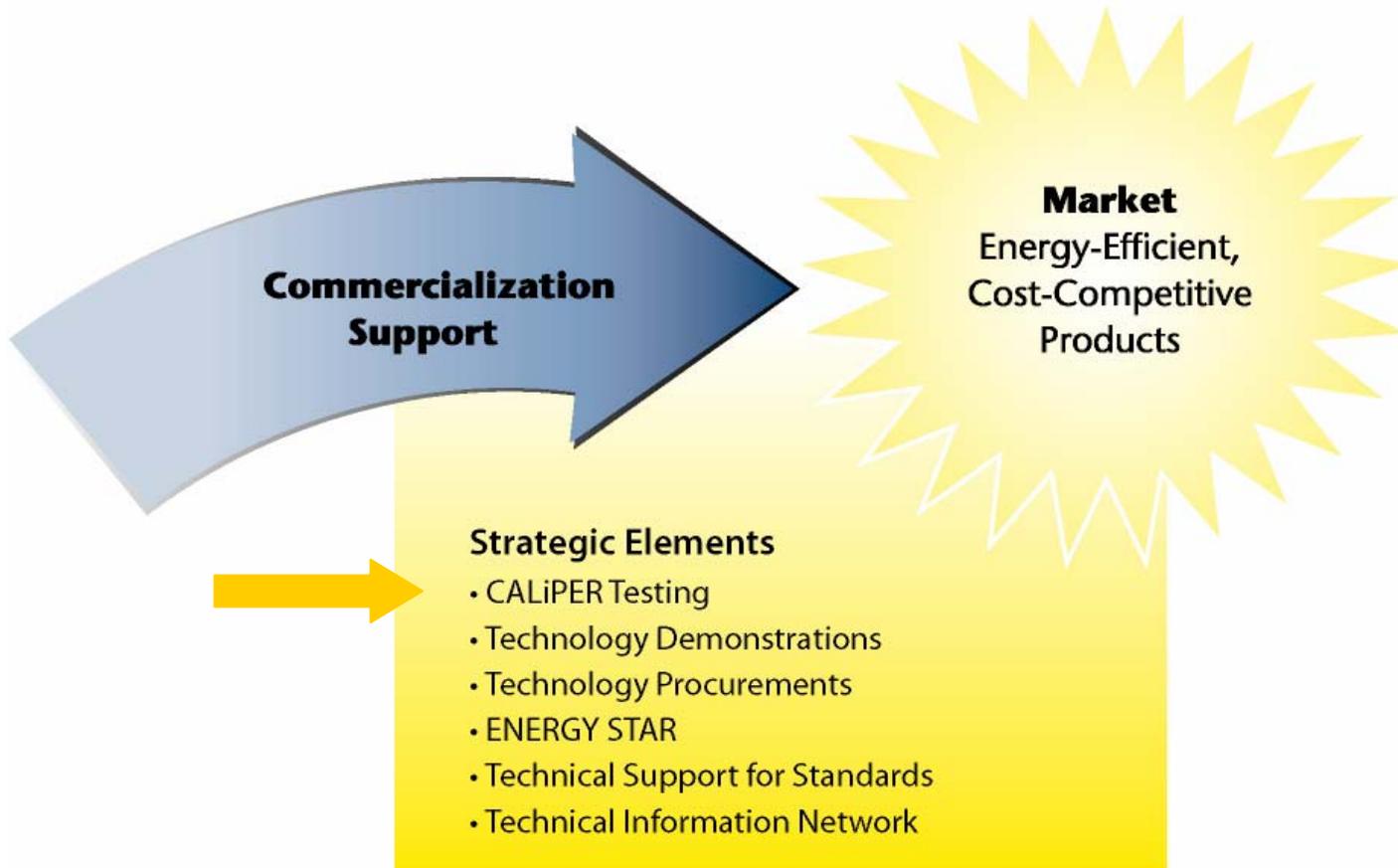


● *Guiding technology advances from laboratory to marketplace*

<http://www.netl.doe.gov/ssl/>



DOE SSL Pathways to Market





Purposes of CALiPER

- 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 risk due to buyer dissatisfaction from products that do not perform as claimed



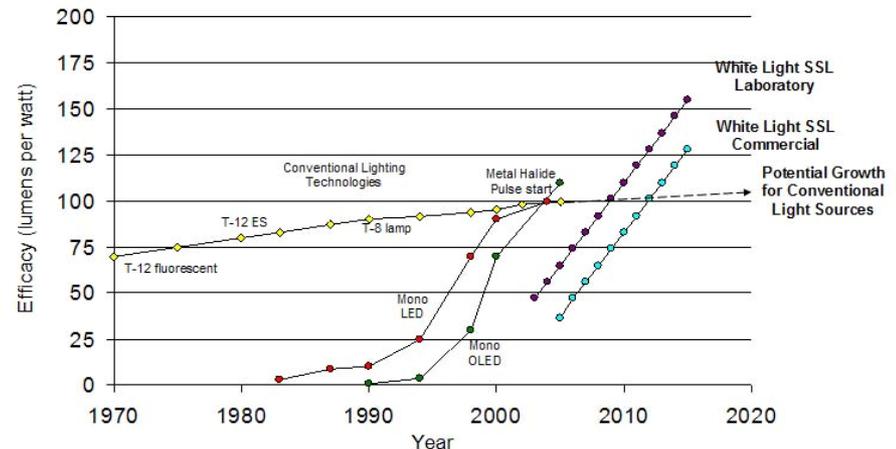
**YOU MAY NEVER CHANGE
ANOTHER LIGHT BULB**

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



Rapidly Changing SSL Technologies

- Steadily improving LED chips
- Better thermal performance
- Manufacturers are announcing new performance records almost every month
- Steady stream of new products
- Immature markets, limited understanding





CFL Lessons Learned

- Avoid same mistakes



Compact Fluorescent Lighting in America: Lessons Learned on the Way to Market

Prepared by
Pacific Northwest National Laboratory

for
U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Building Technologies Program

June 2006



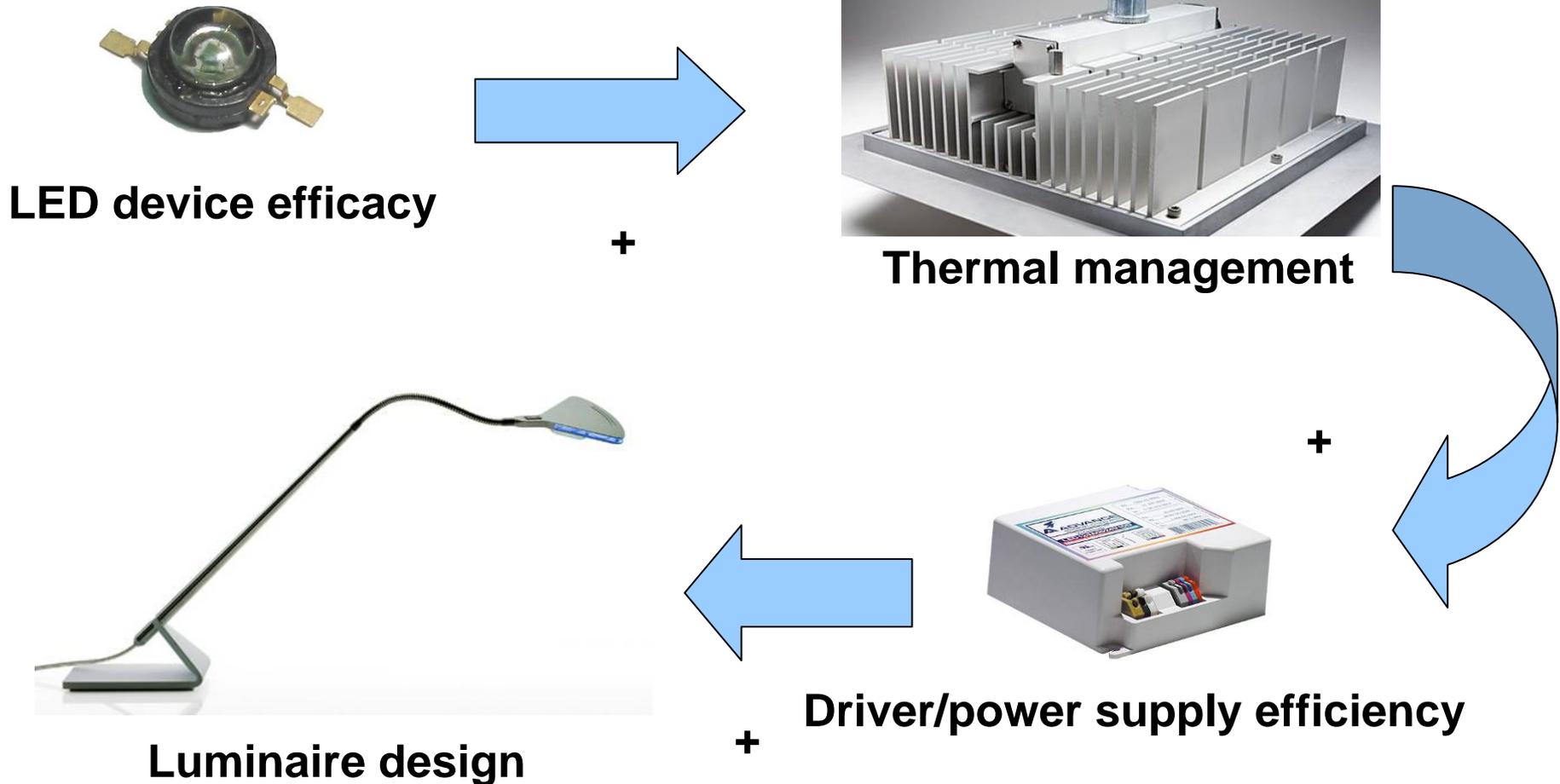


SSL Luminaire Testing

- Must measure luminaire as a complete system
- Uses 'absolute photometry' rather than 'relative photometry'
- Based on IESNA draft standard LM-79
 - Photometric testing methods under development
 - Stakeholders are not all familiar with these new testing paradigms
- DOE CALiPER Program contributing to
 - Standards development process
 - Increase confidence and understanding of SSL testing
 - 'Jump-start' knowledge of testing results

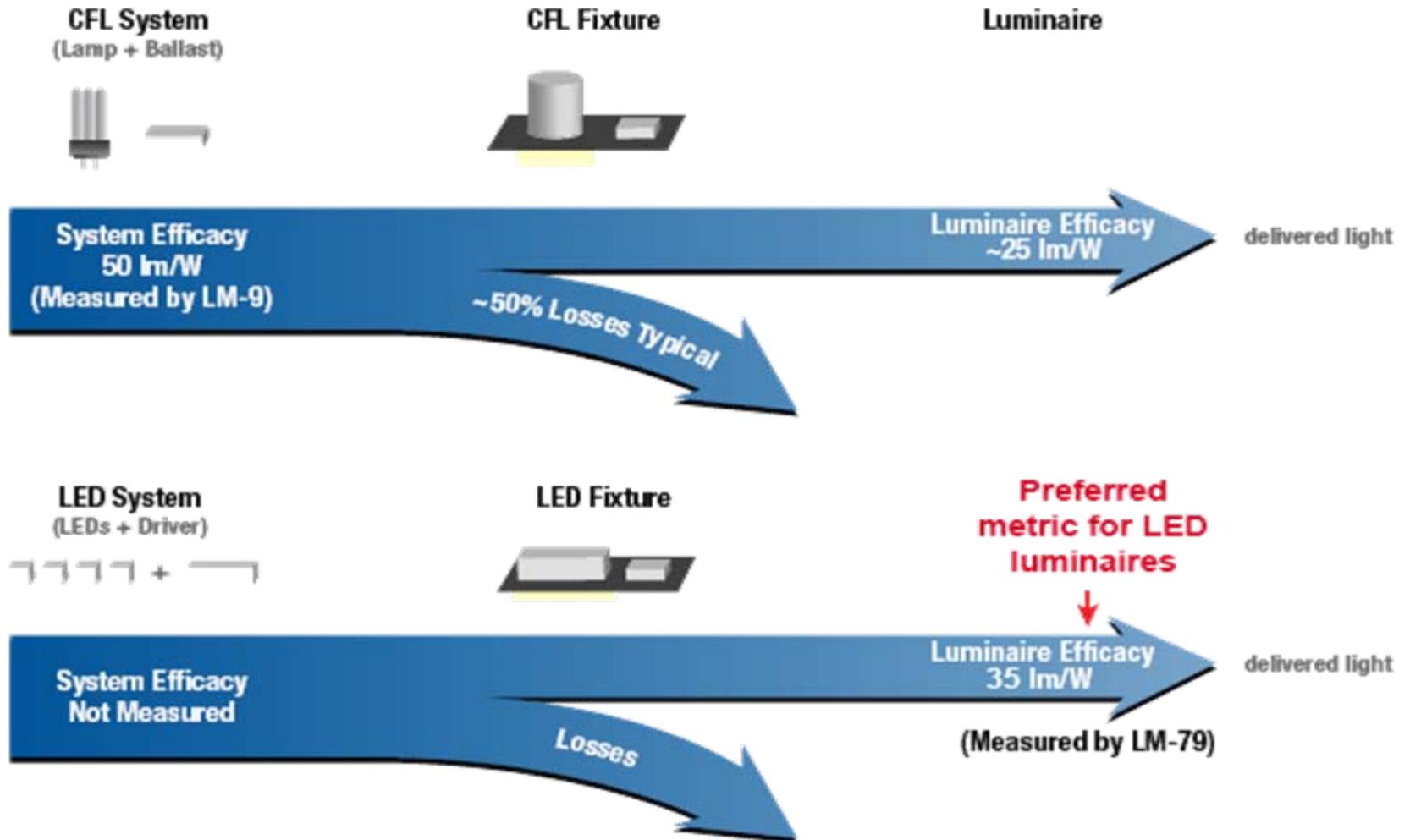


LED energy efficiency is a function of:





System Efficacy Vs. Luminaire Efficacy (Recessed Downlights Example)





Testing Program Scope

- Commercially-available SSL products for the general illumination market
 - Luminaires and replacement lamps (white light)
 - Indoor and outdoor
 - Residential and commercial





Types of CALiPER Testing

- Basic photometry (following IESNA LM-79 draft)
 - Integrating Sphere and Goniophotometry
 - Luminaire light output, efficacy
 - Color quantities (spectral power distribution, CCT, CRI)
 - Beam characteristics and intensity distributions
 - Electrical measurements, thermal characteristics
 - Benchmarking (other light sources)
- Other, non-standardized testing
 - “In Situ” Testing (relative measurements)
 - Environmental chamber
 - Insulated ceiling, recessed can
 - Lumen depreciation testing
 - Draws from IESNA LM-80 draft
 - Exploratory testing
 - Thermal imaging, dimming...

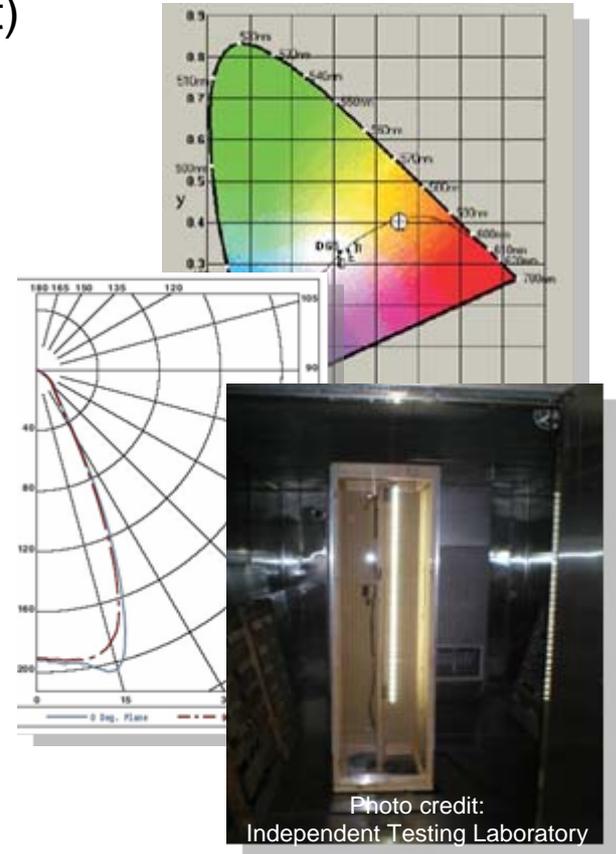


Photo credit:
Independent Testing Laboratory



Testing Program Process

- Quarterly product selection & acquisition
- Multiple independent test labs
- Assembly and analysis of results
 - Courtesy sharing of results with manufacturers
 - Retesting options
- Publication of results
 - Summary reports
 - Detailed test reports
 - Analyses and studies
- “No Commercial Use” Policy

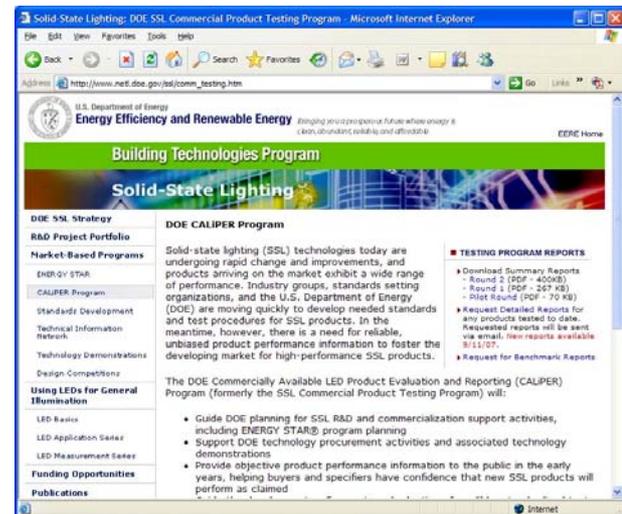


Photo credit: Luminaire Testing Laboratory



Progress to Date

- Quarterly rounds of testing
 - Started late 2006
 - Selection → Acquisition → Testing → Analysis → Reports
- Current Status
 - Rounds 1-3 completed
 - Round 4 testing underway
 - Round 5 pre-selection





Testing Rounds 1-3 Results

- 50+ products tested
- Focus: overall luminaire performance
- Wide range in products & results
- Small sample size, more testing Round 4

The image shows two overlapping document pages. The top page is a 'DOE SSL Commercial Product Test Report' cover. It features a blue header with the DOE logo and the text 'DOE SSL Commercial Product Test Report'. Below the header, it lists 'DC Product Test Ref', 'DOE TEST REPORT 06-05-', 'Product Category', 'Product Description', 'Date of Test(s)', 'CPTP 06-05-01 spectra', 'CPTP 06-05-02 points', 'Laboratory Performing Testing', 'Tests Performed', 'Total Luminaire Light Output', and 'Luminaire Efficacy'. A 'Product Photo' section shows a photograph of a luminaire. The bottom page is a 'Summary of Results: Round 1 of Product Testing' document. It has a white background with black text. The title is 'DOE Solid-State Lighting Commercial Product Testing Program Summary of Results: Round 1 of Product Testing'. It is dated 'U.S. Department of Energy UPDATE - March 2007'. At the bottom, it includes the 'Building Technologies Program Energy Efficiency and Renewable Energy U.S. Department of Energy' logo and a circular seal. A grid pattern is visible at the bottom of the summary page.



CALiPER Results: Downlights

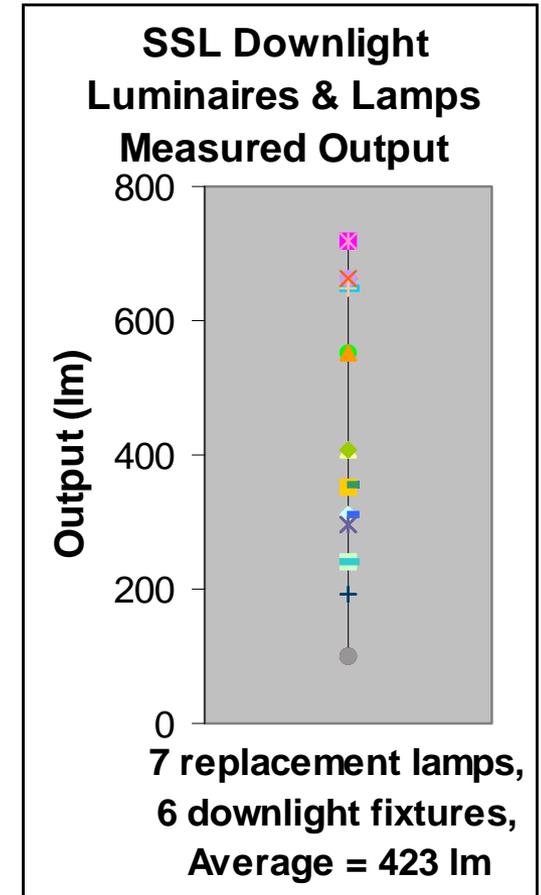
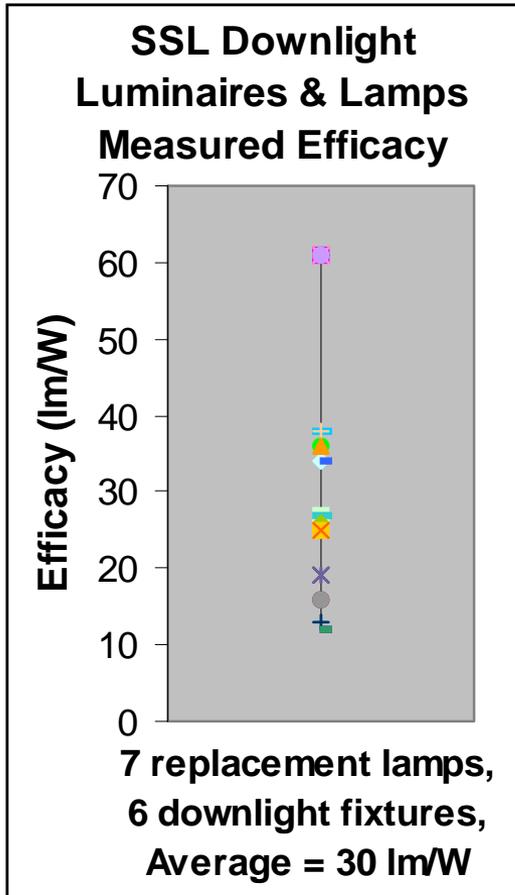
SSL DOWNLIGHTS					
CALiPER Reference	<i>Manufacturer Published Output or Efficacy</i>	Output (lumens)	Efficacy (lm/W)	Correlated Color Temp. (K)	Color Rendering Index
Directional Replacement Lamps Suitable for Downlights					
07-31, Warm White Retrofit	<i>650 lm</i>	719	61	2754	95
07-47, Soft White Retrofit	<i>650 lm</i>	663	61	3402	91
07-19, Warm White Par30	<i>990 lm</i>	650	38	2854	52
07-09, Cold White R30	<i>500 lm</i>	310	34	5973	82
07-08, Warm White R30	<i>400 lm</i>	239	27	2945	72
07-13, Warm White R30	<i>400 lm</i>	406	26	2689	14 (RGB)
07-14, Cool White R30	<i>400 lm</i>	352	25	4006	13 (RGB)
Downlights (Complete Luminaires)					
07-35, Soft White Downlight	<i>40 lm/W</i>	553	36	3442	81
07-05, Cool White Downlight	<i>642 lm</i>	662	25	4402	76
06-03, Warm White Downlight	<i>45 lm/W</i>	298	19	2724	67
07-42, Warm White Downlight	<i>42 lm/W</i>	101	16	2719	66
06-01, Warm White Downlight	<i>40 lm/W</i>	193	13	3012	70
07-04, Cold White Downlight	<i>477 lm</i>	357	12	5964	76



CALiPER Results: Downlights

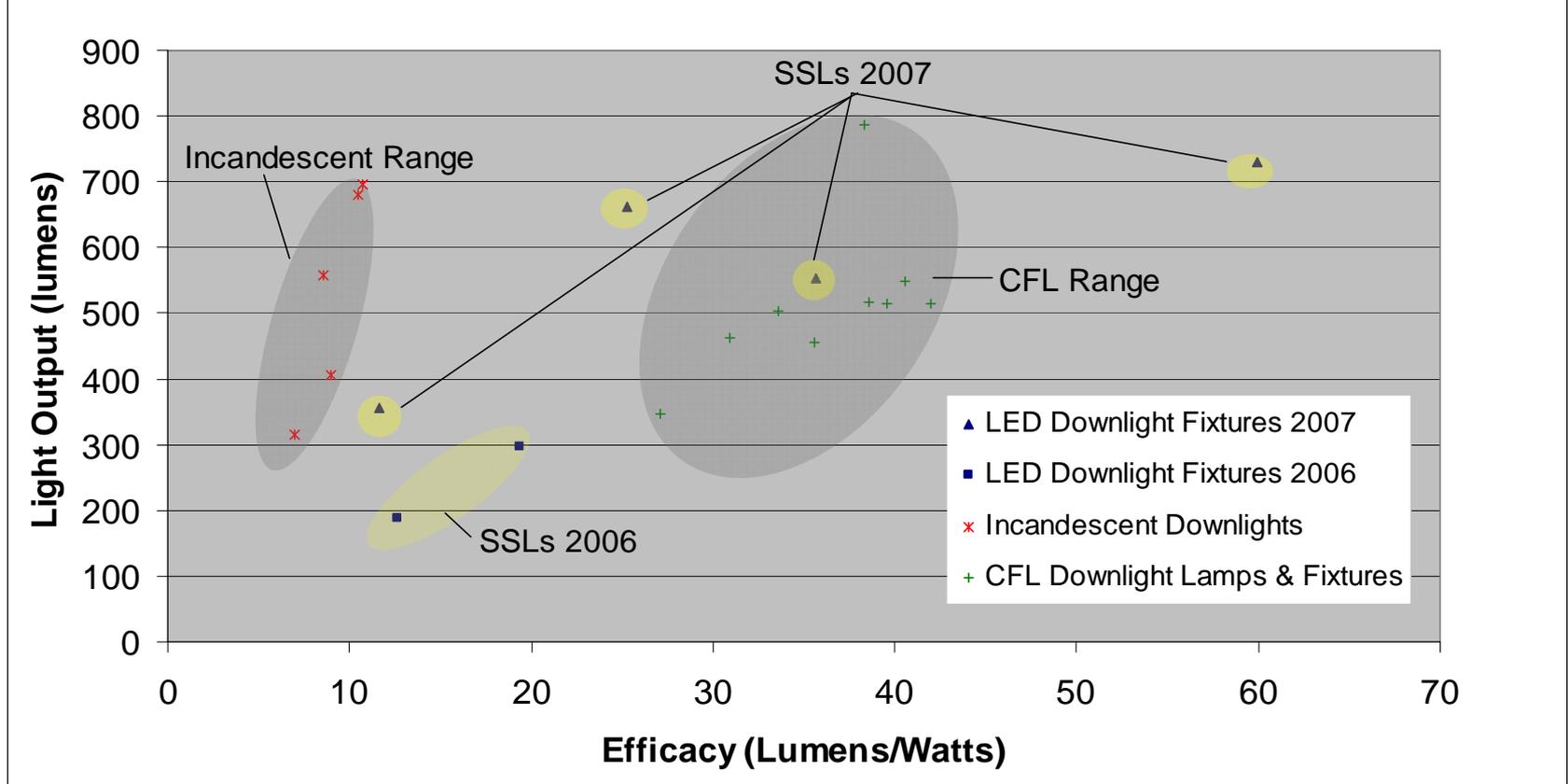
Key Points

- Best luminaire efficacy = 60 lm/W
- Worst = 12 lm/W
- Top half comparable to CFLs
- Manufacturer literature
 - Almost half provide accurate information (within 15% measured)
 - More than half provide imprecise information (on average 70% overstated)





Benchmarking for Downlight Comparisons



* Values for LED downlights are from CALiPER testing.

** Values for CFL and incandescents are assembled from CALiPER testing, earlier photometric testing and product catalogs.

*** A fixture efficiency of 0.9 is applied to all replacement lamps unless tested inside a fixture.



CALiPER Results: Task

- Undercabinets and desk lamps tested
 - 5 SSL undercabinets, 8 SSL desk lamps
 - 2 fluorescent tube undercabinets, 1 CFL luminaire
 - 1 halogen desk lamp
- ~5 SSL products show comparable or better efficacy than fluorescent
- Most would be better than halogen, but many consume off-state power

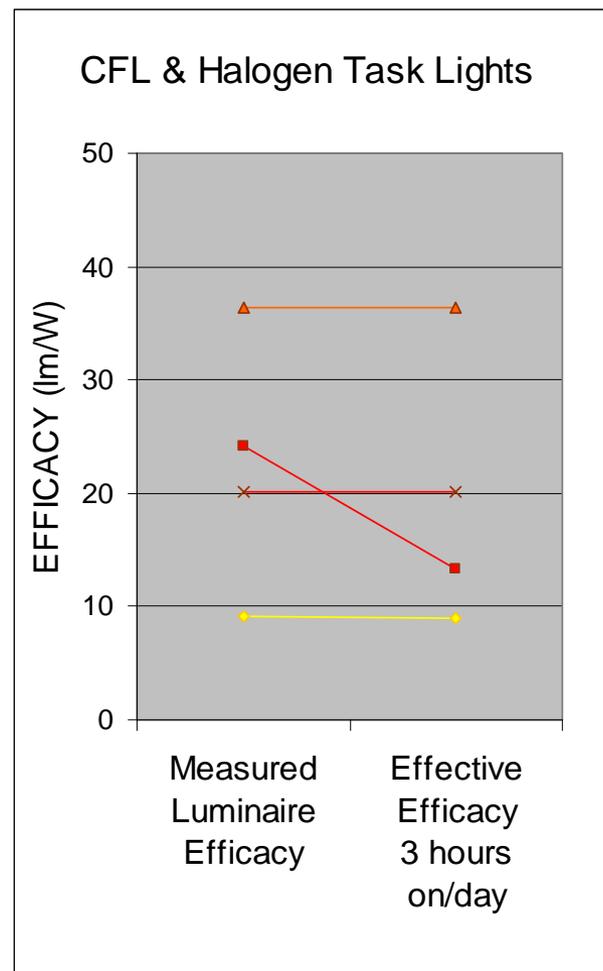
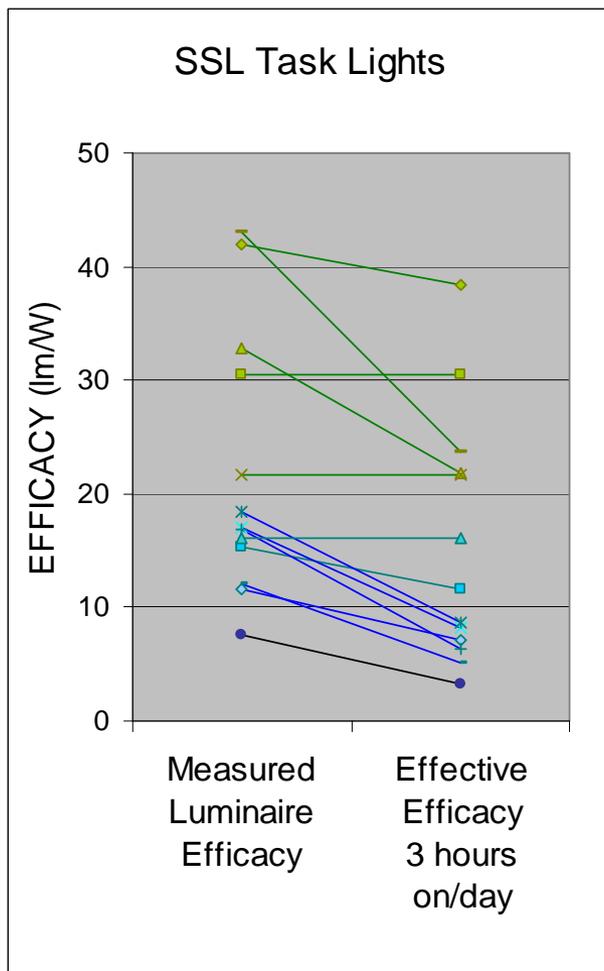
<i>SSL task lights</i>	<i>from</i>		<i>to</i>
Power	4.4 W	↔	21 W
Output	75 lm	↔	430 lm
Efficacy	8 lm/W	↔	43 lm/W
CCT	2700	↔	>7000
CRI	70	↔	85



Off-State Power Concern

Undercabinet and Desk Lights with On/Off Switches

- Off-state power use ranges from 0 W to 2.6 W, reducing efficacy





Direct Comparisons

Same desk/task light, two different sources

Example Luminaire 1	CFL	LED
Luminaire Output (lm)	236	226
Luminaire Efficacy (lm/W)	24.2	18.4
CCT	3432	5939
CRI	79	74
Power Factor	0.54	0.92

Example Luminaire 2	Halogen	LED
Luminaire Output (lm)	351	157
Luminaire Efficacy (lm/W)	9.2	12
CCT	2856	3204
CRI	99.5	74
Power Factor	1.0	0.79



CALiPER Results: Outdoor

SSL Outdoor Lights					
	<i>Manufacturer Published Output or Efficacy</i>	Output (lumens)	Luminaire Efficacy (lm/W)	Correlated Color Temp. (K)	Color Rendering Index
Outdoor Area					
07-26, Area	<i>59 lm/W</i>	9808	52	--	--
06-05, Area	<i>24 lm/W</i>	2638	24	4661	<i>20 (RGB)</i>
Outdoor Parking					
07-24, Parking	<i>59 lm/W</i>	6272	54	5948	76
Outdoor Wall					
07-25, Wall	<i>59 lm/W</i>	3758	53	6145	77
07-34, Wall	<i>40 lm/W</i>	124	27	3270	70
07-01, Wall	--	92	16	2693	68
Outdoor Path					
07-37, Path	--	24	6	3792	77



More Examples of Results

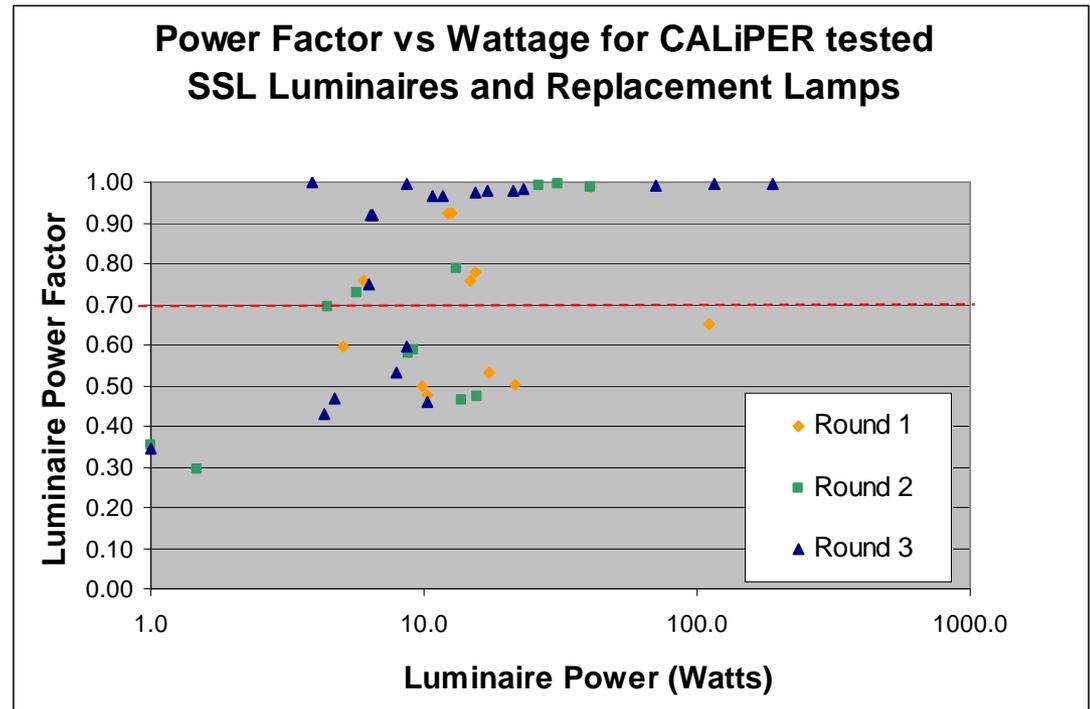
SSL Various Applications					
	<i>Manufacturer Published Output or Efficacy</i>	Output (lumens)	Luminaire Efficacy (lm/W)	Correlated Color Temp. (K)	Color Rendering Index
Refrigerated Display Case					
07-07	<i>31 lm/W</i>	1237	30	5261	70
Surface Mount					
06-06	<i>55 lm/W</i>	964	24	3410	75
Step/Wall					
06-07	--	25	4	2854	70
Non-Directional Replacement Lamps					
07-23*	<i>31.5 lm/W</i>	33	48	3099	70
07-06	<i>22 lm/W</i>	10	16	3161	70
07-12	--	20	13	25263	79

* 07-23 is a manufacturer retest of the next generation of product tested in 07-06



Testing Results: Power Factors

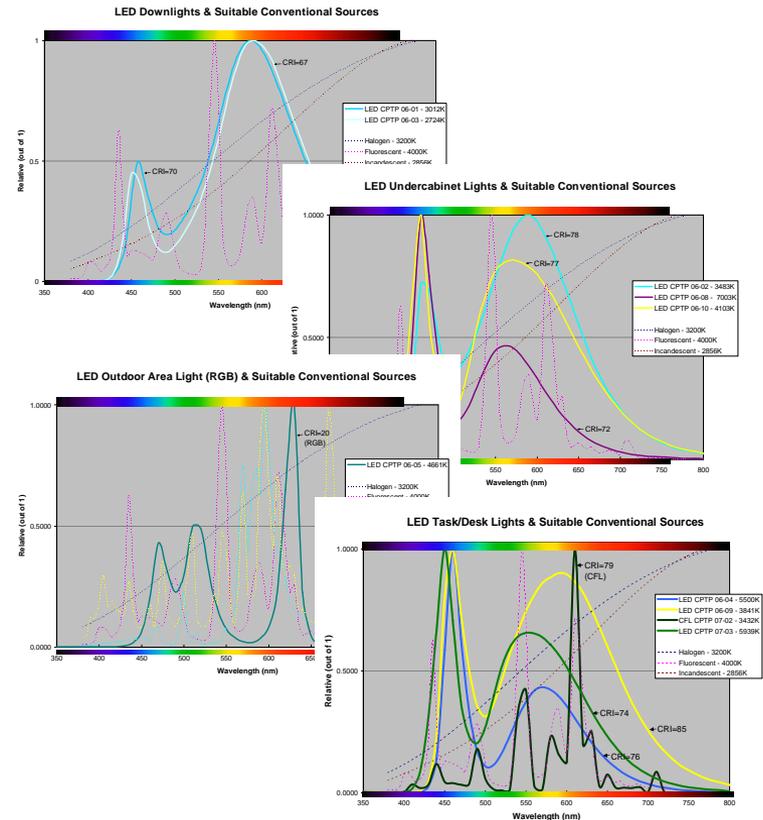
- Range of values
 - 0.3 to 1.0
- Small sample size for now
 - Small PF/power correlation
 - Small PF/efficacy correlation





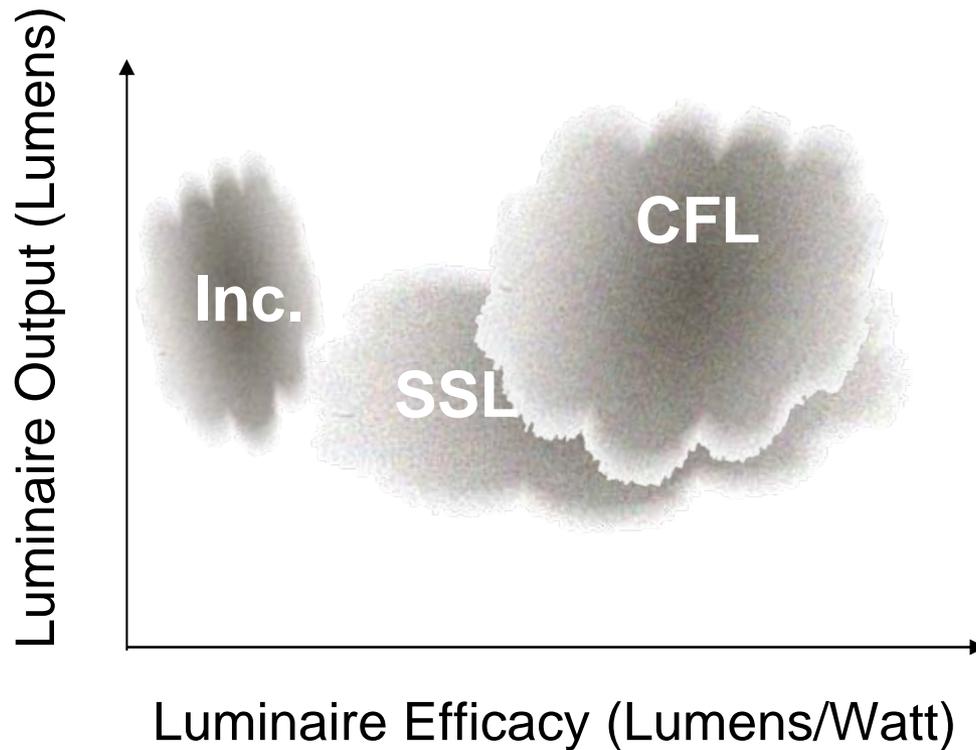
Round 1-3 Results: Color Qualities

- Range of color qualities
 - CCT range: 2600 K to 36000 K
 - Phosphor-conversion LEDs CRI range: 51-95
 - Three RGB luminaires tested





Energy Use and Light Output



General Observations

- Luminaire Outputs: comparable for some applications
 - Undercabinets
 - Desk/Task
 - Downlights
- Luminaire Efficacies
 - SSL surpasses incandescent
 - SSL \rightarrow $\frac{1}{2}$ CFL to surpassing CFL
- Caution:
 - Wide differences \rightarrow DO NOT generalize
 - SSL evolving
 - More benchmarking
 - Continue testing



CALiPER Rounds 1-3 Range of Results

- Tests include a wide range of products
- Results show a very wide range of performance

	<i>from</i>		<i>to</i>
Power	0.6 W	↔	189 W
Output	10 lm	↔	6272 lm
Efficacy	4 lm/W	↔	62 lm/W
CCT	2600	↔	>7000
CRI	<50	↔	95



Be careful not to generalize!



Rounds 1-3 Key Conclusions

- Product literature not always consistent, not always reliable
 - Be informed. [Request luminaire testing results.](#)
- CALiPER positive influences
 - Market/industry awareness & involvement
 - Testing standards validation & refinement

Round 1-3 products designed from 2005-2007, showing some now rival fluorescent (CFLs and small linear), and one product exceeds CFLs in luminaire output and efficacy



Great promise for upcoming generation of commercially available SSL luminaires



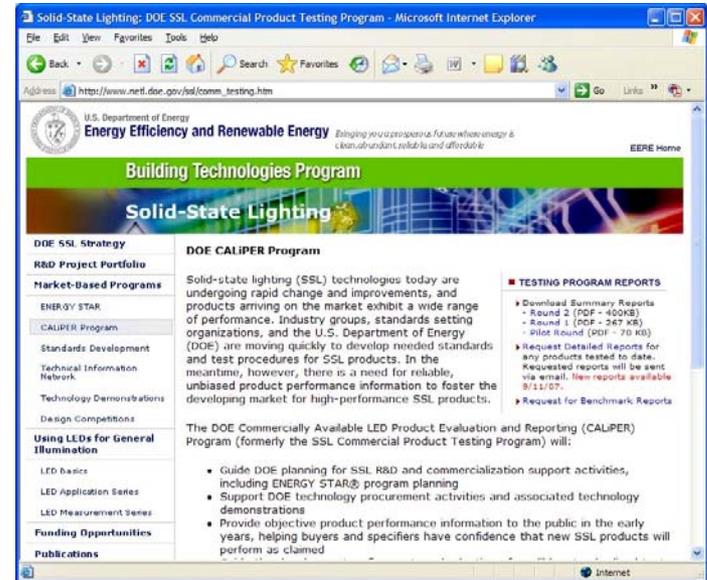
Be an Informed Buyer

- Bottom-line: understand and request SSL luminaire testing
- ENERGY STAR® for SSL is coming shortly
 - Effective date set for September 30, 2008
 - Products tested for:
 - Total luminous flux (light output) of luminaire
 - Luminaire efficacy
 - Correlated Color Temperature
 - Color Rendering Index
 - Intensity distributions
 - Steady State Module/Array Temperature
 - Maximum Power Supply Case/TMP Temperature



More Info on CALiPER

- Via website
 - Summary reports
 - Detailed reports
 - Must be requested via web form
 - Requestor's contact information must be provided
 - Must agree to adhere to 'No Commercial Use Policy'



http://www.netl.doe.gov/ssl/comm_testing.htm



No Commercial Use Policy

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