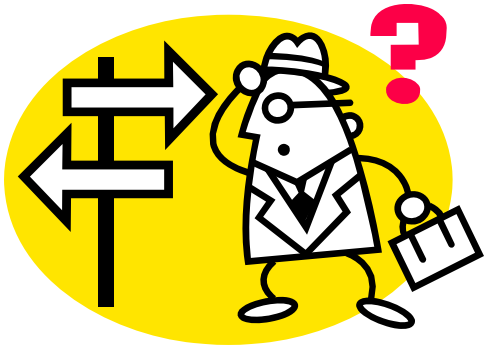
Status of LED Standards and Guidelines – And How Real Products are Measuring Up

Kelly Gordon

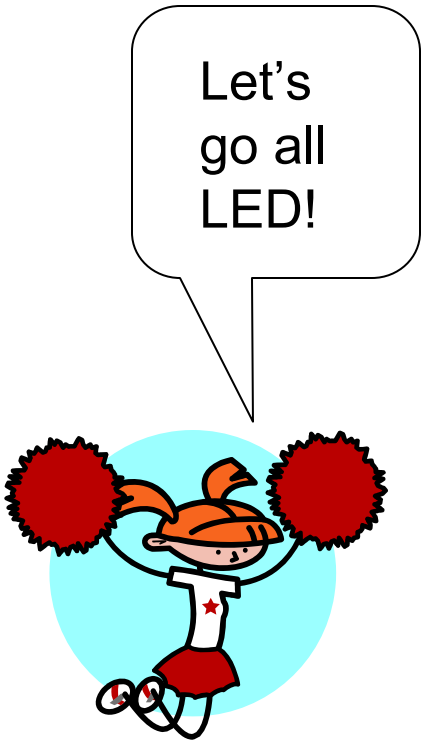
Pacific Northwest National Laboratory

April 1, 2009

What's the status of LEDs today?



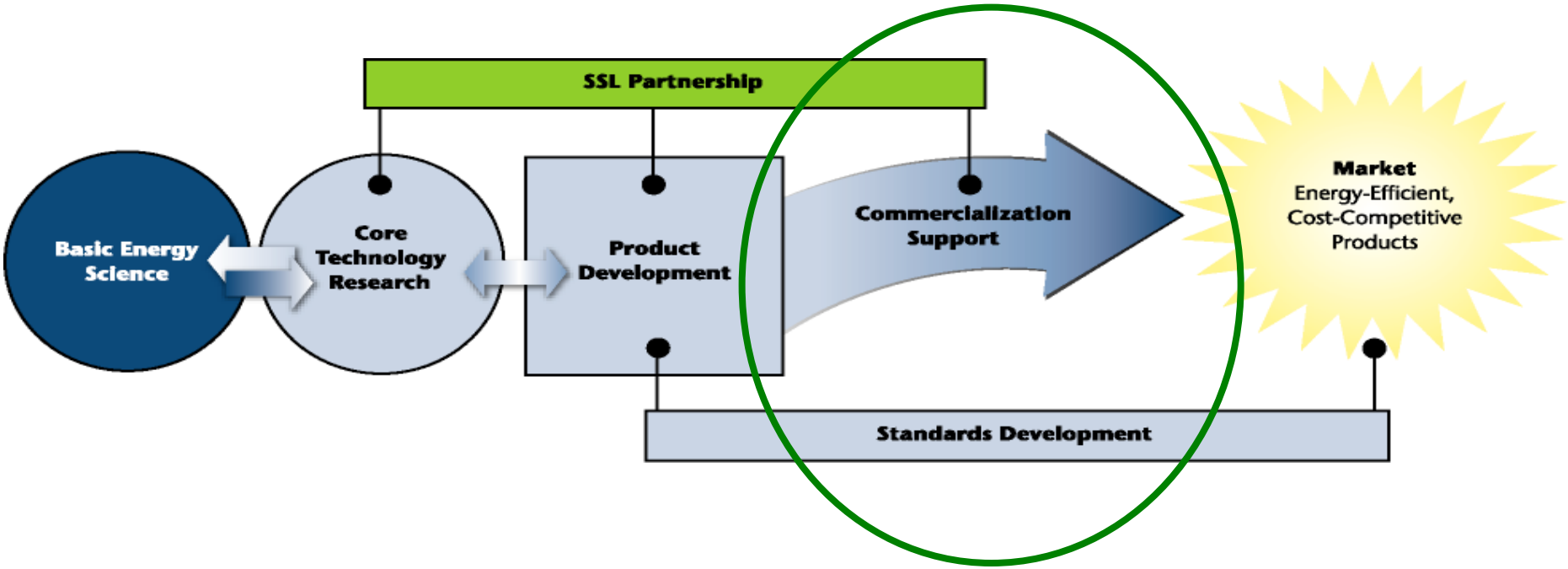
The truth is somewhere in between …



Today's Topics

- Standards and test procedures
- ENERGY STAR for SSL
- How are real products performing?
  - CALiPER testing results
  - GATEWAY demonstrations

DOE SSL Program Strategy



Guiding technology advances from laboratory to marketplace

GATEWAY DEMONSTRATIONS

ENERGY STAR

Technical Information Network

SSL Quality Advocates

NEXT GENERATION LUMINAIRES

L PRIZE™

LIGHTING for tomorrow

Retailer Energy Alliance

CALiPER

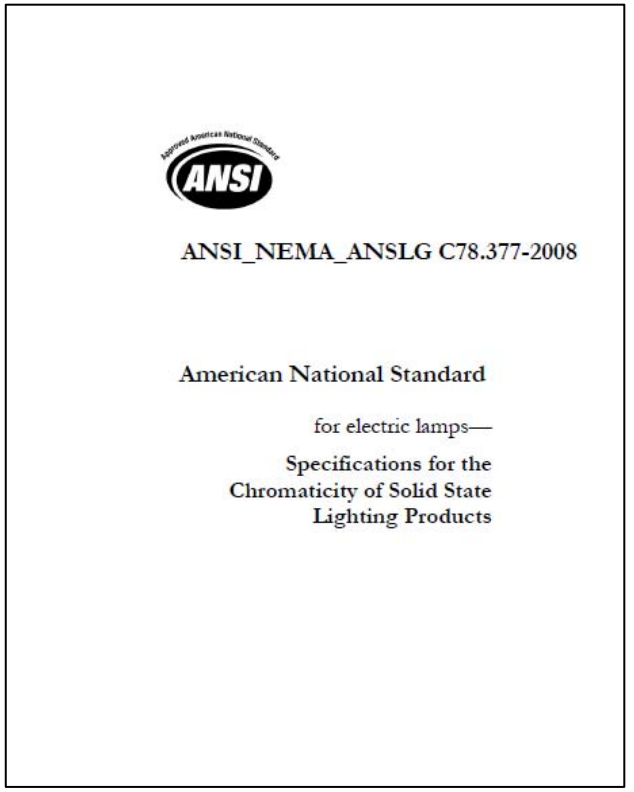
STANDARDS

Key Standards and Test Methods

- **ANSI C78.377-2008** *Specifications for the Chromaticity of SSL Products for Electric Lamps*
- **IESNA LM-79-2008** *Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products*
- **IESNA LM-80-2008** *Approved Method for Measuring Lumen Maintenance of LED Light Sources*

ANSI C78.377 Scope

- "…specify the range of chromaticities recommended for general lighting with solid state lighting (SSL) products…"
- "…LED-based SSL products with control electronics and heat sinks incorporated … those devices that require only AC mains power or a DC voltage power supply to operate…"
- "…covers fixtures incorporating light sources as well as integrated LED lamps…"

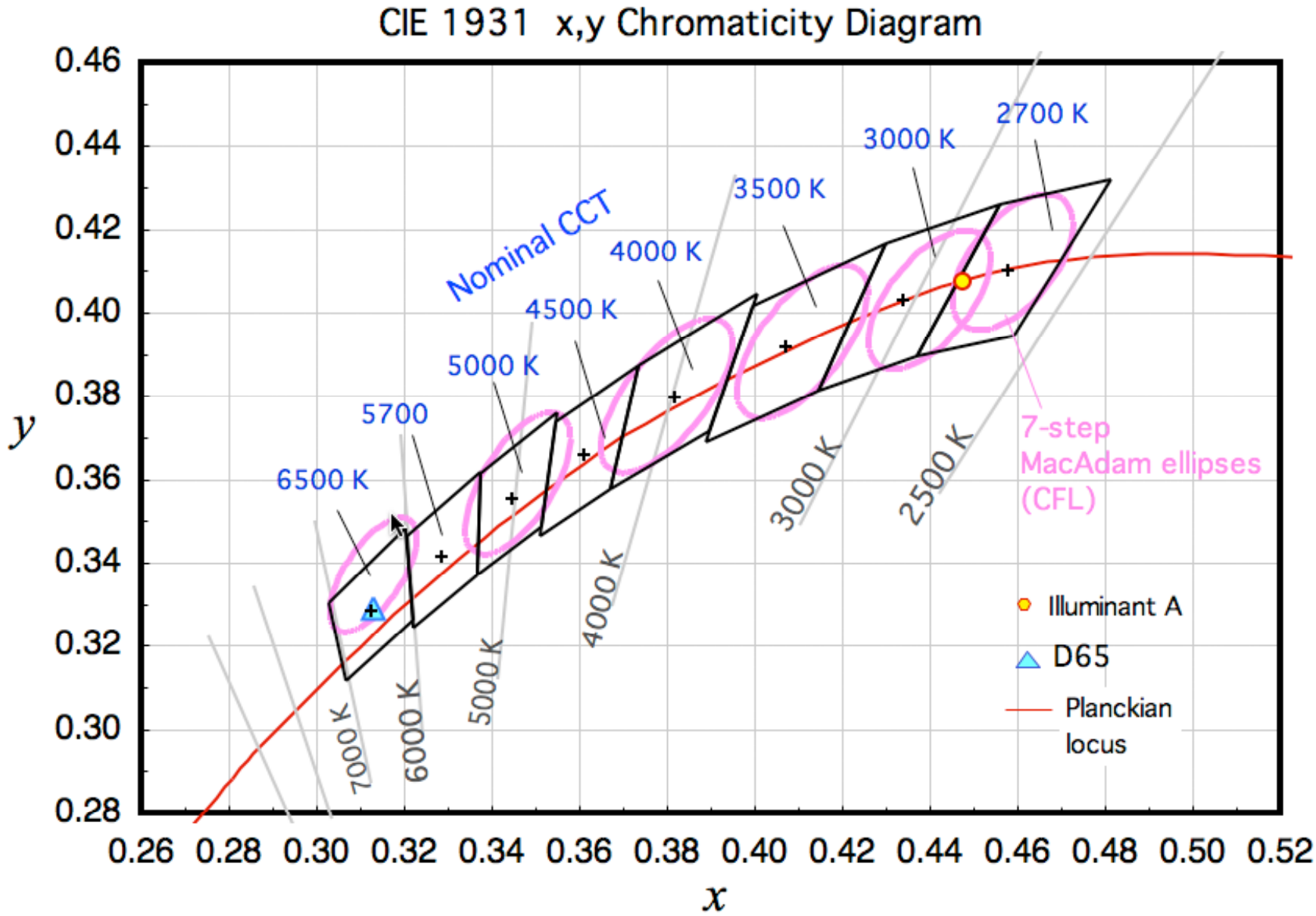

ANSI_NEMA_ANSLG C78.377-2008

American National Standard

for electric lamps—

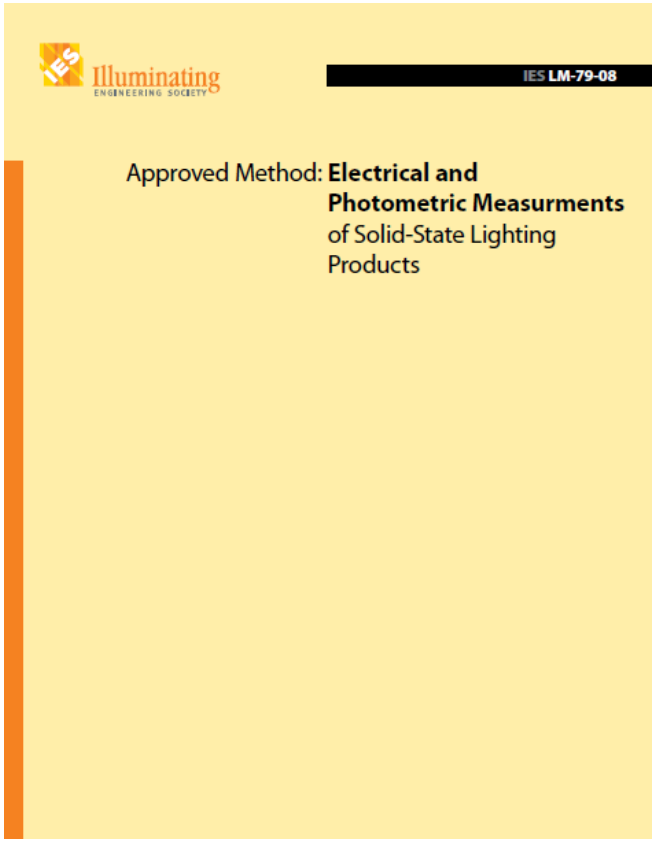
Specifications for the Chromaticity of Solid State Lighting Products

ANSI C78.377-2008



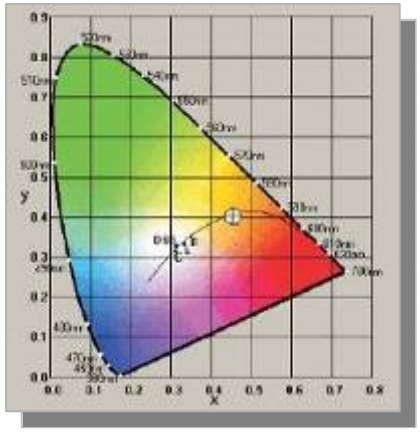
LM-79-08 Scope

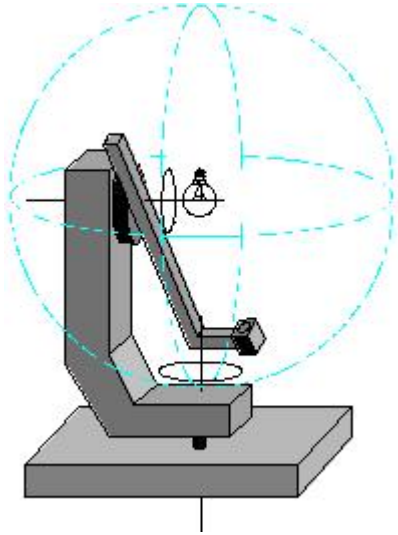
- …"LED-based SSL products with control electronics and heat sinks incorporated, […] devices that require only AC mains power or a DC voltage power supply to operate."



LM-79-08

- Methods for measuring:
  - Total luminous flux
  - Electrical power
  - Luminous intensity distribution
  - Chromaticity





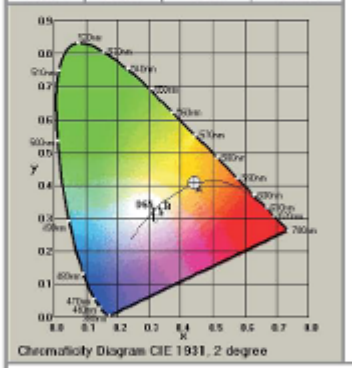
LM-79-08 report examples

LTL LUMINAIRE TESTING LABORATORY, INC.

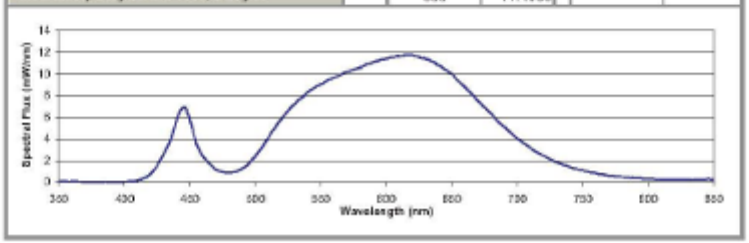
905 Harrison Street - Allentown, PA 18103 - 610-770-1044 - Fax 610-770-8912 - www.LuminaireTesting.com

LTL Number: 13592 Date: 07-16-2008
Prepared For: Cooper Lighting
Catalog Number: ML706830/H750ICAT/494WB06
Luminaire: Formed steel housing, formed brushed aluminum upper reflector, spun matte white stepped aluminum lower reflector with white enamel aluminum trim ring.
Lamp: One white LED
LED Power Supply: One unmarked LED power supply
Luminaire Efficacy: 45.8 Lumens/Watt

Lamp Arc Voltage	Lamp Current	Lamp Watts	Frequency
120.0VAC	0.1177A	13.816W	60.0 Hz
Radiant Flux mW	**Luminous Flux lumen**	**Corr.Color Temperature K**	**Color Rend. Index Ra**
2122.226	632.893	2970	80.2
Chroma x	**Chroma y**	**Chroma u**	**Chroma v**
0.4414	0.4097	0.251	0.3495



Wavelength in nm	Spectral Flux in mW/nm	Wavelength in nm	Spectral Flux in mW/nm
350	0.0778	610	11.6310
360	0.0595	620	11.7420
370	0.0571	630	11.4020
380	0.0494	640	10.8030
390	0.0398	650	9.9865
400	0.0581	660	8.7959
410	0.1748	670	7.5149
420	0.8048	680	6.3227
430	2.6120	690	5.1171
440	5.7686	700	4.0495
450	5.6687	710	3.1690
460	2.4041	720	2.4481
470	1.1795	730	1.8758
480	0.9032	740	1.4115
490	1.2715	750	1.1003
500	2.4128	760	0.8379
510	4.1652	770	0.6452
520	5.8796	780	0.5103
530	7.2159	790	0.4220
540	8.3087	800	0.3364
550	9.0951	810	0.2547
560	9.6703	820	0.2649
570	10.1880	830	0.2331
580	10.5980	840	0.2605
590	11.0900	850	0.2752
600	11.4000		



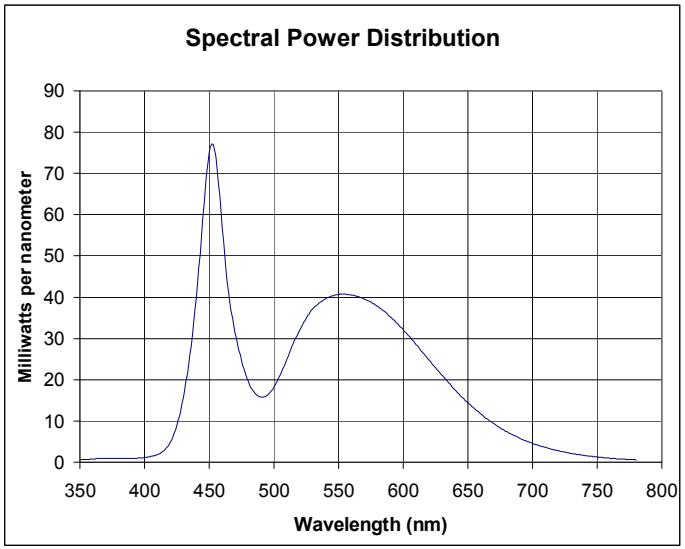
TESTING WAS PERFORMED IN ACCORDANCE WITH IES LM-79-08. Approved By:

itl boulder
THE LIGHT CENTER OF THE INDUSTRY SINCE 1955

INDEPENDENT TESTING LABORATORIES, INC.
3386 LONGHORN ROAD, BOULDER, CO 80302 USA
PHONE: (303)442-1255 • FAX: (303)449-5274 • E-MAIL: itl@itlboulder.com • WEBSITE: www.itlboulder.com

REPORT NUMBER: ITL60203 DATE: 06/03/08 Page 8 of 12
PREPARED FOR: RDS

LUMINAIRE: FABRICATED FINNED METAL POST TOP FITTER, FOUR FABRICATED WHITE PAINTED METAL MOUNTING PLATES EACH CONTAINING CIRCUITRY AND HEAT SINKS FOR TWELVE LEDS MOUNTED IN FOUR TIERS, ONE FORMED METAL REFLECTOR WITH PREMIUM SPECULAR BOTTOM AND SPECULAR TOP ABOVE EACH TIER OF LEDS, OPEN SIDES AND BOTTOM.
LAMP: FORTY-EIGHT WHITE LIGHT EMITTING DIODES EACH WITH CLEAR SEMI-HEMISPHERICAL INTEGRAL PLASTIC LENS, LEDS AIMED 11-DEGREES BELOW HORIZON.

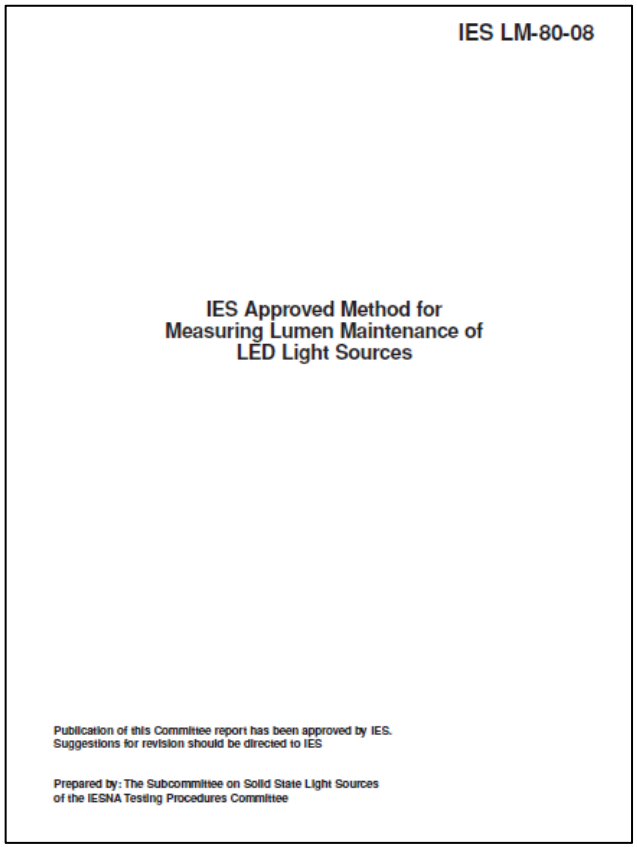


LM-80-08 Scope

- "[…] methods of measurement of lumen maintenance of sources including LED packages, arrays and modules only."
- "[…] does not provide guidance or make any recommendation regarding predictive estimations or extrapolation for lumen maintenance determined from actual measurements."

LM-80-08

- Minimum 6000 hours of device operation
- Operation at three different case temperatures
  - 55°C, 85°C, and one other temp selected by manufacturer
- Drive current held constant
- Ambient temp within -5°C of case temp
- Humidity < 65 RH throughout test period
- Chromaticity measurements


IES LM-80-08

IES Approved Method for
Measuring Lumen Maintenance of
LED Light Sources

Publication of this Committee report has been approved by IES.
Suggestions for revision should be directed to IES

Prepared by: The Subcommittee on Solid State Light Sources
of the IESNA Testing Procedures Committee

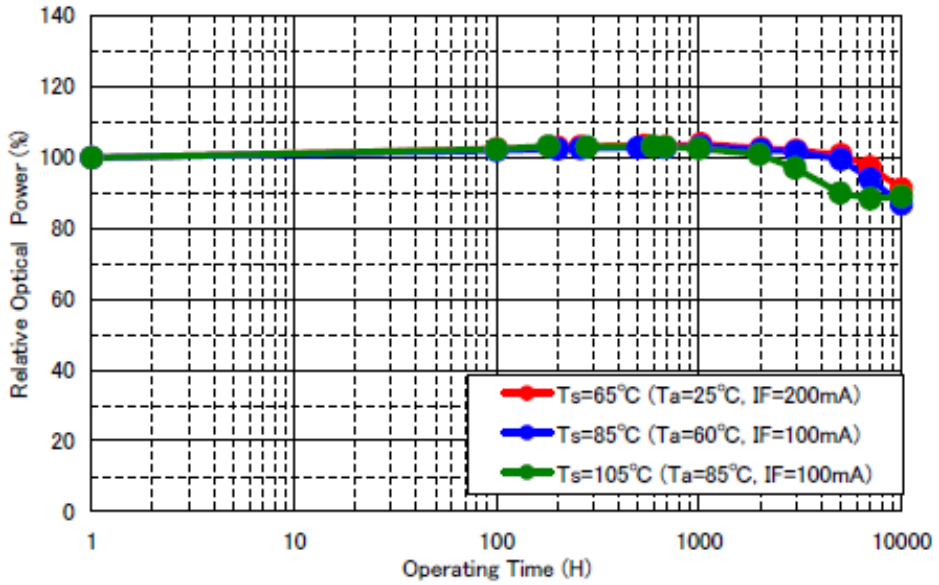
LM-80 – Current situation

- LED device manufacturers do in-house testing
- LM-80 published Sep 08 with last-minute changes
- Manufacturers transitioning to full alignment with LM-80
  - New test chambers
  - Starting test cycles
- 6000 hours takes at least 8.3 months

Sample LM-80 data

If = 350mA

Lamp	0	100	200	300	400	500	1000
2	74.8	74.7	76.4	78.2	77.9	78.1	78.9
3	79.2	78.6	81.0	81.7	81.7	81.0	82.4
4	78.6	78.0	78.8	79.0	78.8	78.4	79.1
5	61.8	61.1	62.1	62.0	61.5	60.9	61.5
6	80.4	79.4	80.3	81.2	80.6	80.0	80.7
7	81.8	81.4	82.4	82.6	82.1	81.3	82.0
8	86.0	85.8	85.9	86.7	85.9	85.3	86.0
9	74.5	74.1	76.5	77.8	78.2	77.8	79.4
10	89.1	88.6	88.7	88.6	87.8	87.1	87.6



Standards in development – or still needed…

- TM-21 – Extrapolation methodology for lumen maintenance data
- Light engine test procedure
- Reliability tests for luminaires and integral lamps
- Dimming standard

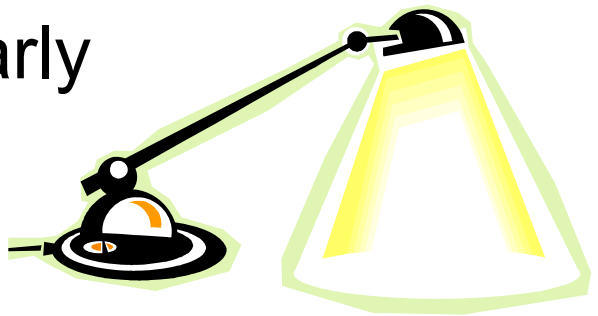
ENERGY STAR SSL

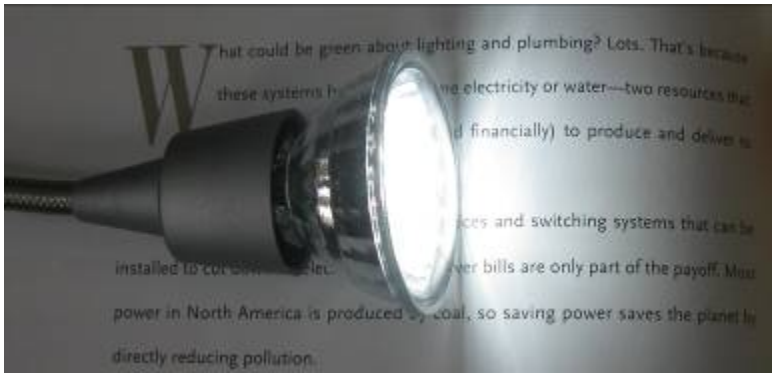
Scope and Basic Approach

- LED systems for “white light” general illumination
- Both commercial and residential
- Key metric: Luminaire efficacy
- Two categories:
  - Category A: prescriptive specifications for near-term lighting applications
  - Category B: performance specification for all applications (long-term)

Why a staged approach?

- Ensure energy savings
  - Take advantage of LED directionality
- Avoid user disappointment in early LED products
- Learn from past experience





Category A Applications - Residential

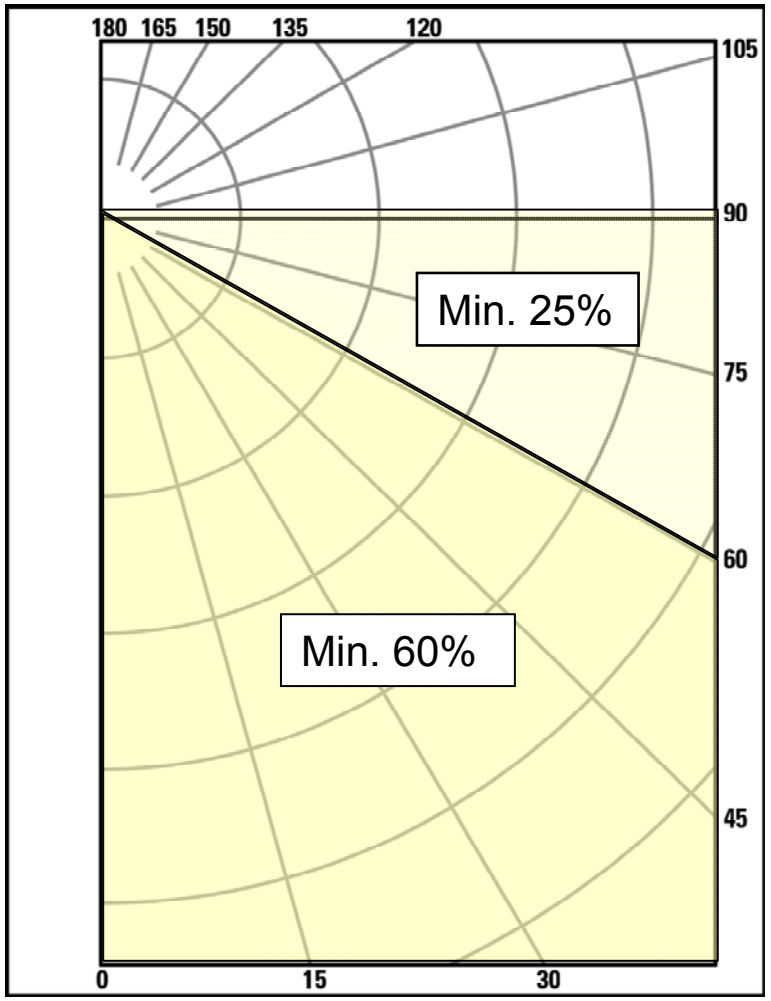
- Undercabinet kitchen
- Portable desk task
- Ceiling mounted w/diffuser
- Surface, pendant, recessed downlights
- Cove lighting
- Surface mounted with directional heads
- Outdoor porch, path, step, post-top

Category A Applications – Non-residential

- Undercabinet shelf-mounted task
- Portable desk task
- Surface, pendant, recessed downlights
- Wall wash luminaires
- Outdoor bollards

Example: Undercabinet shelf-mounted task lights

- **Minimum Light Output**
  - 125 lumens per lineal foot
- **Zonal Lumen Density**
  - Min. 60% in 0-60° zone
  - Min. 25% in 60-90° zone
- **Luminaire Efficacy**
  - ≥ 29 lm/W
- **CCTs:**
  - 2700 - 5000K



Life/lumen maintenance requirements

- Hours to 70% lumen maintenance L_{70}
- Indoor residential: min 25,000 hours
- Outdoor and all non-residential: min 35,000 hours

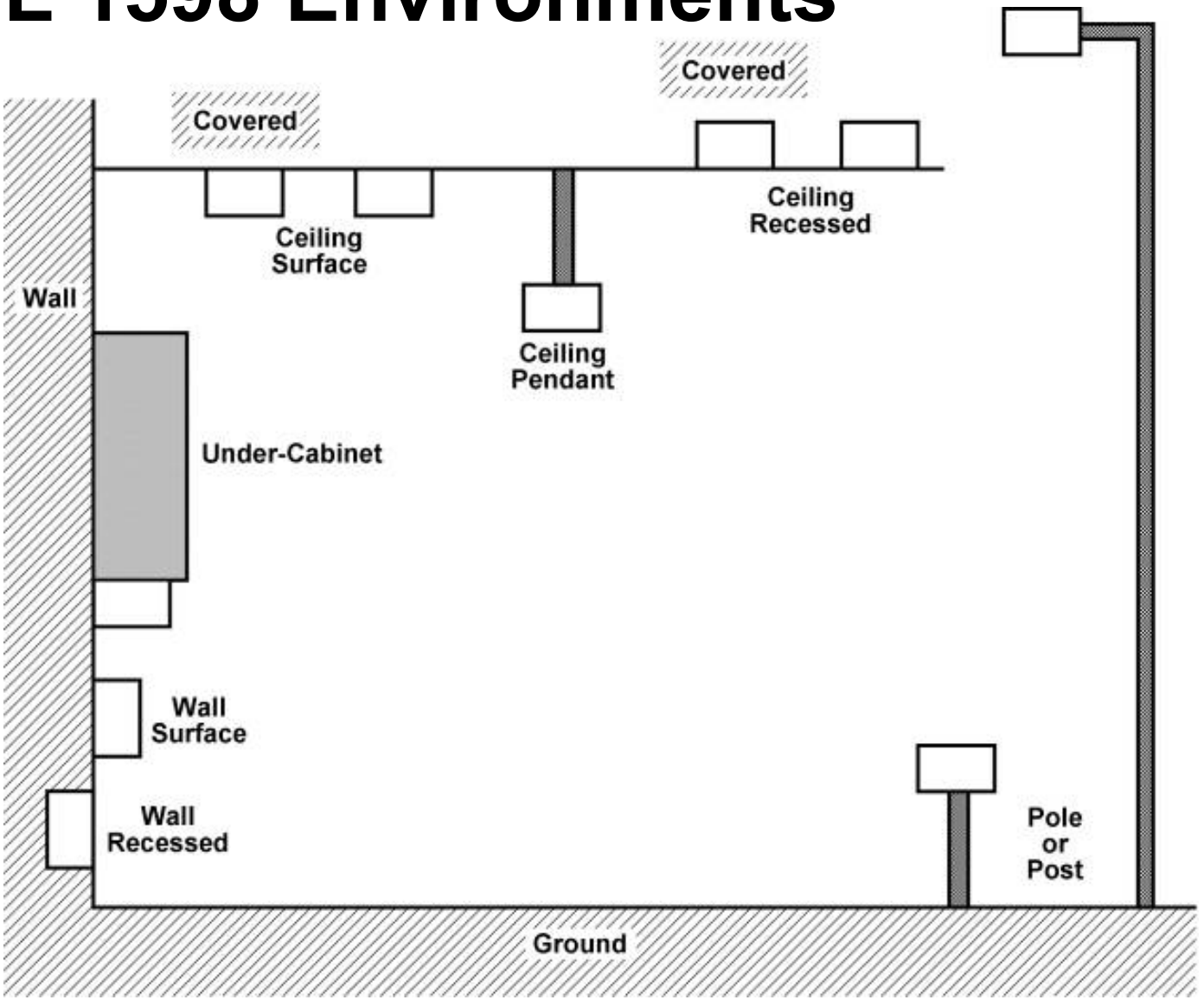
Qualification Process

- LM-79 luminaire photometric report
- LM-80 lumen maintenance data for LEDs used in luminaire
- Luminaire *in situ* temperature verification

In Situ Testing Requirement

- Life (lumen maintenance) determined by *in situ* temperature measurements of:
  - Module, Array or "Light Engine"
  - Power Supply/Driver
- Testing may be conducted at the same time as UL 1598.

UL 1598 Environments



Temperature Measurement Point (TMP)

- Manufacturer designated TMP correlating to LM-80 test report or power supply warranty
  - Module/Array
    - Solder Joint Temperature T_s
    - Case Temperature T_c
    - Board Temperature T_b
  - Power Supply
    - Case Temperature T_c
    - Could also be T_b for integral Power Supplies

Lumen Maintenance Qualification

- Option 1: Component Performance
  - Applicable if:
    - Module/Array has a current LM-80 test report
    - Module/Array has a designated TMP
    - TMP is accessible for in situ measurement
  - Otherwise manufacturer must use Option 2
- Option 2: Luminaire Performance
  - Entire luminaire LM-79 tested at 0 and 6000 hours

Lumen Maintenance "Passing" Criteria

A luminaire passes the L_{70} threshold (≥ 25,000 hours for indoor residential and ≥ 35,000 for all others) …

- if the in situ measured drive current is the same or lower

AND

- if the in situ measured TMP for the device/module/array is the same or lower

… than the LM-80 test report provided for the device/module/array.

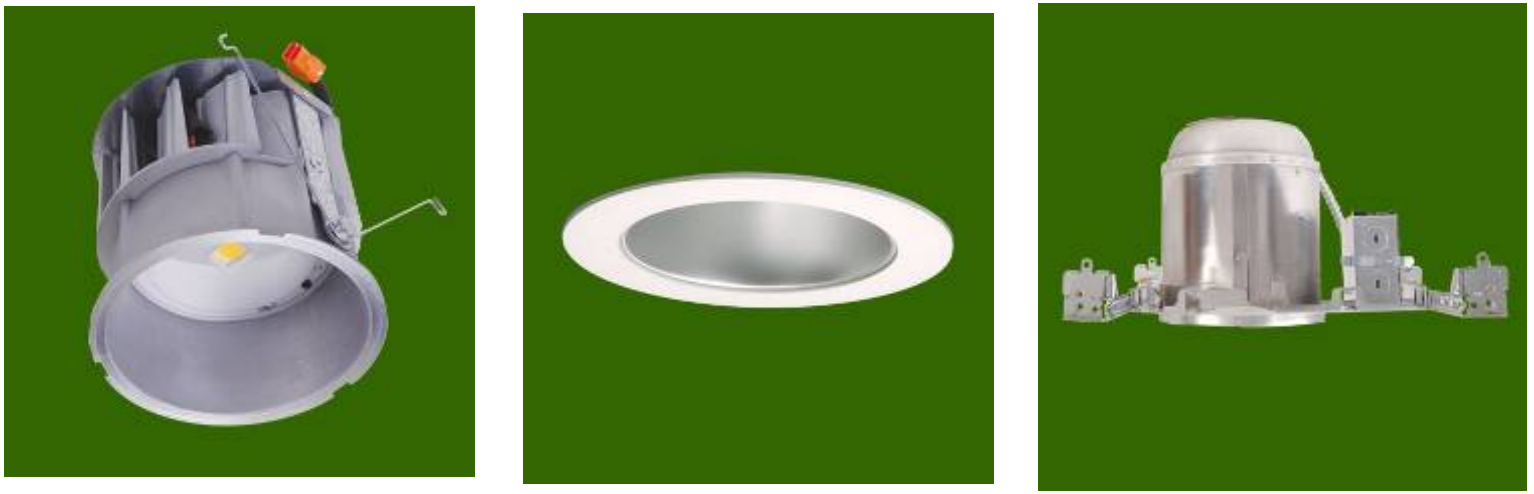
ENERGY STAR SSL Qualified

Kichler Design Pro Undercabinet

ENERGY STAR SSL Qualified

Cree Lighting LR6 Downlight

ENERGY STAR SSL Qualified



Cooper Halo Downlight

ENERGY STAR SSL Qualified

Kichler Adjustable Rail Lights

Possible additions to Category A

- Outdoor area and roadway
- Outdoor area decorative
- Outdoor wall packs
- Parking garage luminaires

Integral LED Lamps – Draft Criteria

- Published Jan 16, 2009
- Comments due Feb 27, 2009
- 2nd round of comments
- Includes:
  - Omni-directional (A type)
  - Directional (MR,PAR type)
  - Decorative (candelabra type)
  - Lamps using ANSI bases

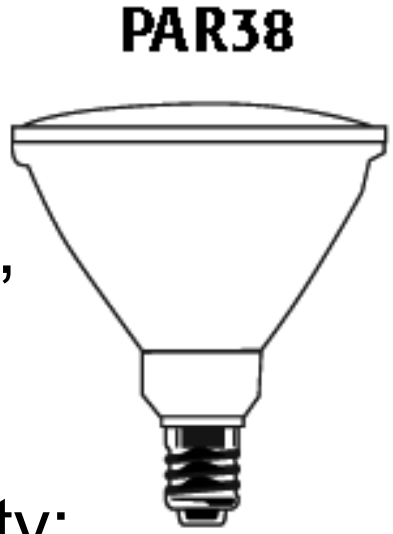
Key Issues for Industry Feedback

- Dimming
- Non-standard lamp forms
- Low-voltage MR-16 replacements
- Reliability testing

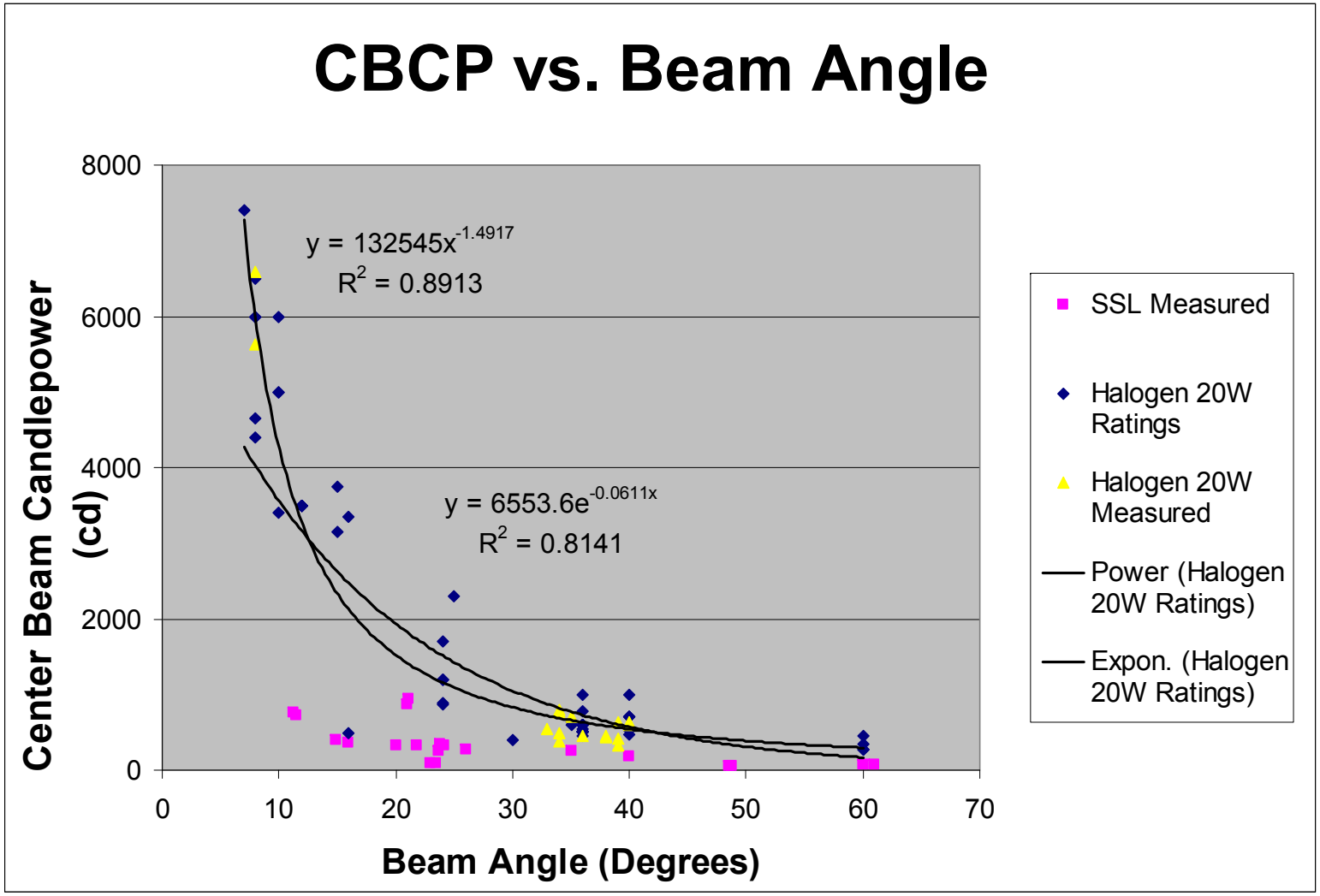
Integral LED Lamp Draft Criteria

Directional Lamp Draft Requirements

- Applies to ANSI lamps: BR,ER,K,MR,PAR,R
- Applies to diameters: MR16, PAR16, PAR20, PAR30S, PAR30L, PAR38
- 45 lm/W
- PAR and MR16 center beam intensity: based on statistical analysis of incandescent/halogen lamps
- Min. lumens = target wattage x 10

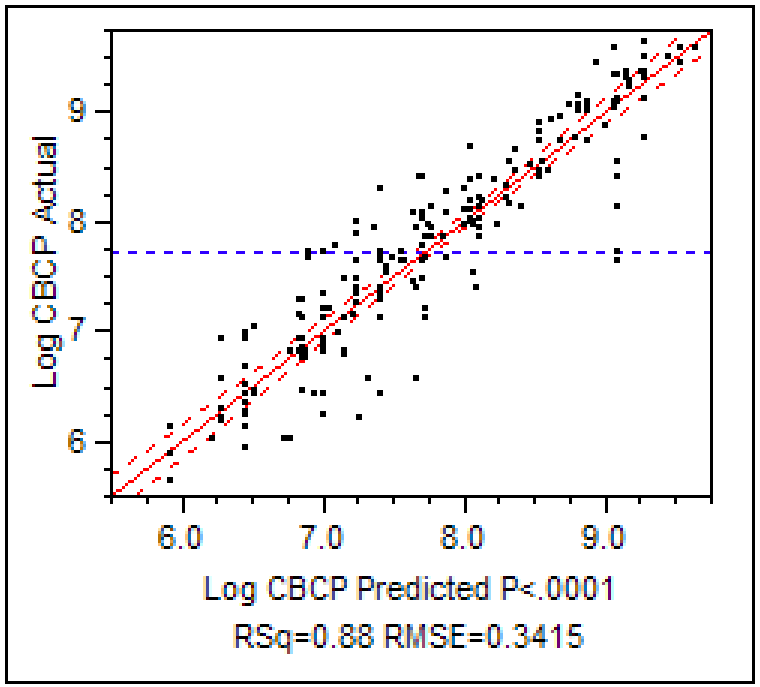


Integral LED Lamp Draft Criteria



Integral LED Lamp Draft Criteria

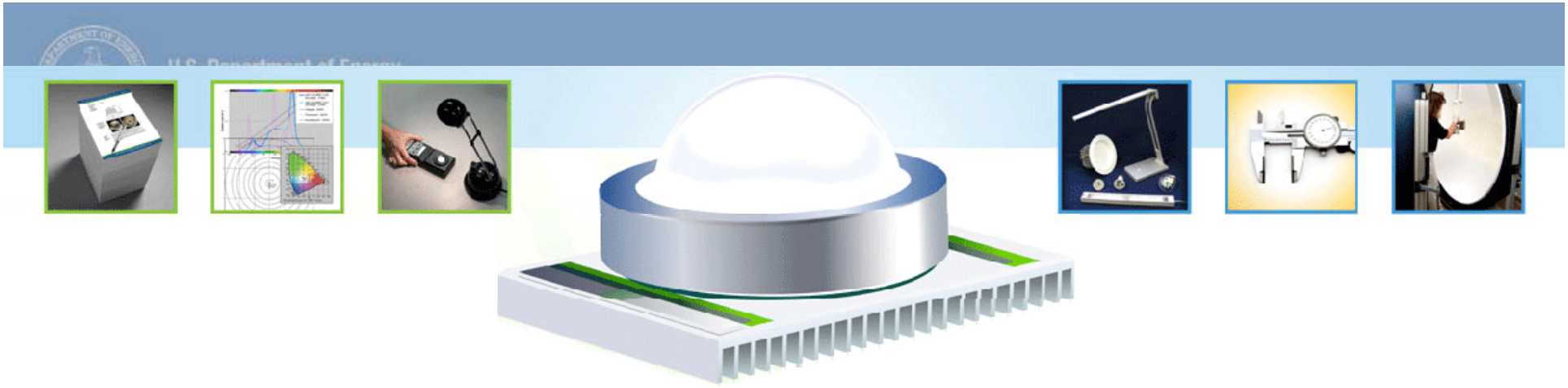
Statistical Analysis of Incan/Halogen → Tool for Determining Min. CBCP



- Inputs: target beam angle & wattage
- Output: Min. required CBCP
- Min. required CBCP is 2 σ below predicted value of model

How are real products performing?

- CALiPER Testing
- GATEWAY Demonstrations



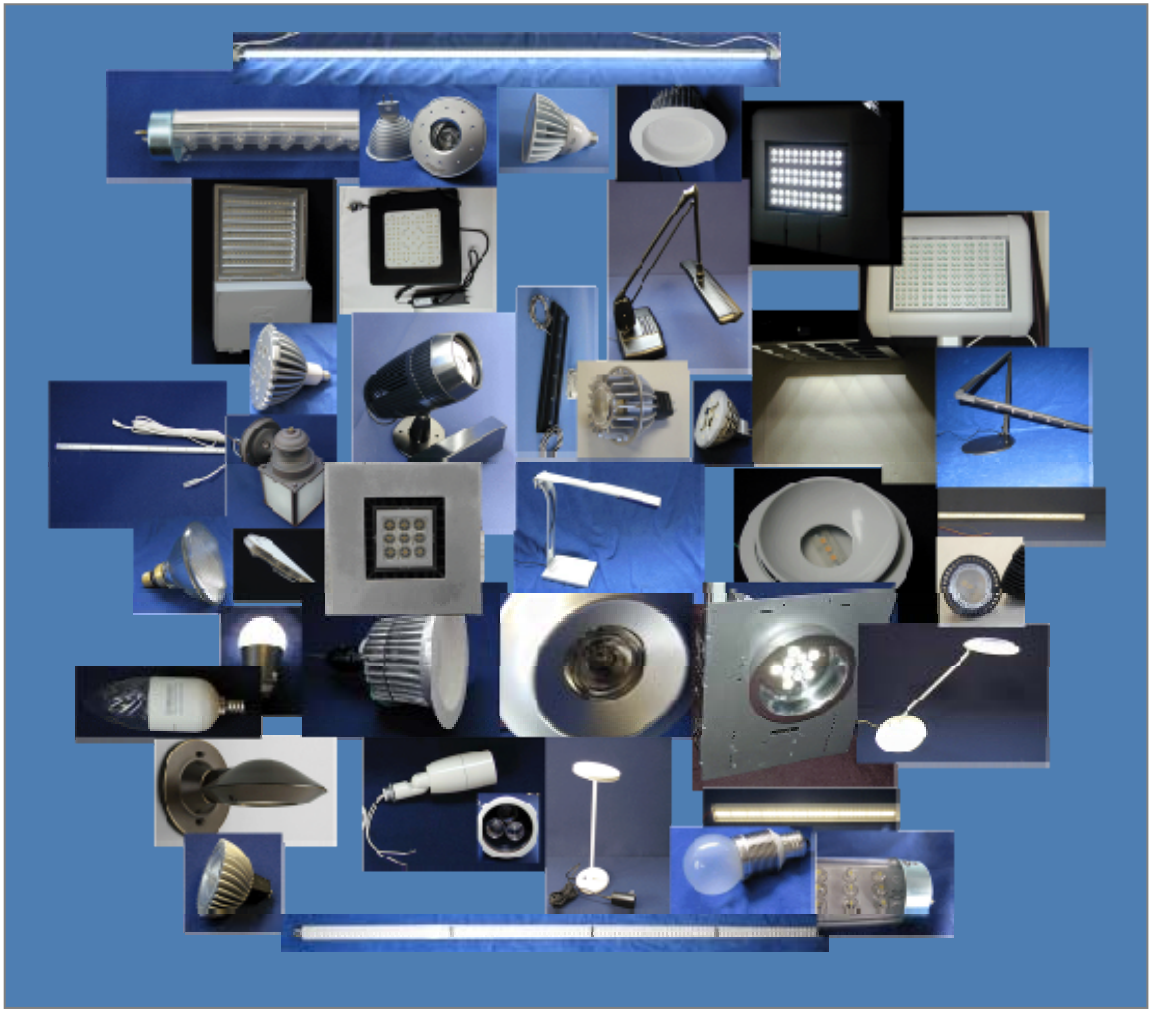
SSL Luminaires and Replacement Lamps

- Lots of marketing hype, but where do we get the truth?
  - Which products are good? Which products aren't?
  - How do they compare to what we know?
  - How do we avoid the early negative CFL experience?

CALiPER

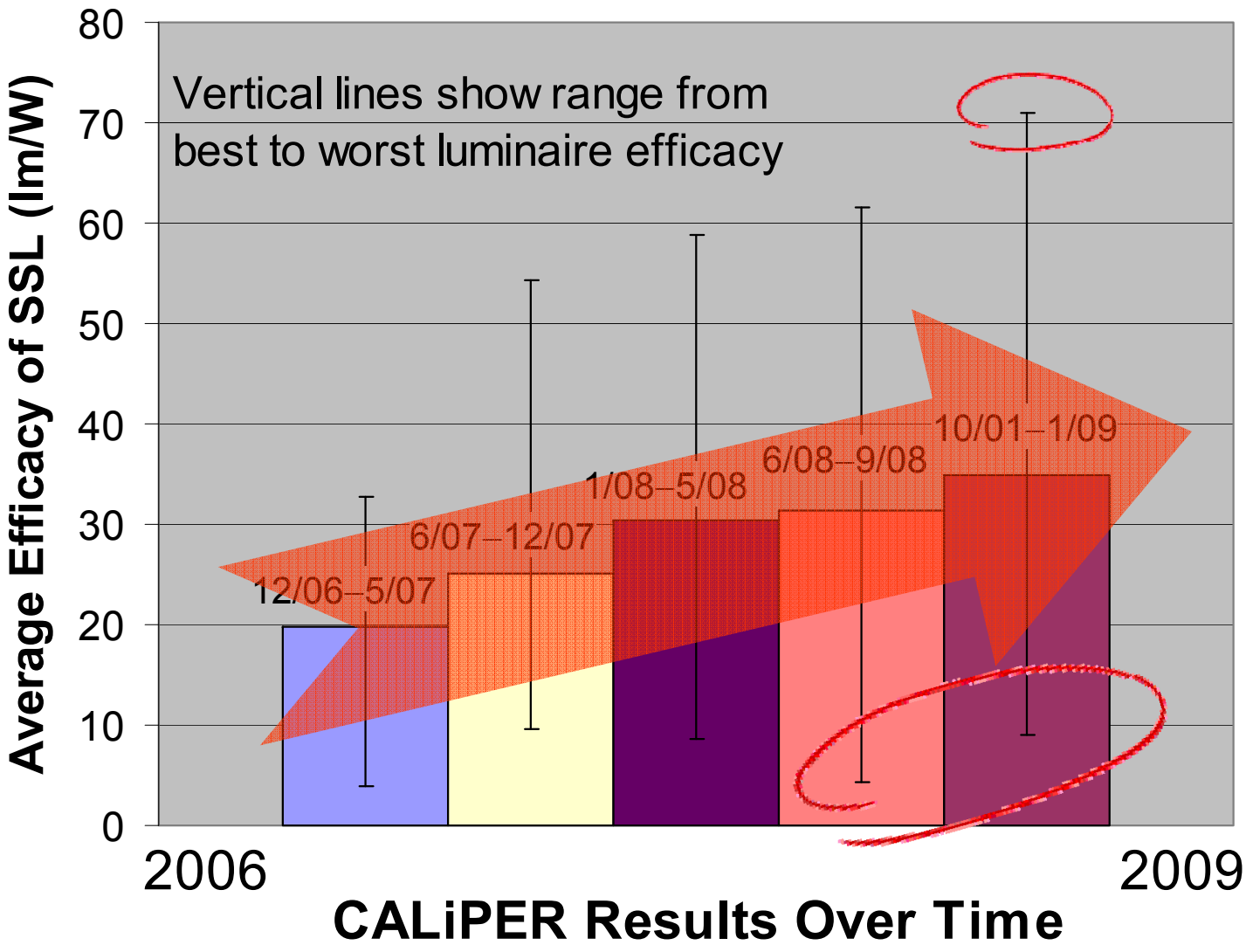
Scope

- SSL
- General illumination
- White light
- Market-available



CALiPER

CALiPER Testing: Measurable Progress



Recent CALiPER Testing: Round 7

- Outdoor Fixtures
  - Streetlights
  - Bollards
- Downlights
- Replacement lamps
  - Directional (MR16, PAR…)
  - Omni-directional (A-lamp)
- Side-by-side comparisons

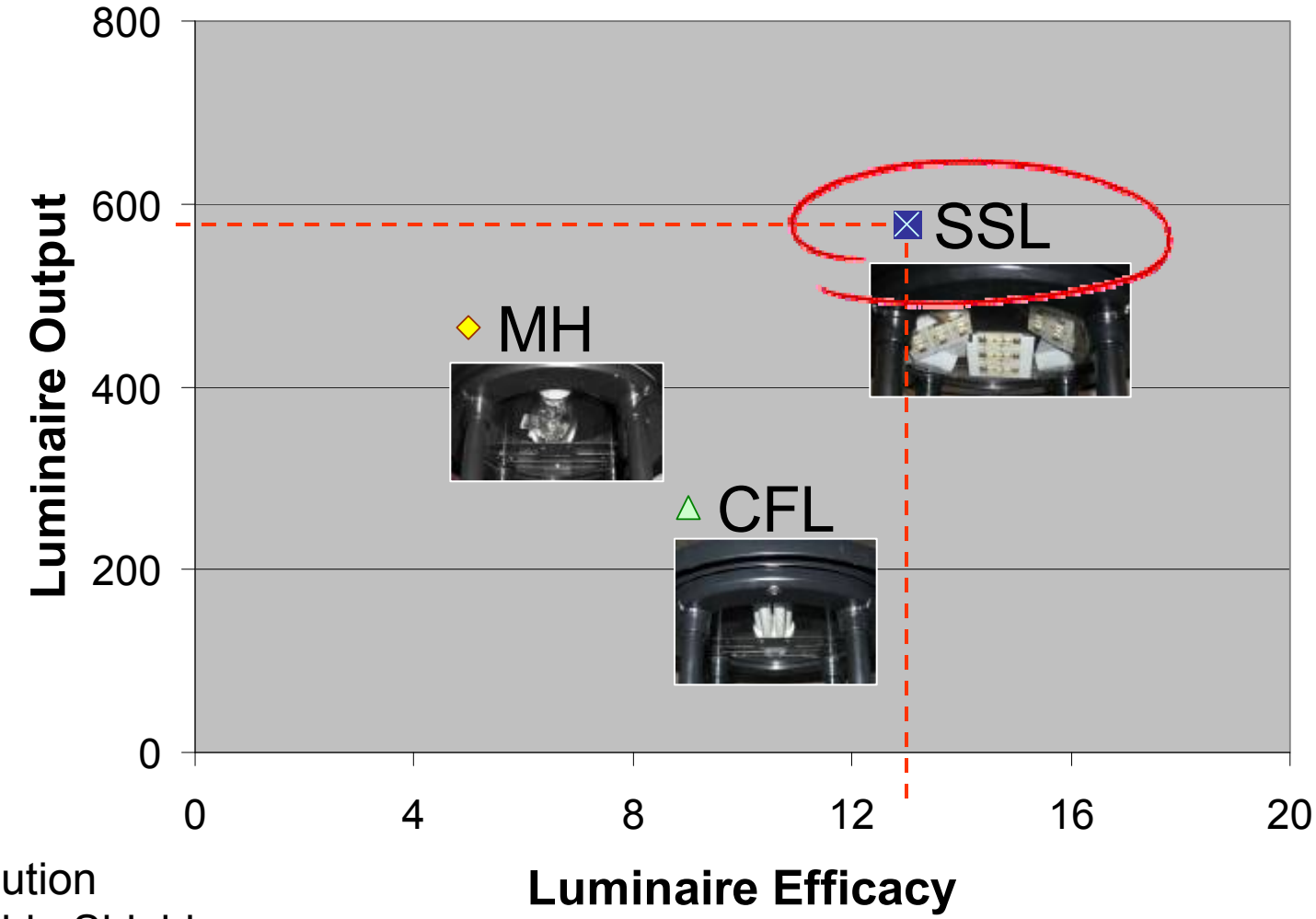
Outdoor Applications

Streetlights comparison

	W	Lumens	lm/W	CCT	CRI	PF
SSL 1	55	1028	19	14628	74	0.93
SSL 2	58	3179	55	6227	75	0.99
SSL 3	73	3440	47	6052	72	0.99
SSL 4	37	2588	70	5210	68	0.99
SSL 5	95	3105	33	3101	72	0.99
HPS	117	6540	56	2042	21	0.44
Induction 1	69	3828	55	3906	75	0.96
Induction 2	70	3398	49	4253	77	0.99

CALiPER

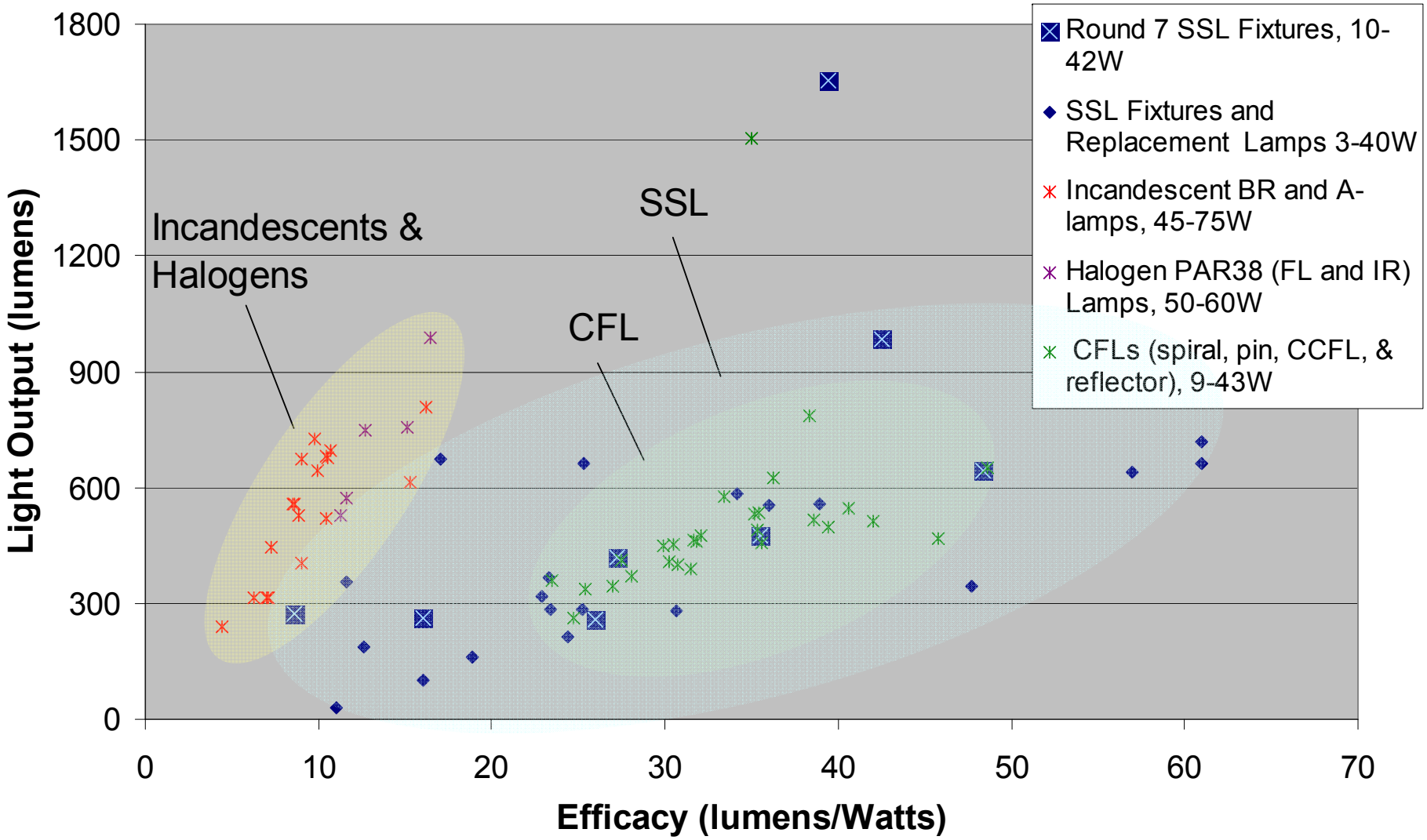
Bollards Side-by-Side Comparison



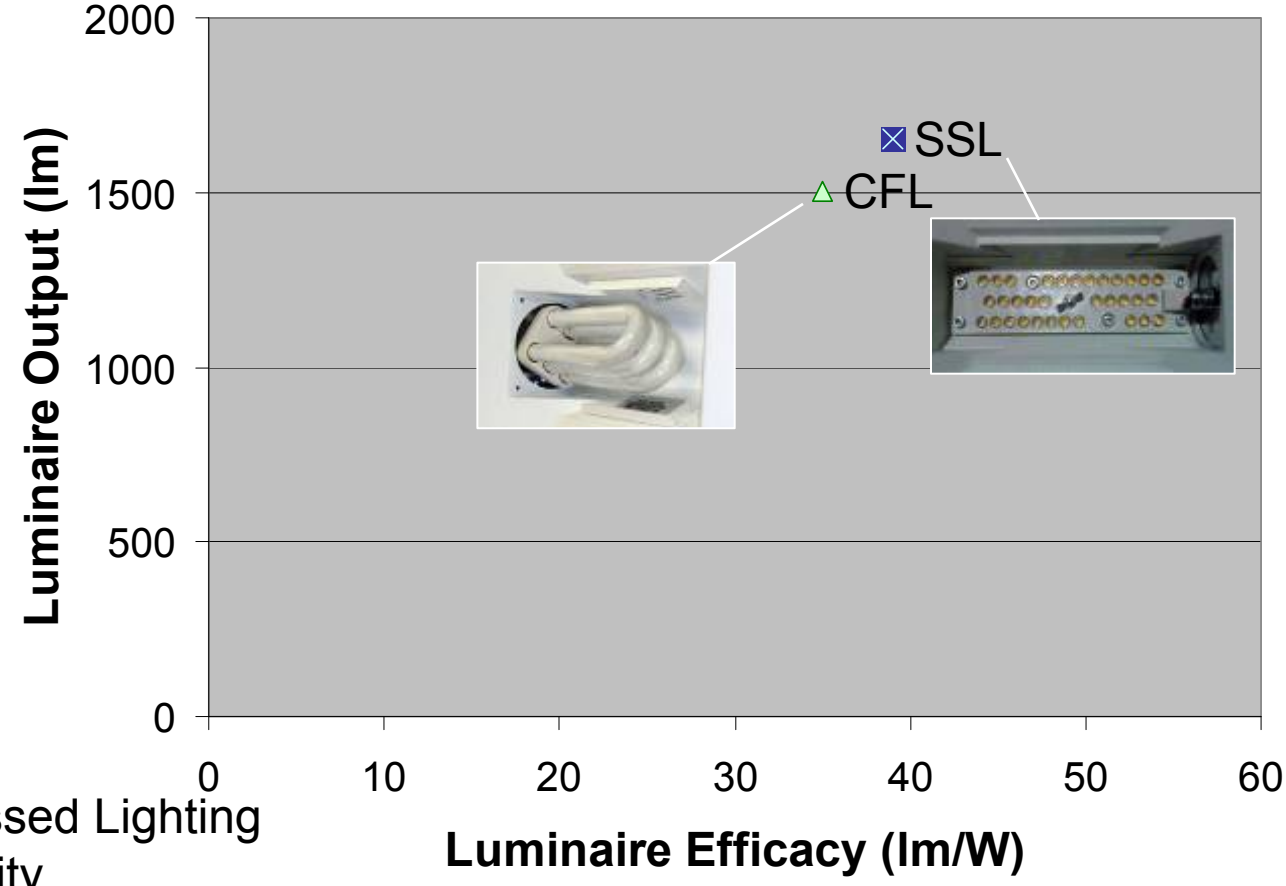
- Same Model
- Similar Distribution
- With House-Side Shield


Downlights

SSL Downlight Performance



Downlights Side-by-Side Comparison

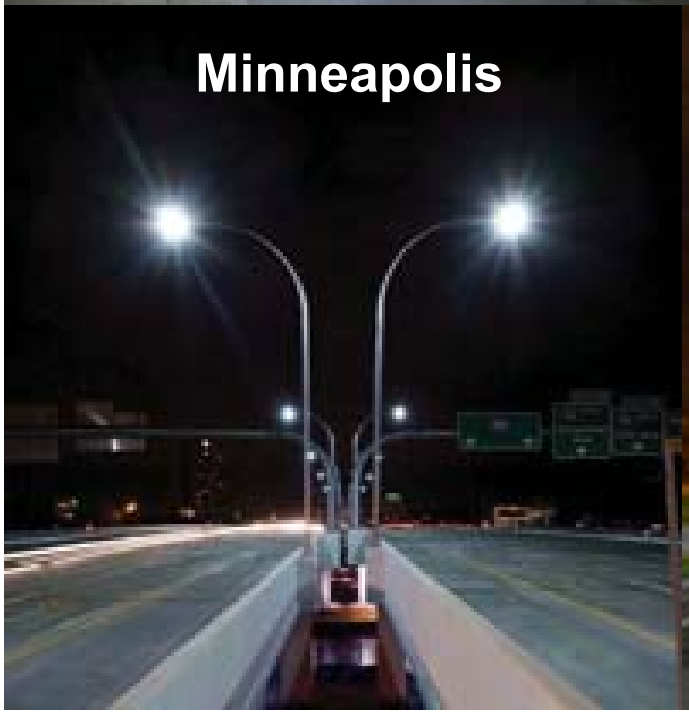


- Same Model
- 1’ x 1’ Square
- Volumetric Recessed Lighting
- Same Color Quality
- Similar Distribution
- SSL Initial Cost ≈ 2 x CFL Initial Cost

Demos


San Francisco


Atlantic City


Minneapolis


Oakland


Portland

LED Street Light Assessment - Oakland

- Emerging Technologies Field Assessment
  - Collaboration with PG&E, DOE, City of Oakland, Beta LED
  - Basecase: 100 W HPS
  - Phase 2
    - November 2007
    - 3-bar Beta LED Edge
  - Phase 3
    - July 2008
    - Beta LEDWay

www.etcc-ca.com or www.ssl.energy.gov

LED Street Light Assessment - Oakland

- **Measured Power Consumption**

Fixture	HPS	Phase 2 LED	Phase 3 LED
Power (W)	121	78	58
Savings		43	63
Percent Reduction		**36%**	**52%**

Source: PG&E Emerging Technologies Assessment

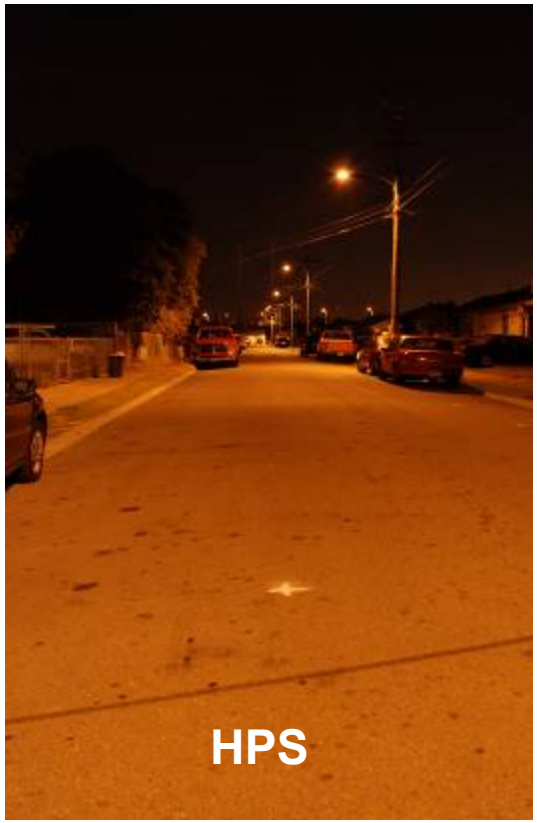
LED Street Light Assessment - Oakland

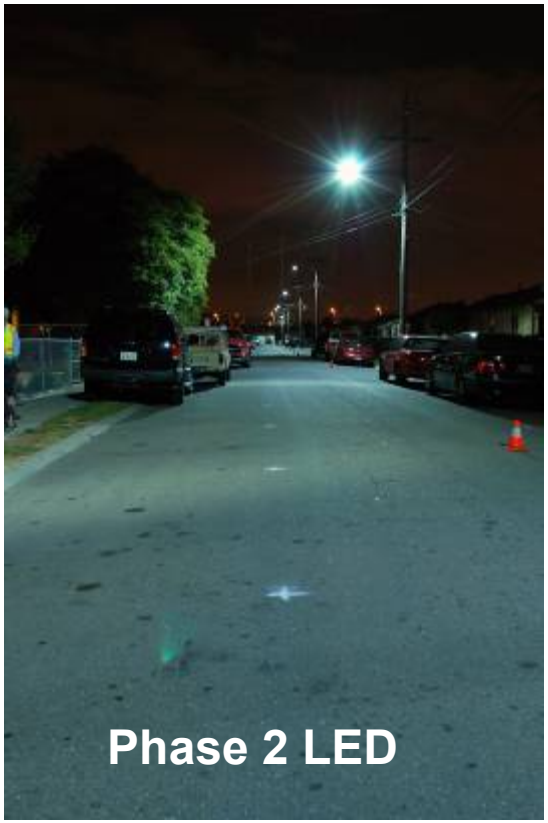
- **Lighting Performance**

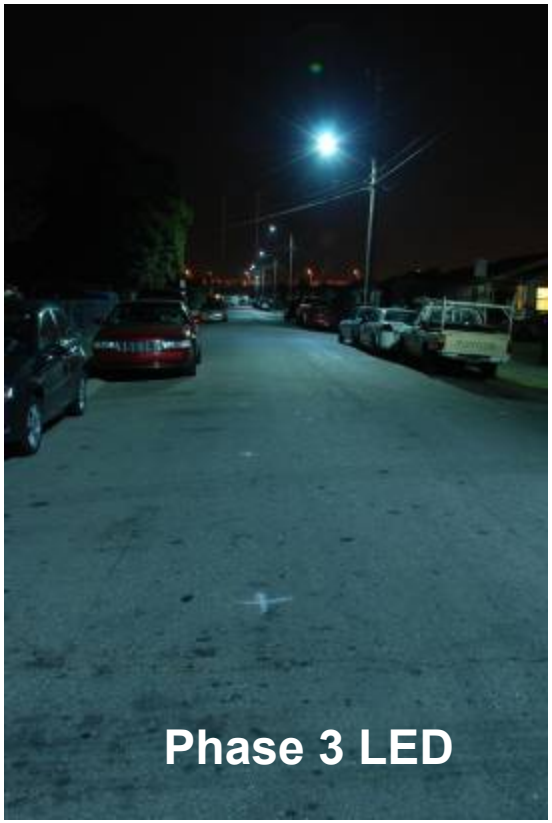
Fixture	Avg Illum (fc)	Max Illum (fc)	Min Illum (fc)	Max to Min
HPS	1.00	3.53	0.19	19.0:1
Phase 2 LED	0.58	1.21	0.19	6.5:1
Phase 3 LED	0.50	1.21	0.19	6.5:1

Source: PG&E Emerging Technologies Assessment

LED Street Light Assessment - Oakland







Source: PG&E Emerging Technologies Assessment

LED Street Light Assessment - Oakland

- Customer Acceptance
  - 60 households contacted
  - 20 noticed the new lights
  - 70% preferred LED lights
  - Perceived improved visibility, overall appearance and nighttime safety

Source: PG&E Emerging Technologies Assessment

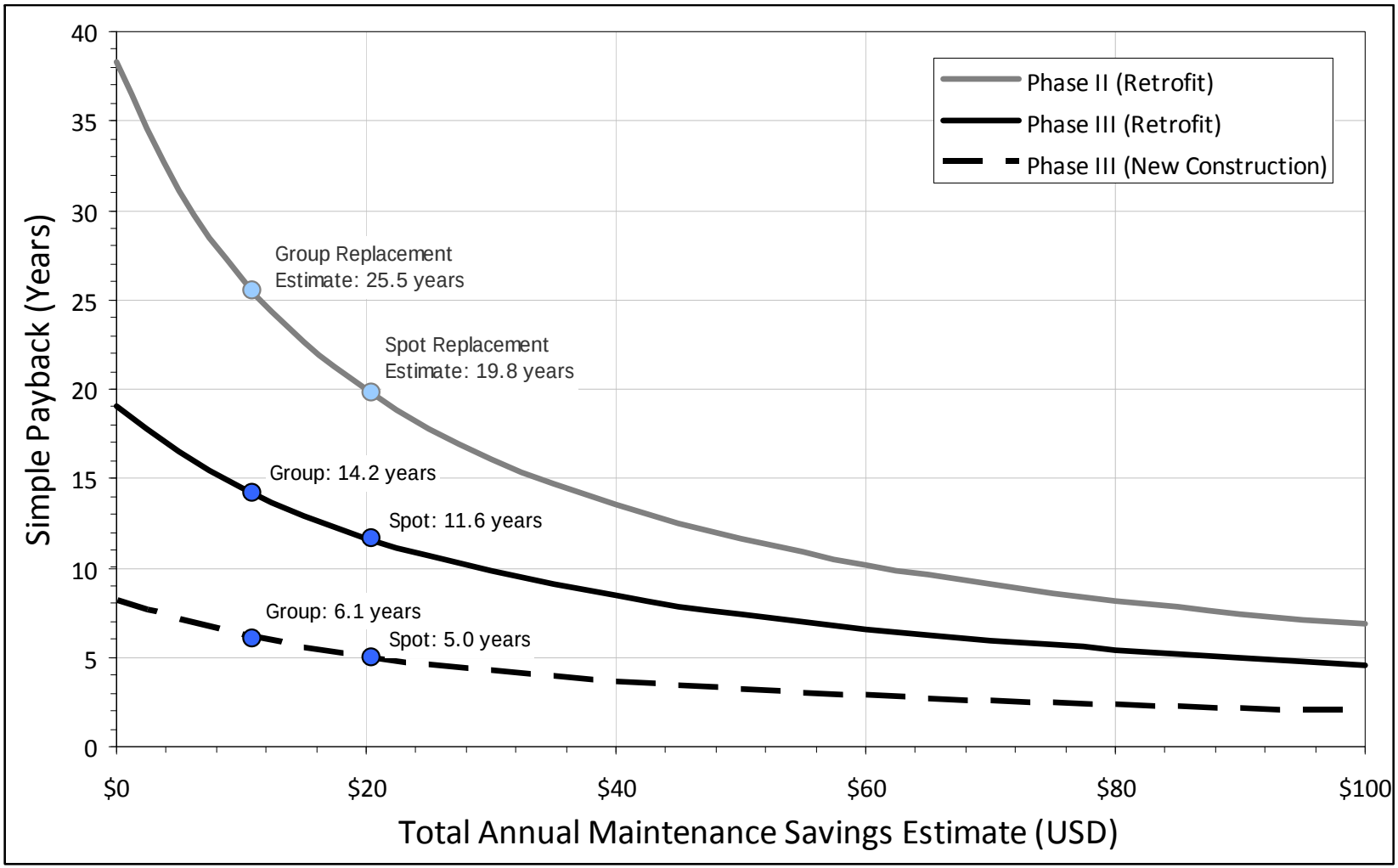
LED Street Light Assessment - Oakland

- **Economic Performance**

Retrofit Scenario	Installed Cost ($)	Total Annual Savings ($/yr)	Estimated Payback (yr)
HPS	$0	$0	NA
Phase 2 LED	$833	$42	~20
Phase 3 LED	$605	$52	~12

Source: PG&E Emerging Technologies Assessment

Streetlight payback estimates



Oakland Streetlighting Demonstration Phase III

LED Street Light Assessment - Oakland

- **Progress in 12 Months**
  - Cost reduced 34%
  - Energy consumption reduced by 20 W (25%)
  - Lighting performance maintained
    - Same LEDs, better engineering

Source: PG&E Emerging Technologies Assessment

Questions?

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DOE SSL Website: www.ssl.energy.gov