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

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Pacific Northwest National Laboratory
April 1, 2009
What’s the status of LEDs today?

LEDs are not ready!

The truth is somewhere in between …

Let’s go all LED!
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
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…”
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
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
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

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![Graph showing relative optical power over operating time for different temperatures and currents.]
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**
  - $\geq 29$ 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 \textit{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 ($\geq 25,000$ hours for indoor residential and $\geq 35,000$ 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
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
CBCP vs. Beam Angle

y = 132545x^{-1.4917} 
R^2 = 0.8913

y = 6553.6e^{-0.0611x} 
R^2 = 0.8141

Center Beam Candlepower (cd)

Beam Angle (Degrees)
Statistical Analysis of Incan/Halogen Tool for Determining Min. CBCP

- Inputs: target beam angle & wattage
- Output: Min. required CBCP
- Min. required CBCP is $2 \sigma$ 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?
Scope

- SSL
- General illumination
- White light
- Market-available
CALiPER Testing: Measurable Progress

Vertical lines show range from best to worst luminaire efficacy
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

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Bollards Side-by-Side Comparison

- Same Model
- Similar Distribution
- With House-Side Shield
Downlights
SSL Downlight Performance

- Round 7 SSL Fixtures, 10-42W
- SSL Fixtures and Replacement Lamps 3-40W
- Incandescent BR and A-lamps, 45-75W
- Halogen PAR38 (FL and IR) Lamps, 50-60W
- CFLs (spiral, pin, CCFL, & reflector), 9-43W

Graph showing light output (lumens) vs. efficacy (lumens/Watts) for different types of lighting fixtures.
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
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

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<th>Fixture</th>
<th>HPS</th>
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<th>Phase 3 LED</th>
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<td>Savings</td>
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<td>Percent Reduction</td>
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<td>36%</td>
<td>52%</td>
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Source: PG&E Emerging Technologies Assessment
LED Street Light Assessment - Oakland

• Lighting Performance

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<th>Fixture</th>
<th>Avg Illum (fc)</th>
<th>Max Illum (fc)</th>
<th>Min Illum (fc)</th>
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Source: PG&E Emerging Technologies Assessment
LED Street Light Assessment - Oakland

HPS  Phase 2 LED  Phase 3 LED

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**

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<th>Retrofit Scenario</th>
<th>Installed Cost ($)</th>
<th>Total Annual Savings ($/yr)</th>
<th>Estimated Payback (yr)</th>
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<td>$0</td>
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<tr>
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<td>$42</td>
<td>~20</td>
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<tr>
<td>Phase 3 LED</td>
<td>$605</td>
<td>$52</td>
<td>~12</td>
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Source: PG&E Emerging Technologies Assessment
Streetlight payback estimates

Group Replacement Estimate: 25.5 years
Spot Replacement Estimate: 19.8 years
Group: 14.2 years
Spot: 11.6 years
Spot: 5.0 years
Group: 6.1 years

Total Annual Maintenance Savings Estimate (USD)

Simple Payback (Years)

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