CALiPER Round 11 Testing

U.S. DOE Solid-State Lighting
February 8, 2011

Mia Paget
Pacific Northwest National Laboratory
CALiPER Testing Program


How are products really doing today?

What’s new in CALiPER findings?
CALiPER Focuses

- **2006 Pilot phase**
  - 4 products (hard to purchase)
- **2007 Rounds 1-3**
  - Small replacement lamps, desk lamps, undercabinets, small downlights
- **2008 Rounds 4-6**
  - Adding downlight and T8 in situ testing, benchmarking, replacement lamps
- **2009 Rounds 7-9**
  - Streetlights, bollards, downlights, 2x2 panels, 2x4 troffers, replacement lamps
- **2010 Round 10**
  - Parking garage, wallpack, cove lights, replacement lamps
- **2010, Round 11**
  - Roadway, arm-mount luminaires
  - Roadway, post-top luminaires
  - Linear replacement lamps
  - High-bay luminaires
  - Small replacement lamps (MR16, PAR lamps, A-lamps, and a candelabra lamp)
Key Performance Points

- CALiPER Round 11
- Larger, higher wattage products
- Improving reporting practices (Lighting Facts & IESNA LM-79)
- More competitive applications
- Wide range of performance
Overall Achievements

- **Efficacy:**
  - On average the same for replacement lamps and outdoor
- **CCT**
  - On average warm for replacement lamps, cold for outdoor
- **CRI**
  - On average better for replacement lamps
- **Power Factor**
  - close to 1.0 for outdoor
  - Over 0.8 for replacement lamps
Benchmark and SSL Roadway Luminaire Efficacy

- CALiPER Benchmarks: HPS, Induction
- Average CALiPER Rounds 7-8: Roadway SSL
- CALiPER Round 11 Roadway SSL

Total Efficacy (lm/W)

- 117W HPS BK08-122
- 67W Ind. BK08-152
- 71W Ind. BK08-153
- Average Rounds 7-8 (64W)
- 38W 09-62
- 79W 09-113
- 73W 10-09
- 72W 10-10
- 44W 10-14
- 150W 10-26
Roadway Luminaires

Luminaire Efficacy Is NOT Everything

Consider illuminance, throw, application needs...
Roadway Luminaires

**Measured Overall Luminaire Wattage**

- **HPS BK08**: 117W
  - 4940 lm
  - 56 lm/W
  - 278 kMounting Height
- **SSL 09-62**: 38W
  - 26 lm/W
  - 67 lm/W
  - 278 kMounting Height
- **SSL 10-05**: 73W
  - 4940 lm
  - 68 lm/W
  - 278 kMounting Height
- **Induction 8K**: 67W
  - 95 lm/W
  - 278 kMounting Height
- **SSL 09-111**: 70W
  - 34 lm/W
  - 71W
  - 278 kMounting Height
- **SSL 10-10**: 72W
  - 44 lm/W
  - 70 lm/W
  - 278 kMounting Height
- **Induction 8K**: 71W
  - 95 lm/W
  - 278 kMounting Height
- **SSL 10-26**: 150W
  - 70 lm/W
  - 47 lm/W
  - 278 kMounting Height
- **SSL 10-14**: 44W
  - 90 lm/W
  - 40 lm/W
  - 278 kMounting Height
Light Output and Average Illuminance*

<table>
<thead>
<tr>
<th>BENCHMARKS</th>
<th>SSL</th>
<th>SSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>6540 lm</td>
<td>970 lm</td>
<td>4994 lm</td>
</tr>
<tr>
<td>0.7 fc</td>
<td>0.1 fc</td>
<td>0.6 fc</td>
</tr>
<tr>
<td>3960 lm</td>
<td>2549 lm</td>
<td>4469 lm</td>
</tr>
<tr>
<td>0.3 fc</td>
<td>0.1 fc</td>
<td>0.4 fc</td>
</tr>
<tr>
<td>3561 lm</td>
<td>7004 lm</td>
<td>3994 lm</td>
</tr>
<tr>
<td>0.2 fc</td>
<td>0.5 fc</td>
<td>0.3 fc</td>
</tr>
</tbody>
</table>

* Average illuminance calculation based on 24-foot wide 2-lane street with 27-foot high, luminaires set back 6-foot and spaced 170-foot on center
Roadway Luminaires

Uniformity of Light Distribution (e.g. Avg:Min)

* Uniformity calculation based on 24-foot wide 2-lane street with 27-foot high, luminaires set back 6-foot and spaced 170-foot on center
Roadway Luminaire Assessments

• Consider overall luminaire performance, initial, and projected over life
• Performance analysis of complete lighting system
  – Mounting height, spacing, position, street width, application requirements...
  – Overall input watts
  – Overall light output
  – Average illuminance & uniformity
  – Light distribution (forward, lateral, BUG → caveats)
  – Glare (no simple way to predict), uplight, backlight
  – Color
• 5 out of 6 meet manufacturer claims

But…CAUTION: Equivalency claims may be valid for some specific installation scenarios but will not be valid in every case
Post-Top Luminaires

**Metal Halide**
- Prismatic glass refractor
- Ceramic Metal Halide
- 178 W
- 9104 lm
- 51 lm/W

**versus**

**LED**
- Opaque top, prismatic lens
- SSL
- 48 W
- 2701 lm
- 48 lm/W

- Opaque top, pulse-start Metal Halide
- 192 W
- 7812 lm
- 41 lm/W

- Opaque top, clear lens
- SSL
- 25 W
- 854 lm
- 35 lm/W
Post-Top Luminaires

**BENCHMARKS**

**Metal Halide**

- PMH BK10-15 178W
  - 9104 lm
  - 51 lm/W
  - B3 - U5 - G3
  - 14 ft Mounting Height

**LED**

- SSL 10-13 48W
  - 2701 lm
  - 48 lm/W
  - B1 - U1 - G1
  - 14 ft Mounting Height

- SSL 10-27 25W
  - 854 lm
  - 35 lm/W
  - B0 - U2 - G0
  - 14 ft Mounting Height
Post-top Luminaire Assessments

• Consider overall luminaire performance, initial, and projected over life

• Performance analysis of complete lighting system
  – Mounting height, spacing, position, application requirements…
  – Overall input watts, overall light output
  – Average illuminance & uniformity
  – Light distribution, glare, uplight
  – Color

• 1 out of 4 has complete, accurate manufacturer claims
  – Manufacturer does not publish data on opaque-top benchmark!
  – One SSL product supplies overstated data (by 25%)
  – One SSL product supplies no data and performs poorly

CAUTION: Published photometric data for the exact luminaire is necessary to evaluate and compare performance.
Linear Replacement in Troffers

• Tested as bare lamps and in parabolic louvered troffer
• Compared to T8 fluorescent tubes in
  – Same parabolic louvered troffer
  – Architectural (high performance) troffer
  – Single lamp, high performance troffer
Linear Replacement in Troffers

- Two SSL T8 lamps in parabolic louvered troffer
- Compared to two fluorescent T8 lamps in architectural troffer
- Compared to one fluorescent T8 lamp in high performance troffer
- Luminaire efficacy: similar for SSL/troffer systems vs fluorescent/troffer systems
- Luminaire light output: 2 lamp SSL/troffer systems just reaching output level of 1 lamp fluorescent system
Linear Replacement in Troffers

**Overall Luminaire Performance of 48” Replacements Lamps in Troffers**

- **Benchmarks of Troffers Using Two T8 Lamps**
- **Benchmark of Troffer with Single T8 Lamp**

---

**Same parabolic troffer used for SSLs as for this fluorescent benchmark**

- **SSL Lamps in Parabolic Louvered Troffer, Round 11**
- **SSL Lamps in Parabolic Louvered Troffer, Round 9**
- **SSL Lamps in Parabolic Louvered Troffer, Round 5**
- **Fluorescent T8, High Perf. Single Lamp Troffer, Round 11**
- **Fluorescent T8 Lamp in Volumetric High Perf. Troffer, Round 9, BF=0.88**
- **Fluorescent T8 Lamp in Volumetric High Perf. Troffer, Round 9, BF=1.18**
- **Fluorescent T8 Lamp in Parabolic Louvered Troffer, Round 5**
- **Fluorescent T12 Lamp in Prismatic Lens Troffer, Round 5**

- **Efficacy = 40 lm/W**
- **Efficacy = 60 lm/W**
- **Efficacy = 75 lm/W**
BUT,

- SSL T8 lamps in parabolic louvered troffer definitely **do not** provide light distribution breadth or intensity of fluorescent T8 lamps

- Tested in the same troffer, SSL T8 lamps have lower spacing criteria (SC) implying **more** fixtures will be needed for installed systems
## Linear Replacement in Troffers

<table>
<thead>
<tr>
<th>CALiPER Sample</th>
<th>Manufacturer Claimed CCT</th>
<th>Target CCT Range (K)</th>
<th>Target $D_{uv}$</th>
<th>CALiPER Measured CCT (K)</th>
<th>CALiPER Measured $D_{uv}$</th>
<th>Both CCT and $D_{uv}$ Within Tolerance?</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-16</td>
<td>5000K (nominal CCT)</td>
<td>4717-5283</td>
<td>-0.004 to 0.008</td>
<td>5394</td>
<td>-0.004</td>
<td>NO</td>
</tr>
<tr>
<td>10-17</td>
<td>3400K (flexible CCT)</td>
<td>3178-3622</td>
<td>-0.006 to 0.006</td>
<td>3249</td>
<td>0.007</td>
<td>NO</td>
</tr>
<tr>
<td>10-19</td>
<td>4000-4500K (two nominal CCTs)</td>
<td>3725-4745</td>
<td>-0.005 to 0.007</td>
<td>5091</td>
<td>0.008</td>
<td>NO</td>
</tr>
<tr>
<td>10-36</td>
<td>4100K (flexible CCT)</td>
<td>3803-4397</td>
<td>-0.005 to 0.007</td>
<td>4300</td>
<td>0.012</td>
<td>NO</td>
</tr>
<tr>
<td>BK09-67</td>
<td>3500K (fluorescent nominal CCT)</td>
<td>Fluorescent 3500K, $x=0.411$, $y=0.393$</td>
<td>4-step MacAdam Ellipse</td>
<td>(\text{CCT}= 3248, \ x=0.4227, \ y=0.4033)</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>BK10-34</td>
<td>3500K (fluorescent nominal CCT)</td>
<td>Fluorescent 3500K, $x=0.411$, $y=0.393$</td>
<td>4-step MacAdam Ellipse</td>
<td>(\text{CCT}= 3387, \ x=0.4163, \ y=0.4056)</td>
<td>YES/NO*</td>
<td></td>
</tr>
</tbody>
</table>

Target CCT and $D_{uv}$ ranges as defined for LED products in ANSI_NEMA_ANSLG C78.377-2008 and for fluorescents as defined in ANSI C78.376-2001.

*Sample BK10-34 would meet target CCT and $D_{uv}$ ranges for SSL products (based on a 7-step MacAdam Ellipse), but does not fall within the tighter, 4-step MacAdam Ellipse, range required for fluorescent products.

### Color quality discrepancies with all tested troffer systems
- Products do not meet manufacturer claims for CCT
- $D_{uv}$ places chromaticity outside of tolerances for white light

### Chromaticity tolerances for fluorescent are tighter than for SSL, the benchmarks fail to meet their tighter tolerances

### Large variations in chromaticity can result in perceptible variation in color and can increase color matching challenges in the long-term
Issues

• Efficacy is increasing, but be careful to look at luminaire efficacy
• Light output does not achieve levels of fluorescent (for same number of lamps in same troffer)
• Light distribution does not achieve levels and broad distribution of fluorescent
• Color quality not within tolerances and poorer than fluorescent
• Reliability is problematic (samples failing, so in situ testing not possible on all products)
• Variety of wiring and driver approaches introduces challenges for retrofitting
• Manufacturer equivalency claims are misleading

Caution: These SSL T8 lamps are NOT direct replacements for T8 fluorescent lamps
MR16 Replacement Lamps

Benchmark values are based on CALiPER benchmark tests, surveyed ratings, and averaged manufacturer ratings for 20W MR16 halogen lamps. Values are based on initial output, not average life-time output, 12V AC or DC input.
MR16 Replacement Lamps

Center Beam Intensity for MR16 Equivalent Lamps

- Round 11 SSL MR16
- Earlier SSL MR16 Tests
- 20W Halogen Minimum
- 35W Halogen Minimum
- 20W Halogen Benchmarks
- 35W Halogen Benchmarks

- 35W Halogen MR16 Benchmark Samples
- CALiPER Sample 10-30
- CALiPER Sample 10-02
MR16 SSL Replacement Lamps

• Recent SSL MR16 samples are meeting or close to meeting light output and CBCP levels of 20W halogen MR16
• Not yet achieving light output and CBCP of 35W halogen
• Significantly surpassing halogen MR16 in efficacy
• Warm-white CCT and good or passable CRI
• Product 10-30 with Lighting Facts label meets claims
• Sample 10-30 would meet ENERGY STAR® photometric criteria for integral LED lamps

• Attention
  – Lamps exceed standard maximum length
  – One lamp “not for use in totally enclosed fixtures”
PAR38 and PAR30 Replacement Lamps

Earlier CALiPER Rounds

CALiPER Round 11 PAR30 & PAR38 SSL

Benchmark HIR PAR30 & MH PAR38

Total Light Output (lumens)

0 200 400 600 800 1000 1200 1400 1600

Average Rounds 1-8 (10W) Average Rounds 9-10 (8W) 12W PAR30 11W PAR38 17W PAR38 18W PAR38 25W PAR38 Metal Halide 46W HIR PAR30

Total Efficacy (Im/W)

0 10 20 30 40 50 60 70

Light Output  Efficacy

www.ssl.energy.gov
PAR38 and PAR30 Replacement Lamps

For same beam angle, SSL PAR lamps meet or exceed CBCP of 45W HIR

For same beam angle, SSL PAR lamps do not meet CBCP of 25W CMH

Center Beam Intensity per Beam Angle for PAR Lamps

Note: Halogen 50W & 75W curves based on ENERGY STAR criteria.
PAR38 and PAR30 Replacement Lamps

- Recent SSL PAR30 and PAR38 lamps are meeting or exceeding light output and CBCP levels of 45W HIR
- Significantly surpassing HIR in efficacy
- Not yet achieving light output, CBCP, or efficacy of 25W CMH
- Most products warm-white CCT and good, some with not good color qualities

**Attention**
- Most products do not meet claims, particularly for equivalency claims
- Some lamps not standard format (length, diameter, neck…)
- Some lamps very heavy
Small Omni-Directional Lamps

Claims to be 60W incandescent equivalent

Claims to be 40W incandescent equivalent

Benchmark values are based on CALIPER benchmark tests, surveyed ratings, and averaged manufacturer ratings for Incandescent and CFL lamps. Values are based on initial output, not average lifetime output. Minimum equivalency values are as defined in ENERGY STAR criteria for SSL.
Small Omni-Directional Lamps

- Definite improvement in output and efficacy
- One product exceeding 40W incandescent light output
- One candelabra product meeting 15W incandescent light output
- Most products warm-white CCT and good CRI
- All three products meet numerical ratings

**Attention**
- Two products do not meet equivalency claims
- One lamp exceeds diameter for A19 bulb
- Light distribution for SSL A-lamps is more directional than incandescent A-lamps ("optimized for downlight applications")
Photometric Flicker

- CALiPER flicker study underway
- Waveforms of photometric output
  - Some SSL lamps comparable to incandescent
  - Some SSL lamps exhibit significant amplitude modulation, dropping to zero or close to zero light output with every modulation
  - Huge variety of photometric flicker behavior observed
  - Flicker can be accentuated with dimming
Manufacturer Claims

↑ A majority of SSL products in Round 11 have accurate manufacturer specs

↑ Having Lighting Facts label increases probability of accurate claims (but is not a guarantee)

↓ Many products still provide no ratings or false ratings

↓ Equivalency statements are almost always false or misleading

Lighting Facts Label

<table>
<thead>
<tr>
<th>Nominal wattage of lamp to be replaced (watts)</th>
<th>Minimum initial light output of LED lamp (lumens)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>200</td>
</tr>
<tr>
<td>35</td>
<td>325</td>
</tr>
<tr>
<td>40</td>
<td>450</td>
</tr>
<tr>
<td>60</td>
<td>800</td>
</tr>
<tr>
<td>75</td>
<td>1,100</td>
</tr>
<tr>
<td>100</td>
<td>1,600</td>
</tr>
<tr>
<td>125</td>
<td>2,000</td>
</tr>
<tr>
<td>150</td>
<td>2,600</td>
</tr>
</tbody>
</table>

Grappling with equivalency claims
Bottom Line

• Overall increases in light output, efficacy, light distribution, power factor
• Suitability often depends on application
  – Comparable products are now found in many lighting applications
  – Poor performing products are also found
• Careful comparisons based on accurate performance data is an absolute necessity
  – For most applications and products, in situ checks are vital
• Be wary of subtler quality issues: glare, flicker, color tolerances, physical formats
• Reliability is always a factor (availability of products, shipping damage, failure rates, lumen depreciation…)
CALiPER & Other Resources

- CALiPER reports
  - Summary reports
  - New detailed listings
  - Benchmark Reports
  - Roundtable proceedings
  - Exploratory studies

- NEMA activities
  - Standard development (following best practices whitepaper)
  - With DOE support

www.ssl.energy.gov/caliper.html
The U.S. Department of Energy (DOE) is a federal agency working in the public interest. Published information from the DOE SSL CALiPER Program, including test reports, technical information, and summaries, is intended solely for the benefit of the public, in order to help buyers, specifiers of new SSL products, testing laboratories, energy experts, energy program managers, regulators, and others make informed choices and decisions about SSL products and related technologies. **Such information may not be used in advertising, to promote a company’s product or service, or to characterize a competitor’s product or service.** This policy precludes any commercial use of any DOE SSL CALiPER Program published information in any form without DOE’s express written permission.