



LED Replacement Lamps: Current Performance and the Latest on ENERGY STAR®

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on behalf of the U.S. Department of Energy

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Introductions and Project Background

- Rich Karney, U.S. Department of Energy
- Terry Shoemaker, Pacific Northwest National Laboratory

LED Replacements for Omnidirectional and Directional Incandescent Lamps

- Robert Lingard, Pacific Northwest National Laboratory

Update on ENERGY STAR® for Integral LED Lamps

- Kelly Gordon, Pacific Northwest National Laboratory

Questions & Answers

- Robert Lingard, Kelly Gordon and Jeff McCullough
Pacific Northwest National Laboratory



LED Replacements for Omnidirectional and Directional Incandescent Lamps

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Lighting Scientist
Pacific Northwest National Laboratory
for the U.S. Department of Energy



They're here!

- LED replacement lamps are proliferating in the marketplace.
- U.S. DOE responds:
 - CALiPER testing
 - ENERGY STAR® criteria
 - L.Prize™ competition



Image Credit: GeoBulb™



Image Credit: GBL LED Lighting



Image Credit: EarthLED



What are we replacing?



Image Credit: Smithsonian Institution

- Common incandescent / halogen:
 - *Omnidirectional lamps (e.g., A-lamps)*
 - *Directional lamps (e.g., R, PAR, MR)*
- Characterize via CALiPER testing and manufacturer data.
- Develop ENERGY STAR criteria for high-performing LED products that meet consumer expectations and save energy.



Omnidirectional incandescent lamps

- Most common electric light source in use today.
- Low initial cost, easy to use, but inefficient.
- Familiar performance and format.



A (Arbitrary)



B (Bulged)



C
(Conical)



CA (Conical,
Angular Tip)

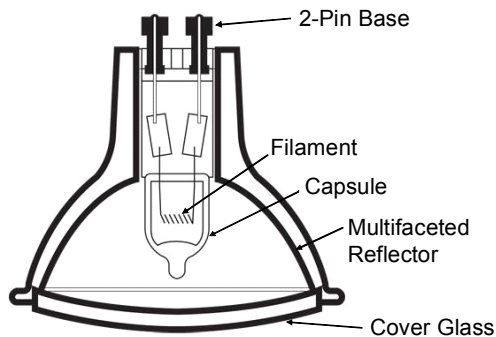


F
(Flame)





Halogen MR16 (directional) lamps



- Common directional light source used in highlighting and accent applications.
- Compact filament and reflector design allow precise optical control.
- Wide variety of distributions (e.g., flood, spot) and intensities (i.e., CBCP).



LED replacement lamps

- Emerging technology.
- Potential for high efficiency and long life.
- Manufacturer claims!
- Variety of formats.
- How do they perform? Are they worth the extra cost?





CALiPER benchmark testing

Omnidirectional:

- A-Lamps (25W, 40W and 60W).
- Decorative candelabra-style lamps (4-25W).
- Evaluated manufacturer data for > 400 incandescent lamps; tested six lamps.
- Compared with test results for 10 LED replacement lamps.

CALiPER





CALiPER benchmark testing

MR16 (directional):

- Focused on 20W MR16 products.
- DOE evaluated manufacturer data for > 60 halogen MR16 lamps; tested six lamps.
- Compared with test results for 10 LED replacement lamps.

CALiPER





CALiPER benchmark testing

Lamp characteristics:

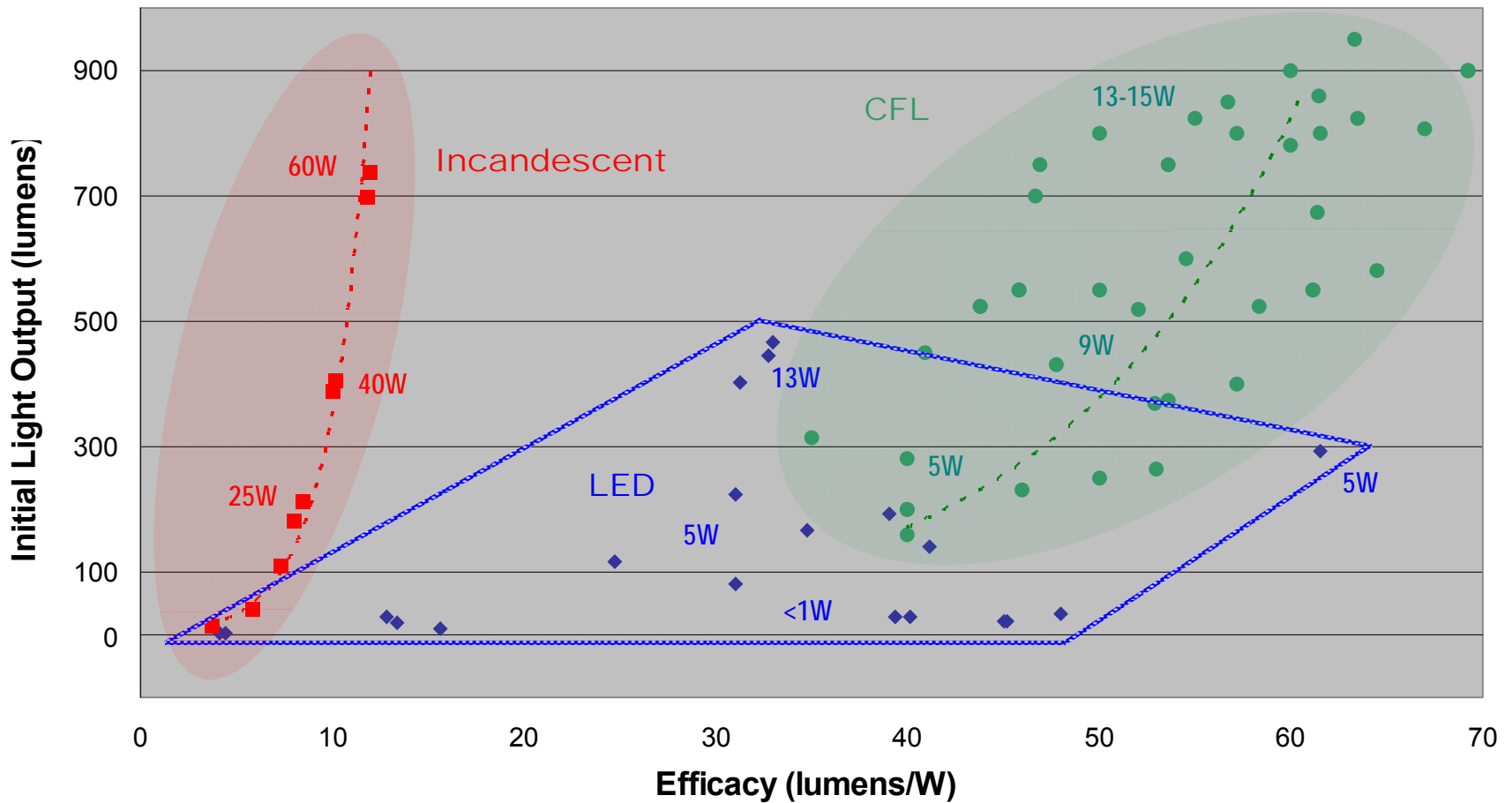
- Light output and efficacy (initial)
- Color
- Distribution
- Format and “fit”
- Claimed performance vs. actual

CALiPER



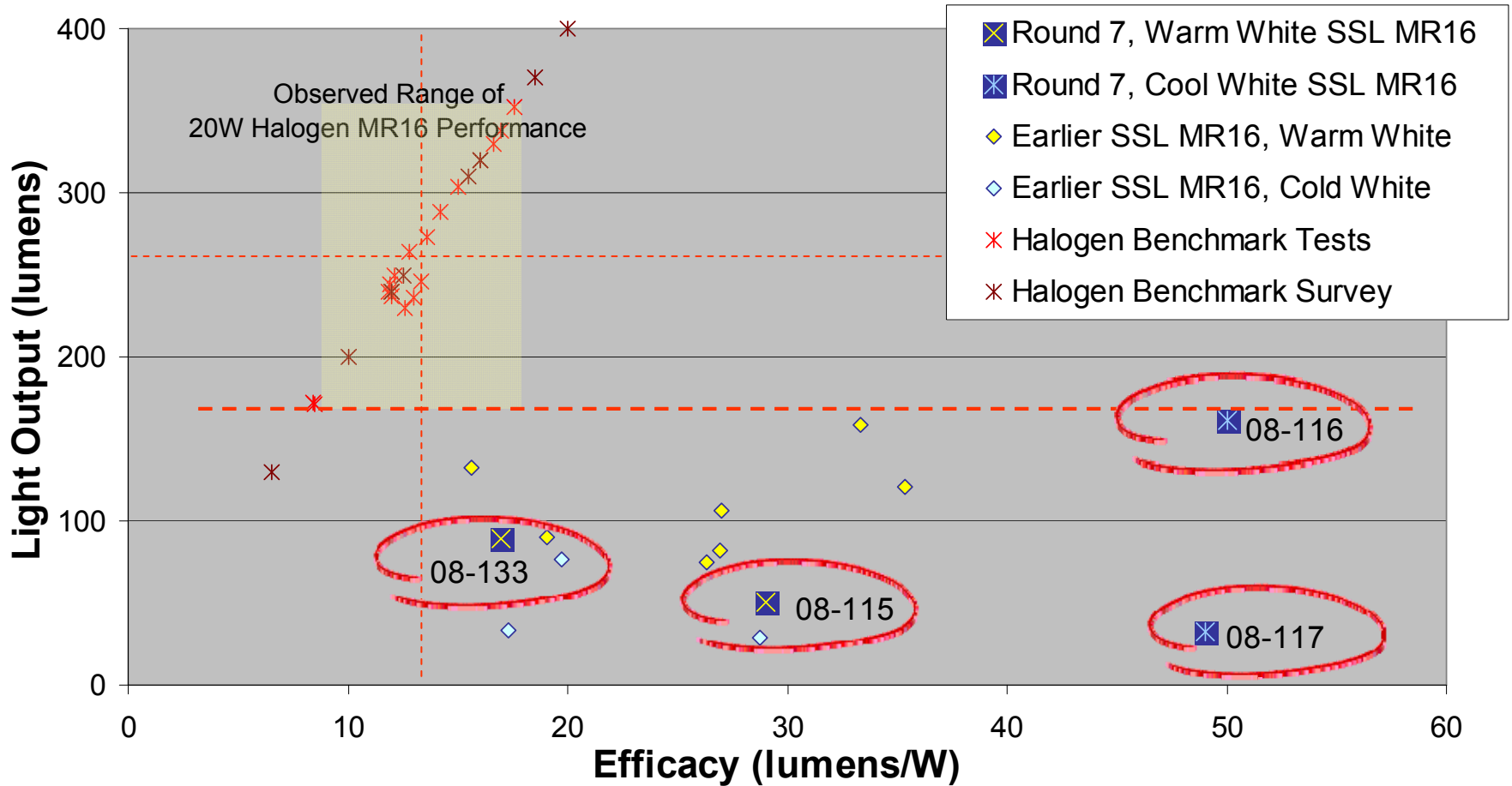


Omnidir. light output and efficacy (initial)





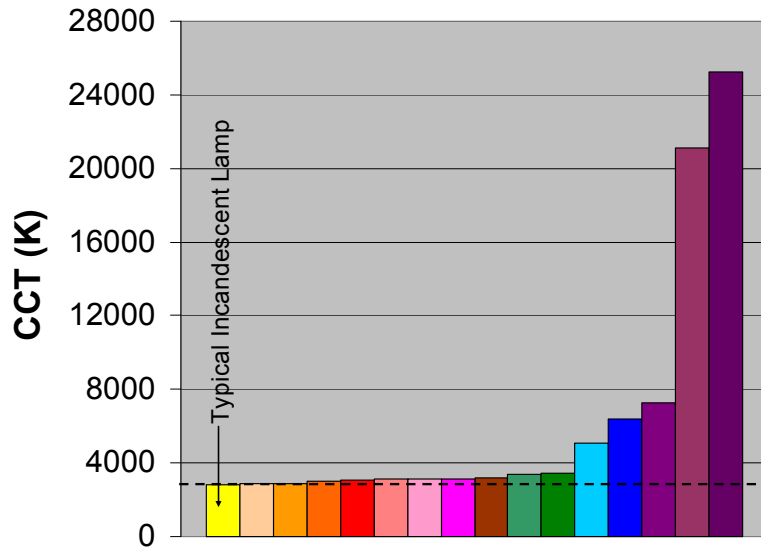
MR16 light output and efficacy (initial)



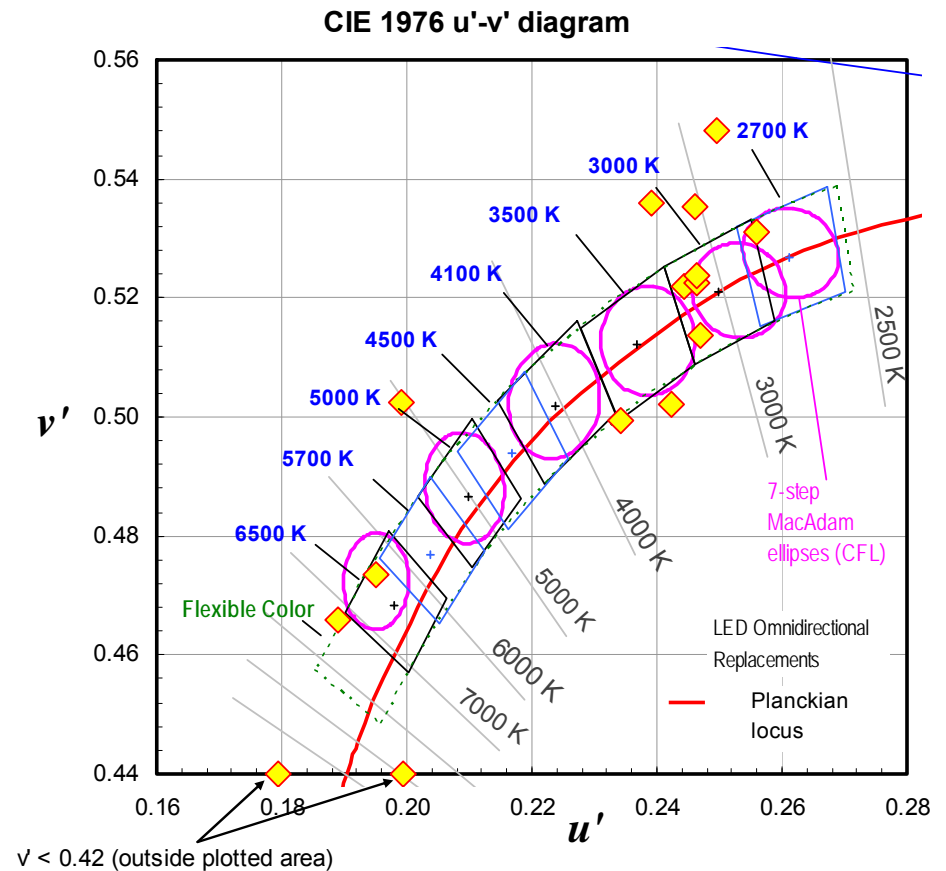


Color characteristics (omnidir. replacements)

Correlated color temperature (CCT)

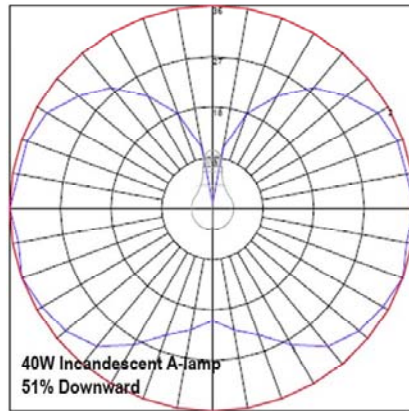


CCT and D_{uv}

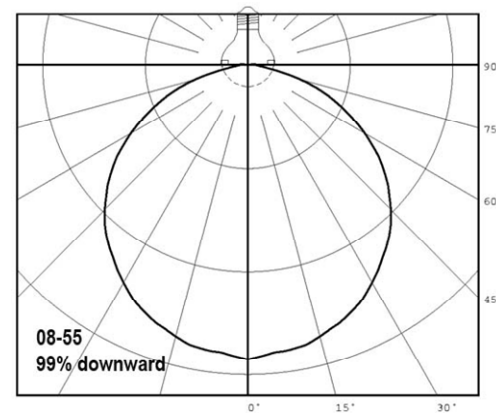




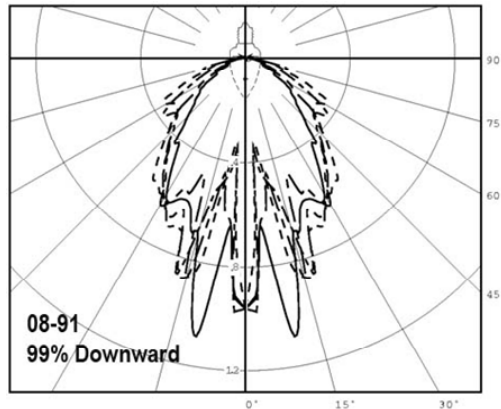
Light distribution (omnidir. replacements)



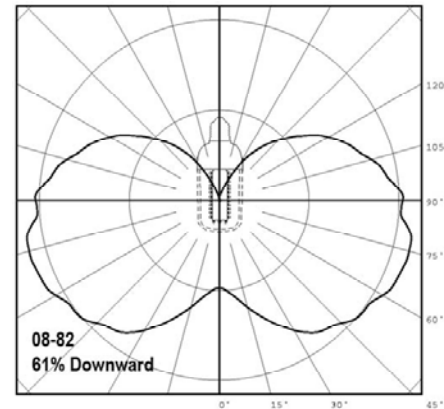
(a) Incandescent A-Lamp Distribution



(b) LED Replacement Lamp
“Flood” Distribution



(c) LED Replacement Lamp
“Spiky” Distribution



(d) LED Replacement Lamp
“Semi-Diffuse” Distribution



Replacements that fit

- Form factor can be an issue.
- Some LED products longer, larger in diameter, or wider at base than lamps they're supposed to replace. Some are **HEAVY**.
- Some LED products similar to A-lamp in shape, but with directional light output.



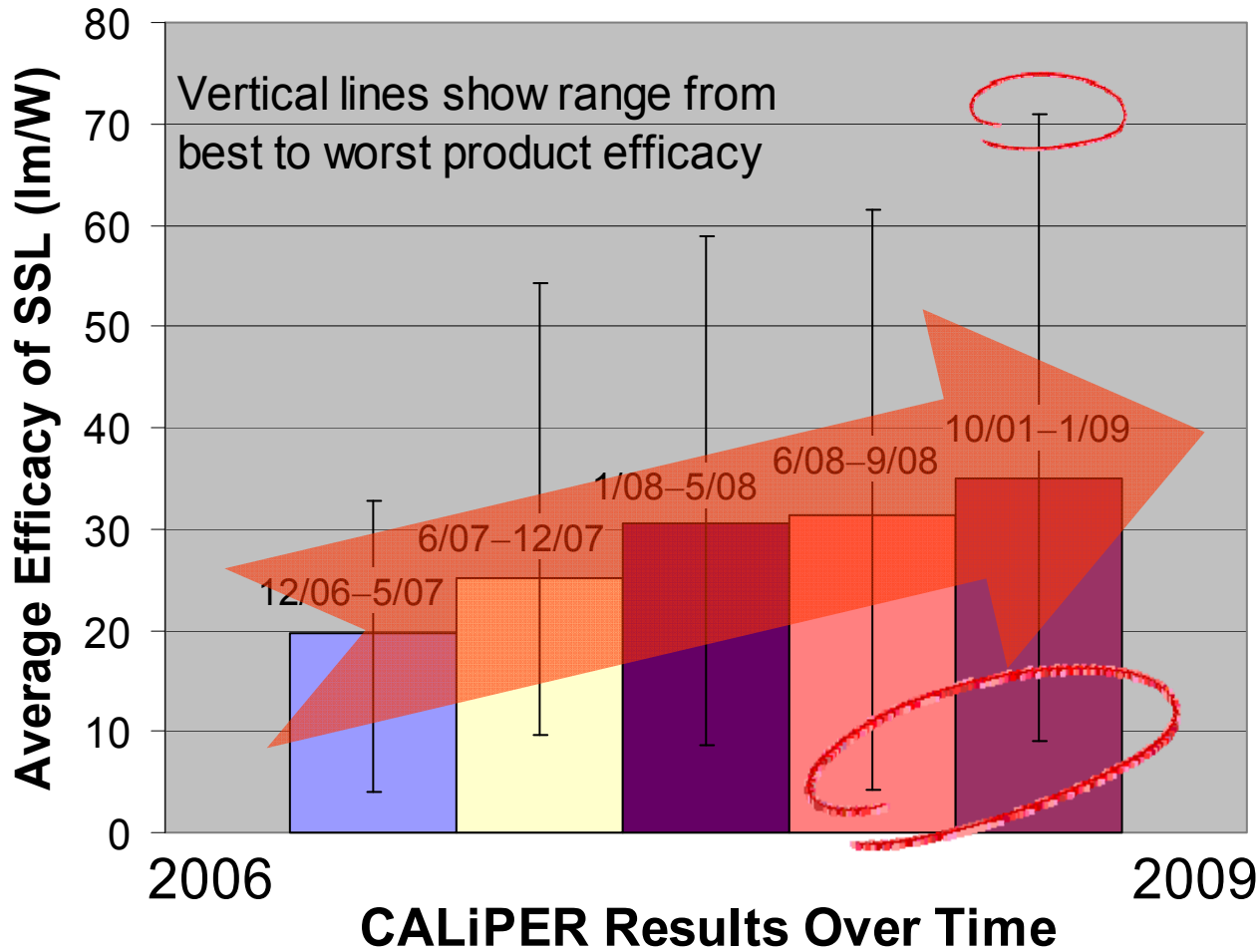


Manufacturer claims

- Most tested LED replacements do not meet performance claims.
- Most products claim equivalency, e.g., “replaces a 40-W lamp,” “90% more efficient than a 60-W lamp.”
- Typically produce only 10-60% of claimed light output.
- Extraordinary life claims (e.g., 50,000 hours or more), yet long-term reliability is largely untested.



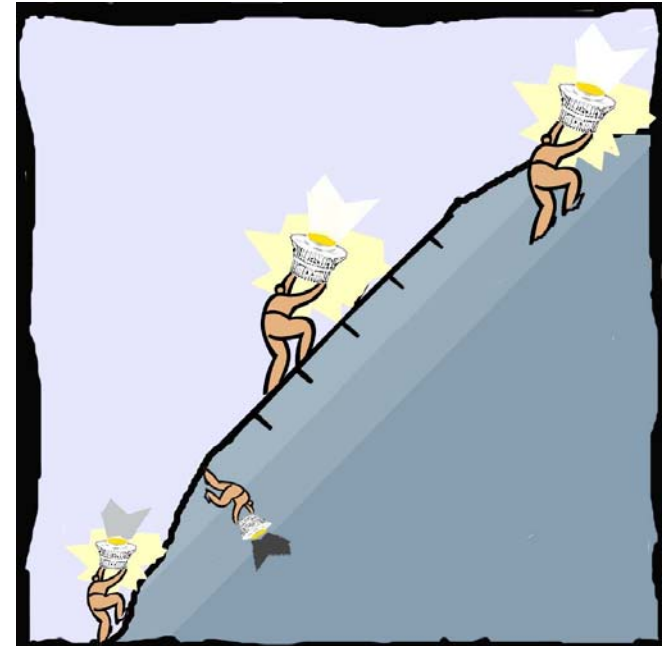
CALiPER Testing: Measurable Progress!





Be Wary of Potential Pitfalls

- **Color**: some 'white' light products are quite 'bluish' or quite greenish
 - Both CCT and D_{uv} matter
- **Comparisons**: verify that LED product performance is based on standardized photometric testing (IES LM-79)
- **Claims**: product literature is often erroneous or misleading
- **Lifetime performance**: true *in situ* long-term performance is still a great unknown
 - Initial lumen maintenance results are mixed
- **Learning curves**: some manufacturers are at the top, many still just setting foot on the slope



Ascending the SSL Learning Curve



Looking for the Full Story?

www.ssl.energy.gov/caliper.html

- Round by round summaries
- Detailed photometric reports
- Benchmark reports
 - Linear replacement lamps
 - MR16 replacement lamps
 - Omni-directional replacement lamps
- Exploratory reports
 - Dimming study
 - Long-term testing study
 - Variability and repeatability study

CALiPER



Update on **ENERGY STAR[®] for Integral LED Lamps**



Kelly Gordon, LC
Pacific Northwest National Laboratory
for the
U.S. Department of Energy



Scope and Schedule

- Includes:
 - Omnidirectional (e.g., A-type)
 - Directional (e.g., MR, PAR type)
 - Decorative (e.g., candelabra type)
 - Lamps using ANSI bases
- 1st draft published Jan 16, 2009
- 1st comment period ended Feb 27
- 2nd draft published May 19
- 2nd comment period ends Jun 26



Why Now?

- Integral LED lamps will soon compete on most performance parameters
- Urgent need for market guidance because many poor performing products already being introduced
- Utilities and others asking for criteria
- Provides targets for manufacturers





Overall Approach

- Products claiming parity with incandescents should perform similarly to lamps they claim to replace
- Should not inhibit innovation; allow for non-standard lamp forms
- Lamps should provide significant energy savings relative to lamps they are intended to replace





Draft 1 Comments

- From 24 organizations including:
 - 20 manufacturers + NEMA/NGLIA
 - 1 utility + CEE (signed by 17 members)
- Support addressing integral LED lamps at this time





DOE Invited Feedback on Key Issues

- Dimming
- Non-standard lamp forms
- Low-voltage MR16s
- Reliability testing





Format for Reviewing Key Issues

What Draft 1 said

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

Integral LED Lamp Draft Criteria

Dimming – Draft 1

- Must be dimmable
- Specific requirements TBD
- Invited stakeholder feedback on:
 - Feasibility of common dimming protocol
 - Need for transition to LED compatible dimmers
 - What DOE and ENERGY STAR can do to help

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Feedback received

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

Integral LED Lamp Draft Criteria

Dimming - Feedback

- Too soon to require all lamps to dim
- Industry needs to develop dimming standards
- DOE should work with industry standards organizations to support development of standards and protocols
- DOE should consider role for step dimming and interactions with utility load management programs

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What Draft 2 says New/revised in blue

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

Integral LED Lamp Draft Criteria

Dimming – Draft 2

- NOTE: DOE has engaged industry expert to spearhead dimming standards development
- Lamps may be dimmable or non-dimmable
 - Require label to clearly state "dimmable" or "non-dimmable"
- 3-way or other step dimming allowed
- All lamps must be "dimmer safe"
 - No catastrophic failure when operated on dimming circuit
- Must have web page providing dimmer compatibility information
- Must carry warning label

This product may not be compatible with all dimmers. Please see [URL] for up-to-date dimmer compatibility information.

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Dimming – Draft 1

- Must be dimmable
- Specific requirements TBD
- Invited stakeholder feedback on:
 - Feasibility of common dimming protocol
 - Need for transition to LED compatible dimmers
 - What DOE and ENERGY STAR can do to help



Dimming – Feedback

- Too soon to require all lamps to dim
- Industry needs to develop dimming standards
- DOE should work with industry standards organizations to support development of standards and protocols
- DOE should consider role for step dimming and interactions with utility demand response programs



Dimming – Draft 2

- NOTE: DOE has engaged industry expert to coordinate dimming standards development
- Lamps may be dimmable or non-dimmable
 - Require label to clearly state “dimmable” or “non-dimmable”
- 3-way or other step dimming allowed
- All lamps must be “dimmer safe”
 - No catastrophic failure when operated on dimming circuit
- Must have web page providing dimmer compatibility information
- Must carry warning label

This product may not be compatible with all dimmers. Please see [URL] for up-to-date dimmer compatibility information.



Non-Standard Lamps – Draft 1

- Luminous efficacy: 55 lm/W
- Minimum lumens: 400
- Must provide LM-79 goniophotometer report
- Must indicate intended applications
- Invited stakeholder feedback on:
 - Need to specify intensity distribution and minimum lumens
 - Limits on product claims and equivalency to avoid misleading consumers
 - How to avoid performance loopholes



Non-Standard Lamps – Feedback

- Address expectations through labeling
 - Indicate appropriate applications, perhaps through checklist of most common
 - Should indicate beam distribution
- Question need for minimum lumens
- Agree statements of equivalency to existing lamps should not be allowed



Non-Standard Lamps – Draft 2

- Luminous efficacy: 55 lm/W
- Minimum lumens: 400
- Must provide LM-79 (Sec. 10) goniophotometer report (LM-63 .ies file)
- Labeling must show beam distribution in simple graphical form
- Labeling must indicate intended applications

Example graphics:





Low-Voltage MR16s – Draft 1

- Invited stakeholder feedback on:
 - How to address compatibility of LED MR16 lamps with existing low-voltage transformers
 - How to address minimum load issues



Low-Voltage MR16s – Feedback

- Clear labeling and instructions for use with existing fixtures is needed
- Transition to new electronic low-voltage transformers with lower load requirements
- Require testing with low-voltage transformers, in multiple lamp combinations
- No stakeholders suggested excluding this lamp category



Low-Voltage MR16s – Draft 2

- Manufacturers must provide results of in-house testing of their LED MR16 lamps on commercially-available low-voltage transformers
- Labeling must identify known incompatibilities
- Must have web page containing low-voltage transformer compatibility information
- Must carry warning label

This product may not be compatible with all transformers used in low-voltage fixtures. Please see [URL] for up-to-date compatibility information.



Reliability – Draft 1

- Minimum 6,000 hours with at least 10 samples tested under elevated temperature conditions
- Average lumen maintenance of the 10 samples tested must be greater than 91.8% after 6,000 hours of operation, and no more than 3 individual samples can have a lumen output less than [87%]
- Invited stakeholder feedback on:
 - What requirements should be considered to minimize the likelihood of premature failure of ENERGY STAR qualified integral LED lamps
 - Duration of testing needed to verify long-term performance



Reliability – Feedback

- Need industry standard test procedures
- Suggest burn-in (4 hrs @ 60°C) or pre-burn (24 hrs @ 25°C)
- Suggest HALT (highly accelerated life testing) with acceleration factors for each component
- Suggest 45°C for immediate elevated temperature test
- Suggest life (6000 hr) testing at 25°C ambient



Reliability – Draft 2

Lumen maintenance:

- LM-80 for LED devices or modules used in lamp
- Lamp TMP verification

Reliability tests under consideration:

- Burn-in test (4 hours at 60°C)
 - NEMA proposed to define a procedure
 - To weed out weak electronic components
- Wet high temperature operating life test (WHTOL)
 - Ref std: EIA/JESD22-A101-B (EIA and JEDEC)
 - Temp, humidity, power cycling, total time to be determined
- Elevated temperature testing + rapid cycling stress testing



Key Draft Criteria

- CCT: 2700 K, 3000 K, 3500 K, or 4000 K
 - Add D_{uv} tolerances per ANSI C78.377
- CRI: minimum 80
- Product equivalency claims: if referencing a standard ANSI lamp type, cannot claim higher wattage equivalency than level approved under ENERGY STAR



Omnidirectional Lamp Draft Requirements

- Applies to ANSI lamps: A,G,P,PS,S
- Draft 1: 55 lm/W for all
- **Draft 2: differs by LED lamp power**
 - 50 lm/W for < 10 watts LED lamp power
 - 55 lm/W for ≥ 10 watts LED lamp power





Omnidirectional Lamp Draft Requirements (cont'd)

- Min. lumens based on claimed equivalency, e.g., 800 lm for 60W
- Intensity distribution:
 - Draft 1: within 0° to 150° , shall not differ more than 10% from mean intensity in that zone
 - Draft 2: within 0° to 135° , shall not differ more than 20% from mean intensity in that zone





Decorative Lamp Draft Requirements

- Applies to ANSI lamps: B, BA, BT, C, CA, DC, F
- Draft 1: 45 lm/W
- **Draft 2: 40 lm/W**
- Minimum lumens =
 - Draft 1: target watts x 10
 - **Draft 2: target watts x 7**
- No intensity distribution requirement



B (Bulged)



C (Conical)



F (Flame)



CA (Conical,
Angular Tip)



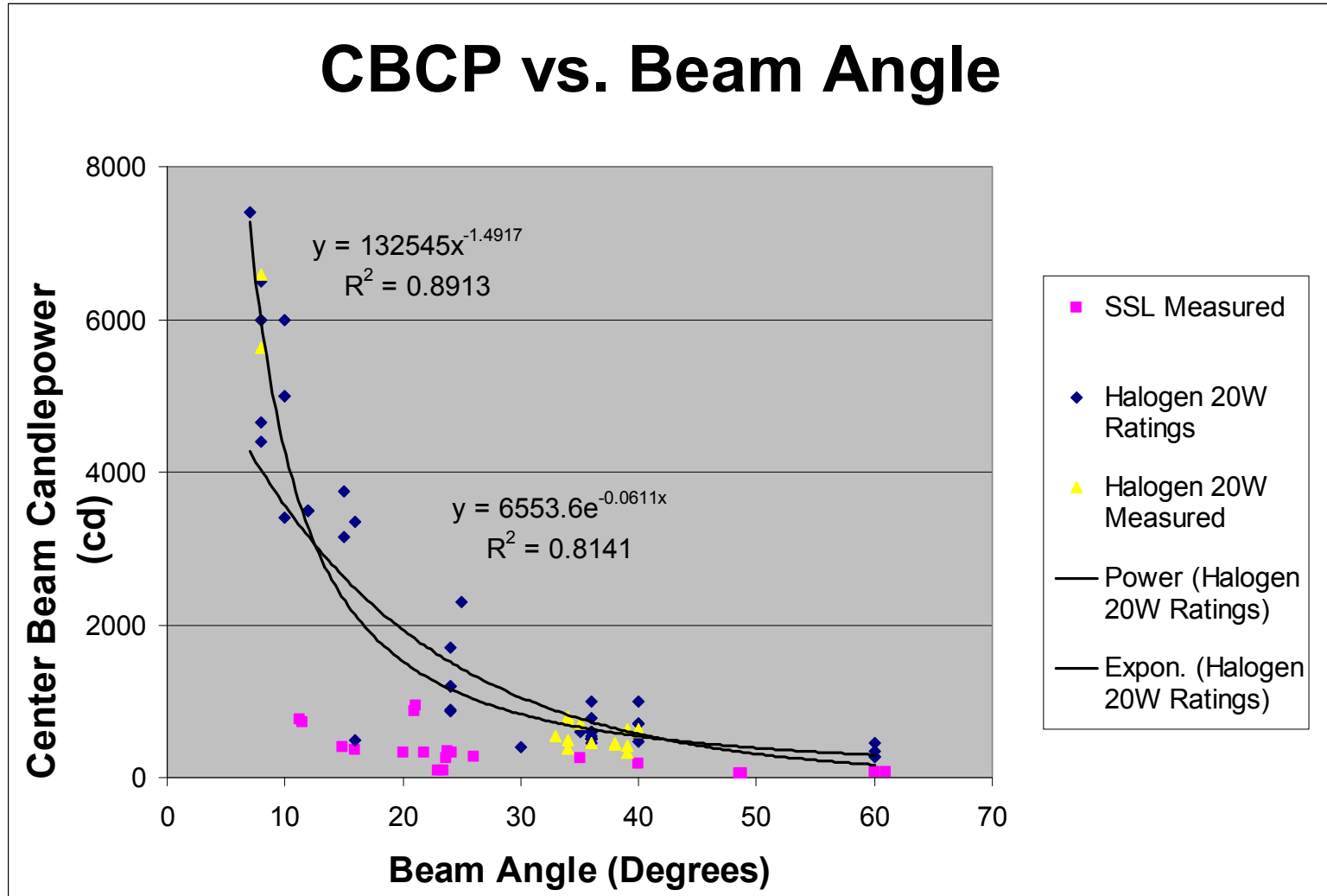
Directional Lamp Draft Requirements

- ANSI lamp shapes:
BR, ER, K, MR, PAR, R
 - PARs: 16/20/30/38
 - MR16
- Draft 1: 45 lm/W for all lamps
- **Draft 2: differs by lamp diameter**
 - 40 lm/W for $\leq 20/8$ " diameter
 - 45 lm/W for $> 20/8$ " diameter
- PAR and MR16 center beam intensity: based on statistical analysis of incandescent/halogen lamps



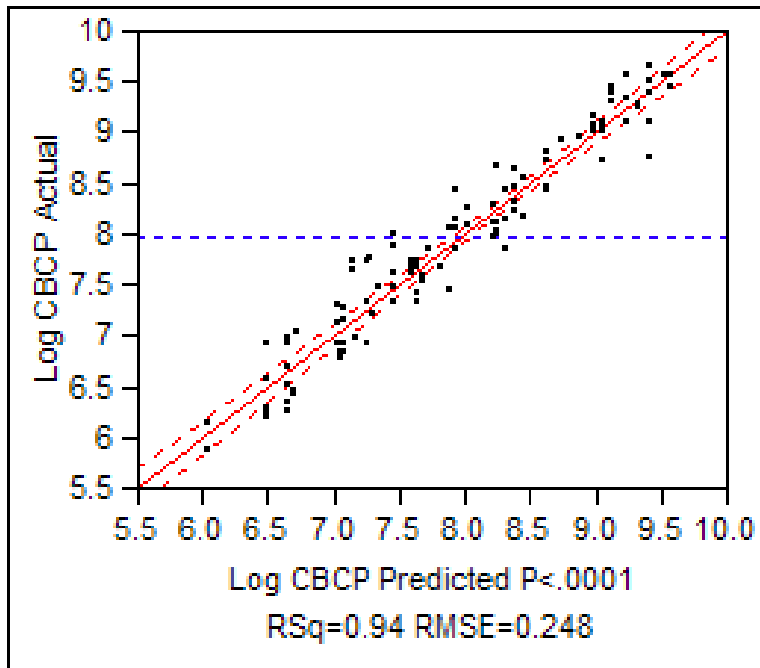


CBCP vs. Beam Angle





Statistical Analysis of Incan/Halogen → Tool for Determining Minimum CBCP



Halogen MR16 lamps, 122 models

- Inputs:
 - target beam angle
 - target lamp wattage
 - PAR lamp diameter
- Output: predicted CBCP
- Minimum required CBCP is 2σ below predicted value of model



PAR, MR16 Beam Requirements

- Relatively uniform gradient across beam angle
 - To avoid “spike” or “hot spot” and steep drop-off within the beam angle
 - Seeking additional stakeholder feedback
- Proposed field angle requirement:
 - Field angle is where intensity is 10% of maximum
 - At $1.3 \times$ beam angle + 3 degrees the intensity should be at least 10% of max candela



Next Steps

- Draft 2 Comments due – June 26, 2009
- Final criteria ~ August 2009





More information

www.energystar.gov

Get updates at: www.ssl.energy.gov



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Thank you!

For more information

DOE ENERGY STAR for SSL
www.ssl.energy.gov/energy_star.html

DOE CALiPER
www.ssl.energy.gov/caliper.html

DOE's Solid State Lighting Program
www.ssl.energy.gov