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

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Presentation Overview

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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PNNL-SA-66480

LED Replacement Lamps

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.

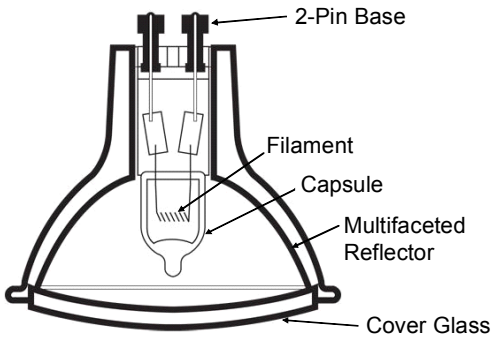
Omnidirectional incandescent lamps

- 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)

LED Replacement Lamps

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

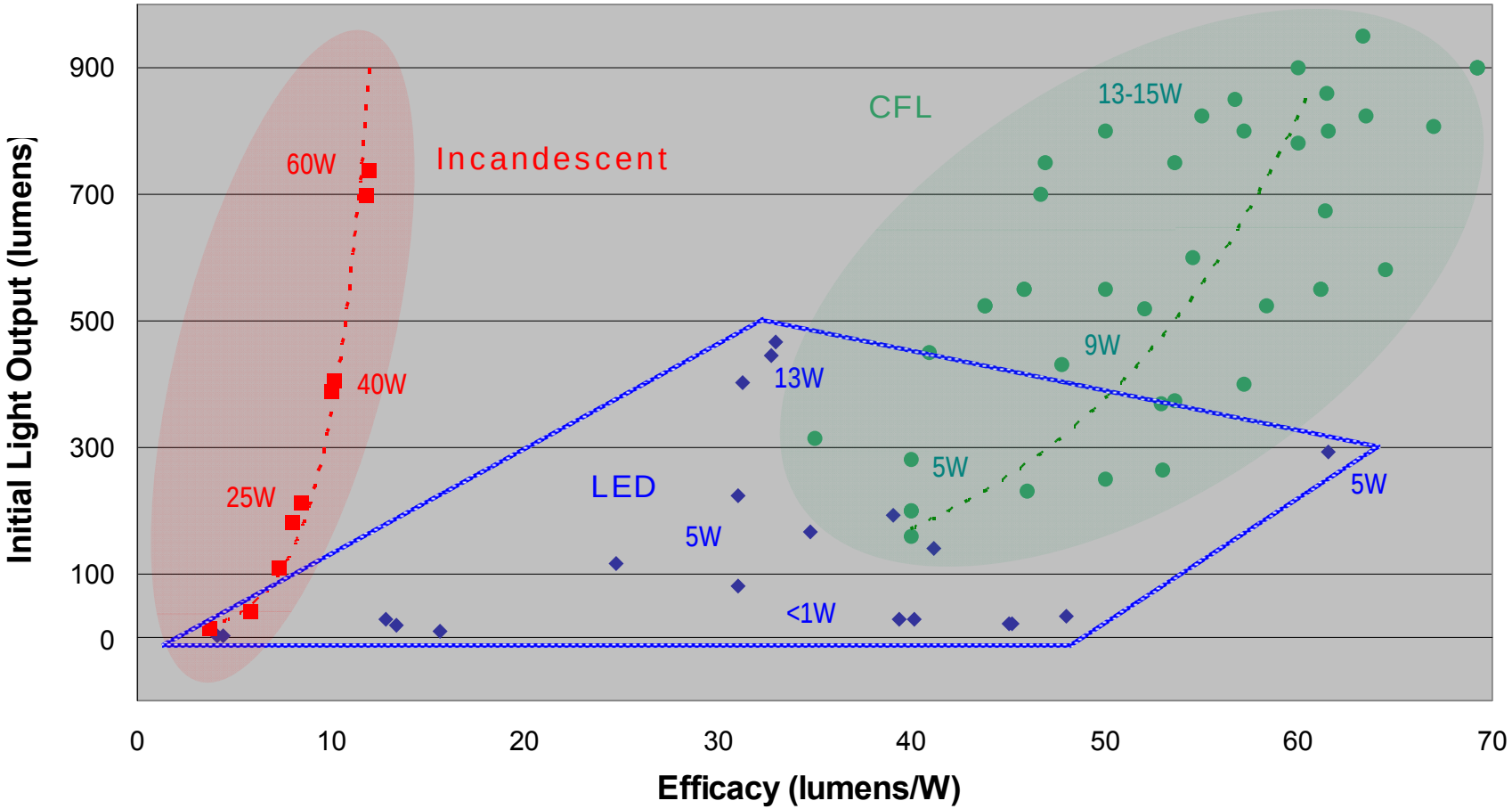
Lamp characteristics:

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

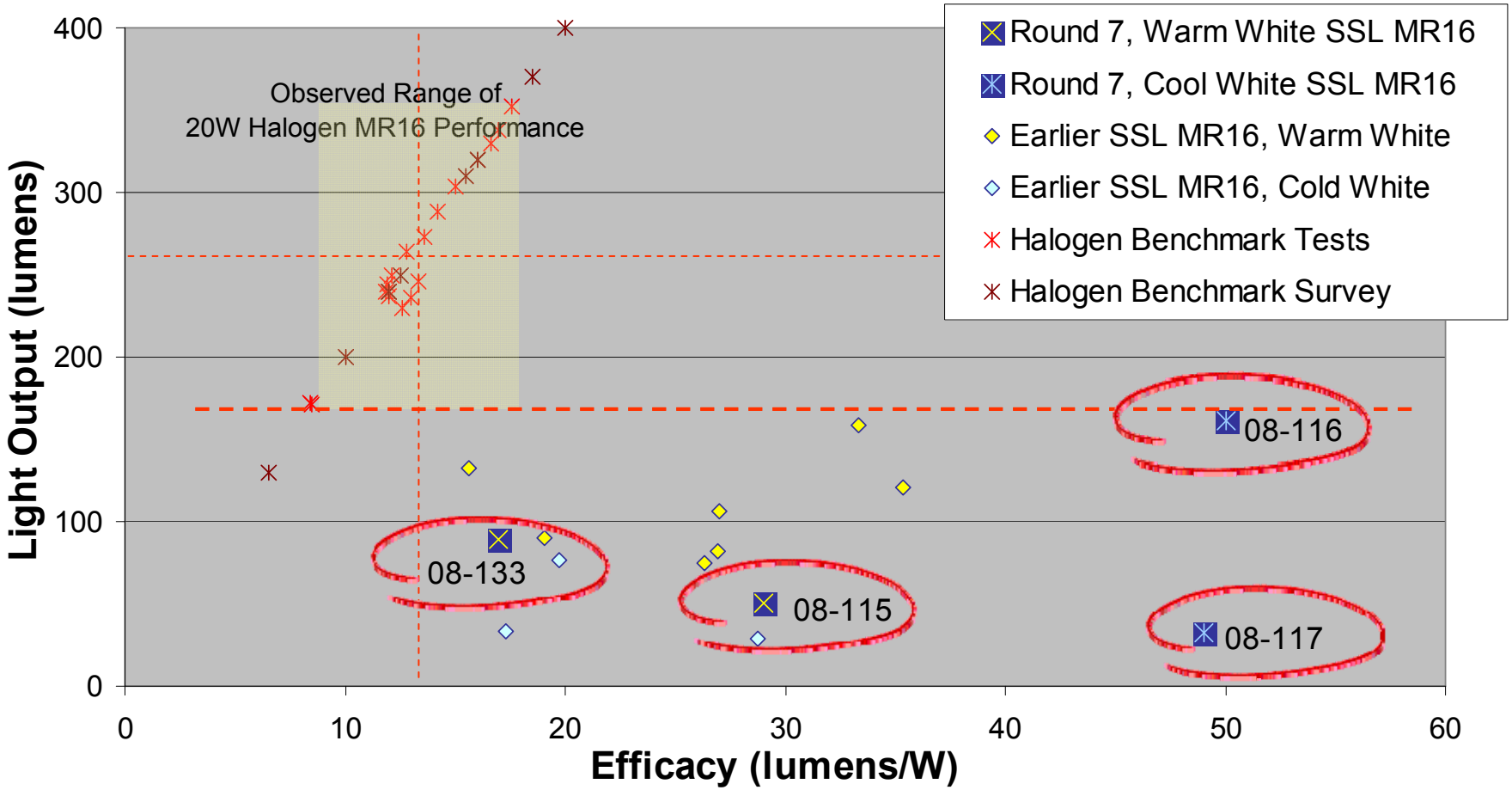
CALiPER

LED Replacement Lamps

Omnidir. light output and efficacy (initial)

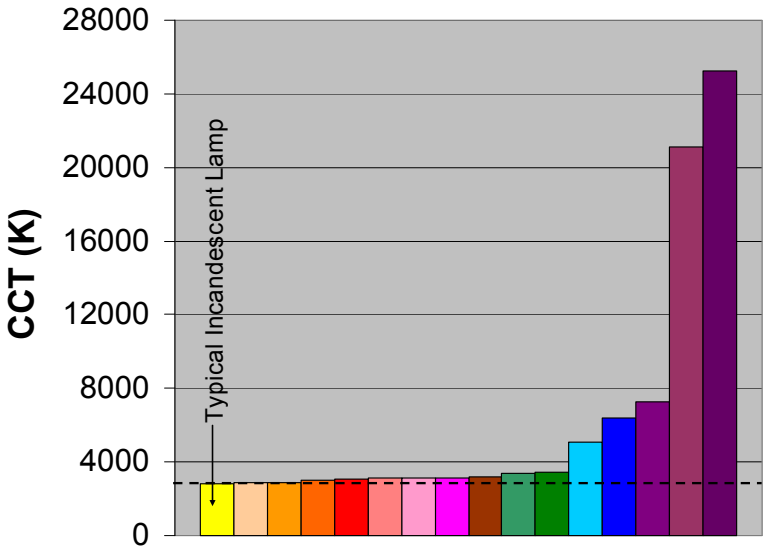


MR16 light output and efficacy (initial)

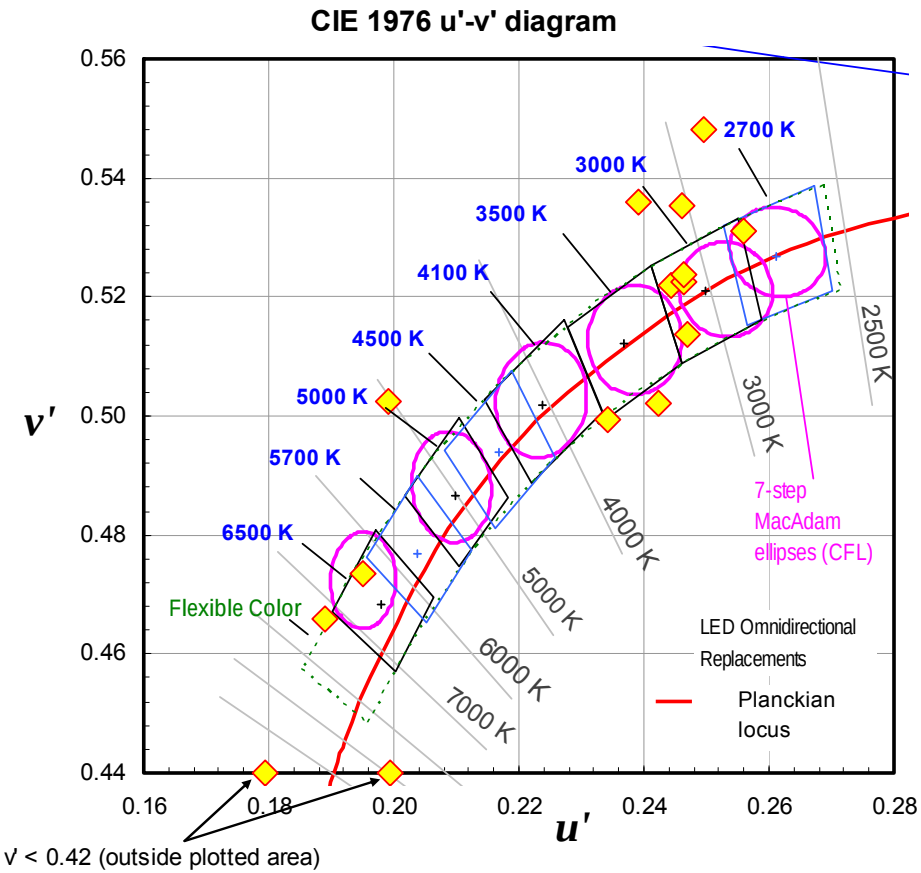


Color characteristics (omnidir. replacements)

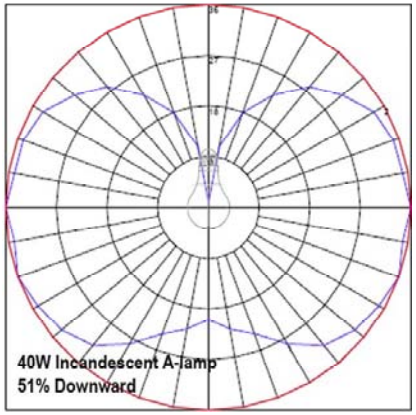
Correlated color temperature (CCT)



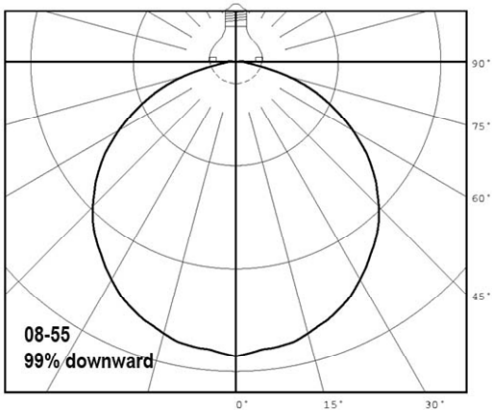
CCT and D_{uv}



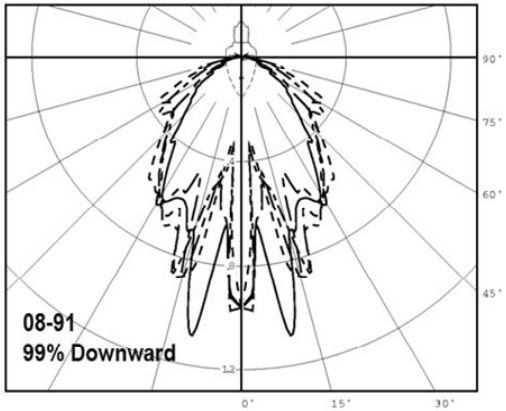
Light distribution (omnidir. replacements)



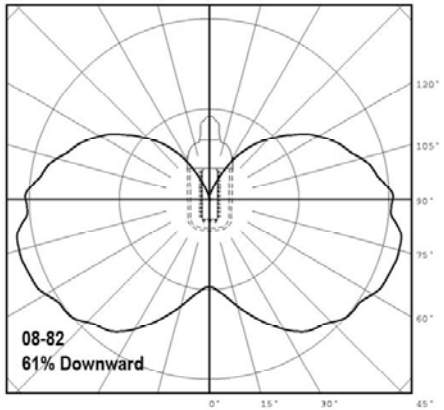
(a) Incandescent A-Lamp Distribution



(b) LED Replacement Lamp "Flood" Distribution



(c) LED Replacement Lamp "Spiky" Distribution



(d) LED Replacement Lamp "Semi-Diffuse" Distribution

LED Replacement Lamps

Replacements that fit

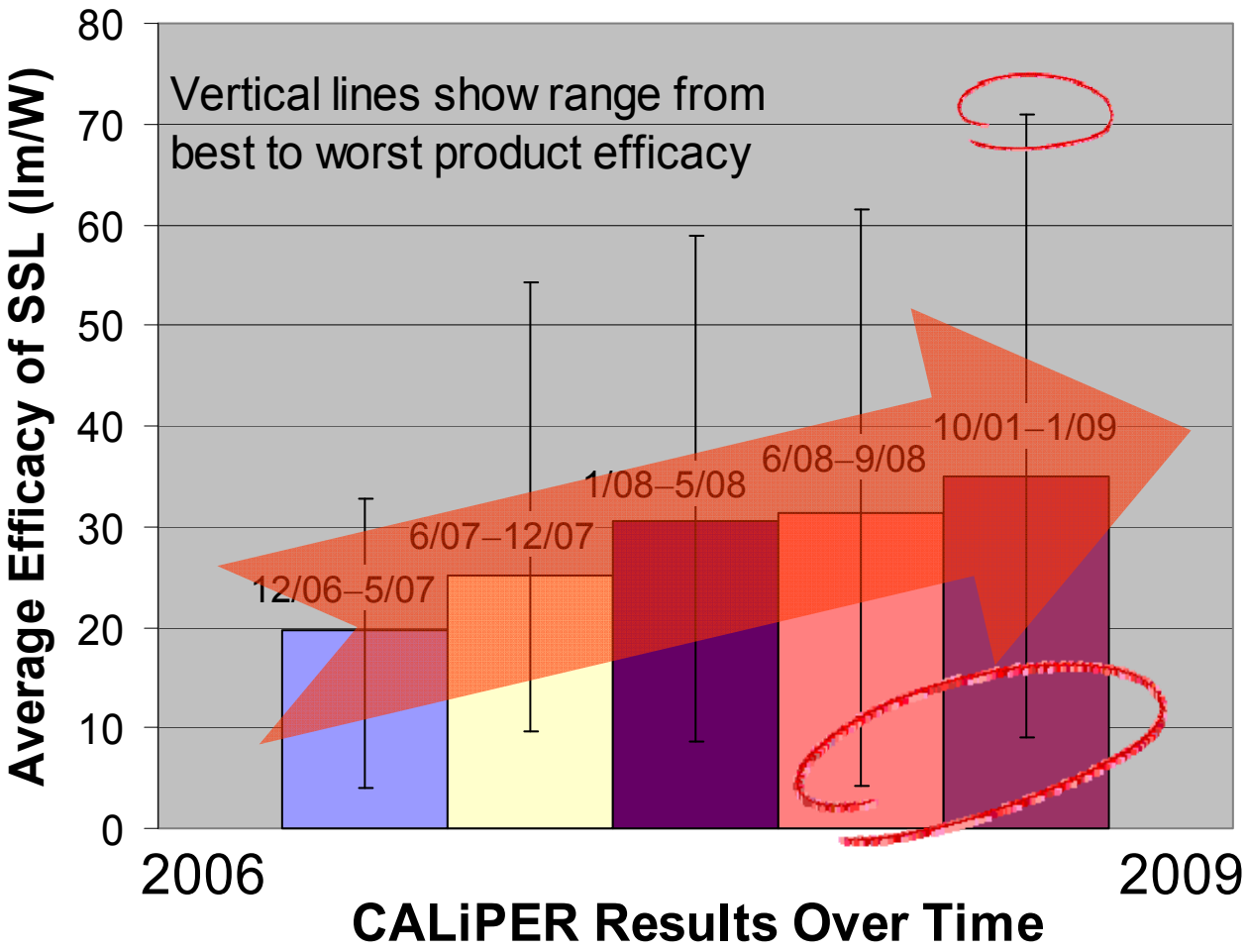
- Form factor can be an issue.
- Some LED products longer, larger in diameter, or wider at base than lamps they're supposed to replace. Some are **HEAVY.**
- Some LED products similar to A-lamp in shape, but with directional light output.

LED Replacement Lamps

Manufacturer claims

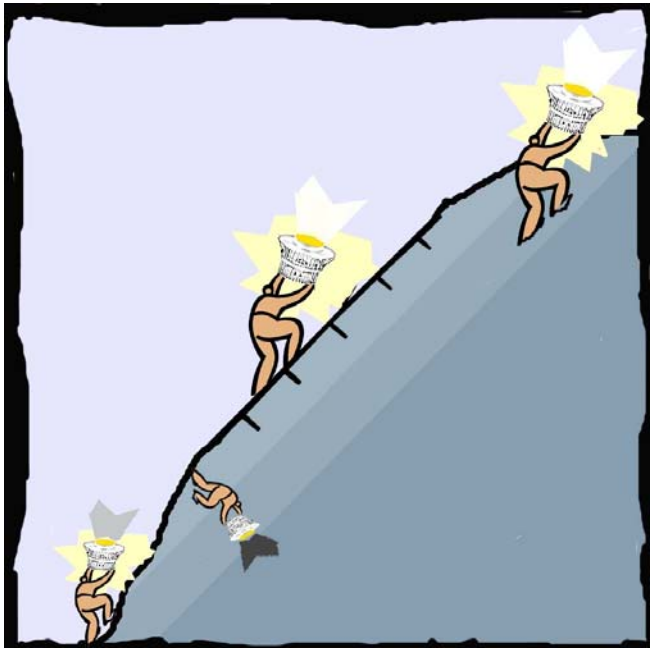
- Most tested LED replacements do not meet performance claims.
- Most products claim equivalency, e.g., “replaces a 40-W lamp,” “90% more efficient than a 60-W lamp.”
- Typically produce only 10-60% of claimed light output.
- Extraordinary life claims (e.g., 50,000 hours or more), yet long-term reliability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

PNNL-SA-66551

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

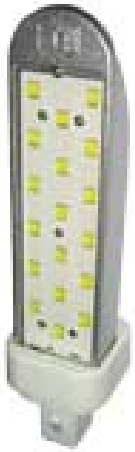
- Products claiming parity with incandescents should perform similarly to lamps they claim to replace
- Should not inhibit innovation; allow for non-standard lamp forms
- Lamps should provide significant energy savings relative to lamps they are intended to replace

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

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

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

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

EIA: Electronic Industries Alliance
JEDEC: formerly Joint Electron Devices Engineering Council

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)

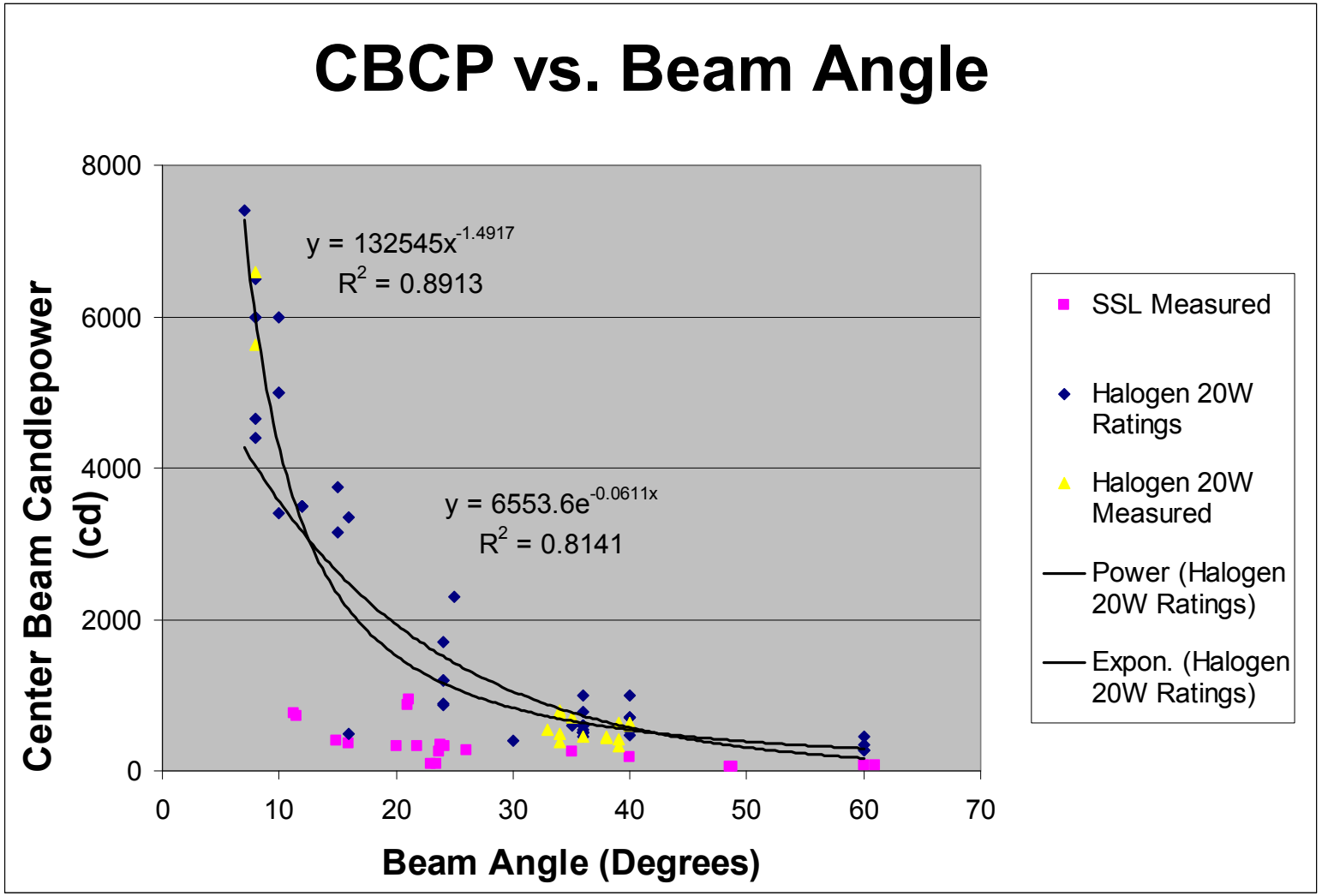
F (Flame)

CA (Conical, Angular Tip)

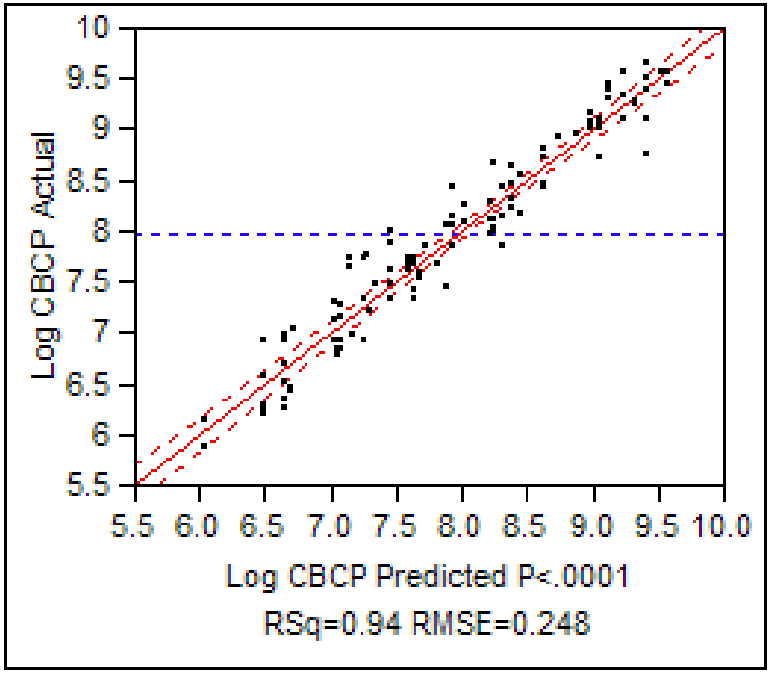
Directional Lamp Draft Requirements

- 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 ≤ 20/8” diameter
  - 45 lm/W for > 20/8” diameter
- PAR and MR16 center beam intensity: based on statistical analysis of incandescent/halogen lamps

Integral LED Lamp Draft Criteria



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 2 σ 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 * 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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ENERGY STAR

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