SORAA Simply Perfect Light™

SORAA Simply Perfect.™

California Energy Commission
DOCKETED
12-AAER-2B
TN # 70726
MAY 09 2013

Submission to California Energy Commission 2013 Rule Making (by email)

Re: Docket No. 12-AAER-2B – Lighting

Documents submitted (attached to email):
Cover Letter Soraa 130507 -pdf
Data for Lighting products - Soraa 130507 –pdf
Data for Light Emitting Diode (LED) Lamps - Soraa 130507 –pdf
Data for small diameter directional MR16 lamps - Soraa 130507 -pdf
A_Critical_Advance_In_MR16_Lamps-Benya – pdf

Soraa expresses its gratitude for the opportunity to submit supporting material for considered energy measures related to lighting appliances.

At Soraa we have specific interest in MR16 lamps, as it is one of the products that we make. We observe that high quality LED MR16 products are available on the market today, that allow the replacement of halogen lamps with no compromise on light quality (>90CRI), light distribution (all beam angles) and light level (50W equivalent and more) while saving 80% of the energy required. In most commercial environments, the annual energy cost savings exceed the purchase cost of the lamp and a less than a year payback can be achieved without energy rebates.

With the support of stakeholders with a background in lighting design, lamp manufacturing and energy production, Soraa advocates standards and rule making that accommodate high quality lighting. For market adoption, it is well documented that consumers and commercial users put priority on quality of light when considering an energy saving light source. Soraa supports the requirements for light quality in the California LED lamp quality specification.

The data that we submit include topics on rendering of white material and requirements for safe use of LED MR16 lamps in different lighting systems. These are important topics for successful adoption of LED based MR16 replacement lamps.

Realizing that the material submitted is a brief summary covering many topics, we offer to provide further explanation to the Energy Commission staff members.

Best regards,

Willem Sillevis Smitt
Sr. Director Product Marketing
SORAA Inc.
wsmitt@soraa.com

SORAA
Simply Perfect Light™

# Data for Small Diameter Directional (MR) Lamps

Provided by Soraa Inc., 6500 Kaiser Drive, Fremont CA 94555

May 2013

# Dimensions along which MR16 lamps of different categories can be categorized

SORAA
Simply Perfect Light™

| Attribute | Categorization |
|---|---|
| Beam angle / profile | Narrow spot 10 degree or less<br>Spot 15 degree<br>Narrow flood 25 degree<br>Wide flood 36 degree<br>Very wide flood 60 degree<br>Beam angle is defined by the full angle at which the lamp maintains >50% of peak intensity |
| Input voltage | 12VAC, requires separate transformer<br>12VDC, requires separate transformer<br>120VAC, mains voltage |
| Lamp base | GU5.3<br>GU10 (twist lock) |
| Lamp output | Best defined by Peak Intensity (Cd)<br>Alternatively by beam lm or beam + field lm .<br>Beam defined by >50% of peak intensity<br>Field defined by >10% of peak intensity |
| Lamp Correlated Color Temperature | 2,700K; 3,000K; 4,000K, etc. |
| Lamp ability to render colors and whites | Available metrics: CRI, R9 or CQS. Preferred is either CRI in combination with R9 or CQS. |
| Lamp fixture requirement | Suitable for fully enclosed fixtures<br>Suitable for damp environments |
| Lamp ability to dim | |
| Lamp power consumption | |
| Lamp technology | Halogen<br>- Halogen IR<br>- Reflector coating type<br>LED |

| Attributes related to applicability | Attributes related to performance |
|---|---|
| Input voltage<br>Lamp base<br>Lamp fixture requirement<br>Lamp ability to dim | Beam angle<br>Correlated Color Temperature<br>Ability to render colors and whites<br>Output<br>Power consumption |

We recommend to categorize lamps by applicability, and rank them based on performance related attributes

# Test data for halogen, halogen-IR and LED lamps

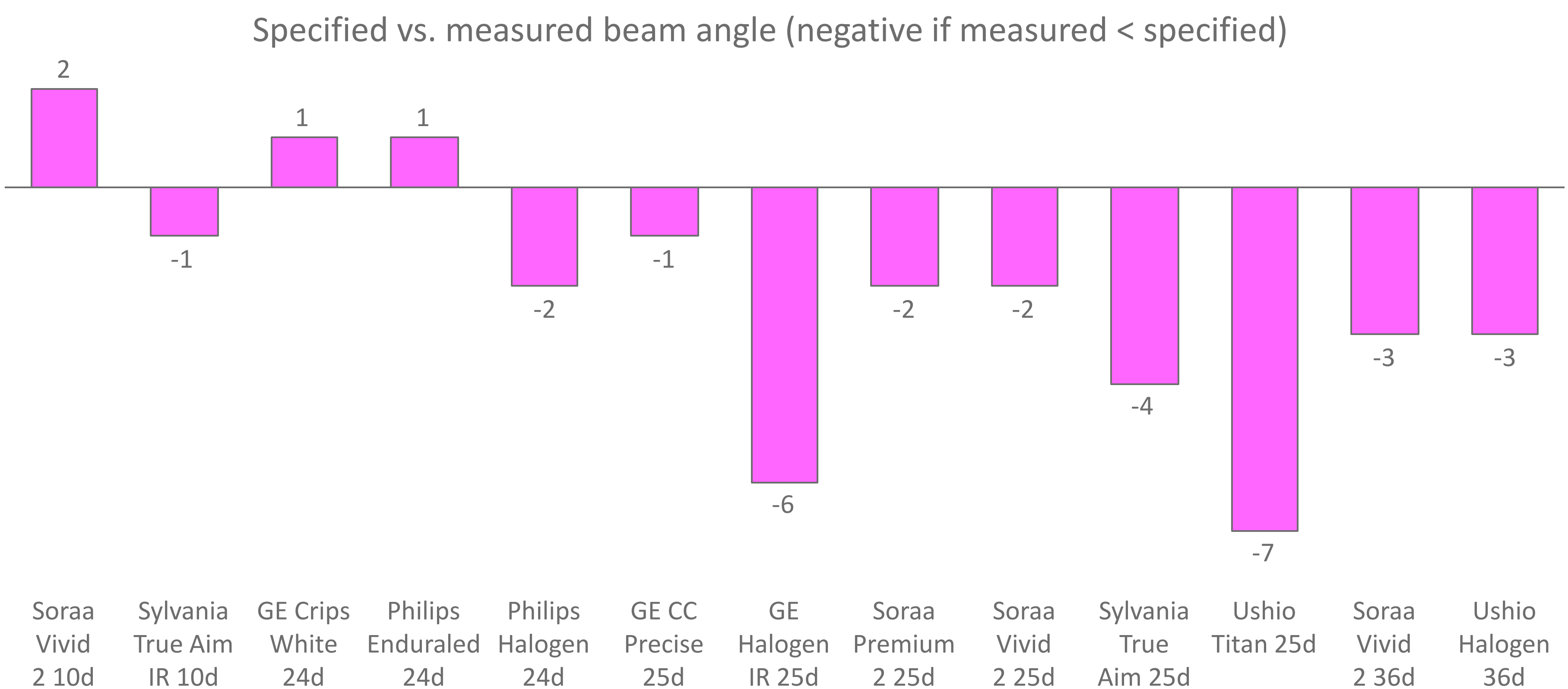
| | |
|---|---|
| Tested lamps | Lamps from multiple manufacturers, across multiple beam angles and different bulb and reflector technologies |
| Measurement method | Intensity profile was measured after thermal stabilization.<br>Lamps driven off 12VAC<br>Measurement device: photo goniometer, 0.5 degree increments, -90 to 90 degree, single axis<br>One lamp per type and measurement |
| Analysis | Lm distribution calculated from intensity profile |
| Definitions | CBCP: maximum intensity<br>Beam angle: total included angle at which intensity is greater or equal to 50% of CBCP<br>Field angle: total include angle at which intensity is greater or equal to 10% of CBCP<br>Spill: light at larger angles than field<br>Accuracy for determining field or beam angle with this method is +/-0.5 degree |

# Test data for halogen, halogen-IR and LED lamps

| Manufacturer | Lamptype | Claimed Beam | Power | CBCP | Actual Beam | Total Lm | Beam Lm | Field Lm |
|---|---|---|---|---|---|---|---|---|
| Soraa | Vivid 2 | 10 | 10 | 6437 | 12 | 396 | 150 | 246 |
| Sylvania | True Aim IR | 10 | 20 | 4464 | 9 | 376 | 62 | 147 |
| GE | Crips White | 24 | 50 | 240 | 25 | 755 | 286 | 513 |
| Philips | Enduraled | 24 | 10 | 1903 | 25 | 451 | 197 | 379 |
| Philips | Halogen | 24 | 50 | 2349 | 22 | 620 | 193 | 377 |
| GE | CC Precise | 25 | 50 | 2278 | 24 | 599 | 216 | 411 |
| GE | Halogen IR | 25 | 37 | 2997 | 19 | 524 | 200 | 326 |
| Soraa | Premium 2 | 25 | 11.5 | 3441 | 23 | 582 | 313 | 466 |
| Soraa | Vivid 2 | 25 | 11.5 | 2890 | 23 | 489 | 263 | 391 |
| Sylvania | True Aim | 25 | 50 | 1975 | 21 | 471 | 146 | 285 |
| Ushio | Titan | 25 | 50 | 3618 | 18 | 622 | 206 | 361 |
| Soraa | Vivid 2 | 36 | 11.5 | 1276 | 33 | 468 | 234 | 386 |
| Ushio | Halogen | 36 | 50 | 1359 | 33 | 587 | 267 | 410 |

# Measured vs. Specified beam angle

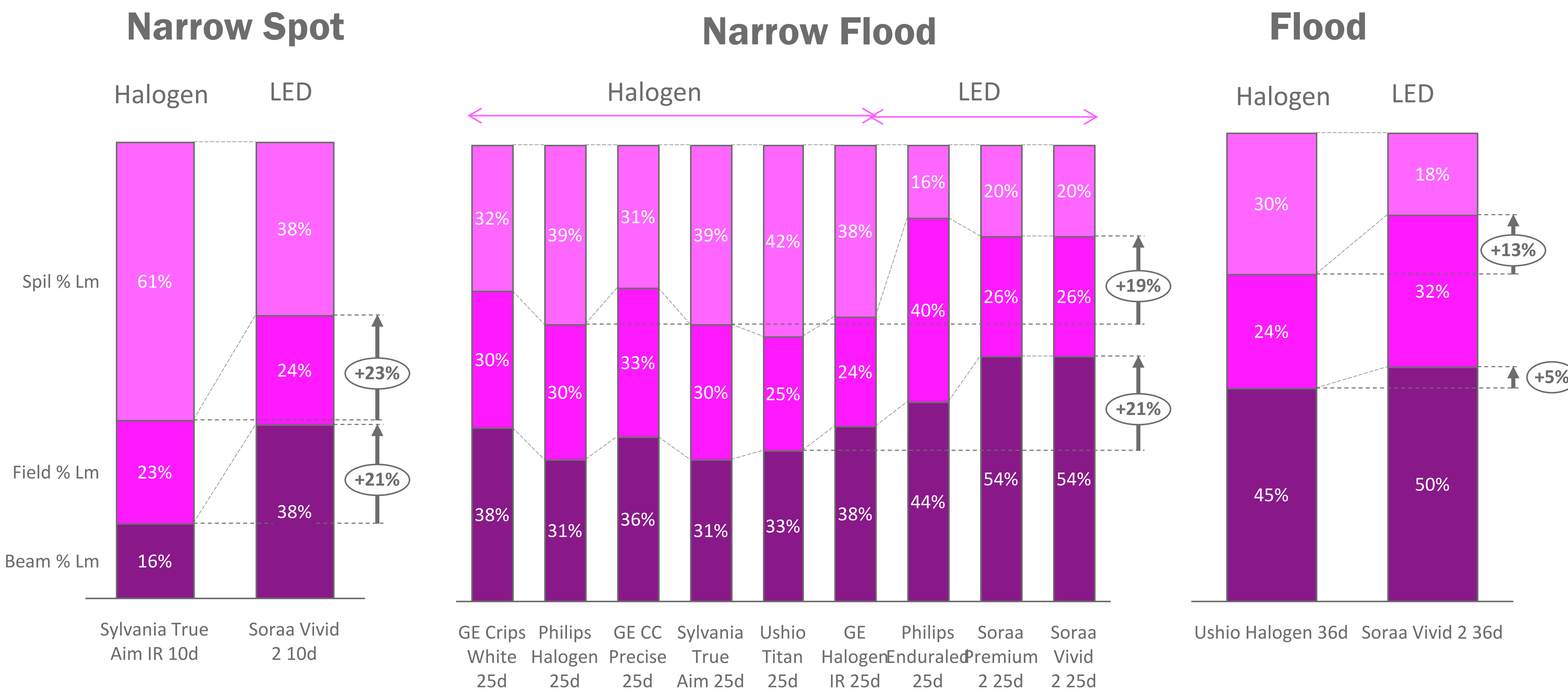
- Differences of up to 7 degrees in specified vs. measured beam angle



# Lm distribution, beam – field - spill

SORAA
Simply Perfect Light™

- LED provide a substantially larger fraction of the lm in the beam and the field
- Wider beam angle lamps have a larger % of lm in the beam

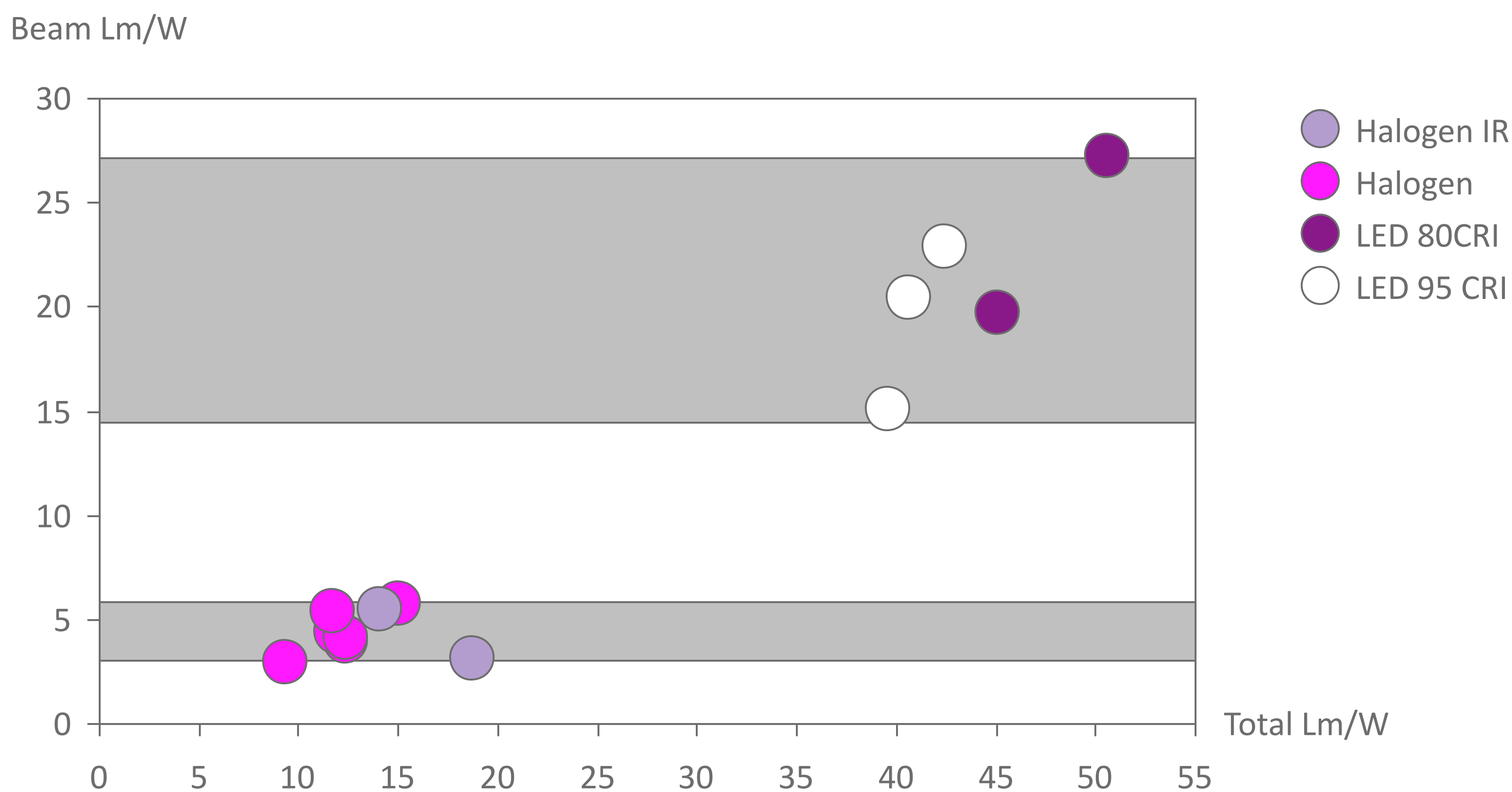




5/9/2013

# Beam Lm/W comparison

| | |
|---|---|
| Halogen IR | 3-6 lm/W |
| Halogen | 3-6 lm/W |
| LED 95CRI | 15 – 22 lm/W |
| LED 80CRI | 20 – 28 lm/W |

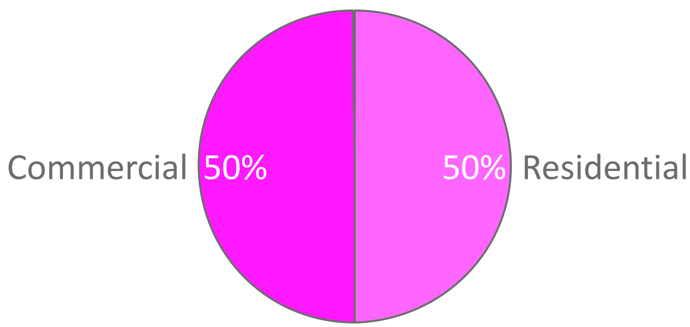


# Test data for halogen, halogen-IR and LED lamps - All data

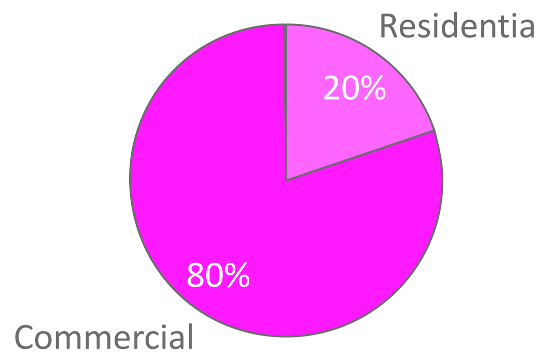
| Manufacturer | Lamptype | Technology | Claimed Beam | Power | CBCP | Actual Beam | Total Lm | Beam Lm | Field Lm | Total lm/W | Beam Lm/w | Field Lm/W | Spec vs. Meas Beam | Beam % Lm | Field % Lm | Spil % Lm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sylvania | True Aim IR | Halogen IR | 10 | 20 | 4464 | 9 | 376 | 62 | 147 | 19 | 3 | 7 | -1 | 16% | 23% | 61% |
| Soraa | Vivid 2 | LED hi CRI | 10 | 10 | 6437 | 12 | 396 | 150 | 246 | 40 | 15 | 25 | 2 | 38% | 24% | 38% |
| GE | Crips White | Halogen | 25 | 50 | 240 | 25 | 755 | 286 | 513 | 15 | 6 | 10 | 0 | 38% | 30% | 32% |
| Philips | Halogen | Halogen | 25 | 50 | 2349 | 22 | 620 | 193 | 377 | 12 | 4 | 8 | -3 | 31% | 30% | 39% |
| GE | CC Precise | Halogen | 25 | 50 | 2278 | 24 | 599 | 216 | 411 | 12 | 4 | 8 | -1 | 36% | 33% | 31% |
| Sylvania | True Aim | Halogen | 25 | 50 | 1975 | 21 | 471 | 146 | 285 | 9 | 3 | 6 | -4 | 31% | 30% | 39% |
| Ushio | Titan | Halogen | 25 | 50 | 3618 | 18 | 622 | 206 | 361 | 12 | 4 | 7 | -7 | 33% | 25% | 42% |
| GE | Halogen IR | Halogen IR | 25 | 37 | 2997 | 19 | 524 | 200 | 326 | 14 | 5 | 9 | -6 | 38% | 24% | 38% |
| Philips | Enduraled | LED | 25 | 10 | 1903 | 25 | 451 | 197 | 379 | 45 | 20 | 38 | 0 | 44% | 40% | 16% |
| Soraa | Premium 2 | LED | 25 | 11.5 | 3441 | 23 | 582 | 313 | 466 | 51 | 27 | 41 | -2 | 54% | 26% | 20% |
| Soraa | Vivid 2 | LED hi CRI | 25 | 11.5 | 2890 | 23 | 489 | 263 | 391 | 43 | 23 | 34 | -2 | 54% | 26% | 20% |
| Ushio | Halogen | Halogen | 36 | 50 | 1359 | 33 | 587 | 267 | 410 | 12 | 5 | 8 | -3 | 45% | 24% | 30% |
| Soraa | Vivid 2 | LED hi CRI | 36 | 11.5 | 1276 | 33 | 468 | 234 | 386 | 41 | 20 | 34 | -3 | 50% | 32% | 18% |

# Market share estimates

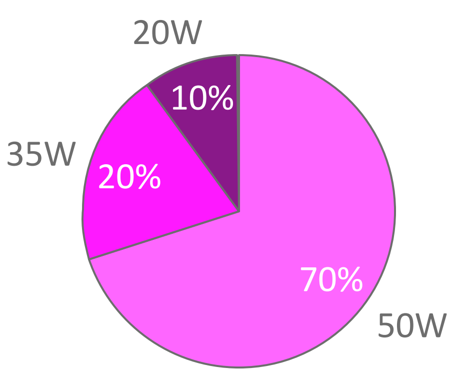
Sockets



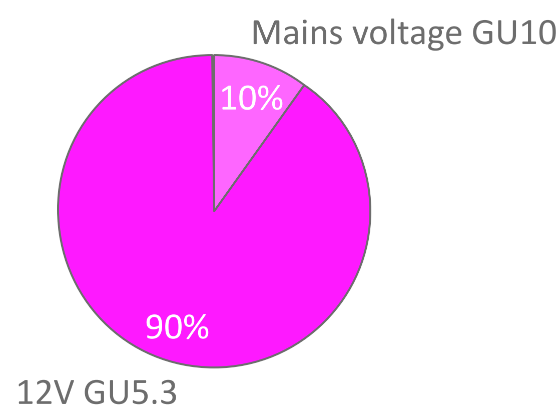

Lamps sold




Sockets and lamps sold



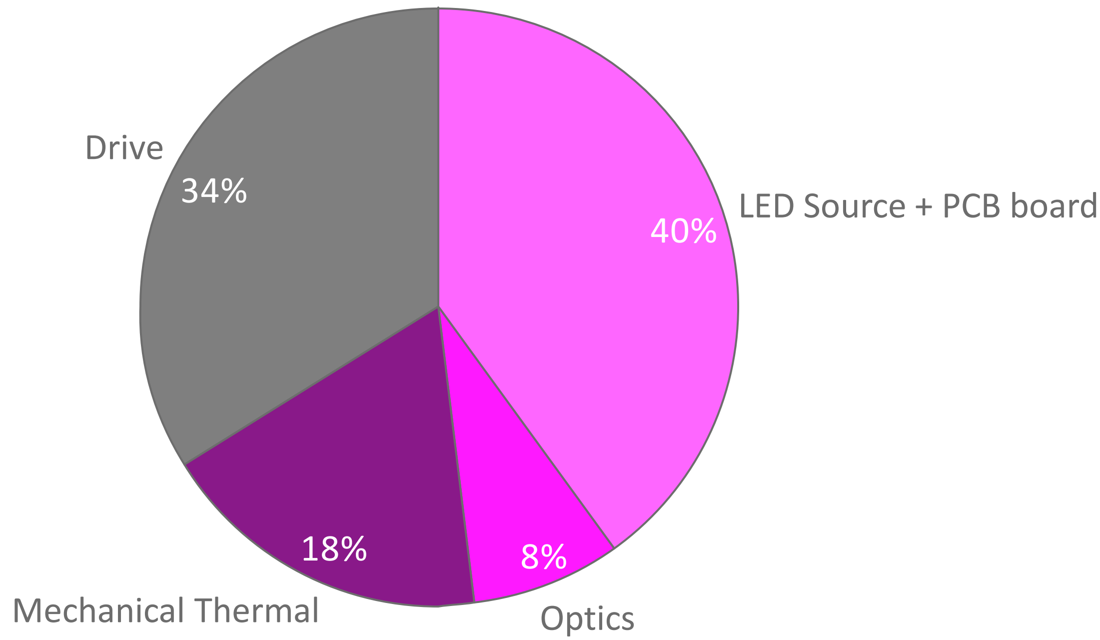

Lamps sold




Source: Navigant DOE 2012

No data available on halogen vs. halogen IR vs. LED MR16

# Cost of LED MR16 lamp




- Source: Strategies Unlimited 2012
- Labor and manufacturing overhead , import, transport not included
- Based on price levels for warm white LEDs around 100lm/$, total BOM in the range of $10 - $17.50 for a 50W equivalent MR16, excluding manufacturing cost, transport, 6% import.

# Comment on energy use metric

- Beam lm/W is a good metric
  - Note that beam lm/W tends to be higher for larger beam angle lamps
  - Especially 10 degree lamps have lower lm% in beam
  - Already in use in Japan
- Total lm/W is a poor metric
- Field lm/W is a reasonable metric as well

# Important Notes

- Issue of overall lamp height and fixture compatibility and temperature
  - Halogen lamps in use are substantially smaller than ANSI / IEC standard
  - Lamps that deviate from practical overall lamp height may have fit issues depending on the fixture
  - Recommend that halogen practical lamp height is used for referencing lamp height
- Forward look: LED roadmap beyond halogen
  - LED lamps already exceed halogen 50W MR16 in light output. With future LED efficiency improvements, even higher lamp performance can be achieved
- Whitepapers: white rendering, color rendering and Benya MR16 white paper (send as appendix)
- Mains voltage: expected to increase with new installations. LED lamps do not have a performance penalty in contrast to halogen for the capability to run on high voltage
- Meeting UL Class 1 and Class 2 is critically important. Many installations are Class 1 (example low voltage track lighting) and require LED MR16 lamps that meet corresponding UL safety standards.

SORAA®
Simply Perfect Light™

# Data for Light Emitting Diode (LED) Lamps

Provided by Soraa Inc., 6500 Kaiser Drive, Fremont CA 94555

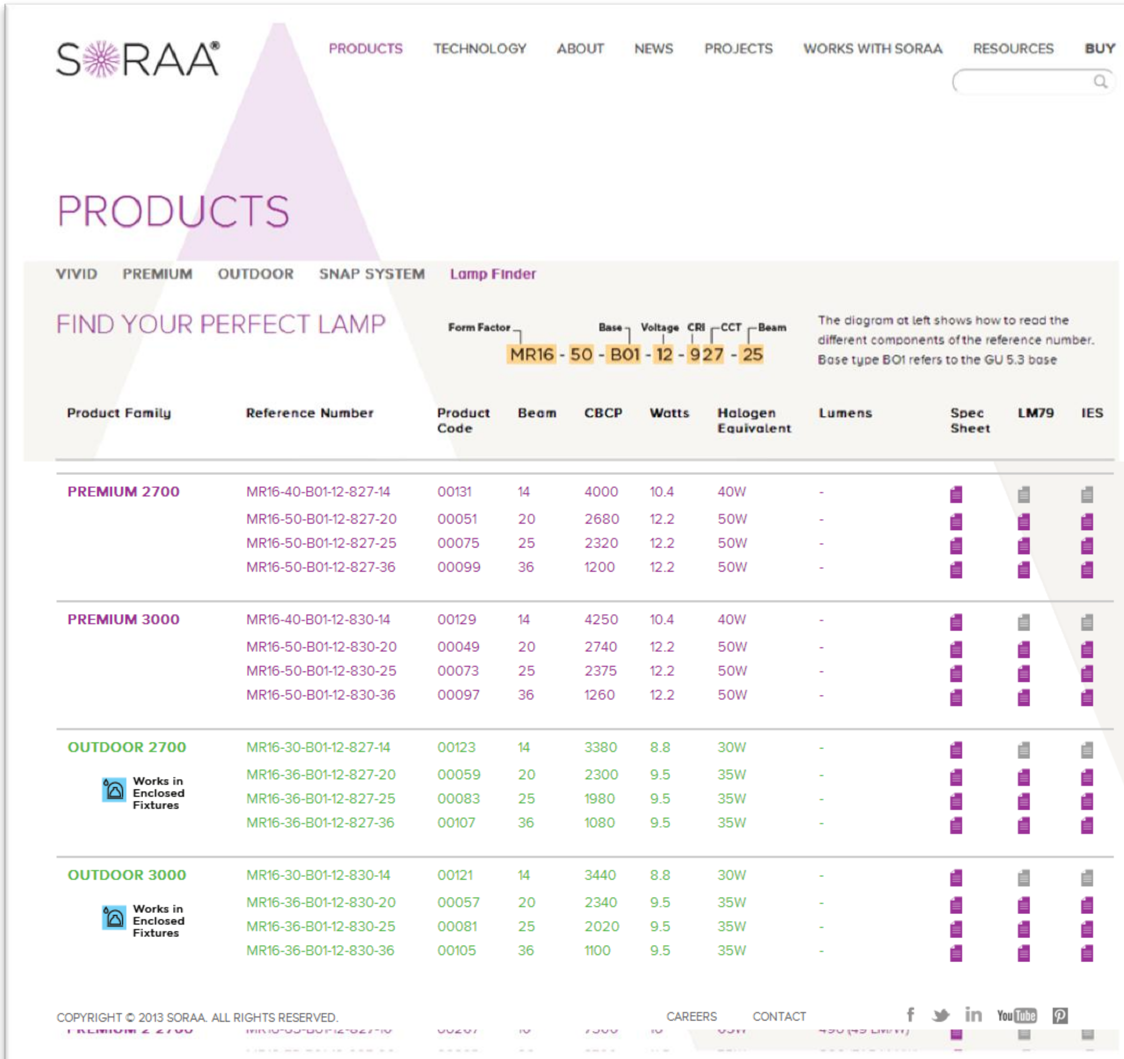
May 2013

# Logical Characterization

| | |
|---|---|
| Lamp category that is replaced | Example: MR16, A19, PAR20, PAR30, etc<br>In addition – socket type<br>MR16 GU5.3, MR16 GU10 |
| Lamp output or equivalent wattage | Can be following Energy Star metrics for equivalence and output, both for directional and non directional.<br>Note: it is expected that for directional that LED technology will deliver higher output lamps than currently available in halogen.<br>Examples: 2,000+lm PAR30 and PAR38<br>4,400Cd 25° MR16 (~75W)<br>The energy star calculator for watt equivalence does not work accurately when extrapolating beyond currently available halogen options |
| Market share by category | http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-adoption-report_2013.pdf |

# LM79 and TM-21 reports

- Available for download at [http://www.soraa.com/products/lamp-finder](http://www.soraa.com/products/lamp-finder)




| Product Family | Reference Number | Product Code | Beam | CBCP | Watts | Halogen Equivalent | Lumens | Spec Sheet | LM79 | IES |
|---|---|---|---|---|---|---|---|---|---|---|
| PREMIUM 2700 | MR16-40-B01-12-827-14 | 00131 | 14 | 4000 | 10.4 | 40W | - | | | |
| | MR16-50-B01-12-827-20 | 00051 | 20 | 2680 | 12.2 | 50W | - | | | |
| | MR16-50-B01-12-827-25 | 00075 | 25 | 2320 | 12.2 | 50W | - | | | |
| | MR16-50-B01-12-827-36 | 00099 | 36 | 1200 | 12.2 | 50W | - | | | |
| PREMIUM 3000 | MR16-40-B01-12-830-14 | 00129 | 14 | 4250 | 10.4 | 40W | - | | | |
| | MR16-50-B01-12-830-20 | 00049 | 20 | 2740 | 12.2 | 50W | - | | | |
| | MR16-50-B01-12-830-25 | 00073 | 25 | 2375 | 12.2 | 50W | - | | | |
| | MR16-50-B01-12-830-36 | 00097 | 36 | 1260 | 12.2 | 50W | - | | | |
| OUTDOOR 2700 | MR16-30-B01-12-827-14 | 00123 | 14 | 3380 | 8.8 | 30W | - | | | |
| Works in Enclosed Fixtures | MR16-36-B01-12-827-20 | 00059 | 20 | 2300 | 9.5 | 35W | - | | | |
| | MR16-36-B01-12-827-25 | 00083 | 25 | 1980 | 9.5 | 35W | - | | | |
| | MR16-36-B01-12-827-36 | 00107 | 36 | 1080 | 9.5 | 35W | - | | | |
| OUTDOOR 3000 | MR16-30-B01-12-830-14 | 00121 | 14 | 3440 | 8.8 | 30W | - | | | |
| Works in Enclosed Fixtures | MR16-36-B01-12-830-20 | 00057 | 20 | 2340 | 9.5 | 35W | - | | | |
| | MR16-36-B01-12-830-25 | 00081 | 25 | 2020 | 9.5 | 35W | - | | | |
| | MR16-36-B01-12-830-36 | 00105 | 36 | 1100 | 9.5 | 35W | - | | | |


CAREERS CONTACT

# Types of dimming circuitry & minimum dimming levels

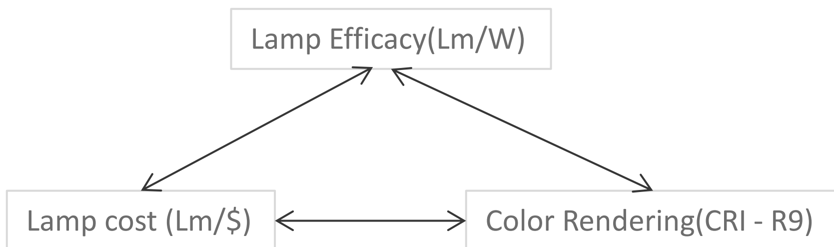
| Dimming / Transformer | Leading Edge phase cutting | Trailing Edge phase cutting | 0-10V | Wireless – multiple options |
|---|---|---|---|---|
| None | | | | |
| Electromagnetic | | Not recommended | Not recommended | |
| Electronic | Not recommended | | Not recommended | |

Dimming levels are best defined by light output levels.
Specific look at hysteresis: minimum level while dimming down, up and whether the lamps comes on after switching on/off
Quoted dimming level showed be the highest level of these three scenarios

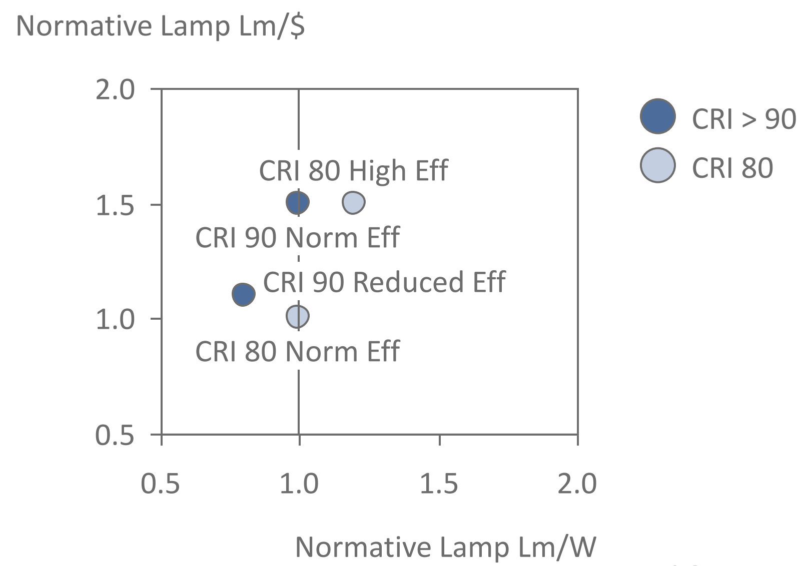
NEMA activities ongoing related to standardization of terminology and compatibility around dimming (example SSL7)

# Cost of improved color consistency and quality

- Improved color consistency:
  - Comments related to violet LED – 3 phosphor systems
  - Within 3McA ellipse currently produced without substantial additional manufacturing cost
  - Color consistency over the life of the product within Energy Star norms without adding manufacturing cost. Long term reliability testing itself adds high costs
- Consistency over the life
  - Requires the selection and qualification of stable phosphor and other lamp / LED materials. This increases LED component cost by 10 - 50% and limits the operating temperature which can be a very substantial cost adder at system cost (higher LED component count, increased heat sink size)
- Improved color quality
  - At lamp level there is a trade-off between color rendering and product efficacy and / or cost inherently tied to a fundamental trade-off between CRI and efficacy for white LEDs




| Color Rendering | Normative Lm/W | Normative Lamp Cost (Lm/$) |
|---|---|---|
| CRI 80/ R9 20 | 100% | 100% |
| CRI 80/ R9 20 | 120% | 150% |
| CRI 90 / R9 50 | 100% | 150% |
| CRI 90 / R9 50 | 80% | 110% |

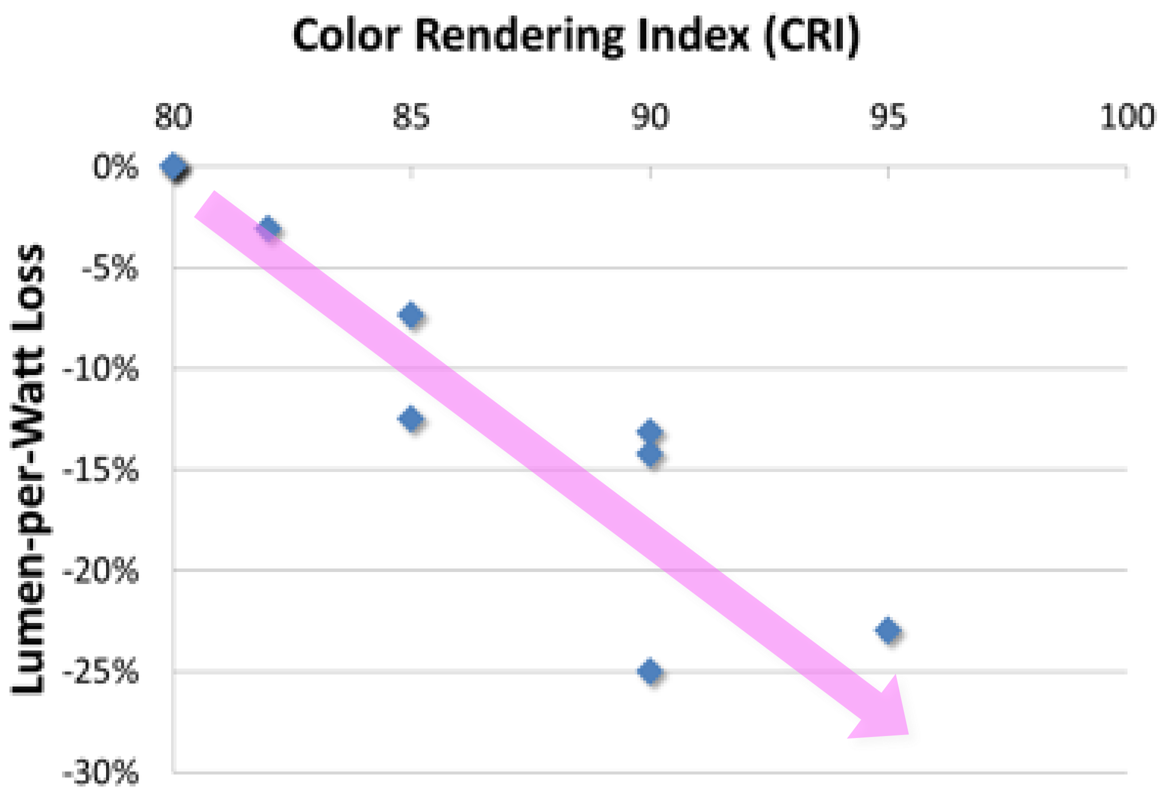



Refer to appendix for calculation examples

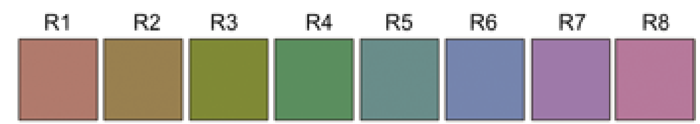
# APPENDIX – Cost of improved color rendering

# COLOR RENDING vs. EFFICACY

- LEDs show strong dependence of performance on Color Rendering Index (CRI)
- Top-tier suppliers: ~1.5-2% decrease in Lumens-per-Watt (LPW) per point of CRI
- CRI 80 → 95: ~25-30% penalty in LPW




Datasheet typicals from several top-tier LED companies, normalized




Munsell Color Samples (1st eight)

# LOW vs. HIGH CRI PRODUCT IMPACT
## *Under ENERGY STAR Draft 3*

| | | SPACE CONSTRAINED – FIXED # LEDs (e.g, MR16) | |
|---|---|---|---|
| | | CRI 80 | CRI 90 |
| LED Datasheet LPW | lm/W | 100 | 80 |
| Lamp Thermal Res. | K/W | 7 | 7 |
| Number of LEDs | | 4 | 4 |
| Tj | K | 104 | 104 |
| LED Operating LPW | lm/W | 83 | 66 |
| Power per LED | W | 1.8 | 1.8 |
| Lamp Power | W | 7 | 7 |
| Total Lumens | lm | **425** | **340** |
| Lamp Operating LPW | lm/W | **60** | **48** |
| | | | |
| LED Costs | | $ 2.80 | $ 2.80 |
| Driver Cost | | $ 2.00 | $ 2.00 |
| Heatsink + Optics Cost | | $ 1.25 | $ 1.25 |
| Total BOM | | $ 6.05 | $ 6.05 |

Light output not competitive

Efficacy Penalty (no E*)

Light output not competitive

E* ok, but price not competitive

Assumptions: Ta = 45C, driver eff = optics eff = 85%, 70c per power LED

SORAA

# LOW vs. HIGH CRI PRODUCT IMPACT

## *Under Proposed High-CRI Targets for ENERGY STAR*

| | | SPACE CONSTRAINED - FIXED # LEDs (e.g, MR16) | | | | UNCONSTRAINED- VAR. # LEDs (e.g, PAR38) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CRI 80 | CRI 90 | CRI 80 | CRI 90 | CRI 80 | CRI 90 | CRI 80 | CRI 90 |
| LED Datasheet LPW | lm/W | 100 | 80 | 100 | 80 | 100 | 80 | 100 | 80 |
| Lamp Thermal Res. | K/W | 7 | 7 | 7 | 7 | 2 | 2 | 2 | 2 |
| Number of LEDs | | 4 | 4 | 4 | 4 | 12 | 12 | 12 | 12 |
| Tj | K | 104 | 104 | 104 | 139 | 99 | 94 | 99 | 124 |
| LED Operating LPW | lm/W | 83 | 66 | 83 | 52 | 83 | 69 | 83 | 55 |
| Power per LED | W | 1.8 | 1.8 | 1.8 | 2.9 | 1.9 | 1.7 | 1.9 | 2.7 |
| Lamp Power | W | 7 | 7 | 7 | 11 | 22 | 20 | 22 | 33 |
| Total Lumens | lm | **425** | **340** | **425** | **425** | **1300** | **1000** | **1300** | **1300** |
| Lamp Operating LPW | lm/W | **60** | **48** | **60** | **37** | **60** | **50** | **60** | **40** |
| | | | | | | | | | |
| LED Costs | | $ 2.80 | $ 2.80 | $ 2.80 | $ 2.80 | $ 8.40 | $ 8.40 | $ 8.40 | $ 8.40 |
| Driver Cost | | $ 2.00 | $ 2.00 | $ 2.00 | $ 2.00 | $ 2.00 | $ 2.00 | $ 2.00 | $ 2.00 |
| Heatsink + Optics Cost | | $ 1.25 | $ 1.25 | $ 1.25 | $ 1.25 | $ 1.25 | $ 1.25 | $ 1.25 | $ 1.25 |
| Total BOM | | $ 6.05 | $ 6.05 | $ 6.05 | $ 6.05 | $ 11.65 | $ 11.65 | $ 11.65 | $ 11.65 |

Light output not competitive

Efficacy Penalty (E* ok) ✓

Light output not competitive

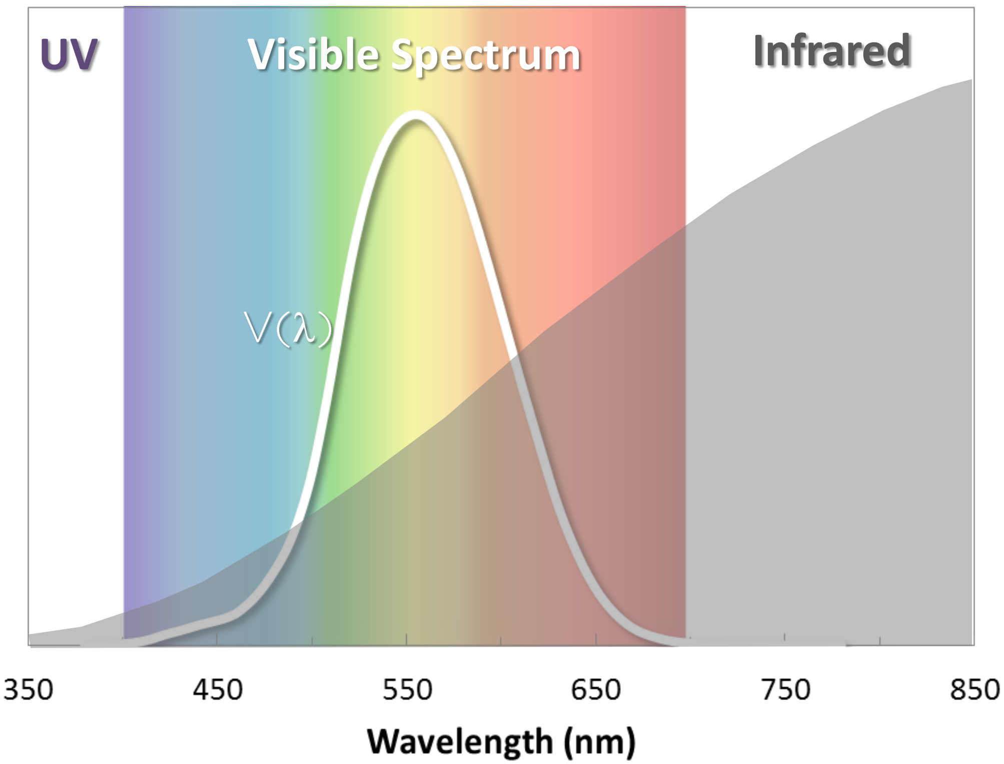
E* ok, price competitive ✓

Assumptions: Ta = 45C, driver eff = optics eff = 85%, 70c per power LED

# IMPACT OF RED EMISSION

- Luminosity and CRI are extremely sensitive to red content
- Truncation of red-emission leads to high luminosity (lumens), but lower CRI

CIE Reference Illuminant A

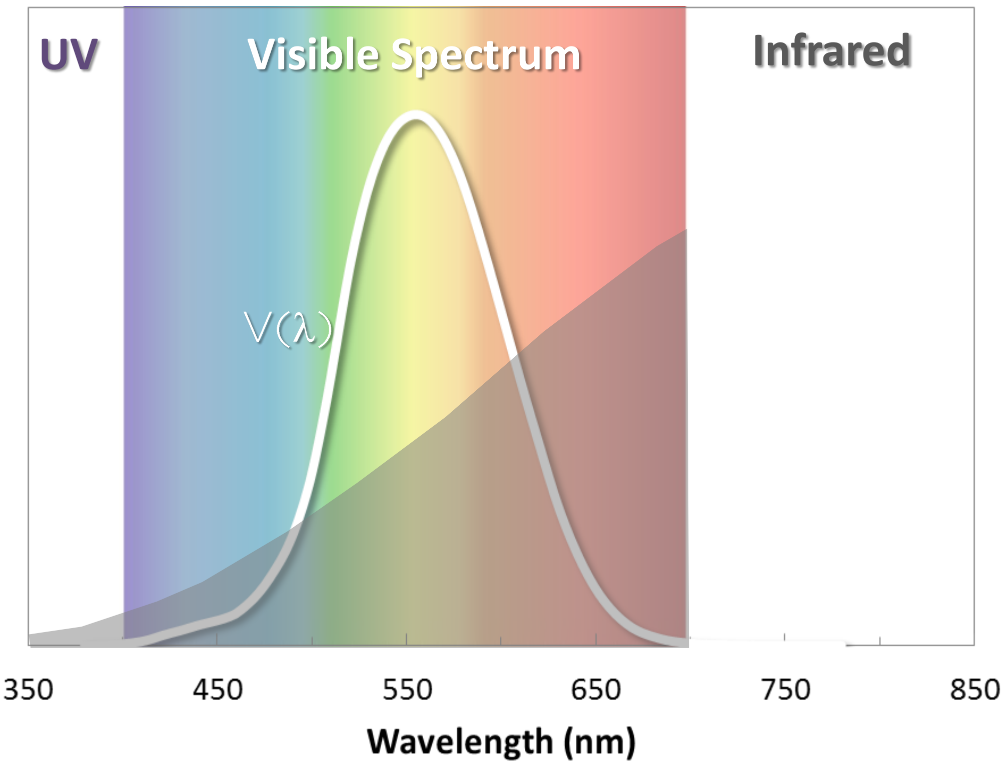



| | CIE A |
|---|---|
| R1 | 100 |
| R2 | 100 |
| R3 | 100 |
| R4 | 100 |
| R5 | 100 |
| R6 | 100 |
| R7 | 100 |
| R8 | 100 |
| Ra | 100 |
| | |
| LUM | 100% |

# IMPACT OF RED EMISSION

- Luminosity and CRI are extremely sensitive to red content
- Truncation of red-emission leads to high luminosity (lumens), but lower CRI

CIE A truncated below 700 nm

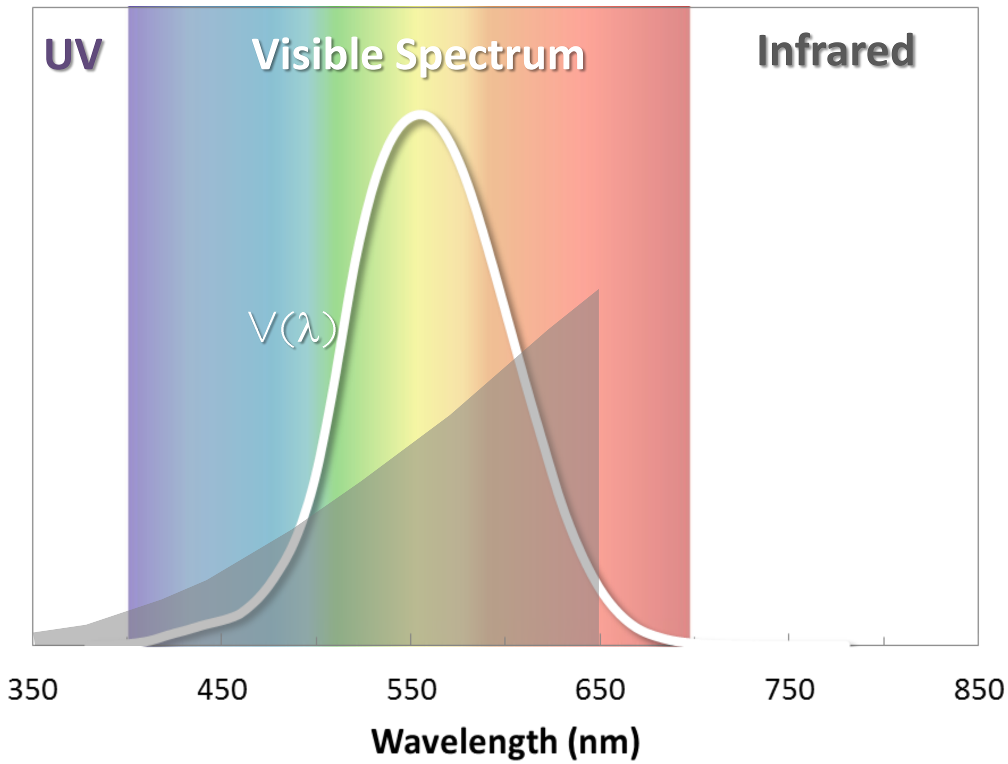



| | CIE A | <700 |
|---|---|---|
| R1 | 100 | 100 |
| R2 | 100 | 100 |
| R3 | 100 | 99 |
| R4 | 100 | 100 |
| R5 | 100 | 100 |
| R6 | 100 | 100 |
| R7 | 100 | 99 |
| R8 | 100 | 99 |
| Ra | 100 | 100 |
| | | |
| LUM | 100% | 155% |

# IMPACT OF RED EMISSION

- Luminosity and CRI are extremely sensitive to red content
- Truncation of red-emission leads to high luminosity (lumens), but lower CRI

CIE A truncated below 650nm

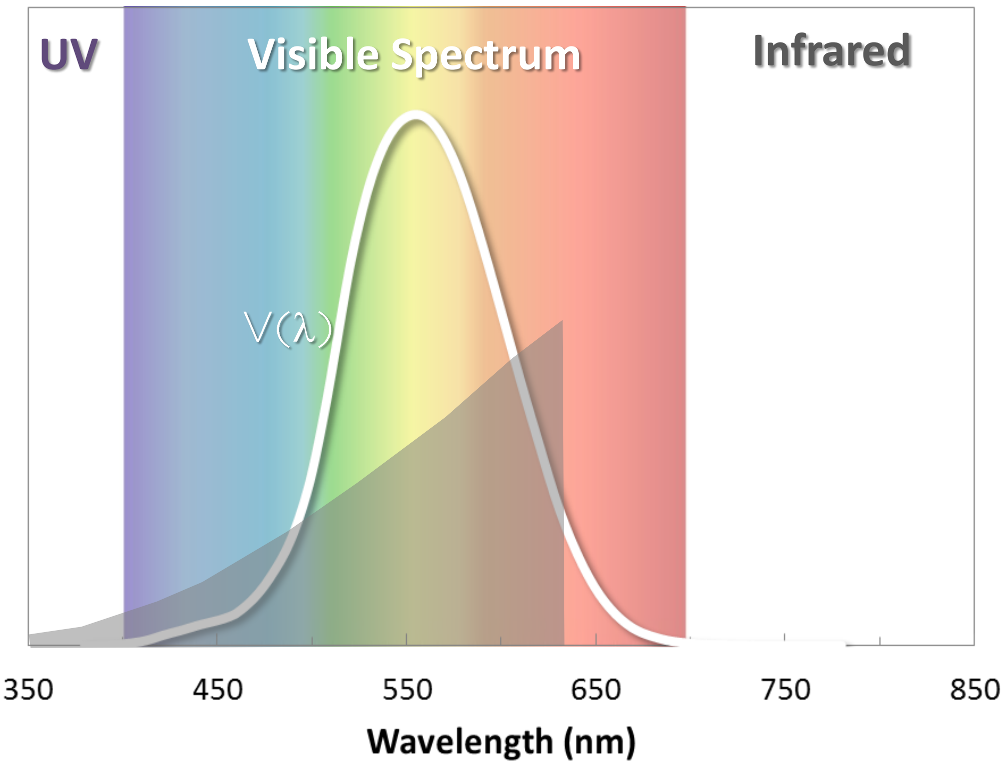



| | CIE A | <700 | <650 |
|---|---|---|---|
| R1 | 100 | 100 | 91 |
| R2 | 100 | 100 | 96 |
| R3 | 100 | 99 | 99 |
| R4 | 100 | 100 | 91 |
| R5 | 100 | 100 | 91 |
| R6 | 100 | 100 | 97 |
| R7 | 100 | 99 | 90 |
| R8 | 100 | 99 | 76 |
| Ra | 100 | 100 | 91 |
| | | | |
| LUM | 100% | 155% | 212% |

# IMPACT OF RED EMISSION

- Luminosity and CRI are extremely sensitive to red content
- Truncation of red-emission leads to high luminosity (lumens), but lower CRI

CIE A truncated below 630 nm




| | CIE A | <700 | <650 | <630 |
|---|---|---|---|---|
| R1 | 100 | 100 | 91 | 73 |
| R2 | 100 | 100 | 96 | 87 |
| R3 | 100 | 99 | 99 | 94 |
| R4 | 100 | 100 | 91 | 73 |
| R5 | 100 | 100 | 91 | 74 |
| R6 | 100 | 100 | 97 | 88 |
| R7 | 100 | 99 | 90 | 77 |
| R8 | 100 | 99 | 76 | 37 |
| Ra | 100 | 100 | 91 | 75 |
| | | | | |
| LUM | 100% | 155% | 212% | 237% |

SORAA
Simply Perfect Light™

# Data Requests: Lighting Products

Provided by Soraa Inc., 6500 Kaiser Drive, Fremont CA 94555

May 2013

# Items covered

Simply Perfect Light™

| | | |
|---|---|---|
| 1 | Category definition and scope | Not covered |
| 2 | Standards (existing or under development) | Covered |
| 3 | Test procedures (existing or under development) | Covered |
| 4 | Sources of test data (confidential or public) | Covered |
| 5 | Energy use metrics (e.g. lumens vs. beam lumens per watt) | Covered |
| 6 | Relevant performance indicators | Covered |
| 7 | Range of typical performance for each indicator | Covered |
| 8 | Incremental costs of energy efficiency features | Covered |
| 9 | Product development trends | Covered |
| 10 | Market barriers to energy efficiency | Covered |
| 11 | Number of California small businesses associated with manfucture, sale, distribution, or installation | Not covered |
| 12 | Commercial vs. residential vs. governmental sector sales | Covered |
| 13 | How do consumers identify effcicient products on the market? | Not covered |
| 14 | Any other information relevant to this proceeding | Covered |

# Standards and test procedures

## 8. METHODS OF MEASUREMENT AND REFERENCE DOCUMENTS

| Organization | Identifier | Description |
|---|---|---|
| ANSI/IEEE | C62.41.2-2002 | IEEE Recommended Practice on Characterization of Surges in Low Voltage (1000V and Less) AC Power Circuits |
| ANSI | C78.20-2003 | Electric Lamps—A, G, PS and Similar Shapes with E26 Medium Screw Bases |
| ANSI | C78.21-2011 | Electric Lamps—PAR and R Shapes |
| ANSI | C78.23-1995 (R2003) | Incandescent Lamps—Miscellaneous Types |
| ANSI/ANSLG | C78.357-2010 | For Incandescent Lamps: Tungsten Halogen Lamps (non-vehicle) |
| ANSI | C78.376-2001 | Specifications for the Chromaticity of Fluorescent Lamps |
| ANSI/ANSLG | C78.377-2011 | Specifications for the Chromaticity of Solid State Lighting Products |
| ANSI | C79.1-2002 | Nomenclature for Glass Bulbs Intended for Use with Electric Lamps |
| ANSI/ANSLG | C81.61-2009 | Specifications for Bases (Caps) for Electric Lamps |
| ANSI/NEMA | C82.2-2002 | Fluorescent Lamp Ballasts, Methods of Measurement of (includes supplements) |
| ANSI | C82.77-2002 | Harmonic Emission Limits—Related Power Quality Requirements for Lighting Equipment |
| ANSI/IES | RP-16-10 | Nomenclature and Definitions for Illuminating Engineering |
| ANSI/UL | 1993-2012 | Standard for Safety of Self-Ballasted Lamps and Lamp Adapters |
| ANSI/UL | 8750-2009 | Standard for Light Emitting Diode (LED) Equipment for Use in Lighting Products |
| CIE | Pub. No. 13.3-1995 | Method of Measuring and Specifying Color Rendering of Light Sources |
| CIE | Pub. No. 15:2004 | Colorimetry |
| Commission of the European Communities | (EC) No 244/2009 | Commission Regulation (EC) No 244/2009 of 18 March 2009 Implementing Directive 2005/32/EC of the European Parliament and of the Council |
| DOE | 10 CFR 429 | Certification, Compliance, and Enforcement for Consumer Products and Commercial and Industrial Equipment |
| DOE | 10 CFR 430 | Energy Conservation Program for Consumer Products |
| IEC | 62321:2008 (Ed. 1) | Electrotechnical Products - Determination Of Levels Of Six Regulated Substances (lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls, polybrominated diphenyl ethers) |
| IES | LM-9-09 | Electrical and Photometric Measurements of Fluorescent Lamps |
| IES | LM-20-13 | Photometric Testing of Reflector-Type Lamps (renewal anticipated in 2013) |
| IES | LM-40-10 | Life Testing of Fluorescent Lamps |
| IES | LM-54-12 | Guide to Lamp Seasoning |
| IES | LM-65-10 | Life Testing of Compact Fluorescent Lamps |
| IES | LM-66-11 | Electrical and Photometric Measurements of Single-Ended Compact Fluorescent Lamps |
| IES | LM-79-08 | Electrical and Photometric Measurements of Solid-State Lighting Products |
| IES | LM-80-08 | Measuring Lumen Maintenance of LED Light Sources |
| IES | TM-21-11 | Projecting Long Term Lumen Maintenance of LED Light Sources |

From Energy Star Draft Lamps specification

# Energy use metrics

SORAA
Simply Perfect Light™

- Beam Lm/W is a reasonable metric for directional lamps
- A single metric for all directional lamps is recommended
- For non directional lamps, total lm/W or total W is a reasonable metric

# Relevant performance indicators

SORAA
Simply Perfect Light™

- Lamp group
- Lamp color and white rendering properties
  - whiteness, CRI, R9, CQS
- Lamp correlated color temperature
- Lamp beam angle
- Lamp maximum operating temperature and fixture compatibility
  - ability to operate in enclosed fixtures or fixtures with limited ventilation at elevated ambient temperatures
- Lamp life (only relevant in the context of fixture compatibility)
- Lamp power consumption
- Lamp dim-ability

# Relevant performance indicators

| Performance indicator | Common range |
|---|---|
| Color rendering | CRI: 50 – 70 – 80 – 90 - >95<br>R9: <0; 30 – 50 - >90<br>CQS: individual color CQS 30 to 100 |
| Whiteness rendering | Whiteness: 80 – 100 - > 120 |
| Correlated color temperature | |
| Beam angle | Narrow Spot, Spot, Narrow Flood, Flood, Wide Flood. Can be non-symmetrical for lamps and fixtures |
| Max operating temperature and ability to run in enclosed fixtures or environments | For lamps: based on worst case ambient temperature and fixture condition<br>For fixtures: ambient temperature |
| Life (only relevant in context of environment) | Minimum of useful life (defined on maintenance of color and output) and survival rate (defined on total loss of output of functionality – failures)<br>1,000h to > 100,000h |
| Power consumption | |
| Dimmability | Non – dimmable vs. 100% dimmable.<br>Defined based on measured light output and observed dimming hysteresis |

# Cost of energy efficiency features

SORAA
Simply Perfect Light™

- Dimming
  - Results in 5% - 10% lower efficiency (lamps)
  - Results in increased testing costs (lamp – dimmer compatibility) and development cost
- Instant on/off
  - No additional cost for LED lamps
- Higher product efficiency
  - Non-linear behavior between product efficiency and product cost – refer to Soraa data for LED lamps
- Better light - beam control
  - No additional cost for LED lamps

# Product development trends

Simply Perfect Light™

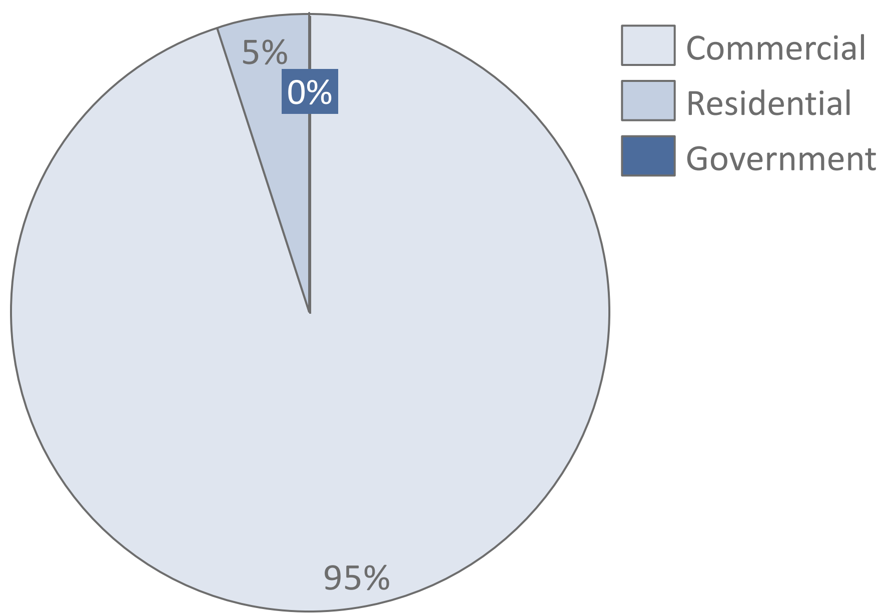
- Mains voltage LED MR16 with similar performance as low voltage MR16
  - Mains voltage LED MR16 and PAR 16 lamps with the same performance as low voltage MR16 lamps
  - The compromised performance of small mains voltage halogen directional lamps does not apply to LED MR16 lamps
- High performance LED lamps and fixtures
  - Resulting from LED technology advances, higher performance than based on incumbent technology is now feasible. Example: 75W equivalent MR16
- Adaptability and ease of use
  - Remote control, color changing, beam changing (example Soraa SNAP system)
- Fixture modularity
  - With increasing LED lamp performance and decreasing LED lamp cost, high performance LED fixture solutions can be based on LED lamps.
  - Efficient qualification of fixtures based on qualified LED lamps, can substantially speed up the availability of energy efficient fixture solutions.

# Market barriers to energy efficiency

- Long qualification times for long life
  - Current emphasis on LED lamps is a minimum of 25,000 hours of 70% lumen maintenance. To proof this, a 6,000h test on LED component and a 3,000h test at lamp level is required (LM-80) with specified extrapolation (TM-21). The time and cost required to complete these tests, delays market introduction and recognition (for example by energy star) of more efficient products and steers manufacturers to not implement incremental changes that require extensive testing
  - The above mentioned approach ignores the typical failure modes of lamps, which are in many cases drive-electronics related and application related. Shorter than expected lamp life is in many cases related to lamps running warmer in poorly ventilated fixtures. High temperatures are directly correlated to shorter lamp life and increased failures.
  - Soraa recommends that life testing is adapted towards real life worst case fixture scenarios (fully enclosed fixtures, no ventilation, elevated ambient temperatures) with an increased focus on low failure levels.
  - 10,000h life under worst case conditions and proportionally reduced qualification times (1,000 to 2,000h accelerated testing) is proposed
  - Benefit is that higher efficiency lighting products can be released to the market quicker and that a more accurate level of expectation is set for consumers (no more early failures on lamps with long claimed life)
- Stroboscopic (flicker) requirements
  - Specifically in the case of small size MR16 lamps. Requirements on color quality, long life, dimmability, compatibility with existing transformers & dimmers and fixture compatibility makes lamp development complex and time consuming. Soraa proposes to make 12V MR16 lamps exempt from stroboscopic requirements, as long as their base frequency is at least 120Hz. This is well beyond the frequency range where health related concerns related to flicker has been documented.
  - Line voltage MR16 faces many of the challenges that low voltage faces. Proposed is a base frequency of 120Hz or greater with no additional requirement on light modulation depth
- Lack of color quality
  - It is well documented that color quality is of prime concern with both commercial users and consumers
- Focus on initial cost vs. total cost of ownership

# Commercial vs. Residential vs. Government sales

- Soraa - Unit based



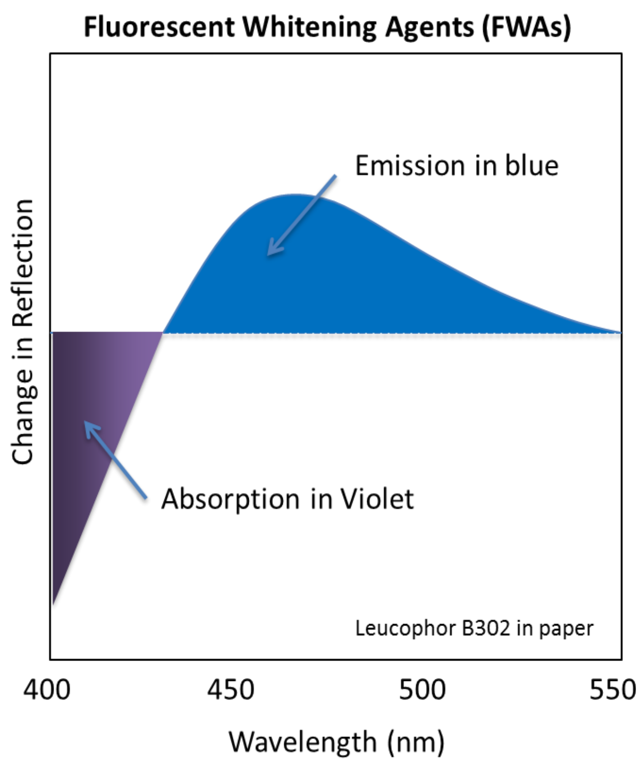
# Additional Comments on Whiteness rendering

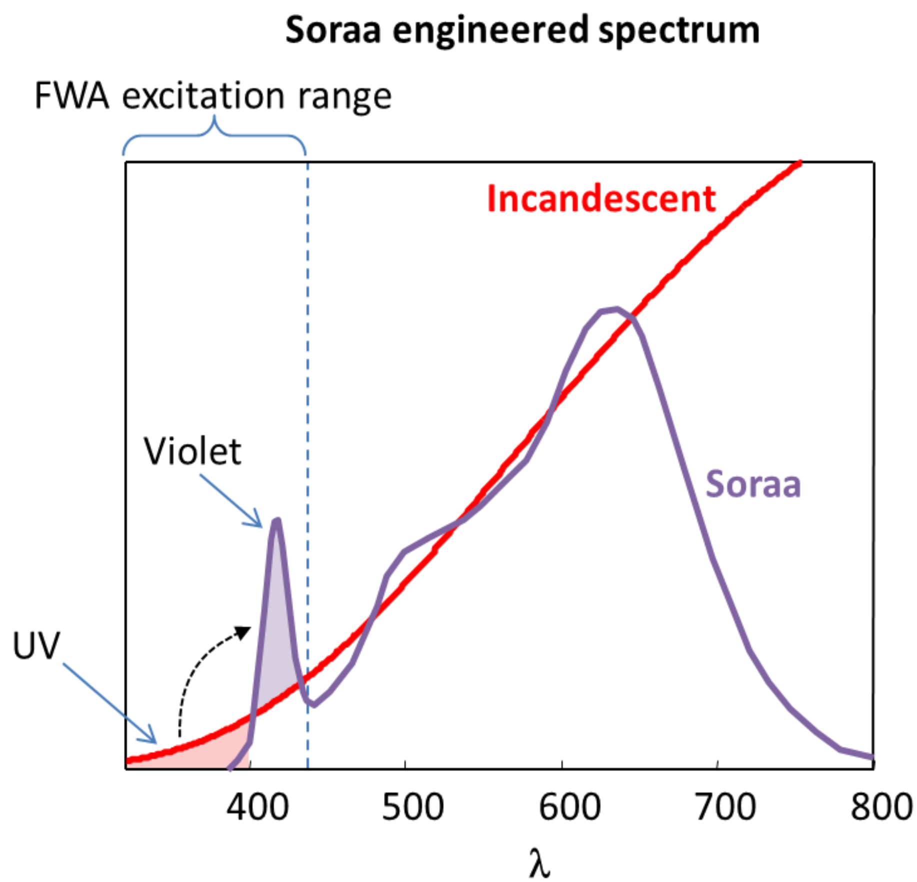
SORAA
Simply Perfect Light™

- The spectral power distribution that the light source emits, has a profound impact on how manufactured white materials (paper, textile, plastics) appear
- Blue pump based white LEDs, fail to render many white materials like incandescent source or daylight
- Understanding of this topic has emerged recently. It is anticipated that metrics for white rendering will be defined in the near future – next slides provide further information.

# Whiteness Effect

- Whiteness is achieved by Fluorescent Whitening Agents (FWAs)
- Clothing, Fiber, Plastics, Cosmetics
- Soraa spectrum can be engineered to excite FWAs to render whites “white”
- Excitation of whitening agents takes place by violet light
- Other LEDs cannot do this

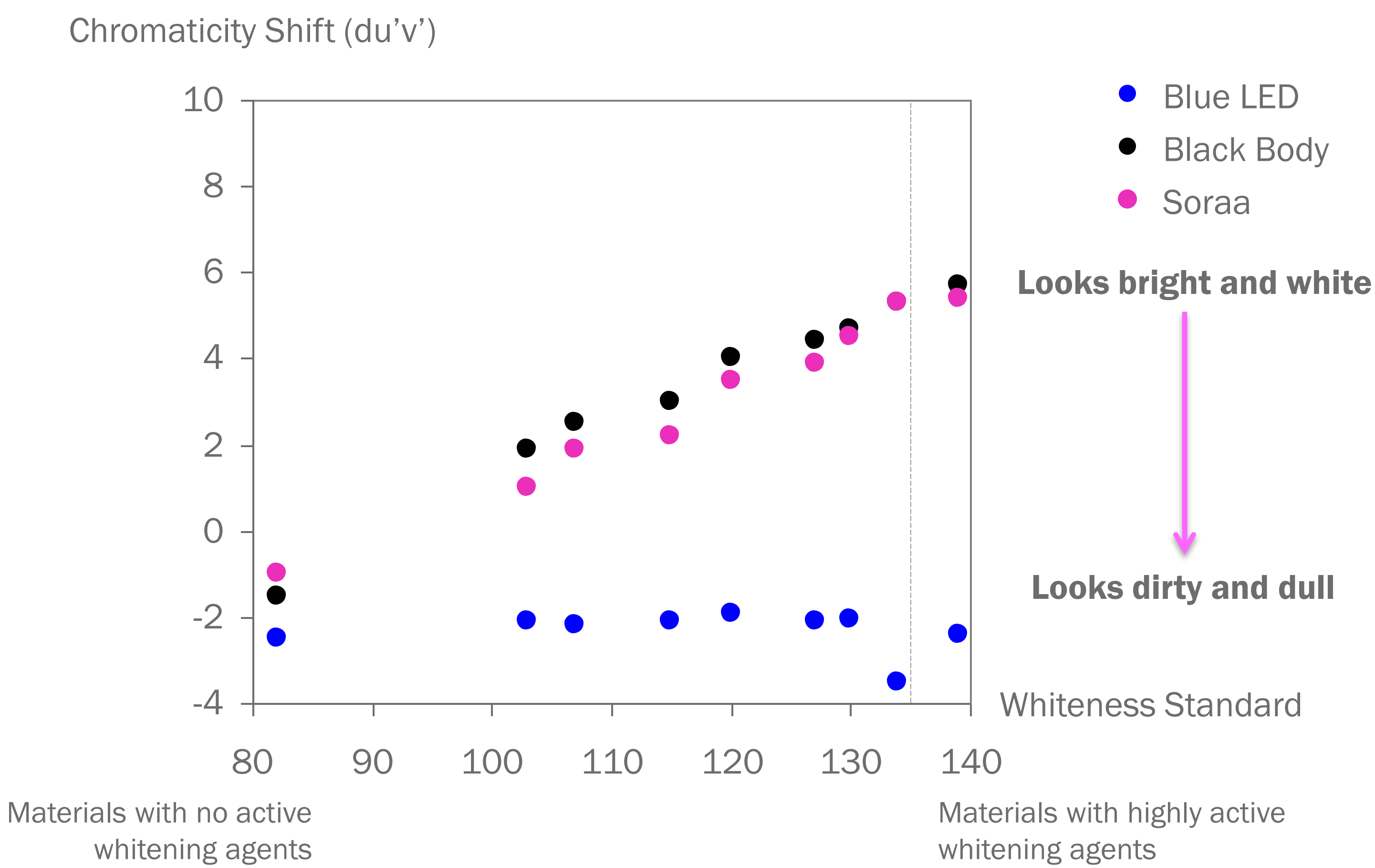


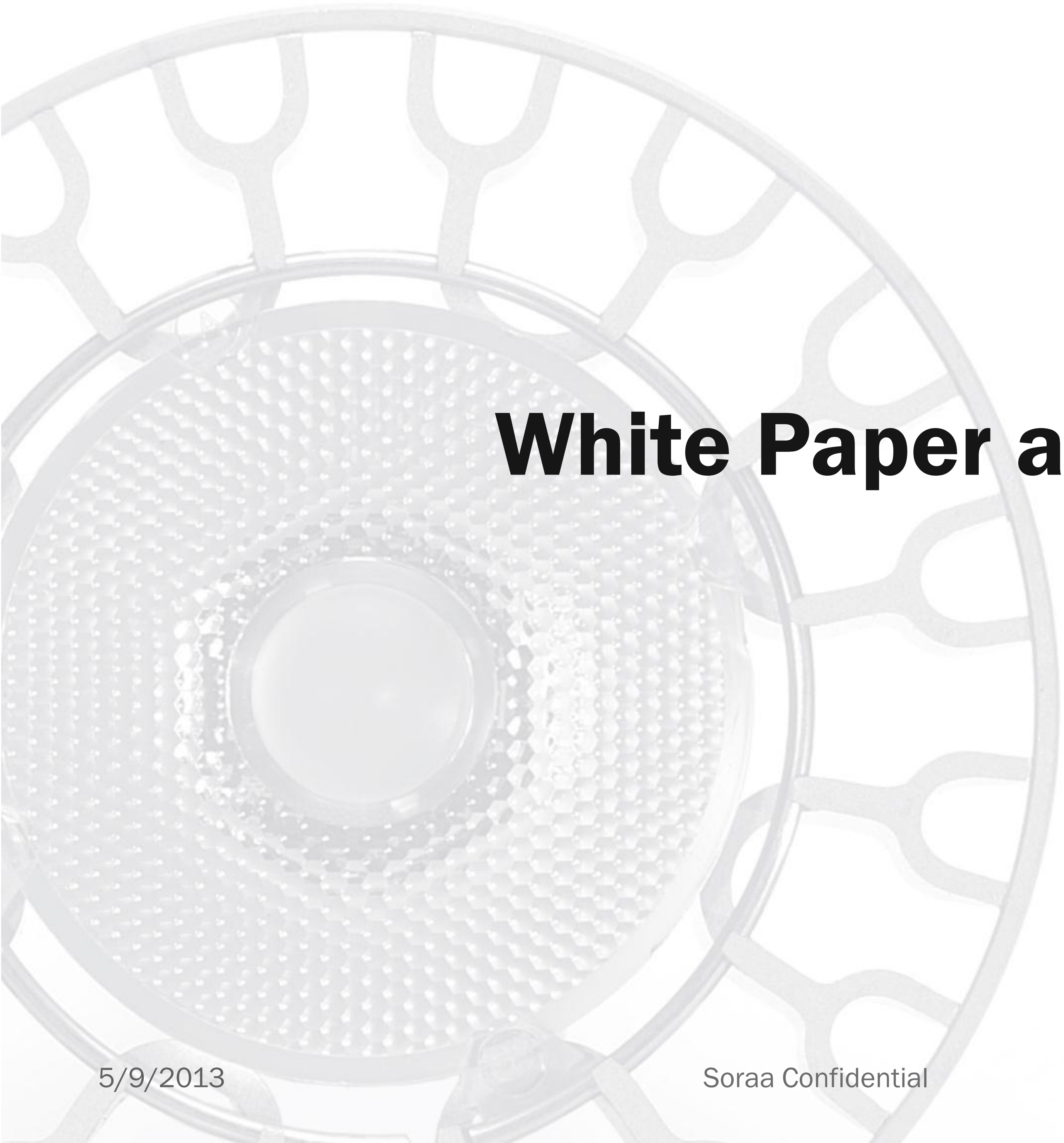



# Whiteness Rendering

SORAA Simply Perfect Light™

- We measured whiteness standard of close to 140 on various fashion and manufactured white products
- SORAA VIVID 2 has substantially increased whiteness compared to regular LEDs





# White Paper about MR16

# A Critical Advance In MR16 Lamps

James R Benya, PE, FIES, FIALD

5/6/2012

Simply Perfect Light™

# A Critical Advance in MR16 LED Lamps

James R Benya, PE, FIES, FIALD

## Abstract

The Holy Grail of lighting is a man-made light source that has superior energy efficiency, long life, good lumen maintenance, wide temperature starting and operating range, instant starting without life degradation, full range dimming, excellent color, low- to-moderate cost, and is capable of being a "point source." All conventional lamps fail substantially in one or more of these fundamental criteria.

As it has evolved, solid-state lighting (SSL or LED) has succeeded in meeting many of these criteria. Various current products demonstrate energy efficiency, long life, good lumen maintenance, wide temperature range, instant starting, and full range dimming. Most recently, superior color has also been achieved. However, while individual LED sources are reasonably close to a point source, they have low lumen density per point, forcing lamp engineers to use multiple point sources to create a highly directional lamp. The multiple sources create multiple shadows and in some cases colored shadows that are considered undesirable in display applications.

The recent commercialization of GaN on GaN technology is a significant breakthrough in energy density, allowing 5-10 times more lumens to be generated per unit volume. The primary benefit is smaller LED emitter size, which in turn reduces the size of directional lamps and results in point source-like behavior. Another important benefit is greater heat tolerance, enabling the dense lumen package to operate more readily in a compact package and in enclosed fixtures.

A commercial product using GaN on GaN technology has been developed as a family of MR16, 12-volt AC lamps. Depending on the version, the lamp family's performance approaches that of generic 50-Watt MR16 halogen lamps and is comparable to 30-35 watt premium or IR halogen lamps. The products include integral drivers that operate well on a number of combinations of transformers and dimmers, which are delineated in product literature. Common applications include track and recessed lighting (provided that the normal glass lens is removed) and one version is specifically for enclosed luminaires such as used in landscape lighting.



Lamp color rendering is available in standard and high CRI versions. The standard version is offered at either 2700K or 3000K and 80 CRI. The high CRI version is offered at either 2700K or 3000K and 95 CRI. To achieve high color rendering with deep red ($R_9$>90), this product employs "violet pumped" triphosphor, achieving a closer match to the blackbody than conventional two phosphor "blue pumped" LED. As a side effect, the lamps' violet emission around 410 nm reacts with optical brightening agents to have a unique whitening effect for display uses.

The resulting product appears to be a significant leap in LED technology for the huge worldwide MR marketplace, with performance that, within practical wattage and lumen limits, rivals common halogen MR16 and the best LED light engines with remote drivers.

## Introduction

While most of the world's politicians and environmentalists are focused on the demise of the common incandescent lamp and the rise of the A-lamp LED for existing lamp sockets worldwide, designers are anxious for the LED MR16 lamp. In a wide range of applications in homes, hotels, stores, offices, and outdoor locations, the MR16 halogen lamp remains in high demand due to its small size, style, crisp-warm tone and highly directional light quality. For over 30 years, the MR16 has been synonymous with "lighting design" more than any other light source.

The lighting community is frustrated that an LED replacement for the MR16 halogen lamp has been too long in coming. Common knowledge about LED lamps, particularly their preference for low voltage power, seems to suggest that MR16 LED lamps should be easy to develop and would be among the most important products for early adopters. But despite a number of product attempts, (even including a lamp with an internal fan), until recently none have posed a reasonable challenge to the performance of the halogen lamps they might replace.

With a fundamental technical breakthrough, a product has been developed that can meet or exceed the expectations of the marketplace. This review indicates that the first MR16 lamp family with performance comparable to generic MR16 halogen lamps appears to have been achieved.

This paper has been developed to critically review the new technology and to assess the accuracy of product claims. While the intended primary audience is the professional engineer or lighting designer, this paper will be useful to many in architecture, interior design, product design, engineering, manufacturing, and others directly engaged in the design, construction, and management of facilities, as well as those particularly concerned with light, lighting and color.



## Understanding GaN on GaN

### *Basic Science*

Light emitting diodes (LEDs) are a special type of diode, which is a common electronic circuit component used in all electronic devices. Like all diodes, an LED passes electric current in one direction only. All diodes dissipate some energy when the electric current passes through; common diodes convert this energy to heat, but LEDs convert the energy substantially to light. The color of light emitted is determined by the type of semiconductor material that is used in the active region of the device, and by the thickness of the individual layers within the active region. All LEDs that generate white light for architectural lighting use Gallium Nitride (GaN) as the semiconductor material. The forward voltage drop (measured in volts) and the current through the diode, (measured in amps or milliamps) measure the wattage of the diode. These are typically regulated by a driver, an electronic circuit between the LED and mains power, that maintains stable voltage and current in order to prevent the LED from fluctuating or burning up.

### *Practical Differences Between GaN on GaN and Other Technologies*

To make an LED, crystal layers of GaN are grown on a substrate material. The substrate material must have certain qualities, and the most commonly used for LEDs today are sapphire and silicon carbide. Due to differences in material properties between GaN and these materials, the GaN crystal grows imperfectly on such foreign substrates, and produces a high incidence of imperfections which reduce the light generation efficiency of the LED.

The primary scientific breakthrough of this product is the ability to grow GaN crystals on its native GaN substrate ("GaN on GaN"). The crystal grows much more perfectly, can accommodate much higher power densities, and allows the LED emit 5-10 times more light from the same crystal area. This is called "light density"- it's the reason that GaN on GaN devices exhibit far more point-source-like qualities. As an added benefit, the GaN on GaN technology is more heat tolerant than other substrate types and allows higher energy conversion in small form factors.

To further increase efficiency compared to other diode types, this family of products uses a design that mitigates LED "droop", a phenomenon observed in GaN-based LEDs wherein efficiency drops as power density is increased. This design allows the LEDs to maintain high efficiency at high operating power densities, and produces a very bright, point-source-like light source.

## Color

### *Common Colorimetry and Color Metrics*

**Introduction**

MR16 lamps are often selected for their ability to render objects vividly and make colors appear natural. Part of the original appeal of the MR16 was its higher Correlated Color Temperature (CCT) in comparison to common incandescent lamps. Objects with higher color temperature than the ambient environment appear brighter and call attention to themselves- hence the old theater lighting axiom of "fill warm and key cool". The halogen MR16 lamp is the perfect addition to regular tungsten lighting, and adds highlights and sparkle to a conventional design in an energy efficient and economical product. No wonder that the MR16 epitomizes ***lighting design***- the lamp enabled the artistic and dramatic potential of lighting in everyday projects.

But the MR16 has other important qualities. It is small, attractive, and adds sparkle and drama to ordinary spaces. It is often used for the general lighting of sophisticated spaces because of its size and the interesting contrast it creates. This legitimizes the concept of 2700K MR16's for fill lighting as well as 3000K MR16's for key lighting. In fact, a commonly applied professional accessory for the MR16 lamp is a 2700K filter, used for precisely this purpose.

**Importance of Color**

MR16 lamps are often used in art display and other situations were color rendering is quite important. From the experience of lighting designers worldwide, however, there are applications where color matters somewhat, and applications where color ***really*** matters. These tend to include:

- Museums
- Galleries
- Retail clothing
- Jewelry
- Food sales and service

LED lamps produce light differently than halogen lamps. Halogen MR16 lamps tend to emit light almost perfectly relative to the reference standard "blackbody". But LED lighting is more like fluorescent lighting, using blended phosphors to fluoresce and emit light of various wavelengths that, working together, synthesize white light. The relative accuracy of this synthesis among different MR16 LEDs is a crucial criteria when specifying sources for lighting design.



**Review of Spectral Power Density (SPD)**

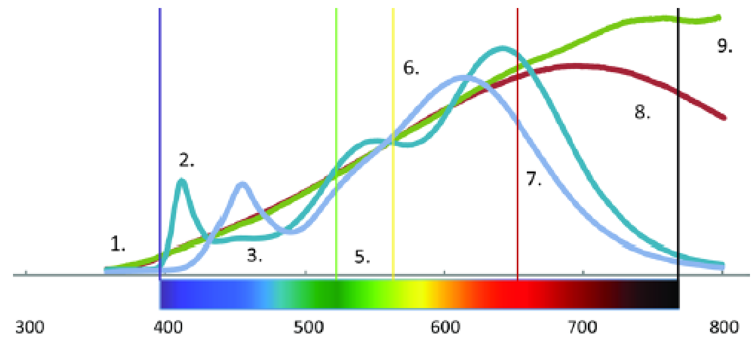



Figure 1-1 Spectral Power Density of MR16 Sources

Professional evaluation of a light source often begins by reviewing its color spectrum. Especially as light sources become more complex and use quantum physics to create light (rather than heat), a spectral power density diagram is an intuitive way to better understand what to expect of the light source.

In figure 1-1, the spectra of several lamps are demonstrated:

- A conventional halogen MR16 lamp with premium dichroic coating
- A halogen IR MR16 (narrow flood)
- A first generation LED (BP2P), blue pump, 3000K at 80 CRI
- An LED using GaN on GaN (VP3P), violet pump, 2700K at 95 CRI

The conventional halogen MR16 lamp emits light very closely matching the blackbody curve, as expected. But note several key observations (keyed to the figure):

1. In the UV region, all LED sources have no emission, but halogen lamps do. While it seems small, UV from most light sources is the principal cause of photodegradation and must be controlled.

2. Violet pumped LED lamps overshoot violet and other near-UV wavelengths, which can improve whiteness rendering (see below). But even short wave visible light is a source of concern with respect to museum lighting. See discussion in the last part of this report.
3. Violet pumped lamps undershoot the blackbody in blue, but not by much.
4. Blue pumped LED lamps strongly overshoot blue at approximately the human circadian response peak, with both positive and negative potential in health and light situations.
5. Blue pumped LED lamps undershoot cyan, reducing color rendering throughout the green-blue range.
6. Most sources are about the same in the green-yellow-orange range.
7. The lower CRI LED products roll-off in medium and long wave red, hence the poor R9 numbers (see below)
8. Pure red is centered at about 687 nm. The high CRI LED lamps approach the response of the halogen IR lamps. While the LED lamps then roll off fairly quickly towards long wave red, the halogen IR lamps roll off more gently.
9. Only the conventional halogen lamp follows the blackbody curve into the IR region.

It is generally recommended that analyzing the SPD of any candidate light source should be the first step in color review. Because human color vision varies due to chromatic adaptation, cognition and other factors, it often helps to identify potential issues from the SPD chart before relying on other metrics or visual inspection.

**Color Rendering Index (CRI)**

The best-known metric for color quality, CRI, is a quantitative measure of the ability of a light source to reproduce objects faithfully relative to an ideal light source. CRI has been criticized and replacement systems proposed (see below), but none has yet managed to replace this well-established system.

CRI is determined by comparing the color of sample color swatches under a test light source versus under a reference light source of the same correlated color temperature. The CRI value is computed using eight colors ($R_1$ through $R_8$) that are unsaturated, pastel-like colors. Six supplementary colors are also tested to provide additional information. $R_9$ through $R_{12}$, for instance, are saturated colors (red, yellow, green and blue). For LED sources, high CRI values are often presented with their $R_9$ value (red), as red is typically the weakest color typically rendered by LED sources but well rendered by the halogen lamps they are intended to replace. For instance, most common 3000K LED MR16 lamps have CRI 80, which is considered good, but $R_9$=0, which means that reds and warm tones will be slightly sallow.



Perhaps the toughest criticism of CRI is that the system was developed primarily for halophosphor fluorescent lamps, whose SPD's exhibit very little peak-and-valley behavior. With sources like LED showing potential for exaggerated peaks and valleys throughout the spectrum, critics claim CRI is not well suited to explain in a single number the quality of state-of-the-art light sources.

**Color Quality Scale (CQS)**

CQS, developed by scientists at the US National Institute of Standards and Technology (NIST), was designed to replace CRI and compensates for most of CRI's shortcomings. However, CQS is one of a number of competing systems being considered by the International Commission on Illumination (CIE). Six other candidate systems from around the world are also in the running. CQS is a leading contender, but for now, CRI is still the recognized system.

## *Creating White Light with LED*

**Red Green Blue (RGB) LED**

LEDs are available in all three colors, and mixed together, can generate white light at virtually any color temperature, or for that matter, any color of light at all. The principle of RGB color mixing is the underlying technology behind television, digital cameras, theatrical lighting, and a multitude of other uses. Using three LED chips in close proximity, LED color changing systems have been popular since the invention and practical dissemination of the blue LED in the late 1990's.

However, there are practical problems with using RGB for a white light source, especially for architectural lighting where the light source is expected to remain stable for 25,000 hours or longer. The three types of LED – red, green, and blue – age and degrade at different rates. This method was long abandoned for use in architectural lighting, and for theatrical lighting, the system was expanded to include more colors of LED.

**Blue Pump Two Phosphor (BP2P) LED**

LEDs are not naturally white – GaN-based LEDs for architectural lighting can be designed to emit any one color in the range of UV-A (380 nanometers) through green (550 nanometers). Most of the LED industry has chosen royal blue (around 450 nanometers) because blue light excites "R" (red) and "G" (green) phosphors, and letting some blue through completes the spectrum. Depending on the color temperature of the LED, the direct amount of narrow band blue radiation (called the "blue spike") is pronounced. Conversely, physical limitations prevent light emission near this blue spike and especially in the cyan range, so most BP2P LEDs exhibit a "valley of cyan" and render those colors poorly (see "Spectral undershoot and overshoot" below).

The "blue spike" in most white LEDs is both a potential benefit and a potential problem. It coincides with the response of the human iPRG cells that cause circadian responses normally associated with daylight, which could be used positively by day but might present a photobiological problem at night.

Similar to fluorescent lamps, white LEDs can employ phosphor engineering to create higher CRI lamps that minimize the peaks and valleys of mainstream white LEDs. Some products also increase the deep red output ($R_9$), which reduces lumens and luminous efficacy but also results in a better display lamp.

**Violet Pump Three Phosphor (VP3P)**

In VP3P technology, violet light at 415 nanometers is used to excite phosphor material containing blue, green and red phosphors, very much like most modern fluorescent lamps. The source exhibits a "violet" spike and a valley of blue, although not as exaggerated as the "valley of cyan" in BP2P diodes. The resulting color spectrum has the potential of higher CRI and luminous efficacy. Besides, the added violet can excite fluorescent materials commonly used as brighteners in fabrics, detergents, and other products, a benefit to the display of certain retail products.

The "violet spike" has its own potential concerns. For display lighting purposes, the amount of visible radiation near UV may possibly create photodegradation damage similar to UV from halogen lamps- this is a potential issue for museum applications. On the other hand the violet spike causes few concerns when it comes to human health, because known detrimental health effects are confined to the ultra-violet range where VP3P LEDs do not emit light.

## *Unique Color Issues of LED*

**Blackbody matching**

The practical reference of "good" color rendering is the blackbody, a theoretical object that can be heated to any temperature without oxidizing or burning. When sufficiently heated, the object glows, and the color of light emitted is referenced to the thermal temperature of the blackbody. Incandescent lamps (including halogen) are essentially blackbody sources, as the



filament is heated to produce light. Natural daylight is also essentially a blackbody. The obvious difference between the two reflects the color temperature difference.

To a certain extent, the human eye can adapt to color deficiencies. It is not necessary for a light source to perfectly match the blackbody to adequately render colors. But for product concept and design, lamp manufacturers make every effort to match the blackbody spectrum, as the closest match will produce higher CRI.

**Spectral undershoot and overshoot**

The peaks and valleys of either LED pump method (BP2P or VP3P) are caused by physical principles that are unavoidable. Fluorescent lamps, in comparison, use mostly ultraviolet light to excite phosphors, and are capable of generating an almost perfect spectrum at any color temperature. But for LEDs, the prospect of an ultraviolet source poses too many possible application risks and problems. Phosphors absorb light at one wavelength and re-emit light at another, longer wavelength. Therefore, there is a "valley" of wavelength between the exciting light and the emitted light. For instance, if a blue LED excites a green phosphor, a valley of emission exists in the cyan range- this is the origin of the detrimental "cyan valley" in BP2P LEDs.

**Deep red**

Critical color rendering evaluations often focus on the deepest reds, as this is where most manmade light sources don't do well. For the true burgundy of fine wine or the deep blood red of certain paints and fabrics, lack of emissions at 700 nanometers will be revealed quickly in comparative visual testing, and these colors will appear more orange with low CRI and low $R_9$ lamps. Lamps with CRI>90 and $R_9$>80 are most likely to appear natural when rendering these colors.

While it is possible to improve $R_9$ with good phosphor engineering, it is important to remember that lumens will be reduced as energy is moved from the green yellow region, to which the eye is most sensitive, to produce long wave red instead. As it was true with fluorescent lamps, it is also true with LED lamps: superior color rendering, especially in red, will result in lamps of lower lumens and lower luminous efficacy.

**Whitening**

In fabrics, printed materials, detergents, and toothpaste, artificial brighteners are used that capture violet and ultraviolet light and then fluoresce blue light, making whites appear

SORAA
Simply Perfect Light™

"brighter." The VP3P system can potentially produce a far more pronounced effect than the BP2P system, where little fluorescence is excited.

**Metamerism**

Metamerism is a complicated effect that describes the ability for a particular set of objects to appear the same color under two different illuminants. A common complaint among retailers is that materials in two products, such as a sweater and a skirt, match under their display lighting system but clash when seen in daylight - a manifestation of what's called ***illuminant metameric failure***.

As a general rule, a light source that carefully follows the blackbody curve will avoid such practical problems of color shift.

## Light Quantity

### *Luminous flux*

The lumens emitted by a source are a historically significant measure of its output and efficacy, measured in lumens per watt. But luminous flux is less valuable when evaluating a directional light source, because the principal interest in the source is the candlepower (see below). Moreover, the lumens of the source contained within the assembly of lamp, reflector and/or lens cannot be used for conventional calculations. For these reasons, many directional light sources do not have published lumen ratings, and for those that do the information is of little practical value.

### *Candlepower*

**Basics**

For most accent and display lighting, the Center Beam Candle Power (CBCP) and beam angle are used to make source selections. Being directional light sources, MR16 lamps are specified by their CBCP and beam angle in degrees. CBCP is the measure peak intensity also referred and is measured in Candela (Cd). Beam angle is defined by the angle at which the intensity is half of the peak intensity.

Less commonly, directional lighting is also described by field angle. Field angle is defined as the angles at which the intensity is 1/10 of peak intensity. Wider angles are called "spill light" and aren't usually described.



**Candlepower "standards"**

Over time, popular names were adopted to describe the beam of common lamps and luminaires. This system was more-or-less officially adopted by the industry and is used by hands-on practitioners, especially in theater, retail and museum applications.

| *Common name* | *Nominal Beamspread* | *Common Variations* | *Use* |
|---|---|---|---|
| Pinspot | 5° | 1-6° | Extreme highlights or extremely long throws |
| Very Narrow Spot (VNSP) | 8° | 7-9° | Intense highlights of small objects or very long throws |
| Narrow Spot (NSP) | 10° | 10-15° | Highlights or long throws |
| Spot (SP) | 15° | 15-20° | Highlights or long throws |
| Narrow Flood (NFL) | 25° | 20-30° | Small area illumination |
| Flood (FL) | 35° | 30-40° | Area illumination and washes |
| Wide Flood (WFL) | 55° | 50-60° | Washes |
| Very Wide Flood | >60° | | Broad area washes |

Table 1 Generic Directional Lamp Beamspreads

Note that there are no specific standards of candlepower values. When lighting energy codes are not significant, users are accustomed to favorite lamps and specifiers are not overly exacting. But with the increased emphasis on energy efficiency, even relatively minor differences could weigh heavily on a purchasing decision.

**Lamp design and candlepower value reporting**

Taking advantage of the indefinite nature of beamspread "classes", in the 1990's lamp manufacturers began to make minor changes in beam angle in order to increase CBCP. For a given light source, every degree the beam narrows, there will be an increase in the CBCP. Likewise, for every degree the field narrows, there can also be an increase.

Consider the many types of MR16 halogen technology variants (see later). The various technologies make a difference, with some having significant impact. Take for instance the "flood" halogen lamps in Table 2. Manufacturers try to maintain a competitive standard candlepower of about 1500 at, which is the more-or-less standard 40-degree ANSI code "EXN" lamp developed in the 1970's. To achieve this, the ultra long life lamp, the premium smooth reflector lamp, and the 30-watt IR lamp are all narrowed to 36 degrees, and the "saver" lamp is narrowed to 32 degrees.

| | Lamp Type | Beam Angle | CBCP |
|---|---|---|---|
| Lamp 1 | 50 watt premium with cover glass[1] | 40 | 1500 |
| Lamp 2 | 50 watt premium | 40 | 1700 |
| Lamp 3 | 50 watt generic cover glass[1] | 40 | 1350 |
| Lamp 4 | 50 watt generic | 40 | 1500 |
| Lamp 5 | 37 watt IR | 40 | 2200 |
| Lamp 6 | 50 watt aluminized | 36 | 2000 |
| Lamp 7 | 50 watt ultra long life | 36 | 1500 |
| Lamp 8 | 24 watt saver lamp | 32 | 1300 |
| Lamp 9 | 50 watt premium lamp, smooth reflector | 36 | 1580 |
| Lamp 10 | 30 watt IR | 35 | 1600 |

Table 2- Common MR16 "Flood" Halogen Lamp Types

[1] *Note that cover glass reduces CPCP by about 10%. This occurs in every halogen fixture with a lens, so actual candlepower of a lamp in use should be reduced by 10%. An LED is often not used with a lens, hence the actual output is as reported.*

## Practical Considerations

### *About the MR16 lamp*

**MR16 Halogen Lamps**

The MR16 lamp made its first appearance in 1965 when it was introduced as a slide and film projector lamp by General Electric. "MR" stands for "multifaceted reflector" and 16 stands for the approximate diameter in 1/8 ths of inches. Over the years, MR16 lamps have become widely used in architectural lighting applications such as museums, retail stores, landscapes, and residential settings for accent, task, and display illumination. They are typically used in track lighting or recessed downlights for interior lighting and in landscape luminaires in outdoor settings.

The conventional halogen MR16 lamp employs a compact halogen lamp ("burner") and a reflector made of coated glass. The burner is a quartz glass envelope compact lamp that must be protected from explosion. The coating is dichroic, which is used to reflect visible light but not infrared light, letting the IR heat out of the back of the lamp to be absorbed and dissipated by the housing. The common reflector style is faceted, although smooth reflectors are also used.

The advantages of MR16 lamps over other lamp types are related to their small size, color properties and beam control. These qualities have been harvested in hundreds of thousands of applications, especially when space is constrained or when aesthetics are of primary interest. Recessed luminaires with trims as small as 3" (76 mm) in diameter and track and landscape luminaires as small as 2.25" (57 mm) in diameter are extremely popular due to their size. Lamps are offered over a very wide range of power, from 10 watts to 75 watts. There are a number of major different beamspreads (see Table 1, above) and versions of varying technologies (Table 2). The differing technology in lamps resulted from demands of the marketplace as well as technical advances; for example, the premium dichroic and aluminized lamps provide stable color over life, and the long life lamps allow the appealing MR16 to serve as a downlight in elevators and other demanding service locations where relamping is inconvenient and expensive over the long term.

SORAA
Simply Perfect Light™

| *Lamp Type* | *Characteristic* | *Discussion* |
|---|---|---|
| Generic | Original dichroic coating and conventional halogen burner | Coating degenerates over time, reducing performance and shifting lamp towards green |
| Premium | Titanium dioxide dichroic reflector, conventional halogen burner | Coating remains stable, lamp color remains consistent |
| Premium UV stop | Burner coated to absorb UV | Reduces UV emissions |
| Aluminized | Aluminized, not dichroic reflector, with conventional halogen burner | Full halogen spectrum in beam |
| GU10 | Line voltage variation of generic lamp, halogen burner | Line voltage, relatively poor performance |
| Twist and Lock | GE's unique version, halogen burner | Premium lamp, special base |
| Colored | Dichroic coating used to alter lamp color temperature or to create a specifically colored lamp | Many niche products ranging from 3500-5500K lamps to tuned lamps (e.g. minus green jewelry display) and saturated colors |
| IR | Special "IR" burner is coated to pass light and reflect IR back onto filament to regenerate heat | Known as IR, HIR and IRC, most lamps are also premium and UV stop |

Table 3 Common Types of MR-16 Halogen Lamps

The key disadvantages of halogen MR16s are short life, relatively low energy efficiency and the heat that they generate. Because of their high operating temperature, direct contact to skin or flammable materials should be avoided. Luminaires can suffer long term degradation of transformer life, socket life and wiring due to heat. Also, heat degradation in sockets is exacerbated by the frequent relamping required by halogen's short life.

Lamp life of halogen MR16 ranges from 2000 hours for generic lamps to 5000-6000 hours for most premium lamps. There are a few long life products rated 10,000 hours or more. Like other halogen lamps, dimming may extend lamp life but there will be considerable reduction in performance.



| *Lamp Type* | *Characteristic* | *Discussion* |
|---|---|---|
| Generic | Original dichroic coating and conventional halogen burner | Coating degenerates over time, reducing performance and shifting lamp towards green |
| Premium | Titanium dioxide dichroic reflector, conventional halogen burner | Coating remains stable, lamp color remains consistent |
| Premium UV stop | Burner coated to absorb UV | Reduces UV emissions |
| Aluminized | Aluminized, not dichroic reflector, with conventional halogen burner | Full halogen spectrum in beam |
| GU10 | Line voltage variation of generic lamp, halogen burner | Line voltage, relatively poor performance |
| Twist and Lock | GE's unique version, halogen burner | Premium lamp, special base |
| Colored | Dichroic coating used to alter lamp color temperature or to create a specifically colored lamp | Many niche products ranging from 3500-5500K lamps to tuned lamps (e.g. minus green jewelry display) and saturated colors |
| IR | Special "IR" burner is coated to pass light and reflect IR back onto filament to regenerate heat | Known as IR, HIR and IRC, most lamps are also premium and UV stop |

Table 3 Common Types of MR-16 Halogen Lamps

The key disadvantages of halogen MR16s are short life, relatively low energy efficiency and the heat that they generate. Because of their high operating temperature, direct contact to skin or flammable materials should be avoided. Luminaires can suffer long term degradation of transformer life, socket life and wiring due to heat. Also, heat degradation in sockets is exacerbated by the frequent relamping required by halogen's short life.

Lamp life of halogen MR16 ranges from 2000 hours for generic lamps to 5000-6000 hours for most premium lamps. There are a few long life products rated 10,000 hours or more. Like other halogen lamps, dimming may extend lamp life but there will be considerable reduction in performance.

www.soraa.com http://www.soraa.com/news/vivid-launch-home Page | 15

**High CRI**

The high CRI lamps, called "Vivid" are 12-watt lamps also rated for recessed luminaires and track heads. CRI is 95 with R9 of greater than 90. Performance is roughly equal to a 35 watt generic FMV.

**Standard Outdoor**

This lamp, which is rated for use in an enclosed and gasketed luminaire, is a 9.5 watt, 80 CRI source with performance roughly equal to a 35 watt generic FMV.

## *Light Quality*

**Beam quality and management**

The optics of this LED product are not unusual, but are unique in 35W+ LED MR16 lamps; because of the single small high-intensity source, the optical system performs exceptionally well. While this LED is fundamentally a directional source, a lens is added to redirect the light energy. This lens is particularly effective at controlling beam, field and spill, essentially eliminating spill. See Figures 1-1 and 1-2, below. The LED is all but free of spill light, making glare shielding easier and more effective.

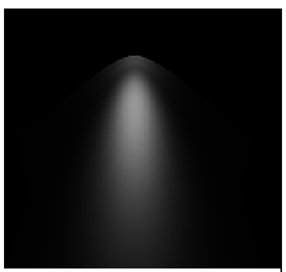


Figure 1-1 GaN on GaN LED

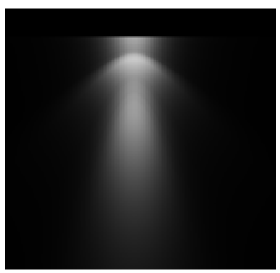


Figure 1-2 Halogen



**Shadowing**

Shadows play an important role in creating a dramatic and effect-rich lighting scene, and in interpreting textures. Especially if the texture structure is fine, small differences in shadow definition can have a big impact on the visual impression.

An infinitesimally small source or (a true "point") source creates a shadow with a crisp, immediate transition between light and dark. All practical light sources have some size and will have some transition between the dark of the full shadow and the unobscured illuminated area. This is illustrated in figure 1-0-2. The larger the source, the larger the transition area. The transition area also increases as the light source moves closer to the object. The transition zone is further increased with the introduction of multiple sources.

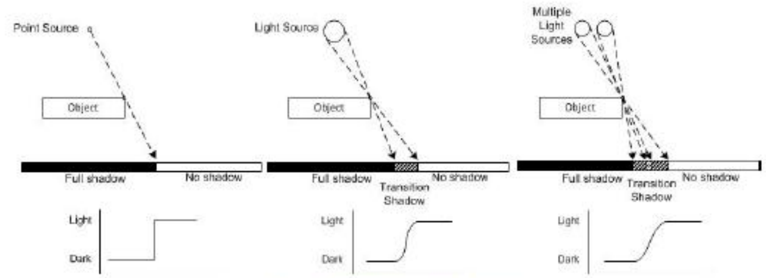



Figure 1-0-2 Shadows from Light Sources

Another advantage of a single source is that duplicate or mushy shadows are avoided (Figure 1-3)

Figure 1-3 Shadows from (left) a large source (Halogen MR16), (center) multiple point sources (first generation LED MR 16 with 4 LEDs) and (right) single point source (GaN on GaN LED MR16) source

**Beam Management Accessories**

The artistry of using MR16s has historically involved external light quality management, notably the use of lenses to alter the beam pattern, and baffles and louvers to shield the spill light from sight. With this generation of products, new methods will need to evolve because:

- The source is relatively spill light free, making the shielding accessories less important
- The beam is relatively halation and striation free, making smoothing lenses mostly unnecessary.
- The beam of this LED is "flat", meaning that the angle of equal intensity is greater than with most halogen lamps, resulting in a steeper run-back near beam edge. Beam edge modification may be needed for some art display and cannot be performed using the standard borosilicate lenses such as solite.

These issues are not generic. Compared to other LED MR16 products, this GaN on GaN family will probably require an accessory holder that maintains free airflow around the lamp (except for the totally enclosed version), and a unique set of accessories, in order to realize its full potential as a high performance display lighting system. This has been discussed with the manufacturer, but at this time, there are no special products.

Lamps were installed and tested relative to other current LED products in open backed arm lights used to light artwork. Because of the ventilation, a conventional accessory holder, solite lens and tube baffle ("snoot") were successfully tested and have operated successfully for months without problems. Although far better than a halogen lamp, the LED lamp has enough spill light to necessitate a snoot and for art display, a softening lens remains important. However, for direct accenting, the beam is very good and a smoothing lens is not needed, as beam imperfections are negligible.

Many MR16 applications require the use of IR and UV filters that alter the color of the light and reduce light output. The violet peak of the GaN on GaN lamp may be of some concern, but compared to halogen lamps, both this family and conventional LED exhibit complete attenuation of UV and short wave indigo, whereas halogen lamps still emit measureable light well in the UV-A region.



## *Color Quality*

**Halogen lamps**

The halogen lamp, especially without filters, is virtually a reference standard blackbody. However, most MR16 halogen lamps have some type of filtering, either in the UV and deep violet and/or in the IR and deep red. Nonetheless, they remain the reference standard against which LED will be judged.

A visual principle called the "Hunt Effect" describes a phenomena in which color quality becomes more important as colors are more brightly illuminated. This supports the notion that LED MR16s of lower CRI (which generate more lumens per watt) might be used for general and ambient lighting, and that less efficacious high CRI LED MR16s might be reserved for more brightly lighted accents. With current technology, the 10- to 12-watt 80 CRI MR16 LED might be used in many situations where full advantage can be taken of the superior efficacy of the LED, while the critical rendering applications would demand the 95 CRI LED and benefit from the long life of the LED source and energy savings.

**Visual Acceptance**

The challenge of the MR16 LED is to be visually acceptable in comparison to halogen MR16s. Taking into account the Hunt Effect and chromatic adaptation, the majority of existing MR16 applications will look best when using either 2700K or 3000K lamps, which will closely match an existing halogen installation. After all, halogen lamps can be dimmed to change color temperature, and the so-called "dim warm" behavior remains a challenge for LED systems. But in a space where the lights are usually dimmed, the 2700K LED can be used to approximate the typical dimmed color temperature.

But even among halogen MR16 lamps, it is common for the designer to seek a warmer color temperature. Often, color temperature warming lenses such as "cosmetic peach" are installed on halogen MR16 lamps to diminish the harsh cool edge of a halogen lamp operating at 3000-3100K. The use of UV filtering lenses for museum lighting applications has a more or less similar effect. In both cases, a 2700K LED would likely be best accepted.

**Metameric behavior**

Metameric pairs are two different colors or materials that match under different illuminants. There do not appear to be any significant differences among lamps, but designers should be forewarned that any two different light sources run the risk of causing different relationships between two different colors or materials, and care should be a consideration in any design.

Future testing is planned to determine whether BP2P and VP3P LED's have any practical differences.

**Whitening effect**

The VP3P system is relatively unique in generating a violet peak. Like UV-A, violet can cause certain whitening agents to fluoresce, and produce the so-called "whiter-than-white" effect. This effect may be of practical benefit in retail lighting and some other applications, with the caveat that it might have other side effects. See the discussion about UV and IR below.

**Deep Red**

Whether to render deep red is a design decision that should be made carefully. Any LED with R9>50 will have lower lumens per watt, lower lumen output, and lower CBCP. When needed, the high CRI lamps do an excellent job, visually rivaling the color and halogen IR and sometimes performing better because of the whitening effect.

### *UV and IR*

**Infrared Light (IR)**

Infrared light (IR) is radiant heat. It can be felt in the beam of an incandescent lamp. In fact, more than 90% of the energy consumed by an incandescent lamp becomes heat. Occasionally, IR has a beneficial effect, as in heat lamps that focus radiant heat for comfort or hot food holding. But most of the time the heat is wasted and often increases cooling loads in buildings.

**Ultraviolet Light (UV)**

Ultraviolet light (UV) consists of UV-A (blacklight), UV-B (which causes vitamin D synthesis, skin damage, skin cancer) and UV-C (which causes eye damage and is used as a germicidal). UV-A can be used for special effects, and a little UV-B causes Vitamin D2 synthesis in the skin. But UV-B and UV-C should be generally avoided in lighting because of their potential for damage. UV corresponds to wavelengths shorter than 400nm.

**LED Considerations**

Some LED emitters are specifically designed to emit UV, and others to emit IR, but these emitters are not used for architectural lighting. Architectural lighting LEDs emit neither UV nor IR.

However, one of the principal considerations involving MR16 LED is their use in the display of fine art and collectibles. Photodegradation occurs when paintings, drawings, apparel, and furnishings are exposed to light or UV, causing colors fade and fabrics to fall apart. Curators





have developed methods for mitigating damage, and in particular, reducing exposure to light and eliminating exposure to UV and IR light are among the most important measures.

As a rule, LED MR16's are free of UV, but cannot be considered to be absolutely safe. In both the VP3P and BP2P systems, short wave visible light peaks are reason for concern. Filtering to reduce the peaks may be required for critical applications.

### *Powering and Dimming Behavior*

The MR16 LED is generally intended as a replacement lamp to be used in existing MR16 halogen sockets. In addition to some type of transformer, a dimmer also controls many MR16 applications.

Since the combination of LED, driver, transformer and dimmer were never designed to operate together, unpredictable interactions can occur. In almost all cases, the low end of the dimming range is still fairly bright compared to a halogen lamp, which can fade to black. In addition, some combinations of lamp and other electrical components will cause the LED to flicker, drop out, or sometimes, not operate at all.

The design of the driver inside the LED is the key to how the device will operate. Without any real standardization, each LED product will most likely operate differently. In the case of this product, like those of other responsible manufacturers, a list of known compatibilities is listed on the product cut sheet and company website.

### *Applications Details*

At present, MR16 LED developers have recognized the market potential of literally millions of existing lamps. Each replacement lamp offers economic benefits (see below) as well as reducing maintenance and being "greener."

However, the MR16 halogen lamp became popular for more than just small size. The ability to accessorize and use the product in an artful manner was important in its initial acceptance and popularity among designers. With this product, the use of conventional MR16 accessories (other than a snoot) is not recommended, as conventional lenses block the airflow around the heat sink of the lamp.

There are a number of other considerations including:

- Rated life in a recessed luminaire or in a track luminaire, provided that the original lens for the halogen lamp is removed
- A special version suited for outdoor lighting in an enclosed fixture
- Proper fit in most MR16 lamp holders (not all of MR16 LEDs fit)

### *Energy Efficiency and Economics*

The basis of this calculation is the original halogen lamp. If replacing a 50-watt generic MR16 with a 12-watt LED, the approximate savings (including reduced transformer loss) will be about 40 watts per luminaire. At 10 cents per kilowatt-hour, the energy savings in a year of typical commercial use (4000 hours) will be about $16.00. This simple payback alone may be adequate justification for use of the lamp.

Dramatically reduced relamping costs are another advantage of the LED. A quality brand generic MR16 lasting 2000 hours costs about $4.00. By warrantying the LED to three years, these LEDs will outlast generic lamps 6 times over, saving $24.00 in lamp costs as well as the cost of relamping.

## Summary

Sample GaN on GaN products were received with little fanfare, and immediately upon being placed into comparative testing, demonstrated visibly superior performance to other MR16 LED lamps. Detailed investigation followed, and the manufacturer's explanations were surprisingly complete, sensible and impressive. This is genuinely different and better technology, especially for the first application of GaN on GaN in architectural lighting as an MR16 lamp alternative. For a wide variety of current MR16 applications, these lamps are respectable alternatives to and perhaps even improvements upon halogen, and provide benefits of lower energy use and longer lamp life without sacrificing color or candlepower performance.

However, lighting design professionals will quickly realize that while this first generation GaN on GaN MR16 LED lamp is a worthy replacement of generic 50W lamps, their output is still less than some state-of-the-art halogen lamps, especially the 30-50 watt IR lamps. Further improvements in the technology will overcome the heat challenges and will provide higher output product in the future. Those designers needing performance and accessories for professional applications will find these LED MR16 products quite useful, but will probably need to continue to rely on light engine technology for a complete product family of more powerful products and proven accessories.