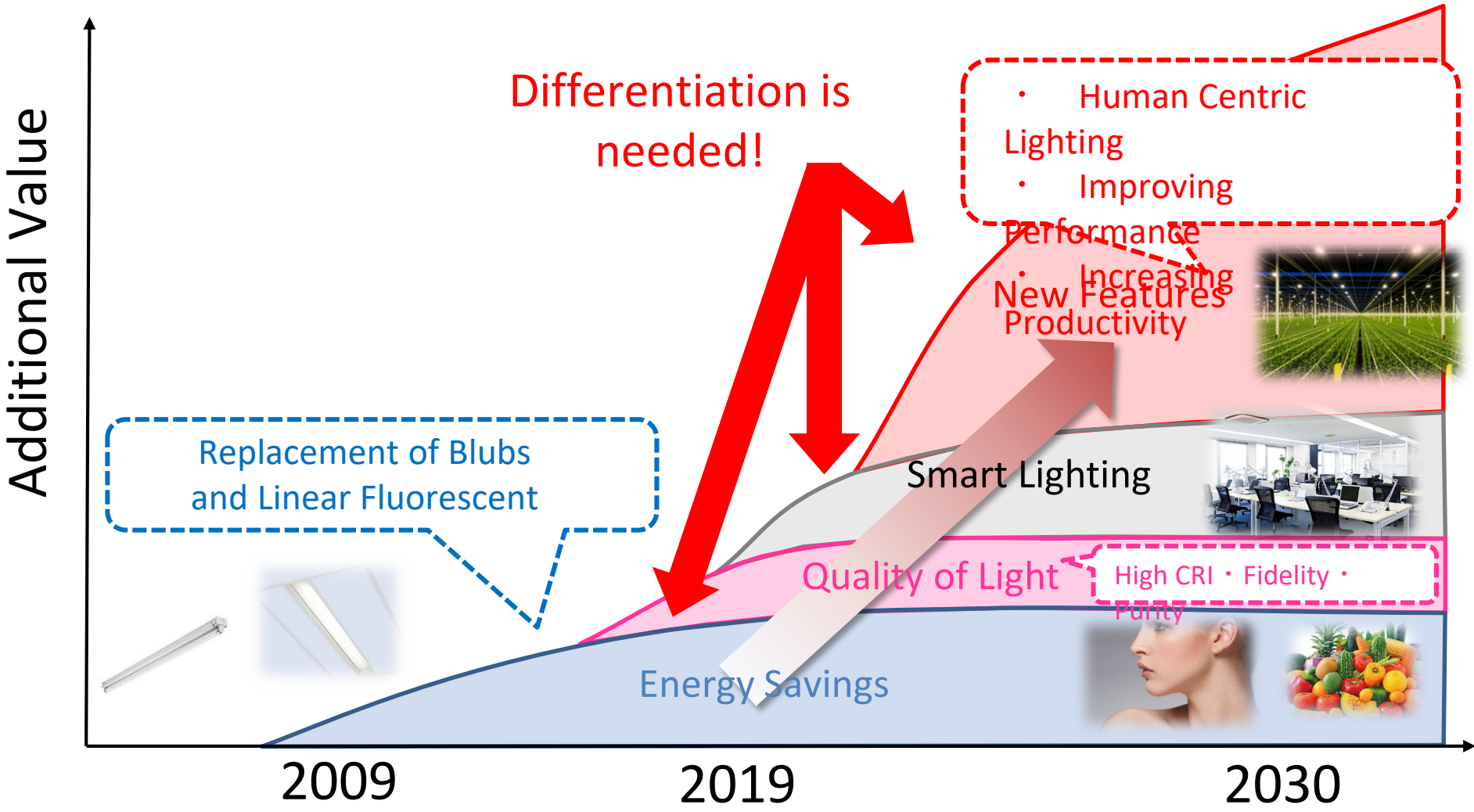
# Raising the Bar

## “Efficacy was so 2015”

**Erik Swenson**
**General Manager**
**Nichia America Corporation**

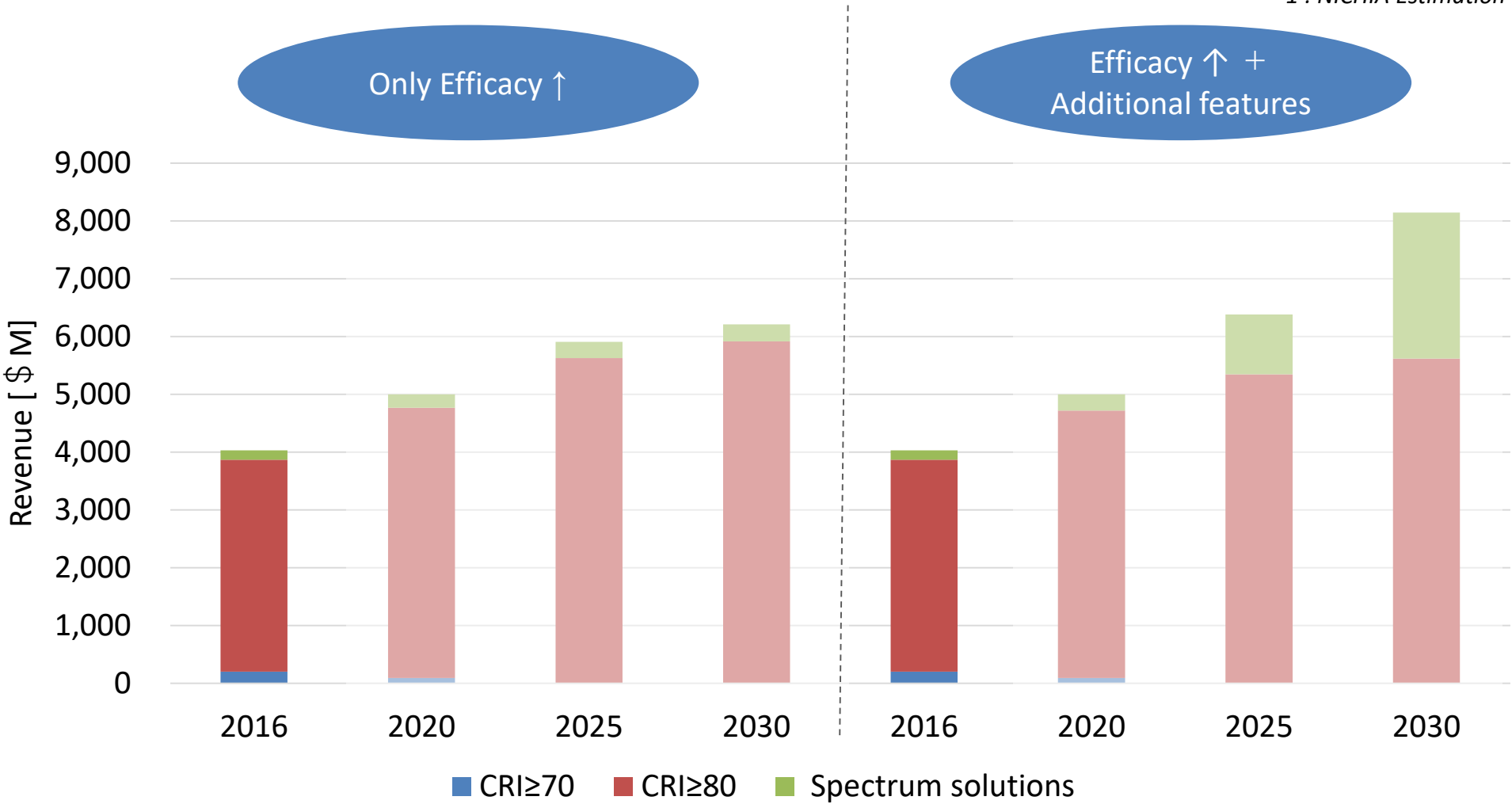
# WHO SAID IT?

**"At the end of my 7th year, my game was complete. Shooting, defense, using the dribble, transition, midrange stuff was all there. Then it was about fine-tuning and trying to improve in each area."**




**To expand the market, we must keep fine tuning!**

*1 : NICHIA Estimation




**By adding new features, the Lighting market will continue to grow.**

# Agenda

1. Where has the focus been?

2. Where is the focus going?
    - Quality of Light
    - Market Specific Spectrums
    - Reliability

3. Questions

### 3. SSL Workshop Presentations

The Workshop had four primary goals: to educate the R&D community on DOE's vision for SSL technology; to update the R&D community on broad-based government funding opportunities related to SSL; to communicate current successes and challenges for SSL from an industry perspective; and to prioritize the SSL R&D tasks to ensure a focused, quality research agenda. All the presentations given at the Workshop are available on the Department's SSL website: http://www.netl.doe.gov/ssl/materials_2005.html

Michael J. McCabe, DOE's Program Manager for Building Technologies, launched the Workshop by welcoming 170 participants to San Diego and emphasizing the significant energy-

**"The commercialized efficacy goal of SSL is to reach 160 lumens per watt, which would represent an order of magnitude increase in efficacy over incandescent lamps and a two-fold improvement over fluorescent lamps.**

**-2005 SSL Program Planning Workshop Report**

At the end of his address, Mr. McCabe reminded participants of the importance of their role at the Workshop, as the Department will use the participants' input to frame and adjust its priorities and accelerate the focus of its research in the proper direction.

Dr. James R. Brodrick, DOE SSL Program Manager, supported these remarks and presented the Department's mission statement for the SSL R&D portfolio:

> *Guided by a Government-industry partnership, the mission is to create a new, U.S.-led market for high-efficiency, general illumination products through the advancement of semiconductor technologies, to save energy, reduce costs, and*

# Projections over the years…

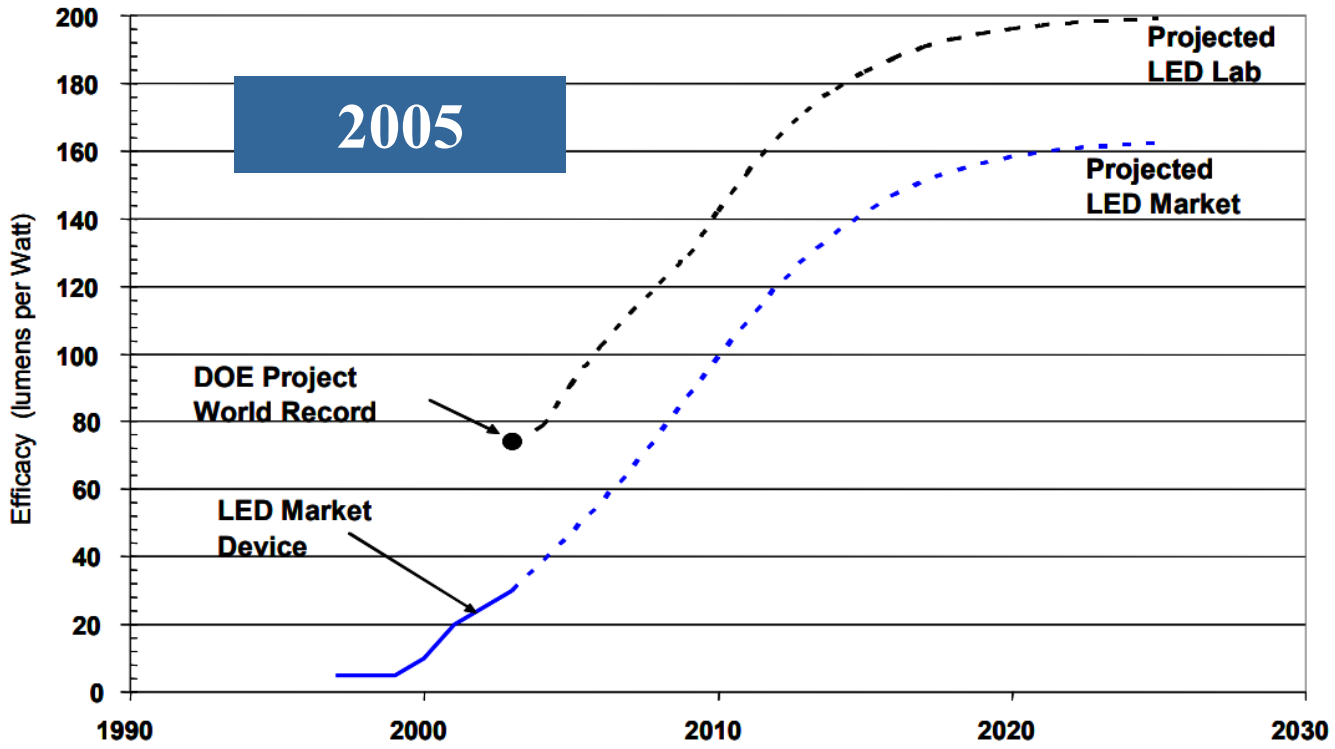



Figure 3-1: White Light Efficacy Targets, Laboratory and Market

# Projections over the years…

**Table 4-1: Summary of LED Device Performance Projections**

| Metric | 2005 | 2006 | 2010 | 2012 | 2015 |
|---|---|---|---|---|---|
| Efficacy- Lab (lm/watt) | 73 | 83 | 119 | 137 | 164 |
| Efficacy- Commercial (Cool White (lm/W) | 47 | 56 | 92 | 110 | 137 |
| Efficacy- Commercial (Warm White (lm/W) | 27 | 36 | 72 | 90 | 117 |
| OEM Lamp Price- Product ($/klm) | 64 | 47 | 14 | 7 | 3 |
| Lamp Life- (1000 hours) | 30 | 37 | 50 | 50 | 50 |

Note:
1. Efficacy projections assume CRI=70 → 80, Color temperature = 5000-6000°K, 350ma drive current, and lamp-level specification only (driver/luminaire not included), reasonable lamp life.
2. Price targets assume "reasonable volumes" (several 1000s), CRI=70 → 80, Color temperature = 5000-6000K, and lamp-level specification only (driver/luminaire not included)
3. Lamp life projections assume 70% lumen maintenance, "1 Watt device," 350mA drive current.
Source: NGLIA LED Technical Committee

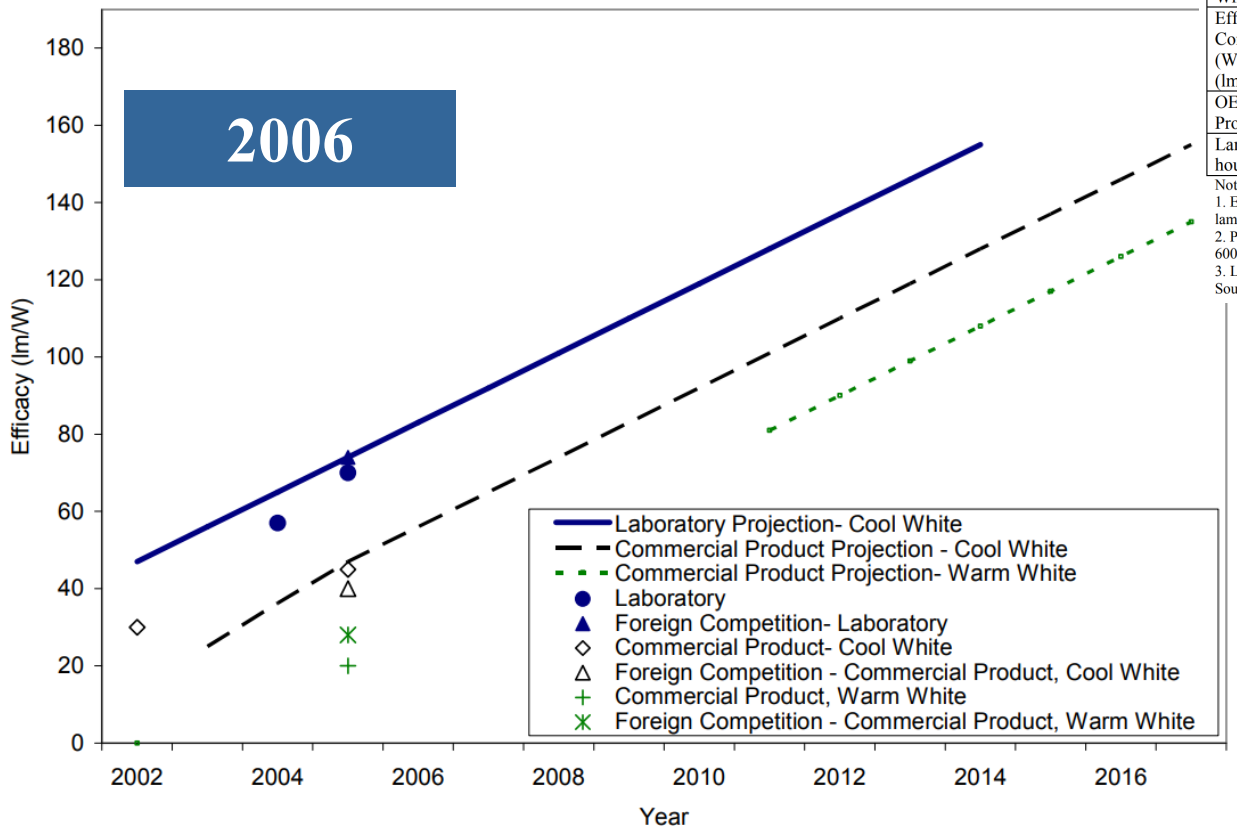



**Figure 4-6: White Light LED Device Efficacy Targets, Laboratory and Commercial**

# Projections over the years…

Table 4-1: Summary of LED Device Performance Projections

| Metric | 2006 | 2010 | 2012 | 2015 |
|---|---|---|---|---|
| Efficacy- Lab (lm/W) | 85 | 129 | 151 | 184 |
| Efficacy- Commercial Cool White (lm/W) | 68 | 113 | 135 | 168 |
| Efficacy- Commercial Warm White (lm/W) | 38 | 83 | 105 | 138 |
| OEM Lamp Price- Product ($/klm) | 35 | 10 | 5 | 2 |
| Lamp Life- (1000 hours) | 37 | 50 | 50 | 50 |

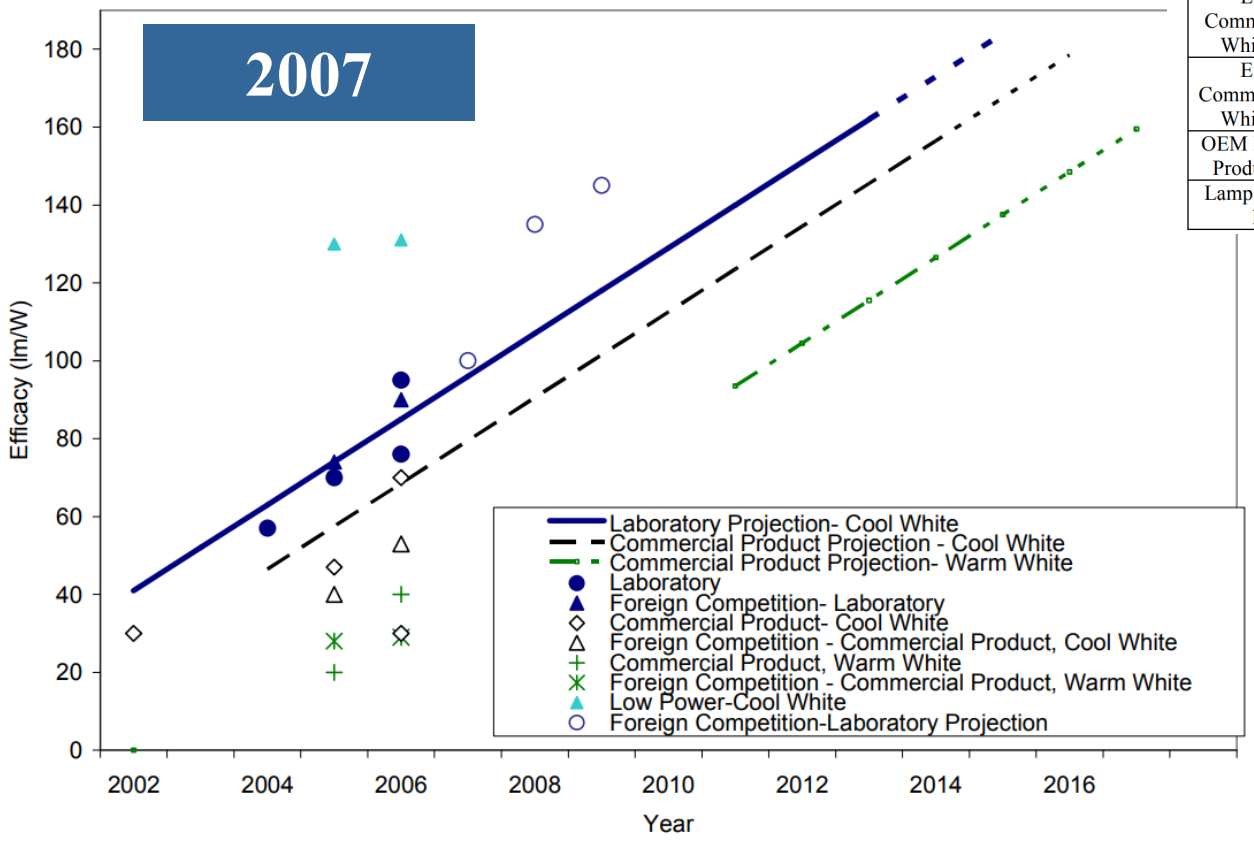
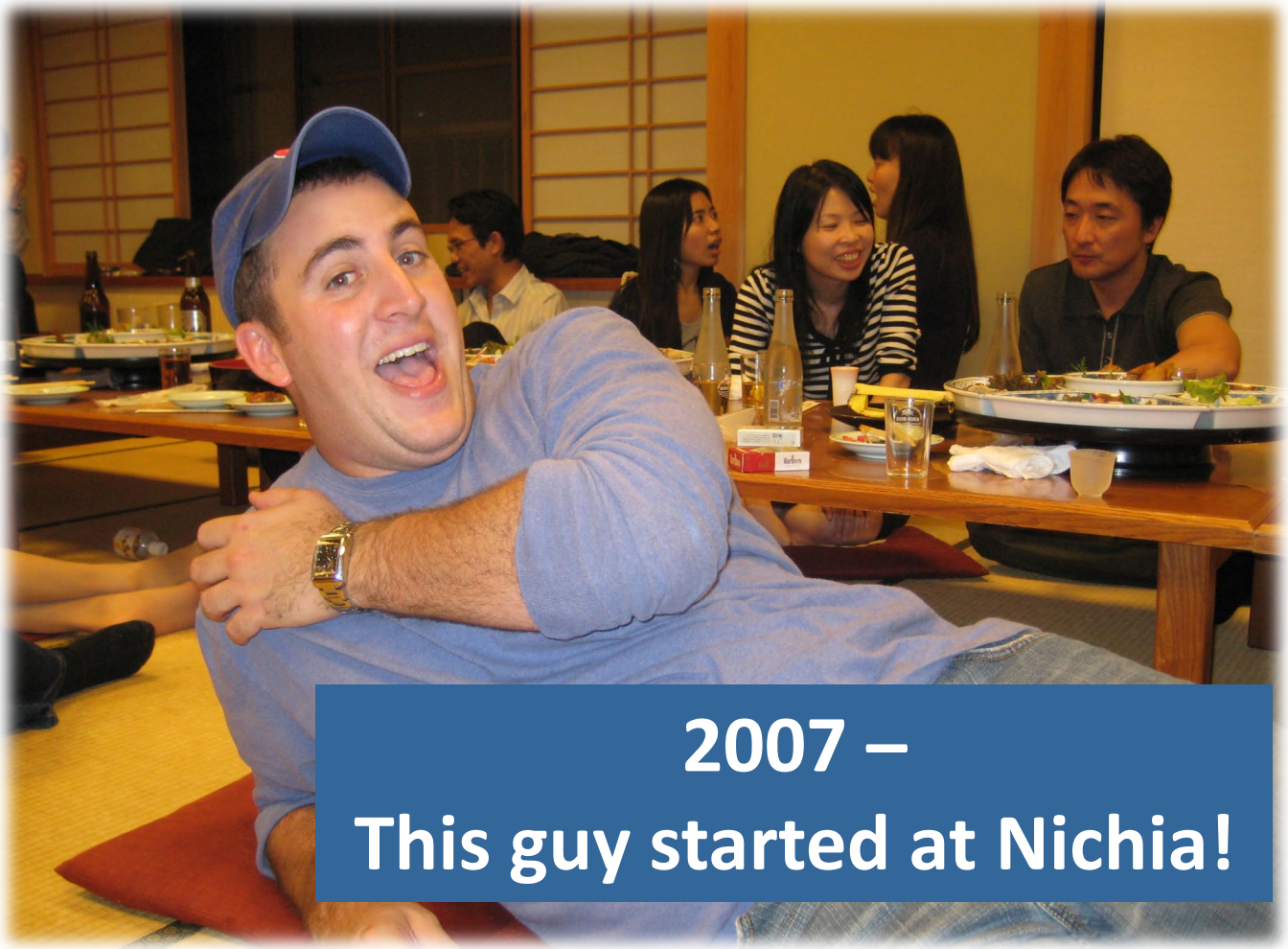



Figure 4-6: White Light LED Device Efficacy Targets, Laboratory and Commercial

Projections over the years…



Leading to an overconfident rookie's presentation…

## SMD Type – Ceramic Package, Long Life

**35 Lumens per Watt!!!**

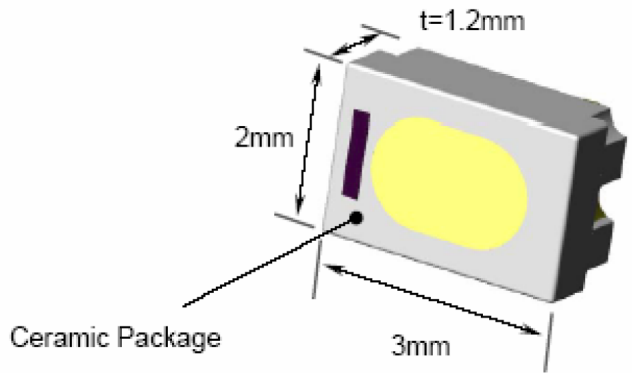
NEW!

# NSSW100C

### Features

- ✓Brightness 1000mcd (2.1lm) @20mA
- ✓Low Forward Voltage: 3.0V
- ✓Luminous Efficacy: 35lm/W
- ✓Long Life Package (High Reliability)

Performance
- White : 1000mcd @20mA
- Color : White
- Easy to Assemble (SMD)
- Topr : -30℃~+85℃
- Tstg : -40℃~+100℃




**NSSW100C (new)**: Best for low profile Channel Letters

# We thought 100 lpW would be the end game!

## Rigel 0.6W NFSx036C

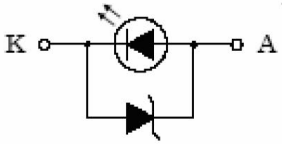
**43 Lumens per Watt!!!**

NICHIARIGEL 0.5W Rigel

### NFSW036C

#### Features

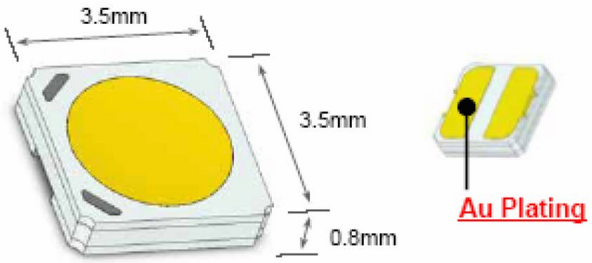
- ✓Compact: 3.5x3.5x0.8mm
  コンパクトサイズ
- ✓Long Lifetime: 50Khrs 70%*
  長寿命：セラミックPKG+シリコーン樹脂+共晶接合　Remaining @Tj=120℃
- ✓Ceramic Package
  セラミックパッケージ
- ✓Colors ○ White ● Warm White




**Schedule**
Sample: '07/2/F, MP: '07/3/F

#### Performance

| | White | Warm White |
|---|---|---|
| Product Type | NFSW036C | NFSL036C |
| Luminous Flux | Typ. 23lm @150mA | Typ. 17.3lm @150mA |
| Thermal Resistance (Package) | 40℃/W Reference | |
| $I_F$max | 350mA Reference | |
| Tjmax | 150 Reference | |
| Topr | -40~+100℃ | |
| Tstg | -40~+100℃ | |
| Environment | RoHS Compliant<br>Pb-Free Soldering Available | |



# more projections over the years…

Table 4-2: Summary of LED Device Performance Projections

| Metric | 2007 | 2010 | 2012 | 2015 |
|---|---|---|---|---|
| Efficacy- Lab (lm/W) | 120 | 160 | 176 | 200 |
| Efficacy- Commercial Cool White (lm/W) | 84 | 147 | 164 | 188 |
| Efficacy- Commercial Warm White (lm/W) | 59 | 122 | 139 | 163 |
| OEM Device Price- Product ($/klm) | 25 | 10 | 5 | 2 |

| Maximum Efficacy (lm/W) | | |
|---|---|---|
| CCT | 75 CRI | 90 CRI |
| 3000K | 182 | 162 |
| 4100K | 220 | 193 |
| 6500K | 228 | 186 |

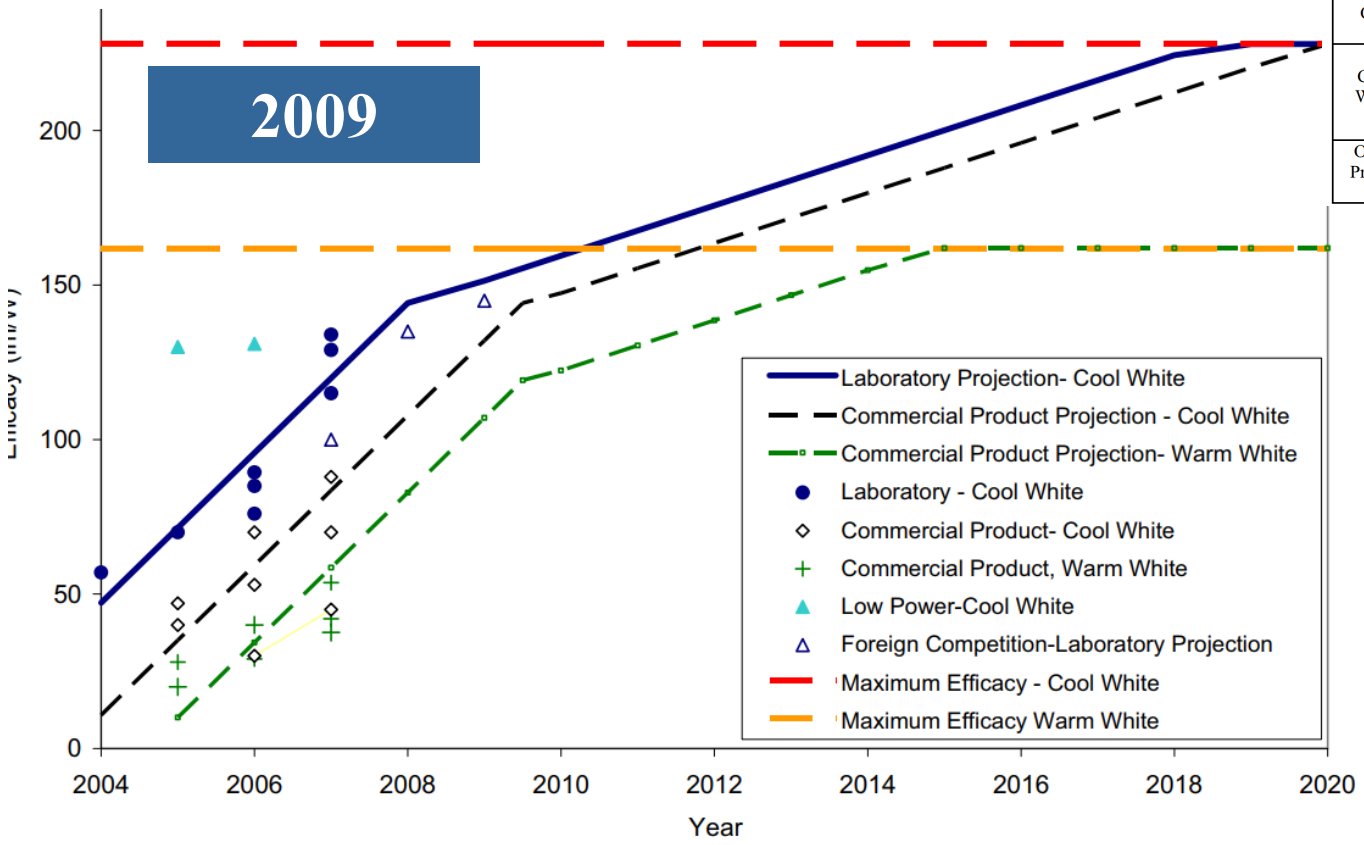



Figure 4-7: White Light LED Device Efficacy Targets, Laboratory and Commercial

# more projections over the years…

Table 4.4: Summary of LED Package Price and Performance Projections

| Metric | 2009 | 2010 | 2012 | 2015 | 2020 |
|---|---|---|---|---|---|
| Cool White Efficacy (lm/W) | 113 | 134 | 173 | 215 | 243 |
| Cool White Price ($/klm) | 25 | 13 | 6 | 2 | 1 |
| Warm White Efficacy (lm/W) | 70 | 88 | 128 | 184 | 234 |
| Warm White Price ($/klm) | 36 | 25 | 11 | 3.3 | 1.1 |

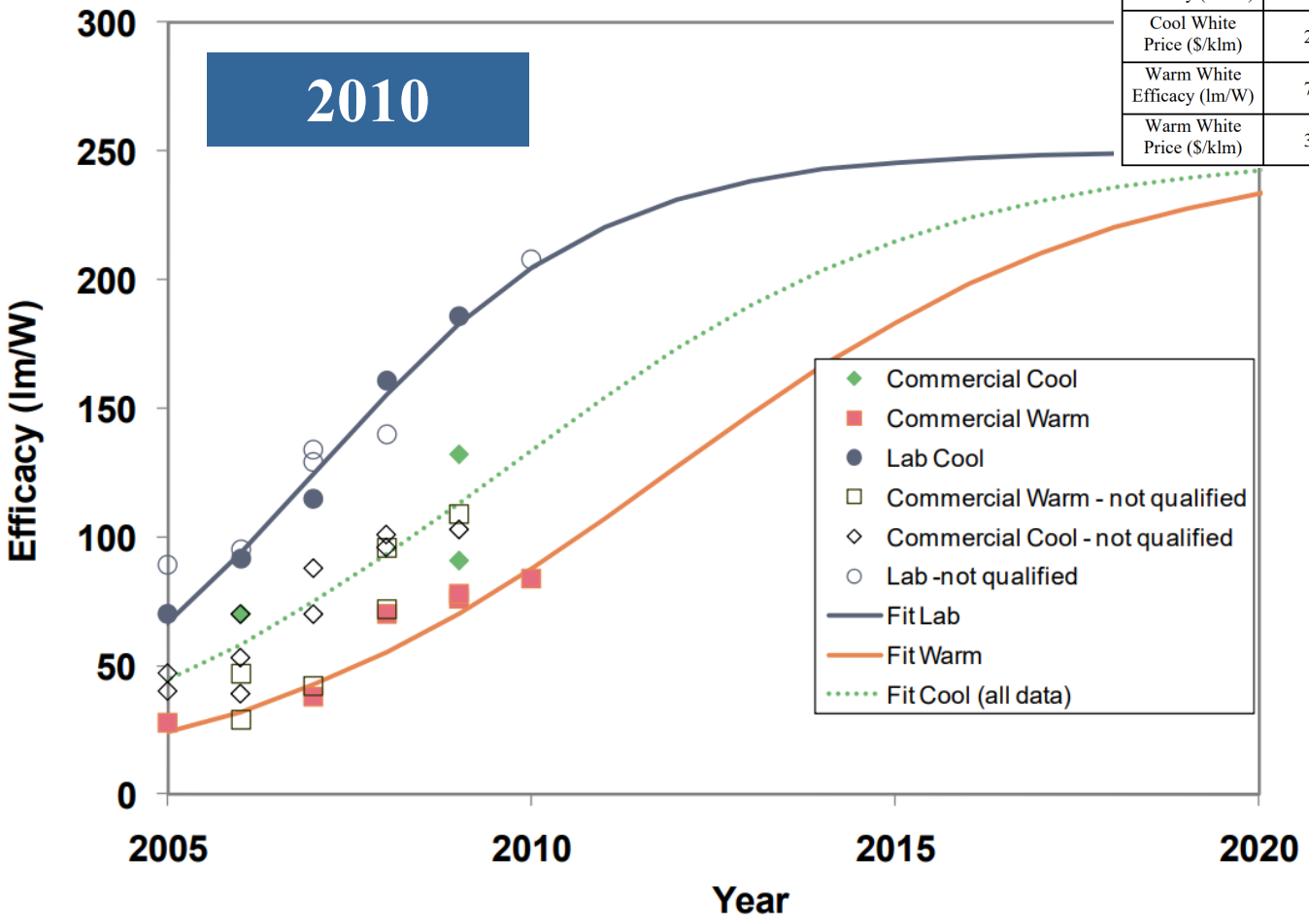



Figure 4.11: White-Light LED Package Efficacy Targets[64], Laboratory and Commercial

more projections over the years…

**2015**

**Table 5.6 Breakdown of Warm-White[1] LED Luminaire Efficiency Projections**

| Efficiency Channel | 2014 | 2015 | 2020 | Goal |
|---|---|---|---|---|
| Package Efficacy Projection[2] (lm/W) | 146 | 162 | 220 | 250 |
| Thermal Efficiency Droop (increased $T_{op}$) | 87% | 88% | 93% | 95% |
| Driver Efficiency | 86% | 87% | 93% | 96% |
| Fixture/Optical Efficiency | 87% | 89% | 94% | 96% |
| Current Efficiency Droop Correction Factor (reduced $I_{op}$) | 1.14 | 1.13 | 1.09 | 1.05 |
| Overall Luminaire Efficiency | 74% | 77% | 89% | 92% |
| Luminaire Efficacy[3] (lm/W) | 108 | 125 | 196 | 230 |

# Agenda

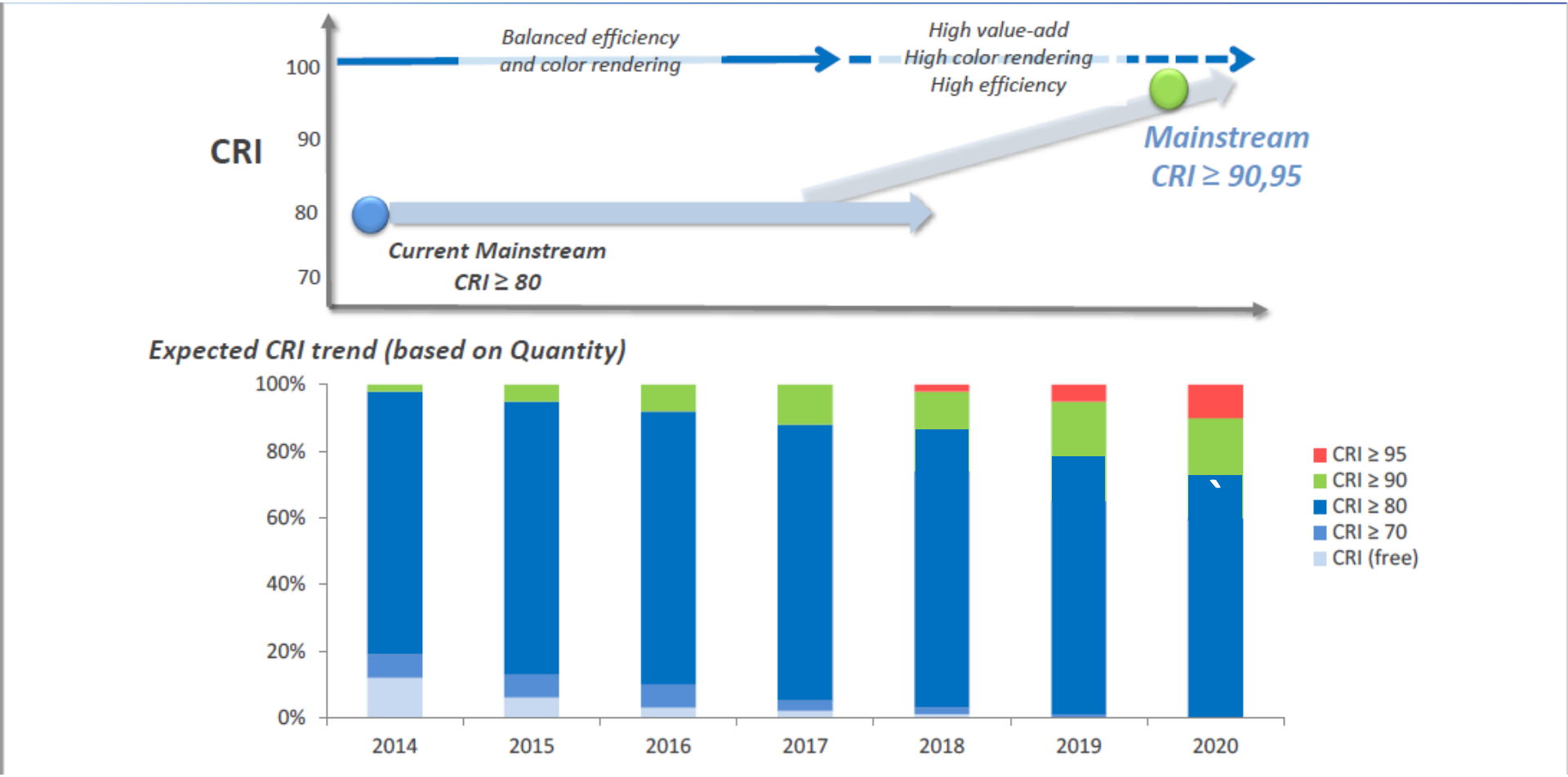
1. “You have to know the past to understand the present.”

2. Where is the focus going?
   - Quality of light
   - Market Specific Spectrums
   - Reliability

3. Questions


THERE'S SO MUCH ROOM FOR
COLOR QUALITY

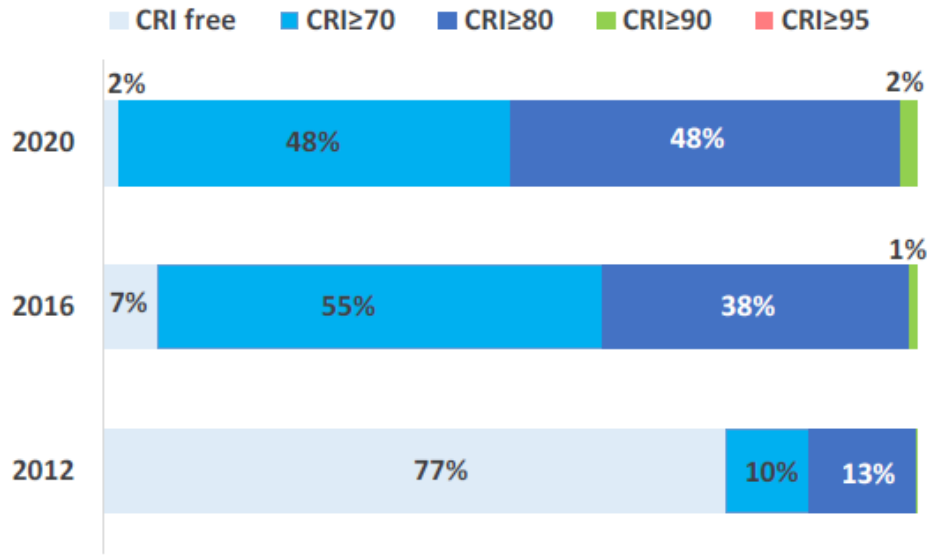
# The Move to High CRI Begins




**Estimated in 2017, but not yet realized…**

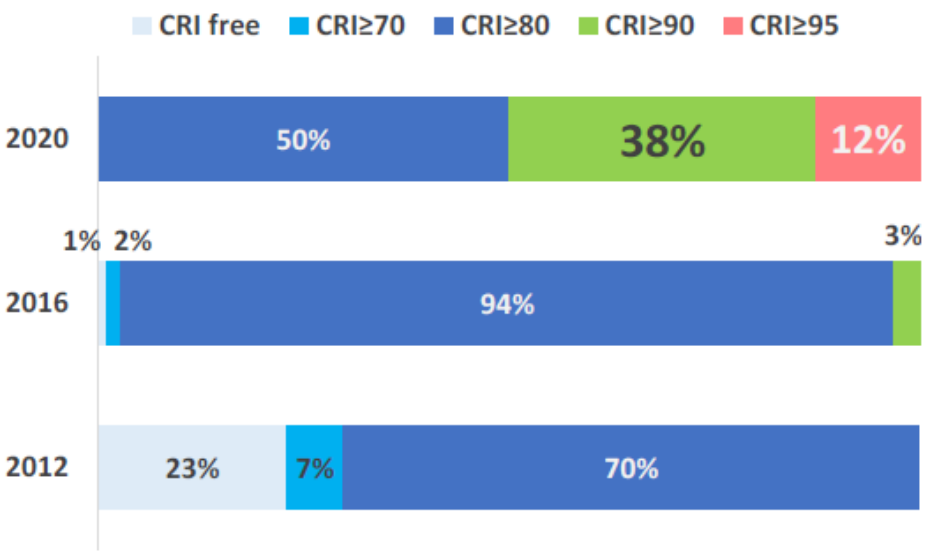
# The Move to High CRI Begins

## Outdoor




*Higher CRI sports lighting fields, especially for HD TV broadcasts.*

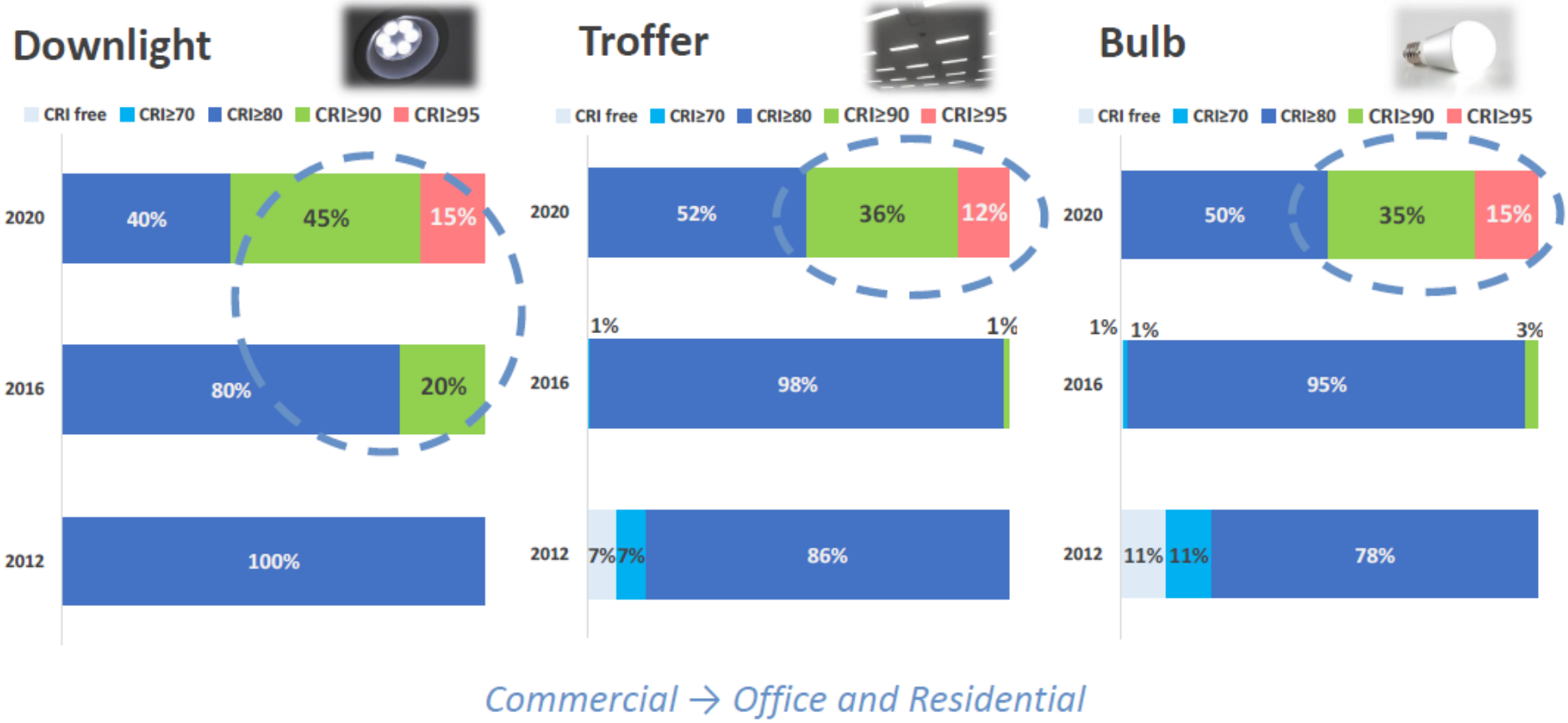
## Indoor




*Not only higher efficacy but higher CRI has been required.*

**Estimated in 2017, but not yet realized…**

# CRI Trend and Estimation




*Commercial → Office and Residential*

**Estimated in 2017, but not realized yet…**

# Applications

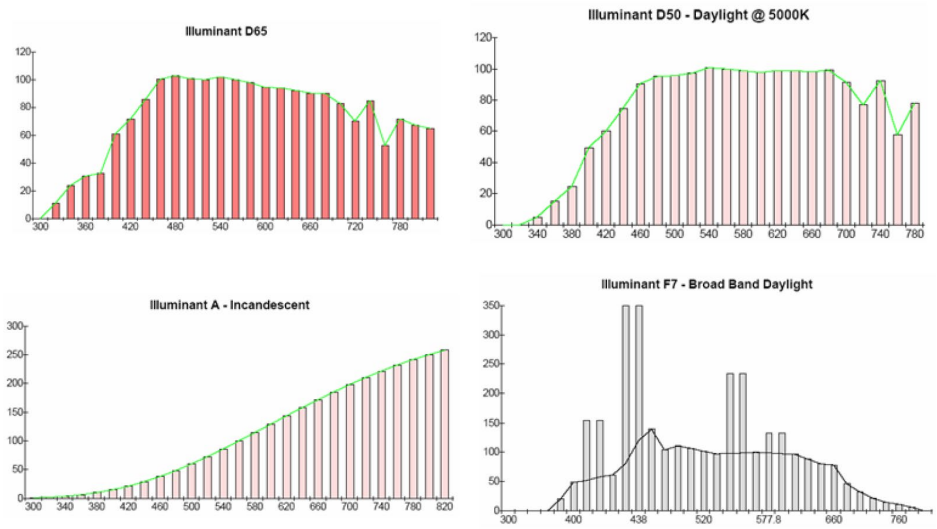
| | Application |
|---|---|
| CRI≈ 100 | Color Evaluation  Photography  |
| CRI ≥ 95 | Museum  Medical Care  |
| CRI ≥ 90 | Commercial, Residential |
| CRI ≥ 80 | Office, Commercial, Residential |
| CRI ≥ 70 | Outdoor, High bay |

*Further demand for high color rendering.*

**Let's not settle for "good enough."**
**Let's continue to fine tune our game & raise the bar!**

# Not all CRI's are created equal…

Same CRI numbers are **not** Equivalent!



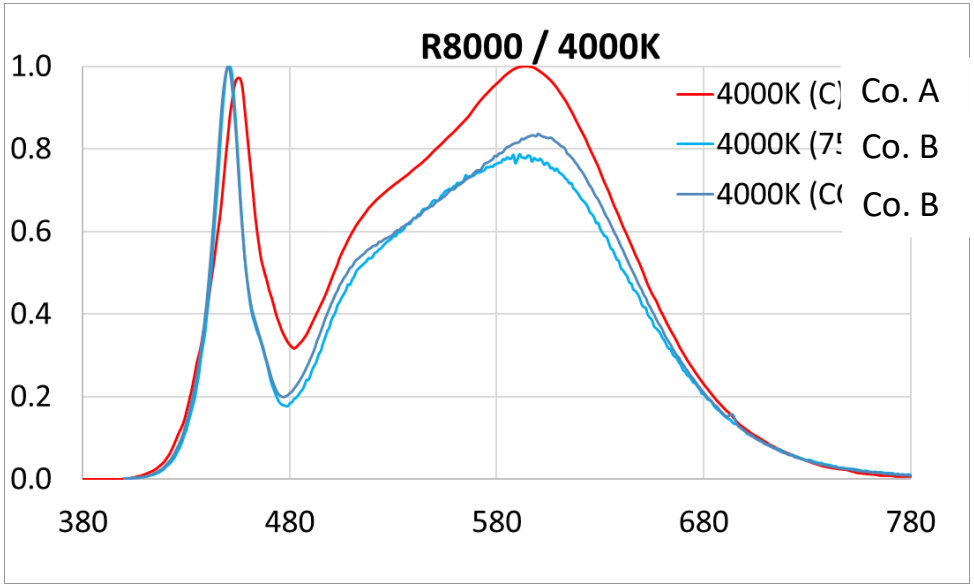

Clearly different but all of these CRIs are 100!

CRI is Misleading

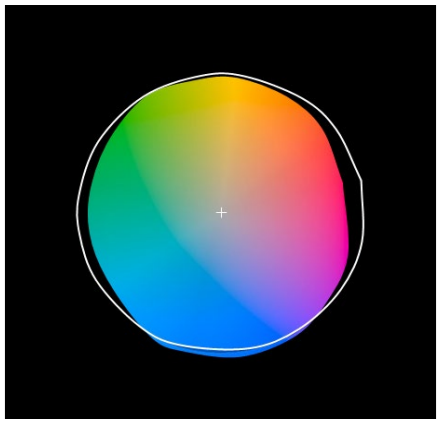
- Incandescent source CRI is 100
- But light does not render all colors well
- Try matching dark Navy Blue & Black socks under a low or medium luminance incandescent light!

*Source: DoE Webinar – LED Essentials 10.11.2007*

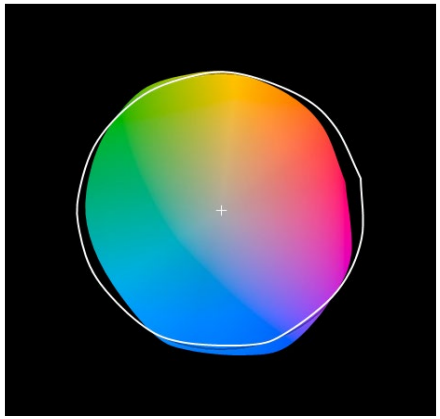
# Spectra Comparison (4,000K / 80 CRI)




Company A COB (4,000K / Ra 80)

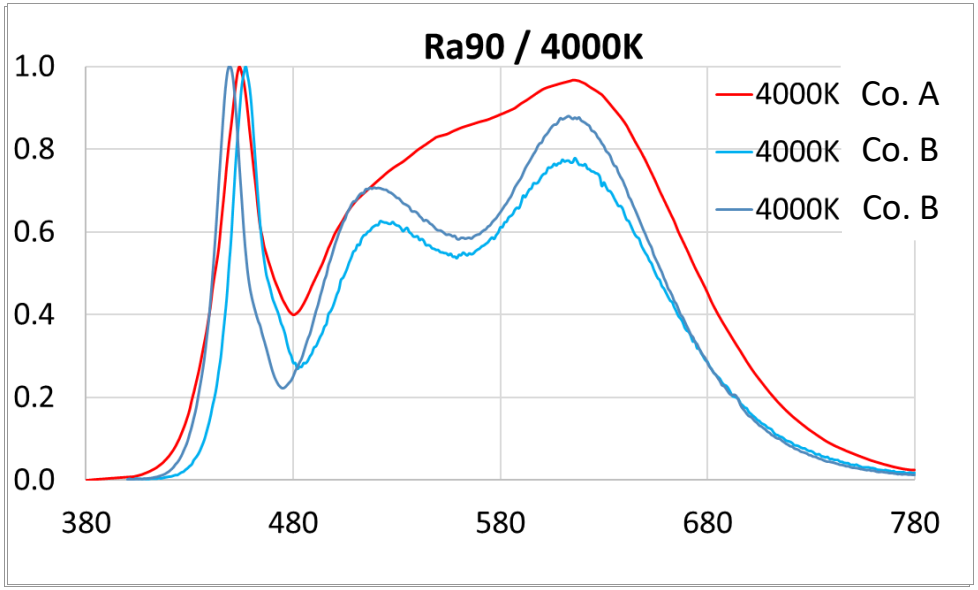


Company B COB (4,000K / Ra 80)



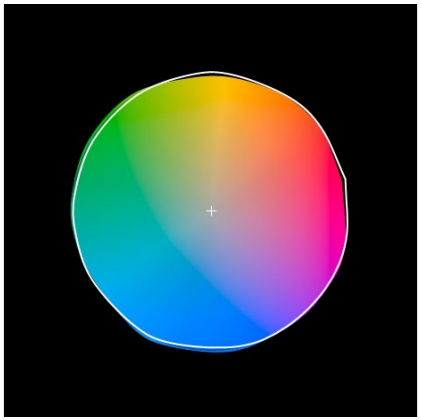
| | Company A | | Company B | |
|---|---|---|---|---|
| | Ra 80 | | Ra 80 (R9 > 0) | |
| CCT | 4000K (O) | 3000K (N) | 4000K (COB) | 3000K (COB) |
| Rf | 82.8 | 83.1 | 83.7 | 83.0 |
| Rg | 94.0 | 94.7 | 97.7 | 98.4 |
| CCT | 4001.4 | 3047.9 | 3930.9 | 3022.7 |
| Duv | 0.002 | 0.000 | 0.000 | 0.000 |
| x | 0.382 | 0.434 | 0.383 | 0.435 |
| y | 0.383 | 0.404 | 0.378 | 0.402 |
| Ra | 83.3 | 82.3 | 84.9 | 83.7 |

# Spectra Comparison (4,000K / 90 CRI)



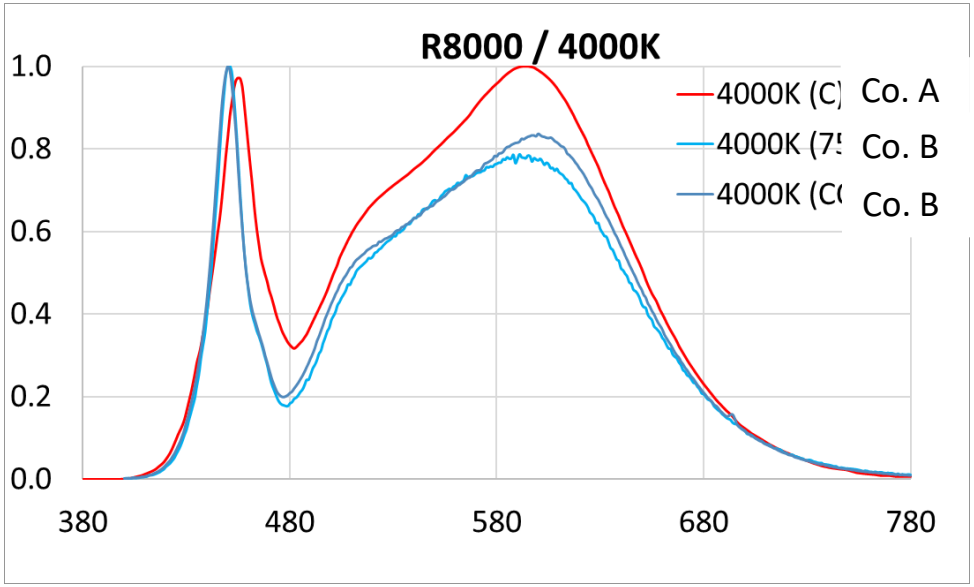

Company A COB (4,000K / Ra 90)

Company B COB (4,000K / Ra 90, R9>50)

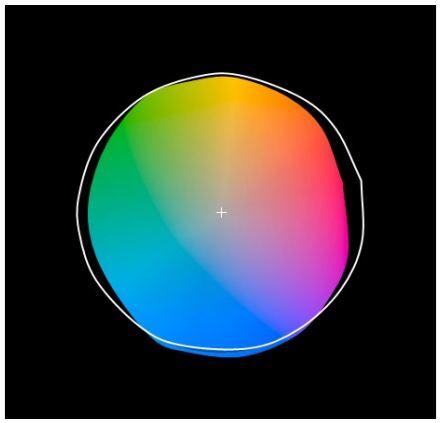


| | Company A | | Company B | |
|---|---|---|---|---|
| | Ra 90 on the BBL | | Ra 90 (R9 > 50) | |
| CCT | 4000K (N) | 3000K (N) | 4000K (COB) | 3000K (COB) |
| Rf | 90.3 | 91.6 | 93.2 | 92.3 |
| Rg | 98.0 | 98.7 | 102.5 | 102.0 |
| CCT | 3993.2 | 3049.6 | 3977.1 | 2986.8 |
| Duv | 0.001 | 0.000 | 0.000 | -0.001 |
| x | 0.381 | 0.434 | 0.382 | 0.436 |
| y | 0.380 | 0.403 | 0.378 | 0.402 |
| Ra | 93.4 | 93.5 | 96.0 | 93.6 |

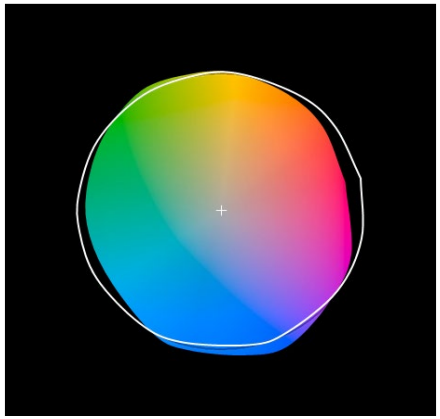
# Spectra Comparison (4,000K / 80 CRI)




Company A COB (4,000K / Ra 80)

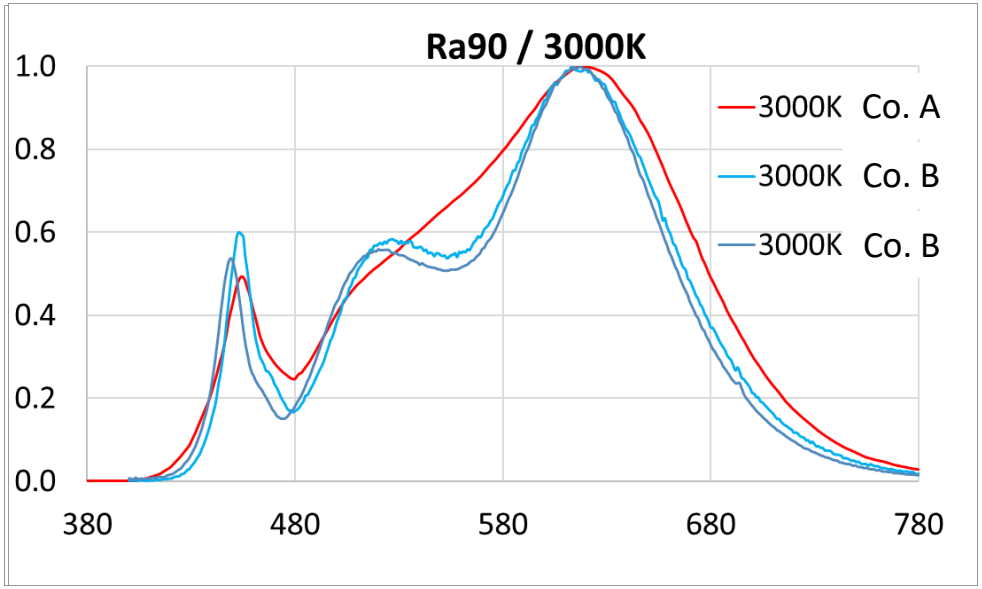


Company B COB (4,000K / Ra 80)

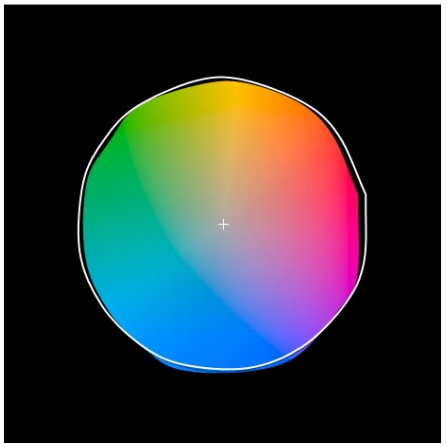


| | Company A | | Company B | |
|---|---|---|---|---|
| | Ra 80 | | Ra 80 (R9 > 0) | |
| CCT | 4000K (O) | 3000K (N) | 4000K (COB) | 3000K (COB) |
| Rf | 82.8 | 83.1 | 83.7 | 83.0 |
| Rg | 94.0 | 94.7 | 97.7 | 98.4 |
| CCT | 4001.4 | 3047.9 | 3930.9 | 3022.7 |
| Duv | 0.002 | 0.000 | 0.000 | 0.000 |
| x | 0.382 | 0.434 | 0.383 | 0.435 |
| y | 0.383 | 0.404 | 0.378 | 0.402 |
| Ra | 83.3 | 82.3 | 84.9 | 83.7 |

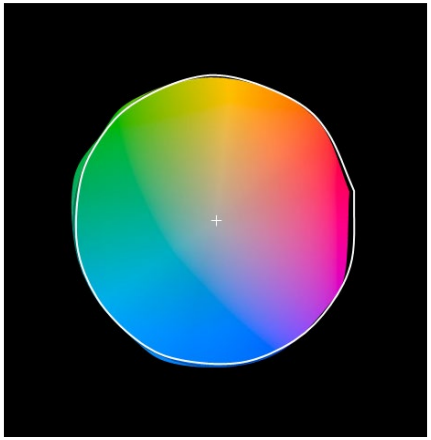
# Spectra Comparison (3,000K / 90 CRI)




Company A COB (4,000K / Ra 90)



Company B COB (4,000K / Ra 90, R9>50)

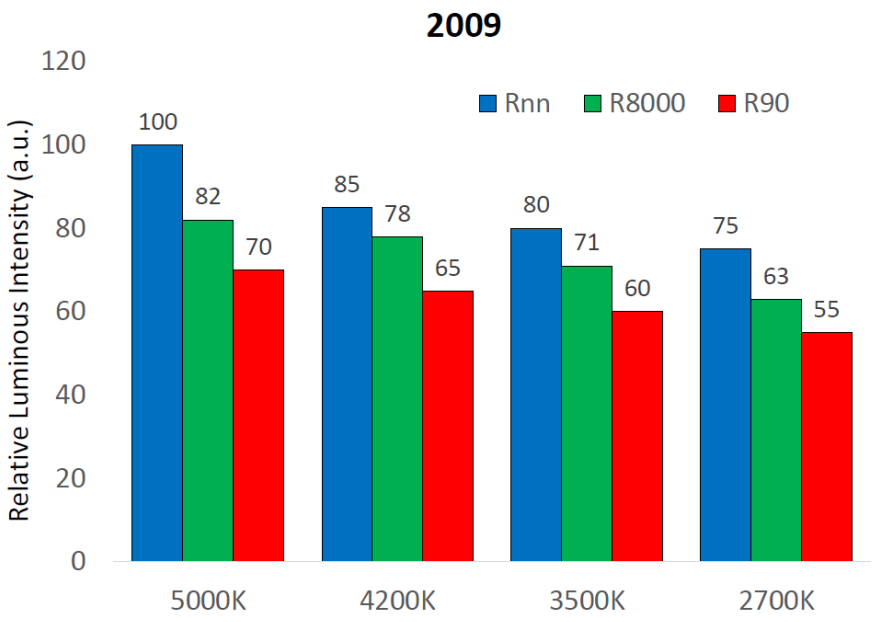


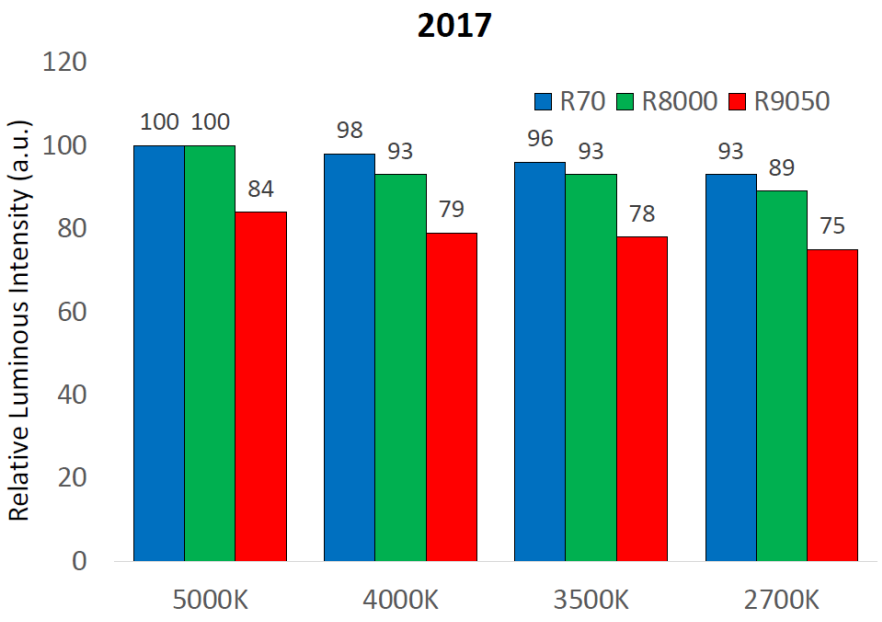
| | Company A | | Company B | |
|---|---|---|---|---|
| | Ra 90 on the BBL | | Ra 90 (R9 > 50) | |
| CCT | 4000K (N) | 3000K (N) | 4000K (COB) | 3000K (COB) |
| Rf | 90.3 | 91.6 | 93.2 | 92.3 |
| Rg | 98.0 | 98.7 | 102.5 | 102.0 |
| CCT | 3993.2 | 3049.6 | 3977.1 | 2986.8 |
| Duv | 0.001 | 0.000 | 0.000 | -0.001 |
| x | 0.381 | 0.434 | 0.382 | 0.436 |
| y | 0.380 | 0.403 | 0.378 | 0.402 |
| Ra | 93.4 | 93.5 | 96.0 | 93.6 |

# What is being done to “fine tune”?

## As we’ve approached peak WPE, focus is put on quality of light

### CCT/CRI vs. Luminous Intensity



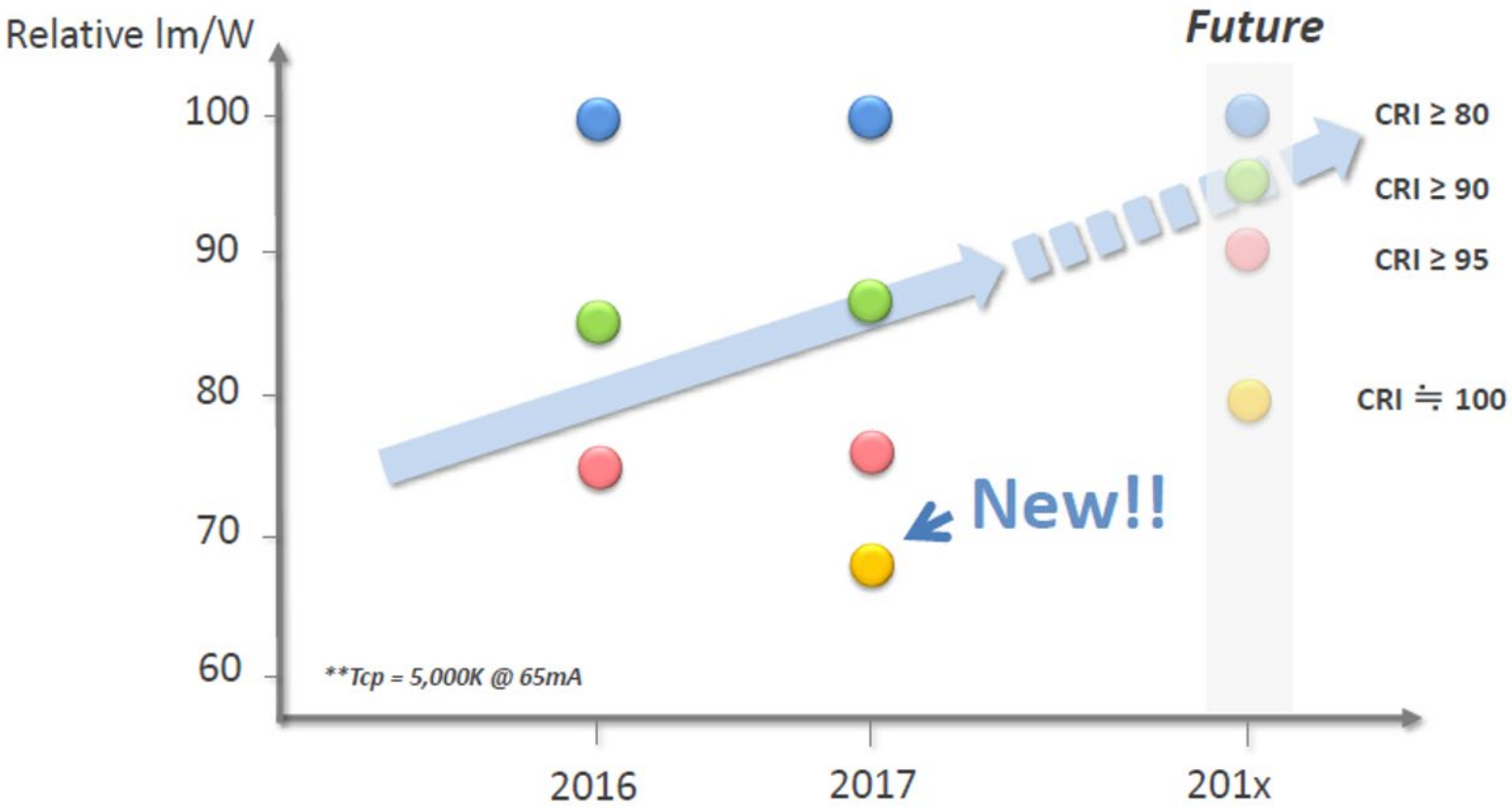




- Low CCT and high CRI require more light from phosphor.
- Luminous Intensity is down due to Stokes loss

# What is being done to “fine tune”?

## As we’ve approached peak WPE, focus is put on quality of light

### CCT/CRI vs. Luminous Intensity



# What is being done to “fine tune”?

## As we’ve approached peak WPE, focus is put on quality of light

### Nichia Rigel 0.5W – High-CRI LED

*High CRI LED*

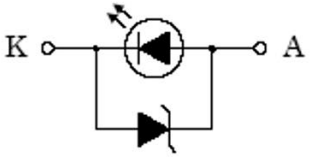
Under Development

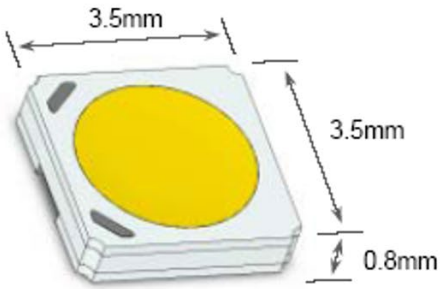
**NFSL036C-H1**

Features

- ✓High CRI : Typ.92
- ✓Compact size: 3.5x3.5x0.8mm
- ✓Long Lifetime: 40Khrs 70%
- ✓Ceramic Package
- ✓Application: General Lighting
  Surgical Lighting

| | |
|---|---|
| Luminous flux | Typ.17lm @ 150mA |
| Forward current | Typ.3.5V/ Max. 3.8V |
| $I_F$max | 350mA |
| Tjmax | 150°C |
| Thermal resistance (Package) | 40°C/W |
| Operating temperature | -40~+100°C |
| Storage temperature | -40~+100°C |
| Environment | RoHS compliant<br>Pb free soldering |




Schedule
Sample: ’07/11/F, MP: ‘08/4/E

33 lpW!

This sheet contains tentative information, we may change contents without notice.

NICHIA Ever Researching for a Brighter World

# What is being done to “fine tune”?

## As we’ve approached peak WPE, focus is put on quality of light

### Mid-Power Series (0.2W Class)

SE-KSE058561B
Jul. 17, 2018

**757G-V3**

3.0 x 3.0 x 0.65mm

**Features**

- Balanced cost and efficacy
- Superior reliability
- Outstanding thermal droop
- 3-step MacAdam Ellipses

**Key Applications**

**172 lpW!**

Tj=25°C

| | Part Number | | NFSW757G-V3 | NFSW757G-V3 |
|---|---|---|---|---|
| | CCT/Ra | | 5000K, Ra ≥ 80 | 5000K, Ra ≥ 90 |
| Rated | Forward Current | mA | 65 | 65 |
| | Forward Voltage | V | 2.85 | 2.85 |
| | Luminous Flux | lm | 37 | 31.8 |
| | Luminous Efficacy | lm/W | 200 | 172 |
| | Thermal Resistance | °C/W | 13 | 11 |
| Max. | Forward Current | mA | 180 | 180 |
| | Junction Temperature | °C | 120 | 120 |
| | LM-80 | | Available | |

An lpW gap still remains…

*Data Subject to change*

# Ultra High CRI – Full Spectrum

# Ultra High CRI – Full Spectrum

## Natural

Light up objects
as they are designed, as they are.

Museum

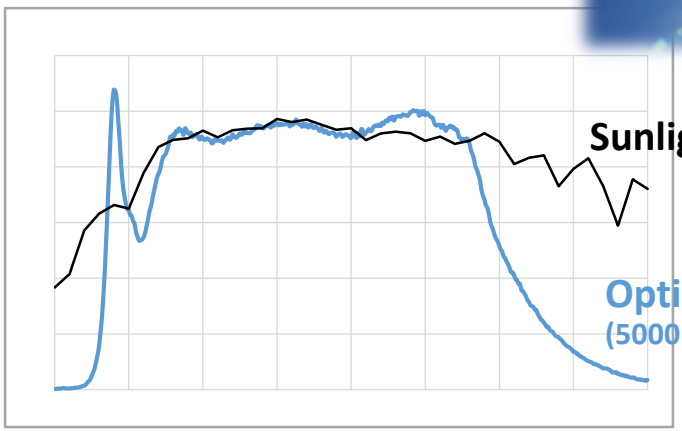
Studio

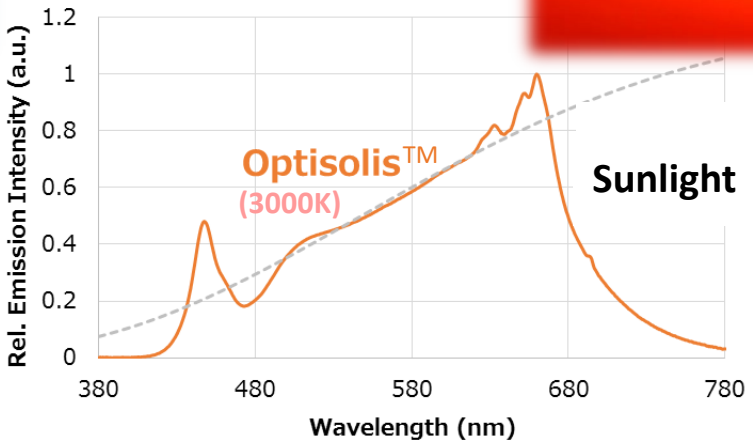
Factory

## Health & Well-being

Synchronize spectrum to the sunlight throughout
the day for humans.

Hospital, Residential etc.

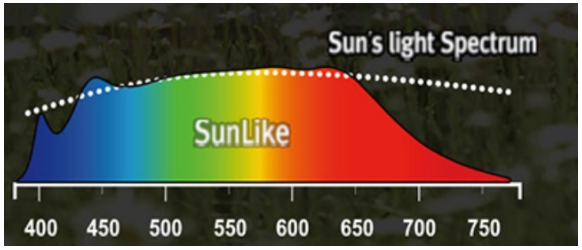



These figures indicate the measurement value of engineering sample. Each value is possible to be different. Please treat this data as the reference.

# Ultra High CRI – Full Spectrum

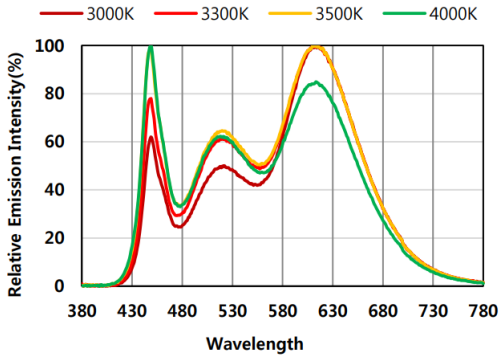
SEOUL SunLike
Powered by TRI-R




SAMSUNG

## Premium Color Series

Rich and Appealing Colors with Superior Performance




# And others…

# Agenda

1. “You have to know the past to understand the present.”

2. Where is the focus going?
   - Quality of light
   - Market Specific Spectrums
   - Reliability

3. Questions

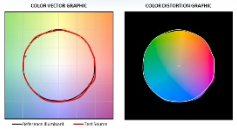
# LED Manufacturer Unique Spectrums

## Higher CRI

R9050
(Ra>90,R9>50)

R95
(Ra>95)

**Full Spectrum**
**(Ultra High CRI)**



## Visual Effect

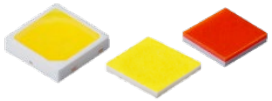

For Meats


For Veggies

**Unique Colors**

For Apparel/ Jewelries

## Horticulture



**Full Spectrum White**
**or**
**Discrete Colors**

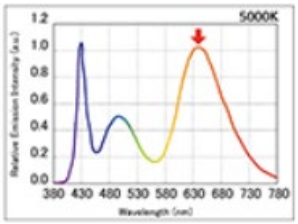
## Productivity

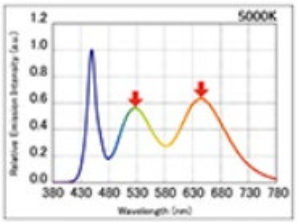
**Light for Productivity**

**Human Centric Lighting**

# Unique Spectrums - Visual Effects

## Meats

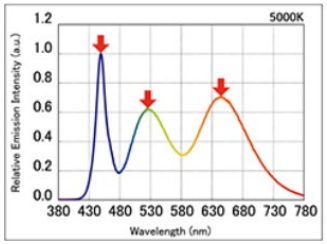




**Enhanced Red**


## Vegetables, Fish & Meat

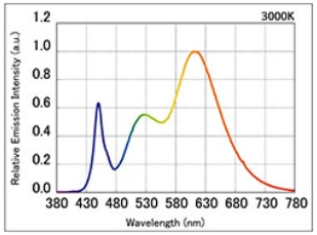

**Enhanced Red & Green**





## Clothing


**Enhanced White**





**Nichia's Data**

LUMILEDS
LUXEON STYLIST SERIES

NICHIA
"Rs020, Rs060"
"Rs030"
"Rs075"

SAMSUNG
"D-Series Special Color"
"Vivid COB Packages"

# Unique Spectrums - Horticulture

## Growth speed & balance

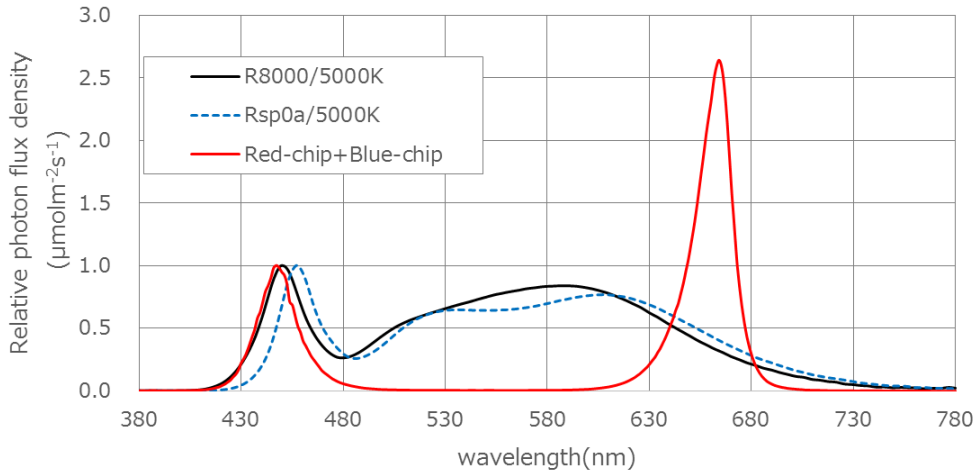

## High reliability

Stable spectrum at high temperature.


## Working environment

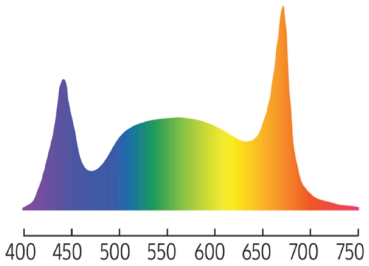
Rsp0a 5000K

R+B LED



# Unique Spectrums - Horticulture

SAMSUNG




## Designed for Well Balanced Growth

Full spectrum light specifically developed for horticulture

With industry leading PPF and PPF/W, Samsung LEDs' full spectrum white-based light stimulates enhanced plant growth compared to narrow spectrums

NICHIA

LUXEON SunPlus Series

*"All in White"*

***Rsp0a***

***Horticulture***

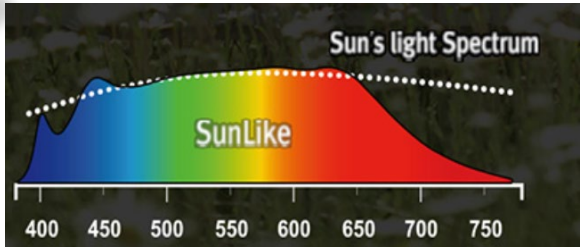
SunLike

Powered by TRI-R

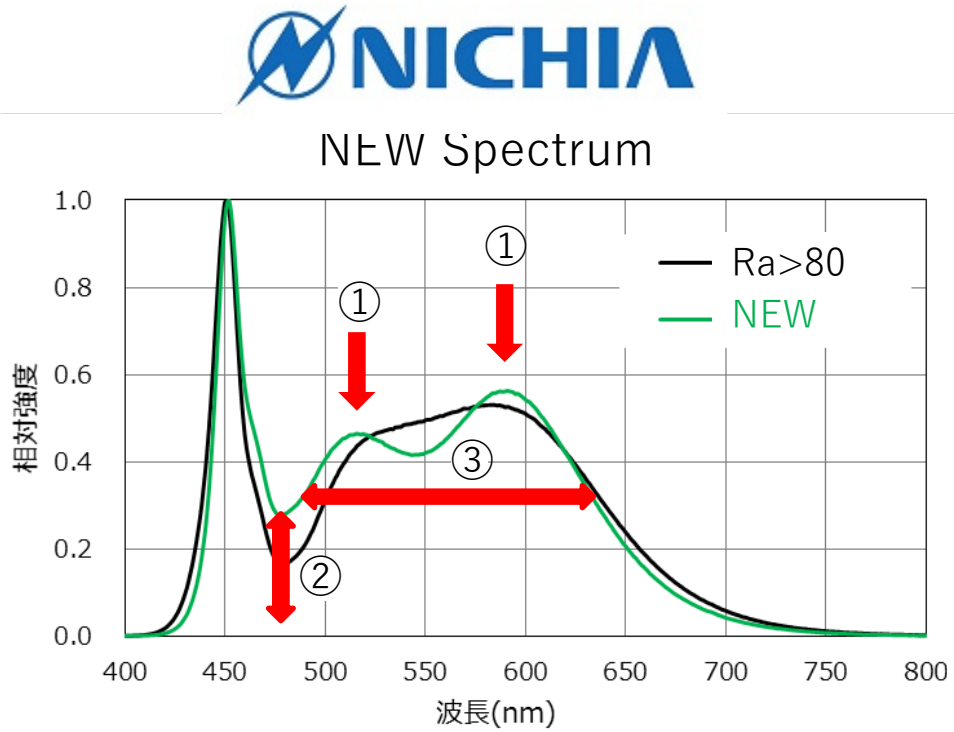
OSRAM

Opto Semiconductors

Horticulture Portfolio




# Nichia's Unique Spectrums – Productivity (TBD)




**Recently verified research proves**

- Better productivity & less fatigue,
- Maximizes Equivalent Melanopic Lux
- Similar Optical Efficacy to CRI 80

# Nichia's Unique Spectrums – Productivity (TBD)

## 1. Clearer Visibility

### Evaluation Method

・Semantic Differential method
10 factors, 7 points scale

・Ranking methods

### Target

White Black Blue Green Red Yellow

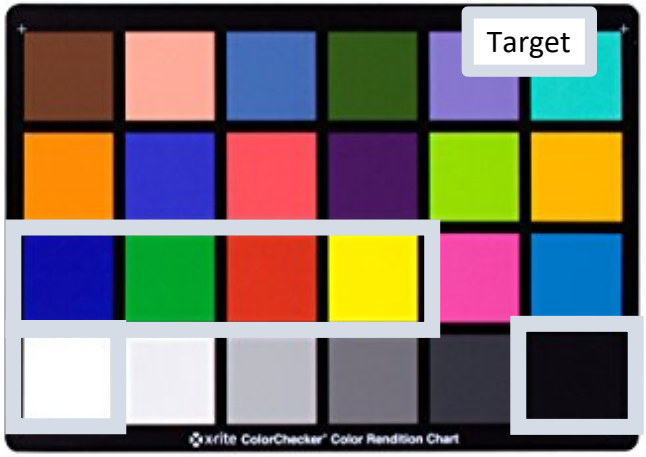
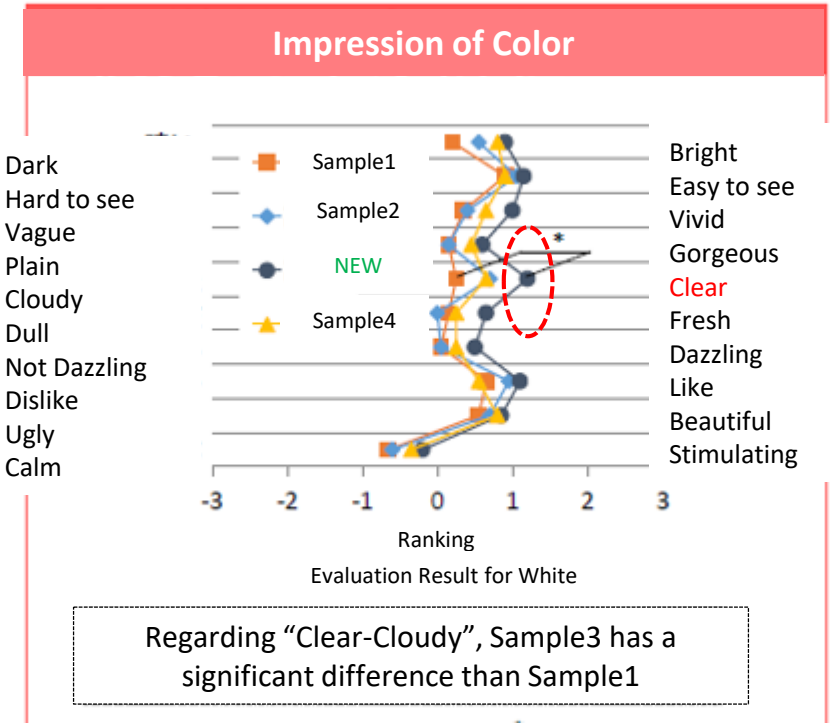



Figure Color Chart




Regarding "Clear-Cloudy", Sample3 has a significant difference than Sample1

1 : Ra>80
2 : Spectrum A
3 : NEW Spectrum
4 : Ra>90

**In this new spectrum, white is evaluated as "clearer."**

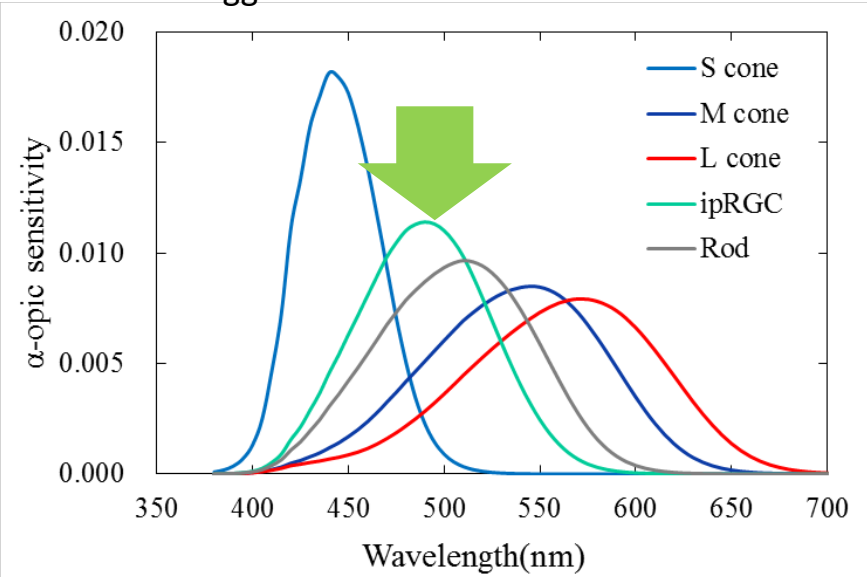
# Nichia's Unique Spectrums – Productivity (TBD)

## 2. How Cyan is Important

### Non-visual sensitivity Importance

Circadian rhythm sensitive

Trigger of Melatonin & Serotonin

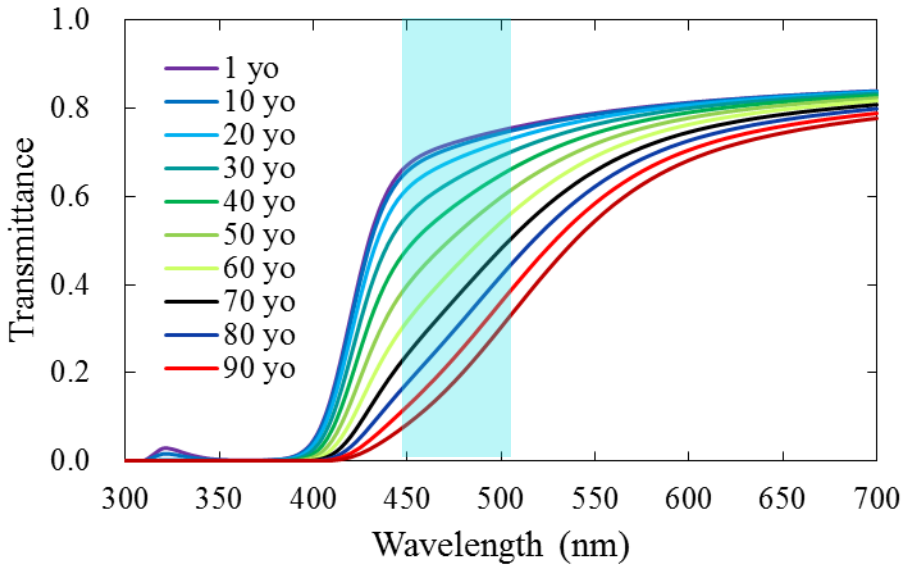



Spectral absorbance of human retinal photo receptors

Lucas,R.J *et al.*, Trends Neurosci. 37, 1(2014)

### Visual sensitivity Importance

Aged people less sensitive

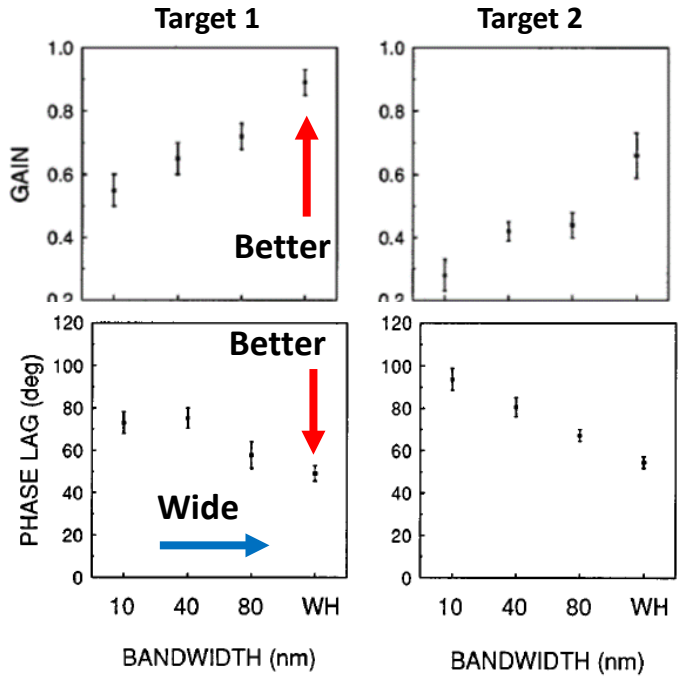



Spectral distribution of the total transmittance of the aging human eye computed via the methods of van de Kraats

"A Computerized Approach to Transmission and Absorption Characteristics of the Human Eye" CIE 203:2012 (incl. Erratum)

# 3. Eyes are less fatigued from a wider spectrum

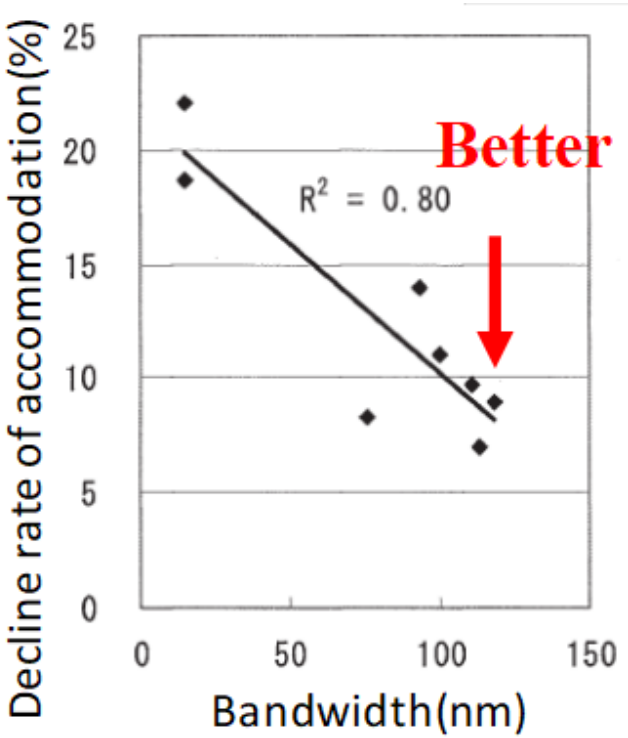
The wider, the faster eye accommodation response




Gain and phase lag of eye accommodation as a function of the spectral bandwidth.

K.R.Aggarwala *et al.*, J. Opt. Soc. Am. A 12, 450(1995)

The wider the less eye accommodation fatigue

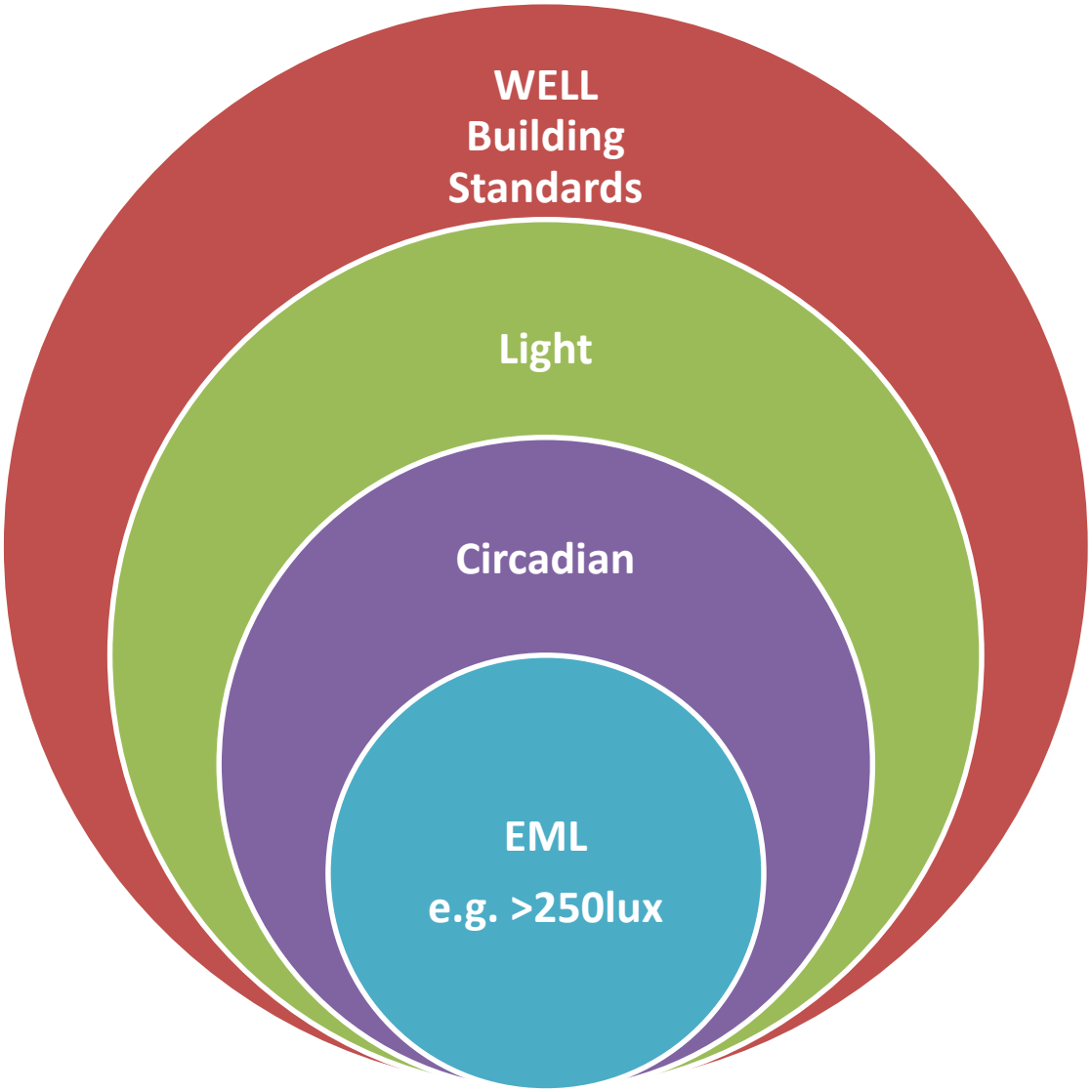



Decline rate of eye accommodation after the visual task as a function of the spectral bandwidth.

C. Kubo *et al.*, J. Illum. Engng. Inst. Jpn. 98, 79(2014)

# Nichia's Unique Spectrums – Productivity (TBD)

## EML = Equivalent Melanopic Lux



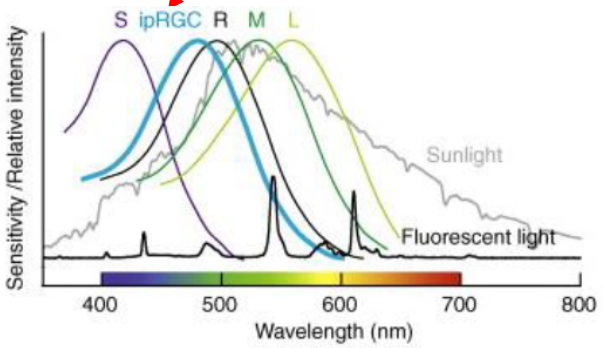

**EML = visual lux x melanopic ratio**

| CCT (K) | Light Source | Melanopic Ratio |
|---|---|---|
| 2950 | Fluorescent | 0.43 |
| 2700 | LED | 0.45 |
| 2800 | Incandescent | 0.54 |
| 4000 | Fluorescent | 0.58 |
| 4000 | LED | 0.76 |
| 5450 | CIE E (Equal Energy) | 1.00 |
| 6500 | Fluorescent | 1.02 |
| 6500 | Daylight | 1.10 |
| 7500 | Fluorescent | 1.11 |

*Source: WELL Building Standard® reference Tables L1 and L2 (p190-192)*

## Melanopic Ratio

$$= \frac{\sum_{730}^{380} Lamp \times Circadian}{\sum_{730}^{380} Lamp \times Visual} \times 1.218$$




Hatori&Panda:The emerging roles of melanopsin in behavioral adaptation to light, Trends in Molecular Medicine, 16-10, pp.435–446(2010)

# Nichia's Unique Spectrums – Productivity TBD)

| Item | NEW | Ra > 90 | Ra > 80 |
|---|---|---|---|
| Efficacy (lm/W) | A | C | A+ |
| Cyan (ipRGC compliant) | A | B | C |
| Eye/Physiological/Phycological fatigue | A | A | C |
| Working Efficiency | A | A | C |
| WELL Building Standard (Efficacy * Cyan) | A | B | B |

**The value of this new spectrum adds to Human Centric Lighting with higher EMA.**

# Unique Spectrums by Manufacturers

current powered by GE

ABOUT CURRENT | PRODUCTS | TECHNOLOGIES | RESOURCES | WHERE TO BUY | CONTACT US

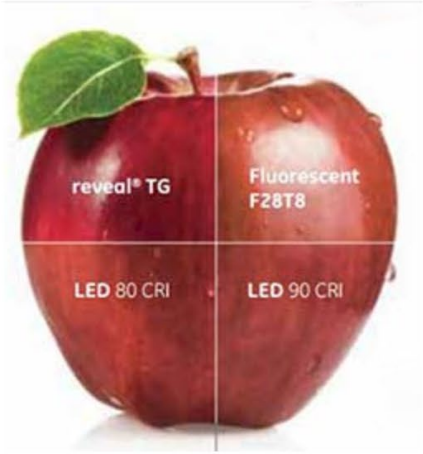
## reveal® TriGain™ / Color Without Compromise

Home » reveal TriGain technology

### reveal® TriGain™ technology changes everything.

GE has developed a narrow-band red phosphor that increases both CRI and R9, while improving LED and system efficacy significantly versus other LED products or systems on the market. By making patented and proprietary technological improvements to phosphor synthesis, reveal® TriGain™ technology is an industry-leading phosphor with premium performance lighting systems for retail and commercial applications. We are doing so without the design complexities of other technologies and with no changes to the luminaire structure of our systems.

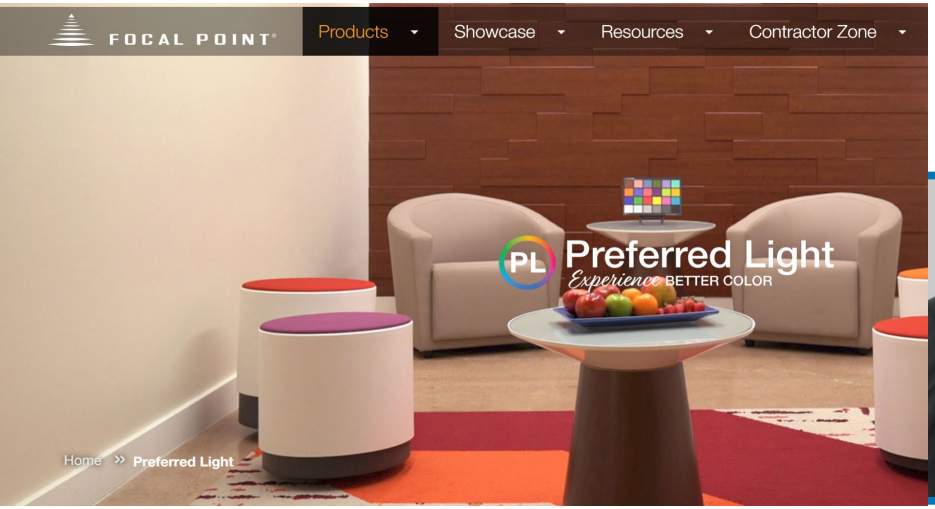
**32% INCREASE in LPW**




*Industry standard 3030 LED measured at the same operating conditions

*Courtesy of current's website*

# Unique Spectrums by Manufacturers





Focal Point Preferred Light uses advanced LED technology to enhance spaces and provide more comfortable environments for building occupants. The unique solution is engineered following results from independent studies about human health and human preference. Preferred Light color delivers enhanced fidelity, gamut, and color saturation, as measured by TM-30-15 resulting in a light quality that effectively renders colors for human preference, creating more comfortable and visually appealing environments.

## The Preferred Light Color Difference

- More natural skin tones
- Warmer, more realistic wood tones
- Increased color vibrancy
- Overall more pleasing visual experience

## Color Comparison

TM-30-15

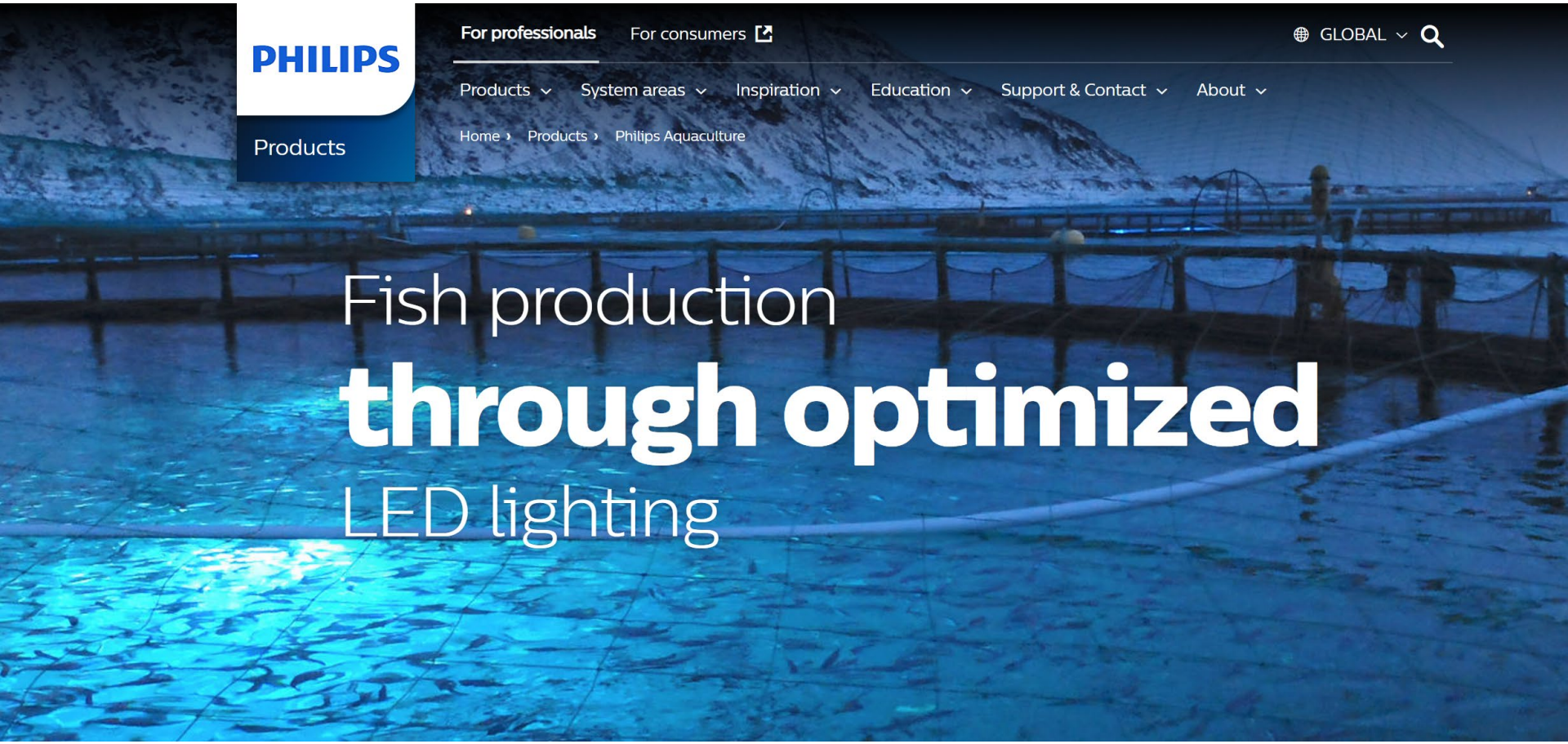
**Typical 80 CRI**

**Preferred Light**

FOCAL POINT

*Courtesy of Focal Point's website*

# Unique Spectrums by Manufacturers



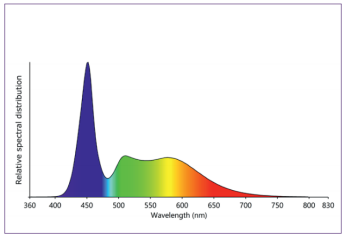

*Courtesy of Signify's website*

# Unique Spectrums by Manufacturers

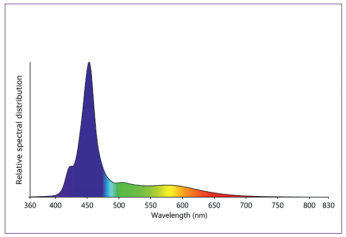




Spectrum – channel 1




Spectrum – channel 2




Spectrum – 2 channels combined

*Courtesy of Signify's website*

# Unique Spectrums by Manufacturers

AcuityBrands.

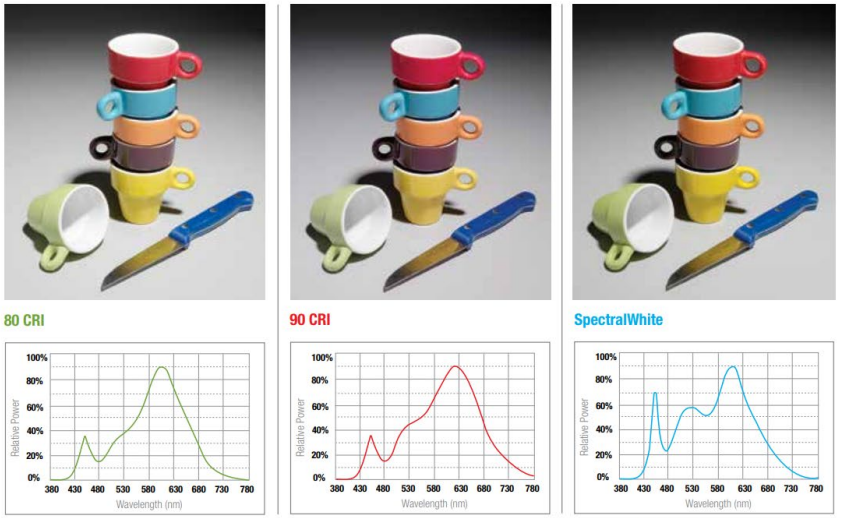
## SpectralWhite

### Offering Superb, 90+ CRI Rendering of Colors & Whites

The SpectralWhite color/white enhancing option renders richer, more vibrant colors and makes whites appear naturally brilliant and vivid. This is achieved using LEDs which employ a custom phosphor, formulated to adjust the spectrum of light emitted by the LED to produce radiant whites while maintaining high efficacy and high color rendering. The resulting light is more balanced than typical 80 CRI or 90 CRI LEDs, enabling colors to be rendered well while also enhancing whites.

Different applications demand different levels of color rendering performance. The CRI decision becomes much simpler when you have determined what is most important for the application. If luminous efficacy is most important, standard 80 CRI is likely the best selection. If color rendering is most important, the 90 CRI Option makes the most sense. If efficacy and color rendering are equally important and enhanced whites are also desirable, the Juno SpectralWhite option becomes the obvious choice.

**Color Rendering Options**




Photography has not been manipulated or digitally enhanced

Photo Credits:
Bruxie Gourmet Waffles, Los Angeles, CA (Doug Salin Photography)

JUNO

*Courtesy of Signify's website*

# Unique Spectrums by Manufacturers


*Courtesy of Signify's website*

# Agenda

1. Where has the focus been?

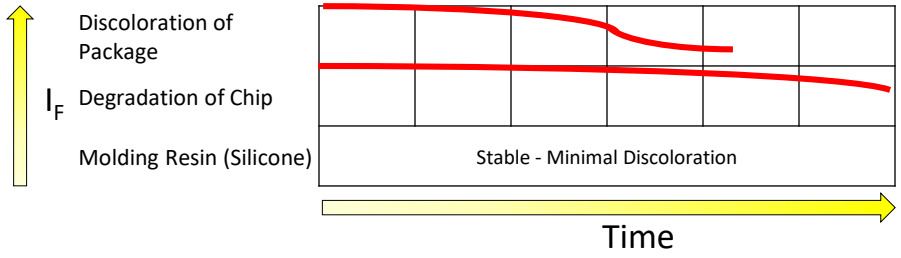
2. Where is the focus going?
   - Quality of light
   - Market Specific Spectrums
   - Reliability

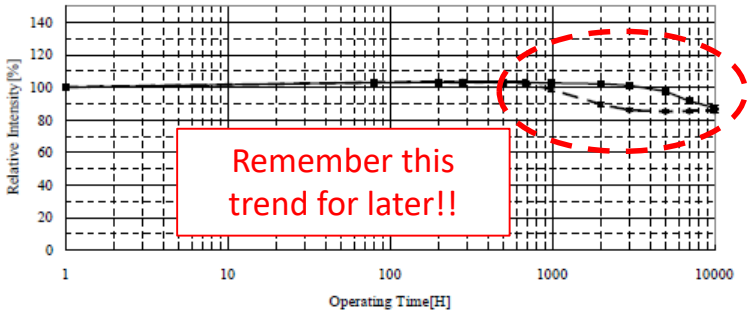
3. Questions

# TM-21 can be misleading

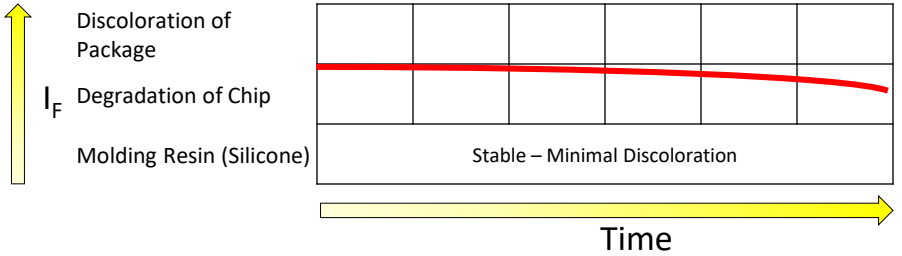
*First, we must understand the breakdown mechanisms of an LED*

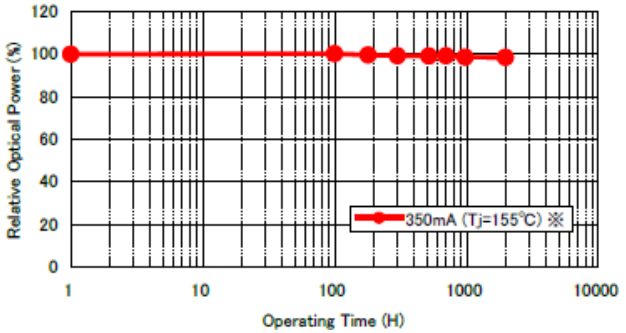
## Heat Resistant Polymer Type




## Flip Chip Ceramic Type



# TM-21 can be misleading

*Is a calculated value truly feasible in real life?*

**TM-21 Projection**

| Time | 4513 h | 5251 h | 6014 h | 6797 h | 7609 h | 8443 h | 9181 h | 10012 h | |
|---|---|---|---|---|---|---|---|---|---|
| ln(Avg.) | -0.0053 | -0.0063 | -0.0046 | -0.0058 | -0.0062 | -0.0083 | -0.0059 | -0.0070 | |

| Test duration used | 4513 h to 10012 h |
|---|---|
| B | 0.9962 |
| α | 3.2532E-07 |
| $R^2$ | 0.3325 |
| Calculated $L_{70}$ (10K) | 1080000 hours |
| Reported $L_{70}$ (10K) | > 60100 hours |

Curve-fit equation:

$\Phi(t)=Bexp(-\alpha t)$

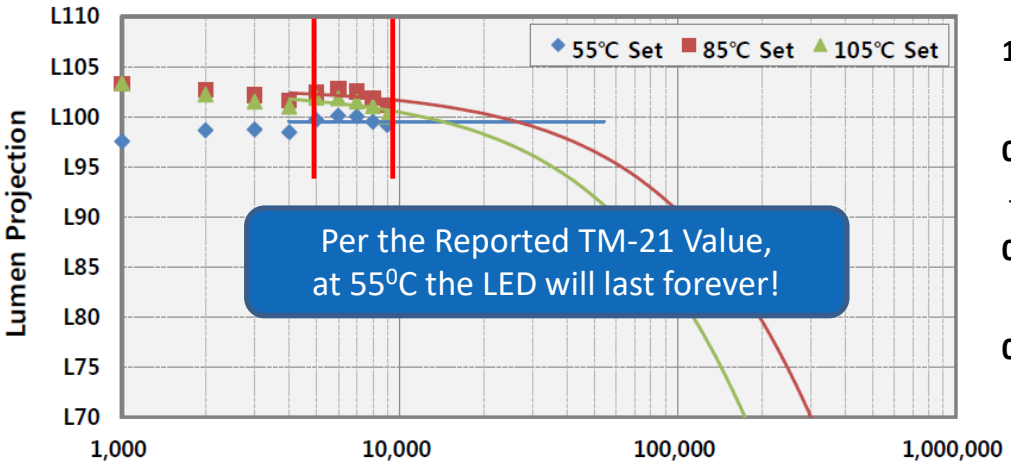
Lumen maintenance life eqation:

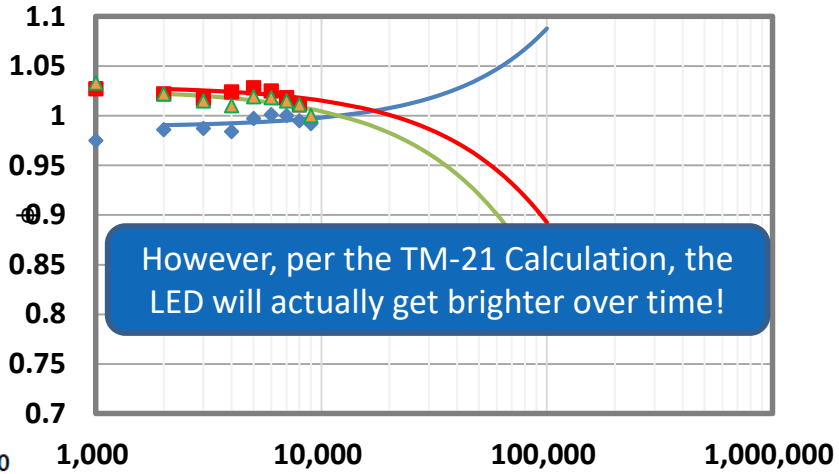
$L_{70}=ln(B/0.7)/\alpha$


L70 = 1 Million hours or 114 years!
or
L90 = 312,000 hours or 35 years!

# TM-21 can be misleading

*Measurements have tolerance and "bounce," especially with a limited test set…*

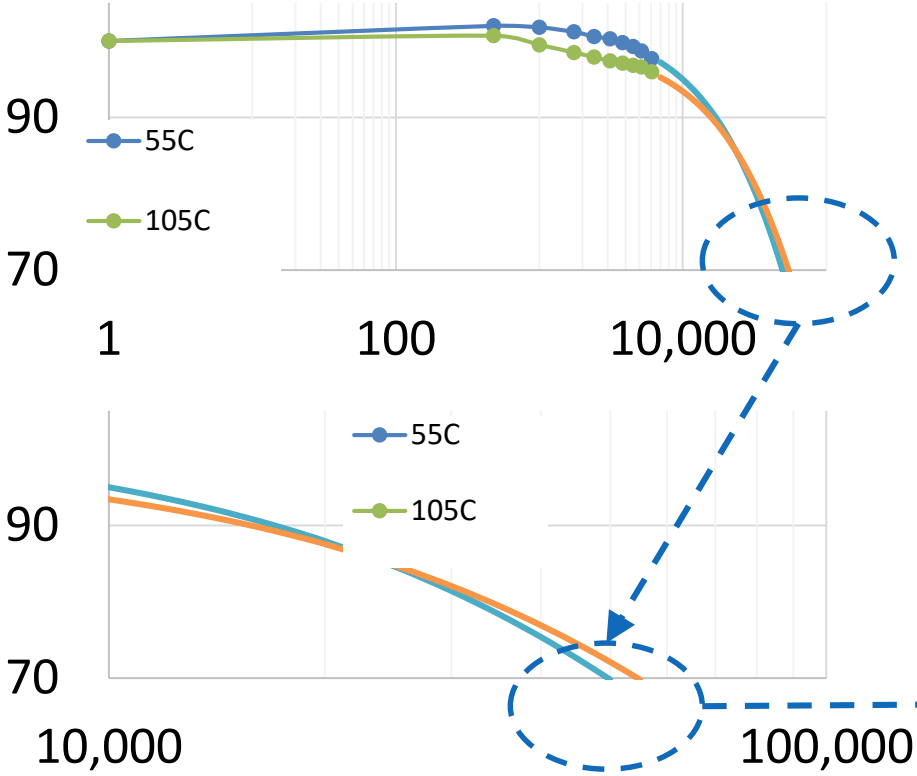




# TM-21 can be misleading

*Shouldn't a test at a higher $T_S$ reflect lower lifetime?*

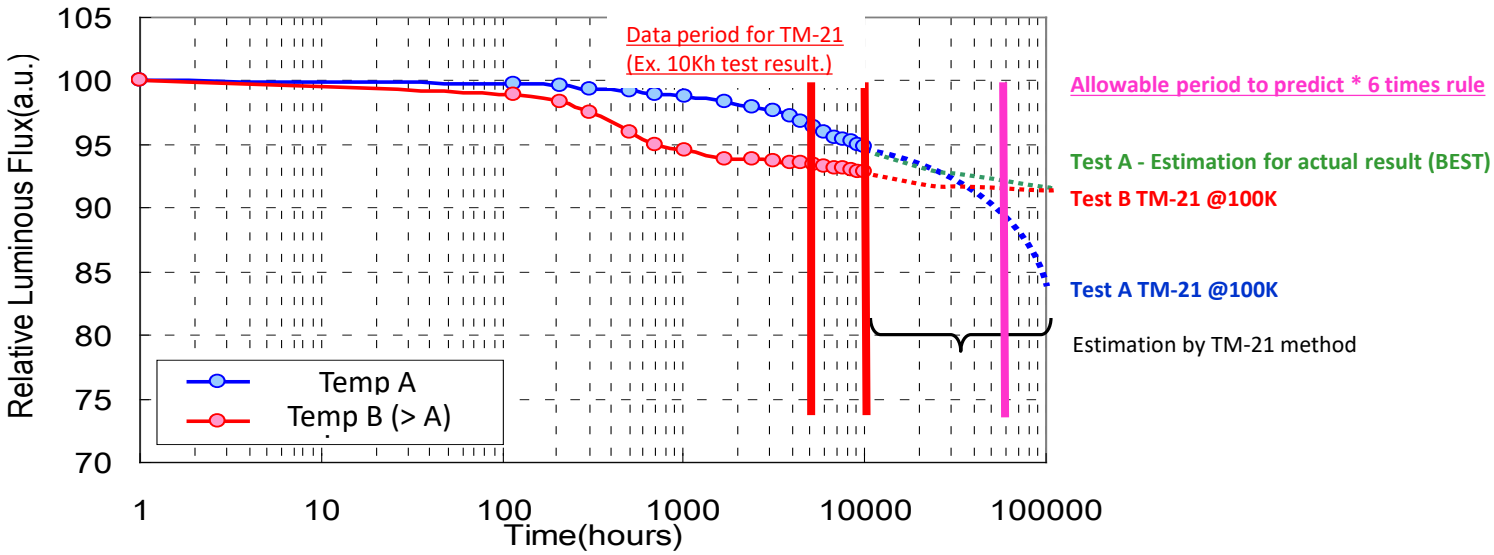




$105^0$C has a better TM-21 Calculated value than $55^0$C?

# TM-21 can be misleading

*Why are these anomalies happening?*

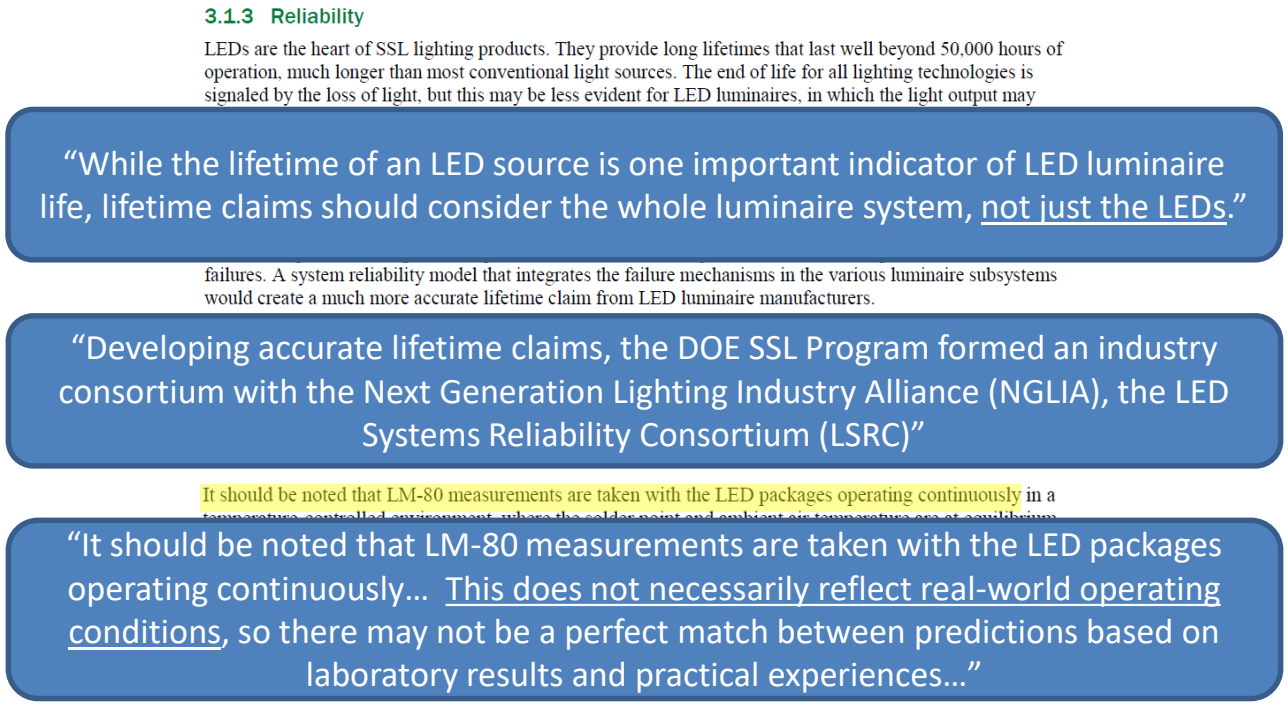



The reasons for lumen depreciation are the same.
However, ***when*** this breakdown occurs has a dramatic effect on the TM-21 value.

**Won't our customers be more upset to see a product breakdown very early, even if it is not to 70% brightness?**

# LM-80 / TM-21 is being misused…

*Excerpts from US DOE SSL 2017 Suggested Research Topics Supplement*



3.1.3 Reliability

LEDs are the heart of SSL lighting products. They provide long lifetimes that last well beyond 50,000 hours of operation, much longer than most conventional light sources. The end of life for all lighting technologies is signaled by the loss of light, but this may be less evident for LED luminaires, in which the light output may

"While the lifetime of an LED source is one important indicator of LED luminaire life, lifetime claims should consider the whole luminaire system, not just the LEDs."

failures. A system reliability model that integrates the failure mechanisms in the various luminaire subsystems would create a much more accurate lifetime claim from LED luminaire manufacturers.

"Developing accurate lifetime claims, the DOE SSL Program formed an industry consortium with the Next Generation Lighting Industry Alliance (NGLIA), the LED Systems Reliability Consortium (LSRC)"

It should be noted that LM-80 measurements are taken with the LED packages operating continuously in a

"It should be noted that LM-80 measurements are taken with the LED packages operating continuously… This does not necessarily reflect real-world operating conditions, so there may not be a perfect match between predictions based on laboratory results and practical experiences…"

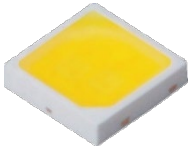
**LM-80 / TM-21 alone is not good enough to judge an LED's reliability, let alone finished product's reliability**

# LM-80 / TM-21 is being misused…

An LED's TM-21 extrapolations DO NOT equal an LED's actual lifetime.
LEDs' actual lifetimes DO NOT equal an LED Luminaire's actual lifetime.
TM-21 extrapolations DO NOT equal an LED Luminaire's actual lifetime.

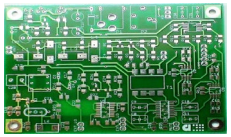
## Secondary Optics

Can discolor, lose reflectiveness. Heat and Optical energy will accelerate this , thus lower light output



## LED

Package and die degradation, etc.



## PCB

Solder joints fail = catastrophic failure. PCB's can discolor, specifically solder resist, becoming less reflective and lower lumen maintenance


## Drivers

Capacitors are one of the main factor for LED driver life. Because of the electrolyte's volatilization, generally even high quality grade capacitor rated life is 40KH@85C. Higher temperatures accelerates this.

## Housing

Chemical Resistance, reflectivity, thermals

## Heat Sink

Chemical Resistance

And more components…

**While an LED does have it's depreciation, we all know it is not the weakest link.**
**So why pretend otherwise and reference an LED's calculated lifetime as a fixture's lifetime?**

# LM-80 / TM-21 is being misused…

*Comments heard in the industry…*

"I understand and agree the lifetime is not real, but my competitor is doing it so we must do it too."

"LM-80 / TM-21 is just a 'check-the-box metric' for us. Just give me a report that shows L70 1M hours. I don't care if its realistic."

"This TM-21 value shows L70 100k hours so it must be better than this report that shows L70 80k hours."

"Our end-customers do not really understand lifetime, but they are requiring L90 100k because it is 'better.'"

"5 years, 10 years, 20 years, no difference. In the end, I'd rather they buy more fixtures anyways…"

**With no policing or further testing requirements, this mindset will continue!**

# New Proposals for Lifetime / Robustness Testing

| Test | Reference Standard | Test Condition | Purpose (to evaluate) |
|---|---|---|---|
| **High Temperature Operating Life (HTOL)** | JESD22-A108 | $T_S$=max,<br>$I_F$=max or<br>Corresponding max rated current (1,000hours) | Accelerated test for LED life time |
| **Wet High Temperature Operating Life (WHTOL)** | JESD22-A101C | $T_A$=60C, RH=90%, $I_F$=max (1,000hours)<br>or<br>$T_A$=85C, RH=85%, $I_F$=max (1,000hours) | Accelerated test for LED life time |
| **Temperature Cycling (TMCL)** | JEITA ED-4701 100 105<br>Or<br>JESD22-A108 | -40C to 100C (1,000cycles)<br>or<br>-40C to 125C (500cycles) | Solder joint reliability btw PCB and LED<br>LED structure robustness<br>(ex. Solder crack, Delamination, etc.) |
| **Resistance to Soldering Heat (RSH)** | JEITA ED-4701 300 301 | 260C (-0 / +5C), 10second<br>Precondition : according to MSL rating (2 times) | Robustness of LED materials against heat. |
| **Electrostatic Discharge** | JEITA ED-4701 300 304 | HBM 2kV (3 pulses) | Robustness against ESD |
| **Sulfuration Test** | - | $T_A$=40C, RH=75% : H2S 2ppm, NO2 4ppm (240hrs)<br>or<br>$T_A$=40C, RH=80% : H2S>10ppm (96hours) | Robustness against Harmful gas. |

**Creating LM-80 was a great 1st step. Establishing TM-21 was a great 2nd step.**

***The industry now deserves a 3rd step to more accurately predict product lifetime so better comparisons can be made vs. just establishing a minimum bar (i.e. TM-21)***

Solid State Lighting still has so much potential
to enable much more than lighting has ever done.

Let's not limit ourselves with complacency to just "replace."

Continue to push the limits &
fine-tune our game!


Thank you for your time!
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