LEDs: Where's the Revolution?

Technology Transfer from Displays to Lighting

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Introduction to JNB

- MA in mathematics, Cambridge University
- Ph.D. in theoretical physics, University of Manchester
- 20 years as a physics professor, mainly at University of Pittsburgh
- 30 years research in atomic & molecular physics & ionized gases
- 15 years managing research at Lawrence Livermore National Lab
- 15 years as advisor to industry on displays & lighting
- 4 years as consultant to the DOE Solid State Lighting Program

I know a little about a lot of things
but am not an expert on anything

- My major goal is to encourage collaborations
  to bring technology from the lab to market
- I do not make market forecasts or give investment advice

The Lighting Revolution….

- **"LED lighting is arguably the most profound change the lighting industry has witnessed since the invention of electric light itself. LED's are transforming the nature of lighting by opening up new possibilities for how and where artificial light is used to enhance the human experience".**

  Philips Lighting - http://www.lighting.philips.co.uk/lightcommunity/trends/led/ (2011)

Source: Arfon Davies: OLED Lighting Design, London, June 2011

The Lighting Revolution….

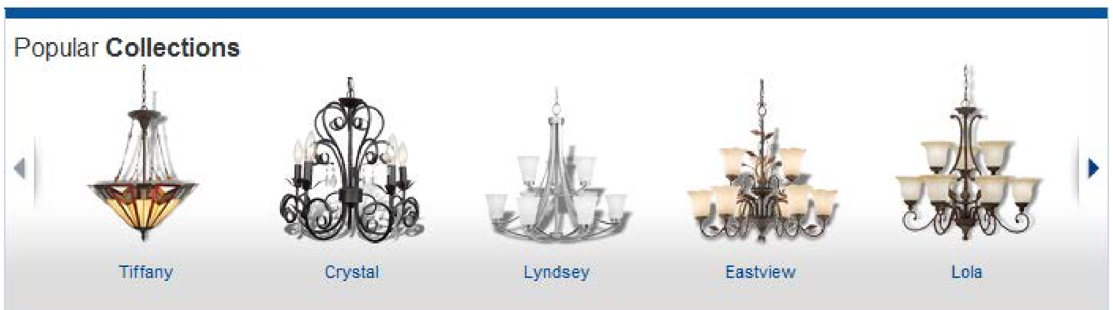
- "LED lighting is arguably the most profound change the lighting industry has witnessed since the invention of electric light itself.

LOOK FAMILIAR?

Source: Arfon Davies: OLED Lighting Design, London, June 2011

ARUP

Hiding The Light: A Waste of Energy and Money?



Sources: Lowes.com; Lighting Direct.com; Lithonia; Thomas

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The next innovative step

Source: Sebastian Ludwig,
OLED Lighting Design Summit 2011

OLED to complete SSL-light sources

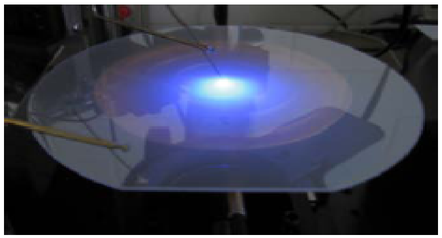
„Big Players“ bring OLED into first applications

pictures: www.oled.info

Lighting Industry Evolution as Seen by RPI

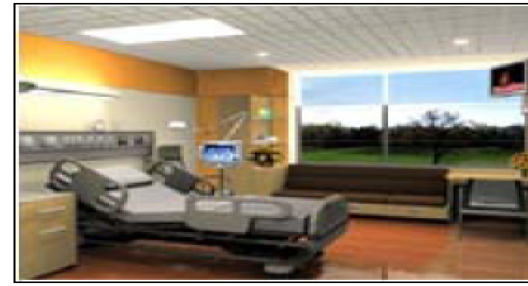
New Chip Concepts

New Materials and Methods



- Efficient full spectrum LEDs without droop
- Versatile, low cost light sensors
- OLED thinking applied to inorganic LEDs
- Opto-electronic Integration

- Chip to Fixture Thinking
- Leverage Optoelectronic Integration for lower costs
- Novel integrated controls, optics and thermal management
- Flexibility for Artistic Expression



- Lighting Systems as capital equipment
- Fusion of Display and Lighting Technologies
- Adaptive, self- commissioning installations
- No Light Switches
- Smart Building & Grid Interfaces

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Source: Robert Karlicek, DOE SSL Workshop 2011

More than a Rival - LED Growth Path

- Opportunities for LED
  - More Intelligent Fixtures:
    - Constant Light Output (CLO)
    - End of Life Monitoring
    - Design based on Desired Life of System
  - Design Constraints Changed
    - Will allow new Form Factors
    - Color Available
  - Improvements in Technology: Steeper Curve than Fluorescent (Haitz's Law)

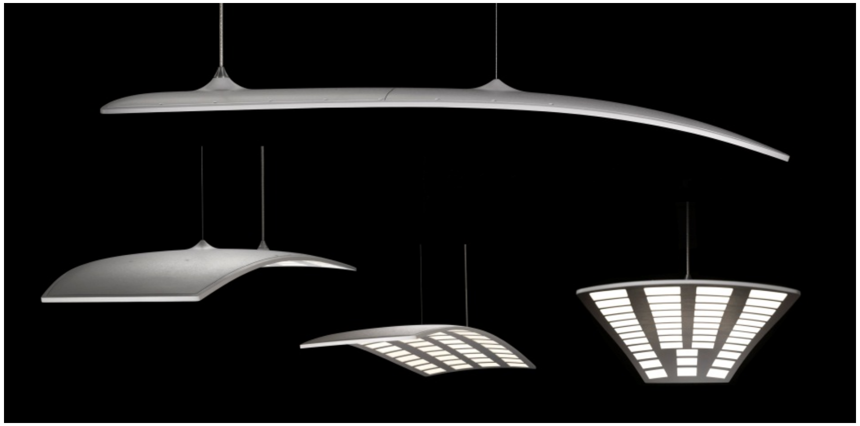
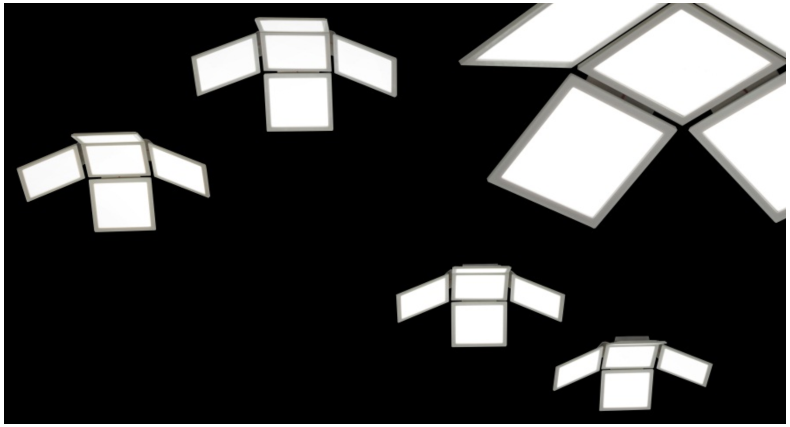
Source: Colleen Pastore, DOE SSL Meeting 2011

PHILIPS
LIGHTOLIER

Outline

- **Large Area Lighting Sources**
  - Thin, flexible, transparent
  - OLED vs LED
  - OLED challenges
- Efficacy gains – Application enabler
- Digital Controls
  - Automated or user controls
  - Wireless networks
- Color Control
  - Market pull
  - Implementation issues
- Broadband Communications
- Evolving lifestyles
  - Age gap
  - Flat panel displays and off-desk memory

Prototype OLEDs

Acuity

GE

Novaled

UDC-Armstrong

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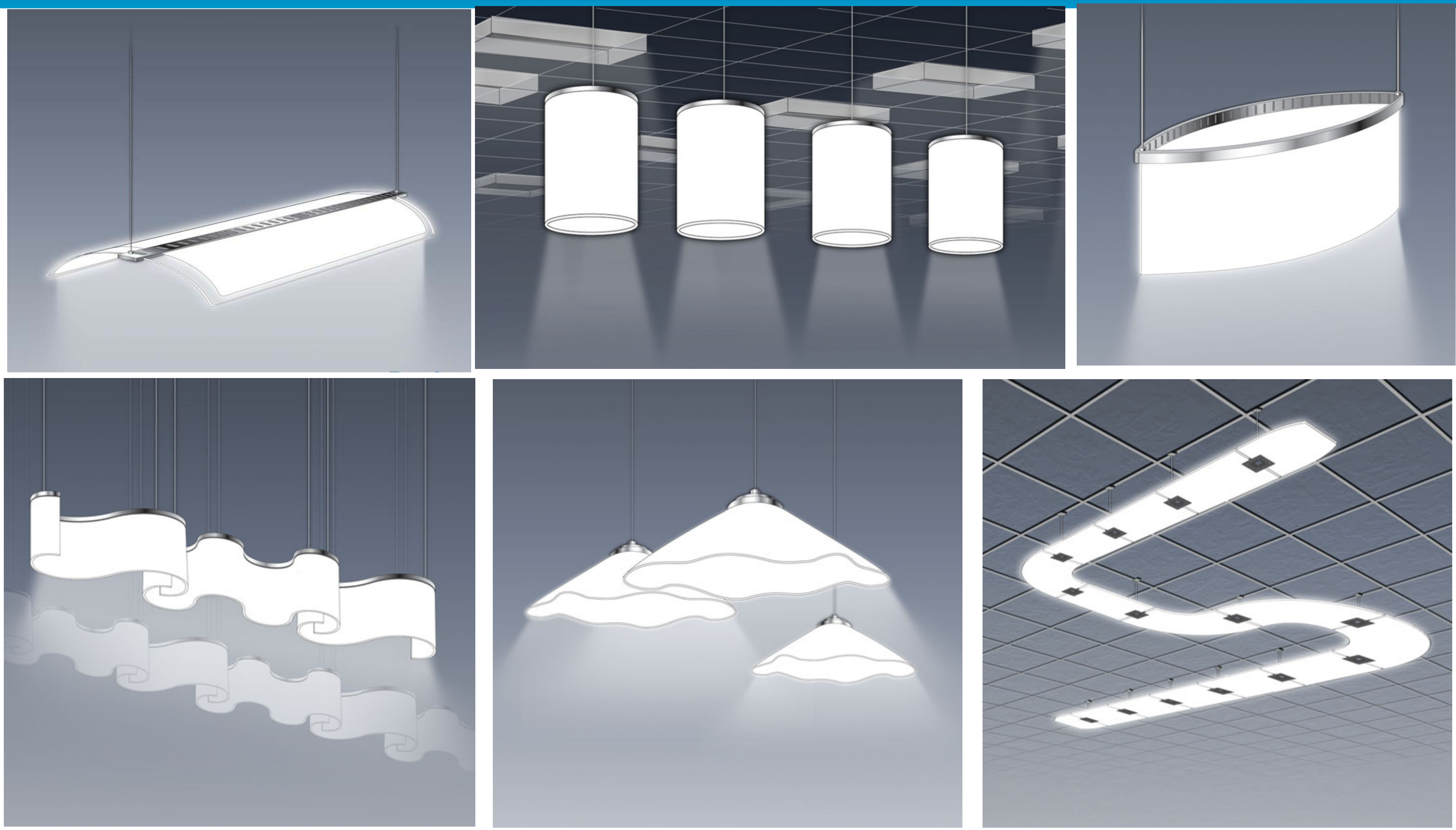
Suspended Ceiling Lights?



Pentelic Designs from Rambus

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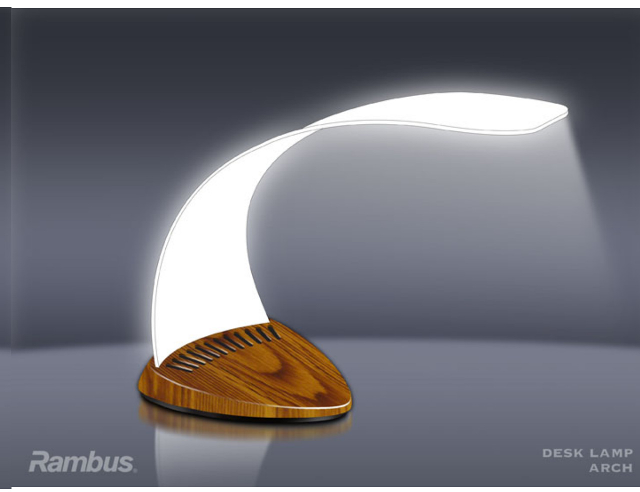
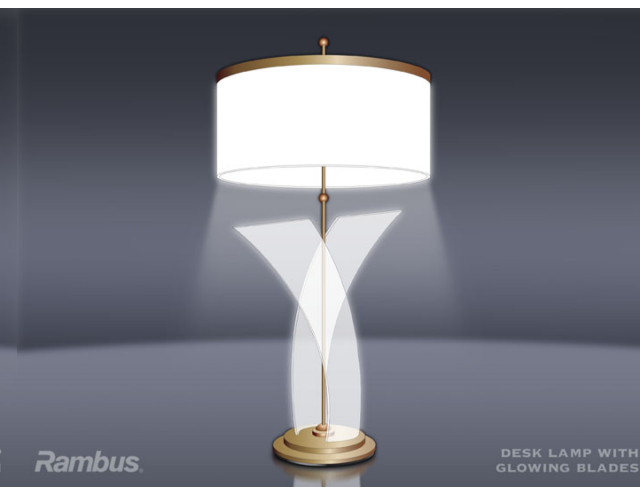
Table or Desk Top Lamps?





Pentelic Designs from Rambus

OLEDs vs LEDs as Diffuse Sources

Characteristic	OLED	LED
Energy transport	Multi-component current conduction	Bouncing photons
Light extraction	Very difficult	Micro-lens arrays
Angle control	Even more difficult	Patterned extraction
Color control	Complex patterning	Need RGBXY sources
Flexibility	Difficult encapsulation	Straightforward
Arbitrary shape	Not yet demonstrated	Straightforward
Thermal management	<10^0C; still needs work	~50^0C; needs work
Cost	100x too high	2-10x too high

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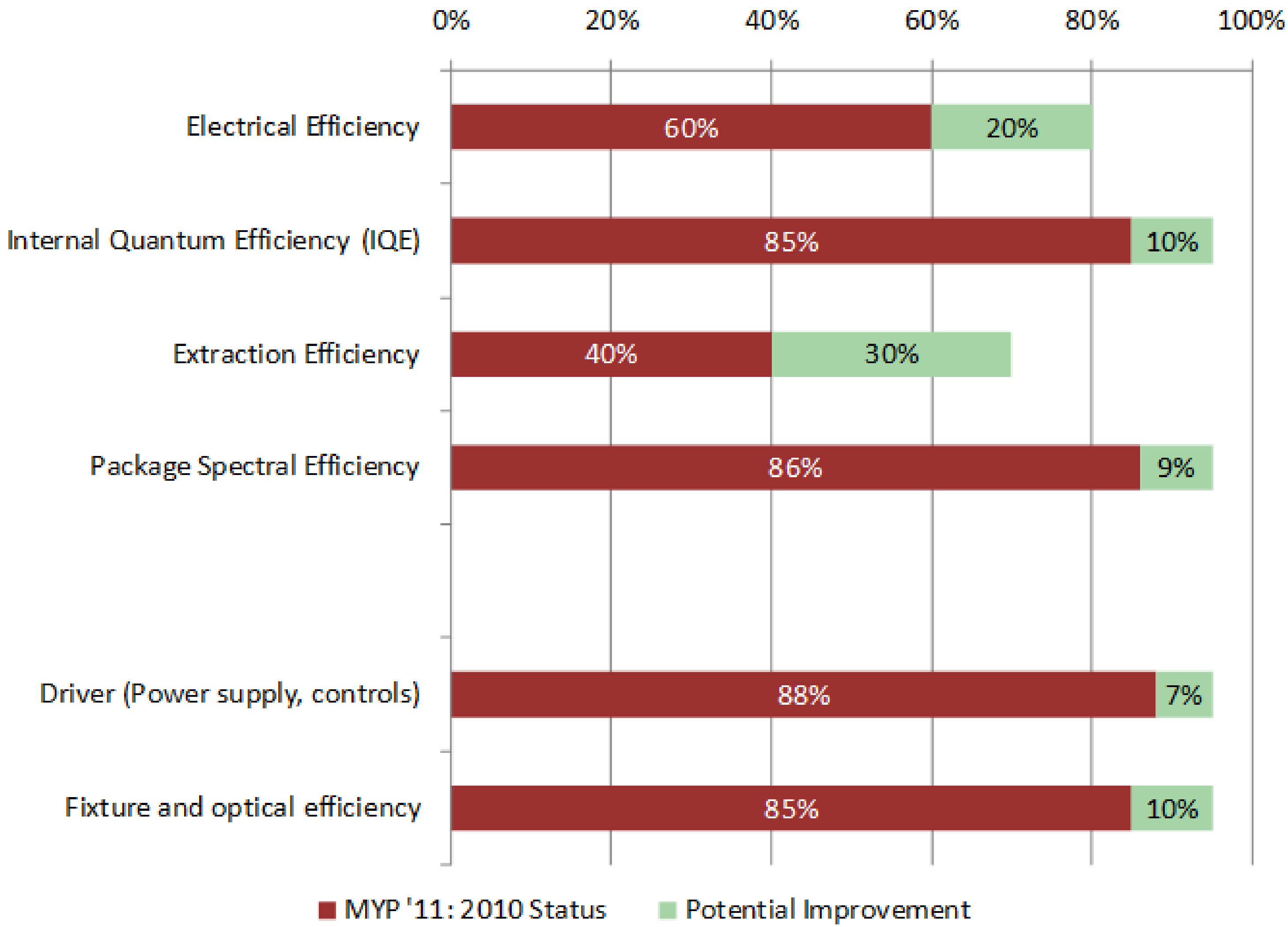
OLED Efficiency Analysis (Lab Devices)



DOE SSL R&D Multi-Year Program Plan, March 2011

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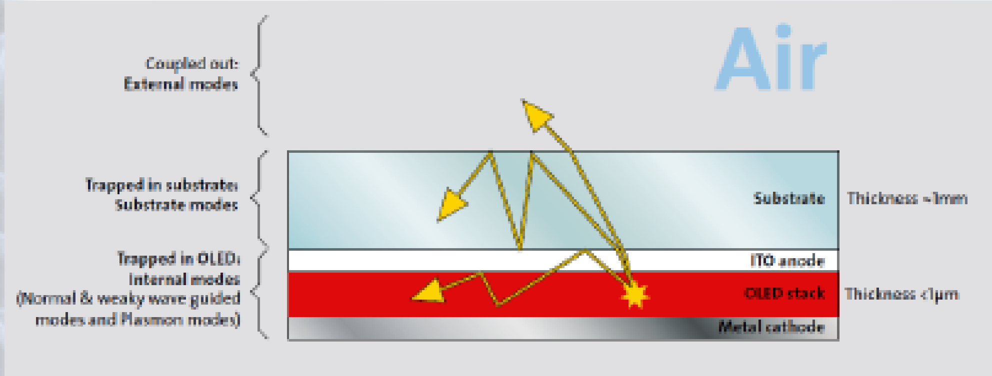
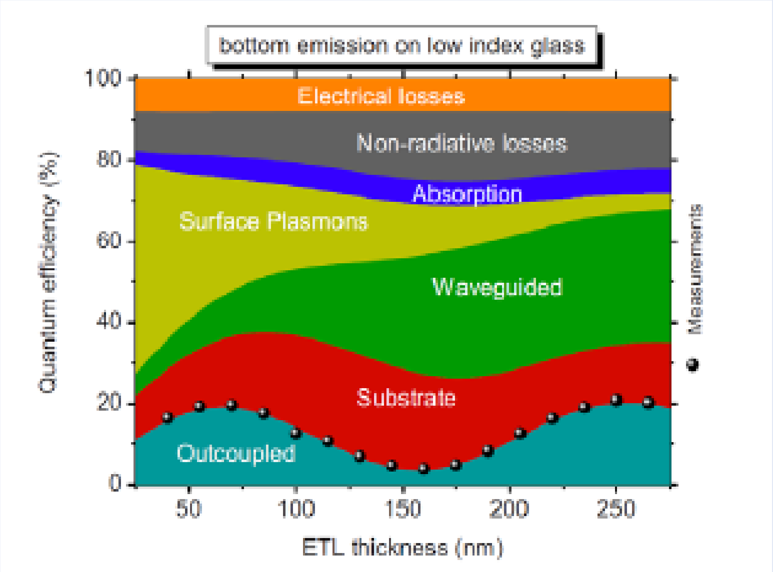
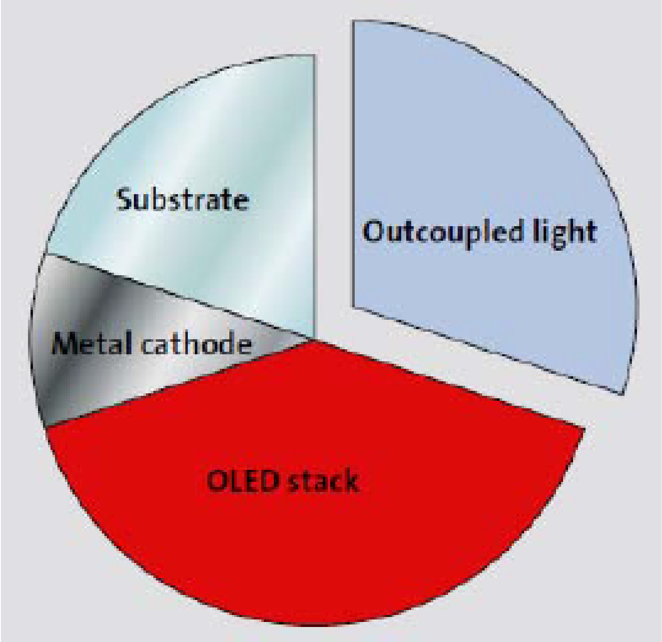
Energy Losses in OLED



source: Novaled AG



source: Meerheim et al., Appl Phys Lett 97, p253305 (2010)



- only 20 … 30% of light is actually coupled out
- work on extraction from
  - substrate → external
  - OLED stack → internal

Source: Florian Pschenitzka, DOE SSL Workshop 2012

Improved Light Extraction is Critical

Should be accomplished through thin-film structures

- Where?
  - Outer surface of transparent substrate
  - Between substrate and transparent conductor
  - Inside transparent conductor
  - Between the electrodes
  - At edges
- How?
  - Scatter light
  - Bend light rays (without chromatic aberrations)
  - Micro-cavities or multi-layers (without chromatic aberrations)
- Uncertainties
  - **Low-cost high-index substrates**
  - **Energy losses in metal electrode**
  - **Manufacturability of sub-micron patterns**
  - **Complementarity of partial solutions**

Methods to improve the OCE

Research for Outcoupling enhancement

Aero gel layer
Adv. Mater. 13 (2001) 1149

grating structure
Appl. Phys. Lett. 90 (2007) 091102

Textured surface
Appl. Phys. Lett. 63 (1993) 2176

low refractive index grid
Nature photonics VOL 2 2008 483

Micro lens array
J. Appl. Phys. 90 (2002) 3324

high refractive index substrate
Nature vol 459 2009 234

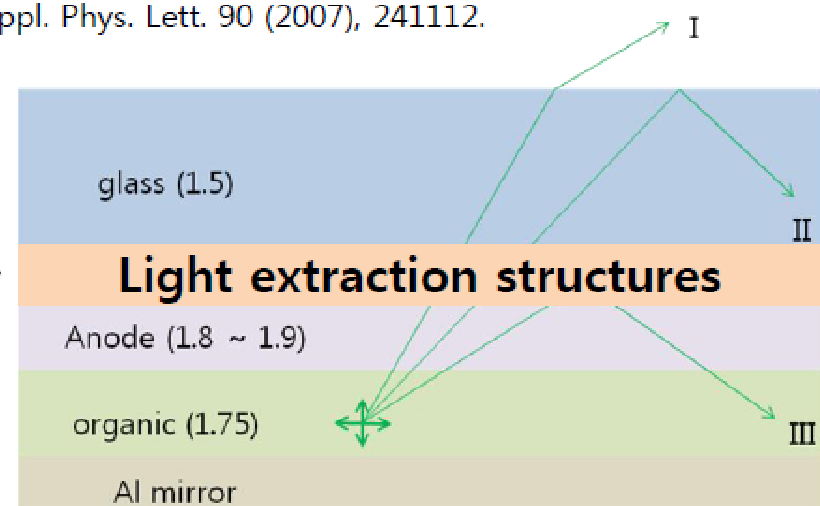
Meshed surface
Appl. Phys. Lett. 92 (2008) 083307

Scattering layer
SID 2010

Periodic or aperiodic dielectric mirrors
Appl. Phys. Lett. 90 (2007), 241112.

photonic crystal structure
Adv. Mater. 15 (2003) 1214
Appl. Phys. Lett. 81 (2003) 3779
Appl. Phys. Lett, 92 (2008) 223307
Appl. Phys. Lett. 90 (2007) 111114

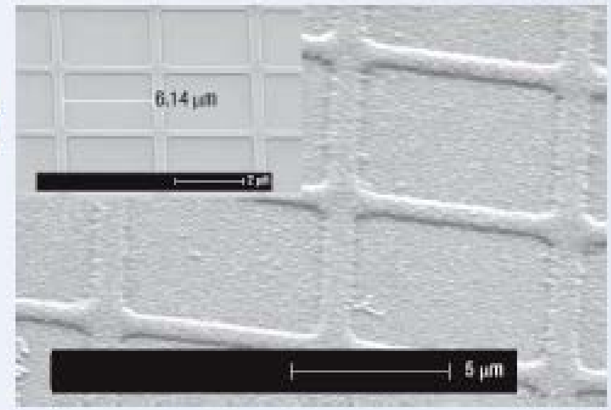
Random pattern for White OLED
&
solution process
(UV-NIL + sol-gel process)

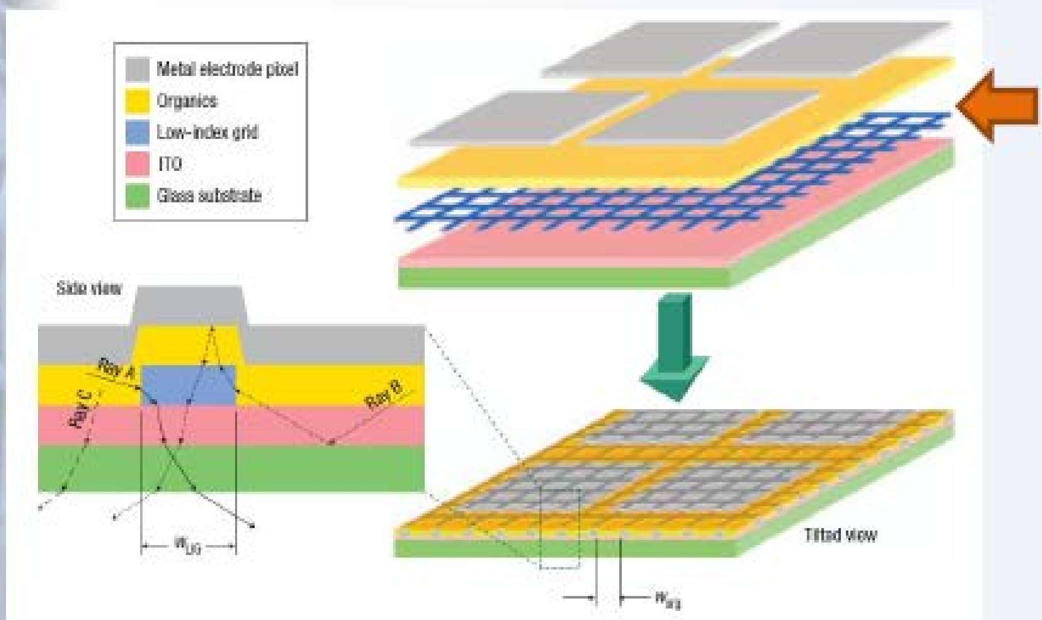


Source: Jang-Joo Kim (Seoul Nat U, 2011)

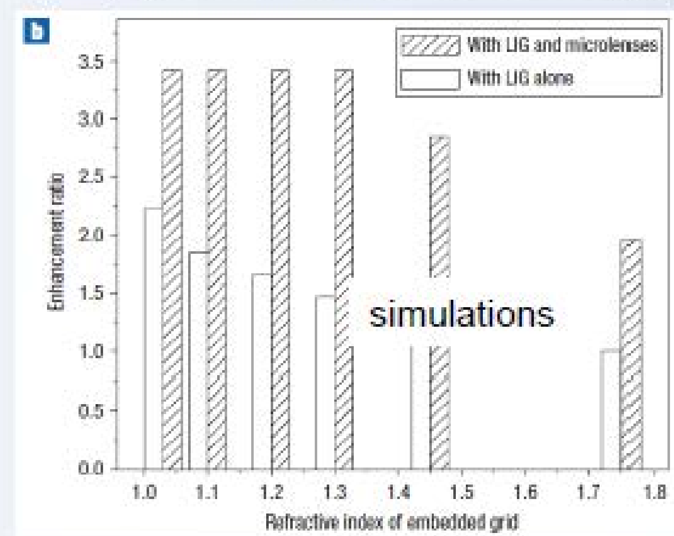
Internal Outcoupling Technologies

- low-index-grid on top of ITO layer
  - grid material: SiO_2 (n=1.5)
  - grid patterned by photolith
  - power efficiency was improved by 2.3x





source: Sun et al., Nature Photonics, Vol 2, p483 (2008)

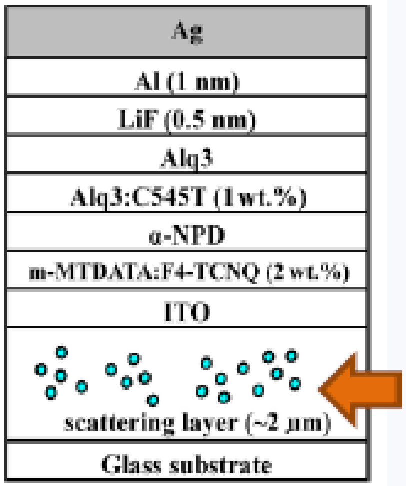


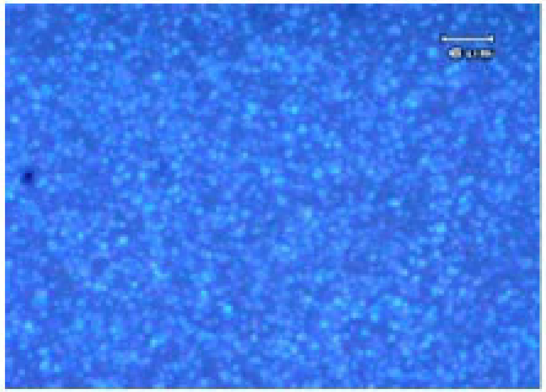
Source: Florian Pschenitzka, DOE SSL Workshop 2012

CAMBRIOS

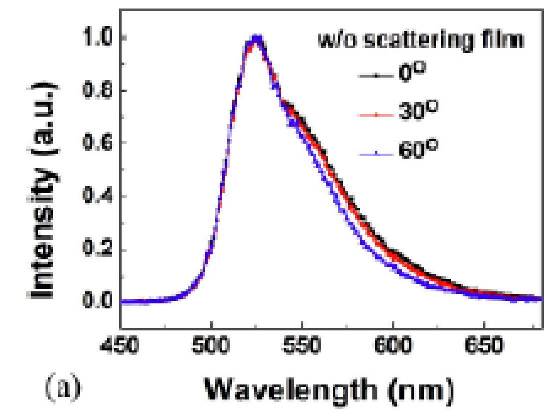
Internal Outcoupling Technologies

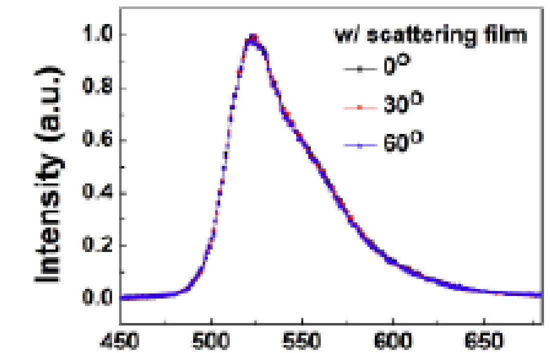
- scattering layer between ITO and glass substrate
  - TiO_2 particles (size 400nm)
  - more than 100% improvement in efficiency
  - better color stability vs. angle

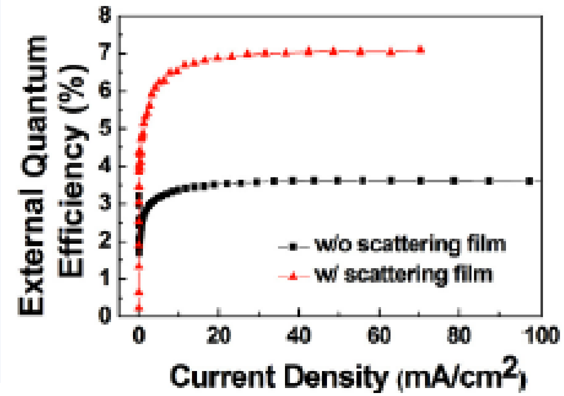




source: Chang et al., Journal SID 19/2, p196, (2011)



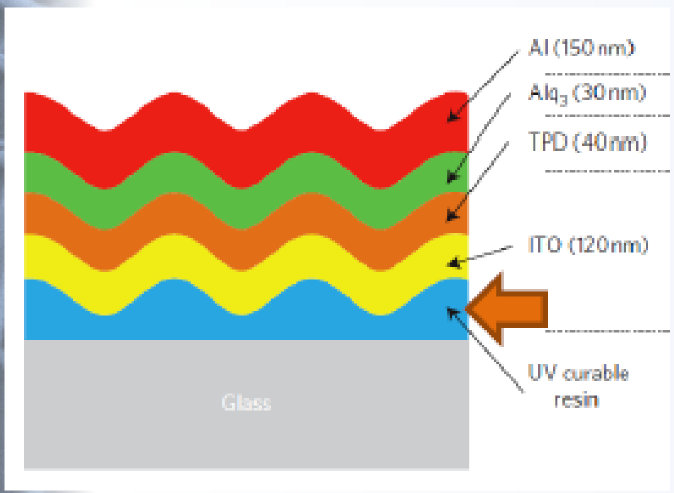




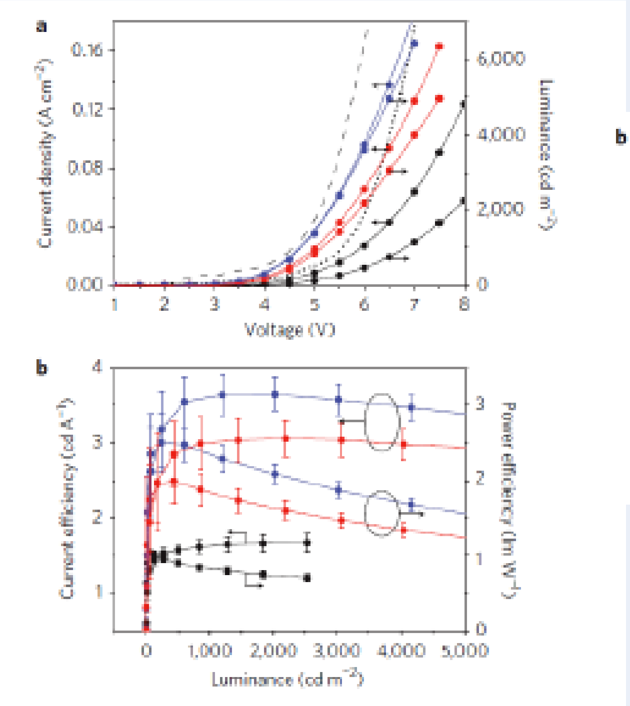
Source: Florian Pschenitzka, DOE SSL Workshop 2012

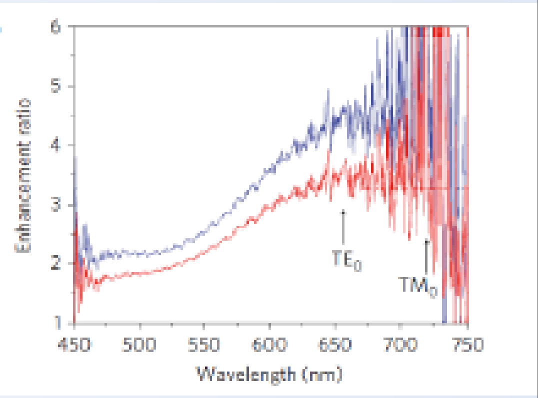
Internal Outcoupling Technologies

- "buckles" underneath ITO and organic stack
  - PDMS stamp with "buckles" used to transfer features to UV-curable resin before ITO was sputtered onto this layer
  - power efficiency was improved by 80% … 400%



source: Koo et al., Nature Photonics 4, p222 (2





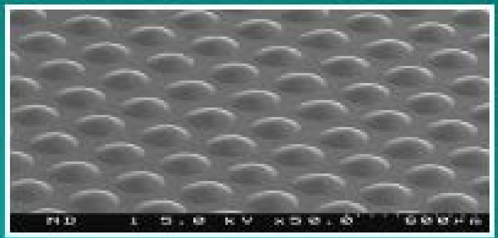
Remark: SPP reduction due to cathode morphology?

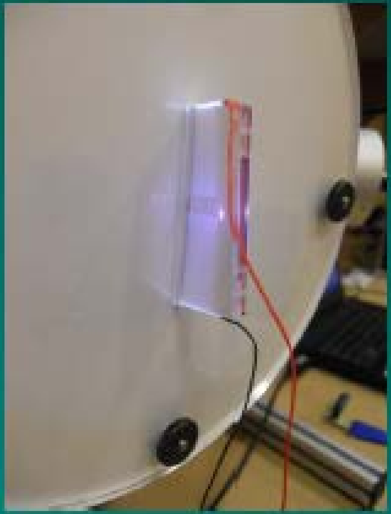
Source: Florian Pschenitzka, DOE SSL Workshop 2012

CAMBRIOS

MicroLens™ Baseline Optical Efficiency

LED Flux:	Measured by putting LED into sphere port slot.	
	10.8	lm
System Flux:	Measured by putting ELU into sphere port slot.	
	10.3	lm
System Efficiency:	system flux/LED flux	
	95.4%	





Source: Kieran Drain, DOE SSL Workshop 2011

Rambus

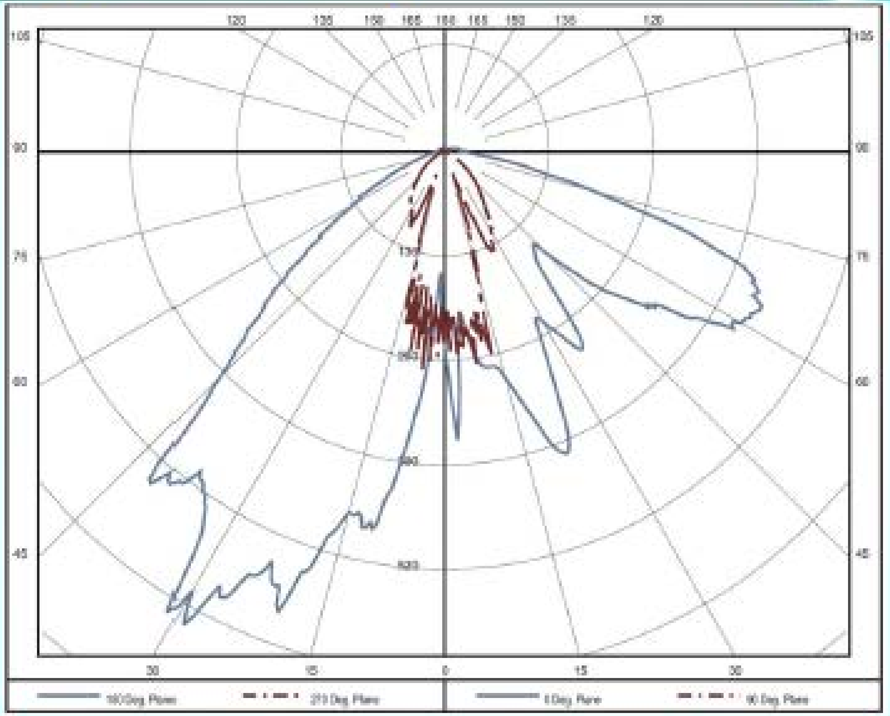
MicroLens™ Combines High Efficiency and Ray Angle Control (94 LPW)

Measured Luminaire Electrical Values:

Voltage:	22.20 VDC
Current:	0.3998 A
Watts:	8.875 W
Power Factor:	1.00
Temperature:	24.9 °C

Measured Luminaire Photometric Values:

Radiant Flux:	2463 mW
Luminous Flux:	834.6 Lumens
Luminaire Efficacy:	94.0 Lumens per Watt
CCT:	4015 K
CRI (Ra):	64.7
Chromaticity (x):	0.3840
Chromaticity (y):	0.3924
Chromaticity (u'):	0.2213
Chromaticity (v'):	0.5088
Duv:	0.0054



MicroLens™ Hanging Blade in an integrating sphere (above)

Tested at LTL Inc PA Oct 2010

Source: Kieran Drain, DOE SSL Workshop 2011

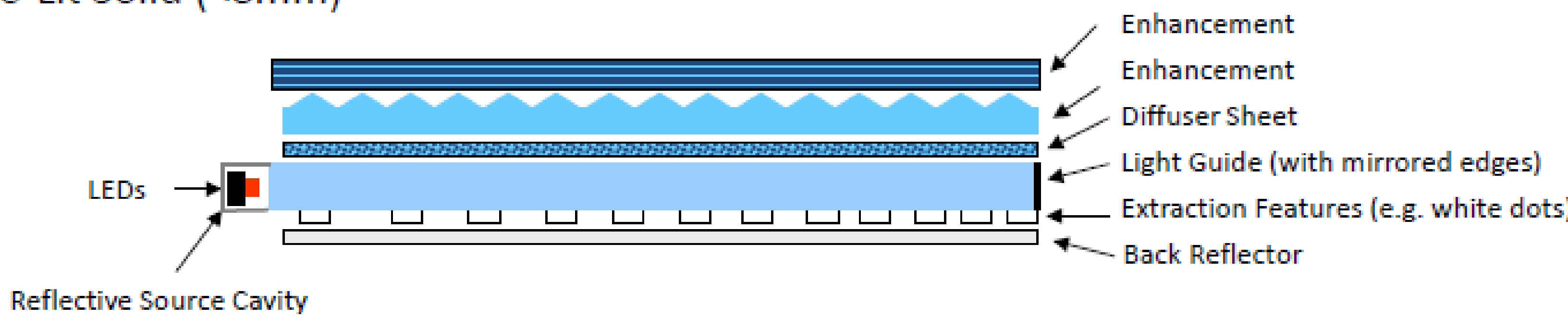
Rambus

Pendant LightBlades: Enable New Lighting Designs

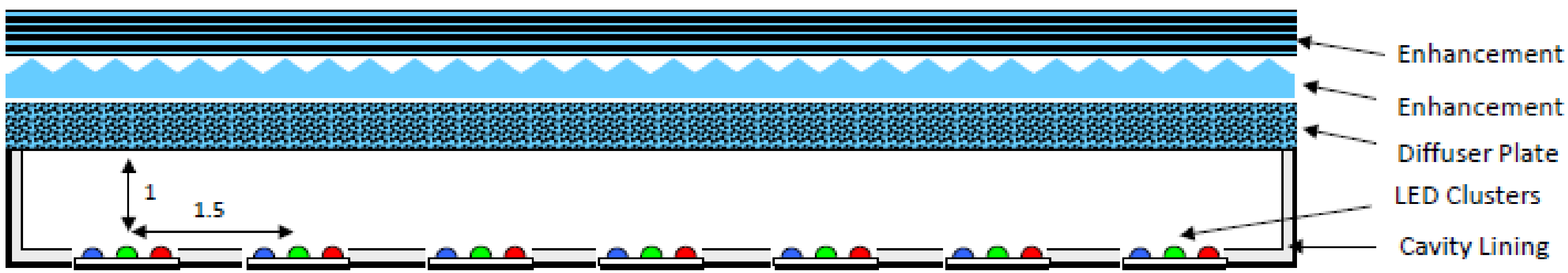
Blade Light – Flat 153mm x 320mm

Backlight Architectures

Edge-Lit Solid (<8mm)



Direct Lit Hollow (<25 mm)



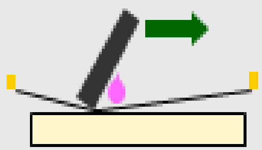
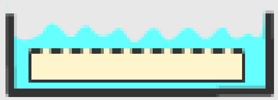
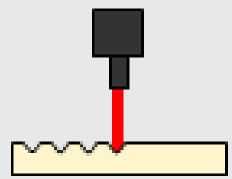
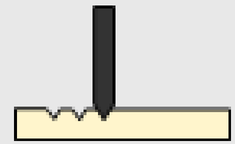
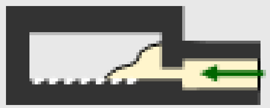
Edge-Lit Hollow (<12mm)

Hollow Light Guides

Solid Light Guides

Source: Tom Simpson, 3M: DOE SSL Workshop, February 2012

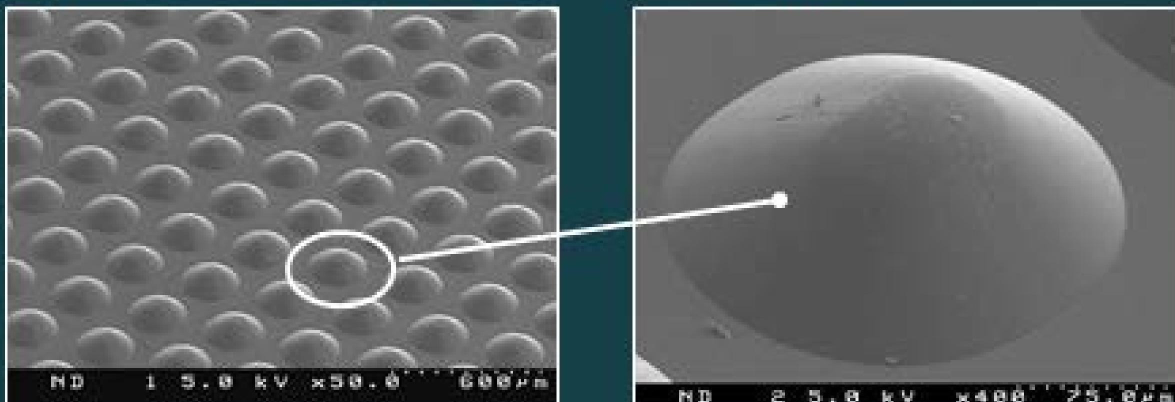
Techniques for patterning the light-guide

Patterning Technology	Printed Dot	Chemical Etch	Laser Etch	V-grooves	Embedded Optics
Method					
Optics	• Diffuse	• Diffuse	• Diffuse	• Diffuse (1D only)	• Specular (ray • angle control) ✓
Optical Efficiency	• Good	• Good	• Better	• Good	• Best ✓
Uniformity	• Good	• Good	• Better	• Good	• Best ✓
Manufacture-ability	• Fast ✓	• Fast ✓	• Slow	• Slow	• Fast ✓

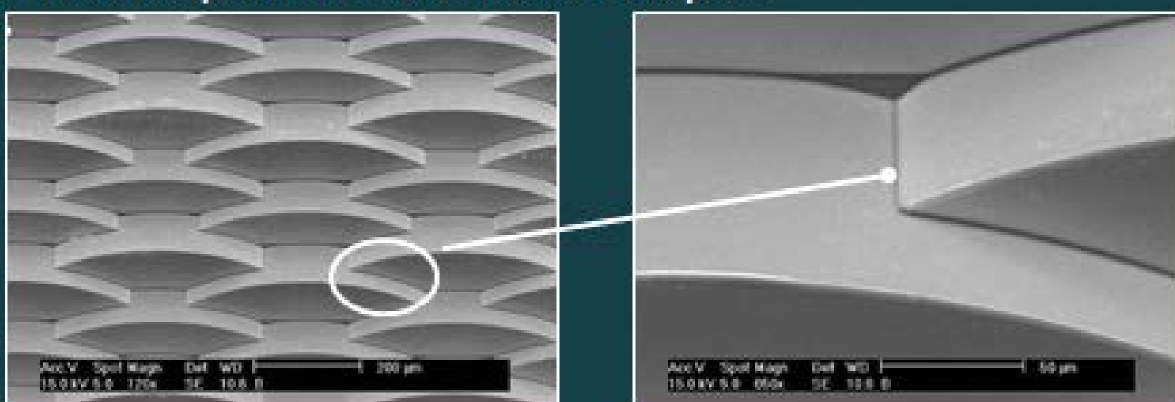
Source John Langevin, Strategies in Light, Japan 2011

Embedded Optics Example: MicroLens® Optics

Injection molded light guide with MicroLens optics



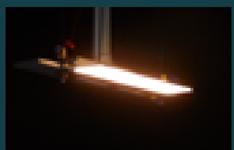
Embossed optical film with MicroLens optics

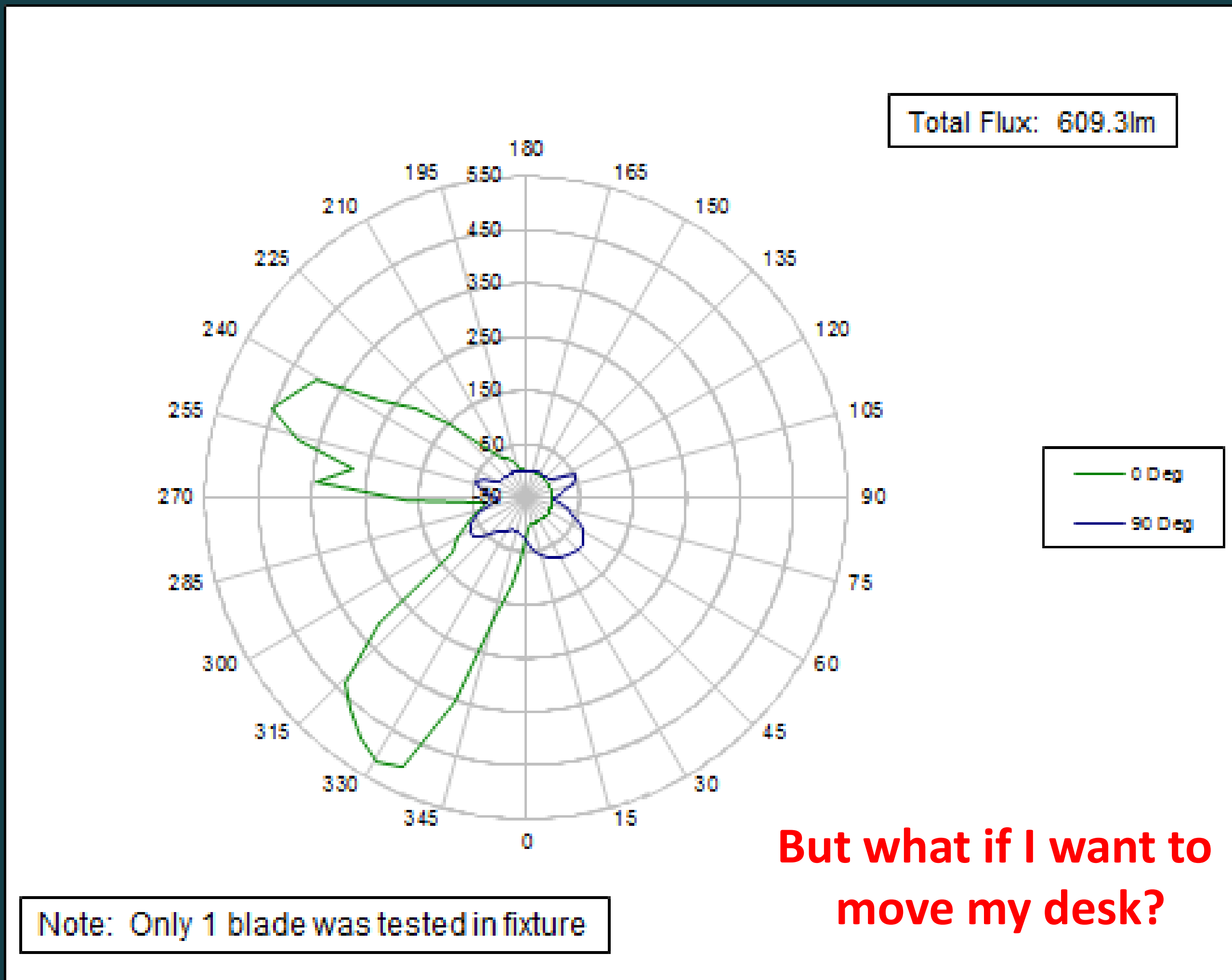


Optical features can be varied by depth, shape, density and location to support any display size and emission requirement

Source John Langevin, Strategies in Light, Japan 2011

MicroLens Light-guide:
Polar Distribution and Luminous Flux

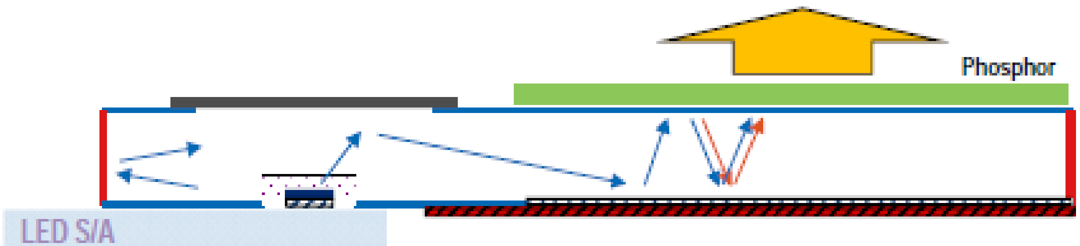




But what if I want to move my desk?

Source John Langevin, Strategies in Light, Japan 2011

Innovation



Optical Packaging for Surface illumination and Planar Remote Phosphor

1

- Advanced in-coupling design
  - Efficient light coupling to FLG:
  - Proprietary optical design to couple the light
  - Optical efficiency of >70%

2

- Embedded LED chips
  - More light from LEDs chips
  - Encapsulation of chips as part of embedding

3

- Bottom coupling
  - Direct (cooling) path to heat sink
  - Direct connection to heat sink for better cooling which results in higher LEDs efficacy

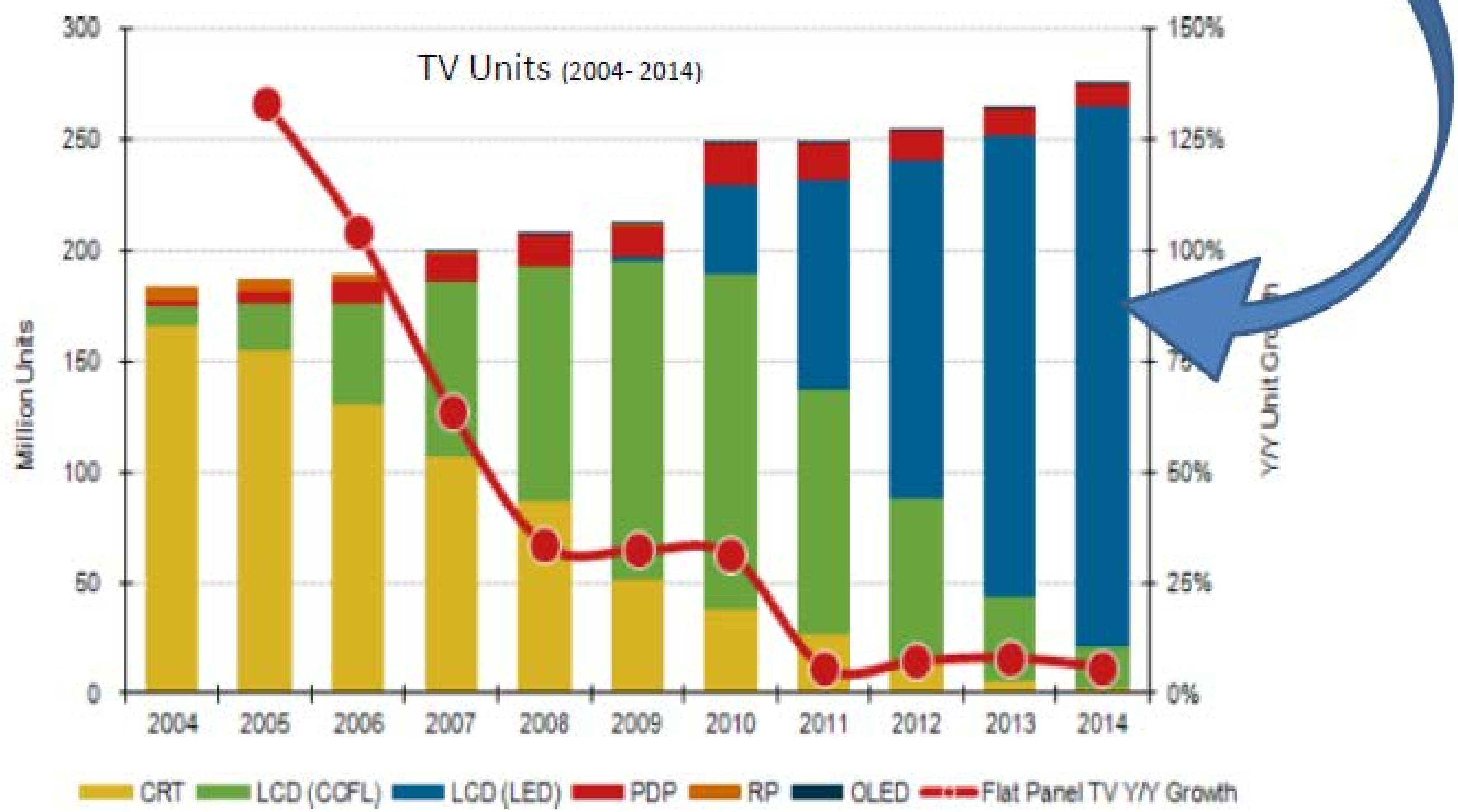
4

- Remote Phosphor
  - Phosphor layer away from hot LED increases conversion efficacy
  - Efficient phosphor conversion of 78%
  - Less loss as reflected light is recycled and not absorbed

Source: Eran Fine, Intertech-Pira LEDs 2011

Technology Source and Cost Reduction Driver

LED Adoption in LCD TV



Source: DisplaySearch

Outline

- Large Area Lighting Sources
  - Thin, flexible, transparent
  - OLED vs LED
  - OLED challenges
- **Efficacy gains – Application enabler**
- Digital Controls
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- Color Control
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- Evolving lifestyles
  - Age gap
  - Flat panel displays and off-desk memory

OLED Luminaire Efficacy Targets

Metric	2010	2012	2015	2020
Panel Efficacy (lm/W)	58	86	125	168
Optical Efficiency of Luminaire	100%	100%	90%	95%
Efficiency of Driver	88%	90%	93%	93%
Total Efficiency from Device to Luminaire	88%	90%	84%	88%
Luminaire emittance (lm/m^2)	3,000	6,000	9,000	9,500
Resulting Luminaire Efficacy (lm/W)	51	77	105	148

Note: Efficacy projections assume CRI > 80, CCT 2580-3710
The values of optical efficiency quoted for 2010 and 2012 assume no light shaping optics

DOE SSL R&D Multi-Year Program Plan, March 2011
http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2011_web.pdf

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(I)LED Luminaire Performance Targets

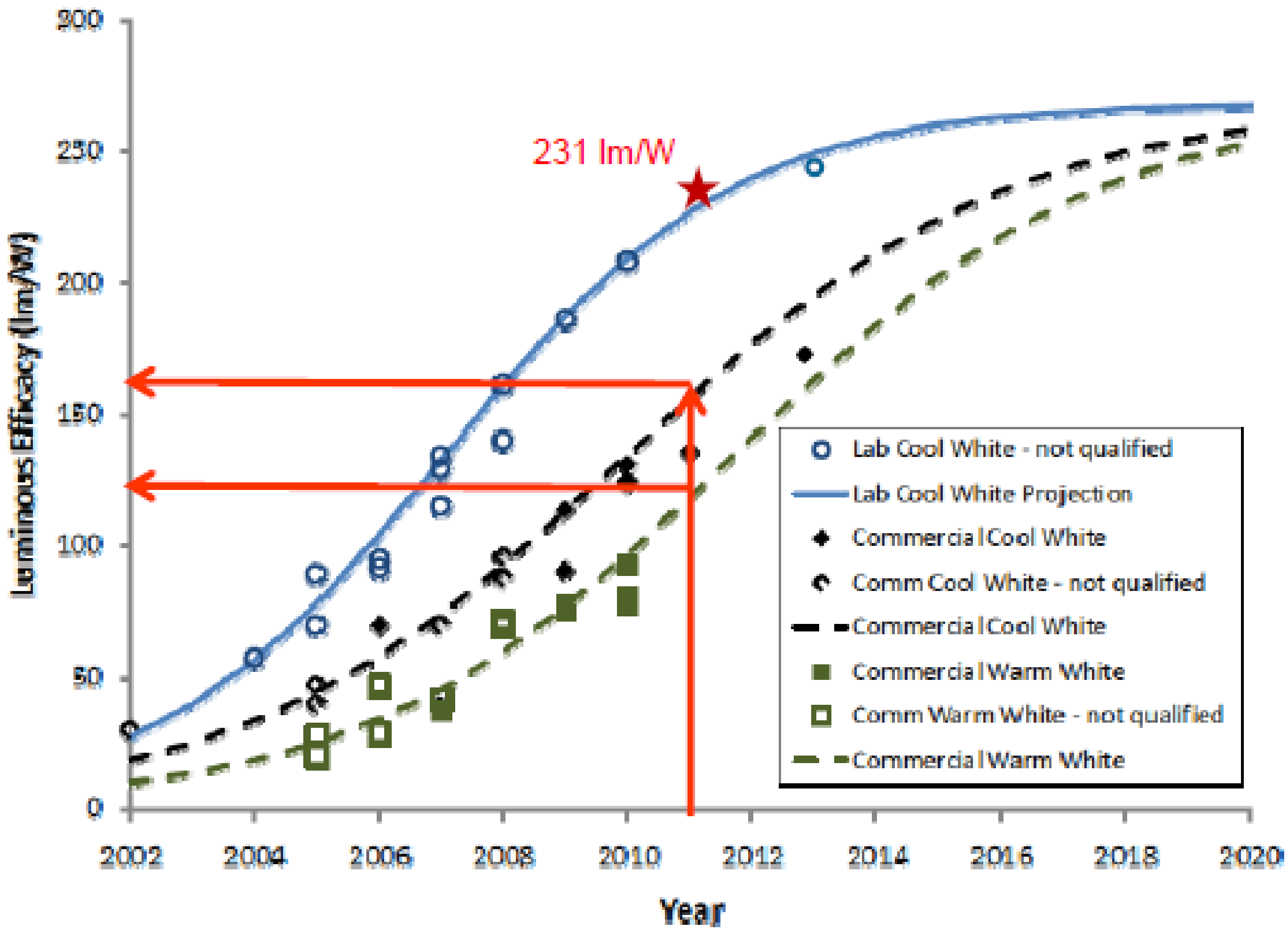
Metric	2010	2012	2015	2020
Package Efficacy – Commercial Warm White (lm/W, 25°C)	92	141	202	266
Thermal Efficiency	86%	86%	88%	90%
Efficiency of Driver	85%	86%	89%	92%
Efficiency of Fixture	85%	86%	89%	92%
Resultant luminaire efficiency	62%	64%	69%	76%
Luminaire Efficacy – Commercial Warm White (lm/W)	57	91	139	202
High Current Luminaire Efficacy – Commercial Warm White (lm/W)	44	74	123	202

Notes:

1. Efficacy projections for warm white luminaires assume CCT=2580-3710K and CRI=80-90.
2. All projections assume a drive current density of 35 A/cm^2, reasonable package life and operating temperature.
3. Luminaire efficacies are obtained by multiplying the resultant luminaire efficiency by the package efficacy values.

DOE SSL R&D Multi-Year Program Plan, May 2011

DOE Roadmap - Performance



XLamp XM-L
160 lm/W Cool
120 lm/W Warm

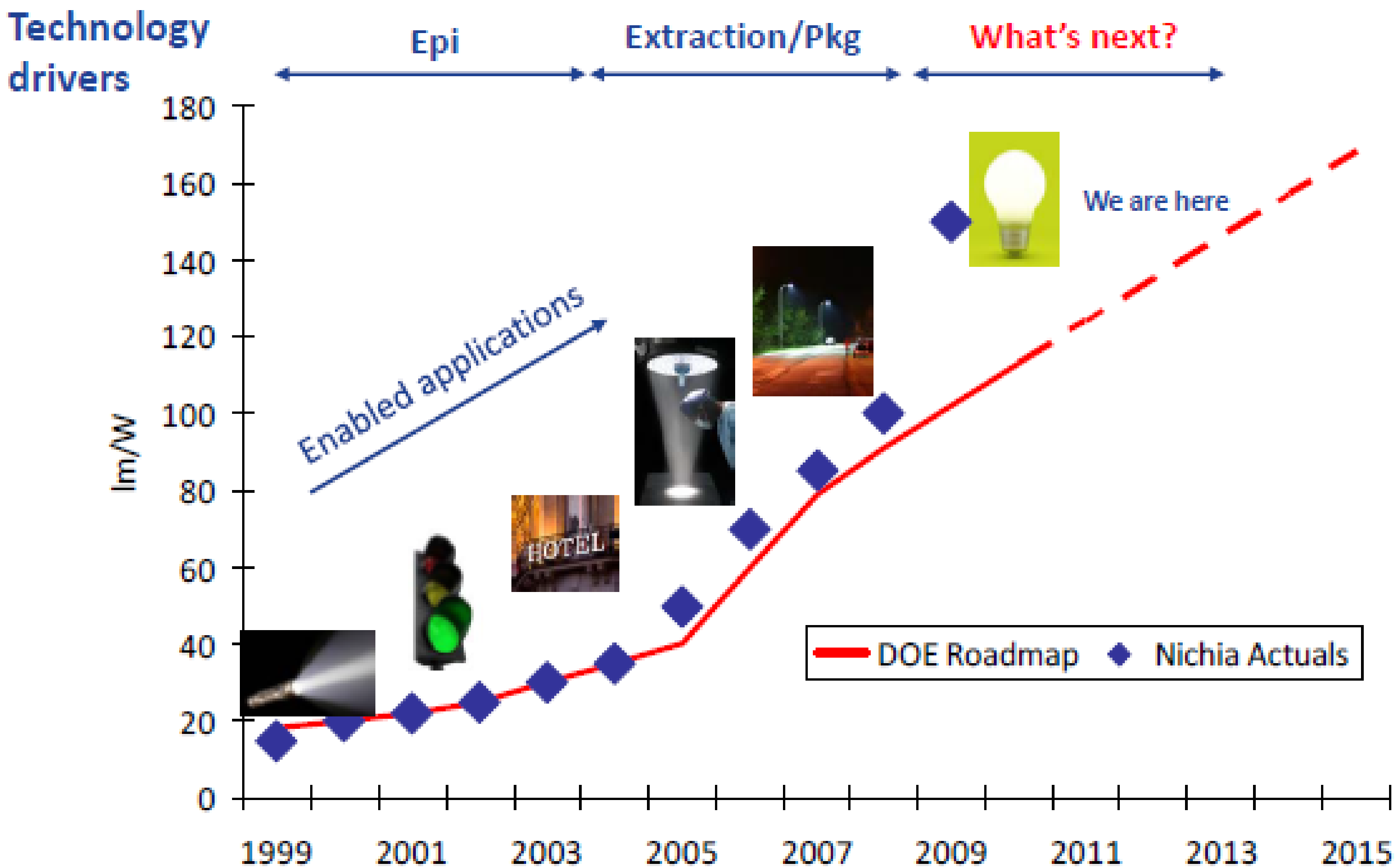
XLamp XP-G
140 lm/W Cool
110 lm/W Warm

US Department of Energy 2011 Multi-Year Plan for SSL, p.62

CREE

Source: Paul Thieken, Intertech Pira LEDs 2011

In the past, Lm/W selected the application …



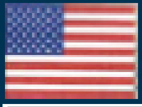
Commercially available cool white LEDs, T_j = 25 deg C

Source: Shawn Du, Intertech-Pira LEDs2011

Lm/W Improvement opens up new applications

- 120 lm/W package can open up the 60W A-bulb replacement
- 160 lm/W package is needed for the 100W A-bulb replacement

A-bulb	Bulb Lumen	Package (lm/W)	Bulb (lm/W)	Bulb (W)	Light	Heat	Required heat sink
40W	450	~ 80	~ 50	~ 9	20%	80%	~ 7 W
60W	800	~ 120	~ 80	~ 10	30%	70%	~ 7 W
75W	1100	~ 140	~ 100	~ 11	40%	60%	~ 7 W
100W	1600	~ 160	~ 120	~ 13	50%	50%	~ 7 W



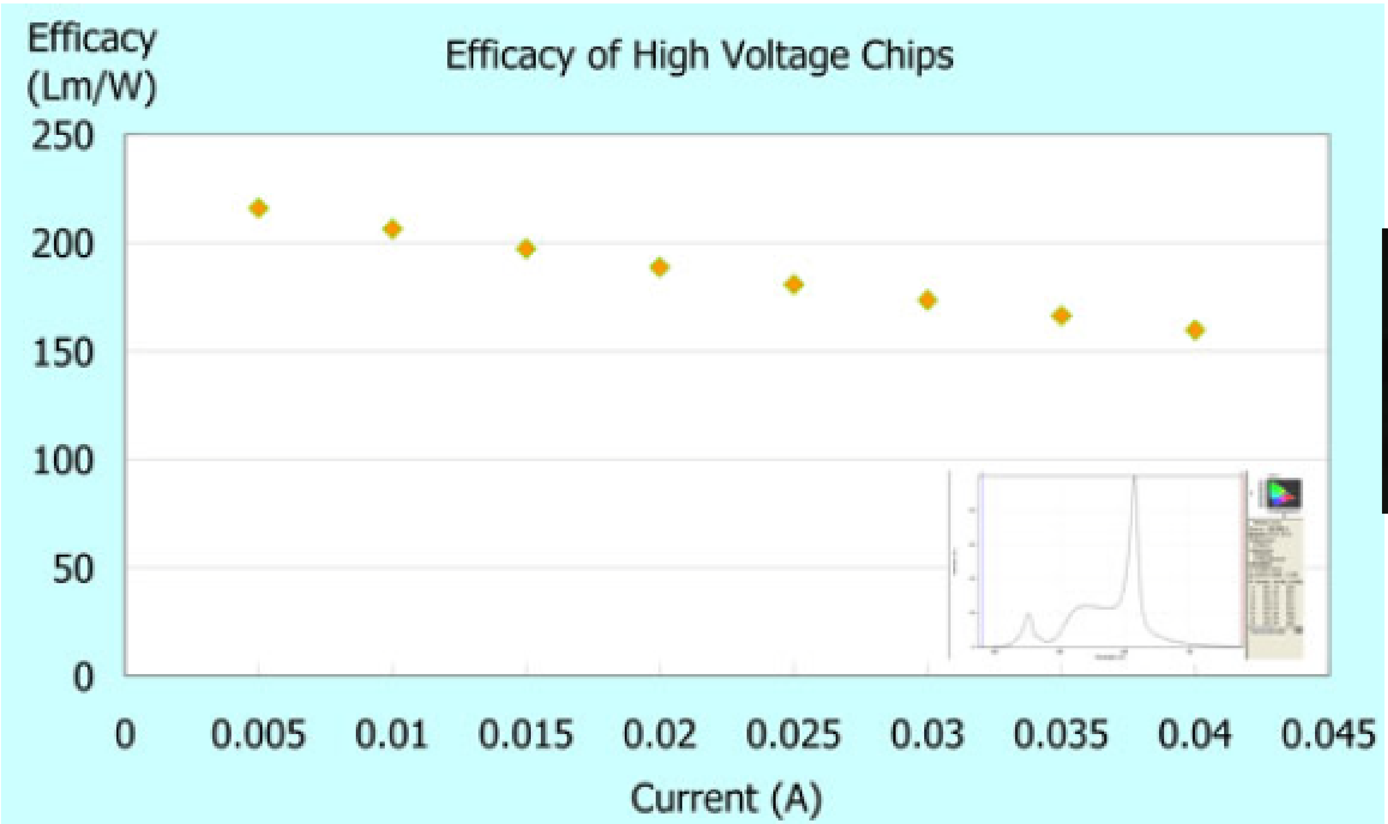
US DOE Roadmap for package LED

Metric	2009	2010	2012	2015	2020
Cool White Efficacy (lm/W)	113	134	173	215	243
Cool White Price ($/klm)	25	13	6	2	1
Warm White Efficacy (lm/W)	70	88 65%	128 75%	184 85%	234
Warm White Price ($/klm)	36	25	11	3.3	1.1

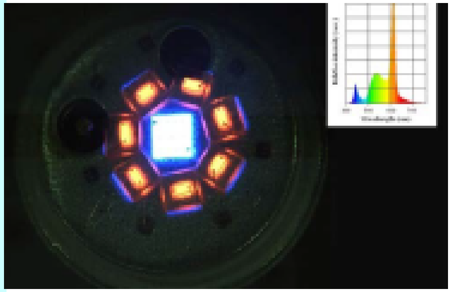
Source: B.J. Lee, DOE Mfg Workshop 2011

Record Demonstration of WW LED by Epistar

- 216 lm/W at 2700K and CRI of 87 using OW plus HV red
  - Chip size, operation temperature and color coordinates unknown

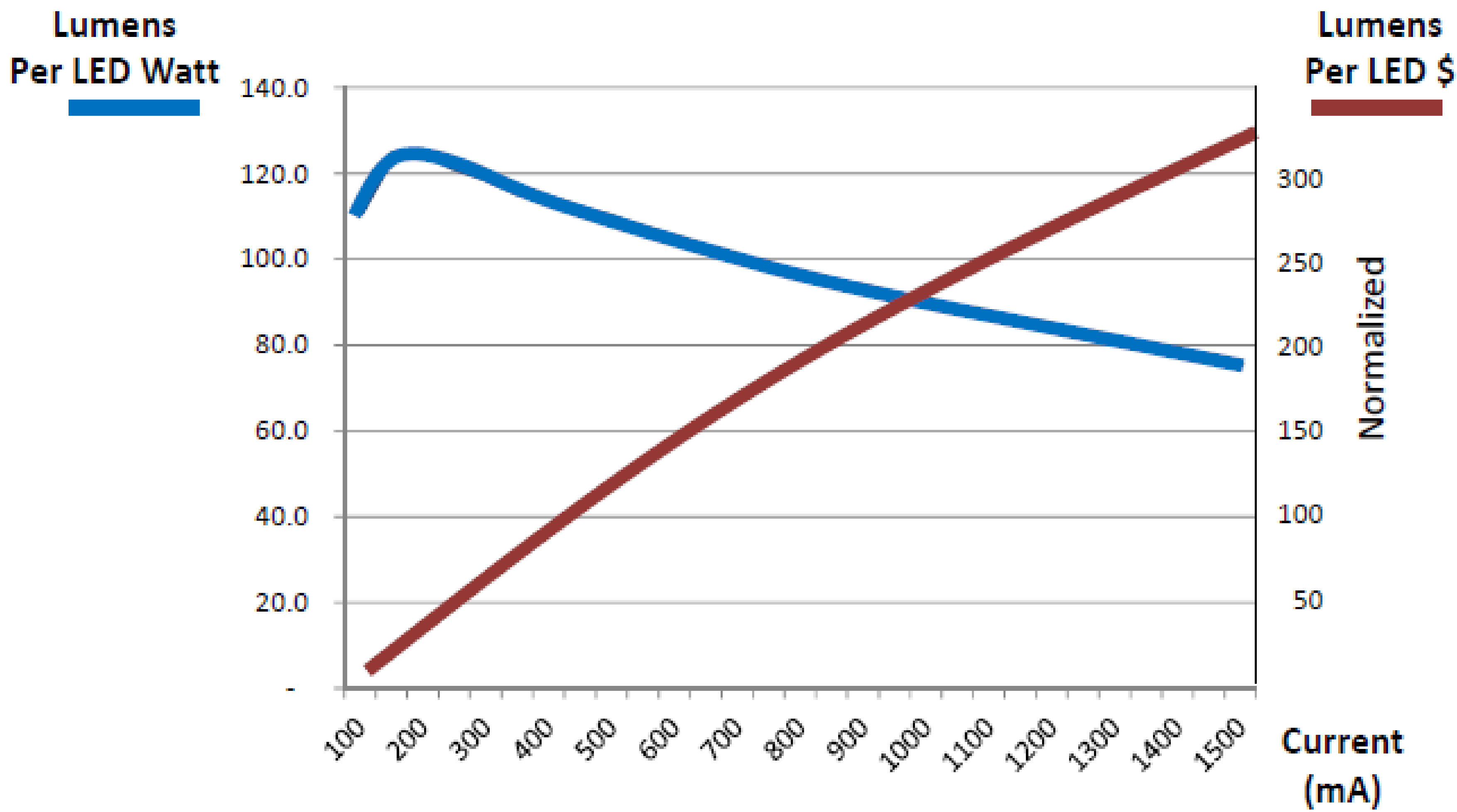


(Source: Epistar website 12/2011)



(Photo from 12/2010 Epistar report of 170 lm/W 2700K record)

Efficacy vs Drive Current



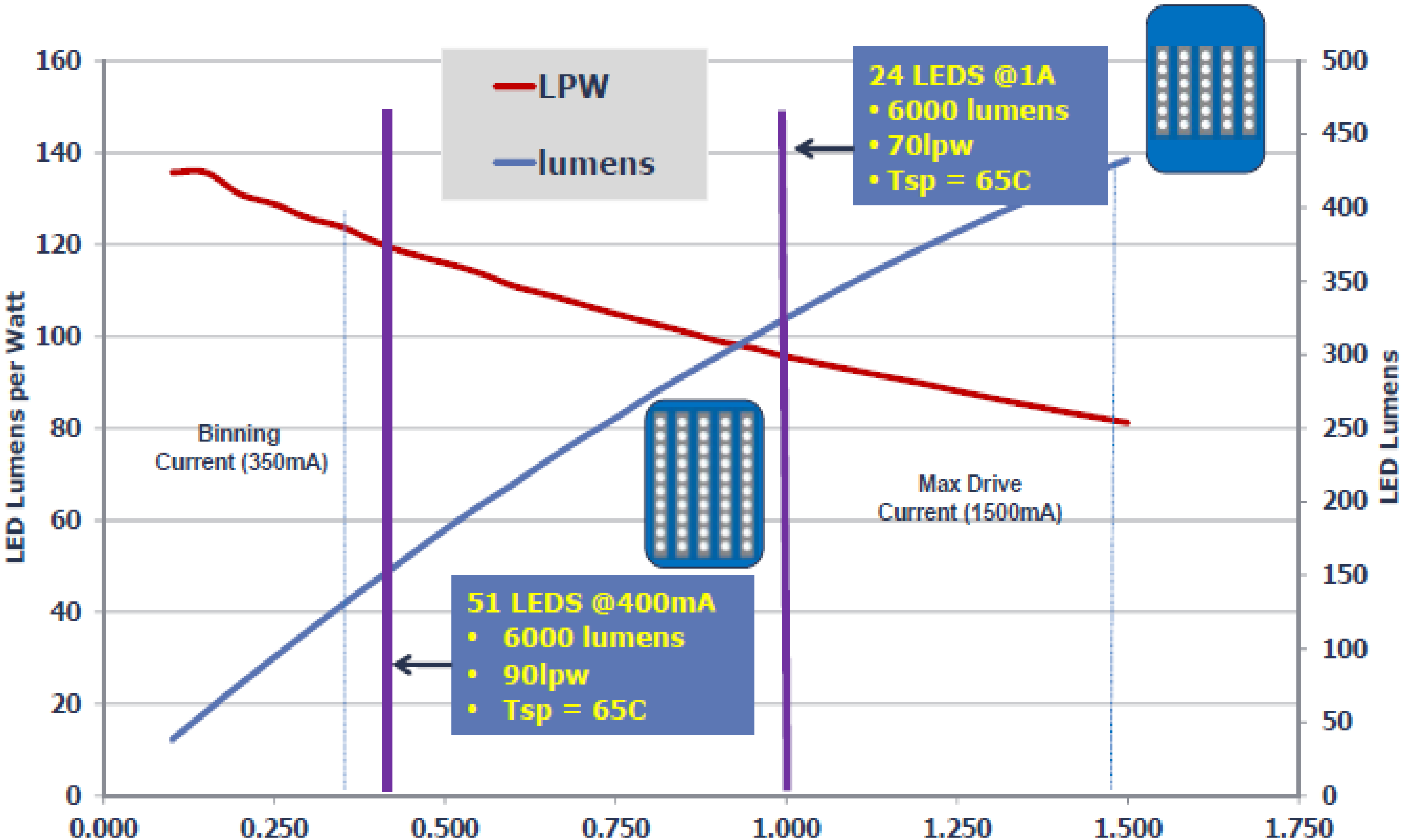
LEDs Bringing Lighting to Life
October 24-26, 2011
San Diego, CA, USA

INVENTRONICS

Source: Marshall Miles, Intertech-Pira LEDs 2011

System Level Example – Lowering Cost

Assumptions: 6000lumens, Tsp=65C, Electrical 90%, Optical 90% efficiency

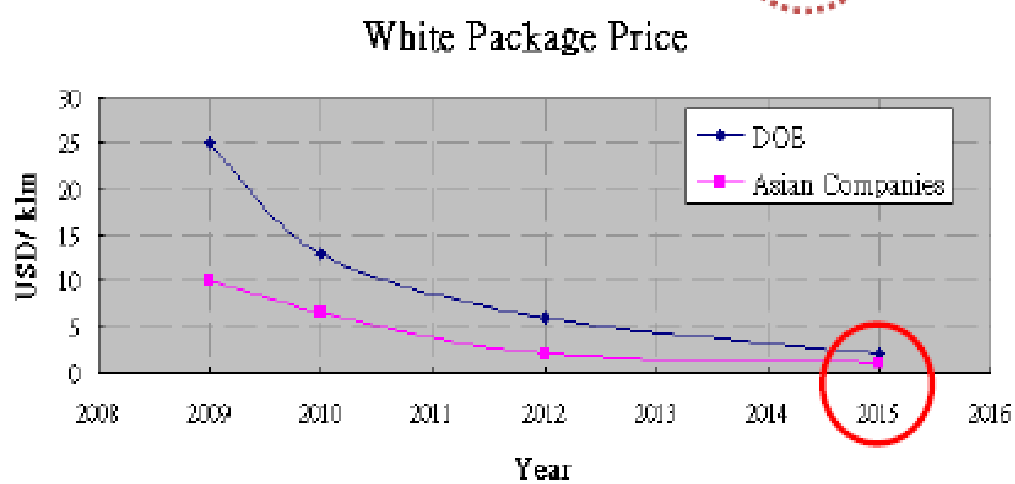


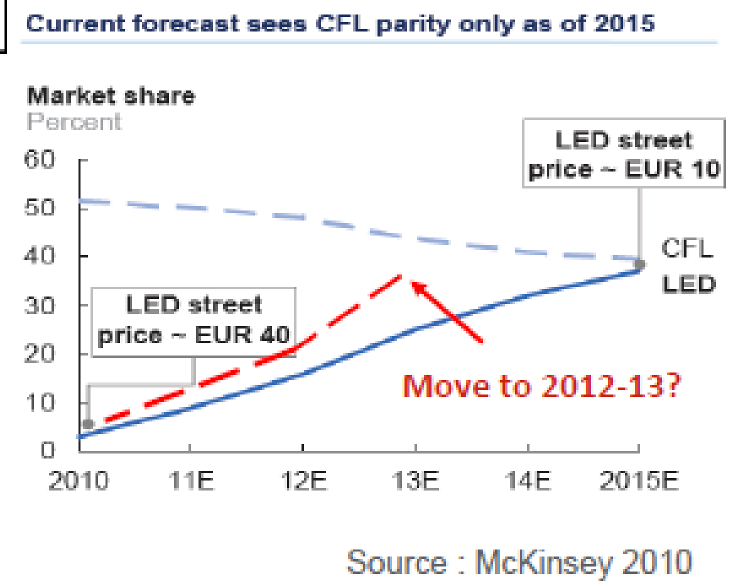
Source: Paul Thieken, Intertech-Pira LEDs 2011

Can we reach 500 lm/$ Package @ 2012….2013

- Asian companies learn from LED TV offers good lm/$ LED packages
- Collaboration between performance leader and cost leader make it happen

USD / klm	2009	2010	2012	2015
DOE	25	13	6	2
Asian Companies	10	6.6	2	1





1,000 lm/$ @ 2015

Source: B.J. Lee, DOE Mfg Workshop 2011

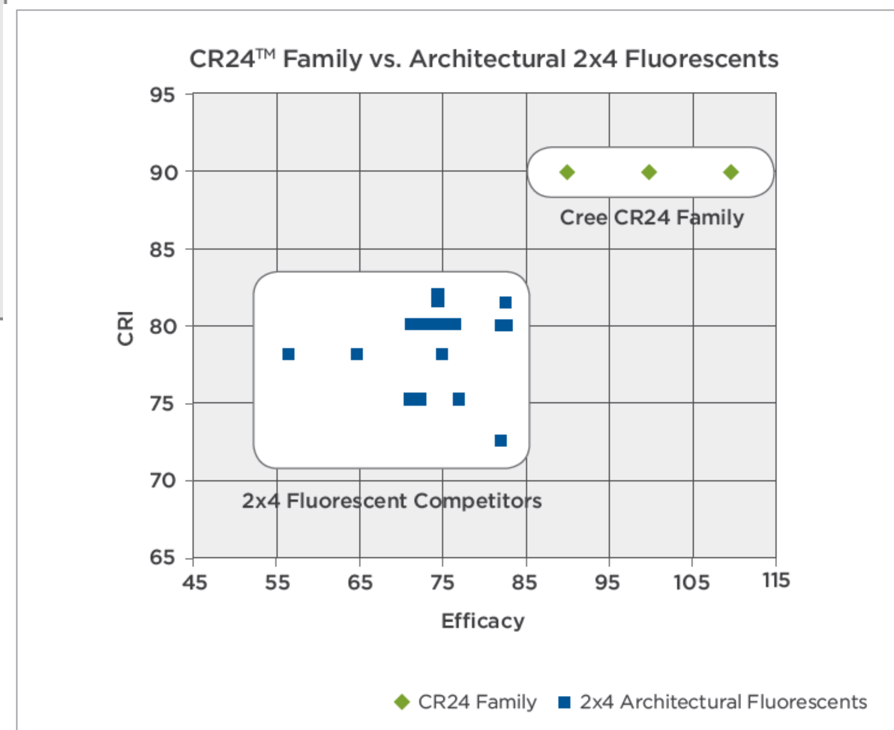
LED Status in 2011!

Cree CR24™ Troffer

Product Series & Size	Lumen Output	Color Temperature
CR24 2'x4'	**22L** 22W 2200 Lumen - 100 LPW **40L** 44W 4000 Lumen - 90 LPW **40L HE** 36W 4000 Lumen - 110 LPW **50L** 50W 5000 Lumen - 100 LPW	**35K** 3500 Kelvin **40K** 4000 Kelvin

50,000 hour lifetime

5-year warranty



Price: $200-300
CR24-40L35K

Bardsley Consulting

Source: Cree web pages

Next steps

Metric	Proposed LED luminaire (2012)	Results so far
LED efficacy (lm/W, 25°C)	114	171
Resultant luminaire efficiency	80%	76 %
Resultant warm white luminaire efficacy (lm/W)	92	130

- The core technology developed will be incorporated into a family of products

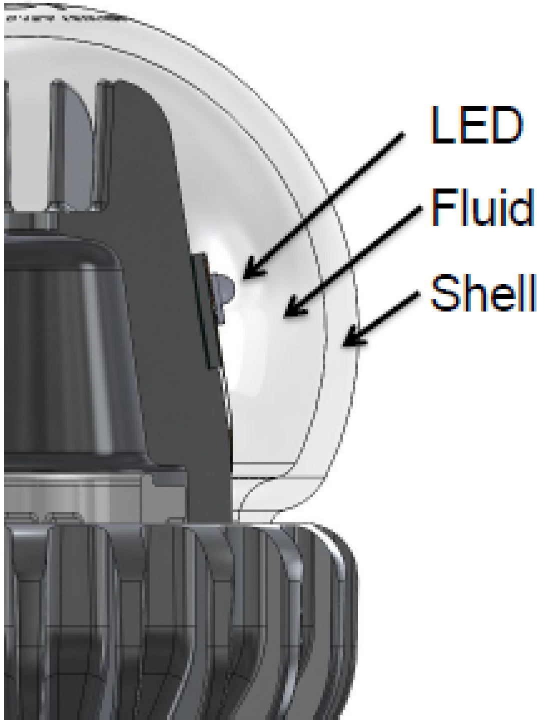
- First product in a family of luminaires scheduled for launch Q2 2012
- Line of products:
    - ECO version (white LEDs solution)
    - Color mixing family of products:
        - 3 lumen output levels (3200, 3500 and 4000)
        - 3 color temperatures (3000K - 4000K range)

Source: Camil-Daniel Ghiu

Switch Fluid Increases Optical Efficiency

Optical Losses are reduced in the Switch lamp due to the fluids ability to index match to the LED and shell material.

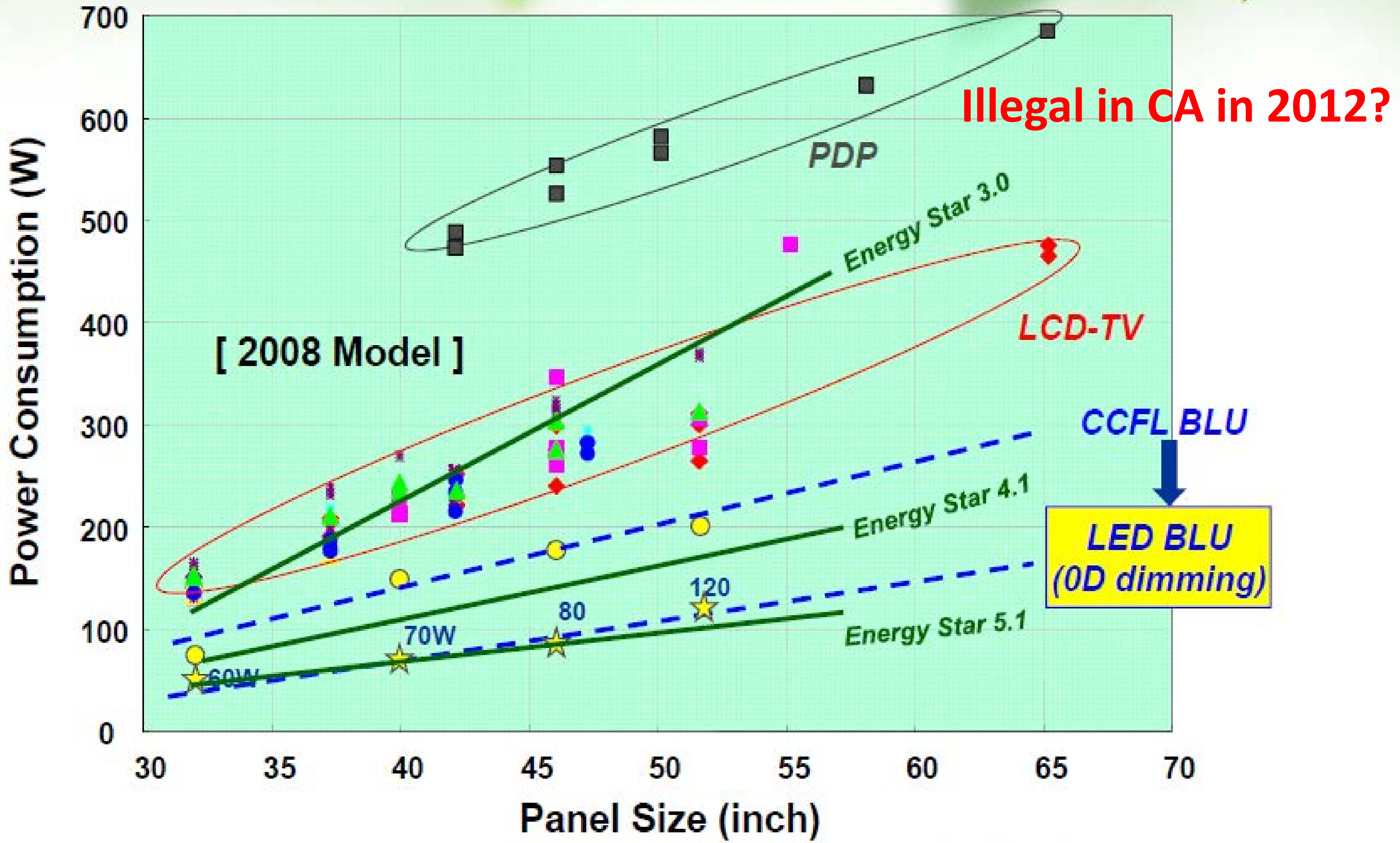
- Switch LED's in fluid dome optical losses ~ 3%
  - LED to fluid interface, ~.1%
  - Fluid to dome interface, ~.1%
  - Dome to air interface, ~3%
- LED in air dome optical losses ~ 8-9%
  - LED to air interface, ~3%
  - Air to dome interface, ~3%
  - Dome to air interface, ~3%



Switch lamp has >5% better in optical efficiency than air lamp geometries.

Source: David Horn, Intertech-Pira LEDs 2011

Power Consumption Comparison

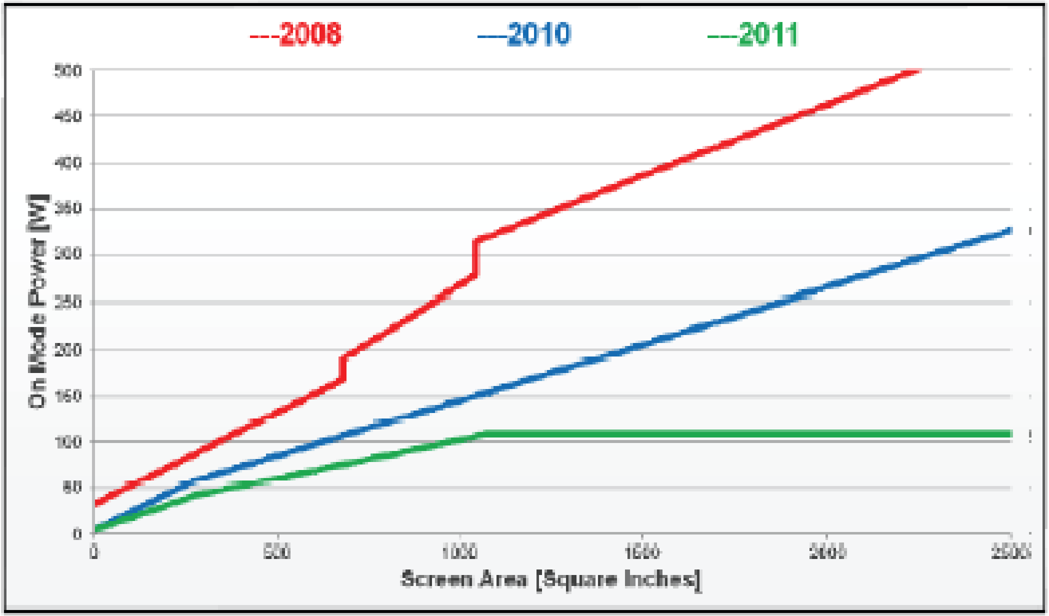


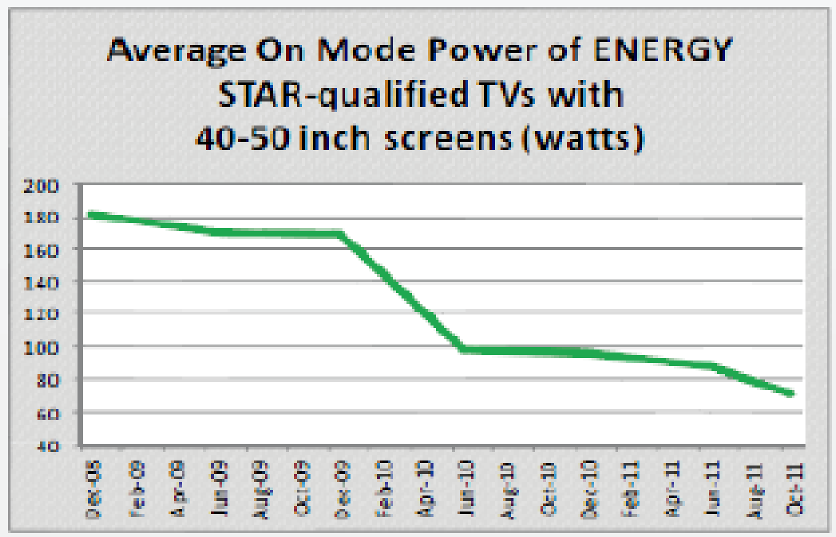
Source: Jun Souk (Samsung MD, 2011)

Overview:

Recognizing Gains in Energy Efficiency

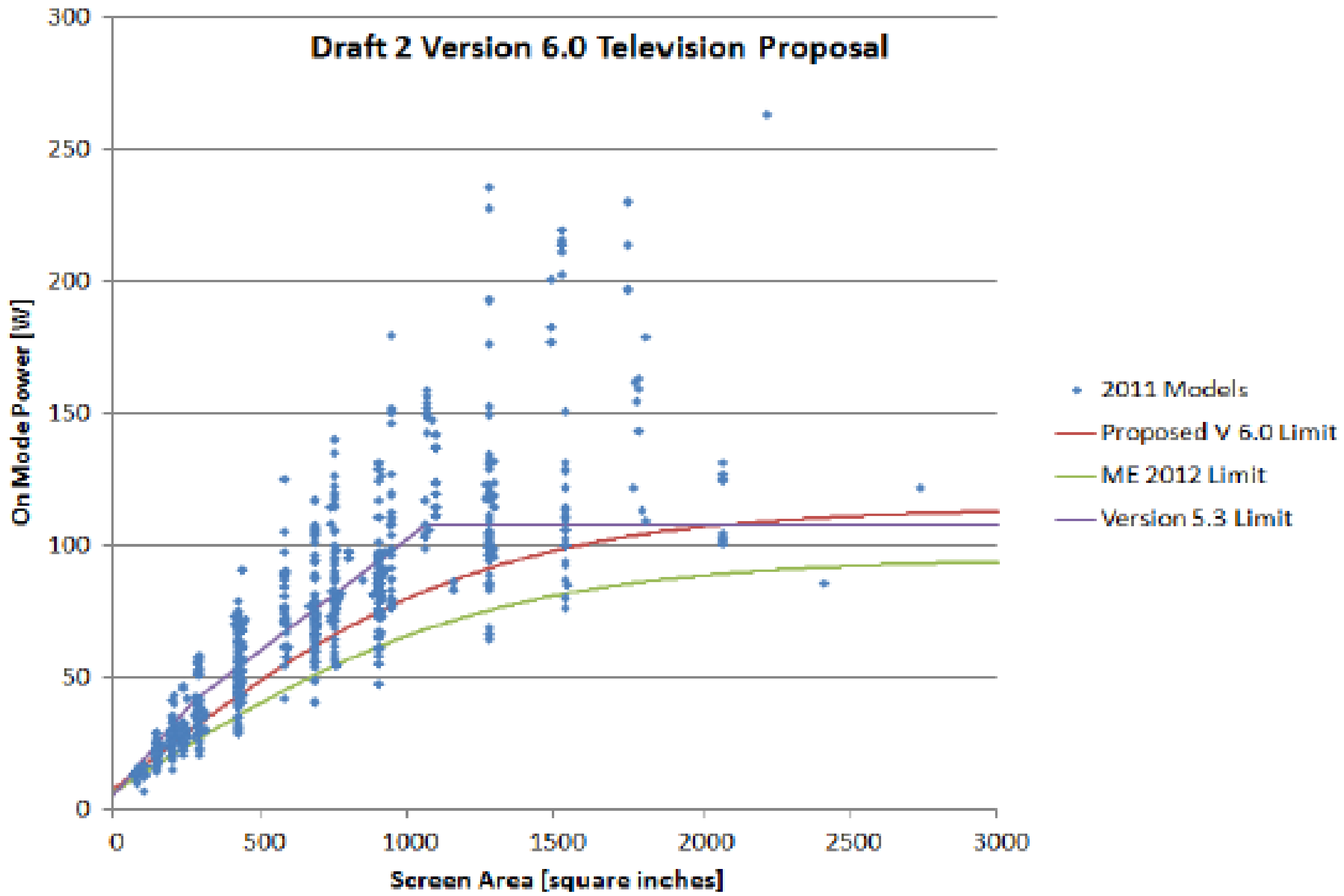
ENERGY STAR TV Specification
Comparison of On Mode Power limits





EPA

On Mode Power:
Proposed Draft 2 Limits

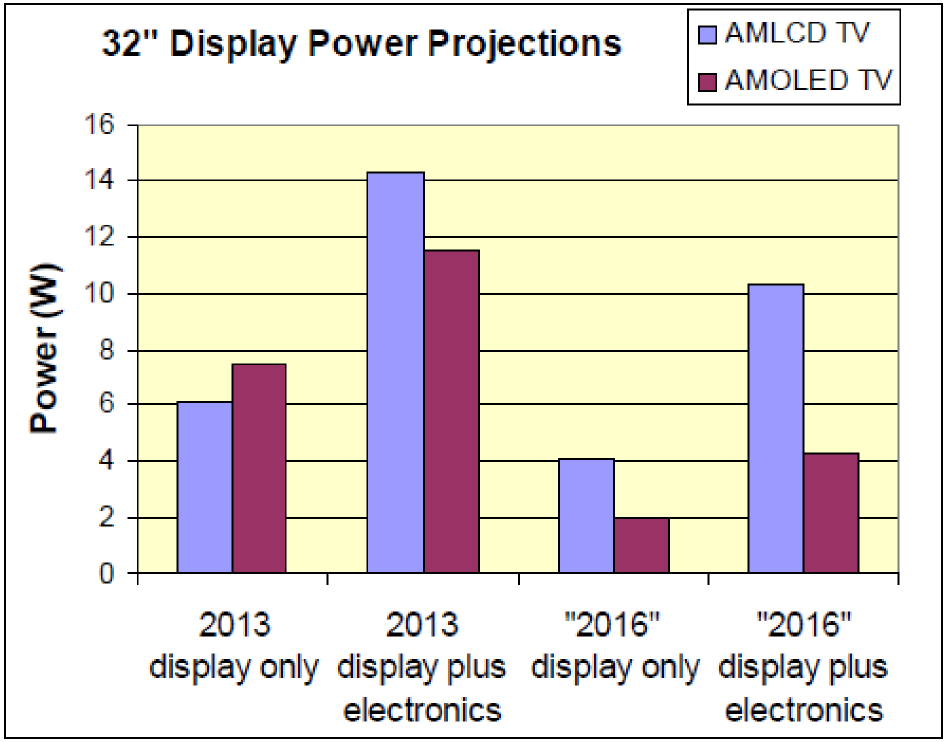


Equation for Proposed V6.0: $P = 100 * \tanh(0.00085*(A - 140) + 0.052) + 14.1$

Power Projections for 32" TVs

AMLCD	AMOLED
LED source = 175 lm/W	OLED white efficiency = 120 lm/W
Sub-pixel fill factor: 70% TVs, 60% mobile display	Voltage losses in backplane 50% of OLED assuming 2 stage stacked architecture
Polarizer efficiency = 50%	60% efficient color filters for high contrast
Savings from backlight dimming: 50% for TVs, 30% for mobile displays	10% IR losses in backplane

Brightness: 450 cd/m² for LCD
360 cd/m² for OLED



Consumption of best LCD-TV in 2011 was 29 W at 188 cd/m²

Source: Mike Hack (UDC), SID 2011

Bardsley Consulting

Outline

- Large Area Lighting Sources
  - Thin, flexible, transparent
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  - OLED challenges
- Efficacy gains – Application enabler
- **Digital Controls**
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  - Market pull
  - Implementation issues
- Broadband Communications
- Evolving lifestyles
  - Age gap
  - Flat panel displays and off-desk memory

Bardsley Consulting

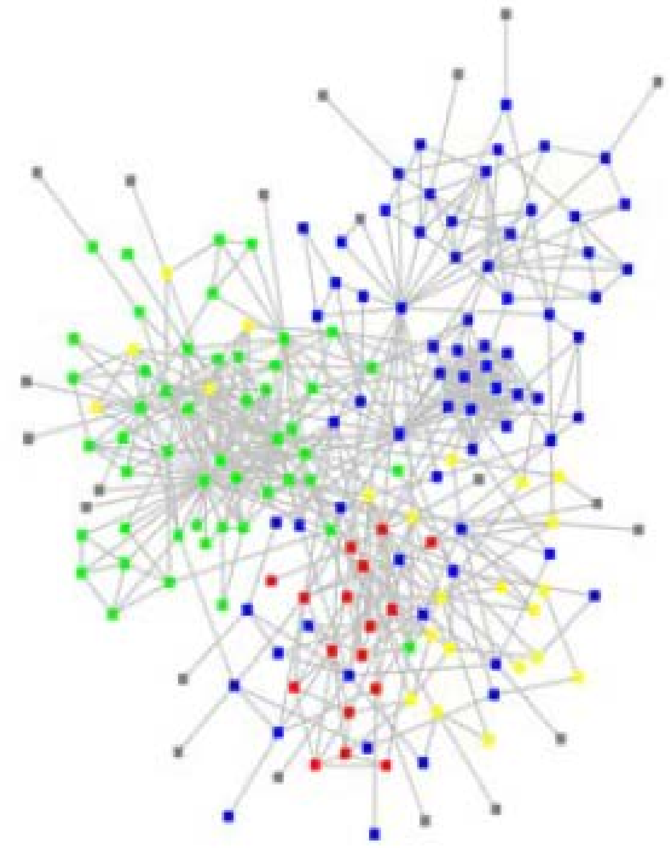
Intelligent Lighting

Example: Home Lighting System

#2 – Create a network

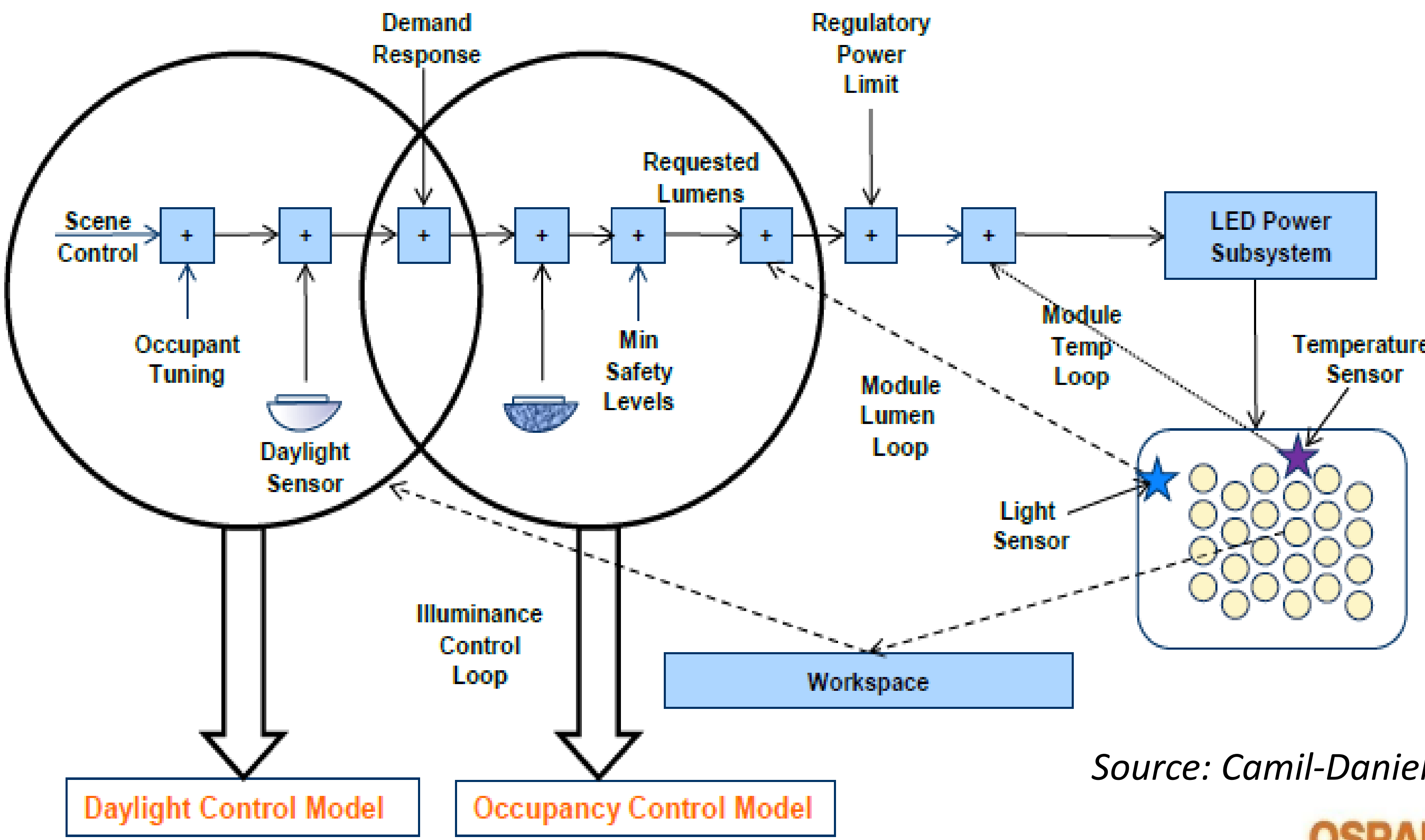
- Scalability
- Interference
- Latency
- Security
- Configuration

Source: Eric Holland,
Lighting Science Group,
Intertech-Pira LEDs 2011



Project results (controls)

- Daylight harvesting and Occupancy control models created and simulated
- Commissioning of the system has been completed in a R&D Laboratory area



Source: Camil-Daniel Ghiu

Sensor Networks from Lighting Science Group

Sensors

Passive Infrared/Ultrasonic

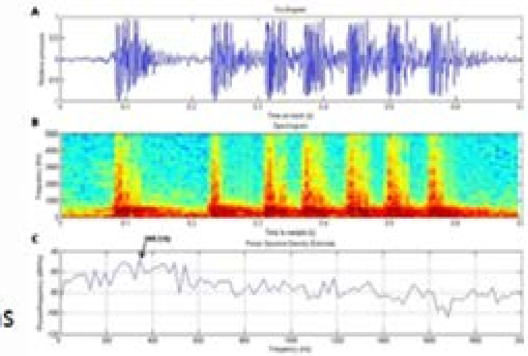
- Inexpensive
- Limited range – 15-25 meters
- Sensitive to environment – temperature/airflow

With more complex applications, probability of detection, probability of false detection start to play a significant role.

Sensors

Acoustic

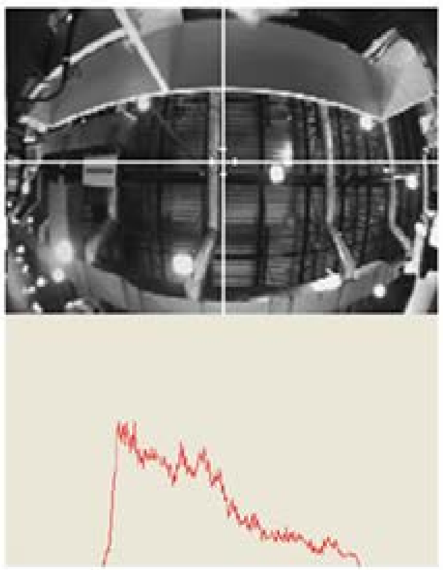
- Inexpensive
- Long range (cars)– 300+ meters
- Requires data/testing
- Direction of travel possible
- Careful tuning to avoid false alarms



Sensors

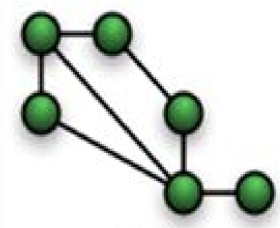
Imagers

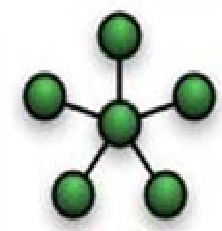
- 3x cost of other options
- Controllable range
- Allows target classification
- Less environmental variability



Communication

- Topology – mesh/star
- Stability
- Latency
- Spectrum – 915MHz/2.4GHz
- **Security** – AES is only a cipher





Source: Eric Holland, Lighting Science Group, Intertech-Pira LEDs 2011

Bardsley Consulting

But what has Google done since May 11, 2011?

Sensor Networking

Making Buildings More Intelligent

Source: Brian Chemel,
Intertech-Pira LEDs 2011

DIGITAL
LUMENS

Intelligent Retail Lighting

Cooperative Occupancy Sensing

Corporate Lighting Dashboard

Automatic Maintenance Alerts

Shopper Activity Tracking

Source: Brian Chemel, Intertech-Pira LEDs 2011

DIGITAL LUMENS

Intelligent Office Lighting

Per-Fixture Occupancy & Daylight Harvesting

Flexible Scheduling

Personal Lighting Profiles

Source: Brian Chemel, Intertech-Pira LEDs 2011

DIGITAL LUMENS

Next-Generation Controls

New Standards Emerging

1st Generation: Wired Controls

2nd Generation: Wireless Controls

3rd Generation: Distributed Controls

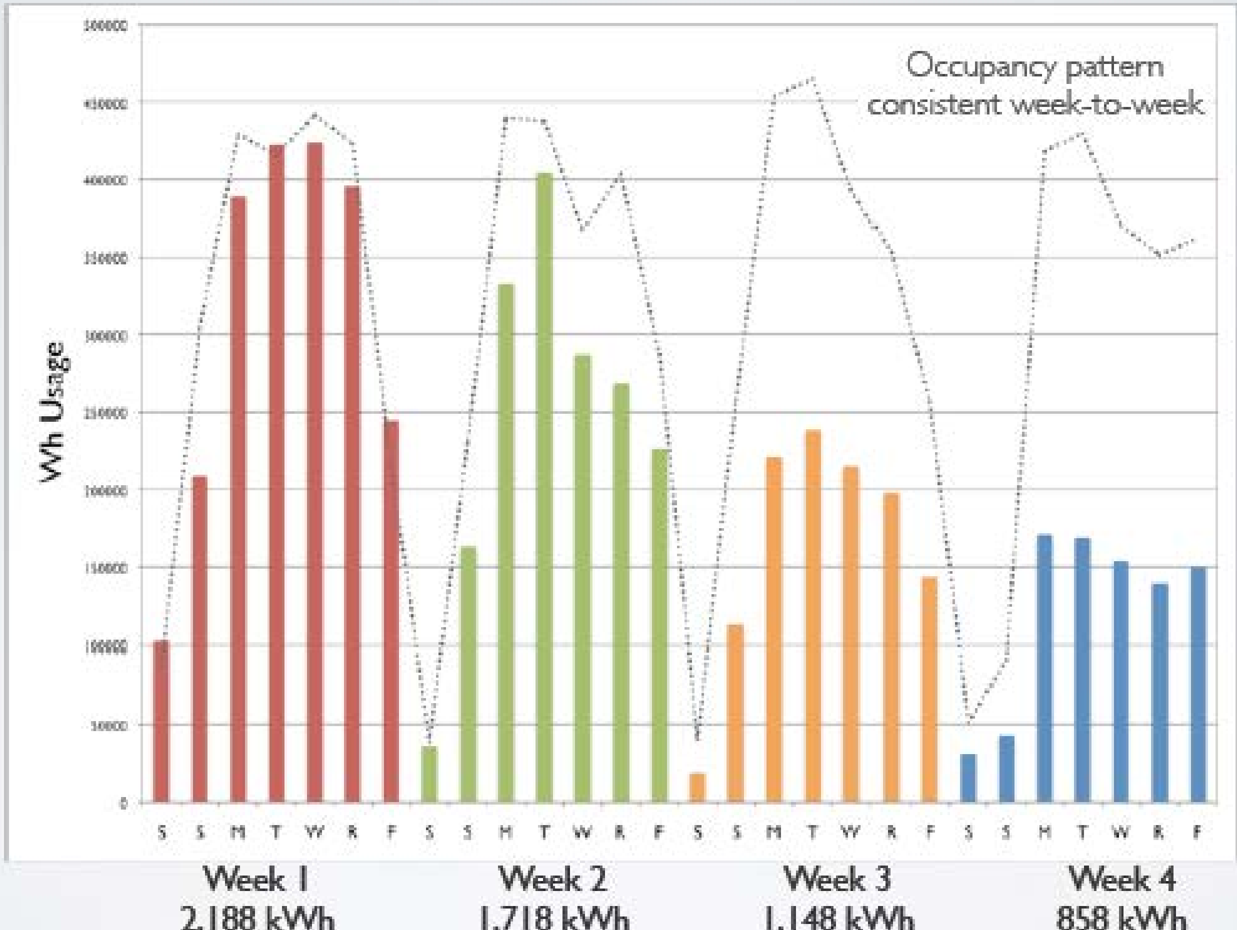
Decision-making moves from a centralized controller to **individual intelligent luminaires**, bringing:

- Sophisticated control behaviors
- Robust fault tolerance
- Centralized configuration and management

Source: Brian Chemel, Intertech-Pira LEDs 2011

DIGITAL LUMENS

Data-Driven Optimization



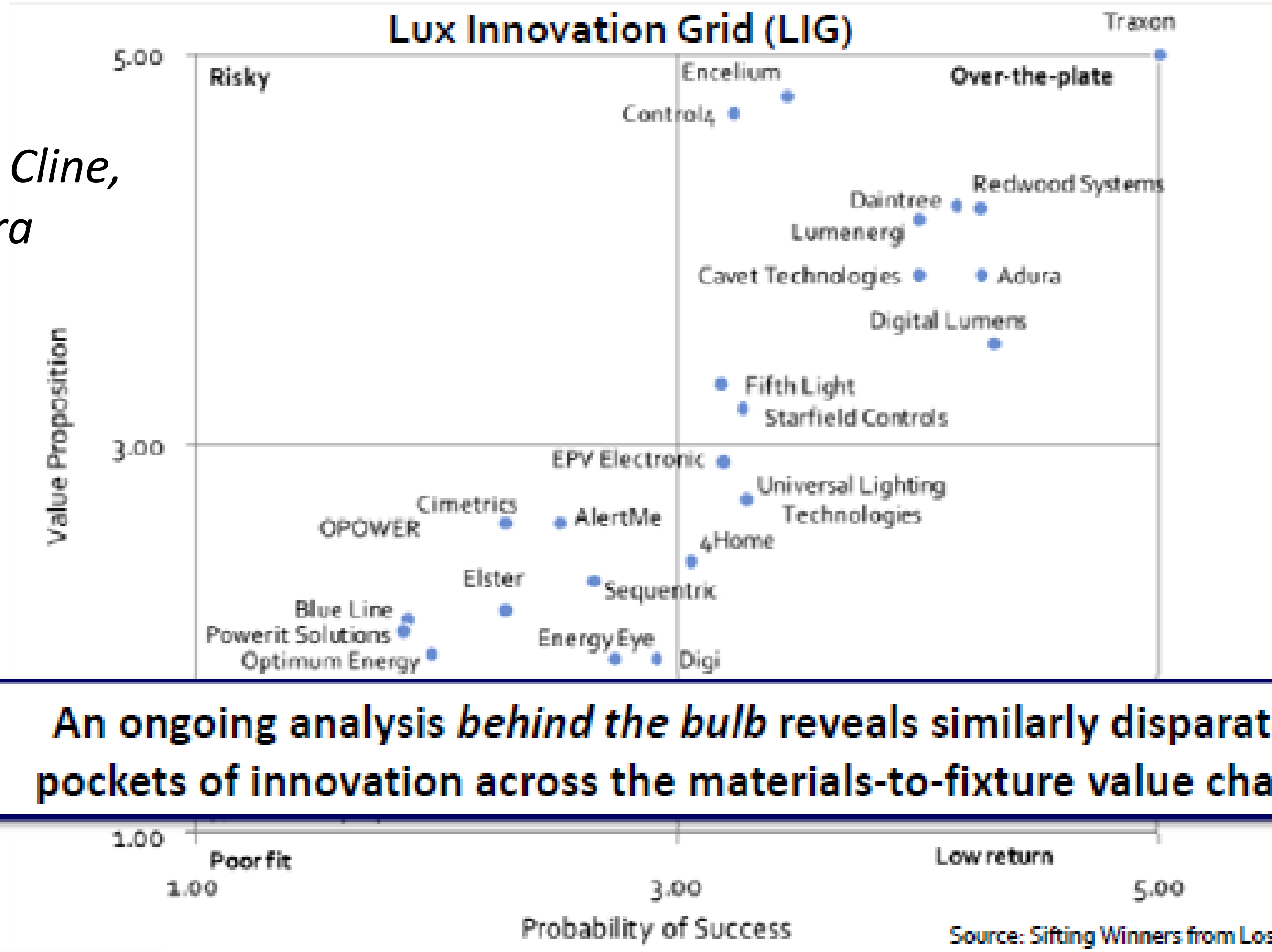
Source: Brian Chemel, Intertech-Pira LEDs 2011

Automated Tuning

DIGITAL LUMENS

Innovation beyond the bulb is rising, but its not all created equal – just consider lighting controls

Source: Dan Cline, Intertech-Pira LEDs 2011



An ongoing analysis *behind the bulb* reveals similarly disparate pockets of innovation across the materials-to-fixture value chain

Source: Sifting Winners from Losers in the Building IT Acquisition Frenzy, Lux Research, December 2010

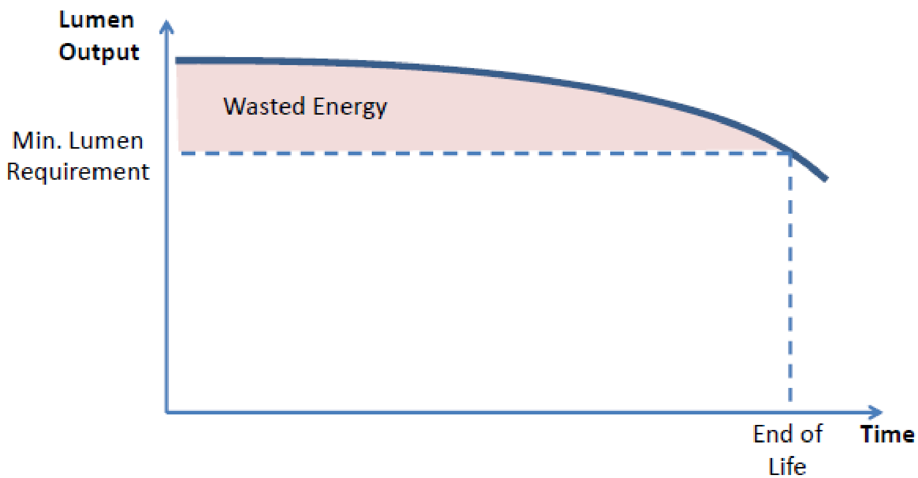
luxresearch

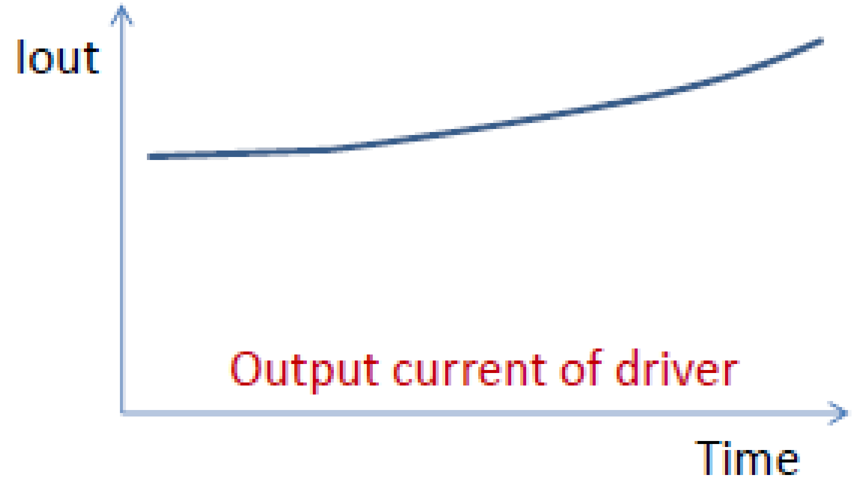
25

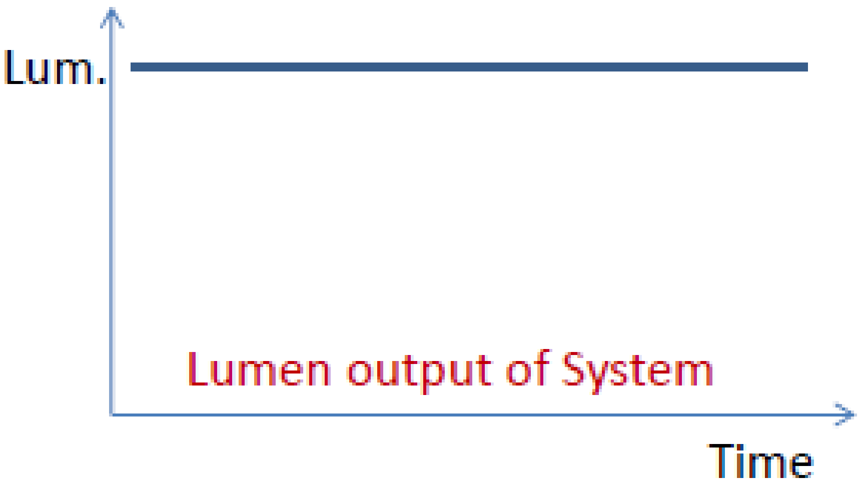
Only 7% of commercial building lighting is controlled

Enhanced Lumen Maintenance

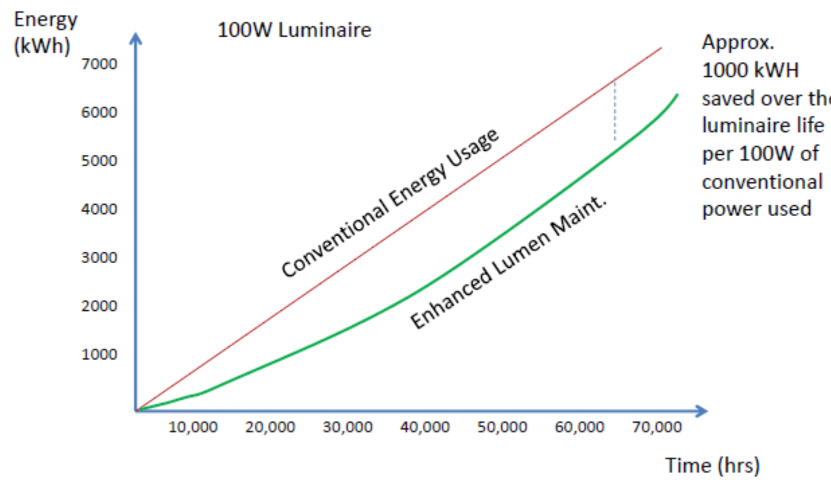
INVENTRONICS





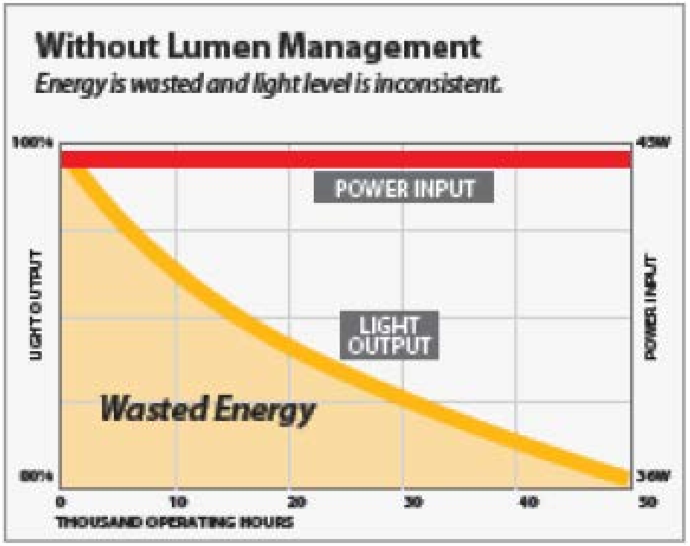


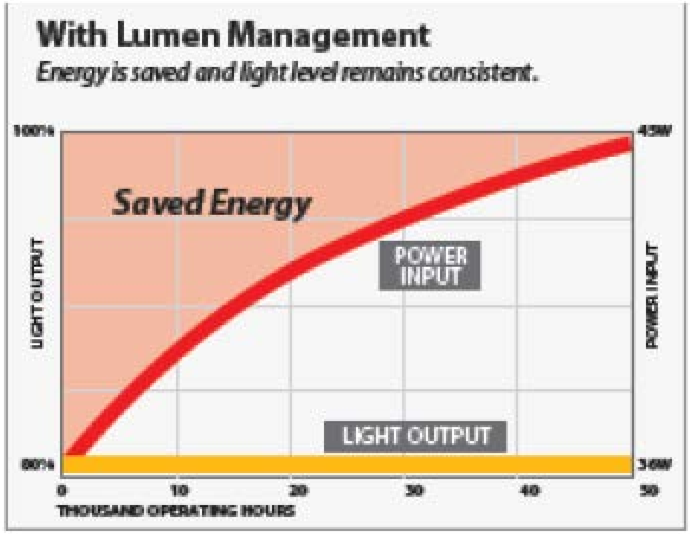
Lifetime Energy Savings



Bardsley Consulting

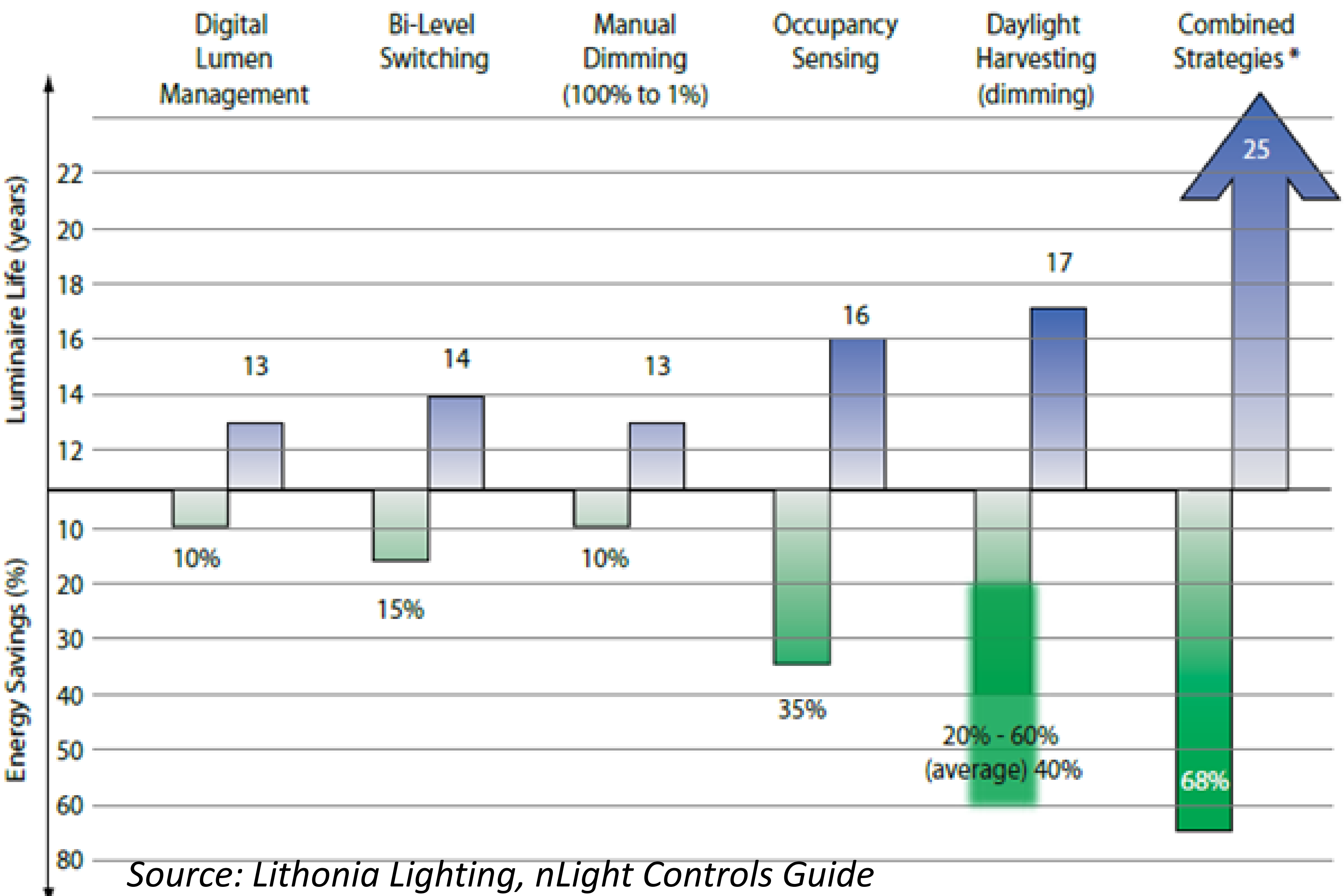
Source: Michael Miles, Inventronics, Intertech Pira LEDs 2011





Source: Bill Ballweg, Lithonia Lighting, Intertech-Pira LED Summit 2011

Extend Lifetime and Save Energy



Source: Lithonia Lighting, nLight Controls Guide

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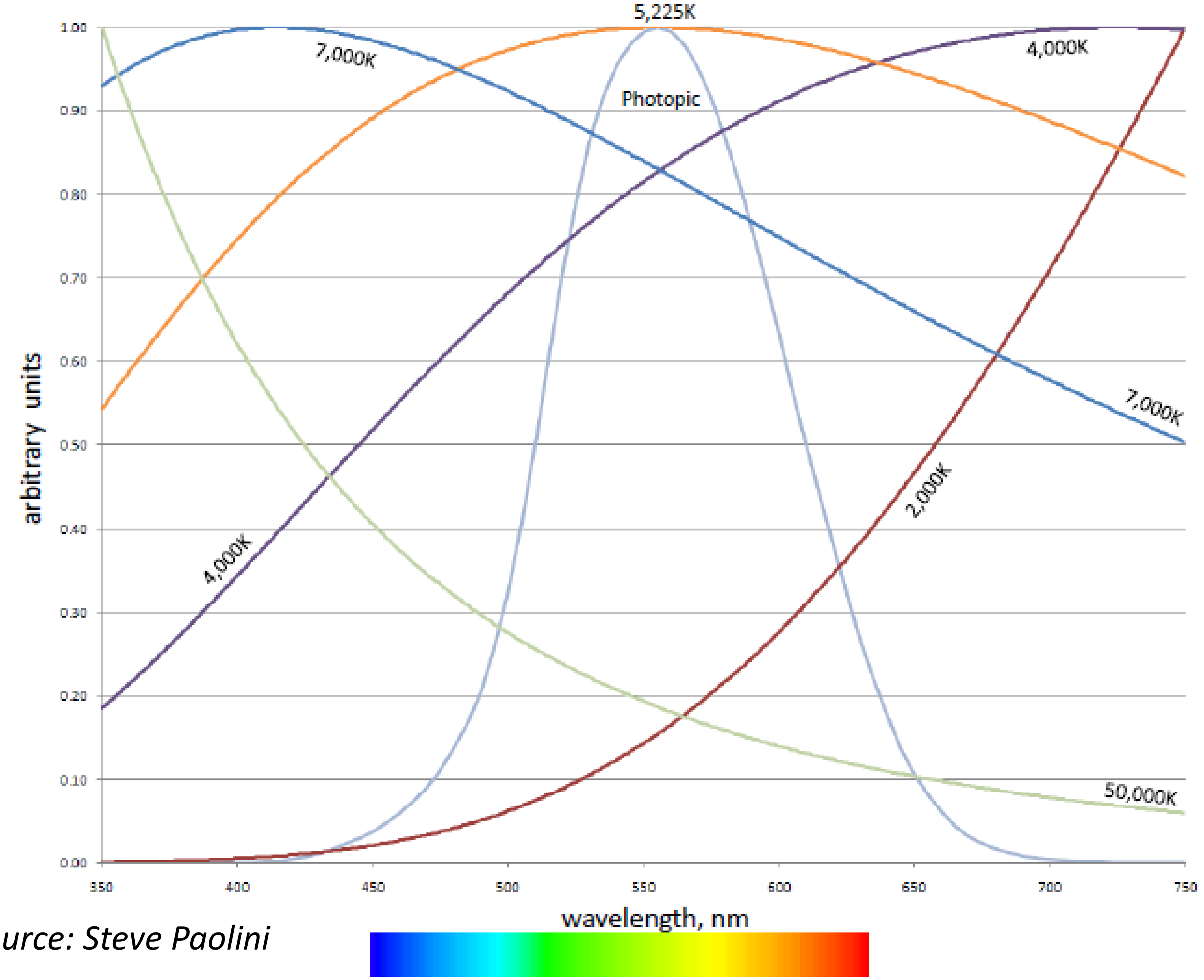
THERE IS MORE TO LIGHT THAN WHITE

Source: Steve Paolini, Lunera & Telelumen; DOE SSL Workshop 2012

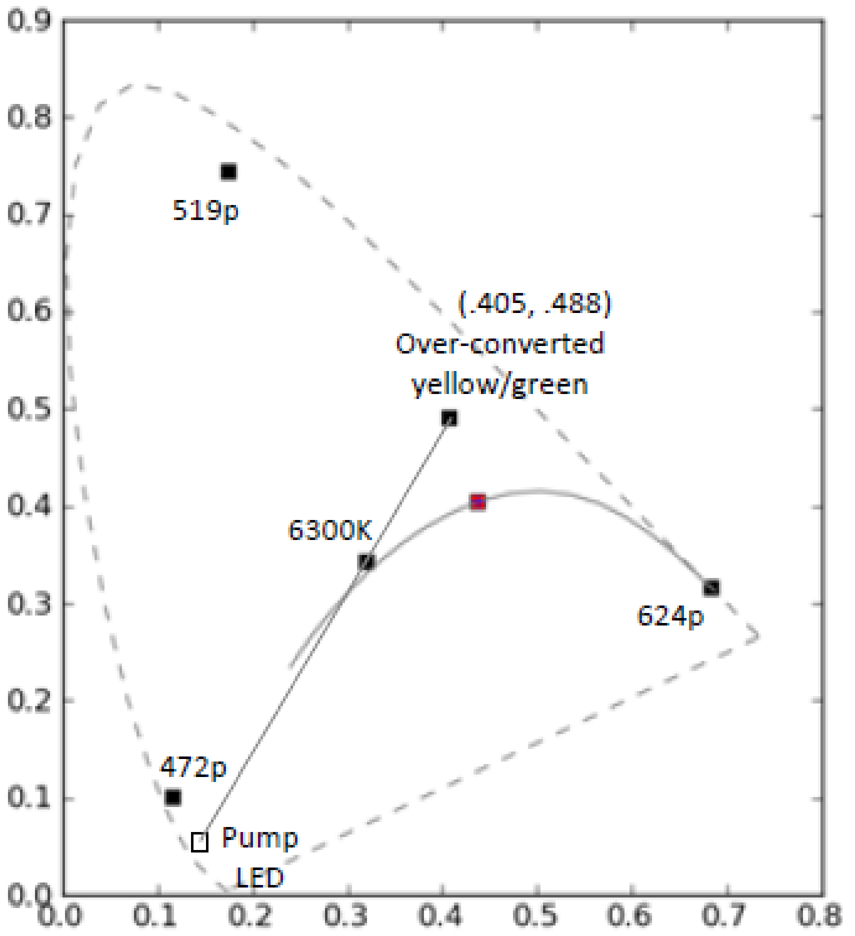
SPECTRAL POWER DISTRIBUTION – SPD

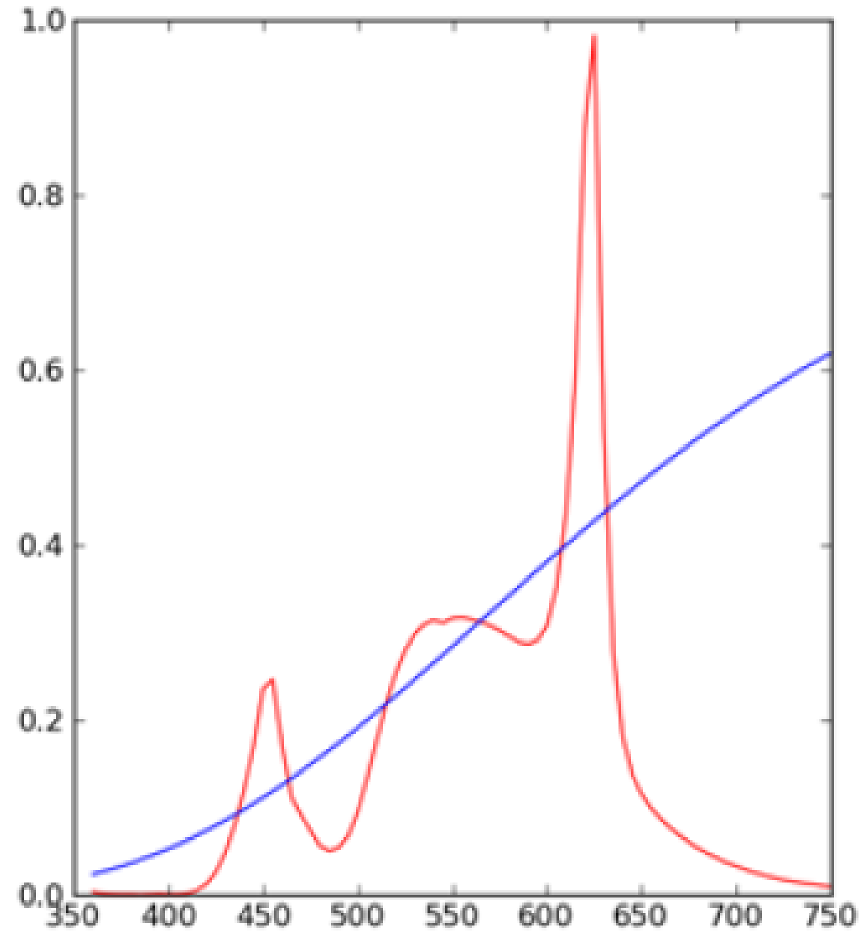


Source: Steve Paolini

3,000K, 144 lm/w (LED), 93 CRI

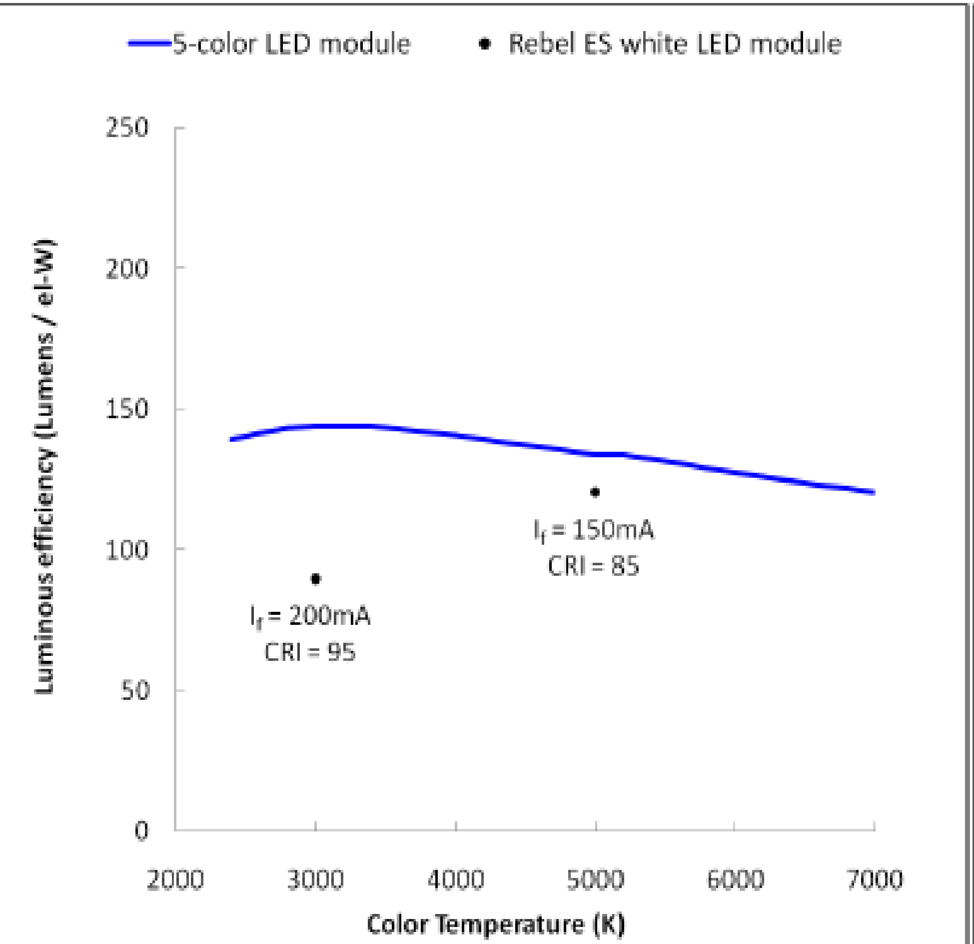
- LEDs are under-driven



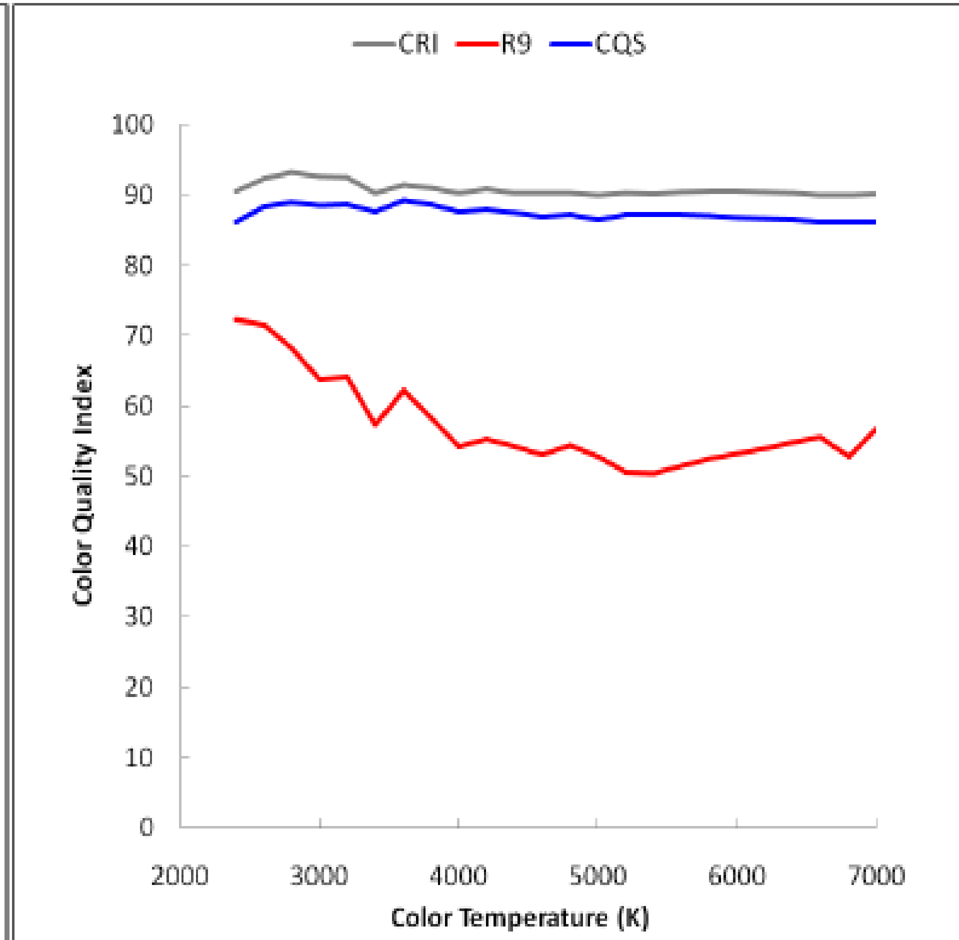


Source: Steve Paolini

LUMINOUS EFFICIENCY



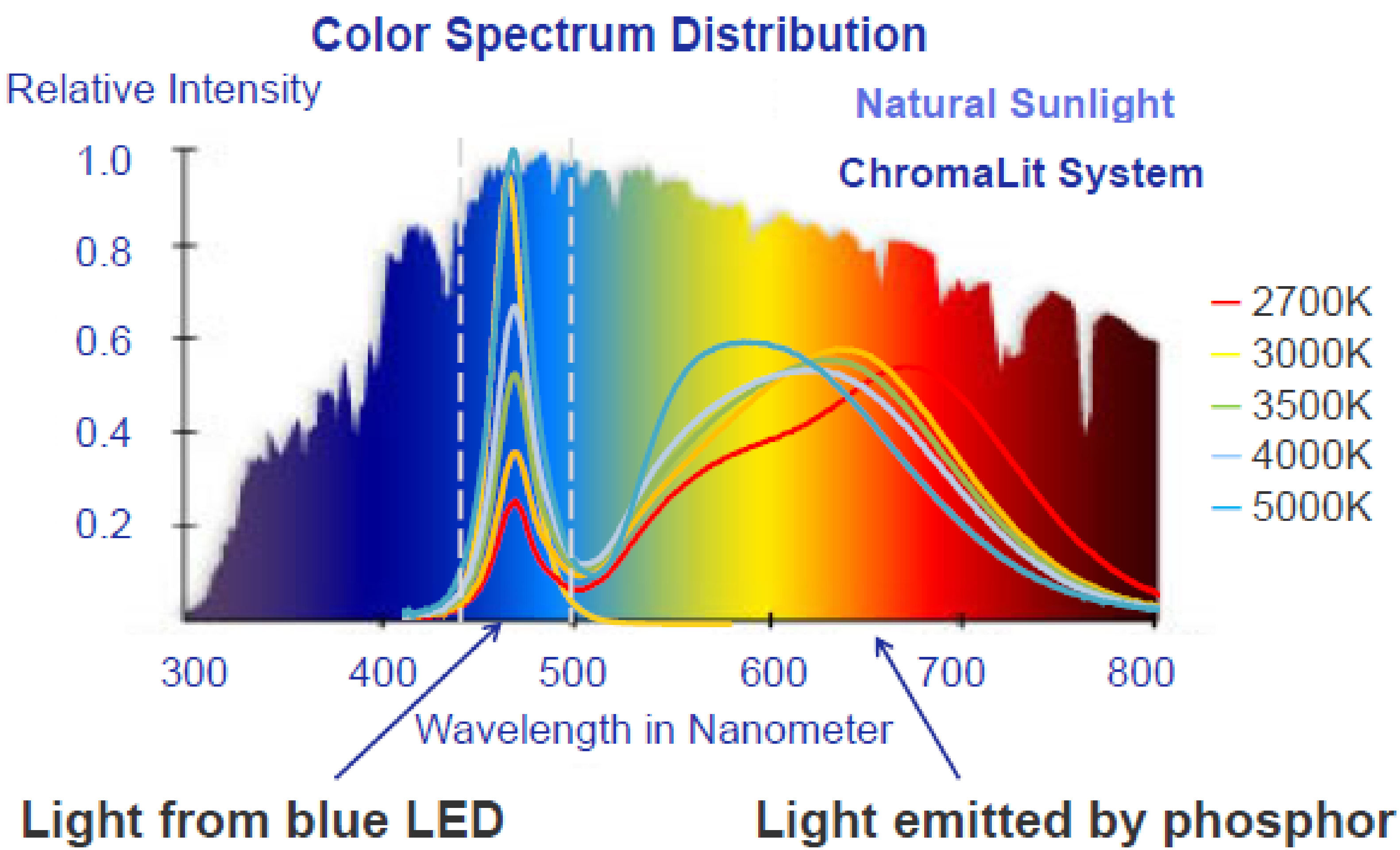
COLOR QUALITY



Source: Steve Paolini

Phosphors create quality white light

Phosphor emits up to 95% visible white light from LEDs



www.intematix.com

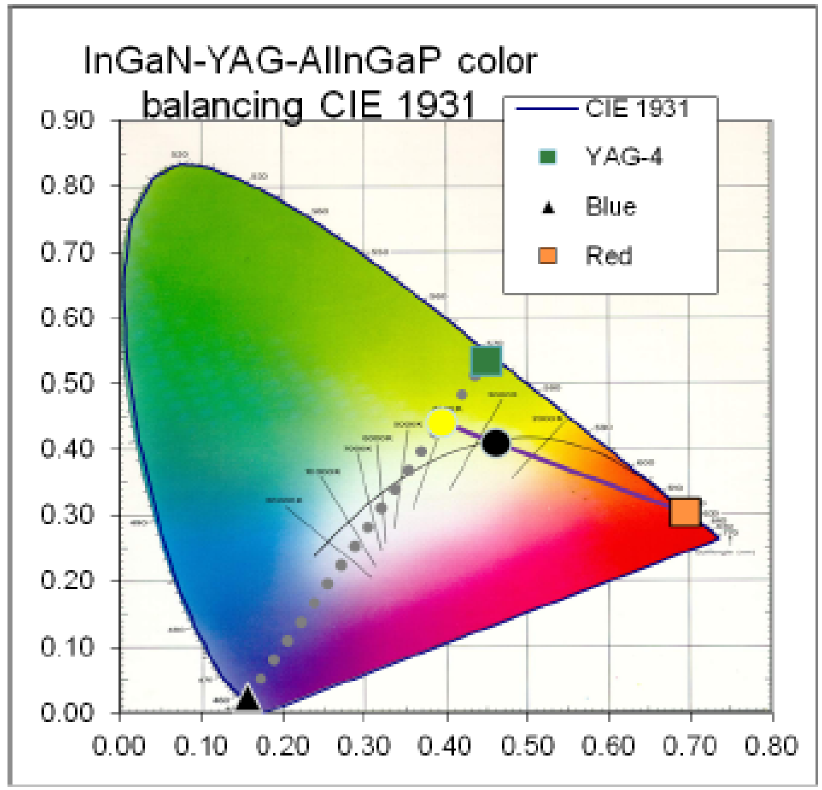
INTEMATIX

Source: Julian Carey, Intertech-Pira LEDs 2011)

Hybrid Warm White LEDs

- Approach
  - InGaN OW LEDs plus AlInGaP direct red LEDs

- Advantages
  - High efficacy
  - High CRI
  - High R9
  - CCT tuning



Source: Decai Sun,
DOE SSL R&D Workshop 2012

Efficient Green LED Sources

Perhaps we do need OLEDs after all

Fraunhofer Institute, LEiDs GmbH ceiling tiles

– RGB and white LEDs simulate sky with moving clouds

he dynamic luminous ceiling gives office staff the pleasant feeling that they are working under the open sky. © Fraunhofer IAO

http://www.fraunhofer.de/en/press/research-news/2012/january/sky-light-sky-bright.html

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Visible Light Communication

Data has been transferred at up to 800Mb/s by modulation of RGB LED light at the Fraunhofer Heinrich Hertz Institut in Berlin.

This could be useful in locations where radio signals are not allowed, e.g. aircraft cabins and hospitals

http://www.hhi.fraunhofer.de/en/project-of-the-month/visible-light-communication/

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The Age Factor

ANSI Office Lighting Standards assume that 50-year old readers require twice the illuminance needed by 20-year olds.

So what about me…

….. and her

Source: Eric Holland,
Lighting Science Group,
Intertech-Pira LEDs 2011

Bardsley Consulting

How Much Desk Space Needs To Be Lit?

and what kind of display will we be using?

Bardsley Consulting

The Lighting Revolution….

- **Daylight, energy, lighting and solar control from one element? SMART GLASS OF THE FUTURE?**

\+

\+

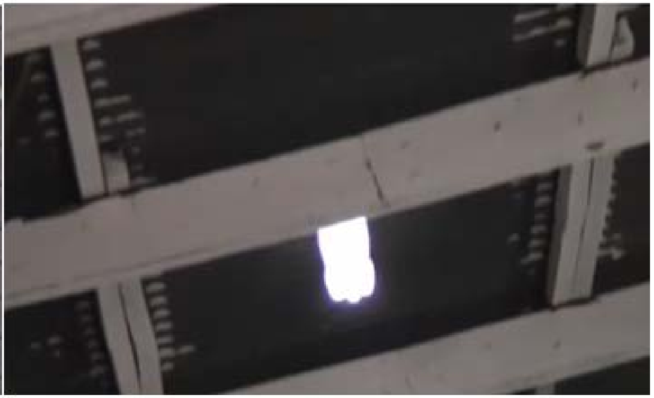
Transparent PV	Switchable glazing	Transparent OLED
POWER GENERATION	VARIABLE DAYLIGHT & SOLAR CONTROL	SUPPLEMENTARY ELECTRIC LIGHT

Source: Arfon Davies: OLED Lighting Design, London, June 2011

ARUP

Daylight Harvesting – Solar Bottle Bulb

Isang Litrong Liwanag



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60W replacement bulb designed at MIT…

http://isanglitrongliwanag.org/

Further Information

http://www1.eere.energy.gov/buildings/ssl/

This DOE web site has a wealth of information including most of the presentations at its meetings and many technical reports. The two technology roadmaps are at:

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2011_web.pdf

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_manuf-roadmap_july2011.pdf

I also recommend a European study published by the IEA Annex 45

http://www.ecbcs.org/docs/ECBCS_Annex_45_Guidebook.pdf

A summary of this long document can be found at

http://lightinglab.fi/IEAAnnex45/guidebook/guidebook_summary_report.pdf

With thanks to

- Bill Ballweg, Lithonia
- Julian Carey, Intematix
- Brian Chemel, Digital Lumens
- Dan Cline, Lux Research
- Arfon Davies, ARUP
- Kieran Drain, Rambus
- Shawn Du, Nichia
- Eran Fine, Oree
- Camil-Daniel Ghiu, Osram-Sylvania
- Mike Hack, UDC
- Eric Holland, Lighting Science Group
- David Horn, Switch
- Robert Karlicek, RPI
- Jang-Joo Kim, Seoul Nat U
- John Langevin, Rambus
- B.J. Lee, Epistar
- Sebastian Ludwig, Trilux
- Marshall Miles, Inventronix
- Steve Paolini, Lunera
- Florian Pschenitzka, Cambrios
- Colleen Pastore, Philips Lightolier
- Tom Simpson, 3M
- Jun Souk, Samsung Mobile
- Decai Sun, Philips Lumileds
- Paul Thieken, Cree

….and to the patient audience

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