OLED Lighting Requirements and Application Efficiency

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Company Overview

- ***N.A. Market Share Leader***
- ***Most recognized brands in the lighting industry***

Mfg Facilities: 17

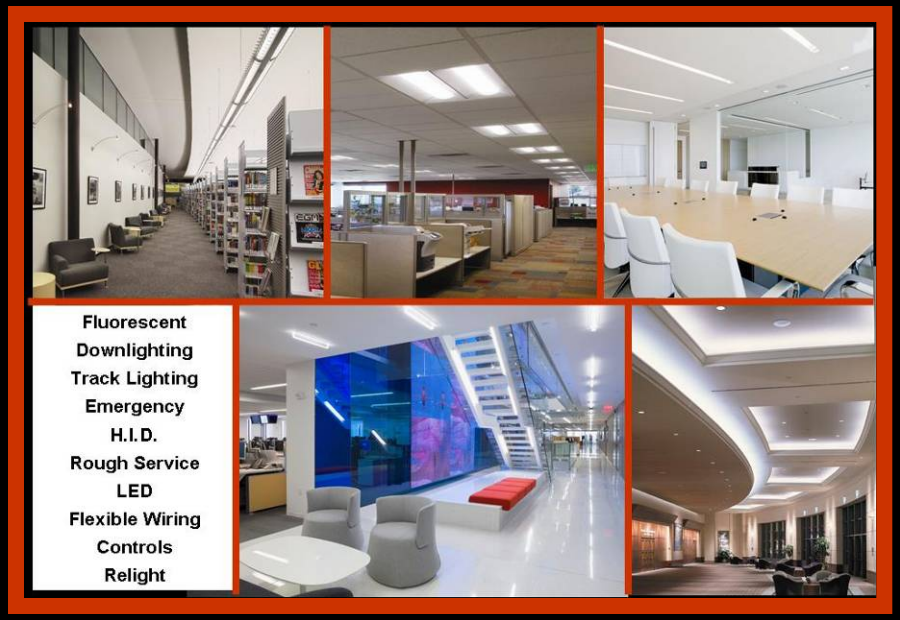
Sales Channels: 14

Customers: 5,000

Products: 500,000 Active Products
2,000 Product Groups

Associates: ~6,000

Indoor & Outdoor Lighting Products



Given the diffuse nature of OLED emission, it's best suited for indoor lighting.

ABL OLED Luminaires — Released 2010

Glimpse™

LightFacet

Unveiled at LightFair International, Las Vegas, May 2010

Current ABL OLED Product Roadmap

OLED Performance Specs

Updated

2012 - 2013

60-80 lm / W
6000 lm/m^2
(2000 cd/m^2)
LT 70: 15-25K Hrs

2014 - 2015

80-110 lm / W
6000-12000 lm/m^2
(2-4000 cd/m^2)
LT70: 30K- 40K Hrs

2016+

110 + lm / Watt
6000-12000 lm/m^2
(2-4000 cd/m^2)
LT85: 40K Hrs

Efficacy, Lumen Output (Luminance), Life, Cost Effectiveness

- Slight time lag between luminaire efficiency projections and product roadmap in order to allow for technology transfer to volume manufacturing.

Visual Effects of Different Types of Lighting

Direct Small Source

Down Light

Up Light

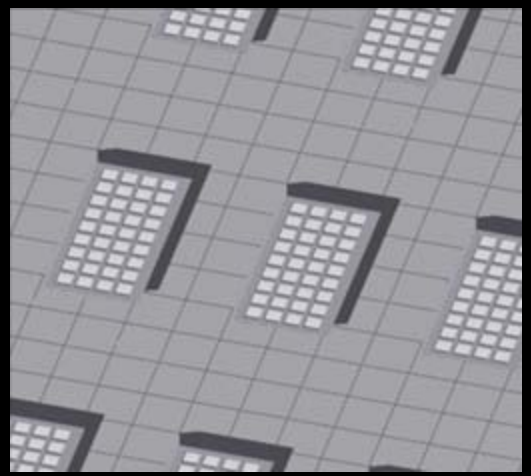
Side Light

Three Quarter Light

Diffused

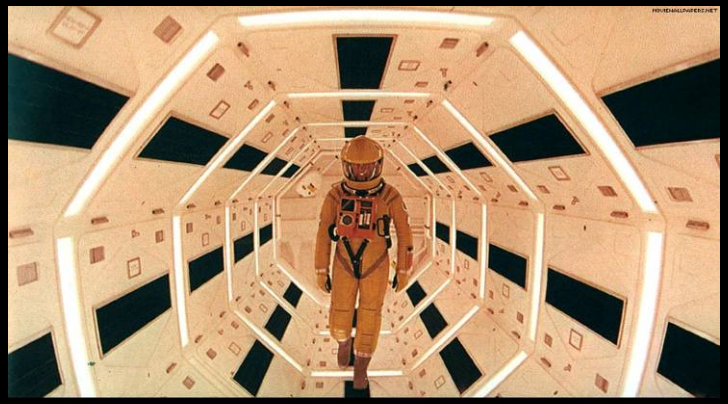
What Not to Do with OLED Lighting

A 2x2 or 2x4 flat panel for light troffer replacements?



Monolithic, sterile, uniform brightness?

OLED lighting design should not be sheets of OLED pasted on the ceilings.



2001: A SPACE ODYSSEY

Kindred™ — Unveiled at LightFair, May 2011

EdisonReport "Must-see" at LightFair 2011

Panels: 60 lm/W panels, CRI>85, CCT 3500K, L_0=3000 cd/m^2, L70 15,000 hrs @ 3000 cd/m^2
Luminaire: 45 panels, 3060 lm total, 58 W total, 53 lm/W including driver loss
Available Q1 2012

Revel™ — Unveiled at LightFair, May 2011

Panels: 60 lm/W panels, CRI>85, CCT 3500K, L_0=3000 cd/m^2, L70 15,000 hrs @ 3000 cd/m^2

Luminaire: 5 panel module, 314 lm total, 6.5 W, 48 lm/W including driver and optical losses

Available Q1 2012

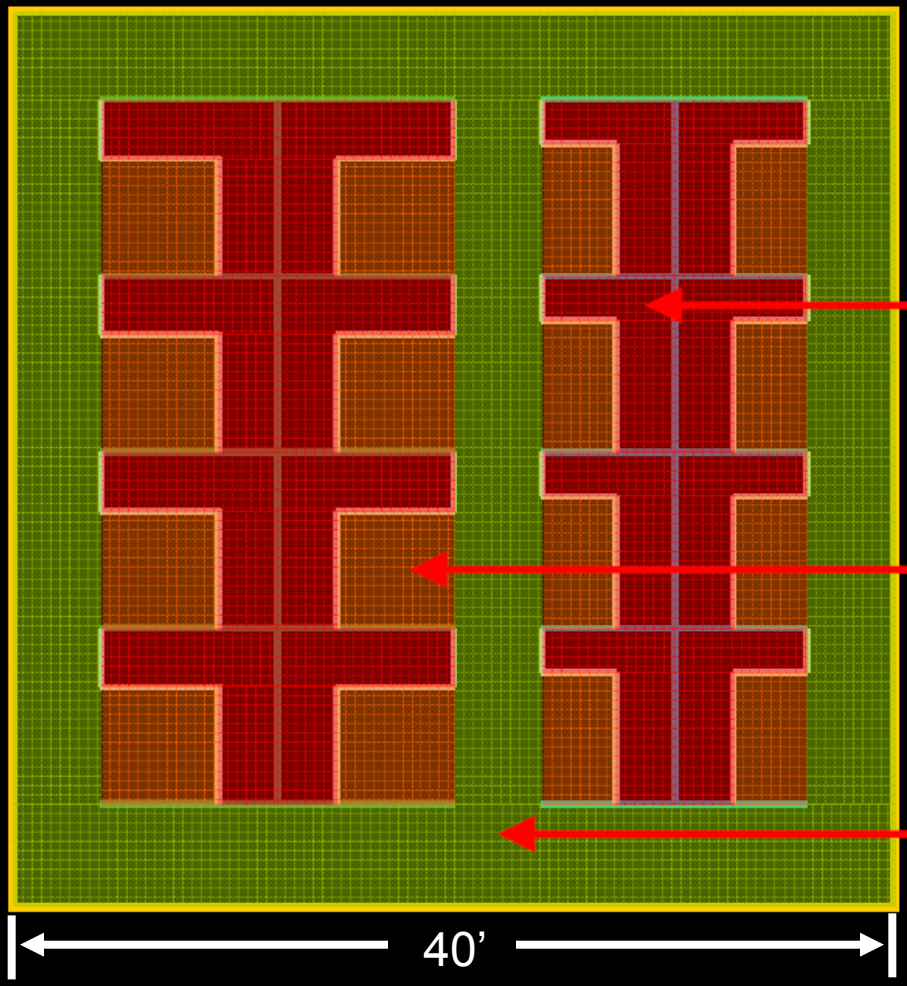
Winner: The Most Innovative Product of the Year, LFI 2011

Application Efficiency – Definitions

Application Efficiency = Theoretical Lumens/Actual Lumens X 100%

- There are illumination requirements on different working surfaces according to, e.g., 50 fc (~500 lux) for task-area, 10 fc for non-task, and 5 fc for circulation.
  - The human eye perceives brightness logarithmically – small differences in perceived brightness translates into large differences in illuminance.
- Traditional lighting design places luminaires on a regimented layout that result in a uniform illumination that satisfies the most demanding visual tasks.
  - Traditional luminaires output 3000-5000 lm each which is a lot of light relative to the pattern of actual illumination required.
- Over-lighting of less visually demanding areas means lumens are wasted.

Application Efficiency – Sample Office with Cubicles



TOTAL
31,920 lumens

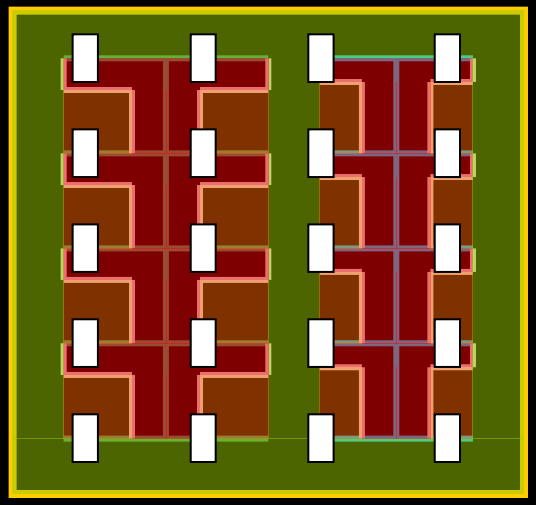
Task Area: Desk Space
50 fc x 486 sf:
24,300 lumens

Non-Task Area: Rest of Cubicle
10 fc x 410 sf:
4,100 lumens

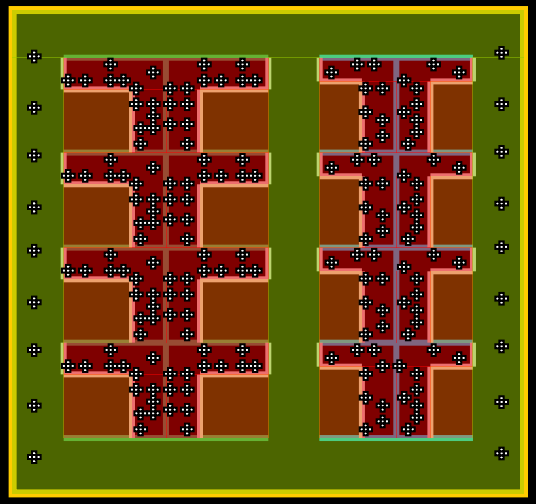
Circulation Area: Hallway
5 fc x 704 sf:
3,520 lumenas

Based on *American National Standard Practice for Office Lighting (ANSI/IESNA RP-1-04)*

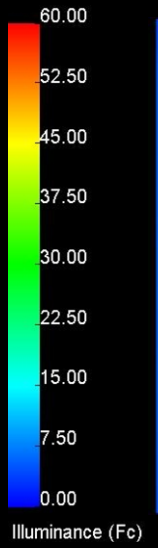
Application Efficiency – Illuminance Patterns

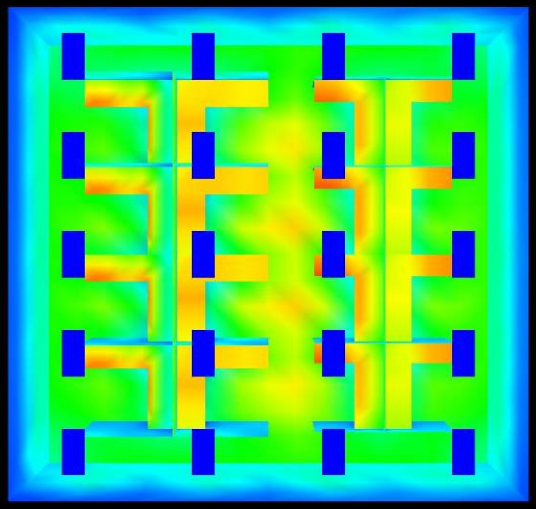


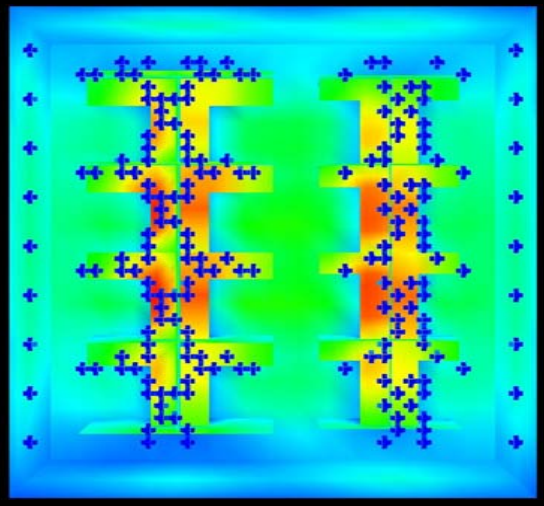
2x4’ fluorescent troffer
Recessed, 8’ x 10’ on center



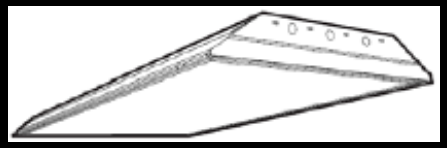
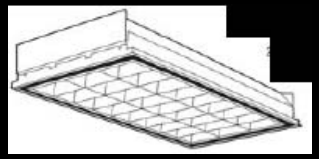
Cluster of OLED panels
Variable Placement Density



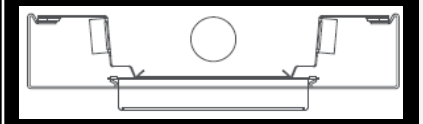




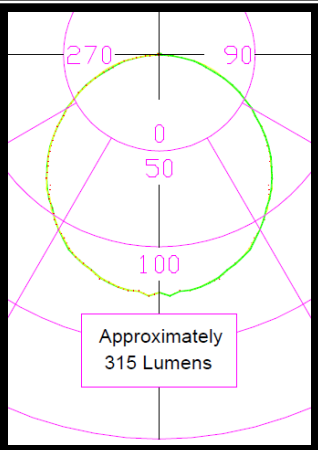
Application Efficiency – Traditional Lighting Systems

Lighting System Type	Layout Description	LPD (W/sf)	Excessive Non-task Illumination	Excessive Circulation Illumination	Application Efficiency
 2x4 fluorescent lensed troffer	Recessed, 8'x10' on center	0.73	6X	8X	28%
 2x4 fluorescent parabolic troffer	Recessed, 8'x10' on center	0.73	6X	8X	28%
 2x4 fluorescent advanced troffer	Recessed, 8'x10' on center	0.71	6X	8X	31%
 Linear fluorescent indirect/ direct	Pendant, continuous rows, 12' on center	0.79	7X	6X	27%

Application Efficiency – Newer Lighting Systems

Lighting System Type	Layout Description	LPD (W/sf)	Excessive Non-task Illumination	Excessive Circulation Illumination	Application Efficiency
 2x4 LED advanced troffer	Recessed, 8'x10' on center	0.62	6X	8X	35%
  Fluorescent low ambient/LED task	Recessed, 8'x10' on center	0.56-0.69	4X	5X	36-44%

Application Efficiency – Low Luminance OLED Tiles

Lighting System Type	Layout Description	LPD (W/sf)	Excessive Non-task Illumination	Excessive Circulation Illumination	Application Efficiency
 Clustered tiles of OLED panels	Surface mounted to ceiling in patterns that reflect task locations	0.47 (100 lm/W panels) 0.78 (60 lm/W panels)	4X	3X	52%

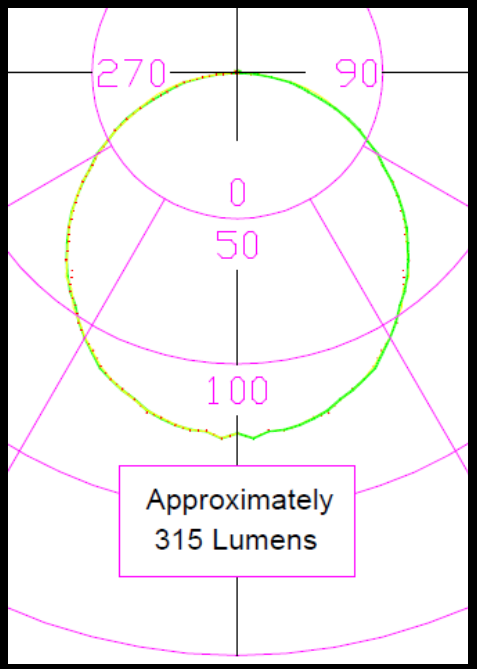
- Our lighting system design using low luminance OLED panels improve application efficiency by 18-93% over existing lighting systems.
- Using this system design, OLED panels at 60 lm/W matches traditional systems using 100 lm/W fluorescent lamps in terms of LDP (lighting power density).

Application Efficiency – Ceiling Coverage

- Ceiling Coverage = % of ceiling area obstructed by luminaire
- There is no need to cover the whole ceiling with OLED panels.

Baseline – Traditional Systems	2x4 fluorescent lensed troffer	10%
	2x4 fluorescent parabolic troffer	10%
	2x4 fluorescent advanced troffer	10%
	Linear fluorescent indirect/ direct	4%
Advanced Alternatives	2x4 LED advanced troffer	10%
	Fluorescent low ambient/LED task	4-10%
OLED	Clustered tiles of OLED panels	7%

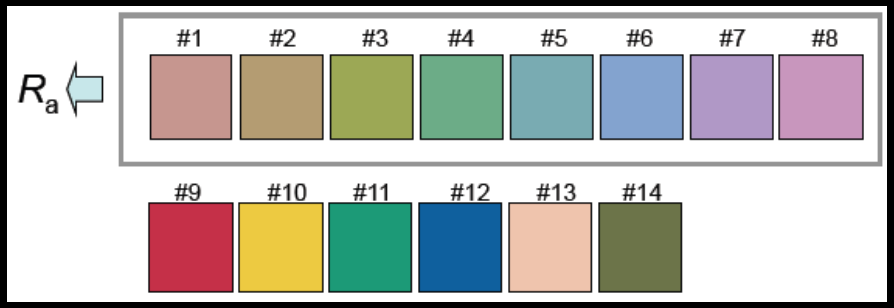
Other Panel Requirements – Emission Profile



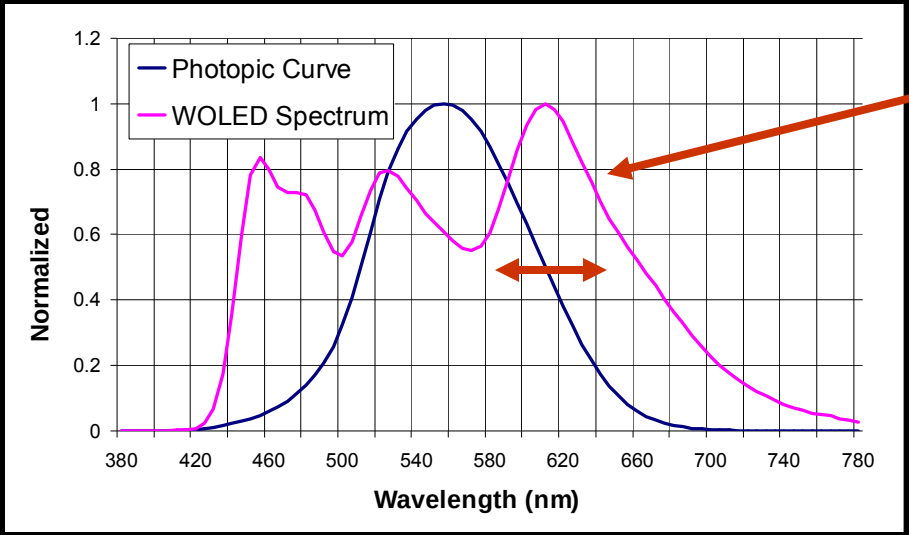
- Exact luminaire shape unimportant
- Calculation based on a panel emission that is substantially Lambertian

- Application efficiency is a function of intensity distribution but the ability to vary placement density is more important.
- Substantially Lambertian emission provides diffuse lighting that is beneficial to visual comfort.
- Strong microcavity effects can produce high intensity along the normal direction but angular dependence of color is a concern.

Other Panel Requirements – Color Rendition



- CRI (R_a) is the average from the first 8 reflectance standards.
- R9 is specifically for rendering red.
- Need both high R_a and R9 for good color rendering.



- Need a saturated red emitter with good efficiency.
- Red emitter needs to have narrow line width to avoid losing too much efficacy due to V(λ).

Realistic Luminaire Performance and Pricing

- To provide the majority of illumination in a space, an over-head luminaire needs to deliver 3000-5000 usable lumens.
- At 3000 cd/m^2, or 10,000 lm/m^2, the total panel area required is 0.3 – 0.5 m^2, equivalent to 15-25 6" panels.
- Commodity grade fluorescent luminaires retail for ~$100 each ($20/klm).
- The most expensive, mass produced, luminaires command a contractor net pricing of ~ $100/klm ➔ $500 for a 5000 lm luminaire.
- DOE manufacturing cost projection (p. 38 of manufacturing roadmap): $300/$m^2$ in 2013 ➔ $ 7.5/6" panel. Assuming a selling price of $10/panel, total panel cost to a luminaire manufacturer is $150-250.

- Are there any panel suppliers ready to provide 6" panels (60-80 lm/W, LT 70>15 khrs @ 3000 cd/m^2) for $10 each in 2013?

Critical Factors in Panel Cost

Table 7. Manufacturing Roadmap for Sheet Processing of OLED Lighting Panels

Stage	Units	Year		
		2011	2013	2015
Light output	lm/m^2	3000	6000	10,000
Substrate area[16]	m^2	0.2	0.67	2.7
Cycle Time	Sec	180	120	60
Yield	%	0.75	0.9	0.95
Annual Uptime	Hours	6000	6900	7500
Annual Production	m^2	14,000	100,000	925,000
Investment[17]	$M	30	80	150
Direct Labor	staff/shift	7	8	10
Indirect Labor	staff/shift	15	15	15
Annual Labor Costs[18]	$M	4.4	4.6	5
Other Operations	$M	1	2	4

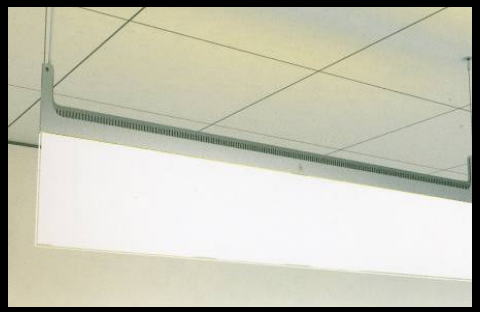
Table 9. Projected Costs of OLED Lighting Panels (sheet processed)

Stage	Units	Year		
		2011	2013	2015
Depreciation[19]	$/$m^2$	420	160	30
Labor	$/$m^2$	305	45	5
Other operations	$/$m^2$	70	20	4
Organic Materials[20]	$/$m^2$	30	15	10
Substrate	$/$m^2$	6	6	6
Electrodes	$/$m^2$	20	15	10
Light extraction	$/$m^2$	20	15	10
Encapsulation	$/$m^2$	10	8	5
Other materials	$/$m^2$	20	15	10
Total cost	$/$m^2$	900	300	90
Total cost	$/klm	300	50	9

- Need shorter TACT to reduce depreciation.
  - Area, linear sources in parallel, “hot wall” configuration
- Need low cost substrates with integrated 2+X light extraction.
- Need low cost, robust encapsulation
  - Not necessarily monolithic
  - Recessed glass lids are expensive

Mind the LEDs

GE Lighting
LED Edgelighting – Suspended
70 lm/W+
50,000 hrs
CRI 80+



GE Lighting
LED Edgelighting – Linear
75 lm/W+
50,000 hrs
CRI 85+ - 90+

The *Rambus* vision
LEDs Magazine Newsletter, May 25, 2011

Conclusions

- We anticipate launching commercial OLED products in 2012 at 60 lm/W.
- With 60 lm/W OLED panels, it is possible to design a system with comparable LPD to traditional systems with 100 lm/W fluorescent lamps due to higher application efficiency.
- OLED panel emission that is substantially Lambertian can still enhance application efficiency with acceptable vertical illumination.
- Color rendition is an important measure of color quality. Rendition of saturated red colors (R9) requires deep red emitters with narrow line width.
- There is stiff competition from edge-lit LEDs. Cost/performance remains an issue. The OLED industry needs to relentlessly drive down cost to remain a relevant SSL technology.

Acknowledgement

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Visit WWW.AcuityBrands.com/oled for more information.