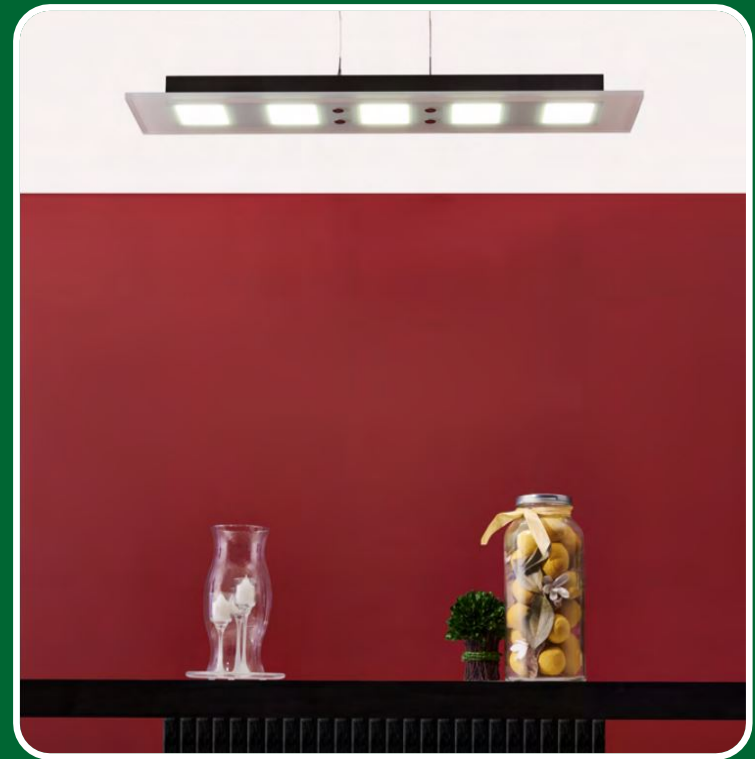


OLED Lighting Products: Capabilities, Challenges, Potential



DesignPlan Lighting Photo: Tom Kosa

DOE SSL Program Webinar

July 28, 2016

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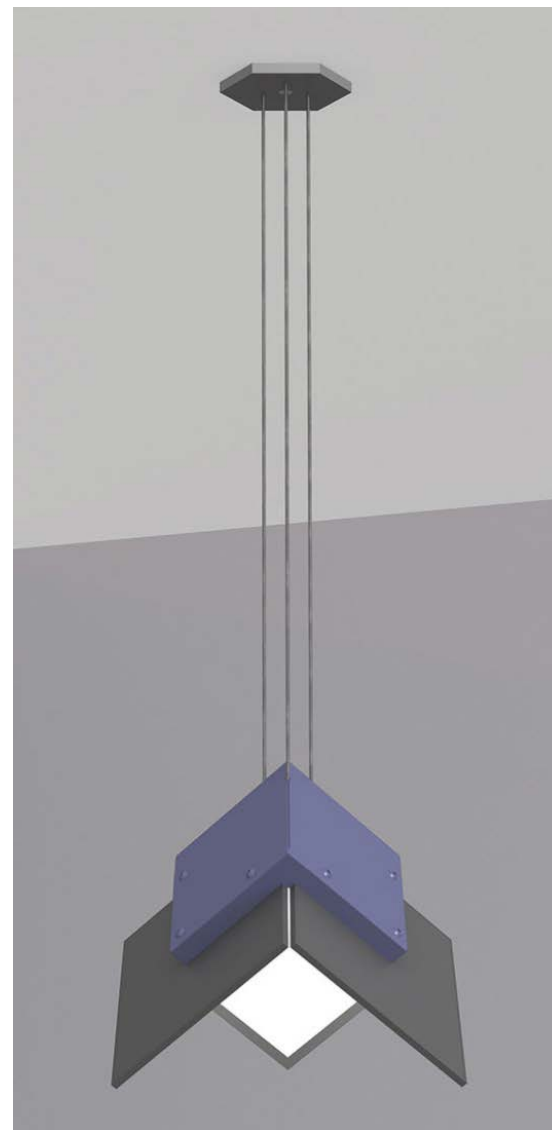


OLED Lighting Products: Capabilities, Challenges, Potential

Webinar outline

- Introduction to OLED panels and drivers
- Dimming, controls protocols, flicker
- Efficacy, power draw over time
- Color performance
- Form factor and panel sizes
- Light output, lumen maintenance, and life
- Other lighting quality issues
- OLED's competition
- Applications and opportunities
- Market hurdles
- Summary

Photo: Visa Lighting



OLED Lighting Products: Capabilities, Challenges, Potential

DOE SSL Program – OLED focus

- GATEWAY case study of OLED lighting installed at Aurora Lighting Design offices in Grayslake IL (March 2016)
- OLED Lighting Products – overview report on technology and application (May 2016)
- CALiPER report (expected Sept 2016) based on independent testing of off-the-shelf OLED architectural lighting products, and PNNL laboratory tear-downs
- Expected additional GATEWAY studies to track future performance

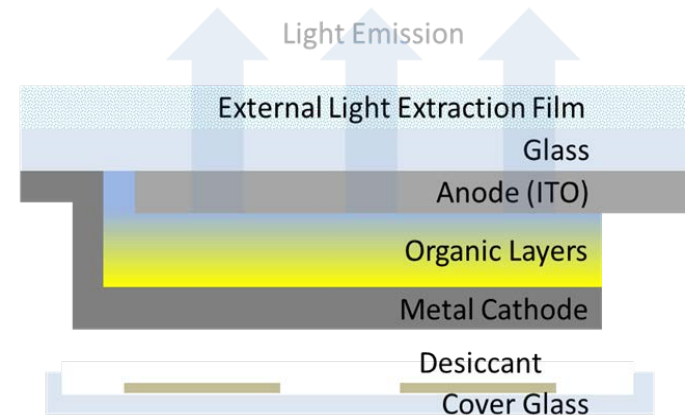


Aurora Lighting Design, Inc., office space
Photo courtesy Acuity Brands Lighting

OLED Lighting Products: Capabilities, Challenges, Potential

OLED panels

- How they work
- Manufacturers: LG Display, OLEDWorks, Kaneka Corporation, Konica Minolta, MC Pioneer
- Typical panel sizes:
 - 50 mm x 200 mm
 - 80 mm x 80 mm
 - 100 mm x 100 mm
 - 110 mm round
 - 200 mm x 200 mm
 - 300 mm x 300 mm



* Layers are not drawn to scale



Photo: LG Display

OLED Lighting Products: Capabilities, Challenges, Potential

OLED panels

- Importance of encapsulation
 - Broken edge seal (glass-on-glass)
 - Thin film encapsulation
- Effect of extraction layer on color, lumens, distribution
 - Reduce angular color shift
 - Increase efficacy (~1.5X)
 - Mirror finish without
- White and solid colors
- Flexible (soon?)

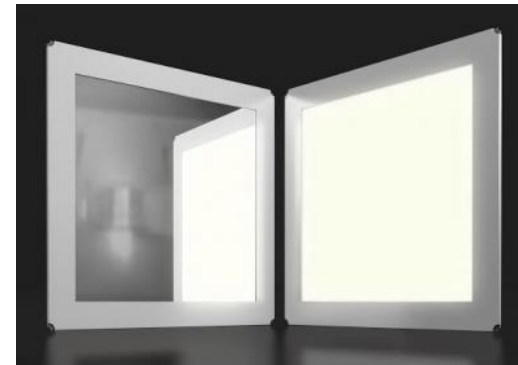
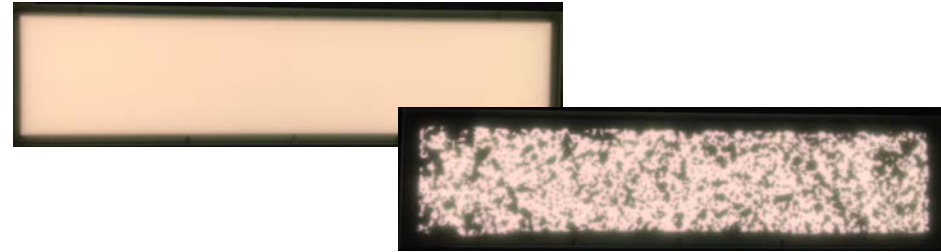


Photo: OLED-Info

Photo: Kaneka Corporation



Photo: LG Display

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Drivers for OLED panels

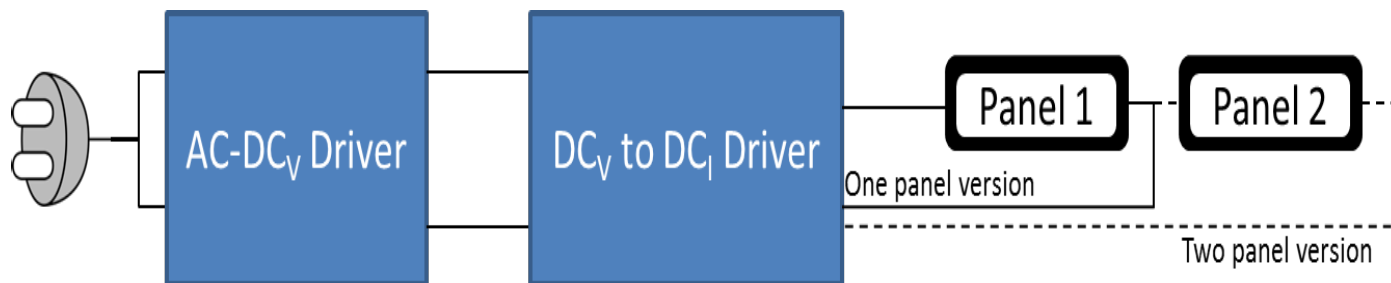
- Deliver a constant current to OLED panel(s)
 - Number of panels possible based on OLED voltage and driver output capability
 - Allow for some voltage rise (due to OLED aging)
- LED drivers
 - Easiest approach
 - Daisy chain drivers (low overall efficiency observed)
- OLED drivers
 - Dimming (CCR vs. PWM), programmable current, OLED protection



Photo: OLEDWorks



Photo: Osram



Driver considerations for OLED panels

- Driver impact on system efficacy
 - Impact of 50% and greater observed
 - Choose wisely (this is often the only system loss)
- Power draw over time
 - OLED voltage will rise over time
 - Driver needs voltage overhead to maintain target current
 - End-of-life management may be appropriate

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Driver Considerations for OLED panels

- Dimming method
 - Pulse Width Modulation (PWM) is appropriate for LEDs, not generally recommended for OLED lighting
 - Internal capacitance => response time not like LEDs
 - Potential issues with spikes that may damage OLED or reduce lifetime
 - Improved efficacy at lower current
 - Constant current reduction (CCR) for dimming is preferable for OLEDs
- OLED panel warms when dimmed
- Dimming performance
 - Light output nearly linear with current
 - Watch out for flicker (PWM or poor driver design)

OLED Lighting Products: Capabilities, Challenges, Potential

Efficacy

- Panel efficacy
 - 40 to 55 lm/W at 3000 K
 - 29 to 60 lm/W at 4000 K
- OLED system efficacy of available architectural products in 2016 (per CALiPER testing)
 - 21 to 44 lm/W

Power draw over time

- Power draw requirements may *increase* 33% over the life of the panel (voltage rise)
- Reasons manufacturers must communicate that end-of-life power draw
 - Lighting and dimming circuits must be designed for their full loads
 - Energy code compliance documentation requires reporting maximum lighting loads

OLED Lighting Products: Capabilities, Challenges, Potential

Dimming, controls protocols, flicker

- OLED driver must be designed to accept dimming signal, usually 0-10V, DALI, or DMX, and translate that using PWM or CCR to dim the OLED
- Most market-available OLED luminaires dim only to 10% output to reduce system cost
- Flicker can be introduced through PWM dimming, unless frequency is high and/or modulation is low
- CCR dimming can reduce the potential for flicker



Flicker top showing stroboscopic effect from OLED lighting installation
Photo: Aurora Lighting Design, Inc.

OLED Lighting Products: Capabilities, Challenges, Potential

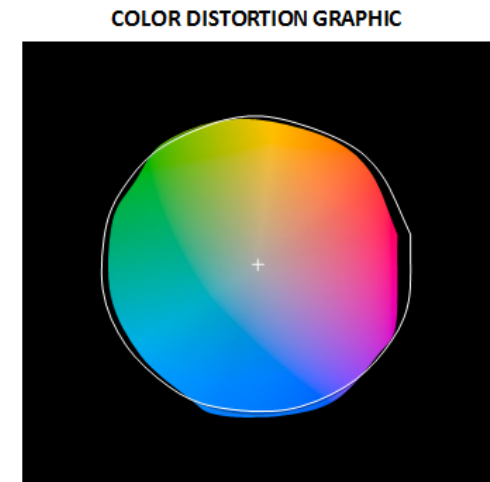
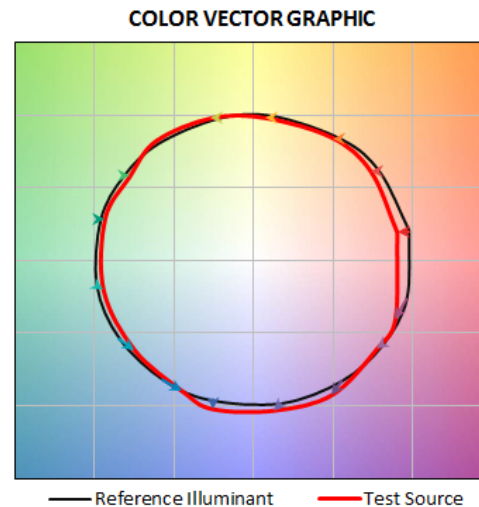
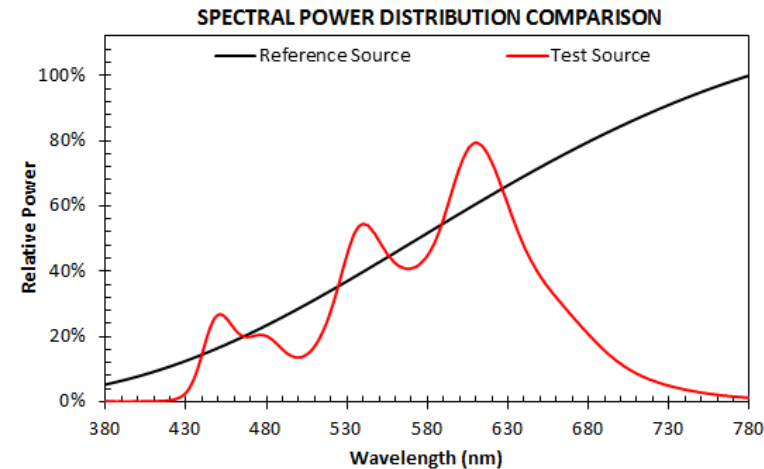
	LG Display N6S Series	OLEDWorks FL300	Kaneka Corp.
Panel size	100 mm square , 200 x 50 mm, 53 x 55 mm, 213 x 113 mm, 200 x 200 mm, 320 x 320 mm, 140 x 140 mm, 110 mm round, 320 x 110 mm, 210 x 50 mm flexible; all matte finish	102 mm square , 50 x 200 mm; shiny and matte finish	80 mm square , 100 mm square, 143 x 23 mm; all shiny finish
Color (CCT, CRI, R_g)	3000 K, 90 CRI; 4000 K, 90 CRI	2500 K (shiny) 2900 K, 80 CRI, R _g = 0 (matte)	3000 K, 86-92 CRI; 4000 K, 92 CRI
L₇₀ panel life, panel lumens	40,000 hrs at 3000 cd/m ² (75 lm), 3000 K; 30,000 hrs at 3000 cd/m ² (75 lm), 4000 K	50,000 hrs at 3150 cd/m ² (115 lm); 10,000 hours at 8300 cd/m ² (300 lm)	50,000 hrs at 3000 cd/m ² (60 lm), 3000 K; No data for 4000 K
Panel efficacy (new)	55 lm/W, 3000 K 60 lm/W, 4000 K	50 lm/W at 0.040 A 42 lm/W at 0.368 A	40 lm/W, 3000 K 29 lm/W, 4000 K
Appearance	Matte white on or off	Panels with extraction layer: matte white on or off; panels without extraction layer: shiny on or off	Shiny finish, becomes mirror when off
Panel luminance, panel wattage	3000 cd/m ² , 2.5 W, 3000 K 3000 cd/m ² , 2.7 W, 4000 K	3150 cd/m ² , 2.5 W at 0.135 A; 8300 cd/m ² , 7.4 W at 0.368 A (new), 10 W at 0.390 A at end of life	3000 cd/m ² , 1.5 W, 3000 K No data for 4000 K

OLED Lighting Products: Capabilities, Challenges, Potential

Color characteristics of LG Display and OLEDWorks panels

- Nom. 3000 K to 4000 K
- CRI (R_a) 78 to 89
- R_f 78 to 86
- R_g 95 to 98
- Good to very good color rendering but tend to undersaturate red hues important for skin tones and retail applications

R_f	86
R_g	98
CCT (K)	2974
D_{uv}	0.0019
x	0.4417
y	0.4105
CIE R_a	89



IES TM-30-15 color graphics for LG Display panel

OLED Lighting Products: Capabilities, Challenges, Potential

Form factor and panel sizes

- **THIN!** Only 0.5 to 2 mm panel thickness
- Doesn't include connectors, mounting hardware and frames, or drivers
- Remote drivers add complexity to installation. Need to plan for number of wires that need to be pulled for entire configuration
- Flexible panels are on the horizon! Bendable, foldable glass and plastic substrates will enable inspiring designs

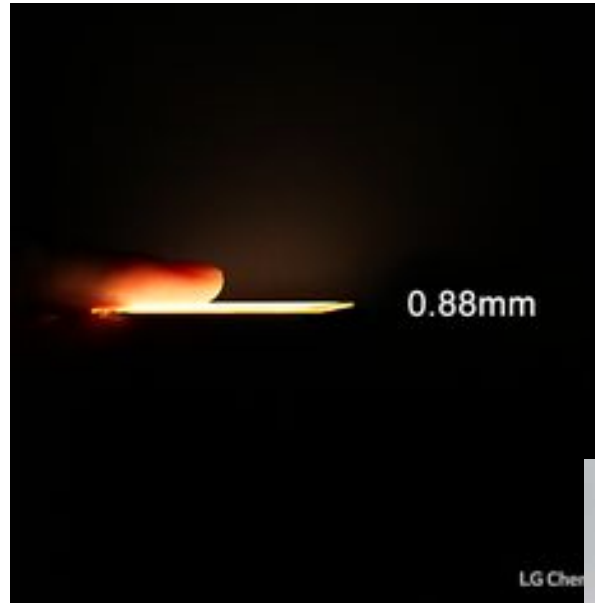


Photo credit: LG Chem

Photo credit: LG Chem



Photo credit: Corning Willow glass

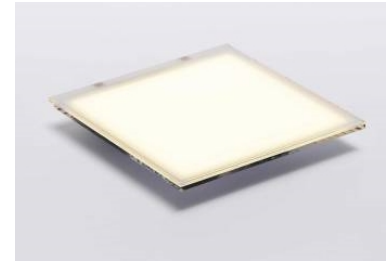
OLED Lighting Products: Capabilities, Challenges, Potential

Light output, lumen maintenance, and life

Panel only: 100 mm x 100 mm (4" x 4") nominal, 3000 K, with extraction layer, unless noted otherwise

Tradeoff between luminance and lumens and life

- LG Display (2.5 W)
 - 75 lm at 3000 cd/m² with estimated 40,000 hours L₇₀ life, 55 lm/W
- OLEDWorks (2.5 W)
 - 115 lm at 3150 cd/m² with estimated 50,000 hours L₇₀ life, 46 lm/W
 - 300 lm at 8300 cd/m² with estimated 10,000 hours L₇₀ life, 42 lm/W
- Kaneka (no extraction layer, 1.5 W)
 - 60 lm at 3000 cd/m² with estimated 50,000 hours L₇₀ life, 40 lm/W



LG Display



OLEDWorks



Kaneka

OLED Lighting Products: Capabilities, Challenges, Potential

Other Lighting Quality Issues

- Appearance of Space and Luminaire
 - Create patterns that lead or entertain the eye
 - Use as tiles of light
 - Produce words or playful patterns
 - Make signage
 - Incorporate into room surfaces, built-in furniture
 - Create dimensional sculptures
 - Create soft task lighting



Photo: Konica Minolta



Photo: Acuity Brands Lighting



Photo: Aerelight

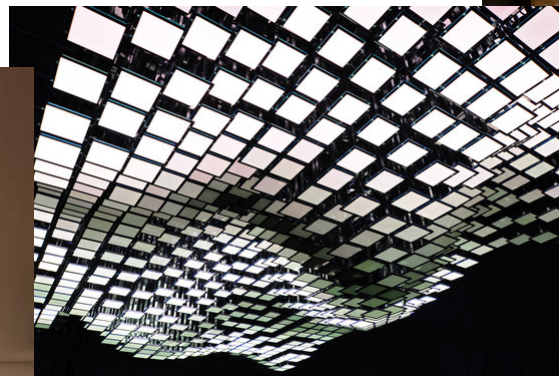
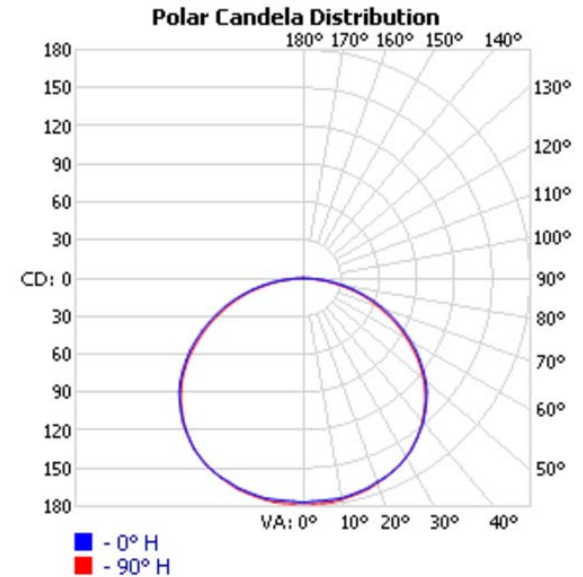


Photo: Philips (now OLEDWorks)

OLED Lighting Products: Capabilities, Challenges, Potential

- Light distribution
 - Panels produce a “cosine distribution” so they theoretically have the same luminance from all viewing angles
 - This distribution can help light vertical surfaces and faces because they emit light at high angles (60° to 90° from nadir), making a space appear brighter, with softer shadows
 - The same high light emission can produce a perception of glare
 - For direct viewing, some luminaire manufacturers limit the luminance to 3000 cd/m^2
 - OLEDs have not yet been optically modified to control glare (lenses, louvers, filters) because it reduces efficacy too much



Polar plot of OLED panel light distribution
Image courtesy Acuity Brands Lighting

OLED Lighting Products: Capabilities, Challenges, Potential

- Facial modeling
 - OLEDs can provide soft, flattering light on faces and bodies in hospitality and retail spaces
 - Panels need to be low luminance, spaced away from the face reflection to avoid disabling glare

Photo: ITRI – OLED lighting mirror luminaire



OLED Lighting Products: Capabilities, Challenges, Potential

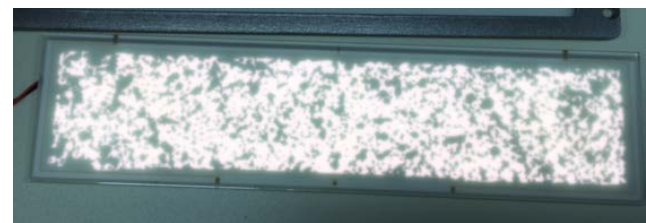
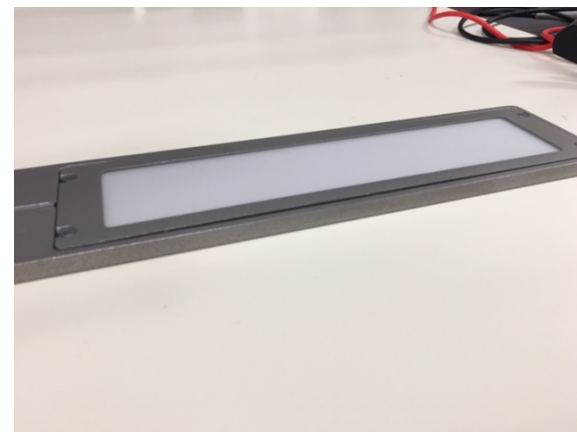
- Lighting uniformity and lack of shadows/highlights
 - OLED light distribution produces almost shadowless spaces
 - Can be dull unless combined with task lighting or accent lighting for visual highlights



Photos: Acuity Brands Lighting

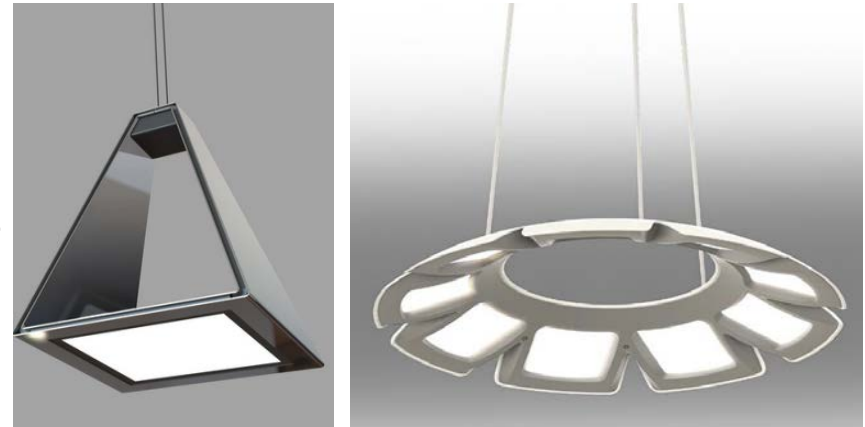
OLED Lighting Products: Capabilities, Challenges, Potential

- Maintenance issues
 - L_{70} life ranges from 10K to 100K hours depending on operating luminance
 - $3000 \text{ cd/m}^2 = \text{approx } 40\text{K hours (10 yrs at 4000 hrs/yr)}$
 - $8300 \text{ cd/m}^2 = \text{approx } 10\text{K hours (2.5 yrs at 4000 hrs/yr)}$
 - Panels need to be replaceable in the field
 - Will panel replacements be available at same luminance, color, connectors? Are they easy to replace?
- Shipping and installation durability
 - Glass panels can be fragile
 - Can OLEDs be safely shipped in the luminaire?
- OLED system cost
 - Task lights can be affordable
 - Other products are specialty items because of system cost
 - Panel costs are dropping; mass-production methods may decrease costs dramatically
 - Until then, economic viability is strained compared to LED technology



OLED Lighting Products: Capabilities, Challenges, Potential

- OLED's competition
 - Edge-lit LEDs
 - Thicker than OLEDs (approx 9 mm)
 - Higher luminance, longer life, higher efficacy
 - More durable in shipping
 - MicroLEDs (in development)
 - Printed LED sheets and strips
 - 30 lm/W
 - 73 CRI, 5000 K



Photos: Blackjack Lighting



Photo: Nth-Light



Photo: Apple Watch

OLED Lighting Products: Capabilities, Challenges, Potential

Applications and opportunities

- Outdoor pedestrian-friendly luminaires (if well-sealed inside luminaire)
- Signage
- Glowing clothing
- Vehicle bodies
- Light-emitting roll-up window shades
- Retail shelf and back-lighting
- Luminous wallpaper – field cuttable
- Combine LED and OLED technologies in single luminaire
- Use OLEDs like ceramic tiles in electrified frame
- Floating luminous planes in lieu of ceilings
- Dynamic shape-changing luminaires on servomotors
- Glowing bar tops in every starship



Graphics: PNNL

OLED Lighting Products: Capabilities, Challenges, Potential

Market hurdles

- Too expensive for routine applications
- Too low in luminance for most workhorse applications, since that would be large in size and exhibit short life
- Too poor in efficacy to use as a light engine, so OLED panel needs to be used exposed for maximum luminaire efficacy
- Clunky remote drivers are too large to be integrated into the sleek OLED luminaire
- Lack of interchangeability of panels and drivers among manufacturers
- Panels somewhat delicate to replace
- Few drivers optimized for OLED systems
- No standards for testing life and lumen maintenance (IES LM-80 doesn't apply)
- Designers don't want to specify OLEDs because they are expensive and unfamiliar and uncompetitive with fluorescent; manufacturers don't want to make OLED luminaires because designers aren't specifying them



OLED Lighting Products: Capabilities, Challenges, Potential

Summary

- OLEDs are struggling through a similar set of difficulties that LEDs experienced
- Today OLEDs are a creative light medium for architectural lighting designers
- They have wonderful properties for facial modeling, cheerful wall luminances, and low-glare ambient lighting, and shadow-free task lighting
- Growing pains include
 - lower efficacy than LEDs
 - higher cost than LEDs
 - lack of standardized connectors and mounts
 - limited optical distribution options (at this point in time)
 - and drivers borrowed from the LED industry that are less than optimized for OLED use
- Tomorrow they may offer dynamic architectural lighting options we've never experienced before
- Don't wait for your next starship to specify them!



Visa Lighting “Limit” pendant
Photo: Visa Lighting



Photo: LG Chem

OLED Lighting Products: Capabilities, Challenges, Potential

<http://energy.gov/eere/ssl/downloads/oled-lighting-products-capabilities-challenges-potential>

Thanks for your attention!

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Felipe Leon, felipe.leon @ pnnl.gov

And now for questions????



Photo: Philips Lumiblade



Graphics: PNNL



Aurora Lighting Design, Inc. Offices
Photo: Acuity Brands Lighting