Progress and Challenges in OLED Lighting

John W. Hamer, COO

OLEDWorks LLC

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Vision

- Jump ahead ~~10~~ 9 years, and I believe that we will find only Solid State Lighting being installed; shared between LED and OLED
- The lighting applications where OLED will be the favored will be:
  1. Applications that are close to the user
     - Low glare, low temperature, broad spectrum – e.g. task lighting and direct-view lighting
  2. Applications using the unique form factor of OLEDs:
     - Thin and light weight – for example transportation
     - With special design elements – for example curved lights – our buying decisions are strongly affected by design

DOE Gateway

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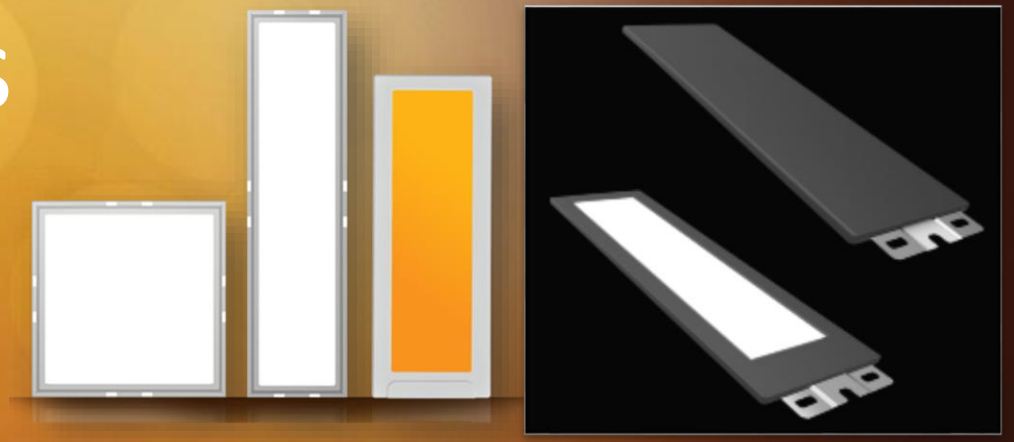
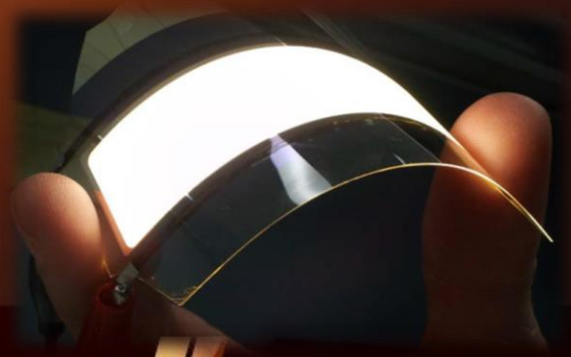
Outline

- Update on the performance of OLED Lighting
- Introduction into commercial fixtures – DKB Gateway Site
- Bendable/Flexible OLED lighting
- Automotive OLED lighting
- Blue Light Hazard
- Summary

OLEDWorks – Capabilities

- **Commercialized product offerings, all high brightness capable**
  - Brite 2
  - Keuka Module
  - Amber
  - On going: extend portfolio performance and form factor
- **Manufacturing Capacity (US line and German line)**
  - Aachen: Bold move to make world's brightest panels, high volume capacity
  - Rochester: Disruptive low cost structure, amber, low volume, scalable
    - Production Capability – 3,000 m2/year scalable to 7,000 m2/year
    - Demonstration of Unique Large-Scale Production Technology
- **Research and Development**
  - Significant and cost-effective research and development capabilities
  - Qualified DOE OLED testing facility
  - Strategic collaboration ongoing, a key to success in the U.S. and Europe
  - Selected for over $8 million in U.S. federal and NYS Government funded projects
- **Joint Development Agreements**
  - Corning® – Willow® Glass





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UPDATE ON PERFORMANCE OF OLED LIGHTING

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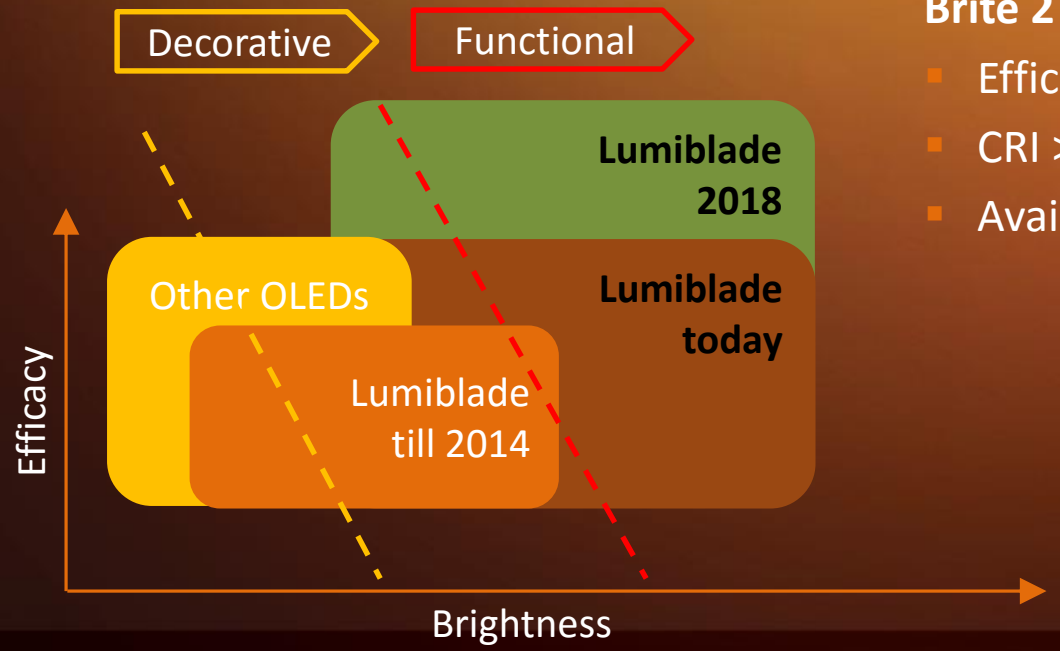
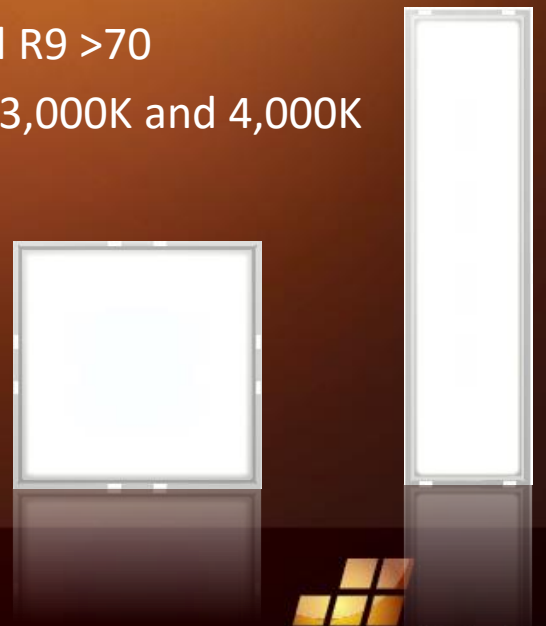
OLEDWorks enables you to revel in possibility

- **2nd generation (Brite2) was launched 2016, 3rd generation follows in 2018**
- **OLEDWorks Lumiblade standout performance with the Brite family**
- **Higher brightness enables many additional applications and is only available from OLEDWorks**



Brite 2

- Efficacy of more than 60lm/W
- CRI > 90 and R9 >70
- Available in 3,000K and 4,000K



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Commercial product performance on steep curve

For commercial products in the last 3 years we…

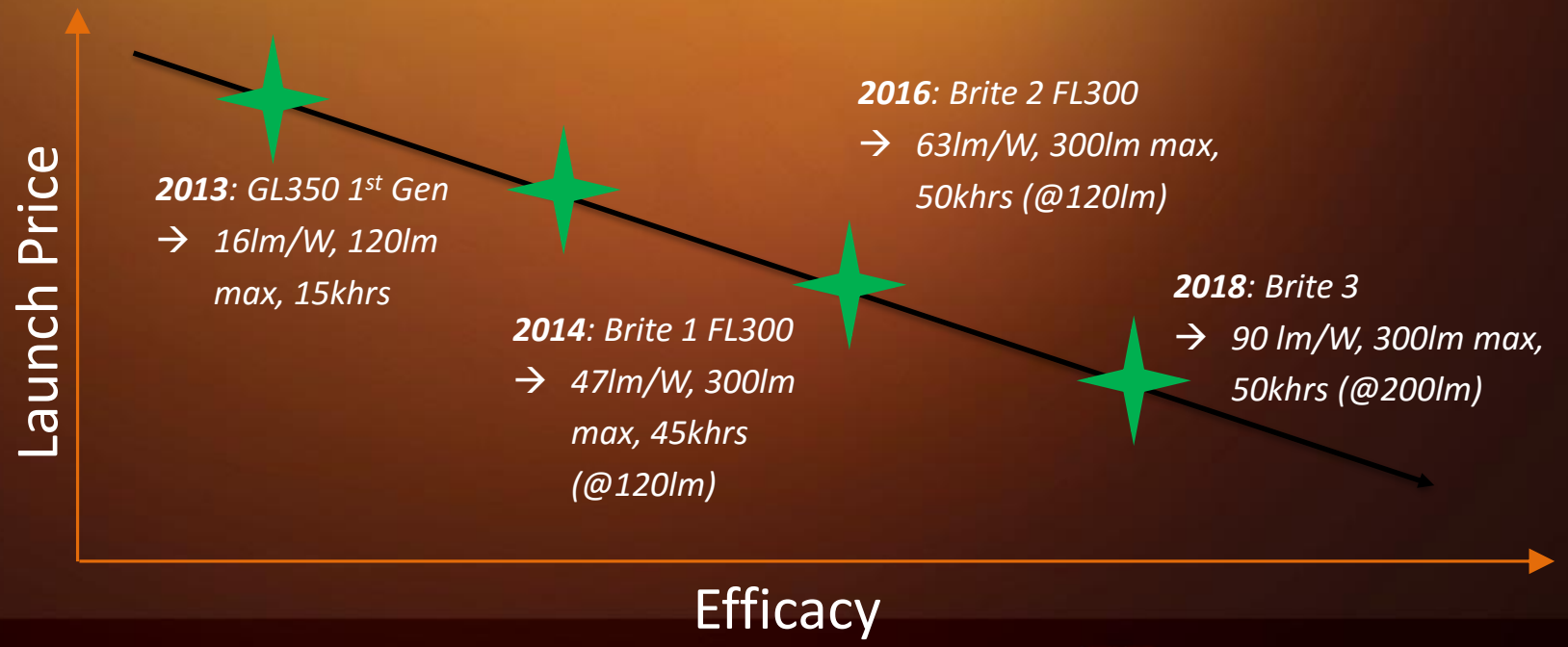
…tripled the efficacy

…tripled the luminance

…tripled the lifetime,

…and cut the price by 3

…and it does not stop here !



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Keuka OLED Module

Beautiful light, easy to use, simple to integrate

The advantages:

- Beautiful light: Lumiblade OLED panels as light source
- Easy to use: dimmable driver on board
- Simple to integrate: easy plug and play system with socket connector and lampholder

Ascend Lamp demonstrates the system and makes OLED light available.

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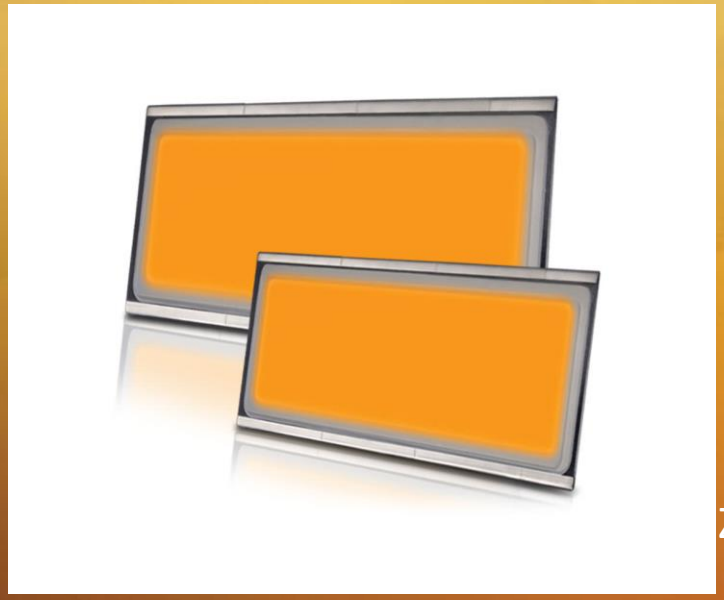
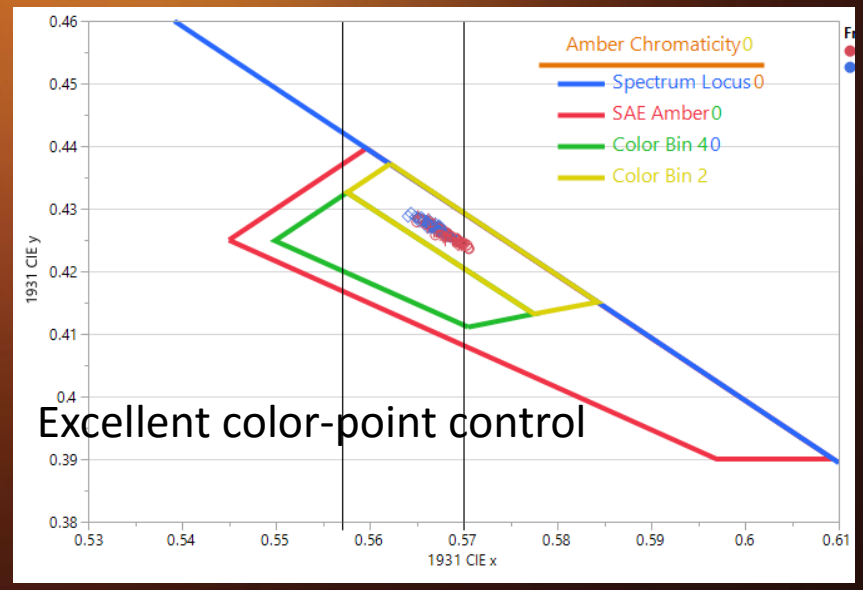
Brite Amber

Thin and healthy light



Zen Room/Mother's Room

- OLEDWorks has commercialized a high brightness amber OLED product with application in the healthcare market, in sleeping areas for elderly and children.
- This product provides a high brightness option
  - Brightness 2000 cd/m2,
  - Efficacy 50 lm/W
  - CIE 0.429, 0.562 – Conforms to SAE Amber Color Spec
- There is no blue wavelength in the amber, compatible with circadian rhythms for sleeping
- Marker size (41mm x 101.6mm) released now.
  - Larger panel size later
- Manufactured in Rochester NY.



Excellent color-point control

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Drivers for OLED Panels

- **"All OLED drivers are LED drivers" but**

  "Not all LED drivers are OLED drivers"

  - OLED Drivers:
    - Are constant current output.
    - Have Analog or Hybrid (Analog w/ PWM at low end) dimming.
    - Have OLED Short Circuit detection/protection (OLED's short differently than LED's).
- **OLEDWorks Driver Strategy**
  1. Educate OLED users on OLED driver requirements
  2. List 3rd Party Drivers (LED & OLED) which are tested to be compatible with Lumiblade OLED panels
  3. Work w/ partner companies to develop & commercialize OLED drivers
- **Driver Strategy: Progress to Date**
  - Still offering 3 Philips legacy OLED drivers
  - Compatibility testing of "3rd Party" drivers
    - 8 complete & listed on OLEDWorks website (w/ more to come)
      - 5 LED drivers and 3 OLED drivers
  - Developing 2 custom OLED drivers (w/ more to come)
    - Small and thin
    - OLED specific w/ "short circuit protection"

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TURNING THE CORNER:
COMMERCIAL FIXTURES AVAILABLE NOW

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Commercially Available Fixtures

- Visa Lighting

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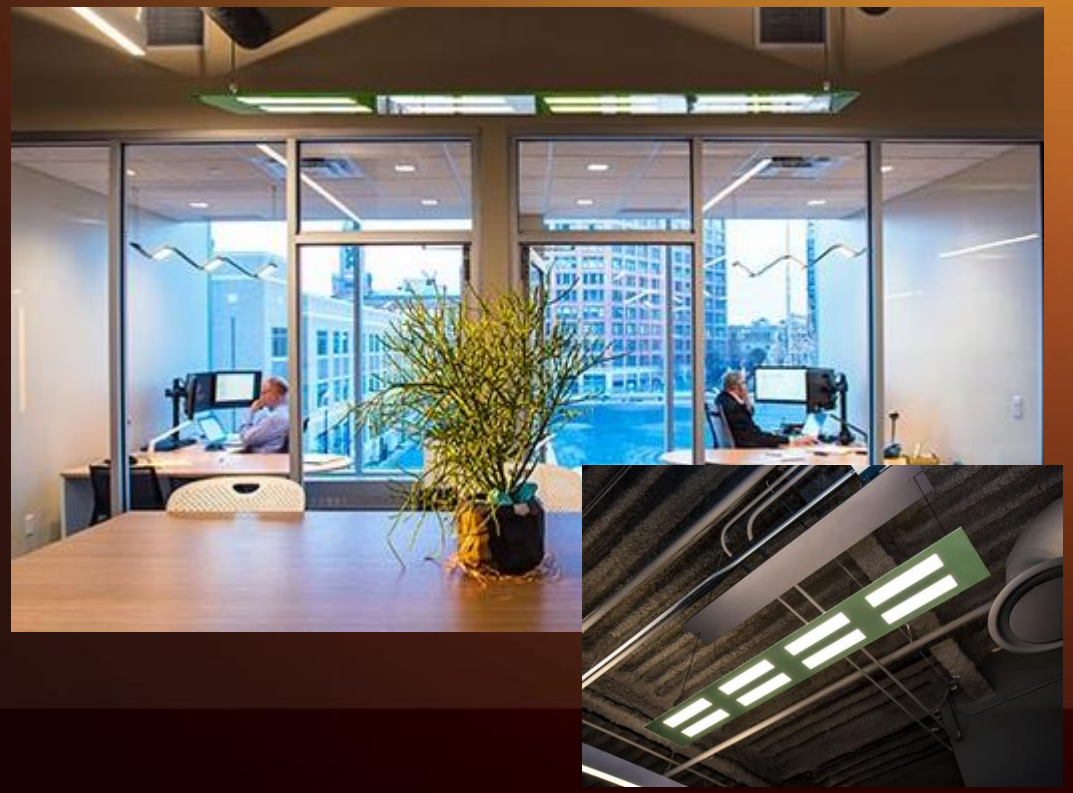
Commercially Available Fixtures

- Acuity Brands Lighting



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Commercially Available Fixtures

- Emdedesign GmbH

- OLED Devices

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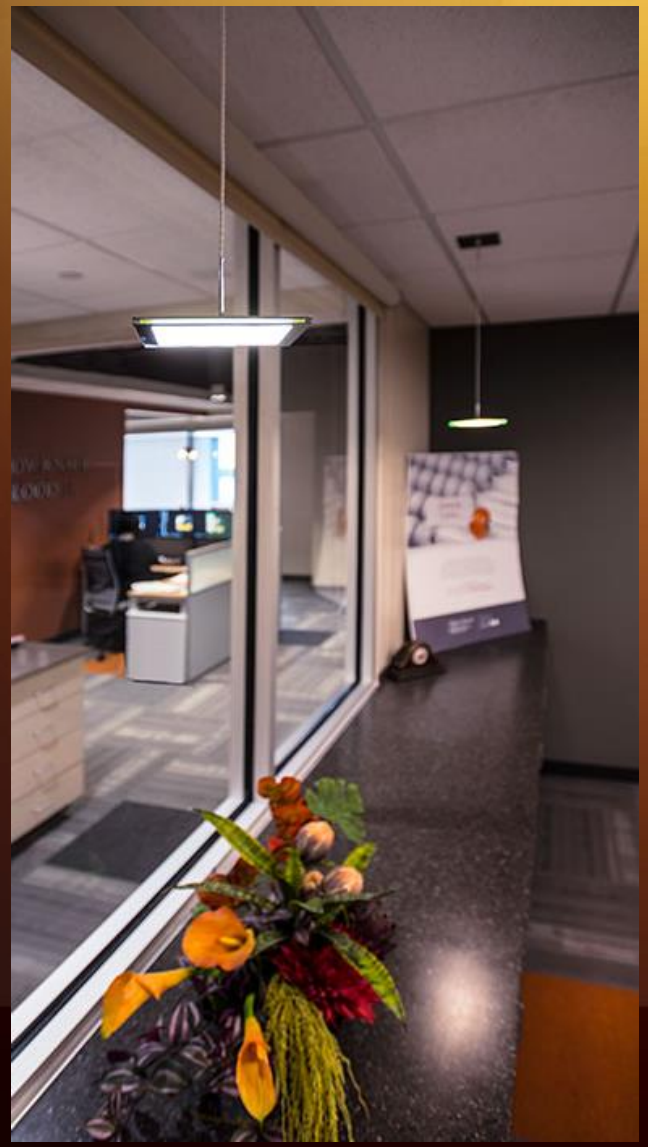
Commercially Available Fixtures

- Birot



- Designplan Lighting

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Commercially Available Fixtures

- Regiolux Capio

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Commercially Available Fixtures

- Aquaform Lighting Solutions

Commercially Available Fixtures

- Eureka Lighting Sail

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BENDABLE/FLEXIBLE OLED LIGHTING

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OLEDWorks Approach

- Step 1: Thin Willow glass for bendable/conformable lights
- Glass is currently the lowest cost substrate for OLED lighting
- “Bendable” is significant improvement over no curvature
- Sheet processing is okay for initial OLED lighting volumes.
- R2R processing will drive down cost at high volume.
- Step 2: Flexible barrier plastic
- Plastic is truly flexible and mechanically more robust
- Cost and barrier performance need some improvement
- LG Flexible OLED lighting panels are based on plastic substrates.
  - Previously reported as using polyimide base
  - This is usually solution coated on glass sheets and barrier coated, not mass produced R2R.

100 um Corning Willow Glass

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OLED Lighting Panels on Corning Willow Glass

- Corning-OLEDWorks JDA
  - Bendable panel process and product development
- OLED lighting panels will be introduced in 2018
  - Bendable/conformable

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AUTOMOTIVE OLED LIGHTING

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OLEDs bring several attractive features to Automobiles:

- **Branding identity based on unique styling features**
- Shape freedom
- Esthetics in off-state (mirror-finish)
- ‘Clean’ design: sharp boundaries, high contrast
- Segmentation for dynamic applications
- Very high uniformity
- Enables ‘3D-effects’
- From 2018/9: curved (Bendable? Flexible?)
- No hot spots, no heat sinks – installation depth
- Instant-on; fully dimmable; *dc* voltage
- **New opportunities at system level**

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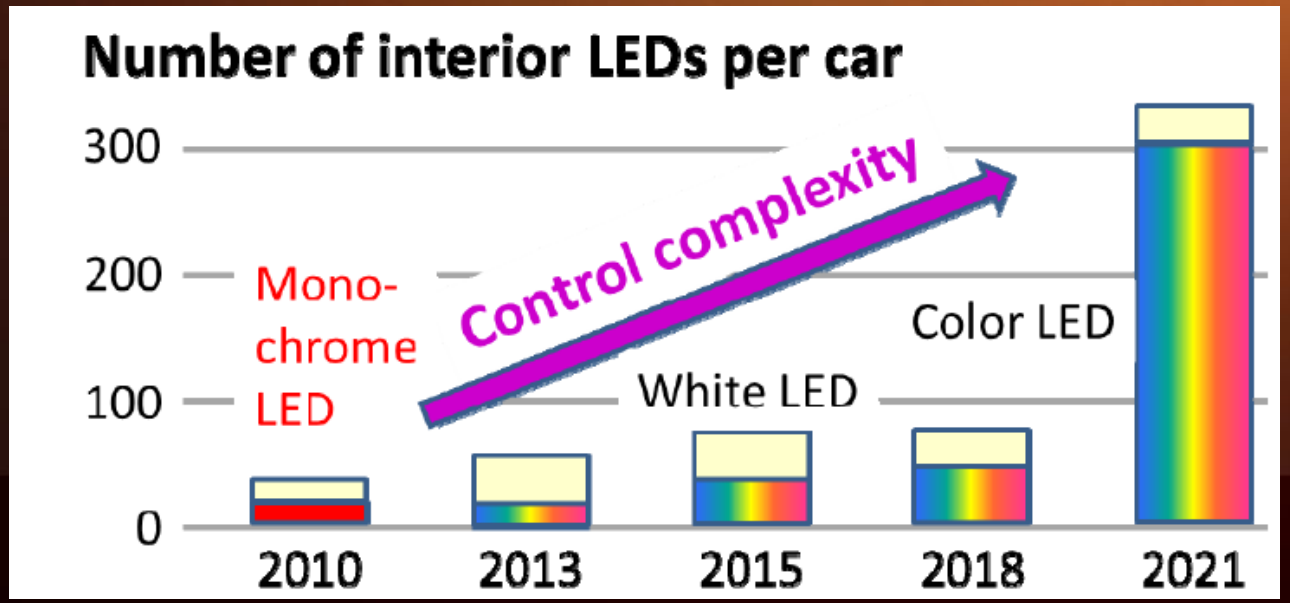
Automotive Interior Lighting Redefined

- ***Presented by Robert Isele, BMW at*** SID 2017 47.1
  - Interior lighting:
    - Creates an emotional response
    - Gives a "first customer perception" in the showroom
    - Defines the design
- ***"Light is the new chrome"***



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OLED Automotive Opportunity

- **The 2018 Audi A8 has OLED rear-lights**
  - **On sale this year**

As cars move towards self-driving, the importance of the ambiance and comfort of the cabin will offer new opportunities for OLED lighting.

https://arstechnica.com/cars/2017/07/meet-audis-new-tech-flagship-the-2018-a8-sedan/

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OLED LIGHTS AS BUILDING MATERIALS

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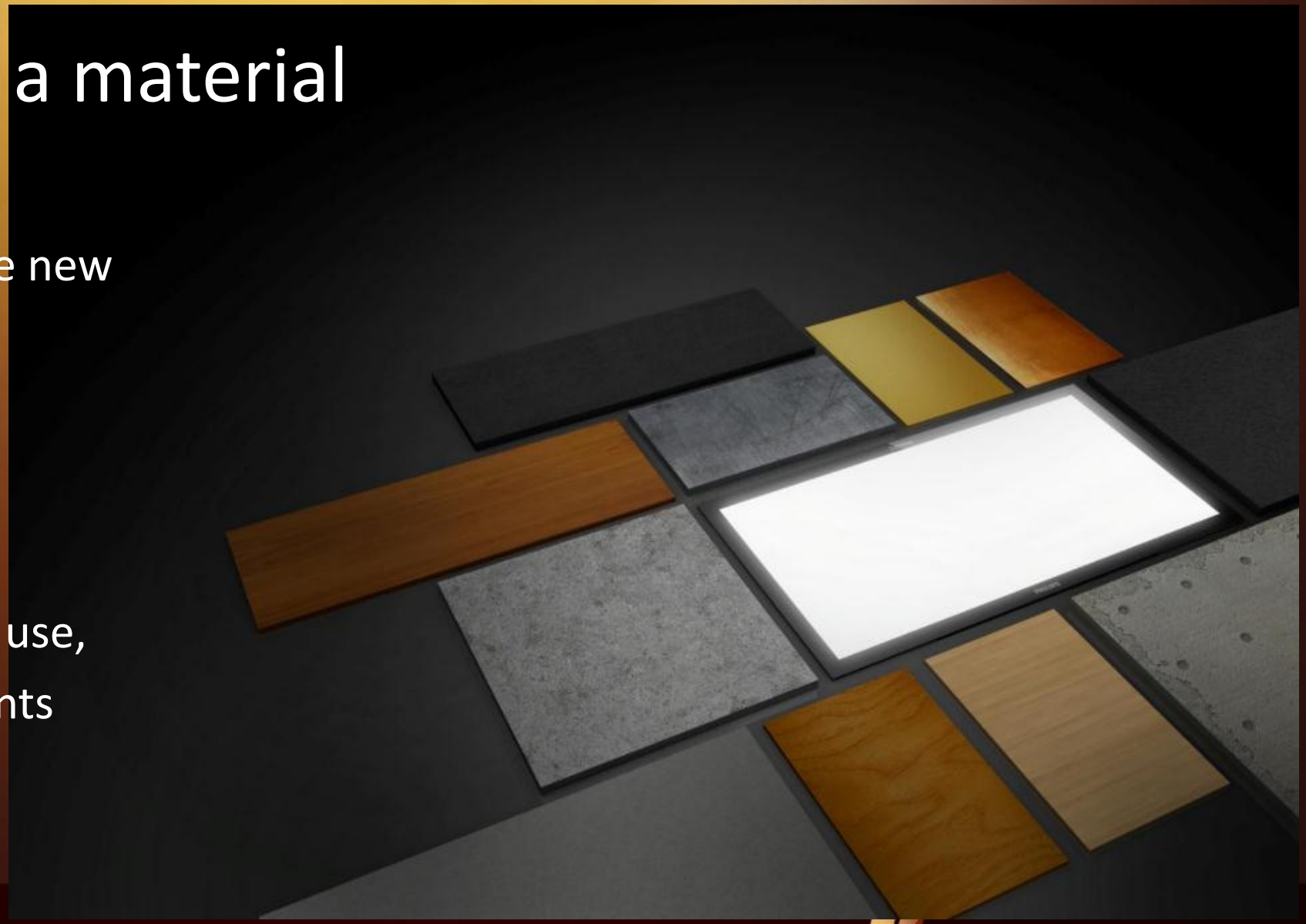
OLEDs - Light as a material

- OLEDs opens up a whole new world of opportunities for working with light. Functional as well as decorative,
- and surprisingly easy to use, organic lighting represents
- a new raw material.



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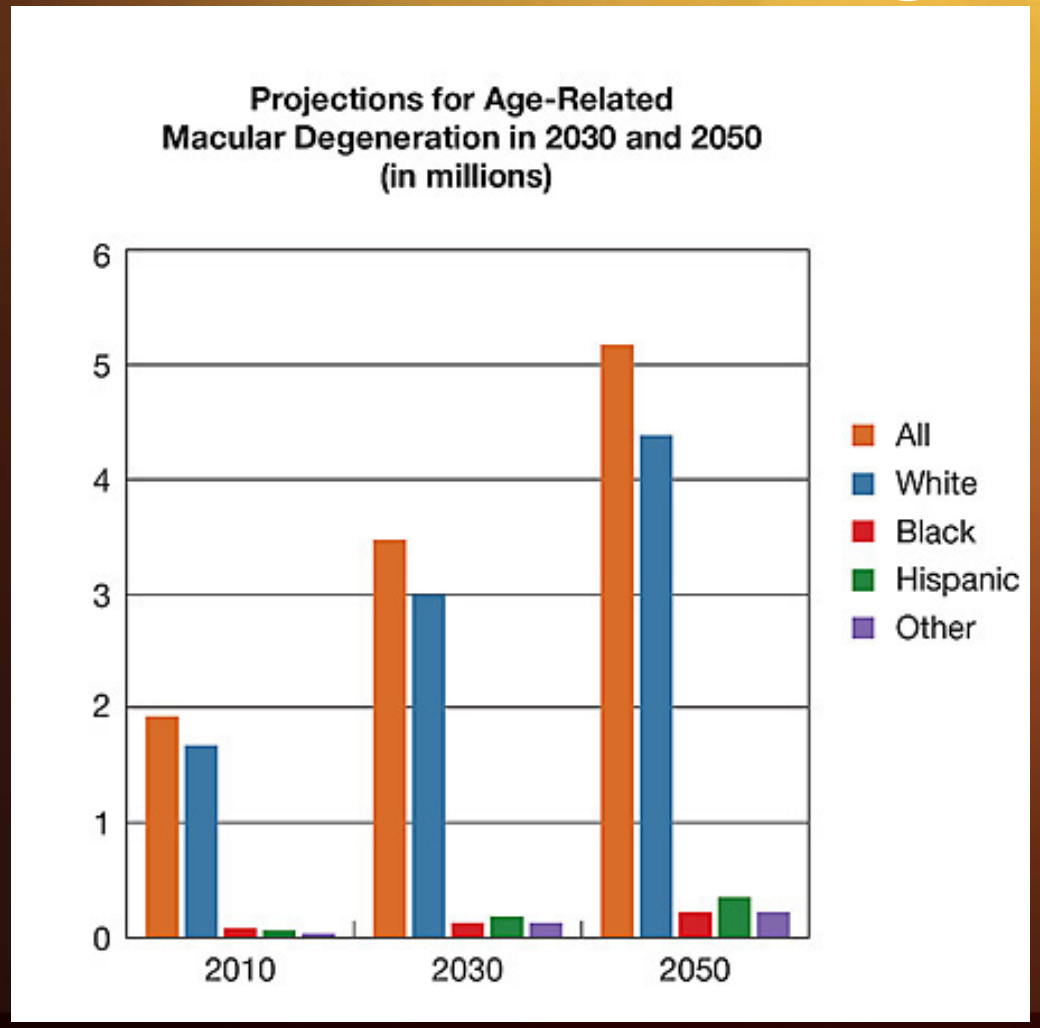
BLUE LIGHT HAZARD (BLH)

Age-Related Macular Degeneration (AMD)



- AMD is a leading cause of vision loss in the U.S.
- It destroys the macula, the part of the eye that provides sharp, central vision needed for seeing objects clearly.
- AMD currently leads to progressive blindness in over 35% of persons over the age of 75.

http://www.sunnexbiotech.com/therapist/draft%20update%20to%20blue%20light%20and%20AMD.pdf

National Institute of Health, National Eye Institute https://nei.nih.gov/eyedata/amd

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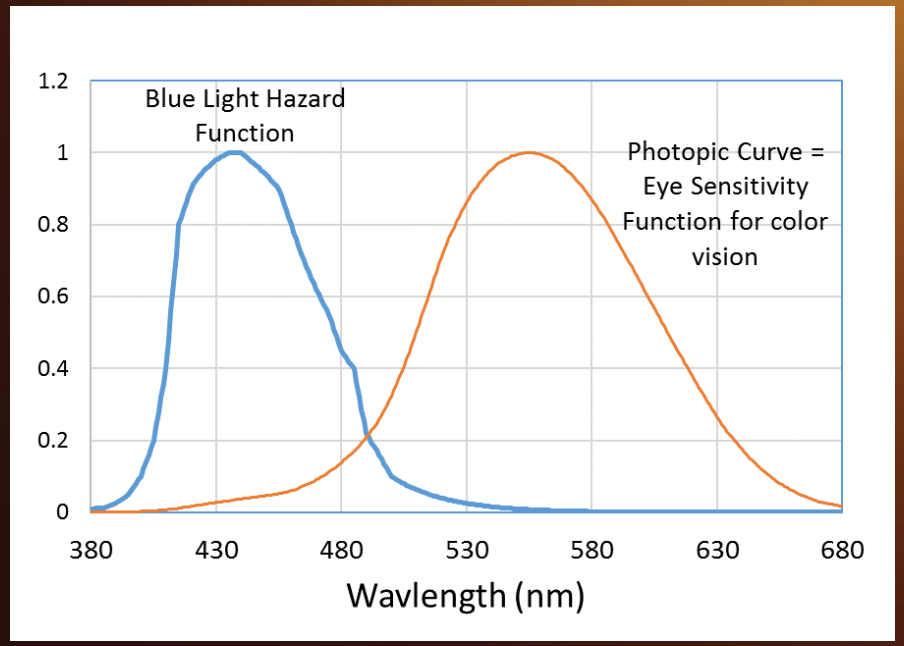
Links Between AMD and Exposure to Short Wavelength Blue Light

Short blue light → Oxidation in Tissues in Retina → AGE → Antioxidant Systems in Eye



Accumulating Photochemical Damage to Retina in the Macula

Age-Related Macular Degeneration

HAM, W.T. Jr, MUELLER, H.A., and SLINEY, D.H. "Retinal Sensitivity to Damage by Short-Wavelength Light". *Nature*, **260(5547)**, 153-155 (1976).

HAM, W.T. Jr, RUFFOLO, J.J. Jr, MUELLER, H.A., and GUERRY, D. The Nature of Retinal Radiation Damage: Dependence on Wavelength, Power Level and Exposure Time. *Vision Res.*, **20(12)**, 1105-1111 (1980).

1- TAYLOR H.R. et al, "The Long-term Effects of Visible Light on the Eye", Arch Ophthalmol. 1992;110(1):99-104. This study examined 838 watermen who worked on Chesapeake Bay.

"These data suggest that high levels of exposure to blue or visible light may cause ocular damage, especially later in life, and may be related to the development of age-related macular degeneration."[1]

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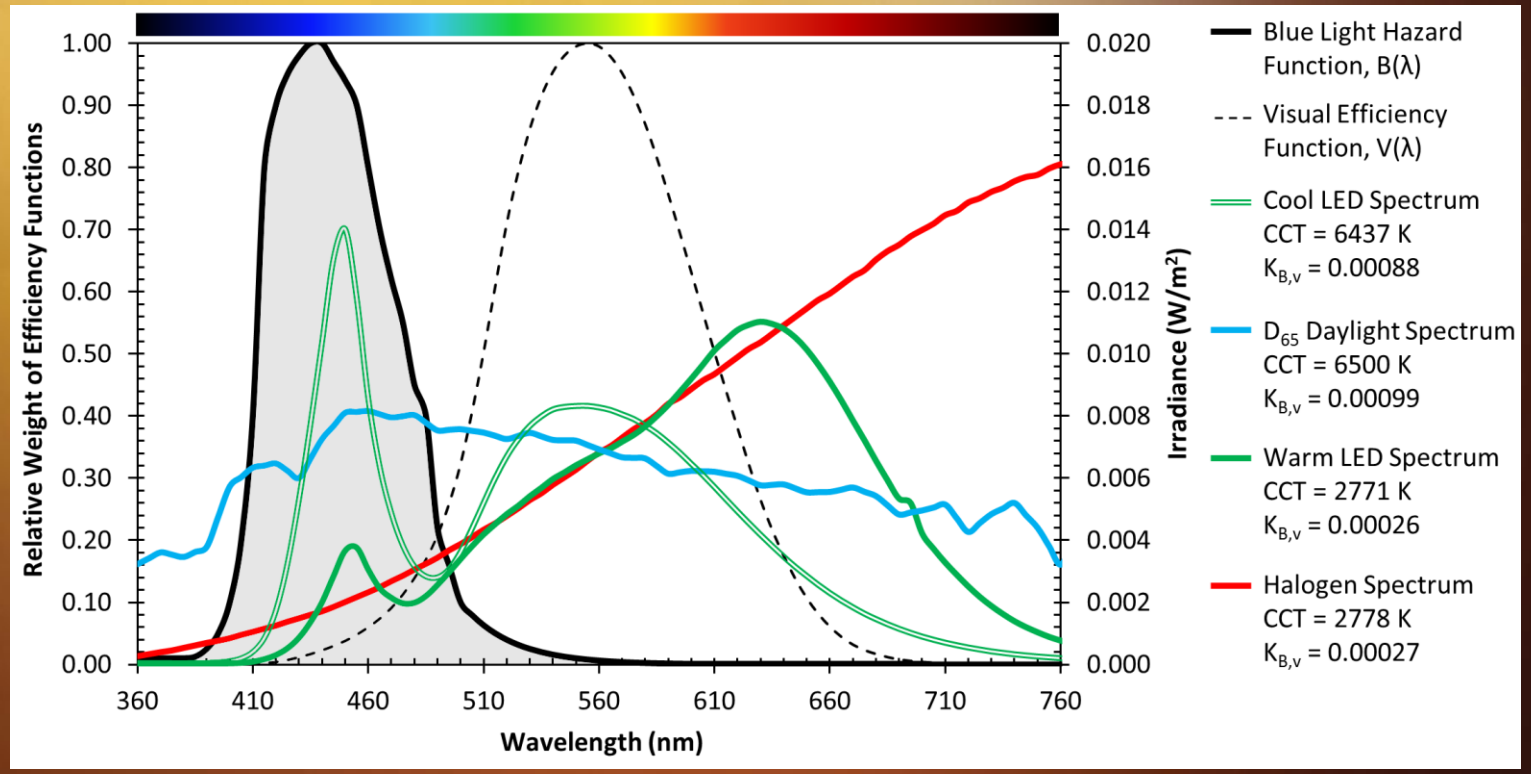
DOE EERE – "Optical Safety of LEDs" (June 2013) [1]



- The Blue Light Hazard risk of the LED blue-pump peak appears to average out. If BLH was based on irradiance, there would be no problem.
- However, the Blue Light damage to the retina depends on the **brightness of the source**.
  - The Blue Light Hazard risk-calculation models the "physiological" radiance from the source on the retina, including models for eye movement based on duration of exposure.

1- https://www1.eere.energy.gov/buildings/publications/.../opticalsafety_fact-sheet.pdf

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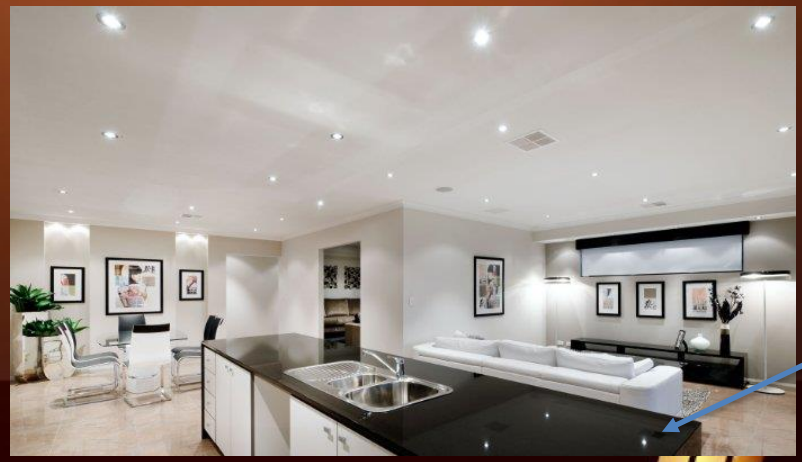
Blue Light Hazard

- Blue Light damage is proportional to radiance (W/m2/sr), which **does not decrease with distance**.
- For distant lights, the number of retinal cells affected goes down because the image is smaller, but **the rate of retinal damage in the affected area is equal**.
- Fortunately, eye and head motion spread the light across the retina reducing the rate of local damage.
- Avoid installing glary (bright) lights, especially ones with high blue content. Once a bright light exists, it hurts everyone who can see it from anywhere.



You can't escape

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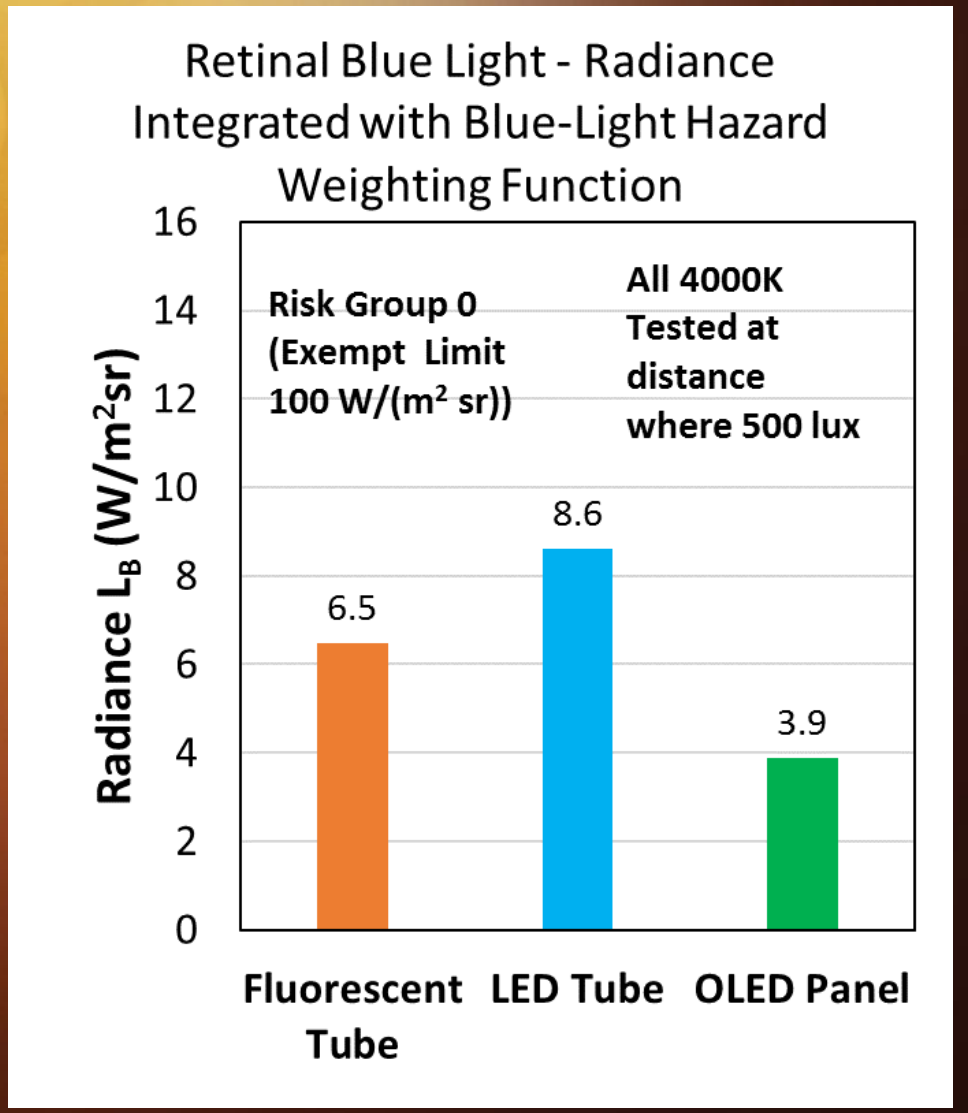
IEC 62471 – Photobiological Safety
Blue Light Hazard (BLH) Results

- The standard covers 6 risks to eye and skin (UV, BLH, IR).
  - Here we consider only the Blue Light Hazard
- IEC 62471 BLH test results are shown at the right for the following 4000K sources:
  - Fluorescent T8 tube[1] - 25% less than LED
  - LED T8 replacement tube[1]
    - Mid-power 150mW LED's @ ~1/cm
  - Lumiblade OLED lighting panel[2] – **55% less than LED**
- All these sources are "Risk Group 0" (< 100 W/(m² sr)) [3]
- OLED sources are better, however the total Blue Light Hazard from all these sources is small



1 - Leccese F., et al., "Evaluation of optical radiation emissions by a measurement campaign on LED sources for general lighting", 2015 IEEE 15th International Conference on Environment and Electrical Engineering (EEEIC), 10-13 June 2015, pp 689 - 694
2 - OLED lighting panel testing done at Intertek Testing Services, NA Inc., Cortland, NY, 13045 USA, 8300 cd/m²
3 - No Blue Light Hazard warning labels are required for Risk Group 0 or Risk Group 1 (down to max permissible exposure of 100 sec)

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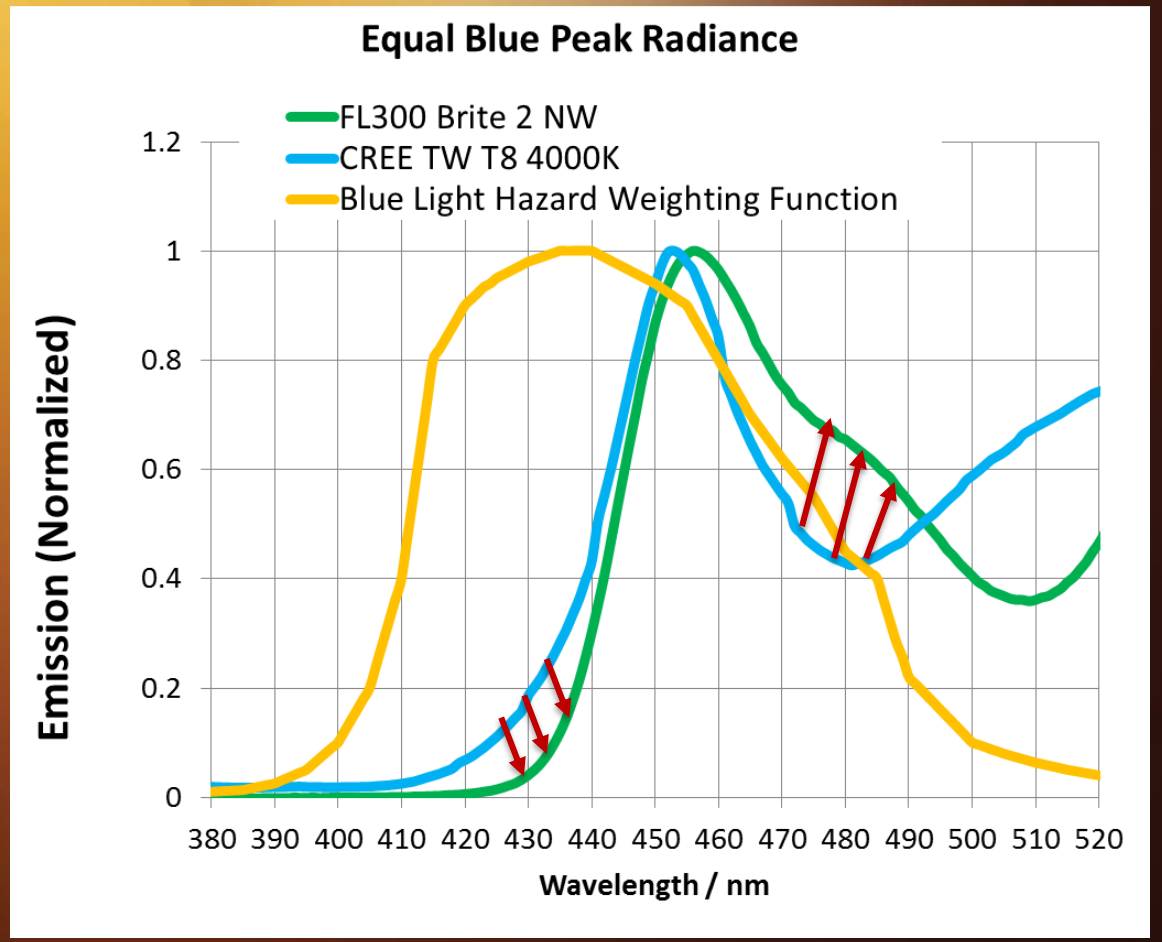
LED vs OLED Blue Light Hazard

- We all need blue light in our white light for good color reproduction (High CRI)
- OLED has less blue light on the short wavelength (higher energy) side and makes up for it with more of the longer-wavelength less-damaging blue light. We achieve CRI > 90.
- The main BLH advantage of OLED lighting is because it is naturally an “area light source” and the luminance (cd/m2, brightness) is lower than LED lighting sources



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Architectural LED Downlights

Cree XHP70

Cree KR4

- High-power LED's have increased from 1W to 32W, white efficacy has increased to 150 lm/W, LED's now offer > 4000 lm per package
- These have allowed very compact LED fixtures with intense tight beams of light for dramatic architectural effects.
- These are very popular in office environments
  - 34 are used to light the conference room shown at right
- 4-inch downlights are available in 3100 lm models
  - Peak luminance to >600,000 cd/m^2 – very bright[1]
    - Compares to the solar disk on horizon which is 600,000 cd/m^2 [2]

Beautiful – with 34 downlights

1 - Gotham EVO 35/30 4AR MD LS 4" LED Downlight 3500K 3300 lm, 5659 cd at center – max cd 5,828, 11 cm aperture http://www.visual-3d.com/tools/PhotometricViewer/Default.aspx?ID=88895

2 - http://www.schorsch.com/en/kbase/glossary/luminance.html

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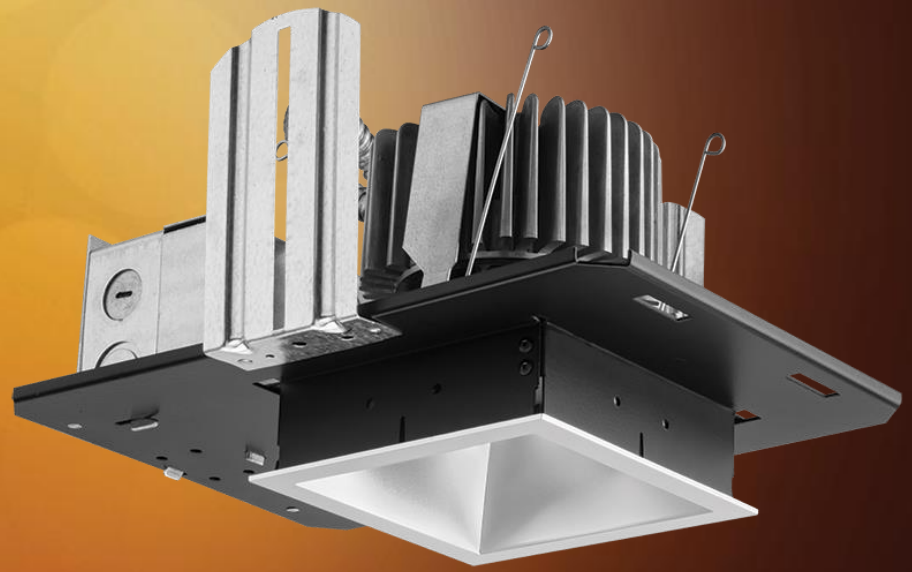
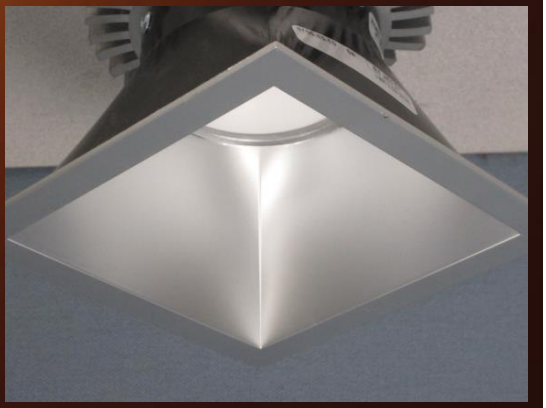
Off-angle Viewing – A Problem

- The light beams are narrow so total light output falls quickly off-angle.
- However, you can still see the bright disk off-angle and although total light is reduced, the brightness of the disk is high.
- For the popular square designs, the bright disk has larger visibility on the diagonal.
  - The smaller the source appears, the more the hazardous intensity is reduce by eye movement.
- Our gaze is attracted by bright light – like by a cell phone in a movie theatre.



View at ~30 degrees above horizontal



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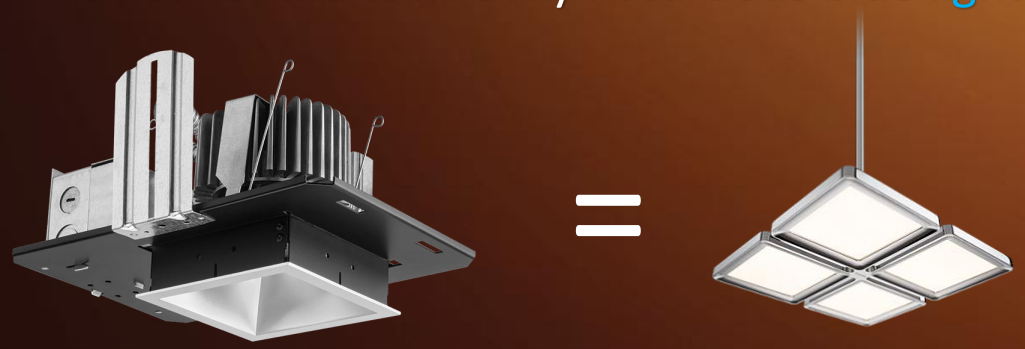
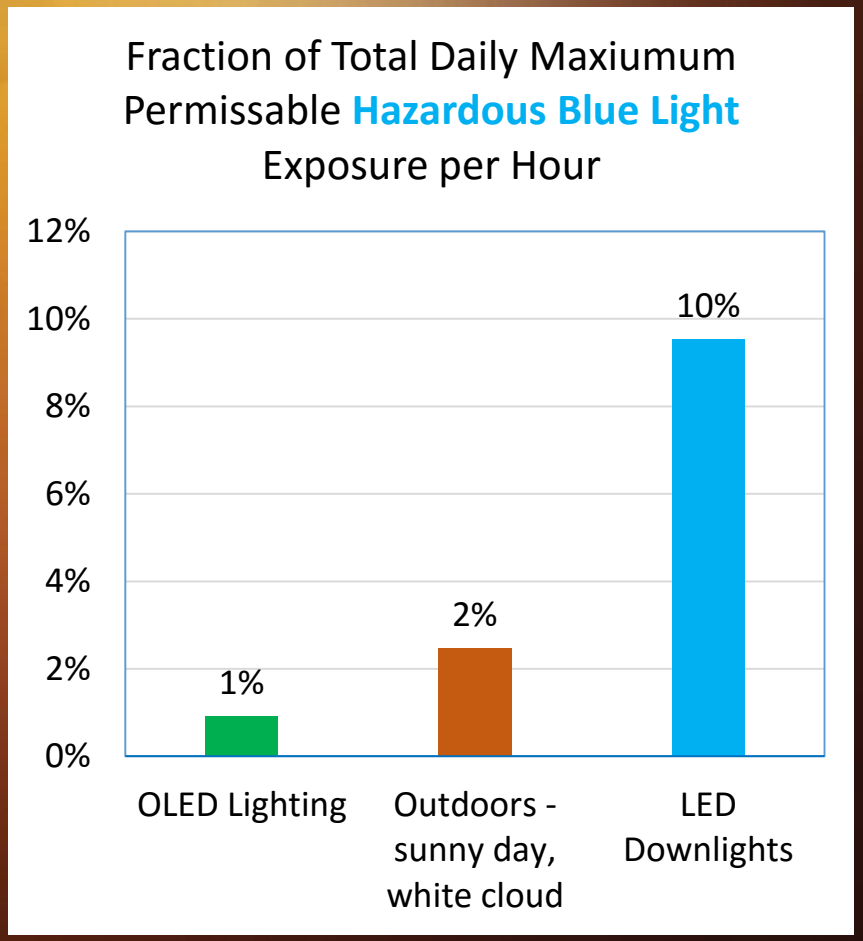
Daily Allowance of Hazardous Blue Light

- Each day the **maximum permissible allowance** of hazardous blue light is about 1 MJ/(m2 sr).
  - Equal to looking at the sun for about 1 sec at noon.
- If all your indoor light was all provided by OLED at 5000 cd/m2 (e.g. Trillia), 18 hours would be 16% of the total daily allowance.[1]
- ➢ Each hour of bright-disk viewing of **1200 lm** LED downlight is 10% of the total daily hazardous blue light allowance.[2]



In terms of total light, these are equal. **The OLED BLH risk is 10 times less.**
The Blue Light Hazard for OLED is independent of the number of panels.



All sources are "Exempt" sources so technically not included in Daily Blue Light Hazard Total

1 – FL300 NNW 4000K, 5000 cd/m2, , $K_{B,v}$ = 0.00051 W/lm, L_B = ~2.6 W/(m² sr). Blue Light Hazard energy = 9.1kJ/(m² sr hr).
2 - Gotham EVO 4" SQ 3500K 1200 lm, 1450 cd max, 500 lx at 1.7m, 64k cd/m2, $K_{B,v}$ = 0.000416 W/lm [IEC TR 62778:2014 pg 13] L_B = ~26 W/(m² sr). Blue Light Hazard energy per hour = 95kJ/(m² sr hr).

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OLED - A Safer Lighting Choice

- Humans need blue light – for good color rendering and for syncing our circadian rhythm to the local time.
- Bright short-wavelength blue light can cause cumulative damage to the retina which has been linked to Age-Related Macular Degeneration.
- LED's have enabled compact fixtures with very high brightness for dramatic architectural purposes.
  - This light can make up a lot of your daily Blue Light Hazard allowance.
- OLED lights can deliver the same amount and quality of light as the LED downlights with significantly less Hazardous Blue Light.

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Light Better™

- Solid State Lighting is the future and OLED will be a significant part of it.
- Applications where OLED will initially grow will be:
  - Close to the user – due to the high light quality, low glare, and low temperature.
  - Low volume and weight.
  - Products where design elements affect buying decisions
  - Reduced **Blue Light Hazard** risk – including for children
- The combination of thinness, lightness, and flexibility of OLED will be key differentiators from LED.
- OLEDWorks will continue to introduce products with higher performance, lower cost and unique form factors to grow the market.

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