OLED Manufacturing and Integration Challenges

Jeff Spindler, OLEDWorks

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OLEDWorks
Naturally Illuminating

Complementary Solid-State Light Sources

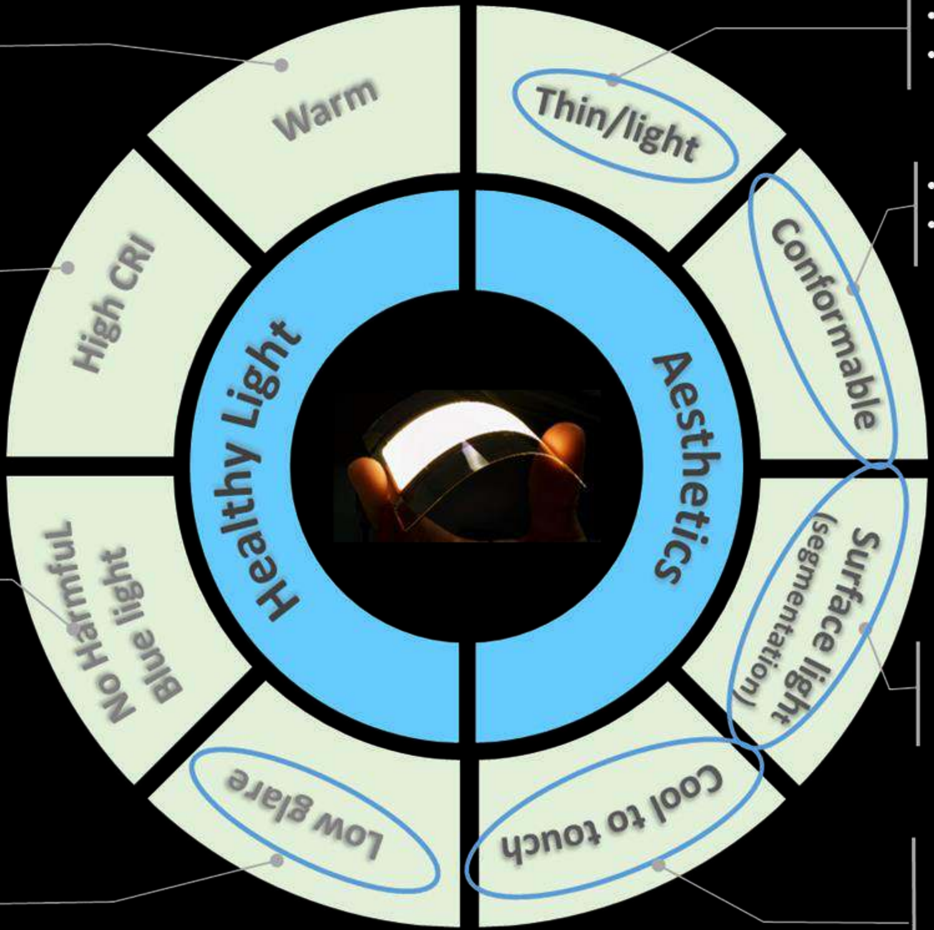
LED: Extremely intense point source of light
Most efficient at cooler CCTs

OLED: Naturally diffuse area light source
Most efficient at warmer CCTs

- Fundamentally different by nature
- Greatest energy efficiency and human benefits realized when used in a complementary manner: “Lighting application efficiency”

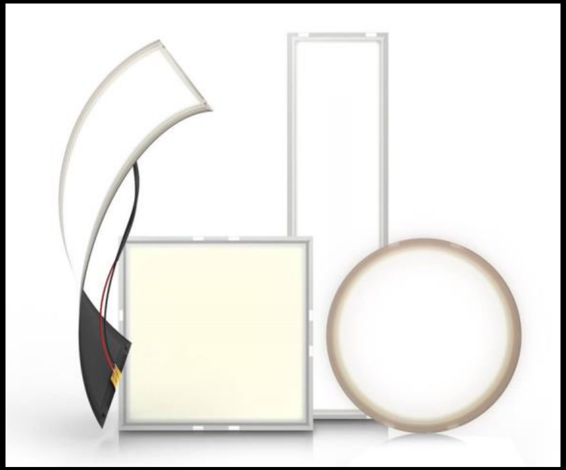
OLED Benefits

- Warm with high efficacy
- Naturally like sunlight without compromising efficacy
- Better for your eyes
- No impact on sleep
- Better for your eyes
- Comfortable lighting

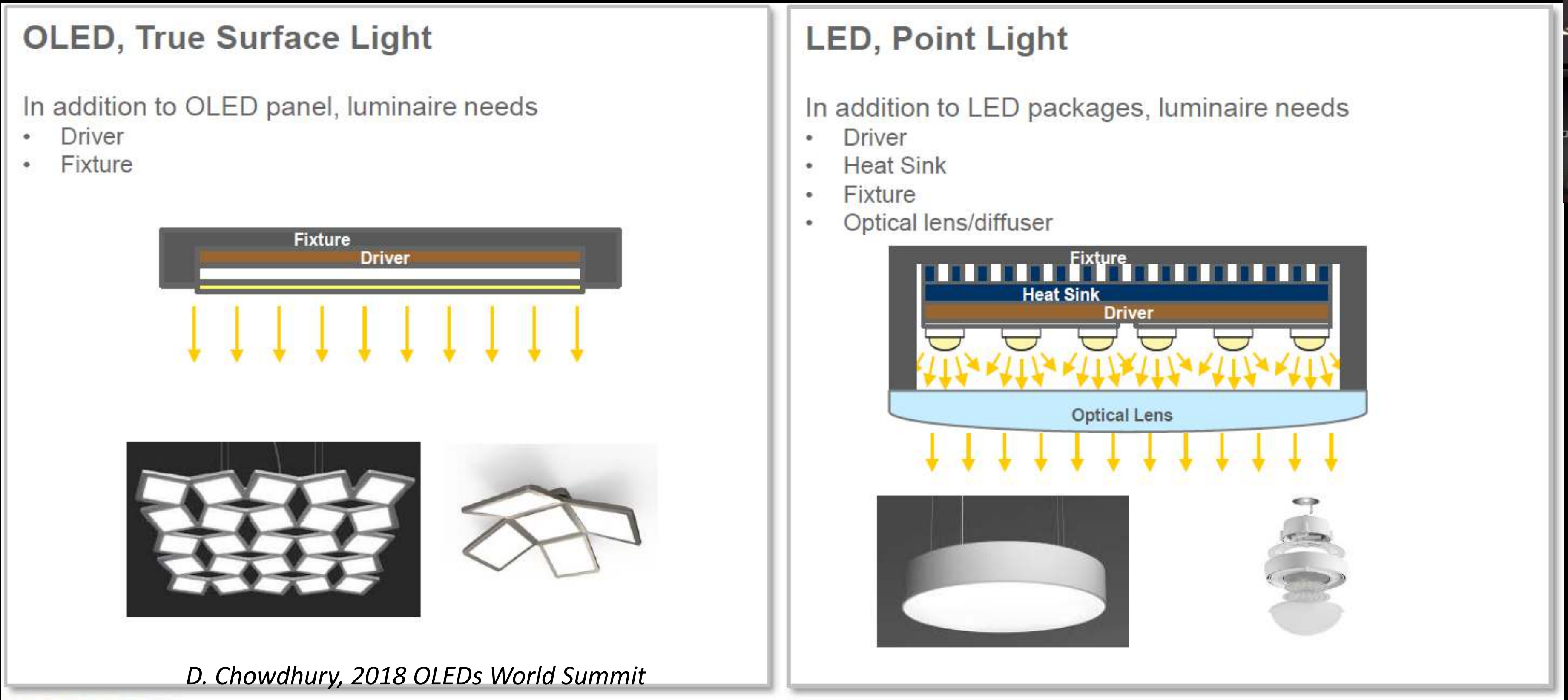


- Easy integration
- Low weight/lumen
- New design space
- Surface integration
- Naturally segmented
- No diffuser
- Closer to user
- Easy to integrate
- No heat sink

Lighting panels or tiles that are thin, lightweight, cool to the touch, both rigid and bendable forms



Luminaire Integration



D. Chowdhury, 2018 OLEDs World Summit

- Simpler integration for OLEDs
- Hybrid LED+OLED fixtures can be very efficient, beautiful, and cost-effective
- Integrated fixture cost is similar even with higher initial cost of OLED panels

Efficacy

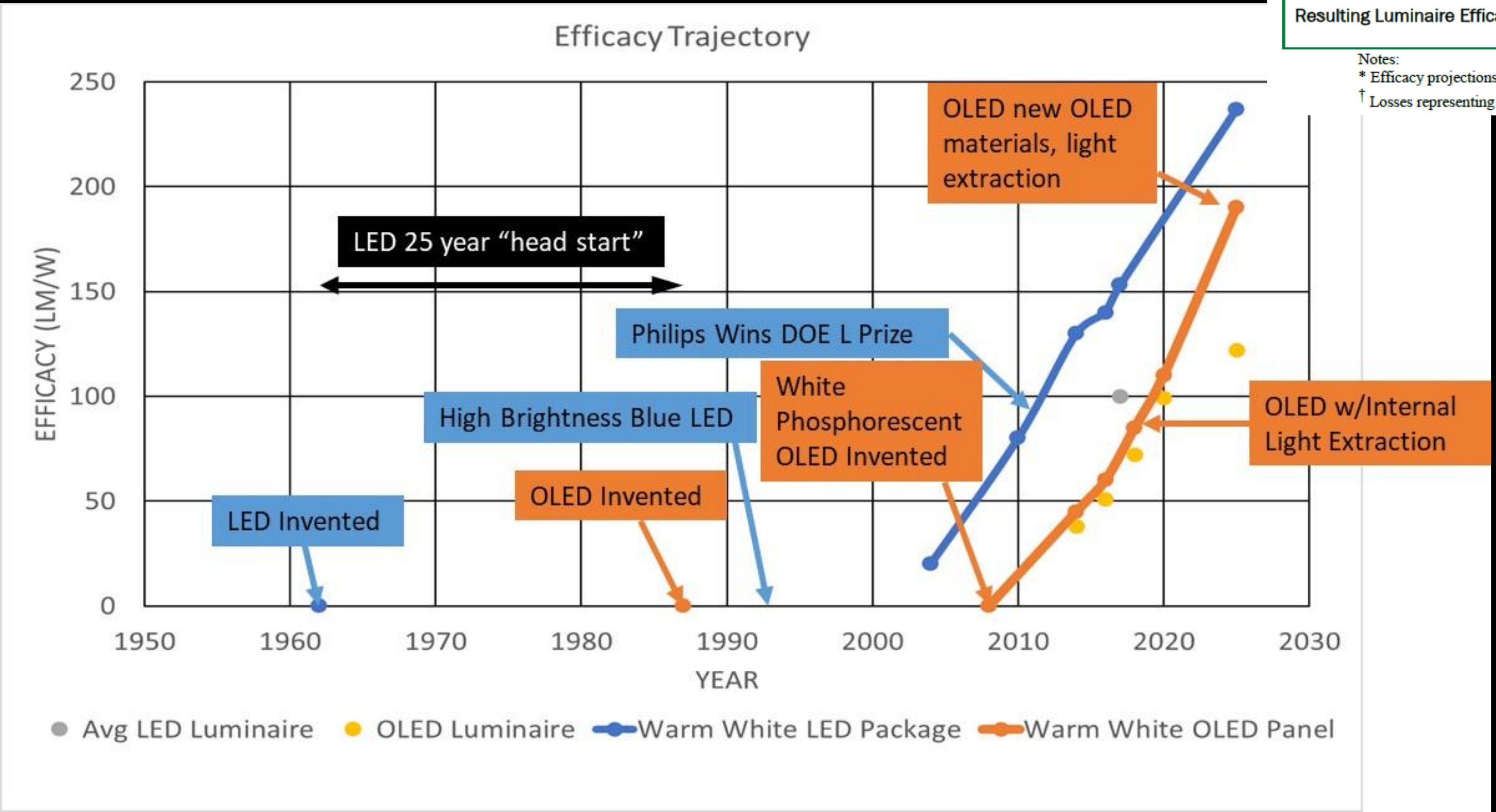


Table 3.8 Breakdown of warm-white OLED luminaire efficiency with historical and targeted performance projections.

Metric	2019	2022	2025	2035
Panel Efficacy[1] (lm/W)	85	120	155	180
Optical Efficiency of Luminaire	100%	100%	90%†	90%†
Efficiency of Driver	88%	90%	92%	95%
Total Efficiency from Device to Luminaire	88%	90%	81%	86%
Resulting Luminaire Efficacy* (lm/W)	72	108	128	154

Notes:
* Efficacy projections assume CRI >90, CCT 3000 K
† Losses representing possible use of beam shaping optics

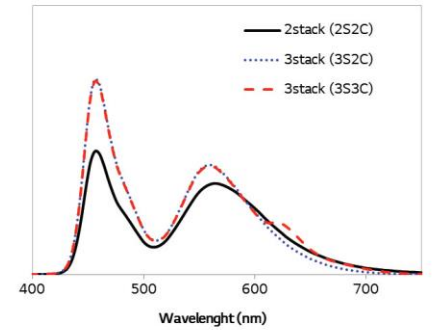
2019 DOE SSL R&D Opportunities

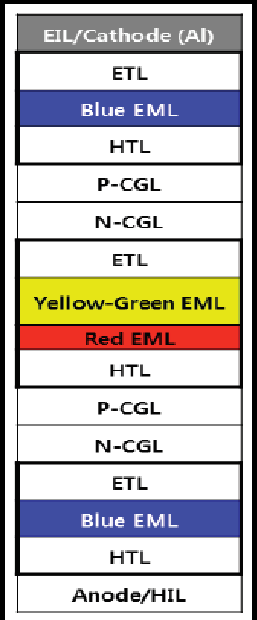
Manufacturing

- LEDs manufactured using semiconductor IC processing techniques
  - 2”-6” Wafer level processing
  - MOCVD is key process
  - Dicing into individual chips or dies
  - Packaging – single chips or multi-chip modules (MCM, COB, etc)
- OLEDs manufactured using flat panel display processing techniques
  - Gen2 (370x470mm) to Gen5 (1100x1300mm) glass substrate processing
  - Organic deposition (VTE) is key process
  - Singulation into individual panels
  - Backend finishing – EEL, electrical connection

Multi-Stack White OLEDs

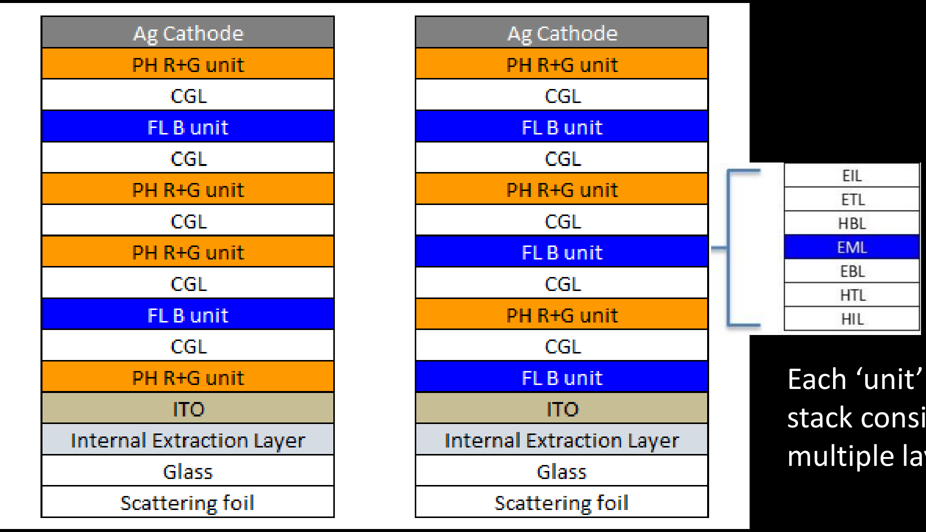
- Makes higher brightness and long lifetime possible
- Up to 6-stack OLEDs with 40+ organic layers



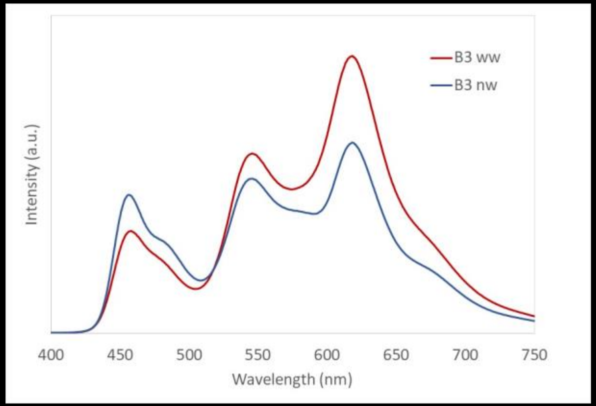


LG Display uses 3-stack white OLED for OLED TV (IDW 2018)

Warm white (3000K) **Neutral white (4000K)**



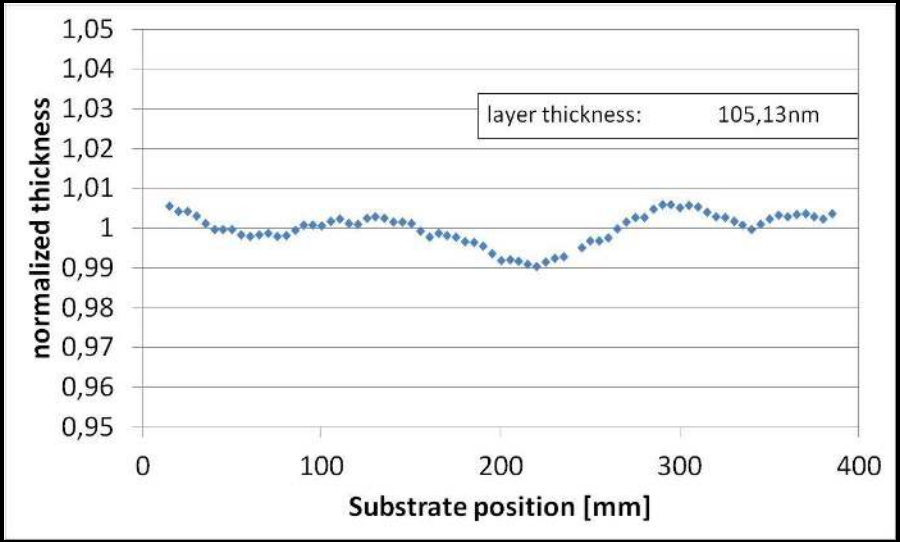
Each 'unit' or stack consists of multiple layers

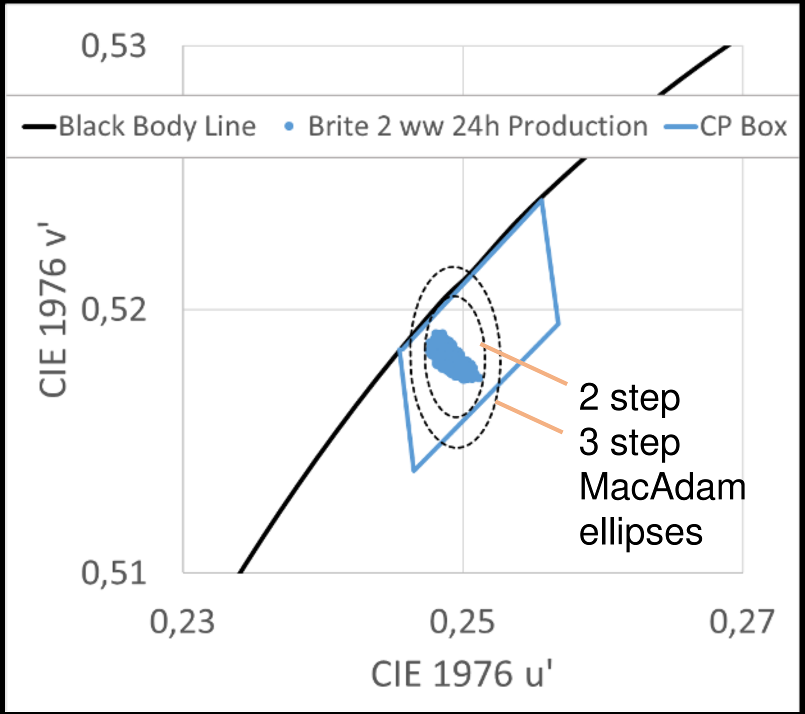


3000K Warm White (ww)	Standard Brightness (3000 cd/m^2) 100 lumens			High Brightness (8300 cd/m^2) 300 lumens		
Metric	B1	B2	**B3**	B1	B2	**B3**
Efficacy (lm/W)	46	63	**85**	42	57	**75**
CRI	80	90	**90**	80	90	**90**
R9	0	70	**55**	0	70	**55**
LT70 (kh)	50	75	**100**	10	15	**30**

OLED Manufacturing

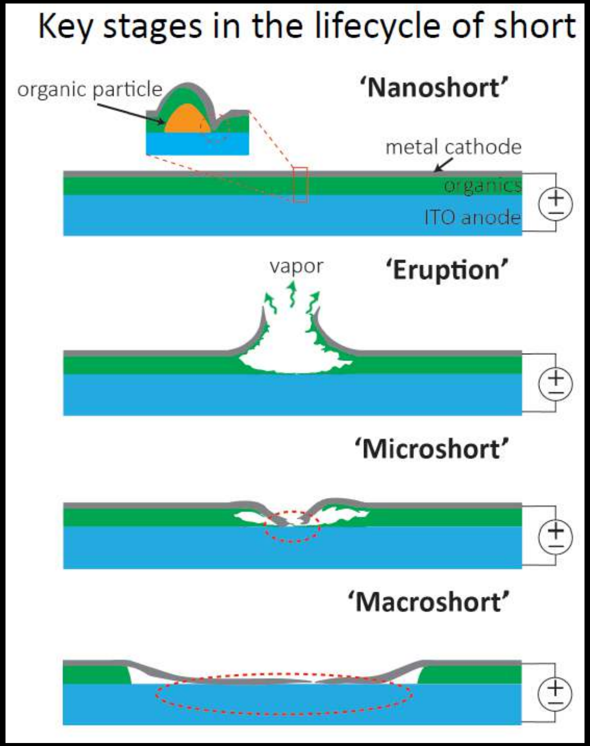
- Precise control of organic layer thickness (+/- 1%) required to maintain color and product quality
- Maintain constant deposition rates for 40+ sources over time, within batch and run-to-run





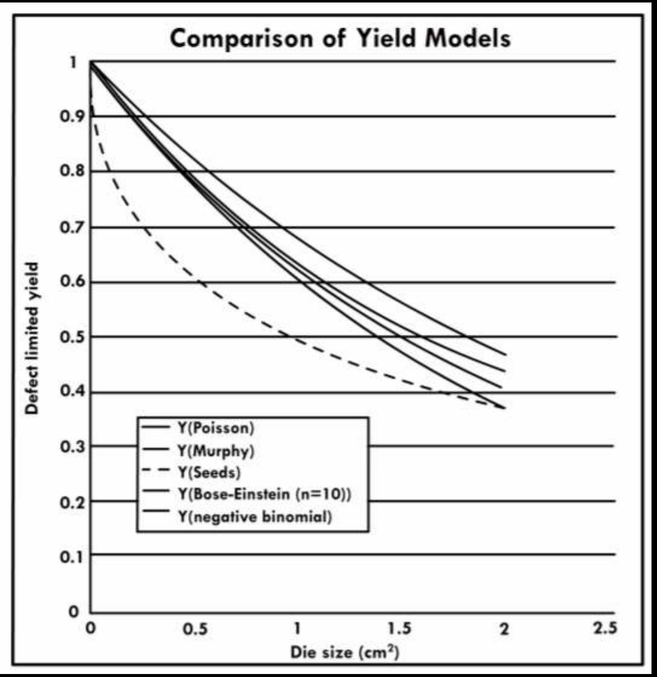
OLED Yield Considerations

- Large area device > 100cm^2 which is susceptible to particle defects and electrical leakage/shorts
- Need short tolerant structures and techniques for high yield
  - Smooth surfaces <5-10nm RMS, no abrupt changes in height
  - Thicker organic stacks
  - Routine cleaning of OLED deposition chamber, masks, etc.
  - Electrical short reduction techniques
  - Fuse-like layers, thin dielectric layers

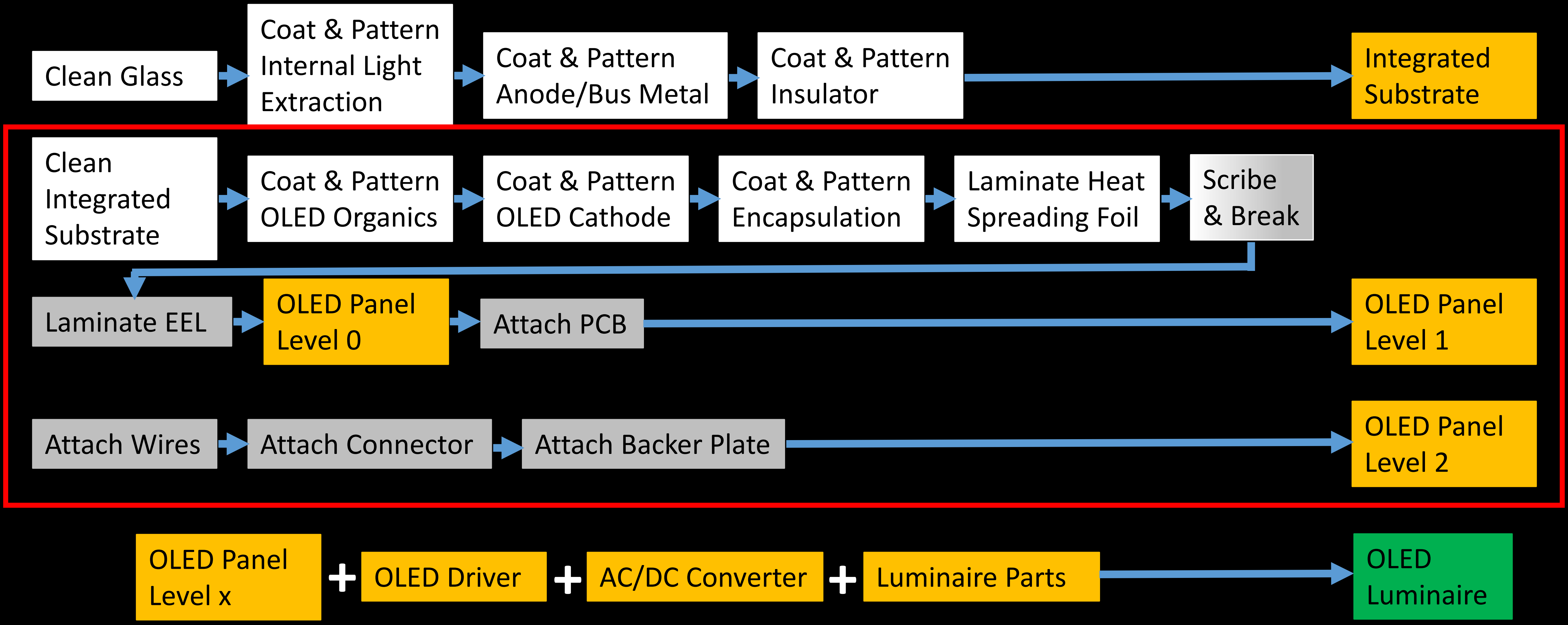


PSU DOE Project "Nature of Catastrophic Shorts in OLED Lighting", N. Giebink et al

Yield models for semiconductor ICs predict OLED yield should be ZERO



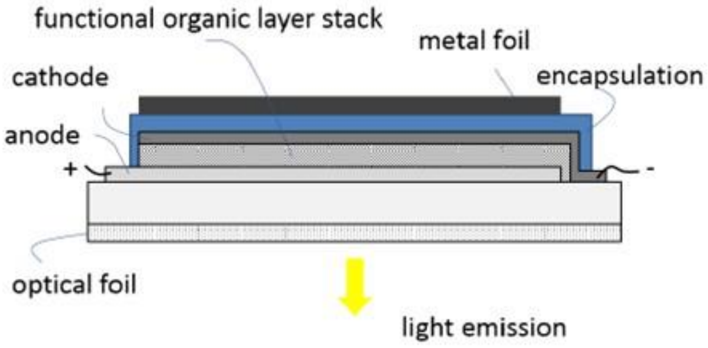
OLED Process Flow



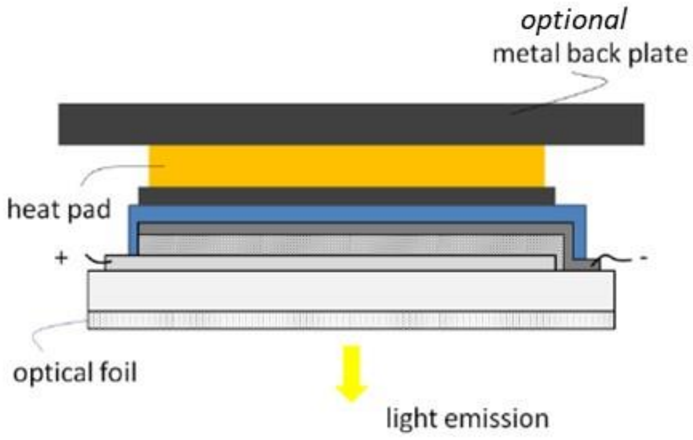
OLED Panel Integration

Level 0
Bare OLED Panel

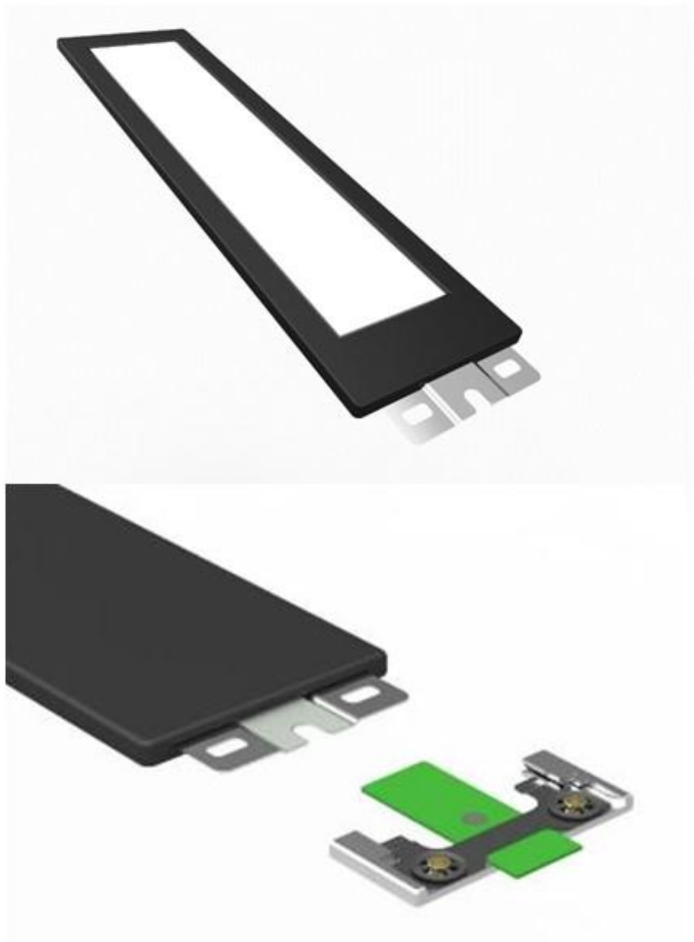
Level 1 PCB



Level 2
OLED Panel + Back Plate + Connector

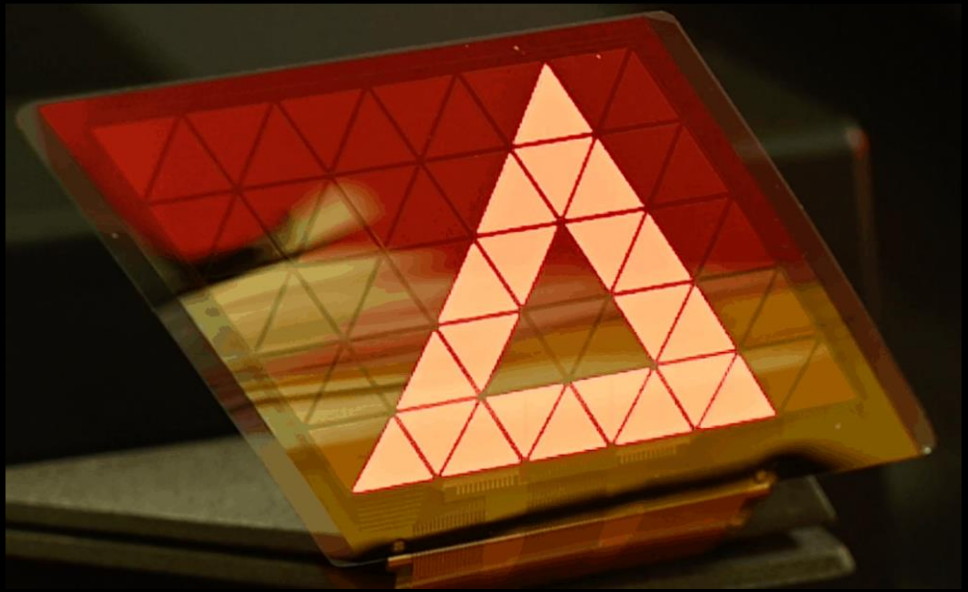


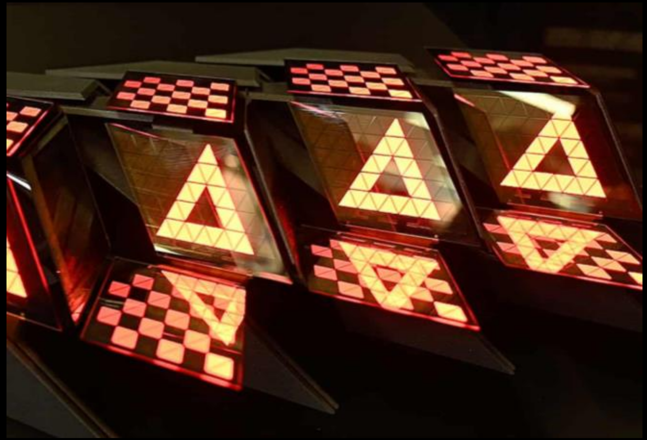
OLED Panel + Driver + Housing



OLEDWorks Keuka OLED Module

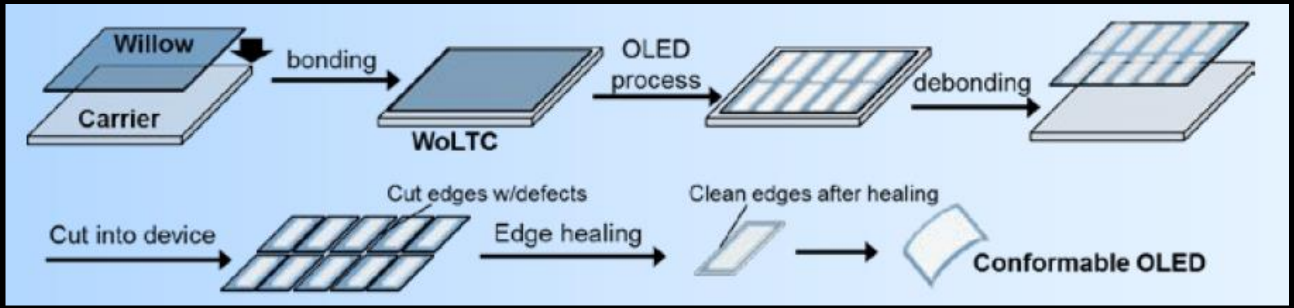
OLED Panel Integration - Automotive



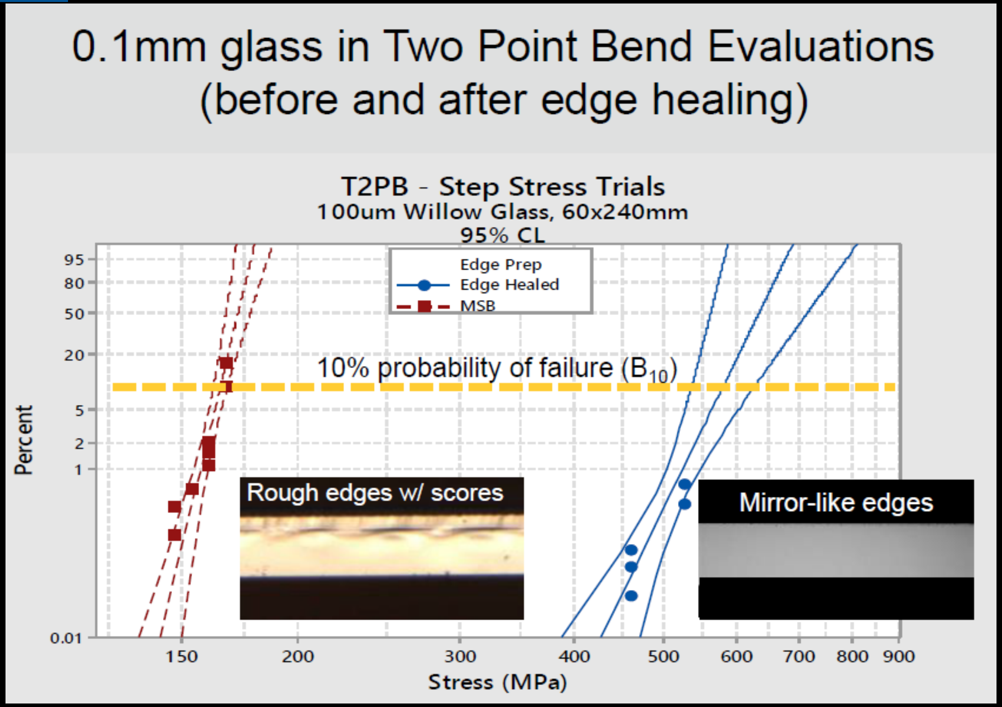


- Automotive panels include metallization on the substrate and flexible printed circuit (FPC)
- FPC connects to PCB containing driving electronics
- Control of individual lit segments, like a display
- Mirror-like ‘chrome’ finish – no light extraction films

Bendable OLED Manufacturing

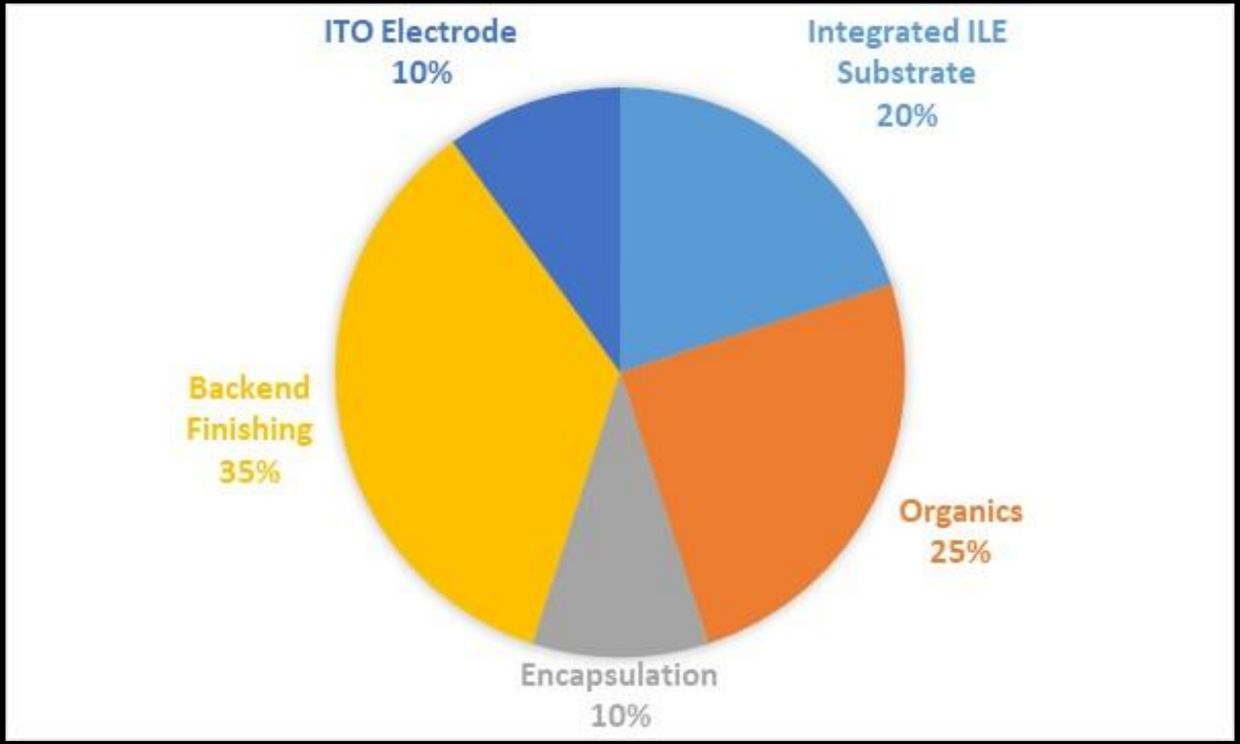


CORNING *D. Chowdhury, OLEDs World Summit 2018*



Bendable OLED Panel Integration

Current BOM Breakdown



Cost Reduction Needs

- Integrated Substrates
  - Higher throughput manufacturing for ILE, anode, insulator
    - Additive manufacturing – printing, etc.
    - ITO alternate
  - Vertical Integration with panel manufacturer (reduce substrate shipping costs)
- OLED Deposition
  - Higher throughput to reduce TACT
    - Thermally stable organic materials
  - VTE alternate? OVPD, OVJP, solution coating/printing, etc.
  - Better organic material utilization
  - Maskless patterning/deposition
- Encapsulation
  - All inorganic? Must be low capital and high throughput
  - PECVD alternate
  - Lamination type
- Backend Finishing
  - Eliminate EEL (external extraction film)
  - Lower cost electrical connection
  - Full automation

- Need lower capital cost options for all areas
- Need to consider R2R or R2S manufacturing for the future

Future Trends

- Higher brightness / more lumens per panel
  - Automotive functions may require > 20,000 cd/m^2 (deep red)
  - Horticulture – white or tuned spectrum
  - General lighting – commercial, outdoor, warehouse, etc. - reduce cost per lumen further
- Larger size OLED panels up to 1,000 cm^2 ($0.1m^2$)
  - General lighting, machine vision
- Spectral tuning for health, productivity, comfort

R&D needs:

- Better extraction efficiency – get the light out
- Light extraction that maintains mirror finish (no haze)
- Multi-stack OLEDs – improved CGLs, lower voltage per stack
- Improved blue emitters
- More conductive TCOs ~ 1 ohm/sq
- Heat management, thermal tolerance
- Yield management strategies, defect tolerance