GovEnergy
www.govenergy.gov
The Premier Energy Training Workshop and Trade Show for Federal Agencies

A River of Energy Solutions

Cutting Edge Lighting Technologies: OLEDs

August 10, 2011

Dr. John W. Curran,
President, LED Transformations, LLC

On behalf of the U.S. Department of Energy and NETL Morgantown

GovEnergy
www.govenergy.gov

Cutting Edge Lighting Technologies: OLEDs

August 10, 2011

Dr. John W. Curran,
President, LED Transformations, LLC

On behalf of the U.S. Department of Energy
and NETL Morgantown

LED Transformations LLC
Your Guide to Solid State Lighting

GovEnergy
www.govenergy.gov

Copyright Materials

This presentation is protected by US and International copyright laws. Reproduction, distribution, display and use of the presentation without written permission of LED Transformations, LLC is prohibited.

Outline

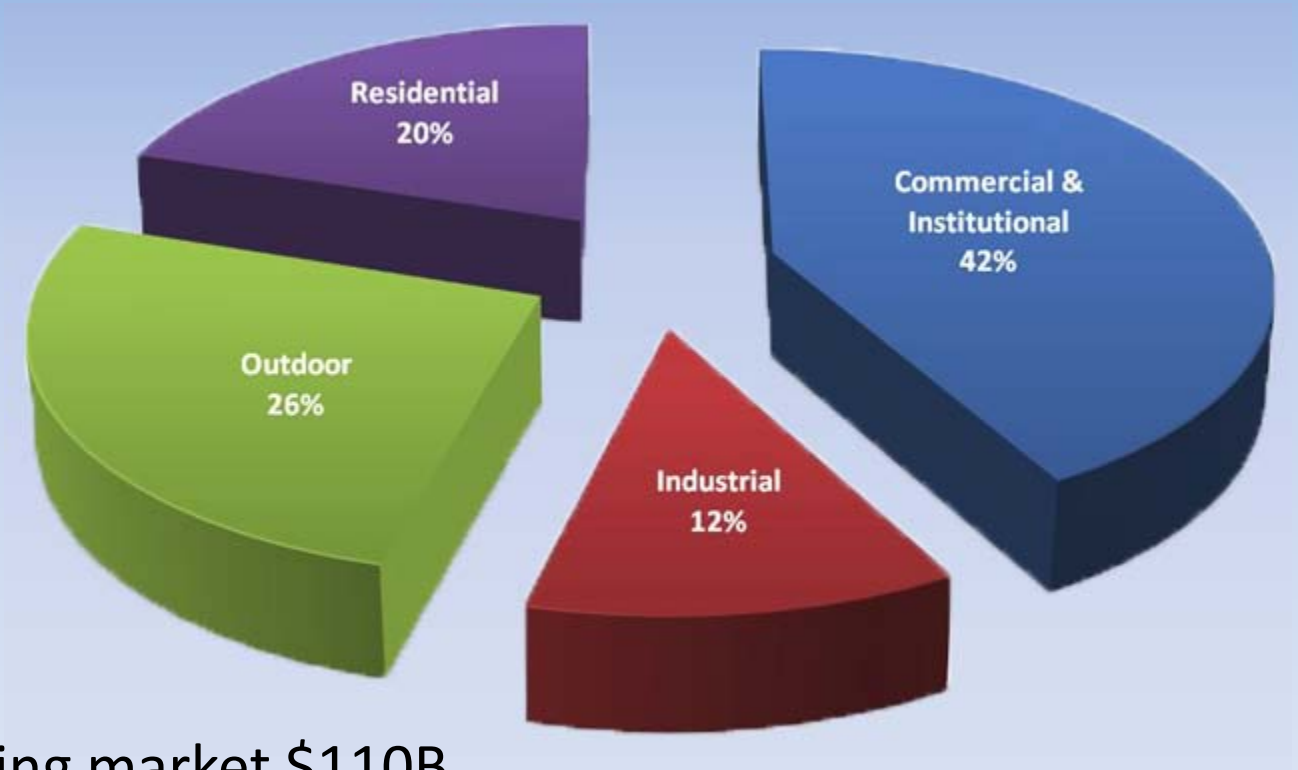
- Introduction – What are OLEDs
- Unique Features – What makes OLEDs different from other light sources?
- DOE Programs – Status of OLED technology and the research efforts to improve its performance
- Applications – Examples of OLED design

Source: GE

©2011 LED Transformations, LLC

The Lighting Market – Segments

Lighting Fixture Market Segments



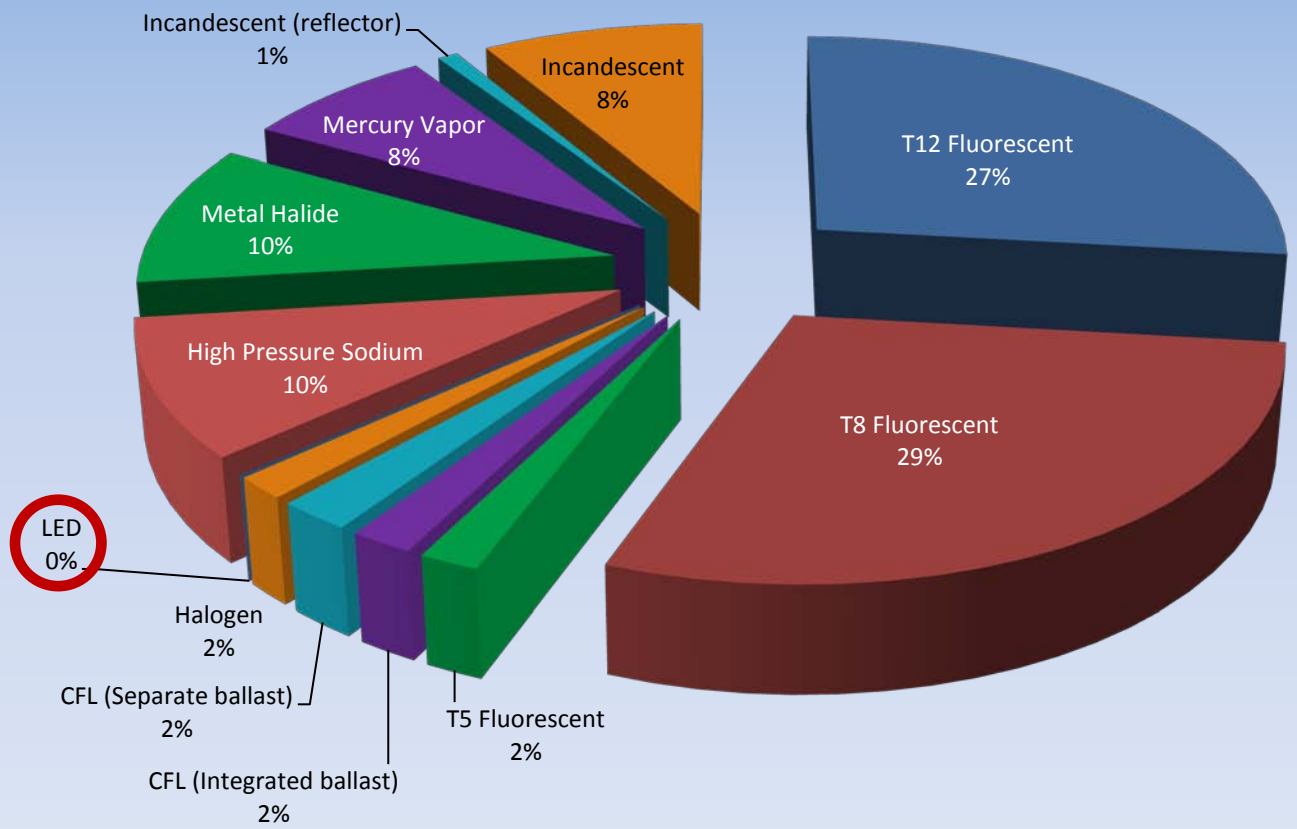
Global lighting market $110B
US market size $27B

Source: US DOE Multiyear Plan 2011

©2011 LED Transformations, LLC

The Lighting Market – Types of lamps in use

Lighting Market by Lamp Type



Data source: Dr Geoff Williams, Thorn, 2009

©2011 LED Transformations, LLC

Ways to Create Light – Two basic methods

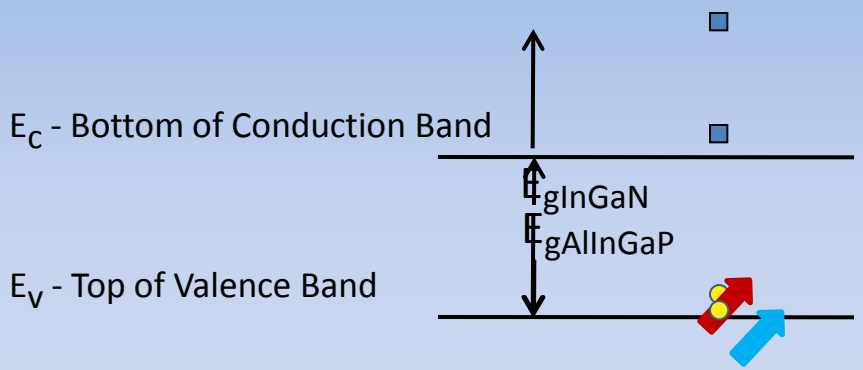
All light is produced by electronic transitions from higher to lower energy states. There are two ways to achieve this:

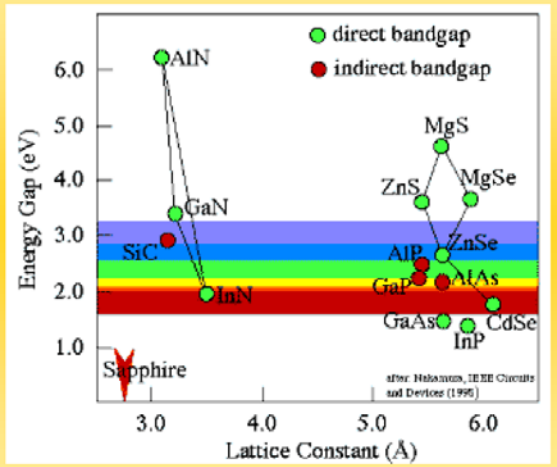
- Incandescence—Any light producing mechanism which involves heat
  - Pyroluminescence—Candles, flames, etc.
  - Filament—an electric current is passed through a resistive element (filament) which as it heats up produces light. The more heat it produces, the more light the filament emits
- Luminescence—Any light producing mechanism which does not involve heat; such mechanisms include:
  - Electroluminescence—how SSL devices work
  - Chemiluminescence—Glow sticks
  - Cathodoluminescence--CRTs
  - Photoluminescence—"Glow-in-the-dark" toys, watches, etc.

©2011 LED Transformations, LLC

How do SSL devices produce light?

Bandgaps – Different gaps, different colors





Source: Ian Ferguson, NC University

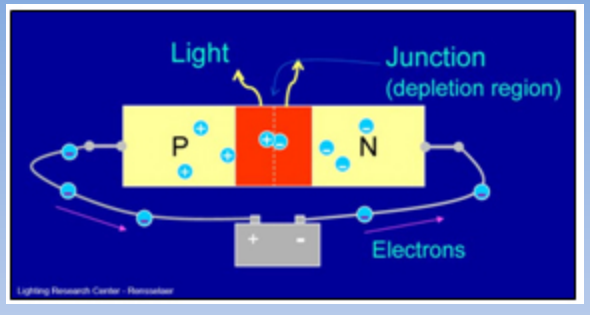
Electron Hole Photon

Smaller bandgap ➔ Lower energy ➔ Longer wavelength photon ➔ Red

Larger bandgap ➔ Higher energy ➔ Shorter wavelength photon ➔ Blue

©2011 LED Transformations, LLC

What is an LED?



An LED (**L**ight **E**mitting **D**iode) consists of a chip of semiconducting material treated to create a structure called a p-n (positive-negative) junction

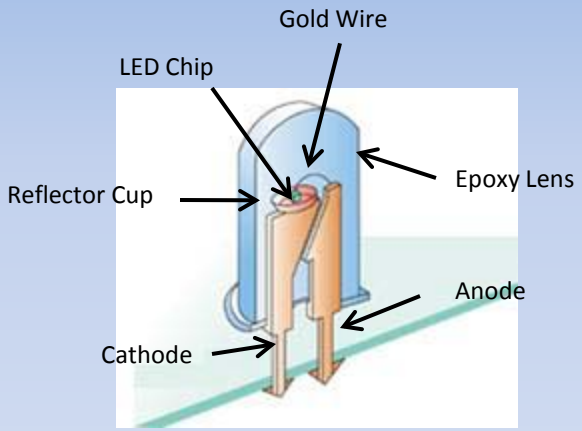


Diagram of a 5mm LED

The <u>heatsink</u> is what allows the high flux LED to generate much more light

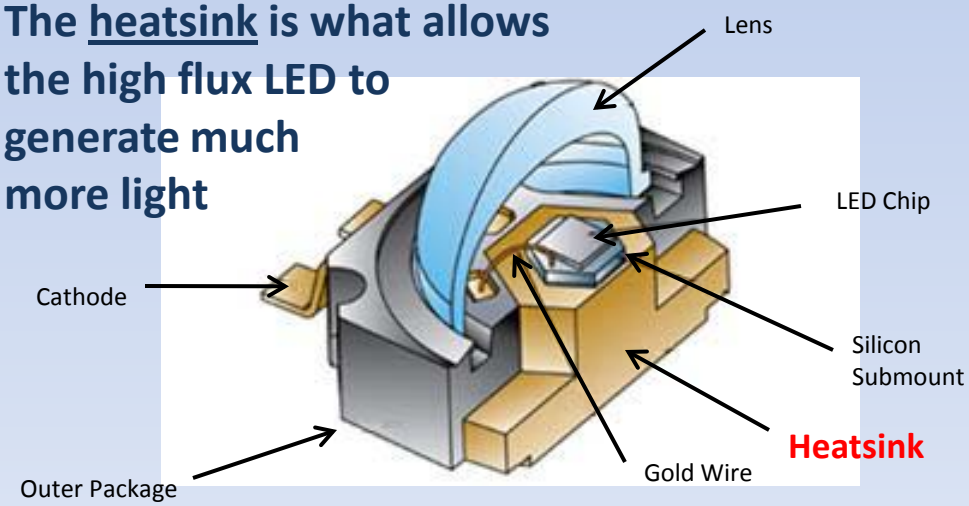


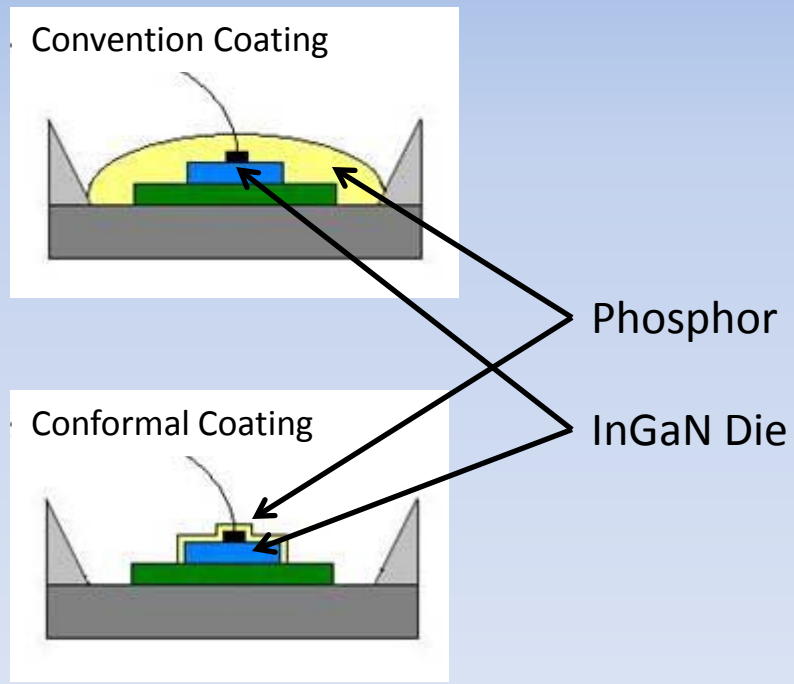
Diagram of a high flux LED

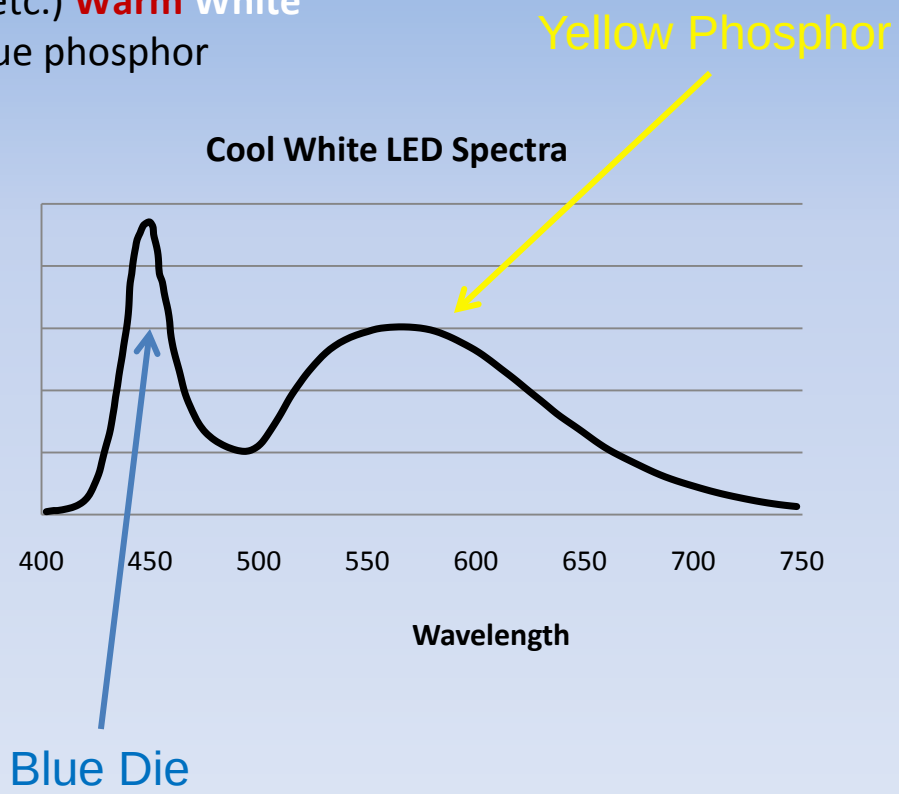
©2011 LED Transformations, LLC

How Do You Make a White LED?

Downconverting Phosphor

- Blue LED + YAG **Cool White**
- Blue LED + YAG + Other phosphor (red, green, etc.) **Warm White**
- UV LED + Red phosphor + Green phosphor + Blue phosphor

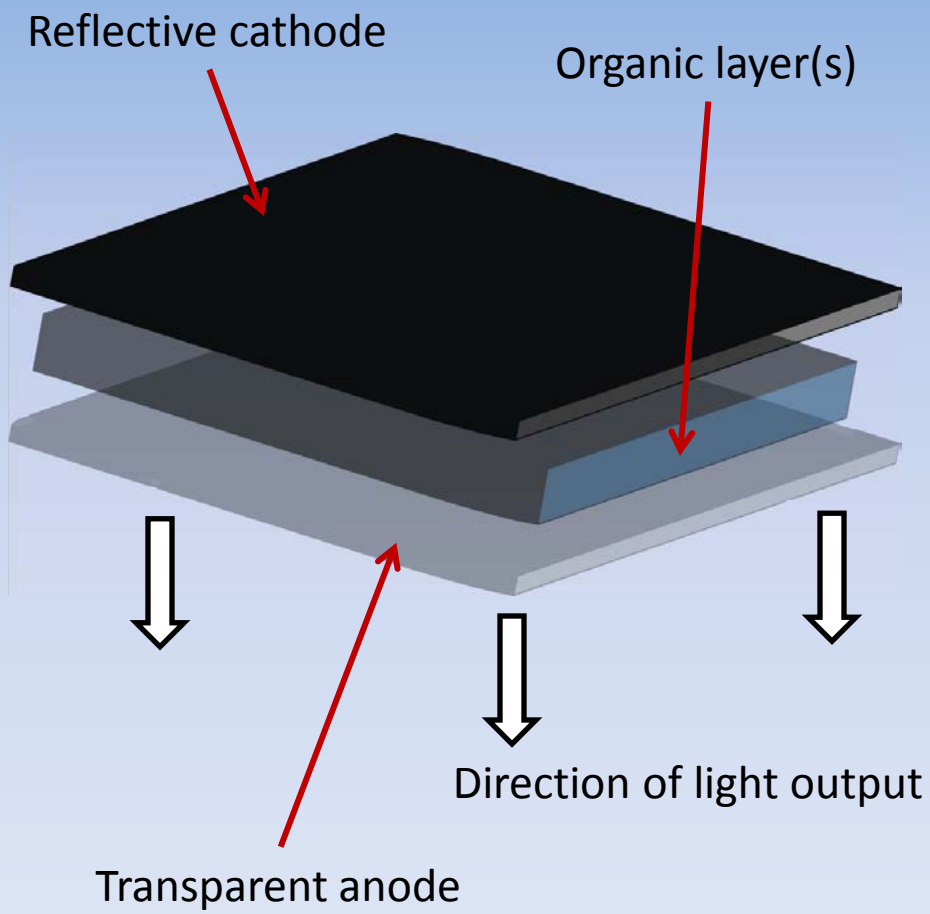




©2011 LED Transformations, LLC

What is an OLED?

- An OLED or organic light-emitting diode is a semiconductor device which consists of an electroluminescent organic layer(s) sandwiched between two electrodes, one of which is transparent.
- The device is fabricated by sequentially depositing organic layers on a conducting substrate followed by another conducting electrode.
- A common device structure comprises a glass substrate coated with indium tin oxide (ITO) as transparent anode and a thin, opaque metal film as cathode.
- Typical separation between layers is 100 nm or less



©2011 LED Transformations, LLC

A Close-up View of an OLED

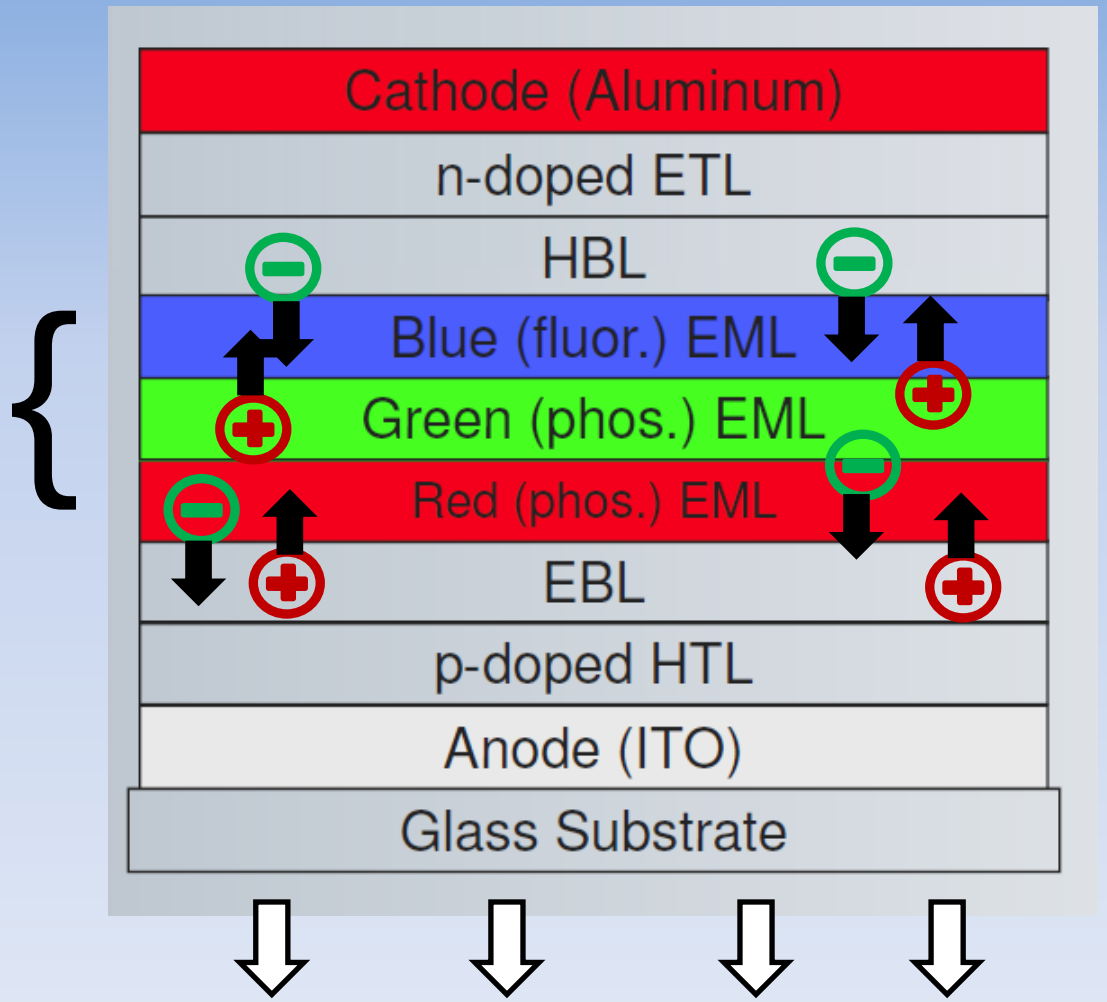
Electron **T**ransport **L**ayer

Hole **B**locking **L**ayer

Emission **L**ayers

Electron **B**locking **L**ayer

Hole **T**ransport **L**ayer



©2011 LED Transformations, LLC

Some OLED Terms

- Small molecule OLEDs – (SM-OLEDs)
  - Majority of today's devices, high performance, generally deposited by vapor phase deposition
- Large molecule OLEDs – (P-OLEDs or Polymer OLEDs)
  - Are solution processable (i.e. ink-jet printing and spin coating fabrication)
- Fluorescent materials (less efficient but last longer)
- Phosphorescent materials (more efficient/lower lifetime blue)

©2011 LED Transformations, LLC

Introduction

A Major OLED problem – Cost

$3.73/lumen

Lumen output 99 lm

Efficacy = 10.7 lm/W

Cost is about $370

Product Series

OLED Lighting Datasheet

Models		Standard (for design purposes)*1									
		Square Models				Rectangular Models					
		P04B0909L-A12A	P03B0909N-A12A	P04A0404L-A12A	P03A0404N-A12A	P04C1312L-A12A	P03C1312N-A12A	P04D0909L-A12A	P03D0909N-A12A	P04E0606L-A12A	P03E0606N-A12A
Extanals											
Size (W x L x T)	mm	145 x 145 x 2.3		97.6 x 97.6 x 2.1		287 x 97 x 2.3		287 x 74 x 2.3		287 x 59.5 x 2.3	
Active Area (W x L)	cm²	125 x 125		77.8 x 77.8		264 x 76.8		264 x 53.8		264 x 39.3	
Weight	g	107		43		143		107		84	
Correlated Color Temperatur	K	2,800 (Lamp Color)	4,900 (Natural White)	2,800 (Lamp Color)	4,900 (Natural White)	2,800 (Lamp Color)	4,900 (Natural White)	2,800 (Lamp Color)	4,900 (Natural White)	2,800 (Lamp Color)	4,900 (Natural White)
Maximum Luminous Flux	lm	99	99	40	40	134	134	94	94	68	68
Maximum Luminance	cd/m²	2,800	2,700	2,800	2,700	2,800	2,700	2,800	2,700	2,800	2,700
Color Rendering Index	Ra	82	81	82	81	82	81	82	81	82	81
Chromaticity Coordinates	(x,y)	(0.45, 0.42)	(0.35, 0.38)	(0.45, 0.42)	(0.35, 0.38)	(0.45, 0.42)	(0.35, 0.38)	(0.45, 0.42)	(0.35, 0.38)	(0.45, 0.42)	(0.35, 0.38)
Rated Current	A	0.90	0.90	0.36	0.36	1.22	1.22	0.85	0.85	0.62	0.62
Rated Voltage*2	V	10.7	10.5	10.7	10.5	10.7	10.5	10.7	10.5	10.7	10.5
Energy Consumption	W	9.6	9.5	3.9	3.8	13.0	12.9	9.1	8.9	6.7	6.5
Energy Efficiency	lm/W	10.7	10.5	10.7	10.5	10.7	10.5	10.7	10.5	10.7	10.5
Life-time 50% luminance @1000 cd/m²	h	50,000	100,000	50,000	100,000	50,000	100,000	50,000	100,000	50,000	100,000
Life-time 50% luminance @3000 cd/m²	h	10,000	20,000	10,000	20,000	10,000	20,000	10,000	20,000	10,000	20,000
Life-time 70% luminance @1000 cd/m²	h	25,000	50,000	25,000	50,000	25,000	50,000	25,000	50,000	25,000	50,000
Life-time 70% luminance @3000 cd/m²	h	5,000	10,000	5,000	10,000	5,000	10,000	5,000	10,000	5,000	10,000
Target Panel Price (@€1=¥115)	€	260	260	115	115	350	350	260	260	210	210
	¥	30,000	30,000	13,000	13,000	40,000	40,000	30,000	30,000	24,000	24,000

<Remarks>
*1 The figures here is subject to be changed without any notice. The panel without an out-coupling film will be a custom-made item.
*2 A constant current power source is needed since a rated current defines a rated voltage. A protection circuit to turn off electricity is needed in case of short circuit. The voltage changes followed by panel temperature. The rated voltages are values under room temperature (23 degrees C).
*3 The above performance data are values obtained when operating at the rated current. Surface temperature of the panel must be not more than 60 degree C.
*4 The above life-time and color shift data are reference values and non-guaranteed values.
*5 The above Panel Price are excluding VAT and transport costs.

© 2011 Lumiotec Inc. All rights reserved.

Lumiotec

OLED Manufacturing Speak – What are "Gens"

"Gen" refers to the generation of manufacturing line which are based on size of glass panel which the line is capable of producing. Each generation is capable of producing larger and larger panels of glass. This brings down the cost of the substrate on which the OLED is manufactured.

Presently Gen 5.5 →

Maximum number of panels per glass sheet

Generation	Dimensions (mm)	Panel size (diagonal inches)								
		3	10	15	32	40	42	46	52	55
1 (AUO)	300 x 400	43	3	1						
1 (SEC)	270 x 360	34	3	1						
2	370 x 470	62	5	2						
3	550 x 650	128	11	5	1					
3.5	620 x 720	160	14	6	1					
4	730 x 920	240	21	9	2	1	1	1		
5	1,100 x 1,250	493	44	19	4	2	2	2	1	1
6	1,500 x 1,850	995	89	39	8	5	5	4	3	2
7	1,870 x 2,200	1,476	132	59	12	8	7	6	4	4
7.5	1,950 x 2,250	1,574	141	62	13	8	8	6	5	4
8	2,160 x 2,460	1,906	171	76	16	10	9	8	6	5
8.5	2,200 x 2,500	1,973	177	78	17	11	10	8	6	5
9	2,400 x 2,800	2,411	217	96	21	13	12	10	8	7
10 (Sharp)	2,850 x 3,050	3,118	280	124	27	17	15	13	10	9
11	3,000 x 3,320	3,573	321	142	31	20	18	15	11	10

Source: CLSA Asia-Pacific Markets

©2011 LED Transformations, LLC

Outline

- Introduction – What are OLEDs
- Unique Features – What makes OLEDs different from other light sources?
- DOE Programs – Status of OLED technology and the research efforts to improve its performance
- Applications – Examples of OLED design

Source: GE

Unique Features

Advantages of OLEDs

- Flat Form Factor
  - Emits light over entire surface; also allows for easy heat dissipation
- Flexibility
  - As encapsulation techniques improve, ability to use flexible substrates such as metal foils or plastic
- Color Tunability
  - Spectra depends on the emitter material; generally wider and more flat than that of inorganic LEDs
- Efficiency
  - Target for 2020 is 190 lumens/W
  - Very low luminaire efficiency losses
- Transparency
  - Transparent OLEDs can be made which emit light from both sides when on, and are see-through in their off state (using transparent electrodes & substrate materials)

Source: DuPont Displays

Source: Novaled

©2011 LED Transformations, LLC

Unique Features

Performance Comparison – With traditional light sources

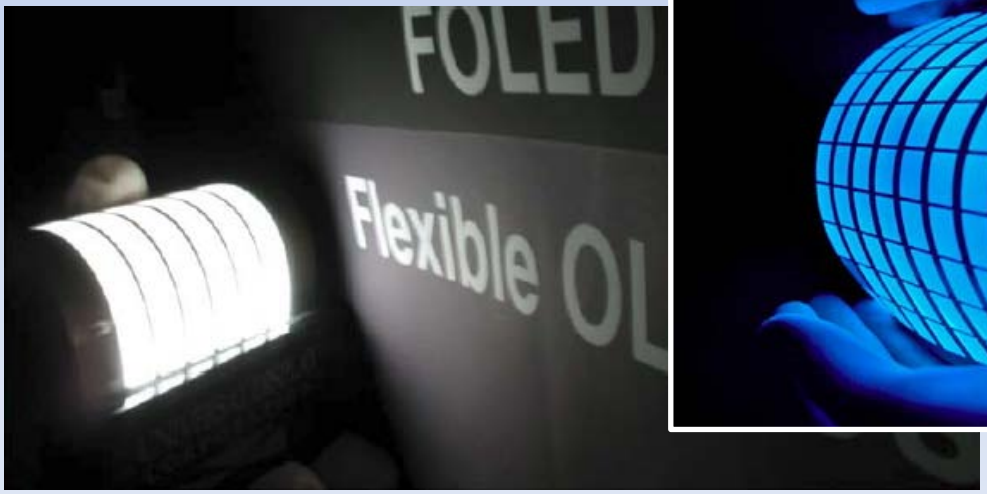
	Incandescent	Fluorescent	LEDs	OLEDs (pixels)
Efficacy	17 lm/W	100 lm/W	80-120 lm/W: White 65-80 lm/W: warm white	**102 lm/W : CRI 70** **79 lm/W : CRI 80**
CRI	100	80-85	80 – white 90 – warm white	**95 with 40 lm/W**
Form Factor	Heat generating	Long or compact gas filled glass tube	Point source high intensity lamp	**Large area thin diffuse source. Flexible, transparent**
Safety concerns	Very hot	Contains mercury	Very hot in operation	**None to date**
LT70 (K hours)	1	20	50	**> 30 with 79 lm/W** **> 4 with 100 lm/W**
Dimmable	Yes, but much lower efficacy	Yes, efficiency decreases	Yes, efficiency increases	**Yes, efficiency increases**
Noise	No	Yes	No	**No**
Switching lifetime	Poor	Poor	Excellent	**Excellent**
Color Tunable	No	No	Yes	**Yes**

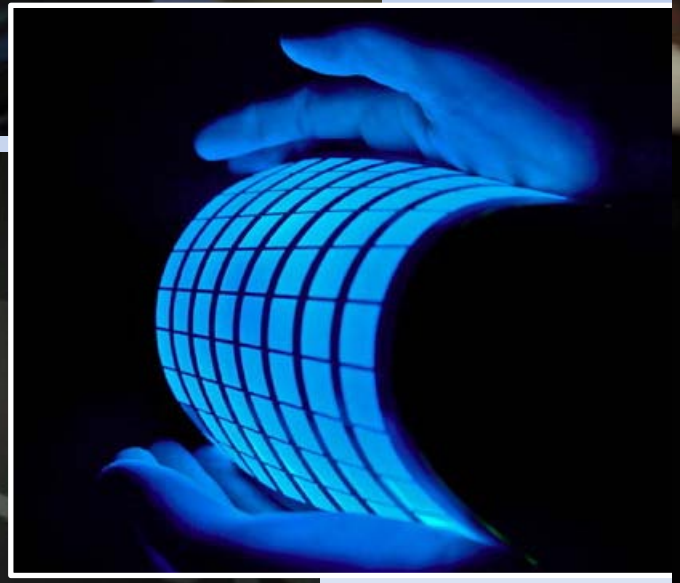
Source: Michael Hack, Universal Display Corporation

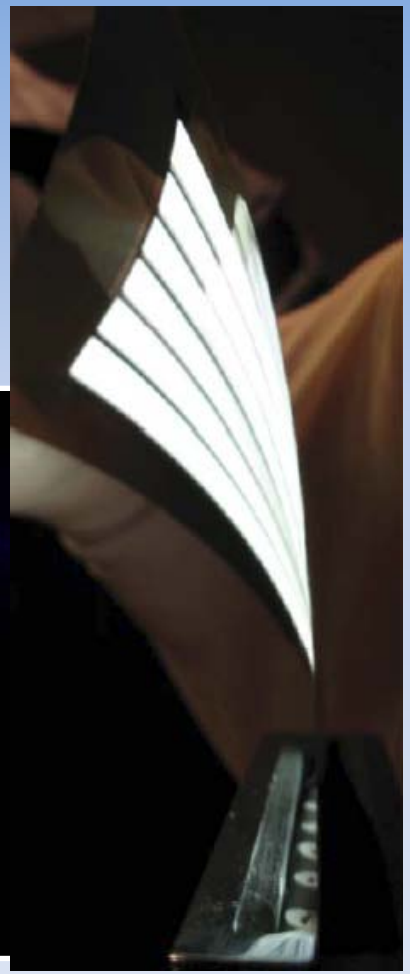
©2011 LED Transformations, LLC

Unique Features

Flexibility







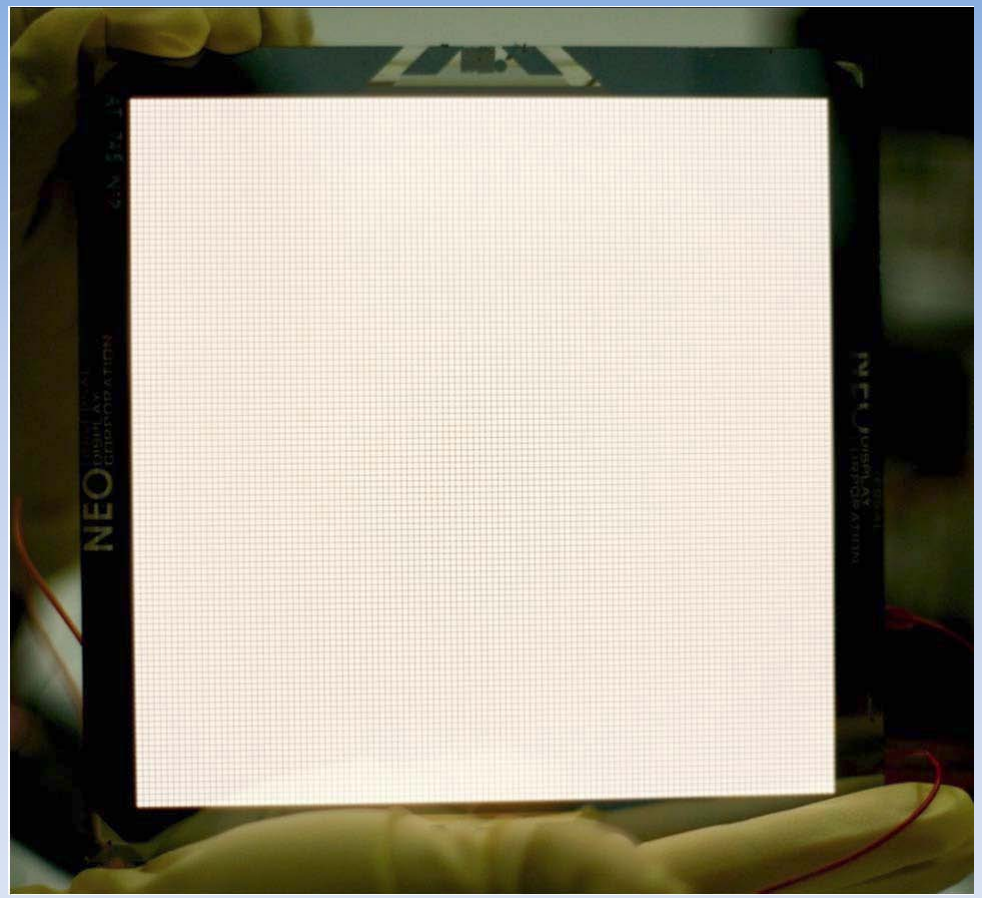
Source: Michael Hack, Universal Display Corporation

©2011 LED Transformations, LLC

Unique Features

Uniform Lighting Surface – No glare

Dimension	15 cm x 15 cm
Active Area	134. 6 cm^2
Fill Factor	77%
Luminance [cd/m^2]	3,000
Luminance Uniformity	88%



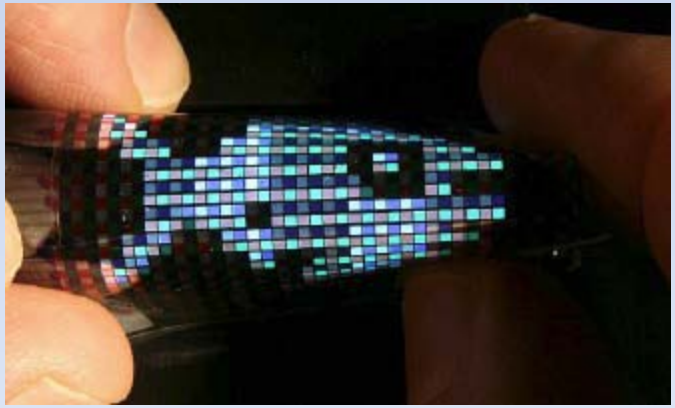
Source: Universal Display Corporation

©2011 LED Transformations, LLC

Unique Features

Transparency – Disappears when not in use

Source: Universal Display Corporation



Source: Yuan-Sheng Tyan, Kodak

©2011 LED Transformations, LLC

Outline

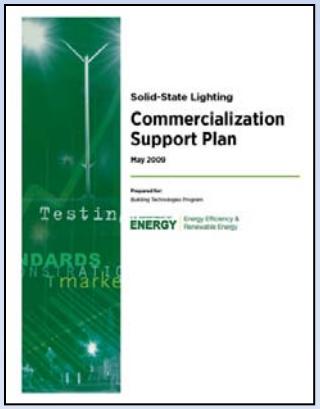
- Introduction – What are OLEDs
- Unique Features – What makes OLEDs different from other light sources?
- DOE Programs – Status of OLED technology and the research efforts to improve its performance
- Applications – Examples of OLED design

Source: GE

DOE OLED Programs

Planning for the Solid-State Lighting Future

- Critical need for ongoing research, technology breakthroughs
- Within the next year, DOE expects to see prototype panels for limited applications
- Multi-Year Plan
  - Identifies R&D areas of need for core research and product development
- Manufacturing R&D Roadmap
  - Identifies specific manufacturing R&D areas of need
  - Complements and extends R&D Multi-Year Plan
- Commercialization Support Plan
  - Outlines strategic, 5-year framework for guiding SSL market adoption
- Annual updates guided by SSL community input



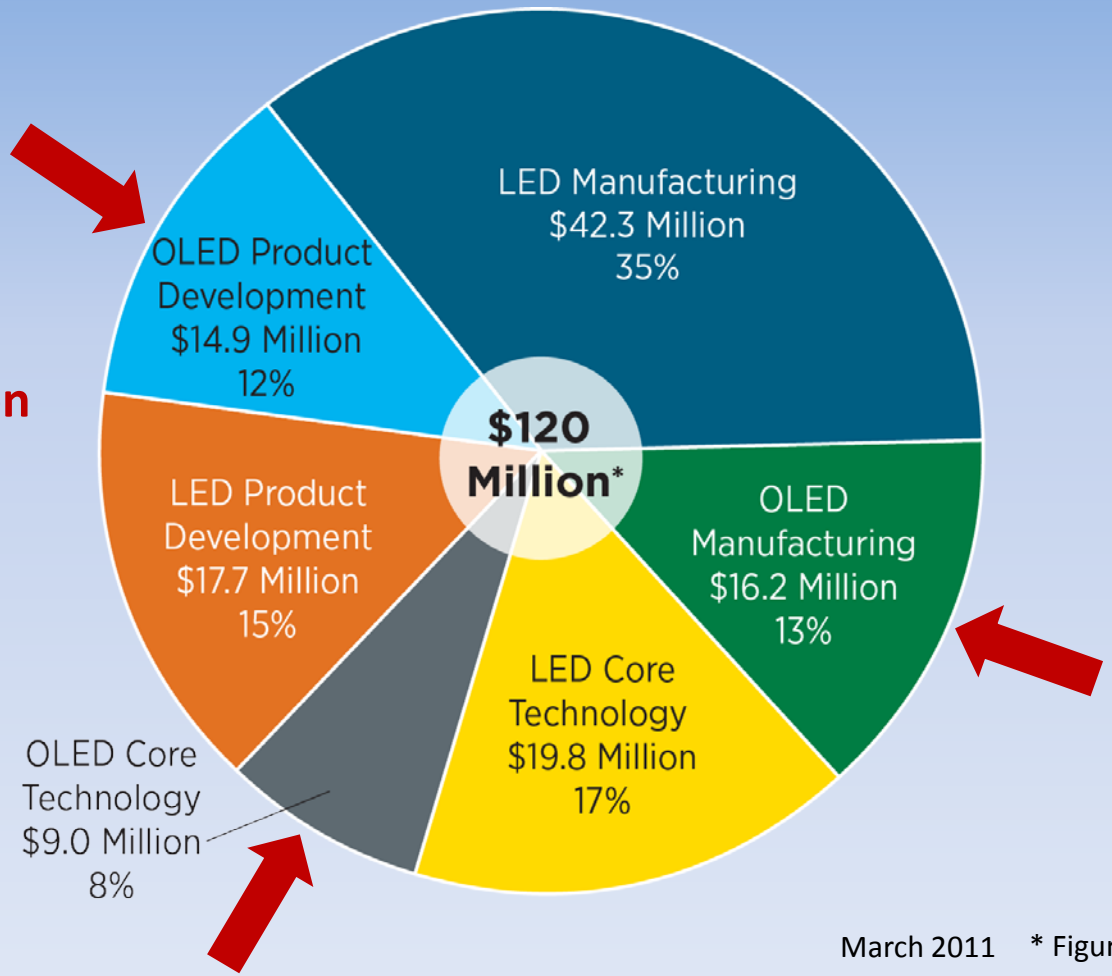
www.ssl.energy.gov/techroadmaps.html

©2011 LED Transformations, LLC

DOE OLED Programs

Solid-State Lighting Research Grants

33% of research money focused on OLED programs



March 2011 * Figures are rounded

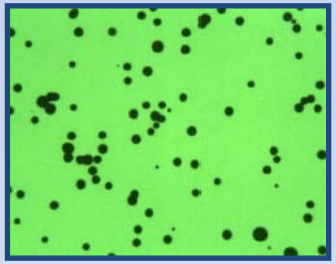
©2011 LED Transformations, LLC

DOE OLED Programs

The Major Issues

- Trapping of light inside OLED layers
- Phosphorescent blue material does not match performance of red and green
  - Use of hybrid fluorescent blue and phosphorescent red and green
- Unlikely development of low cost, low resistance, transparent sheet conductors
  - Use of wire grids may eliminate this issue
- Encapsulation to avoid moisture contamination
- Low volume production means high cost
  - Cost reductions driven by display manufacturing which typically does not require the high light output, long lifetimes and high efficacy required for lighting
  - Initial luminaire may require tiling approach

OLED defects caused by moisture[1]



[1]Source: Yuan-Sheng Tyan, Kodak

©2011 LED Transformations, LLC

The Major Issues

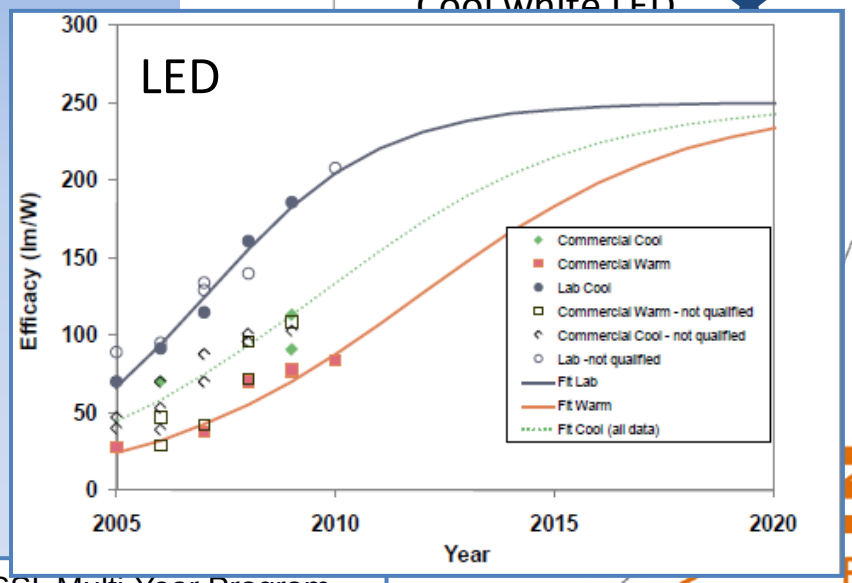
Issue	Problem	Solution
Efficacy	Some lab devices can compete with conventional technologies, early products have low efficacy	Work needed to develop efficient, long-lasting blue emitter; next generation products reaching levels that compete with conventional lighting sources
Lifetime	Short lifetimes for blue materials; susceptibility to moisture intrusion	Work needed on high current density, more stable materials, better and low cost encapsulation
Light Output	Current OLED packages produce “dim” light	Work needed to improve light extraction, high current density
Cost	Too high; lower cost device and luminaire materials are needed	Infrastructure investment needed to develop commercial OLED products
Testing Standards	No standards presently available for testing OLED products	Need for reliable test methods standards to establish consistency and reduce uncertainty

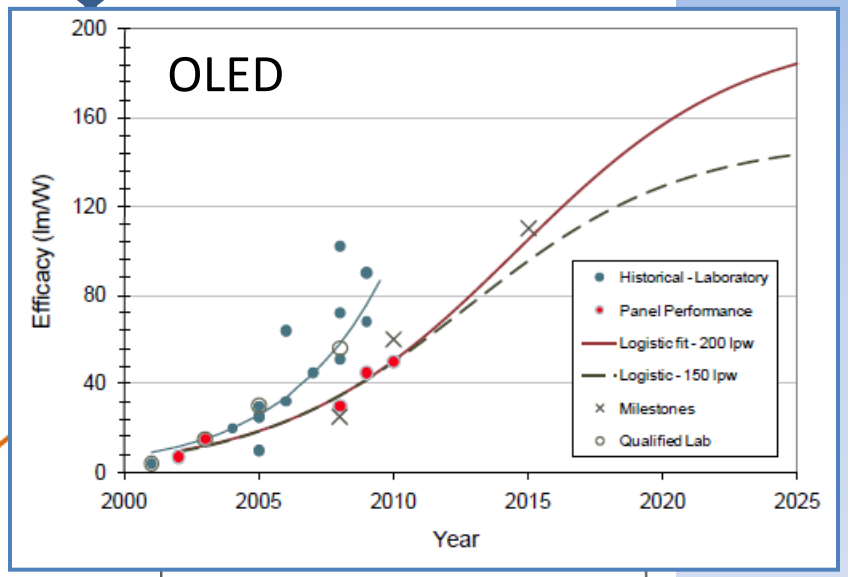
©2011 LED Transformations, LLC

DOE OLED Programs

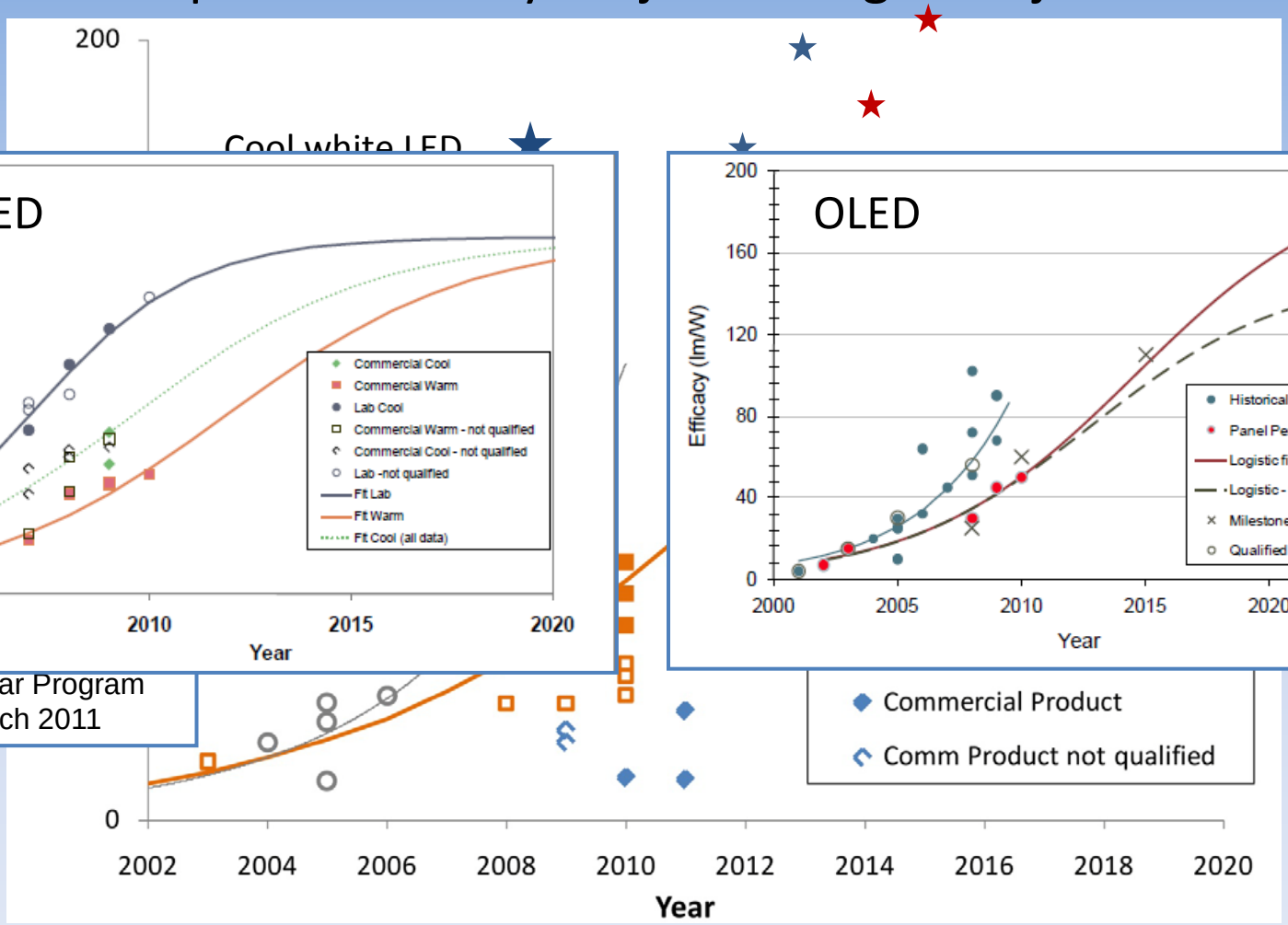
Efficacy – Targets for OLED devices

Comparison of Efficacy Projections





SSL Multi-Year Program Plan, March 2011



DOE OLED Programs

Lifetime – Novel OLED materials

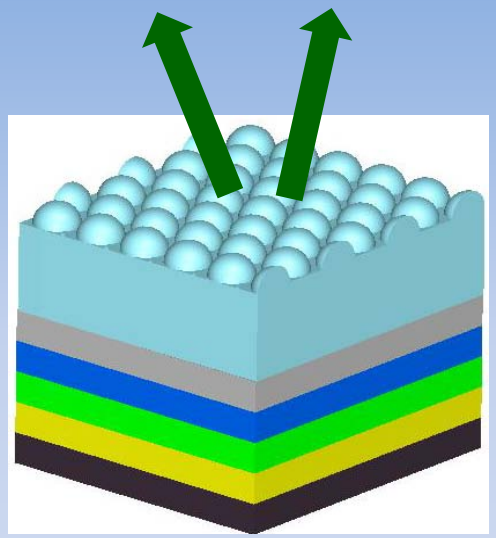
- Joint project with University of Texas at Dallas achieves record performances
- Goal: Develop high-performance platinum-based emitters that simplify and reduce costs for OLED fabrication
  - Platinum is also more readily available than Iridium which is in low supply and expensive
- Novel emitters achieved as much as 65% improvement in efficacy
  - 71 lm/W for turquoise blue OLED devices, compared to 43 lm/W baseline
  - 70 lm/W for warm-white OLEDs using only one or two phosphors

©2011 LED Transformations, LLC

DOE OLED Programs

Light Output – Improving OLED extraction efficiency

- Joint project with Lehigh University and University of Florida to enhance light extraction efficiency in OLED devices
- Preliminary results: Luminance increase of 60% compared to conventional devices (on glass substrate with no extraction enhancement)
- Scalable to large areas and compatible with low cost fabrication techniques
- New technique can be scaled to industrial processes

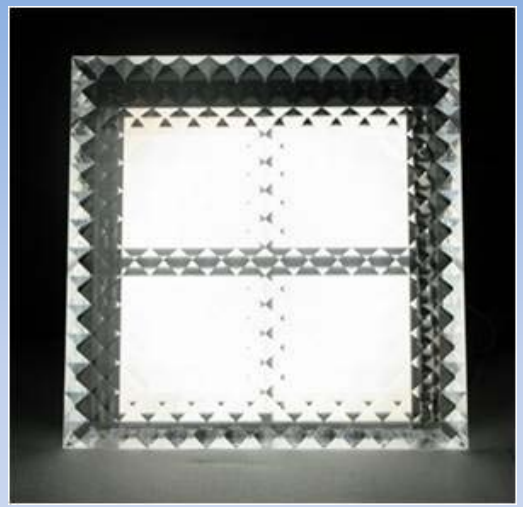


©2011 LED Transformations, LLC

DOE OLED Programs

Light Output – Improved OLED light extraction

- Project with Universal Display Corporation to design high efficiency luminaNovel ire
- extraction technique using index matched fluid coupled lens achieves 2.06 factor improvement
- Efficiency of 66 lm/W, compared to 32 lm/W prototype OLED panel without outcoupling achievement
- Goal: Demonstrate a practical OLED undercabinet lighting system



©2011 LED Transformations, LLC

DOE OLED Programs

Cost – Printable OLED Lighting

- New joint project with DuPont seeks to integrate GE's pre-pilot roll-to-roll manufacturing infrastructure with:
  - High performance, solution processable materials
  - Advanced device architectures
  - Advanced encapsulation using ultra-high multilayer barrier films (alternate ceramic/plastic layers)
- Goal: Eliminate differences in OLED performance between laboratory-scale batch process and pre-pilot production

GE roll-to-roll OLED line demonstration, 2007

©2011 LED Transformations, LLC

DOE OLED Programs

Cost – OLED ceiling luminaire

- Joint project with Universal Display, Armstrong, universities of Michigan and Southern California
- Demonstrated first U.S. phosphorescent OLED luminaire system
  - Includes decorative housing, power supply, mounting, maintenance provisions
  - 51 lm/W: twice as efficient as halogen - based systems
- Snaps into Armstrong TechZone™ ceiling system

©2011 LED Transformations, LLC

DOE OLED Programs

Cost – First domestic OLED manufacturing facility for lighting panels

Located in Canandaigua, NY, the STC will house two pilot phosphorescent OLED manufacturing lines.

- Project partners: DOE, Universal Display Corporation, Moser Baer Technologies, NY's Smart System Technology & Commercialization Center (STC)
- Joint effort to design and set up nation's first pilot production facility for OLED lighting panels
- Facility will provide prototype panels to U.S. luminaire manufacturers to incorporate into products
- Project leverages funding from ARRA, Moser Baer, state government incentives, municipal tax credits

©2011 LED Transformations, LLC

Niche Products – New form factors but high cost

- Most OLEDs currently used for displays
- General illumination applications are available only at extremely high prices
- Handful of niche products exist with high price (e.g. $10k for WAC product below), limited quantities, significant performance limitations

Philips' Lumiblade OLED module (2009)

Acuity Brands' OLED luminaire (2010)*

Flexible, thin OLED light panel from GE

WAC Lighting's SOL OLED Chandelier, featuring ORBEOS lighting from Osram (2010)

Osram PirOLED (2010)

*©John Sutton Photography 2010

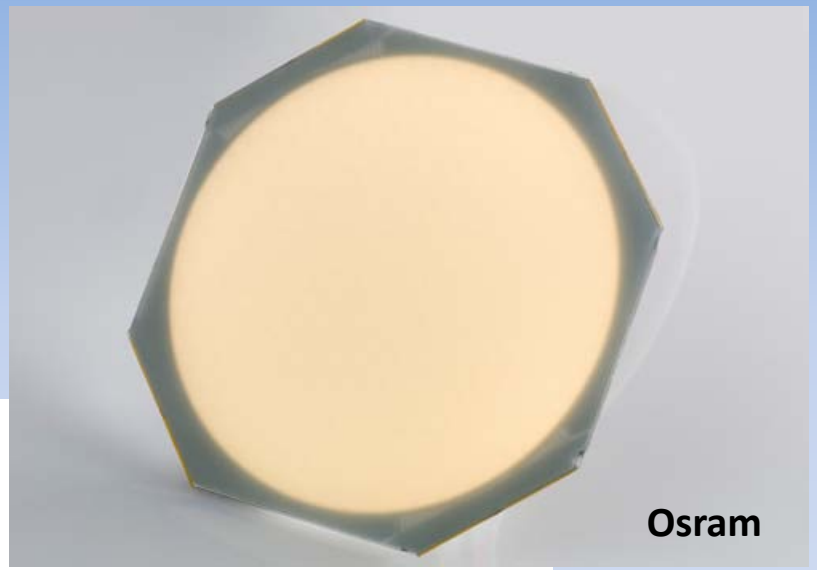
Outline

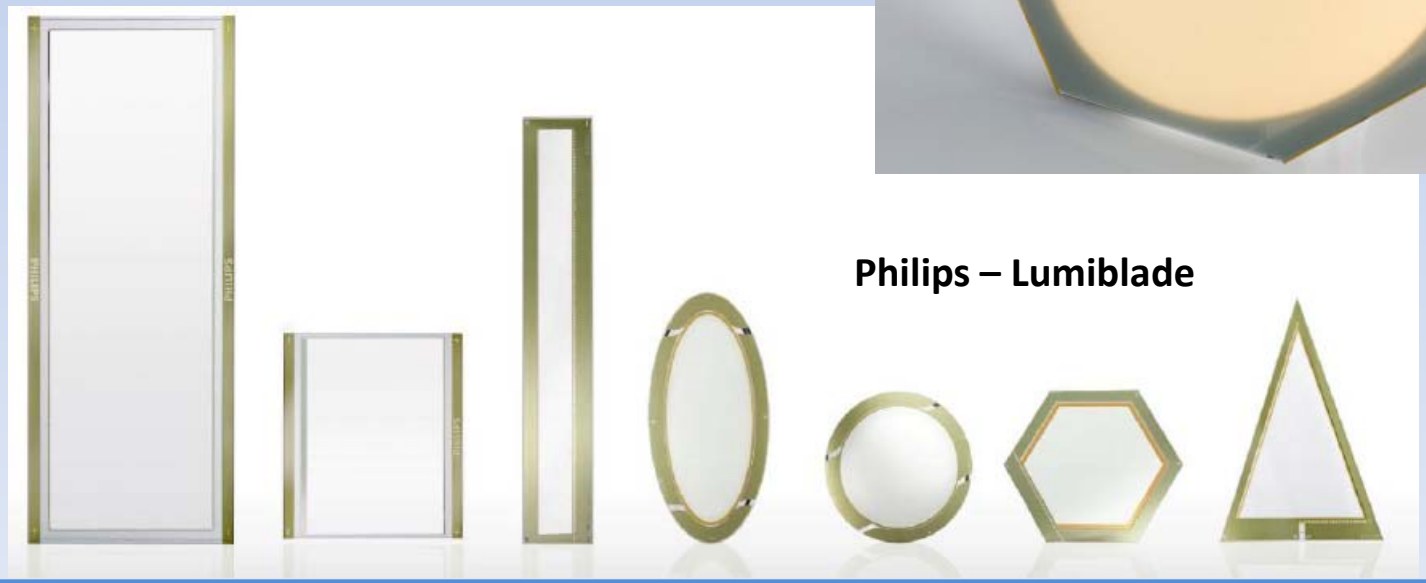
- Introduction – What are OLEDs
- Unique Features – What makes OLEDs different from other light sources?
- DOE Programs – Status of OLED technology and the research efforts to improve its performance
- Applications – Examples of OLED design

Source: GE

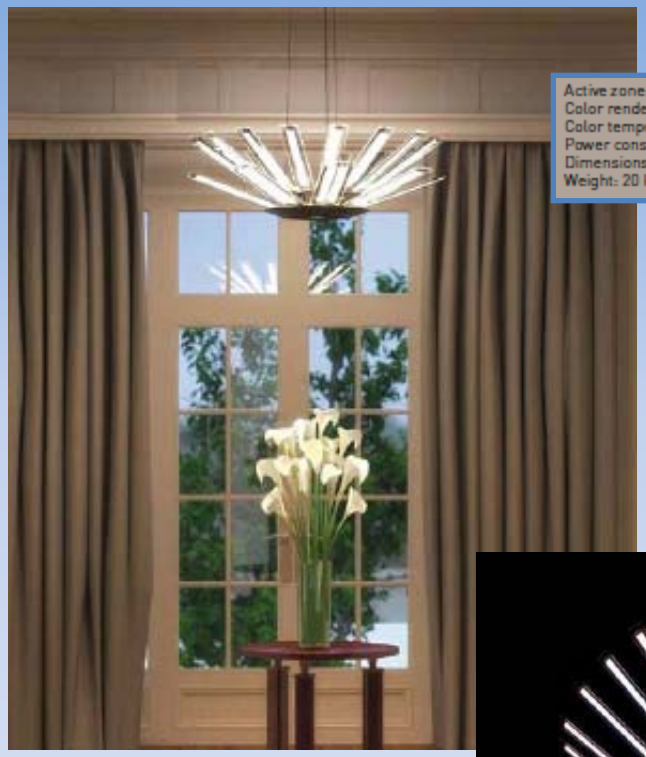
Applications

Demonstration Samples – New form factors but high cost





Niche Products – New form factors but high cost



Active zone: 3200 cm²
Color rendering index: 80
Color temperature: 3000 to 6000 K°
Power consumption: 128 W
Dimensions: Diam: 100 cm, H: 60 cm
Weight: 20 kg

Active zone: 1260 cm²
Color rendering index: 80
Color temperature: 3000 K°
Power consumption: 45 W
Dimensions: L: 87 cm, W: 62 cm, H: 100 cm
Weight: 5 kg

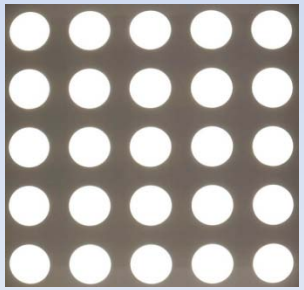
Active zone: 25380 cm²
Color rendering index: 80
Color temperature: 3000 to 6000 K°
Eclairement: 300 lux at height of 3,5 m
Power consumption: 1128 W
Dimensions: Diam: 310 cm, H: 160 cm
Weight: 200 kg

Source: Blackbody (Astrom FIAMM)

©2011 LED Transformations, LLC

Niche Products – New form factors but high cost

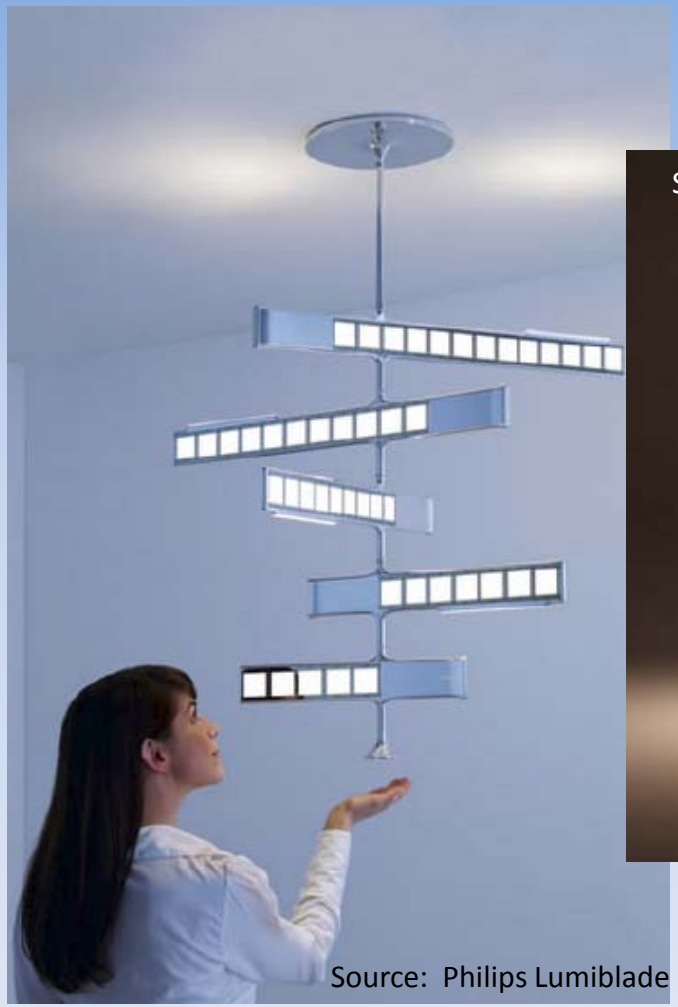
- Offers Architects/Lighting Designers the ability to eliminate the distinction between light source and luminaire
- Its creates a plane of light with no perceptible volume
- Its form factor is very flexible allowing widely varying form factors and shapes
  - Future flexible substrates will allow infinite variation in shapes
- Provides soft, glare-free illumination without requiring diffusers, baffles, etc.



Source: Acuity

Source: Novaled

Niche Products – New form factors but high cost

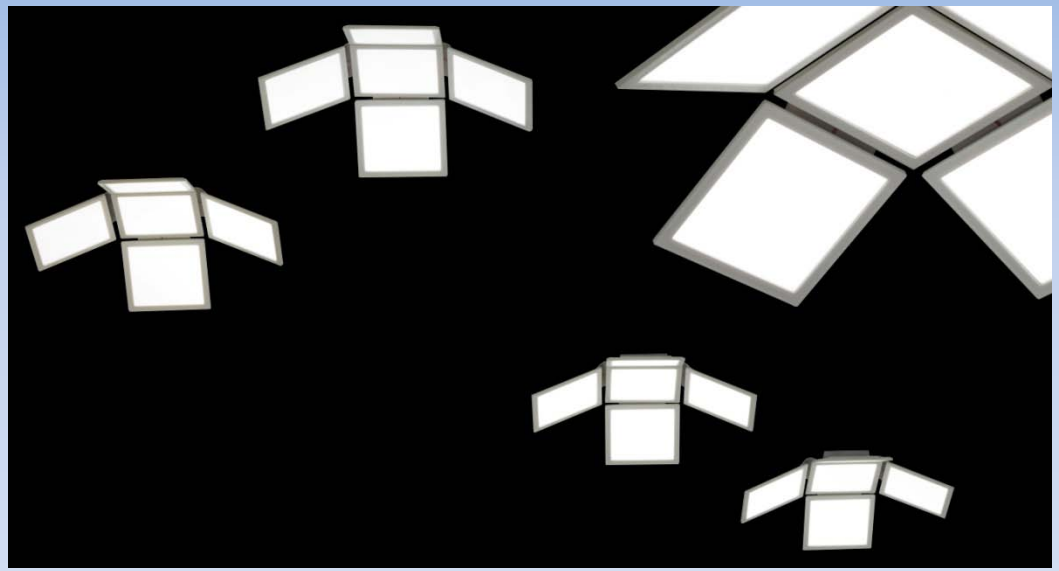

Source: Philips Lumiblade

Source: Universal Display Corporation

Source: Osram

©2011 LED Transformations, LLC

Niche Products – New form factors but high cost



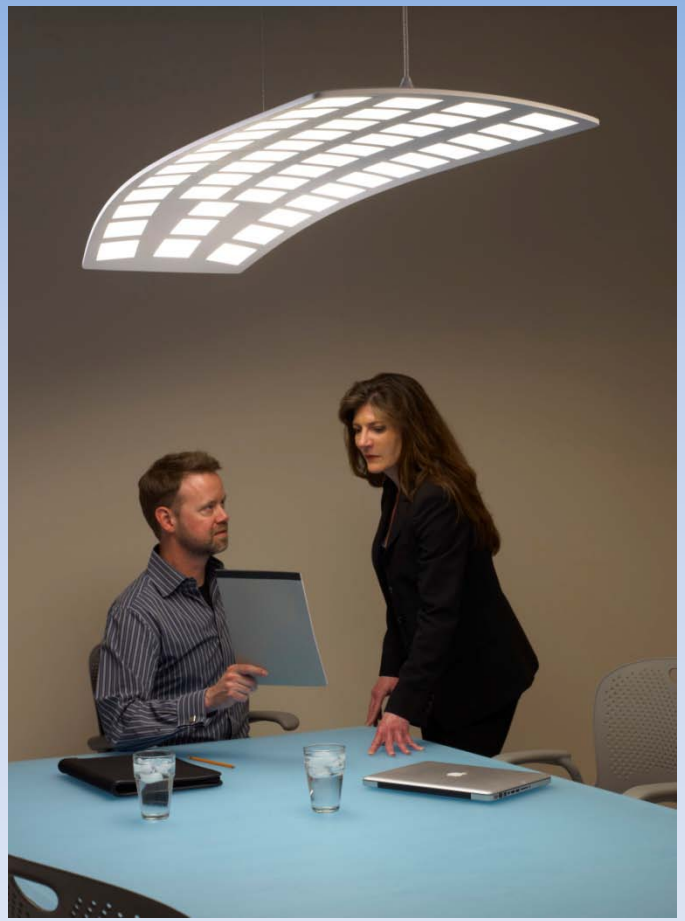
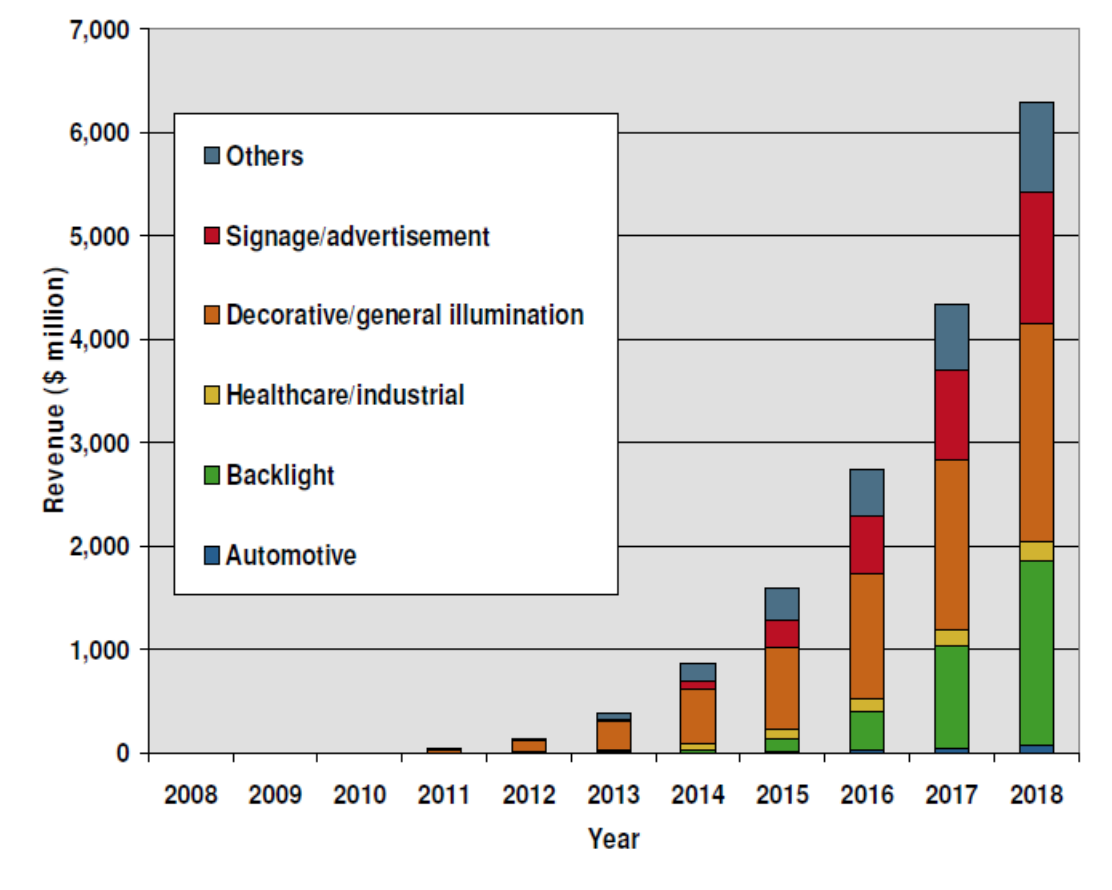


Photo Credit: ©John Sutton Photography 2011

The Future – Expanded use as costs come down

The expanding market for OLED technology is predicted to be over $2B for decorative and general illumination lighting by 2018



Source: DisplaySearch OLED lighting report: 2009 and beyond

©2011 LED Transformations, LLC

The Future – Expanded use as costs come down

Acceptable Fixture Costs

$10,000 each
Not an issue

Image

80 lm/W
2,000 cd/m2
20k hours

$400 each

Specialty & High End

2011 - 2013

110 lm/W
2,000-4,000 cd/m2
35k hours

$200 each

Specification Grade

2013 - 2016

140 lm/W
2,000-4,000 cd/m2
50k hours (L70)

$100 each

Commodity Grade

2016+

Source: Peter Ngai, Acuity Brands

©2011 LED Transformations, LLC

The Future – Expanded use as costs come down

Company	Efficacy (lm/W)	Area (cm^2)	Price ($)	Features
Philips Lumiblade	20	10-60	108-378	Various colors, sizes, shapes
Philips Lumiblade Plus	45	50	169	Highly efficient
Lumiotec 2011	11	100 - 300	162-492	Various colors, sizes, shapes
Osram Orbeos	23	50 (circular) 65 (rectangular)	338	Various shapes Mirrored or Diffuse
LG Chem	45-60			Highly efficient; Q1 2012 availability
Fraunhofer Tabola		25 - 115		Transparent version
Verbatim Velve	28	200		Color tunable
Kaneka	20			Various colors

Data Source: Lisa Pattison Solid-State Lighting Services, Inc

©2011 LED Transformations, LLC

GovEnergy
www.govenergy.gov

Acknowledgement

Support for the development and presentation of this educational seminar was provided by the US Department of Energy and NETL Morgantown

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

©2011 LED Transformations, LLC

GovEnergy
www.govenergy.gov

Thank You

Contact Information:

Dr. John (Jack) W. Curran
President LED Transformations, LLC
PO Box 224
Stanton, NJ 08885
(908) 437-6007
jcurran@ledtransformations.com

LED Transformations LLC
Your Guide to Solid State Lighting

US Department of Energy
www.ssl.energy.gov

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

©2011 LED Transformations, LLC