The need for low cost manufacturing equipment for panels, components and luminaires to enable a U.S. OLED SSL manufacturing industry.
OLED Status vs. DOE Roadmap

Current Products (2012)
- Price: $5,000-20,000/m²
- Price: $500-2,000/klm
- Manufacturers: LG, Panasonic, Blackbody, Osram, Lumiotec, & Philips
- Panel Efficacy: 25-60 lm/W
- L70 @3000 nits: 1-15,000 hr

DOE Roadmap for 2012
- Cost: $270/m²
- Cost: $45/klm
- Manufacturers: At Least 1 US Manufacturer?
- Panel Efficacy: 86 lm/W
- L70 @3000 nits: 11,000 hr

• Grow market by providing sufficient performance at a reasonable cost while enabling unique products.
• Mid to high end of current performance is good enough for initial products, but price is much too high.
• Current manufacturers are using equipment and processes that will not be able to meet current or future cost targets.
• DOE must support novel low cost manufacturing equipment and methods.
LED “Panels” Status

Current Products (2012)

- Price: $400-800/m²
- Price: $40-80/klm
- Manufacturers: Many
- Panel Efficacy: 45-70 lm/W
- L70 @3000 nits: 50,000 hr

- LED price and performance is currently much more competitive with traditional lighting than OLED
- Despite LED’s lead, many lighting designers and luminaire manufacturers believe there is a place for OLED in the lighting market
- Long term OLED price and performance must be competitive with LED
- DOE can enable a U.S. OLED SSL manufacturing industry by supporting the low volume early phase of the market
## How Do We Get Cost Down?

<table>
<thead>
<tr>
<th>Component</th>
<th>Requirement</th>
<th>DOE 2012 Targets</th>
<th>Estimated 2012 Actual*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment (Entire Line)</td>
<td>$100 capital/m(^2)/yr</td>
<td>$5,000 capital/m(^2)/yr</td>
<td>$1,000/m(^2)</td>
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<tr>
<td></td>
<td>$25M total cost</td>
<td>$60M total cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$20/m(^2)</td>
<td>$1000/m(^2)</td>
<td></td>
</tr>
<tr>
<td>OLED Materials</td>
<td>$10/m(^2)</td>
<td>$40/m(^2)</td>
<td>$500/m(^2)</td>
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<tr>
<td>Other Materials</td>
<td>Int. Sub: $15/m(^2)</td>
<td>$60/m(^2)</td>
<td>$400/m(^2)</td>
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<tr>
<td></td>
<td>Encapsulation: $10/m(^2)</td>
<td>$20/m(^2)</td>
<td>$400/m(^2)</td>
</tr>
<tr>
<td></td>
<td>Other: $5/m(^2)</td>
<td>$15/m(^2)</td>
<td>$400/m(^2)</td>
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<tr>
<td>Labor</td>
<td>$5/m(^2)</td>
<td>$400/m(^2)</td>
<td>$1000/m(^2)</td>
</tr>
</tbody>
</table>

*Adjusted for DOE roadmap assumptions for yield, substrate utilization and uptime

- Highest priority is low cost/high throughput/highly automated equipment for every step of the manufacturing process (highest cost step is OLED stack deposition).
- Second highest priority is low cost “other materials” which also requires low cost/high throughput/highly automated equipment.
OLED Manufacturing Example Issue

- Current manufacturers are using Gen 2 scale lines
  - ~ 2 min TAC Time
  - ~ 20% maximum materials utilization
  - DOE estimated capacity is ~ 12,000m²/yr
  - ~ $60M capital investment ($5,000 capital/m²/yr)
  - Depreciation is ~ $1,000/m²

- Scaling to 1 min TACT on Gen 5 for cost reduction will:
  - Require 8x higher evaporation and deposition rates
  - Require 8x more material in source and at temperature for 7-14 days
  - Require 2-4x improvement in materials utilization
  - Require 50x reduction in ratio of capital investment to throughput ($100 capital/m²/yr)

- A novel solution to reducing the ratio of capital investment to throughput while increasing total capacity is needed.
Proposed Priority Tasks

- **M.01** Manufacturing equipment for high speed, low cost, uniform deposition of state of the art OLED structures and layers (OLED stack deposition)
  - Enable novel, low cost manufacturing
  - Enable profitable market entry for panel makers and luminaire manufacturers
  - Cannot ignore depreciation and labor
  - Must be scalable and profitable from low early volumes to high future volumes
  - Must be different than what Asia and Europe are doing

- **M.03** Manufacturing of low cost integrated substrates and encapsulation materials
  - Enable novel, low cost supply of integrated substrates and encapsulation materials
  - Must be different than what suppliers to the display industry are doing
How DOE Can Help?

- Fund novel low cost/high throughput vacuum deposition equipment
  - LOWER ENTRY BARRIER: More US companies can participate in panel manufacturing, odds of success increases, longer term need for government support decreases
  - SURVIVE VALLEY OF DEATH: Cost competitive and profitable early products will provide internal funding required for further performance improvements
  - FASTER MARKET PENETRATION: Faster market growth, faster energy savings and faster performance improvement

- Fund low cost integrated substrates and encapsulation equipment
  - ENABLE EARLY ENTRY: Decreases risk of installing equipment for early low volume market
  - REDUCE PRODUCT COST STRUCTURE: Lighting requires 10x cost reduction vs. displays

Novel approaches are possible!
Novel approaches have been proposed!
Fund these novel approaches appropriately for success!