Economics of LED manufacturing: Yesterday, Today and Tomorrow

DOE SSL Market Introduction Workshop

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Canaccord Genuity
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See disclosures in Appendix
Agenda

- Who we are
- The energy dilemma
- The Second & Third Cycles
- MOCVD
- Policy review
- What does it all mean?
- Beyond the myopic solutions
- OLEDs in lighting
- Summary

See important disclosures in Appendix
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<td>- Debt</td>
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The Energy Dilemma

Photograph: NASA
Energy – Demand

- Global energy demand to increase by 33% from 2010 to 2035
  - China and India alone make up 50% of the growth
Energy - Supply

US Electric Generation Capacity (2011)

- Coal: 32%
- Oil and Natural Gas: 11%
- Combined Cycle: 18%
- Renewables: 13%
- Nuclear: 10%
- Combustion Turbine/Diesel: 14%
- Pumped Storage: 2%
- Fuel Cells: 0%

Renewables to account for much of the incremental supply

- **Oil**: Additional to 2035: 4,500 Mtoe, 2010: 4,000 Mtoe
- **Coal**: Additional to 2035: 3,000 Mtoe, 2010: 3,500 Mtoe
- **Gas**: Additional to 2035: 2,000 Mtoe, 2010: 1,500 Mtoe
- **Renewables**: Additional to 2035: 1,500 Mtoe, 2010: 1,000 Mtoe
- **Nuclear**: Additional to 2035: 1,000 Mtoe, 2010: 500 Mtoe

Source: EIA, IEA
2011: 18 Billion kWh total electricity consumption, 3B kWh was for lighting
The world needs to go on an energy diet
The Second Cycle

First ever bottom up MOCVD reactor supply model

Sustainability – Energy & Power Technologies

The Second Cycle

Worldwide LED supply/demand analysis and technology primer

- Our base case supply/demand scenario highlights that LED manufacturing capacity is quickly heading for a significant shortage around 2016. We conclude that meeting the projected demand will require between 100 and 120 high-capacity MOCVD reactors worth $550 million to $1.4 billion. As such, we see the current cycle as a bullish indicator for both of the equipment suppliers.

- Our projection of a capacity shortage is driven by a 35% CAGR forecast in total LED demand through 2012, resulting in projected revenue ranging from $3.1 billion to $6.2 billion. The largest drivers of this demand forecast are automotive and LCD TV backlights, which we expect to go to LED backlighting and in CAGR-driven penetration by 2012, respectively. We predict general lighting will represent the next wave of LED growth, at only 30% to 40% of total LED revenue in 2012.

- Our analysis indicates that lower cost of ownership will be an essential step in the further vertical integration among chip, package, and module companies in an attempt to lower up-front and as a result of its manufacturing footprint in an effort to drive down costs.

- We see the Chinese market as very large, yet almost impossible to quantify in terms of annual demand. China guarantees a critical value channel for many non-Chinese LED suppliers as an out of the large quantities of "off spec" that they are now the leading buyer in LED capacity and manufacturing process, placing greater emphasis on distribution inertia and preventing consolidation.

- New entrants such as Samsung and LG Electronics should bring greater scale and manufacturing expertise from traditional semiconductor makers. However, it is too soon to predict how successful and what yields these companies will achieve, and what the implications are for the industry’s supply/demand balance.

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Source: Canaccord Genuity
The Third Cycle

Complete proprietary bottoms-up assessment of overall lighting industry & True CoO model for LED penetration over hundreds of scenarios to 2020
Adoption Curves – Cumulative

- 54.8% to 82.5% by 2020

Source: Canaccord Genuity
Adoption Curves – Cumulative

- 73.0B and 167.0B mm² of yielded, packaged epi for lighting between 2012 and 2020

Source: Canaccord Genuity
Projected LED supply-demand

- 200% growth in supply and 90% growth in demand from 2009-2011
  - Oversupply could commoditize the market, spur new wave of LED adoption
- Flattening of LED demand
  - Growing OLED penetration in trad. LED markets, gradual lighting adoption, improvements in LED efficacy
Sapphire Supply-Demand

Supply at 1/1/2012 (80M TIE)

Source: Canaccord Genuity
MOCVD – where is the semi cycle?
MOCVD

• 2,900 to 4,800 tools projected from 2010-2020
  • ~300 average per year
  • 1600 from 2009-2011, only 1500-3200 remain
Gordon Moore

- Moore’s law driven by fundamental geometry changes
- Geometry changes required increasingly complex equipment
  - Created perpetual equipment replacement cycles

Source: Cymer
• Haitz’ law analogous from a cost/performance perspective
• BUT not dependent on physical geometry
  – Does not require equipment upgrade cycles
Replacement cycle

- It is possible to generate high NPV by purchasing **new** equipment
- ROIC much higher by modifying process on **existing** equipment
  - Even modest increases in yield give tremendous returns
What does this all mean to you?
$40 to $4 how does this happen?

60W LED Lamp Bill of Materials

<table>
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<tr>
<th>Category</th>
<th>Cost</th>
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<tr>
<td>Current</td>
<td>$40.00</td>
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<tr>
<td>LEDs</td>
<td>$12.00</td>
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<tr>
<td>PCB</td>
<td>$4.00</td>
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<tr>
<td>Overhead</td>
<td>$3.25</td>
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<tr>
<td>Heat Sink</td>
<td>$4.38</td>
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<tr>
<td>Drivers</td>
<td>$1.50</td>
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<tr>
<td>Socket, Lens</td>
<td>$0.75</td>
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<tr>
<td>Other Electrical</td>
<td>$0.75</td>
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<tr>
<td>Packaging</td>
<td>$0.25</td>
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<tr>
<td>Channel Margin</td>
<td>$13.13</td>
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</tbody>
</table>

Source: Canaccord Genuity
Yield: Epi (MOCVD), Chip, Package

• Yield stacking = 10% - 65% combined!
  – Epi: <30% - 90%
  – Chip: 50 – 80%
  – Package: 65% - 90%

• Memory/Logic market >95%

• Much room for improvement
System Efficiency

• 25% - 30% losses currently
  – Electrical
  – Thermal
  – Optical

Source: Google images
Beyond the myopic solutions
Evolution

LOOK FAMILIAR?
Evolution
Expanding the TAM

• White LED backlighting enabled color screens
• Color screens enabled the smart phone revolution
  – From nearly ZERO in 2000 to 471M units in 2011*

* Canaccord Genuity Global Handset Forecasts
From efficiency...

2007: Lexus LS 600h first car to use LED daytime running lights =1mpg savings!

Source: motorauthority.com
Today we recognize Audi in our rear view mirrors by the headlights

Source: netcarshow.com
From efficiency...

Today it’s all about instant energy savings

Source: Philips, GE
In the future most lighting could be networked, leading to greater insight into our energy consumption patterns and optimized electricity generation/distribution.
OLEDS in lighting
OLED

• Pros
  – Simpler design
  – More flexible form factor

• Cons
  – Manufacturing/scale challenges
  – Lifetime
  – Efficiency hurdles vs. inorganic LED
OLED

- Promising technology but likely limited to niche lighting
- Majority of OLED still driven by display
- Lighting: $200M - $300M annual opportunity

Source: Canaccord Genuity
Conclusions

• LED will be the “hidden gem” of the Cleantech/Sustainability movement

• Upstream investments have been made
  – Allows for costs to come down exponentially

• Government incentives will help but not required
  – Standards might be better

• LEDs will begin as an energy efficiency story
  – Blubs to fixtures
  – As in all other applications of LEDs transformation will occur beyond energy savings

• Downstream innovation and standards are key
Thank you!
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