PV Manufacturing Cost Analysis: 
*Future Cost Reduction Opportunities*

CESA Member Webinar: 
Solar PV Manufacturing Costs

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Michael Woodhouse, 
Ted James

June 22, 2012
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Overview

- **Reported Prices: Market Distortions**
  - Historic-cost reduction factors
  - The rising importance of innovation
  - The role of supply-side subsidies

- **Cost Analysis in-Support of R&D**

- **Future Cost-Reduction Opportunities**
  - Wafer based c-Si modules
  - SJ polycrystalline CdTe modules

- **System-Price Trends**
Top-Down (Reported) Prices

Useful for long-term strategic decisions?
The Ups and Downs of the PV Market

- PV is a nascent industry...prices generally reflect temporary shifts in buyer- or supplier-power

Sources:
- Graph prepared by Douglas M. Powell, MIT using data from:
  - IHS, PV Demand and Installation Surge in Q4, (2011)
Market Distortions Throughout the Supply Chain

- Opportunity for low- to non-Si techs turned out to be limited
- Consider long-term competitive prices

Sources: Graph prepared by David Feldman, NREL using data from:
Graph prepared by David Feldman, NREL, using data from:
Historic Solar PV Module Prices – Top Down

• Historic factors: scale (43%), efficiency gains (30%)

Sources: Graph courtesy of David Feldman, NREL; data sources:
Recent, Dramatic Shift in the Origin of Production

U.S. and China & Taiwan Market Share of Global Shipments of PV Cells/Modules

Sources: Graph prepared by Ted James, NREL using data from:
The Impact of Supply-Side Subsidies


Sources: Alan Goodrich, Peter Hacke, Qi Wang, Bhushan Sopori, Robert Margolis, Ted James, David Hsu, and Michael Woodhouse (2012). “A Wafer-Based Monocrystalline Silicon Photovoltaics Road Map: Utilizing Known Technical Improvement Opportunities for Further Reductions in Manufacturing Costs.” NREL (in preparation)
Bottom-Up Cost Analysis

Long-term competitive pricing
# Methodology Overview

## Technical Cost Models (Busch 1987)

*Relate technical details to costs (according to GAAP)*

### Direct Manufacturing Cost Summary: CIGS, Coevaporated on glass (Annual production volume: 600 MWp DC)

<table>
<thead>
<tr>
<th>VARIABLE COST ELEMENTS</th>
<th>$/Wp</th>
<th>$/module</th>
<th>$/year</th>
<th>percent</th>
<th>investment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Cost</td>
<td>$0.61</td>
<td>$72.03</td>
<td>$363,572,081</td>
<td>56.0%</td>
<td></td>
</tr>
<tr>
<td>Direct Labor Cost</td>
<td>$0.09</td>
<td>$10.71</td>
<td>$54,059,605</td>
<td>8.3%</td>
<td></td>
</tr>
<tr>
<td>Utility Cost</td>
<td>$0.02</td>
<td>$1.95</td>
<td>$9,823,730</td>
<td>1.5%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FIXED COST ELEMENTS</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Cost</td>
<td>$0.15</td>
<td>$17.58</td>
<td>$88,740,016</td>
<td>13.7%</td>
<td>$621,180,110</td>
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<tr>
<td>Tooling Cost</td>
<td>$0.00</td>
<td>$0.02</td>
<td>$9,739</td>
<td>0.0%</td>
<td>$2,733,073</td>
</tr>
<tr>
<td>Building Cost</td>
<td>$0.00</td>
<td>$0.02</td>
<td>$9,739</td>
<td>0.0%</td>
<td>$2,733,073</td>
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<tr>
<td>Maintenance Cost</td>
<td>$0.05</td>
<td>$5.90</td>
<td>$29,772,831</td>
<td>4.6%</td>
<td></td>
</tr>
<tr>
<td>Overhead Labor Cost</td>
<td>$0.00</td>
<td>$0.09</td>
<td>$467,282</td>
<td>0.1%</td>
<td></td>
</tr>
<tr>
<td>Cost of Capital</td>
<td>$0.17</td>
<td>$20.45</td>
<td>$103,221,567</td>
<td>15.9%</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL COSTS**

|                  | $1.08 | $128.73 | $649,748,214 | 100.0% | $623,913,183 |

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### Not pictured:

**Calculate minimum sustainable (long-term competitive) price**

*Pro forma income statement, discounted cash flow analysis*

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DCF Analysis: Minimum Sustainable Price

Greenfield analysis

- Construction, ramp-up periods
- Operating expenses: %-revenue method (industry comparables)
- Accelerated depreciation
- Internal hurdle rate = total cost of capital (including debt):
  exclude interest expense

Sales
Cogs
Contribution margin

SG&A
Overhead labor
R&D
Regulatory
Warranty
Working capital
Depreciation
EBIT

Taxes
Unlevered net income

Plus: depreciation
Less: capital expenditures
Less: NWC
Plus: after tax salvage value
Free cash flow

Price that satisfies NPV = 0, using the “Internal hurdle rate” as the discount rate = Minimum Sustainable Price
Technology Road Maps

The competitive price of alternative tech. pathways:

Wafer based c-Si

SJ poly CdTe
Poly Costs: Capital, Energy Intensive

Solar Grade Polysilicon: Direct Manufacturing Costs

Based on regional differences in plant-scale, technologies, corporate hurdle rates, OPEX, labor & utility rates
Source: NREL internal cost model

- Today’s competitive price ($27/kg) may approach $20/kg in the long-term

Sources: Alan Goodrich, Peter Hacke, Qi Wang, Bhushan Sopori, Robert Margolis, Ted James, David Hsu, and Michael Woodhouse (2012). “A Wafer-Based Monocrystalline Silicon Photovoltaics Road Map: Utilizing Known Technical Improvement Opportunities for Further Reductions in Manufacturing Costs.” NREL (in preparation)
The Value of Thin Wafers

- Potential cost disadvantages:
  - Mechanical yield losses, surface passivation requirements

Sources: Alan Goodrich, Peter Hacke, Qi Wang, Bhushan Sopori, Robert Margolis, Ted James, David Hsu, and Michael Woodhouse (2012). “A Wafer-Based Monocrystalline Silicon Photovoltaics Road Map: Utilizing Known Technical Improvement Opportunities for Further Reductions in Manufacturing Costs.” NREL (in preparation)
U.S. Bulk c-Si Wafers: Cost Road Map

Standard (B-Cz) c-Si Solar PV Wafer Manufacturing Costs:
Cost-Reduction Opportunities, 10 million wafers per month U.S. firm.

Sources: Alan Goodrich, Peter Hacke, Qi Wang, Bhushan Sopori, Robert Margolis, Ted James, David Hsu, and Michael Woodhouse (2012). “A Wafer-Based Monocrystalline Silicon Photovoltaics Road Map: Utilizing Known Technical Improvement Opportunities for Further Reductions in Manufacturing Costs.” NREL (in preparation)
Many known pathways to higher efficiencies

...but, at what cost?
Performance opportunities

- Front side shadowing
- Bulk recombination
- Surface recombination

However, cost trade-offs exist

- Trina: 17.2% cells, $1.16/W module costs\(^1\)
- Sunpower: 24% cells, $1.48/W module costs\(^2\)

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\(^1\)Trina Q2 2011 Earnings Call. August 23, 2011.
Efficiency Adjusted Module Prices (rel. to SunShot)

To achieve SunShot, 15% module may not exceed $47/m² (cost)

- Based on ground mount system costs; efficiency penalty greater for rooftop systems
- 15% BoS penalty (rel. to 20% modules) = ~$40/m²

Sources: NREL internal cost models.
U.S. Wafer Based c-Si PV Road Map

Sources: Alan Goodrich, Peter Hacke, Qi Wang, Bhushan Sopori, Robert Margolis, Ted James, David Hsu, and Michael Woodhouse (2012). “A Wafer-Based Monocrystalline Silicon Photovoltaics Road Map: Utilizing Known Technical Improvement Opportunities for Further Reductions in Manufacturing Costs.” NREL (in preparation)
## CdTe Technical Improvement Pathways

(Single-junction polycrystalline cells. 89% cell-to-module derate)

<table>
<thead>
<tr>
<th>Cell Performance Parameters</th>
<th>Baseline (2011)</th>
<th>Near term</th>
<th>Midterm</th>
<th>Full potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-Circuit Current Density: $J_{sc}$ (mA/cm²)</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>26</td>
</tr>
<tr>
<td>Open-Circuit Voltage: $V_{oc}$ (V/cell)</td>
<td>0.80</td>
<td>0.90</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Fill Factor: FF (%)</td>
<td>70</td>
<td>75</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>AM 1.5 Power Conversion Efficiency (%)</td>
<td>13% Cells (11.7% modules)</td>
<td>16%</td>
<td>20%</td>
<td>21% cells (18% modules)</td>
</tr>
</tbody>
</table>

Malaysia CdTe (on-glass) Module Prices
(Single-junction polycrystalline cells. 89% cell-to-module derate)

System Price Trends

Market Distortions
Regional Variations
1H 2011 NREL-System Price Estimates

Status of the U.S. Solar Industry

Justin Baca
Senior Research Manager
Solar Energy Industries Association
About SEIA

• Founded in 1974
• U.S. National Trade Association for Solar Energy
  • 1,000+ member companies from around the world
  • Members from across 50 states
  • Largest companies in the world as well as small installers
• Our Mission: Build a strong solar industry to power America
• Our Goal: 10 gigawatts (GW) of annual installed solar capacity in the U.S. by 2015
Industry Overview

- The value of solar installations grew to $8.4 billion in 2011, up from $6 billion in 2010
- Solar employment more than doubled from 2009 to 2011, topping 100,000 American workers

Value of PV Installations

<table>
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<tr>
<th>Year</th>
<th>SEIA Estimate</th>
<th>SEIA/GTM Research</th>
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<tbody>
<tr>
<td>2006</td>
<td>$1.0</td>
<td>$1.0</td>
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<tr>
<td>2007</td>
<td>$2.0</td>
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<tr>
<td>2008</td>
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<tr>
<td>2009</td>
<td>$4.0</td>
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<tr>
<td>2010</td>
<td>$5.0</td>
<td>$5.0</td>
</tr>
<tr>
<td>2011</td>
<td>$6.0</td>
<td>$8.0</td>
</tr>
</tbody>
</table>

U.S. Solar Workforce

<table>
<thead>
<tr>
<th>Year</th>
<th>SEIA Estimate</th>
<th>The Solar Foundation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>10,000</td>
<td>10,000</td>
</tr>
<tr>
<td>2007</td>
<td>20,000</td>
<td>20,000</td>
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<td>2008</td>
<td>30,000</td>
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</tr>
<tr>
<td>2009</td>
<td>40,000</td>
<td>40,000</td>
</tr>
<tr>
<td>2010</td>
<td>50,000</td>
<td>70,000</td>
</tr>
<tr>
<td>2011</td>
<td>60,000</td>
<td>90,000</td>
</tr>
</tbody>
</table>
U.S. Solar Business Locations

Source: SEIA National Solar Database

Manufacturer
Contractor/Installer
Other
230,000 PV Systems in the U.S.

- 18,000 installed in Q1 alone
- Average system sizes slowly growing
  - Residential: 5-6 kW
  - Commercial: ~80 kW
  - Utility: 5.7 MW
U.S. Solar Industry Continues Strong Growth

- PV demand grew 85% in Q1 2012 over Q1 2011
U.S. PV Demand Forecast to Grow 75% in 2012 to Nearly 3.3 GW
U.S. to Lead in CSP

- California, Arizona and Nevada are leading states for CSP
- The current CSP pipeline contains some 5,700 MW of projects with signed PPAs
- 1,300 MW under construction

CSP & CPV Forecast
Continued U.S. Market Diversity: Creating Opportunity
U.S. States With >10 MW of PV Installations, 2007

Source: SEIA/GTM Research: Solar Market Insight Q3 2011

Need more U.S. market data? Contact research@seia.org
Solar Continues To Become More Affordable and More Competitive

National Weighted Average System Costs, 2010 – Q1 2012

- Installed Price ($/Wdc)
- Residential
- Commercial
- Utility
- Blended

Q1 2010, Q2 2010, Q3 2010, Q4 2010, Q1 2011, Q2 2011, Q3 2011, Q4 2011, Q1 2012
More Markets Developing in Next 4 Years

Residential PV break-even installed price in **2008** assuming full retail net metering, state incentives and 30% ITC.

Residential PV break-even installed price in **2015** assuming full retail net metering and 30% ITC.

Source: Denholm, Margolis, Ong, Roberts “Break-Even Cost for Residential Photovoltaics in the United States: Key Drivers and Sensitivities” NREL 12/2009
Other Issues

• SolarWorld trade case against Chinese cell manufacturers
• Expiration of 1603 Treasury program at end of 2011 and tax equity supply
• Expiration of 30% Investment Tax Credit at the end of 2016
• Soft Costs
THANK YOU

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