Solar PV Manufacturing Cost Model Group:
Installed Solar PV System Prices

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SEGIS-ADEPT Power
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Systems Workshop

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The Value of Module Efficiency

- $0.05–$0.10/W_{DC} /1\% (absolute)

Source: NREL internal cost model
Installation Cost Model Methodology

- First-hand data from industry stakeholders
  - Installers
  - System developers
  - Utilities
  - Module and other component manufacturers

  ...Supplemented with public data sources
  - For example, Photon International module and inverter price surveys; RS Means labor rates and contractor overhead rates

- External review of results with stakeholders and industry analysts
  - Review critical assumptions
  - Compare results to completed and quoted projects, as well as public databases (e.g., CSI)

- Conduct sensitivity analyses (identify key cost drivers)
  - Continuously review and revise

Actual 2009–2010 project costs (under NDA)
- (40+) residential & commercial rooftop
- 8 utility-scale projects (all > 5 MW)
NREL PV System Price Model: Utility Scale

Modules

Inverters
- Prefabricated storage shed

Installation Materials
- Racking and ground mounts (tracker)
- DC wiring, combiner boxes, disconnect, conduit, and connectors
- AC wiring, meter, monitoring, disconnect, conduit, and connectors

Land and Site Preparation
- Land purchase or lease
- Leveling, plant removal, sediment control, roads, fencing, and surface treatment

Installer Markup
- Inventory and contingency costs

Labor Content and Rates
- Labor type (electrical and hardware)
- Installation time per component
- Overhead
- Installer profit

Indirect Capital Costs
- Environmental permitting
- Grid interconnect (materials and labor)
- Sales tax
Economies of Scale

- Trend towards larger system sizes and building block system designs
- Utility-scale benefits nearly fully realized at 20 MW_{DC}
• Markup on all materials (module, inverter, and BoS) included in “Installer Overhead & Profit”
  Residential $0.89/W_{DC}$, commercial $0.55/W_{DC}$, and utility (fixed-axis) $0.31/W_{DC}$
• Reflects inventory costs (interest during construction) and contingency
## Installation Materials

### Utility-scale Hardware Costs

**Mounting hardware**
- Fixed-axis: $0.20/W_{DC}$
- 1-axis: $0.45/W_{DC}$

**1.2 MW inverter-assembly**
- (2) Inverters, preassembled
- Single 34.5 kV MV transformer (~ 6,700 kg)
- Storage shed (pre-fabricated)
- Roads not needed for installation (80 hrs)

**Utility DC and AC wiring costs**
- Wiring: $0.15–$0.19/W_{DC}$
- Conduit and connectors: $0.05–$0.07/W_{DC}$

**Markup on materials**
- Inventory costs, project delays, and contingency

### Bill of Materials

<table>
<thead>
<tr>
<th>Bill of Materials</th>
<th>Residential</th>
<th>Commercial</th>
<th>Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>System size (kWp dc)</td>
<td></td>
<td></td>
<td>317,000</td>
</tr>
<tr>
<td></td>
<td>5.0</td>
<td>216</td>
<td><em>Fixed axis</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bill of Materials</th>
<th>Residential</th>
<th>Commercial</th>
<th>Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Monitor</td>
<td>$0.09</td>
<td>$0.03</td>
<td>$0.00</td>
</tr>
<tr>
<td>DC, AC-Disconnects</td>
<td>$0.01</td>
<td>$0.01</td>
<td>$0.00</td>
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<tr>
<td>Fuses and Holders</td>
<td>$0.01</td>
<td>$0.01</td>
<td>$0.00</td>
</tr>
<tr>
<td>Wiring (including connectors, conduit)</td>
<td>$0.02</td>
<td>$0.02</td>
<td>$0.16</td>
</tr>
<tr>
<td><strong>Markup on materials</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Markup assumptions</td>
<td>30%</td>
<td>20%</td>
<td>10%</td>
</tr>
</tbody>
</table>

Source: NREL internal cost model
### Installation Labor Costs

**Skilled electrical labor**
- Role in utility-scale installations?
- Opportunities to integrate electrical assembly at factory?

**Overhead rates > 3x national average for electrical contractors**
- Reflects cost of permitting process?
- Design efforts?
- Customer acquisition costs?
- NREL data from inexperienced installers?

#### Table: Installation Labor Costs

<table>
<thead>
<tr>
<th>System size (kWp dc)</th>
<th>Residential</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Rooftop</td>
<td>Rooftop</td>
<td>Mount Utility*</td>
</tr>
<tr>
<td>5.0</td>
<td>24.9</td>
<td>656.3</td>
<td>1,784,482.5</td>
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<tr>
<td>39.8</td>
<td>64.7</td>
<td>2,307.5</td>
<td>2,339,217.6</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>$/Wp dc</th>
<th>$/Wp dc</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Electrical</td>
<td>$0.30</td>
<td>$0.18</td>
<td>$0.34</td>
</tr>
<tr>
<td>Hardware</td>
<td>$0.33</td>
<td>$0.31</td>
<td>$0.07</td>
</tr>
<tr>
<td>Overhead</td>
<td>$0.34</td>
<td>$0.16</td>
<td>$0.06</td>
</tr>
<tr>
<td>Profit</td>
<td>$0.19</td>
<td>$0.10</td>
<td>$0.13</td>
</tr>
</tbody>
</table>

| Worker's Compensation Insurance | 6.4% | 6.4% | 6.4% |
| Federal and State Unemployment insurance | 6.2% | 6.2% | 6.2% |
| Social Security Taxes (FICA) | 7.7% | 7.7% | 7.7% |
| Builder's Risk Insurance | 0.4% | 0.4% | 0.4% |
| Public Liability | 2.0% | 2.0% | 2.0% |
| Operating Overhead | 54.0% | 32.0% | 22.4% |
| Profit | 30.0% | 20.0% | 10.0% |

*Fixed axis

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Source: NREL internal cost model
Indirect Installation Costs

### Indirect Project Costs

#### Environmental permitting
- $1 MM (CA SEQA)

#### Grid interconnect
- Utility scale: Substation materials and labor ($1.5–$3.0 MM, 69–230 kV)
- Rooftop “commissioning” costs?

#### Land acquisition
- $500–$10,000/acre
  - As high as $105K/acre (2008)
- 5–8 acres/MW

#### Site preparation
- $5K–$25K/acre
- Leveling, hydrology, plant removal, roads, and sediment control

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### System size (kWp dc)

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<tr>
<td>Indirect Project Costs</td>
<td>$/Wp dc</td>
<td>$/Wp dc</td>
<td>$/Wp dc</td>
<td>$/Wp dc</td>
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<tr>
<td>Permitting</td>
<td>$0.08</td>
<td>$0.23</td>
<td>$0.00</td>
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<tr>
<td>Grid interconnect</td>
<td>$0.30</td>
<td>$0.01</td>
<td>$0.01</td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.04</td>
<td></td>
</tr>
<tr>
<td>Site Prep</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$0.20</td>
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<tr>
<td>Sales Tax</td>
<td>$0.26</td>
<td>$0.21</td>
<td>$0.21</td>
<td></td>
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<tr>
<td>Total System Price:</td>
<td>$/Wp dc</td>
<td>$/Wp dc</td>
<td>$/Wp dc</td>
<td>$/Wp dc</td>
</tr>
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<tbody>
<tr>
<td>Total System Price:</td>
<td>$5.71</td>
<td>$4.58</td>
<td>$4.40</td>
</tr>
</tbody>
</table>

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**Source:** NREL internal cost model
Hardware and labor costs account for > $\frac{1}{3}$ of system price

- Integrate electrical components and wiring at factories? 
  *Save on-site labor and hardware costs?*
- Limited benefits associated with lightweight inverters? 
  *Roads and concrete pad still necessary: Heavy MV transformers*
- Cost benefits of higher DC voltages? 
  $1,000 \, V_{DC} \rightarrow 1,500 \, V_{DC} \rightarrow 1.2 \, MW_{DC} \rightarrow 2.4 \, MW_{DC}$ inverter blocks

Indirect project costs: 5%–11% of system prices

- Site preparation ~ 5x land acquisition cost 
  *System and component designs to reduce preparation requirements?*
- Commissioning costs?
- Permitting delays, opportunity to *fast track* standard system designs?
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John Bartlett

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Colleagues at NREL who have contributed through both formal and informal discussions.
Utility-scale PV: Uncertainty Analysis (1)

Regional cost differences
• Labor rates
• Installer productivity
• Permitting and delays
• Land costs

Technology selection
• Module efficiency
• Configuration

Economies of scale
• Project size (indirect costs)
• Installer purchasing power
Utility-scale PV: Uncertainty Analysis (2)

2010 Fixed Axis Utility Scale PV System Price:
NREL internal model, Sensitivity to (15) Key Variables

Baseline = $3.77/W_{dc}
Average = $4.09/W_{dc}
Std dev = $0.41/W_{dc}
Median $4.13/W_{dc}
Min $2.96, Max $4.99
n = 997

Source: NREL internal cost model