Balance of System for Building PV
Context, Motivation, and Broader Perspective

Presentation at ARPA-E PV Power Electronics Workshop
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Rocky Mountain Institute works to find profitable and practical solutions to our energy challenges.

Components of the Next Generation Utility:
- Renewable Energy
- Grid Integration
- Electric Drive Vehicles
- Two Way Digital Controls
- Energy Efficiency & Demand Response
- Combined Heat & Power
- Renewable Energy
RMI convened a group of experts to bring coordinated thinking to PV BOS challenges

To Download RMI Report and Summary Presentation:
www.rmi.org/rmi/SolarPVBOSS
Industry-wide collaboration is needed on a systems approach to reduce BoS costs

**Desired End-State:**

**Low-cost large-scale solar industry**

**Area:**

- **Physical Design**
  - Minimize levelized cost of physical system
  - Optimize design for levelized cost
  - Reduce installation time

- **Business Process**
  - Minimize cycle time uncertainty
  - Increase transparency
  - Eliminate non-value-add time

- **Industry Scale**
  - Create/spread industry-specific standards
  - Deploy high-volume lean manufacturing
  - Develop large-scale demand

**Levers:**

- **System Installers**
- **Component Suppliers**
- **Code Agencies**
- **Government Labs**
- **Owners**
- **System Developers**
- **Owners**
- **Financiers**
- **Regulators**
- **Component Suppliers**
- **System Installers**
- **Materials Suppliers**

**Primary Stakeholders:**

- System Installers
- Component Suppliers
- Code Agencies
- Government Labs
- Owners
- System Developers
- Owners
- Financiers
- Regulators
- Component Suppliers
- System Installers
- Materials Suppliers

**Vision:**

- A low-cost, high-performance system design that can be tailored to unique site requirements
- Supporting processes that effectively, efficiently, and predictably support solar deployment
- The world’s largest industry, utilizing an efficient supply chain based on common ground rules

**Overall Goal:**

- Minimize levelized cost of physical system
- Minimize cost and uncertainty of business processes
- Ensure rapid growth and maturation of whole industry

**Supporting processes:**

- Increase transparency
- Reduce installation time
- Eliminate non-value-add time
- Deploy high-volume lean manufacturing
- Develop large-scale demand
Charrette recommendations indicate potential to reduce BoS costs to $0.60-$0.90/watt in the near term.

**ESTIMATED IMPACT OF COST REDUCTION MEASURES**

*(For Ground-Mounted Installation)*

- Baseline Installed Cost: $1.60
- Proposed design: $0.88
- W/ Module savings: $0.68

**Cost savings from baseline**

**BoS-enabled module cost savings**

(Source: RMI analysis based on Solar PV BoS Design Charrette input)
Power electronics play an important role, particularly when looking at the problem from perspective of LCOE Levelized Cost of Electricity (LCOE).

**NEAR-TERM COST REDUCTIONS FOR GROUND-MOUNTED PV SYSTEM**

(LEVELIZED COST OF ELECTRICITY)

- **Baseline**
  - $0.22/kWh

- **Effect of Charrette BoS Design**
  - $0.13/kWh
  - Improve Electrical System Efficiency to 94%
  - Design Inverter for 25 Year Operation
  - Reduce BoS Capital Costs to $0.68/W

- **Effect of Module Cost Reduction**
  - $0.08/kWh
  - Cost Savings from Baseline
  - $0.70/W Modules

**Source:** RMI analysis based on Solar PV BoS Design Charrette input
Power electronics design offers a number of strategies to address a complex system optimization challenge.

Design Themes from RMI Electrical Group

1. Decentralize inversion
2. Raised voltage system
3. Design to maximize utility services
4. High frequency
5. Constrain boundary conditions to allow module cost reduction
6. Minimize serial conversion steps
System architecture options
Implications for buildings: whole system design

- Sales tax (5%)
- Installer overhead and profit
- Site preparation
- Land
- Permitting, Commissioning
- Installation Labor
- Tracker
- Installation Materials
- Inverter
- Module
Implications for buildings: expand solar market
BoS Costs Account for ~50% of Total System Cost

- BoS Costs Account for ~50% of Total System Cost

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost (2010 $/Wp)</th>
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<tbody>
<tr>
<td>Module</td>
<td>$3.50</td>
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<tr>
<td>Ground-Mounted Rooftop System</td>
<td>$3.75</td>
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<tr>
<td>Electrical System</td>
<td>$3.75</td>
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<tr>
<td>Structural System</td>
<td>$3.50</td>
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<tr>
<td>Business Processes</td>
<td>$1.60</td>
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<tr>
<td>Inverter</td>
<td>$1.85</td>
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<tr>
<td>Ground-Mounted Rooftop System</td>
<td>$1.85</td>
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<tr>
<td>Structural Installation</td>
<td>$2.50</td>
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<tr>
<td>Site Prep, Attachments</td>
<td>$2.00</td>
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<tr>
<td>Electrical Installation</td>
<td>$2.00</td>
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<tr>
<td>Wiring, Transformer, etc.</td>
<td>$2.00</td>
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**NOTE ON BASELINE COST ESTIMATES**

These estimates for total system costs and specific cost components are based on discussions with PV industry experts and are intended to represent a best-practice cost structure for a typical commercial system (1-20MW ground-mounted, >250kW flat rooftop). Actual project costs are highly variable based on location and other project-specific factors.

Source: RMI analysis based on industry expert interviews
Charrette Prioritized Recommendations For Near-Term Cost Reductions

RECOMMENDED HIGH-PRIORITY ACTIVITIES TO ENABLE AND ACCELERATE COST REDUCTION EFFORTS

<table>
<thead>
<tr>
<th>Area:</th>
<th>Vision:</th>
<th>Proposed Activities:</th>
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<tbody>
<tr>
<td>Physical Design</td>
<td>A low-cost, high-performance system design that can be tailored to unique site requirements</td>
<td>• Vet/implement charrette structural and electrical system designs</td>
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<td></td>
<td></td>
<td>• Widely use LCOE to evaluate designs and projects</td>
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<td>• Adopt solar-specific codes governing structural systems</td>
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<td>• Develop standard set of wind-tunnel tests and data</td>
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<td>• Enable accelerated reliability testing of new electrical components</td>
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<td>• Quantify the real value and feasibility of full installation automation</td>
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<td>• Implement tool-less installation approaches</td>
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<tr>
<td>Business Process</td>
<td>Supporting processes that effectively, efficiently, and predictably support solar deployment</td>
<td>• Quantify business process costs and drivers</td>
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<td>• Quantify value of consistent regulations between jurisdictions</td>
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<td>• Develop <em>Solar as an Appliance</em> to pre-approve system designs</td>
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<td>• Train regulatory personnel on a large scale</td>
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<td>• Create a National Solar Site Registry to compile site information</td>
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<td>• Increase market transparency through rating of players</td>
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<td>• Use a National Solar Exchange to develop more efficient markets</td>
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<td>Industry Scale</td>
<td>The world’s largest industry, utilizing an efficient supply chain based on common ground rules</td>
<td>• Promote industry standards to enable next-level mass manufacturing</td>
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<td>• Set up an organization to foster industry <em>coopetition</em> that allows competitors to agree on product standards, testing methods, and interchangeability</td>
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<td>• Create an open-source BoS cost analysis calculator to clarify cost and efficiency trade-offs, increase transparency, optimize subsidies and codes, set standards, and foster coopetition</td>
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<td>• Incentivize aggressive cost-reduction with prize</td>
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Source: RMI analysis based on Solar PV BoS Design Charrette input
There are Major Challenges to Cost Reduction in the BoS Industry

BoS costs are driven by value chain fragmentation and the need to accommodate high variability in sites, regulations, and customer needs. As a result:

- **Each PV system has unique characteristics and must be individually designed.**

- **There is no silver-bullet design solution for BoS.**

- **Many incremental opportunities for cost reduction are available across the value chain.**

In order to achieve transformational cost reductions, **a systems approach is needed that spans the entire value chain**, and considers improvements for one component or process in light of their impacts on, or synergies with other elements of the system. Also, **industry-wide collaboration will be necessary**.
Scale. Scale. Scale.