Achieving Low-Cost Solar PV

Industry Workshop Recommendations for Near-Term Balance of System Cost Reductions

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EXECUTIVE SUMMARY

Solar photovoltaic (PV) electricity offers enormous potential to contribute to a low-carbon electrical system. However, **costs must drop to fundamentally lower levels** if this technology is to play a significant role in meeting U.S. energy needs.

"Balance of system"* (BoS) costs currently account for about half the installed cost of a commercial or utility PV system. Module price declines without corresponding reductions in BoS costs will hamper system cost competitiveness and adoption.

In June 2010, Rocky Mountain Institute (RMI) organized a design charrette focused on BoS cost reduction opportunities for commercial and small utility PV systems.

Near-term BoS cost-reduction recommendations developed at the charrette indicate that an **improvement of ~ 50 percent over current best practices** is readily achievable. Implementing these recommendations would **decrease total BoS costs to $0.60–0.90/watt for large rooftop and ground-mounted systems**, and offers a pathway to bring photovoltaic electricity into the conventional electricity price range.

This deck provides an overview of the charrette analysis and recommendations.

Read the full charrette report: http://www.rmi.org/Content/Files/BOSReport.pdf

*"Balance of system" refers to all of the up-front costs associated with a PV system *except the module*: mounting and racking components, inverters, wiring, installation labor, financing and contractual costs, permitting, and interconnection, among others.

Document Overview

I. **PROJECT MOTIVATION & GOALS**
Provides an overview of the importance of, and opportunity for solar PV BoS cost reductions.

II. **CHARRETTE INSIGHT & RECOMMENDATIONS**
Summarizes the major themes of the charrette and the recommended activities to enable implementation of cost reduction strategies.

III. **PROPOSED COST REDUCTIONS & OPTIMIZATION STRATEGIES**
Examines the specific design strategies that contribute to the envisioned reductions in BoS cost, and provides a detailed cost structure for each area.

IV. **APPENDICES**
Offers background information on the charrette.

The charrette would not have been possible without the generous support of the following partners:

Delta DelSolar

U.S. Department of Energy — Energy Efficiency & Renewable Energy

Nationale Postcode Loterij

RioTinto

Fred and Alice Stanback

Technical sponsors: Autodesk, Munro & Associates, Inc.

Project Motivation & Goals

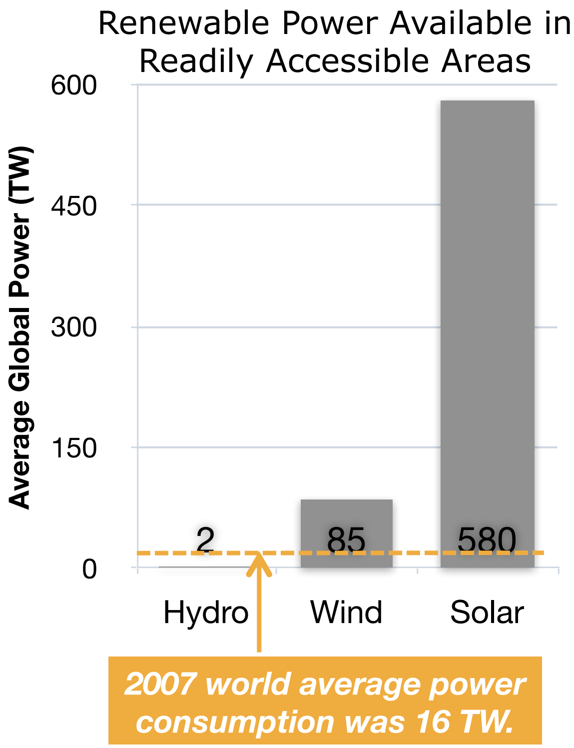
Solar Energy Needs to Become a Major Contributor to US Power Supply

SOLAR ENERGY PRESENTS SEVERAL ADVANTAGES

- **Abundant resource**—the total solar resource is much larger than other renewable energy resources.
- **Distributed resource**—solar energy is widely available. Excellent sites offer only a factor of two more annual energy than poor locations.
- **Correlation with loads**—solar insolation peaks in mid-day (later if facing SW), which allows solar energy to contribute to peak loads on many electric systems.
- **Clean and renewable**—solar energy is inexhaustible and nonpolluting.

TO CAPTURE SOLAR ENERGY, PHOTOVOLTAICS OFFER HIGH POTENTIAL

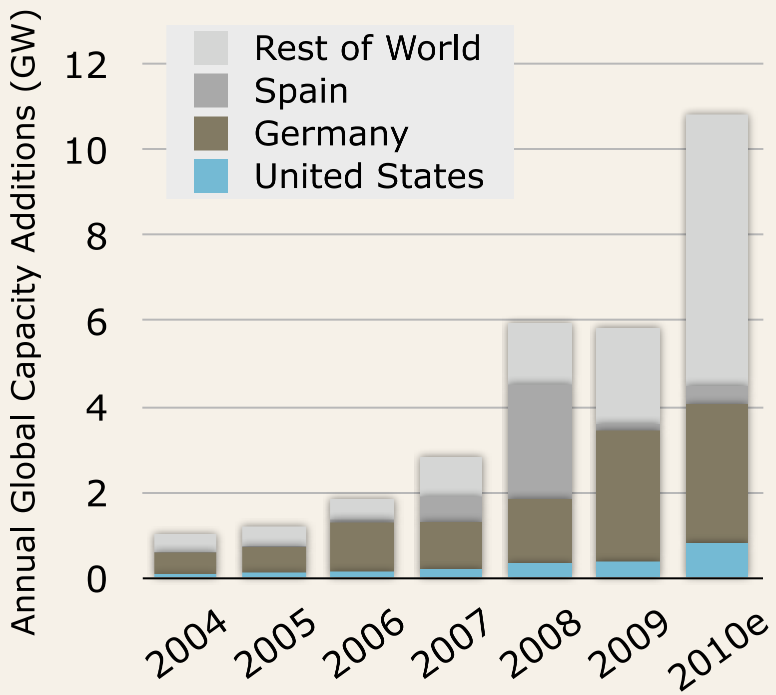
- **Modular technology—**PV systems range in size from 1 kW to 100 MW. This flexibility lets systems be built with short lead times near loads.
- **Reliable performance**—PV modules have demonstrated an ability to run>25 years with little performance degradation or downtime.
- **Clean and quiet operation**—PV modules are unobtrusive, create no emissions or noise, and can often be integrated into building envelope.
- **Low operating costs**—no fuel inputs are required, and annual maintenance costs are low compared to many other energy options.
- **R&D opportunities**—PV systems are relatively new technologies, with high potential for near-term cost and performance improvements and long-term disruptive advances.



PV Adoption is Hindered by Comparatively High Costs

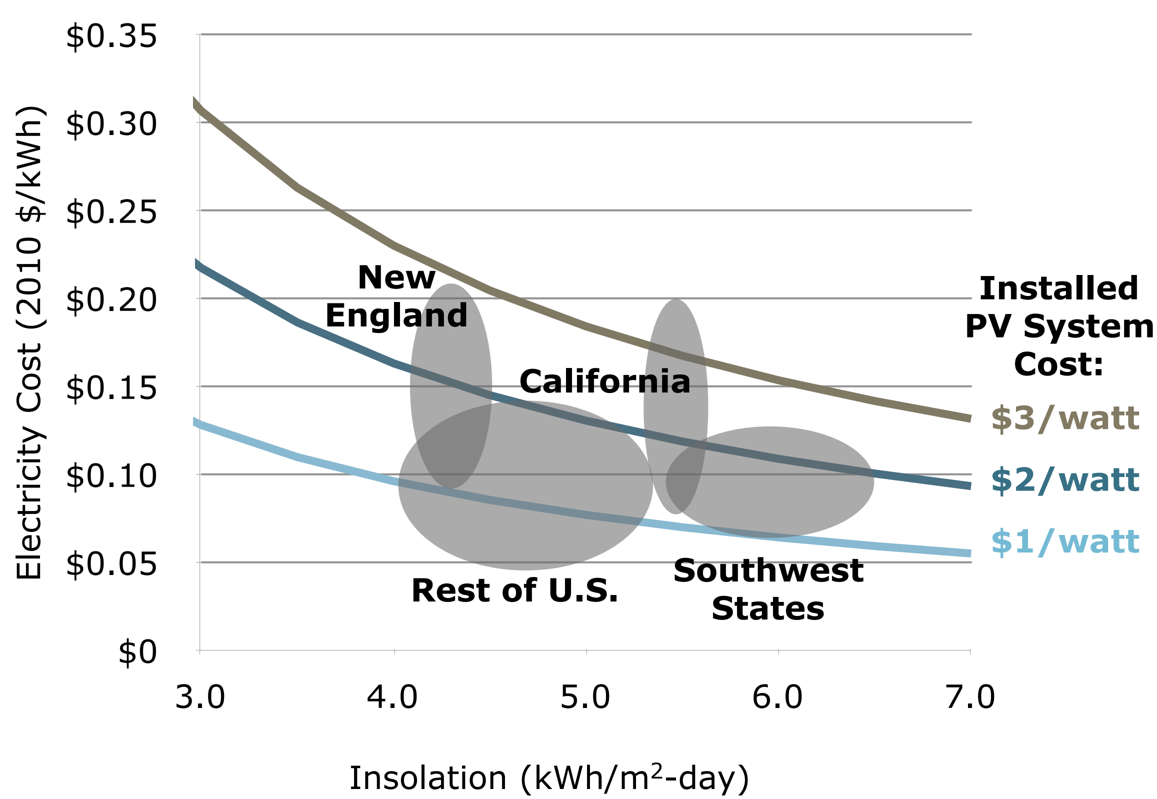
Though the PV industry is growing rapidly...

GLOBAL PV INSTALLATION TRAJECTORY



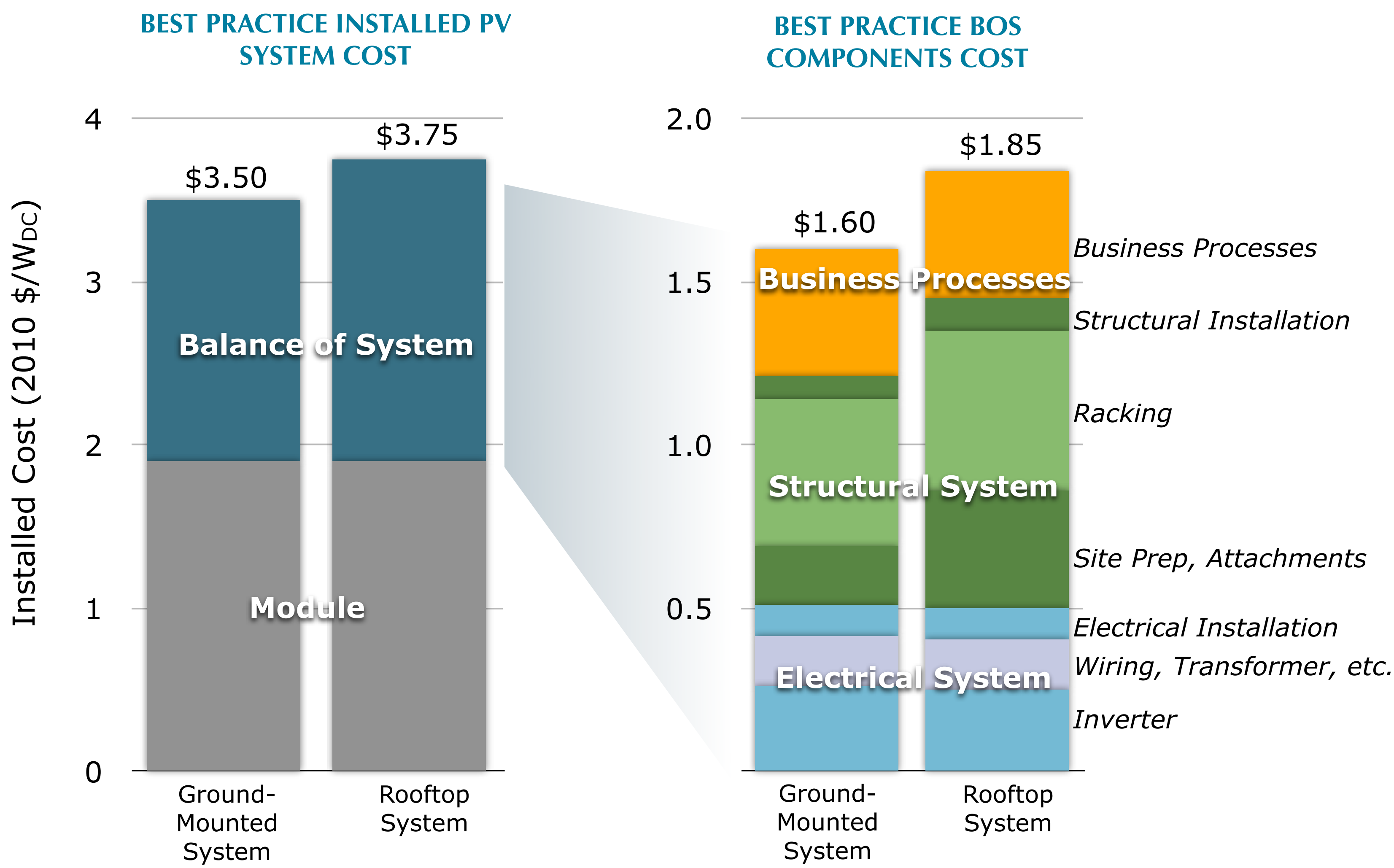
...significant reductions are still required to make the technology a true "game-changer"

PV COST COMPARISON WITH U.S. RETAIL RATES



Sources: Deutsche Bank Global Markets Research, Feb 2010; RMI analysis based on EIA Form-826 Database

BoS Costs Account for ~50% of Total System Cost



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 Insight & Recommendations

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**.

A Systems Approach and Industry-Wide Collaboration Are Required to Significantly Reduce BoS Costs

Desired End-State:	**Low-cost large-scale solar industry**		
Area:	**Physical Design**	**Business Process**	**Industry Scale**
Overall Goal:	Minimize levelized cost of physical system	Minimize cost and uncertainty of business processes	Ensure rapid growth and maturation of whole industry
Levers:	**Reduce forces acting on system** + **Optimize design for levelized cost** + **Reduce installation time**	**Minimize cycle time uncertainty** + **Increase transparency** + **Eliminate non-value-add time**	**Create/spread industry-specific standards** + **Deploy high-volume lean manufacturing** + **Develop large-scale demand**
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**

Charrette Recommendations Could Reduce BoS Costs to $0.60-$0.90/watt in the Near Term

NEAR-TERM COST REDUCTIONS FOR GROUND-MOUNTED PV SYSTEM

LEVERS (partial list):

Structural

- Efficient wind design
- Use of temporary on-site assembly line
- High volume manufacturing
- Structural codes optimized for PV

Electrical

- Incorporation of power electronics in string or module to provide AC output
- Aggregation in AC

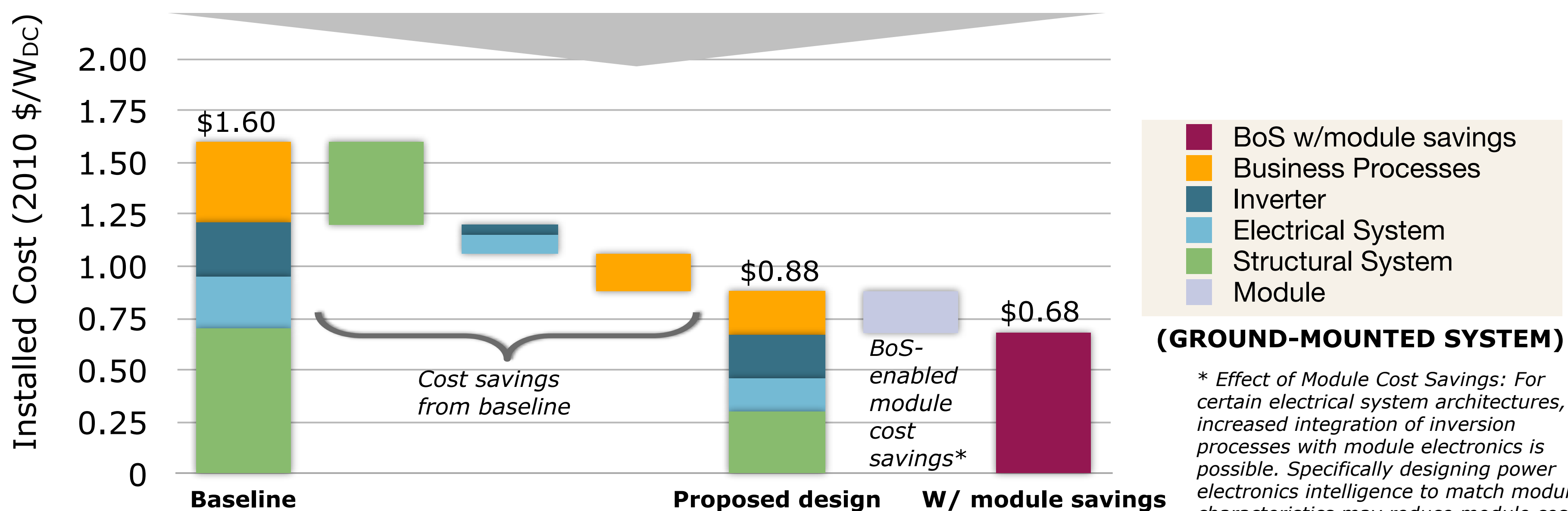
Process

- Readily available site development information
- More efficient processes
- Consistent regulations

Module (BoS-enabled)*

- Eliminating/ downsizing of module blocking diodes, homeruns, backskin material

For more detail on design and process levers, see slides 15-22.



(GROUND-MOUNTED SYSTEM)

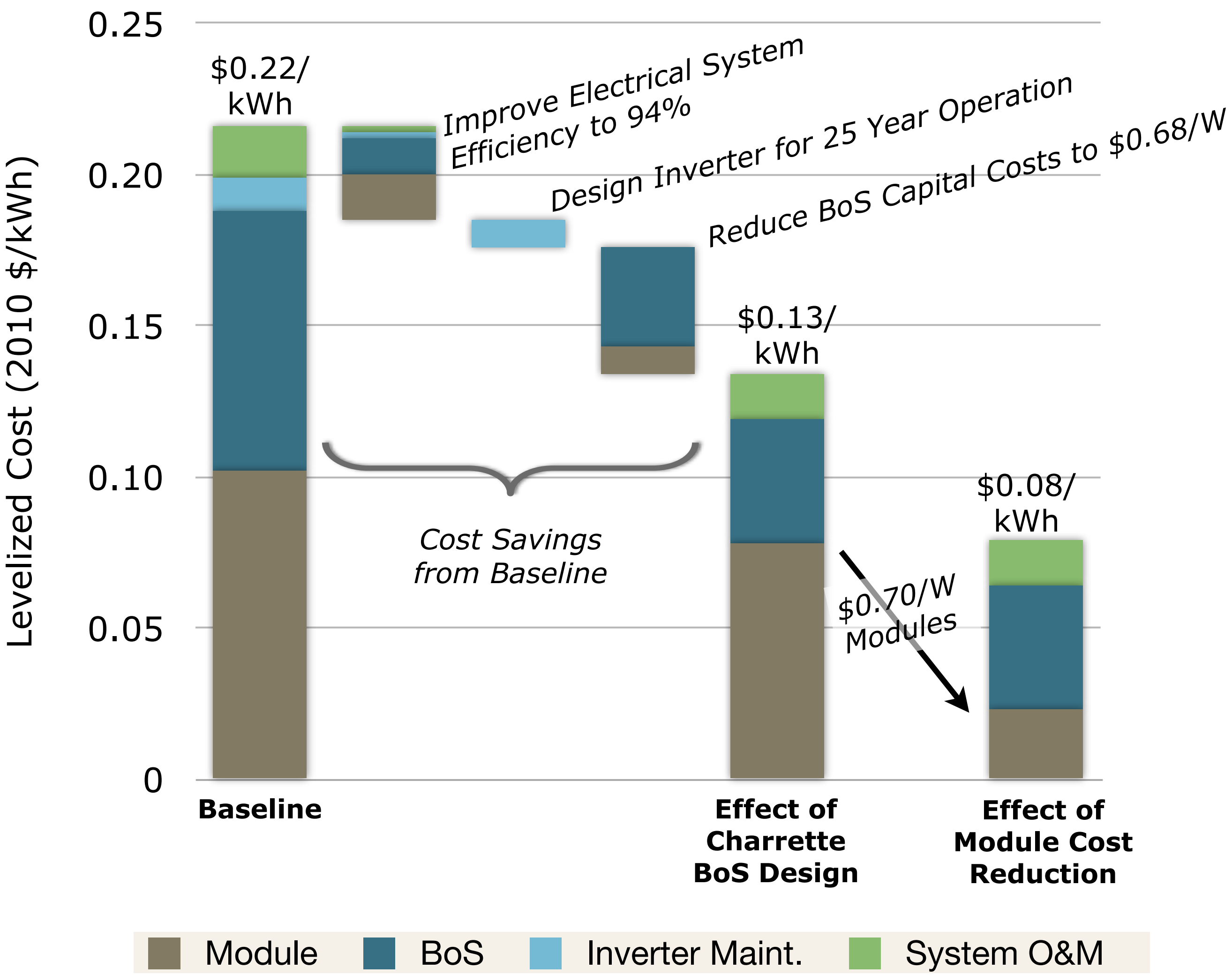
** Effect of Module Cost Savings: For certain electrical system architectures, increased integration of inversion processes with module electronics is possible. Specifically designing power electronics intelligence to match module characteristics may reduce module costs by safely downsizing or eliminating blocking diodes, module home runs, and backskin material.*

Source: RMI analysis based on Solar PV BoS Design Charrette input

Charrette Recommendations, Coupled with Module Cost decrease, Can Bring PV LCOE within U.S. Retail Rates Range

NEAR-TERM COST REDUCTIONS FOR GROUND-MOUNTED PV SYSTEM

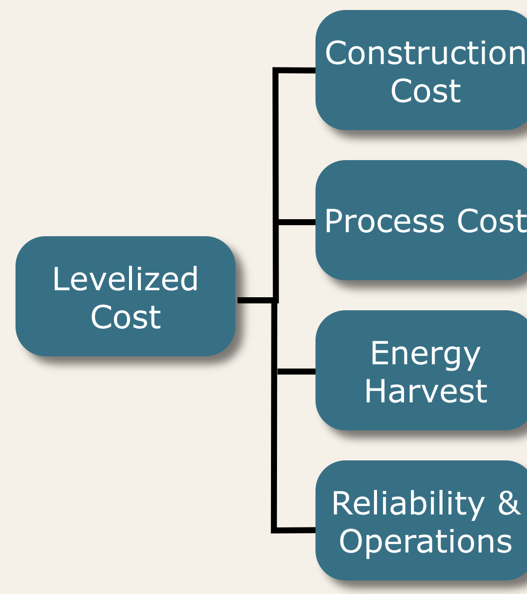
(LEVELIZED COST OF ELECTRICITY)



(GROUND-MOUNTED SYSTEM)

CALCULATING LCOE

In order to evaluate system-level trade-offs, PV system designs should be optimized based on the "levelized cost of electricity" (LCOE). LCOE (in $/kilowatt-hour) distributes the up-front cost over the output of the system, and takes into account such important factors as system performance, reliability, and maintenance costs.



Source: RMI analysis based on Solar PV BoS Design Charrette input

Charrette Prioritized Recommendations For Near-Term Cost Reductions

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

Area:	Vision:	Proposed Activities:
Physical Design	A low-cost, high-performance system design that can be tailored to unique site requirements	• Vet/implement charrette structural and electrical system designs • Widely use LCOE to evaluate designs and projects • Adopt solar-specific codes governing structural systems • Develop standard set of wind-tunnel tests and data • Enable accelerated reliability testing of new electrical components • Quantify the real value and feasibility of full installation automation • Implement tool-less installation approaches
Business Process	Supporting processes that effectively, efficiently, and predictably support solar deployment	• Quantify business process costs and drivers • Quantify value of consistent regulations between jurisdictions • Develop *Solar as an Appliance* to pre-approve system designs • Train regulatory personnel on a large scale • Create a National Solar Site Registry to compile site information • Increase market transparency through rating of players • Use a National Solar Exchange to develop more efficient markets
Industry Scale	The world's largest industry, utilizing an efficient supply chain based on common ground rules	• Promote industry standards to enable next-level mass manufacturing • Set up an organization to foster industry *coopetition* that allows competitors to agree on product standards, testing methods, and interchangeability
All areas (Physical Design, Business Process, Industry Scale)		• 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 • Incentivize aggressive cost-reduction with prize

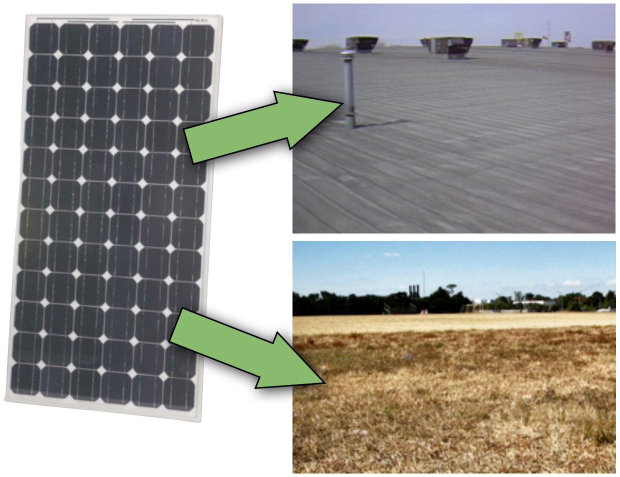
Source: RMI analysis based on Solar PV BoS Design Charrette input

Proposed Cost Reductions & Optimization Strategies

Cost Reduction Recommendations Fall Into Three Interrelated Categories

Physical Design: Structural System Proposed Cost Reductions

Physical Design

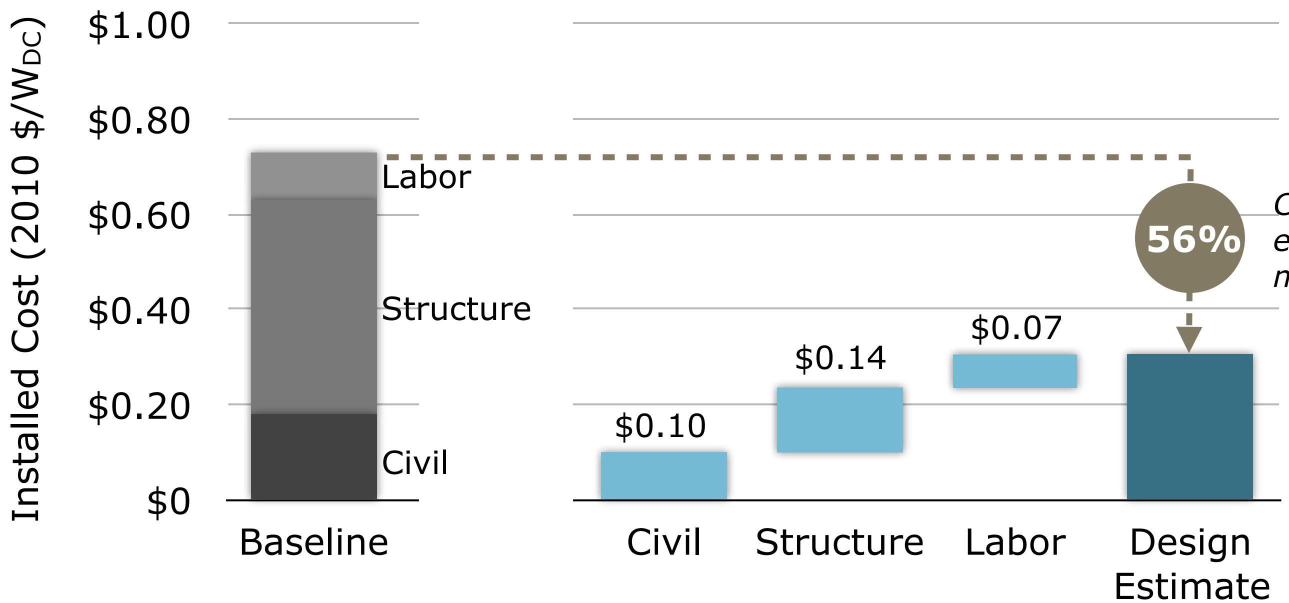


DESIGN OBJECTIVES FOR STRUCTURAL SYSTEM

- Minimize cost—$/W and $/kWh
- Maximize solar exposure and module performance
- Resist forces—downward (gravity, snow), uplift and lateral (wind)
- Maximize lifespan/reliability—as long as the module: 25 years
- Ensure safety—for installers and O&M staff)
- Support scalability ("installability", supply chain, sustainability): thousands of systems, tens of millions of modules per year

PROPOSED GROUND-MOUNTED STRUCTURE COST ESTIMATE

***Note:** This figure indicates the size of the opportunity and should not be taken as a detailed cost estimate for a specific design. The baseline design estimate is for a conventional ground-mounted fixed tilt aluminum racking system.*



For cost estimates for rooftop system design options, see full report.

Source: RMI analysis based on Solar PV BoS Design Charrette input

PHYSICAL DESIGN: STRUCTURAL DESIGN OPTIMIZATION STRATEGIES

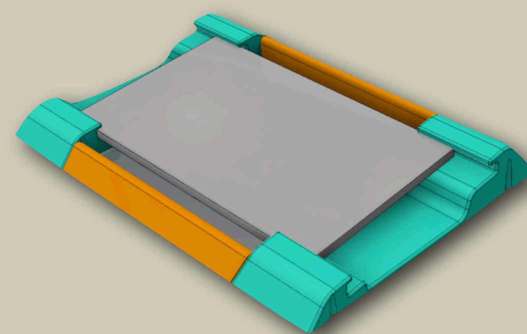
GENERAL PRINCIPLES

REDUCE FORCES AT WORK → OPTIMIZE STRUCTURAL FORM AND MATERIALS → DESIGN FOR LOW COST INSTALLATION

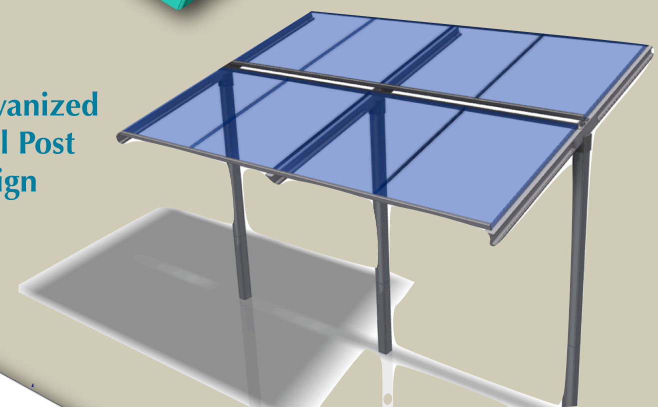
DESIGN OPPORTUNITIES

- **Reduce wind exposure**—enables the downsizing of structural components. Strategies include module spacing, site layout, spoiling and deflection technologies, and flexible structures. Can reduce wind forces on modules by 30 percent or more.
- **Use module for structure**—using rigid glass modules as part of the structural system enables the downsizing of racking systems. Close collaboration between installers, manufacturers, and certification agencies is required to achieve this goal.
- **Minimize installation labor**—increased installation efficiency could save an estimated 30 percent of labor time and cost for ground-mounted systems. For rooftops, where labor is a large share of the cost, the opportunity is even greater.

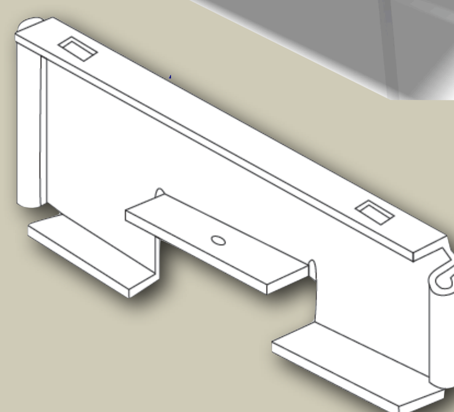
CHARRETTE DESIGN EXAMPLES*



Plastic Rooftop Design



Galvanized Steel Post Design



Proposed Component for Steel Rooftop Design

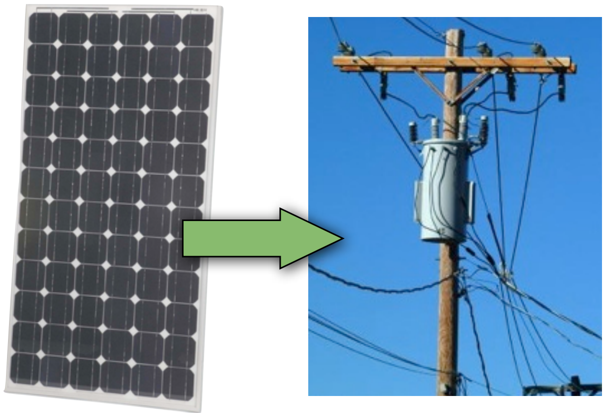
For details of design concepts, see full report.

*Charrette participants used brainstorming and design sessions to develop concepts for rooftop and ground-mounted systems that leverage the best practices for efficient, cost-effective design.

Source: RMI analysis based on Solar PV BoS Design Charrette input

Physical Design: Electrical System Proposed Cost Reductions

Physical Design

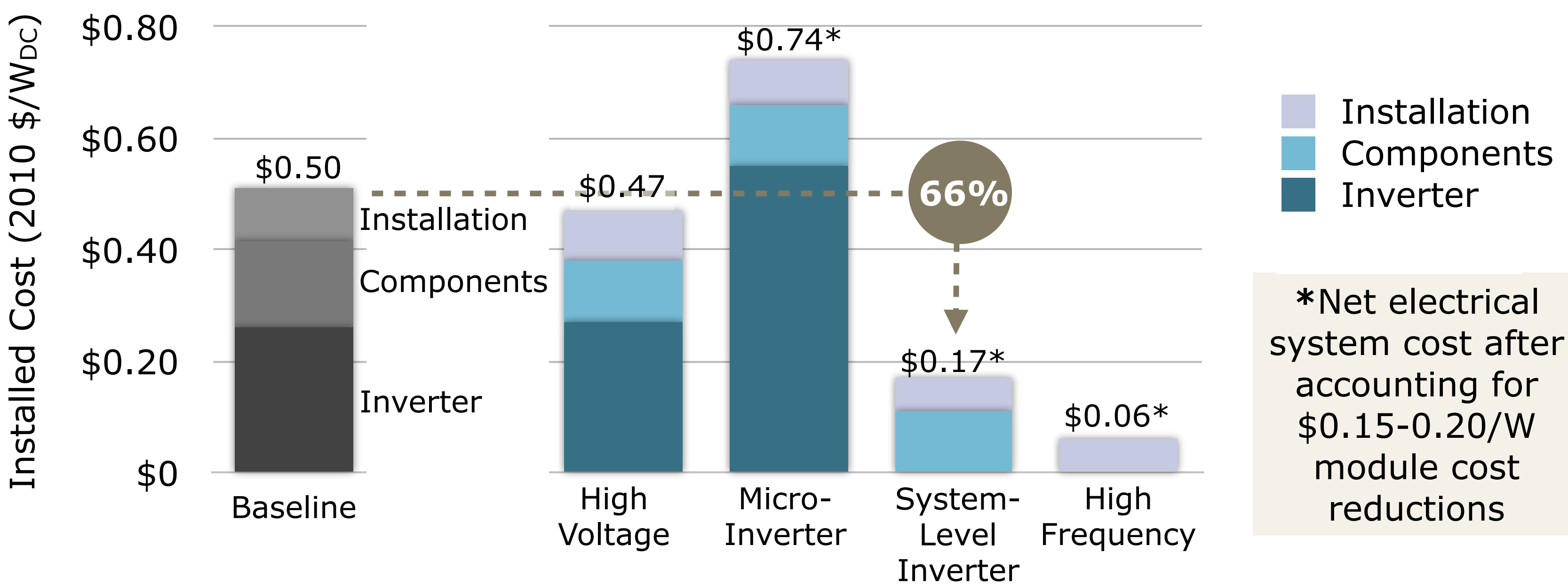


DESIGN OBJECTIVES FOR ELECTRICAL SYSTEM

- Minimize cost—$/W and $/kWh
- Maximize efficiency and system performance
- Maximize lifespan/reliability—as long as the module: 25 years
- Ensure safety—for installers and O&M staff
- Support scalability ("installability", supply chain, sustainability): thousands of systems, tens of millions of modules per year

PROPOSED ELECTRICAL SYSTEM DESIGN COST ESTIMATES

Note: *This figure is based on charrette cost estimates. Significant changes are possible as inverter technologies are produced at scale—central inverters, microinverters, and module integrated power electronics all offer potential to achieve cost reductions through more efficient manufacturing processes.*



*Net electrical system cost after accounting for $0.15-0.20/W module cost reductions

Source: RMI analysis based on Solar PV BoS Design Charrette input

PHYSICAL DESIGN: ELECTRICAL DESIGN OPTIMIZATION STRATEGIES

GENERAL PRINCIPLES

FOCUS ON IMPROVING ELECTRICAL SYSTEM COMPONENT RELIABILITY TO MATCH THE MODULES' EXPECTED LIFETIME

LEVERAGE SCALE OF MASS-PRODUCED AC ELECTRICAL COMPONENTS

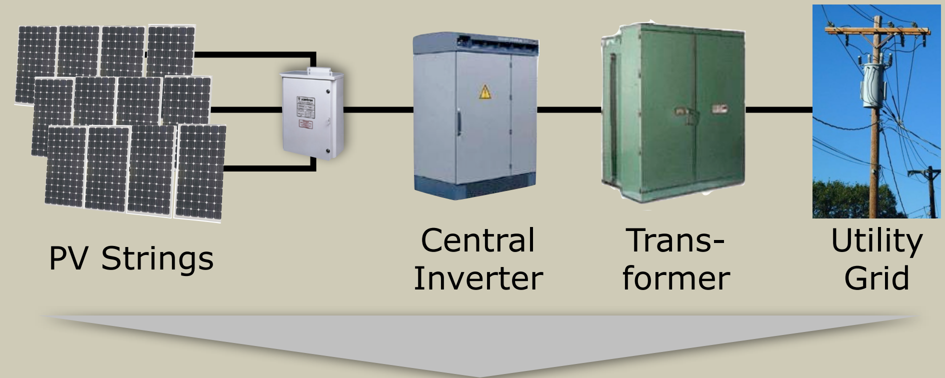
OPTIMIZE BOS POWER ELECTRONICS WITH MODULE DESIGN

DESIGN OPPORTUNITIES

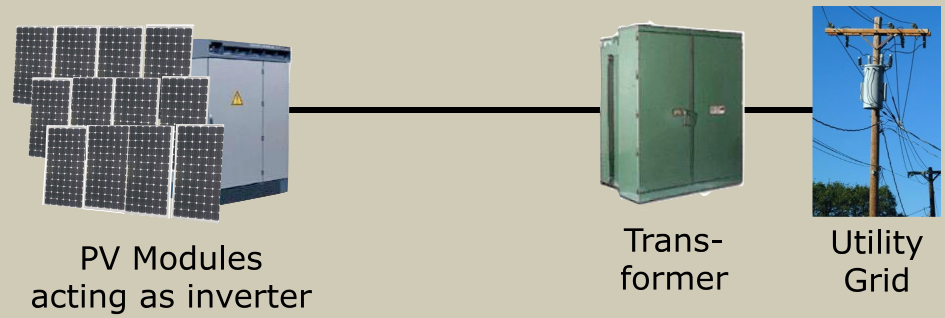
- **Rethink electrical system architectures**—improvements in small inverter cost, reliability, and performance can help capture benefits associated with high-voltage power aggregation and high-frequency conversion.
- **Develop new power electronics technologies**—power electronics offer an opportunity for breakthrough technical design. Integrating AC intelligence into each module of an array or string of modules offer cost reduction potential. Plug-and-play installation approaches may be possible.

CHARRETTE DESIGN EXAMPLES*

BASE CASE



PLANT-LEVEL INVERTER CASE (1 of 4 design cases analyzed)



For details of design concepts, see full report.

*Charrette participants evaluated a variety of system architecture options, which may offer high potential to reduce costs for different types of PV systems and based on technology development and commercialization efforts.

Source: RMI analysis based on Solar PV BoS Design Charrette input

BUSINESS PROCESS: PROPOSED COST REDUCTIONS

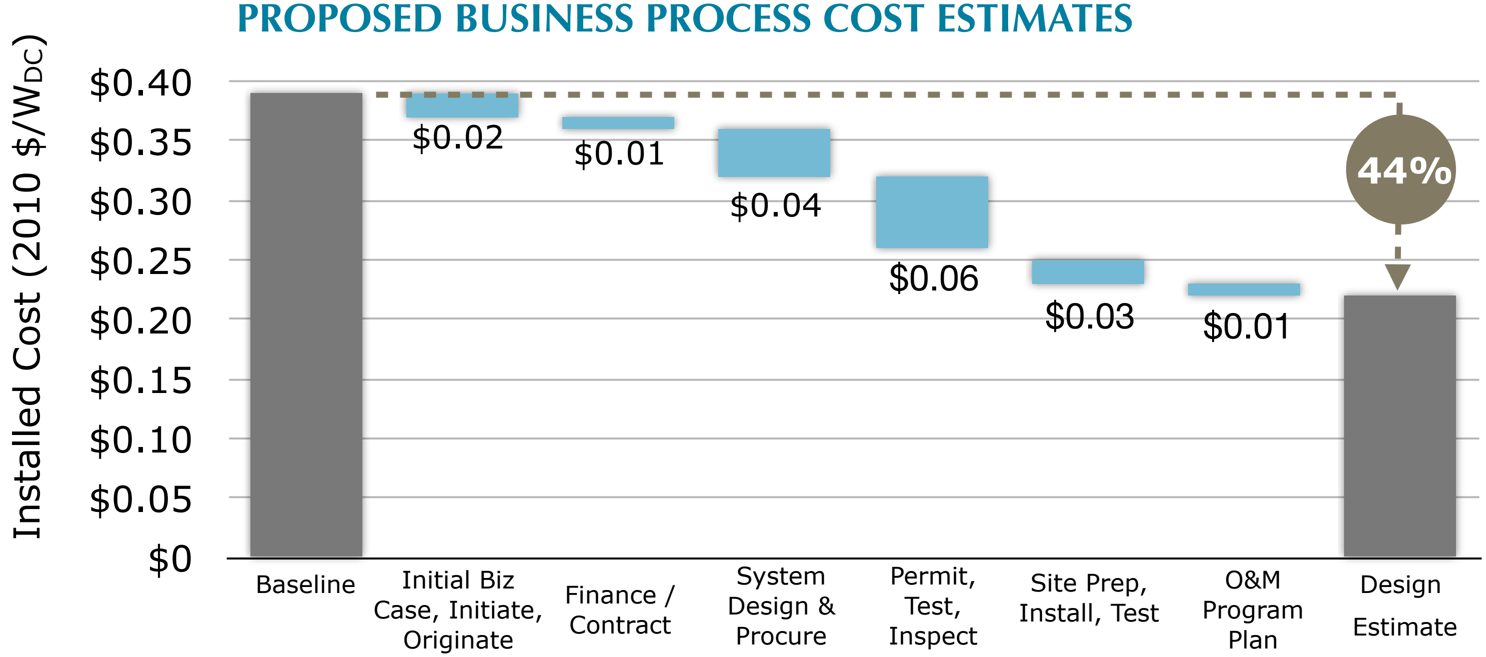
Business Process

BUSINESS PROCESS FLOW CHART

STAGE	PROCESS OBJECTIVE
Initial Business Case, Initiate, Originate	• Identify good projects • Secure customer
Finance/Contract	• Secure funds to complete project • Allocate risk
System Design, Procure	• Develop technically viable projects • Acquire materials and contractors
Permit, Test, Inspect	• Protect public health and safety • Ensure electrical grid reliability
Site Prep, Install, Test	• Ensure fully functional and operational PV system
Operate, Monitor, Maintain	• Meet planned output • Minimize on-going costs

PROPOSED BUSINESS PROCESS COST ESTIMATES

Note: Business process cost baselines and reductions shown are rough estimates based on charrette participants' estimates of the cost breakdown for a typical large installation. Values may vary significantly between projects based on market dynamics, technology, owner, and system type.



Source: RMI analysis based on Solar PV BoS Design Charrette input

BUSINESS PROCESS: OPTIMIZATION STRATEGIES

Business Process

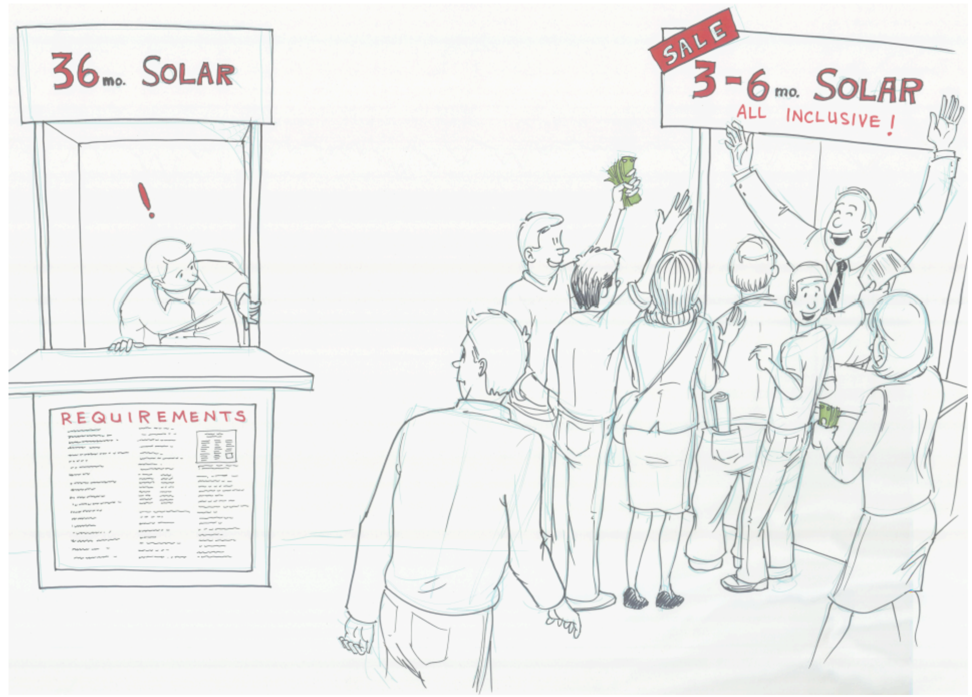
CHALLENGES

DIFFICULTY TO ACCESS INFORMATION ON SOLAR SITE SUITABILITY

SIGNIFICANT SYSTEMS CUSTOMIZATION REQUIRED FOR EACH SITE

WIDESPREAD STAKEHOLDERS INEXPERIENCE WITH PV PROJECTS

LACK OF ACCOUNTABILITY AND OVERSIGHT FOR THE END-TO-END BUSINESS PROCESS



OPTIMIZATION OPPORTUNITIES

- **Eliminate unnecessary steps and streamline processes**—implementing consistent regulations and reducing the uncertainty associated with approval processes can help reduce non-value added time. A detailed process map—with current cycle times and costs, unneeded actions, rework, and other factors driving time, complexity, and cost—is needed.
- **Reduce project "dropouts"**—dropout projects may be caused by unrealistic customer expectations, stakeholder inexperience, unforeseen permitting challenges, or a lack of capital. One way to address these issues might be a database that developers can use to evaluate proposed projects.

Source: RMI analysis based on Solar PV BoS Design Charrette input

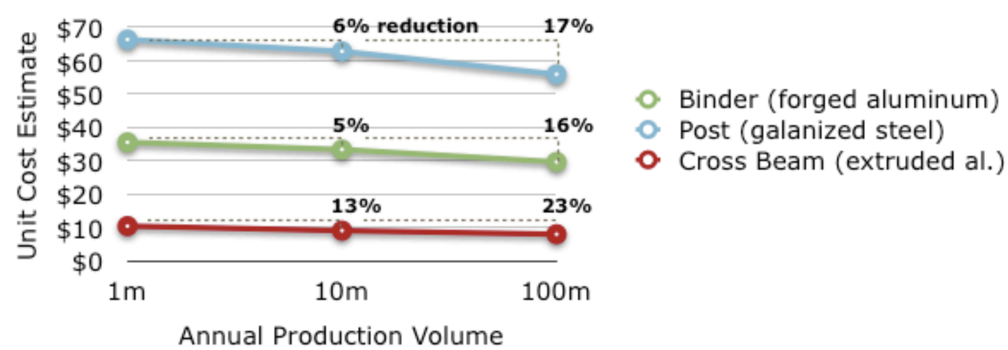
INDUSTRY SCALING COST AND OPTIMIZATION OPPORTUNITIES

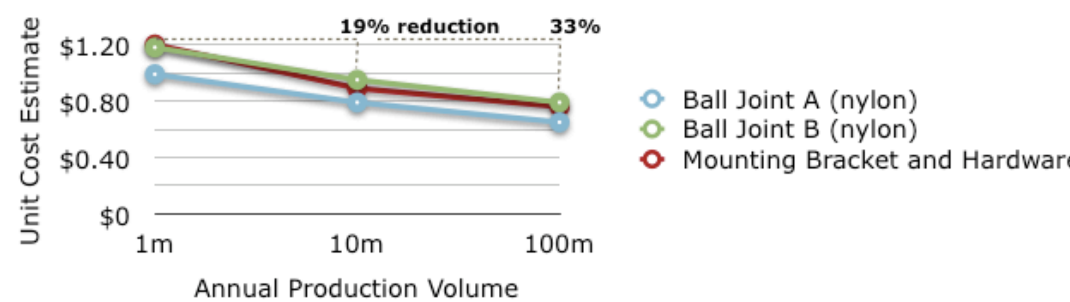
Industry Scale

OPTIMIZATION OPPORTUNITIES

- **Standardize components and processes**—project integrators/systems installers collaborating with suppliers can drive increased standardization and economies of scale for components. "Coopetition" across the value chain is a strong enabler of standardization.
- **Leverage high-volume, lean manufacturing**—the solar BoS industry is typically characterized by 1) use of materials designed and produced for a different industry; or 2) numerous manufacturers with relatively small market shares that produce mutually incompatible products. Lean manufacturing and increasing system size (up to a point) will contribute to costs reduction.

ESTIMATED MANUFACTURING COST REDUCTIONS FROM SCALE





See full report for recommendations for implementing increased standardization and high-volume manufacturing

Source: RMI analysis based on Solar PV BoS Design Charrette input

Appendices

ABOUT THE SOLAR PV BOS DESIGN CHARRETTE

Held in San Jose, California, the *RMI Solar PV BoS Design Charrette* included more than 50 industry experts who participated in a facilitated series of plenary sessions and breakout working groups.

During the charrette process, the participants focused on BoS design strategies that can be applied at scale in the near term (less than five years). Since rigid, rectangular modules account for more than 95 percent of the current market, charrette BoS designs were constrained to this widespread standard. Finally, the charrette addressed relatively large systems (rooftop systems larger than 250 kW and ground-mounted systems in the 1–20 MW range).

A **CHARRETTE** is an intensive, transdisciplinary, roundtable design workshop with ambitious deliverables and strong systems integration. Over a three-day period, the Solar PV BoS charrette identified and analyzed cost reduction strategies through a combination of breakout groups focused on specific issues (rooftop installation, ground-mounted installation, electrical components and interconnection, business processes) and plenary sessions focused on feedback and integration.

CHARRETTE PARTICIPANTS

The following industry stakeholders and outside experts participated in RMI's BoS Charrette.*

Participant	Organization
Scott Badenoch, Sr.	Badenoch LLC
Andrew Beebe	Global Product Strategy
Sumeet Bidani	Duke Energy Generation Services
Bogusz Bienkiewicz	Colorado State University
David Braddock	OSEMI, Inc.
Daniel J. Brown	Autodesk
William D. Browning	Terrapin Bright Green LLC
Gene Choi	Suntech America
Rob Cohee	Autodesk
Jennifer DeCesaro	U.S. Department of Energy
Doug Eakin	Wieland Electric
John F. Elter	CSNE, University at Albany
Joseph Foster	Alta Devices
Seth A. Hindman	Autodesk
Kenneth M. Huber	PJM Interconnection
David K. Ismay	Farella Braun + Martel
Kent Kernahan	Array Converter
Marty Kowalsky	Munro & Associates
Jim Kozelka	Chevron Energy Solutions
Sven Kuenzel	Schletter, Inc.
Minh Le	U.S. Department of Energy
Amory Lovins	Rocky Mountain Institute
Robert Luor	Delta Electronics

Participant	Organization
Kevin Lynn	U.S. Department of Energy
Tim McGee	Biomimicry Guild
Sandy Munro	Munro & Associates
Ravindra Nyamati	Delta Electronics
Susan Okray	Munro & Associates
Roland O'Neal	Rio Tinto
David Ozment	Walmart
James Page	Cool Earth Solar
Doug Payne	SolarTech
Julia Ralph	Rio Tinto
Rajeev Ram	ARPA-E
Yury Reznikov	SunLink Corporation
Daniel Riley	Sandia National Laboratories
Robin Shaffer	SunLink Corporation
David F. Taggart	Belectric, Inc.
Tom Tansy	Fat Spaniel Technologies
Jay Tedeschi	Autodesk
Skye Thompson	OneSun
Alfonso Tovar	Black & Veatch
Charles Tsai	Delta Electronics
Gary Wayne	
David Weldon	Solyndra, Inc.
Rob Wills	Intergrid
Aris Yi	Delta Products Corporation

In addition, many additional contributors to the project are recognized in the full report.

*Attendance of the charrette/contribution to the project does not imply endorsement of the content in this document

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