REDUCING SOLAR PV SOFT COSTS

A FOCUS ON INSTALLATION LABOR

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EXECUTIVE SUMMARY

01

01: EXECUTIVE SUMMARY

Distributed solar energy is a key enabler of the affordable, resilient, secure, and low-carbon electricity future Rocky Mountain Institute (RMI) advocates in *Reinventing Fire*.[1] However, in order for distributed solar to play its role, a number of changes must transpire. The most pressing of these changes is for solar costs to come down to U.S. Department of Energy SunShot levels that enable deployment of cost-effective solar systems across the U.S. Between 2008 and 2012, the price of sub-10-kilowatt rooftop systems decreased 37%. However, over 80% of the cost decline is attributable to decreasing solar PV module costs.[2] Of the average $4.93/W[3] cost of a residential rooftop solar system, over 60% of the total is now attributable to "soft costs," including those associated with installation labor; permitting, inspection, and interconnection (PII); customer acquisition; financing costs; and installer / integrator margin.[4] With module and inverter costs predicted to stabilize at relatively low levels between now and 2020, these soft costs must come down in order for solar energy to be cost competitive across the U.S.

In light of these high soft costs in the U.S., RMI has built upon work conducted by Lawrence Berkeley National Laboratory (LBNL) by partnering with the Georgia Tech Research Institute (GTRI) to focus on the large apparent difference in installation labor costs between the U.S. and Germany, the leader of low-cost PV, through our SIMPLE BoS project (Solar Install, Mount, Production, Labor, Equipment, and Balance of System). With funding in part from the Department of Energy's SunShot Initiative, RMI and GTRI developed a time and motion methodology for tracking installation labor costs for rooftop installations and collected data from 26 sites across the U.S. and Germany.

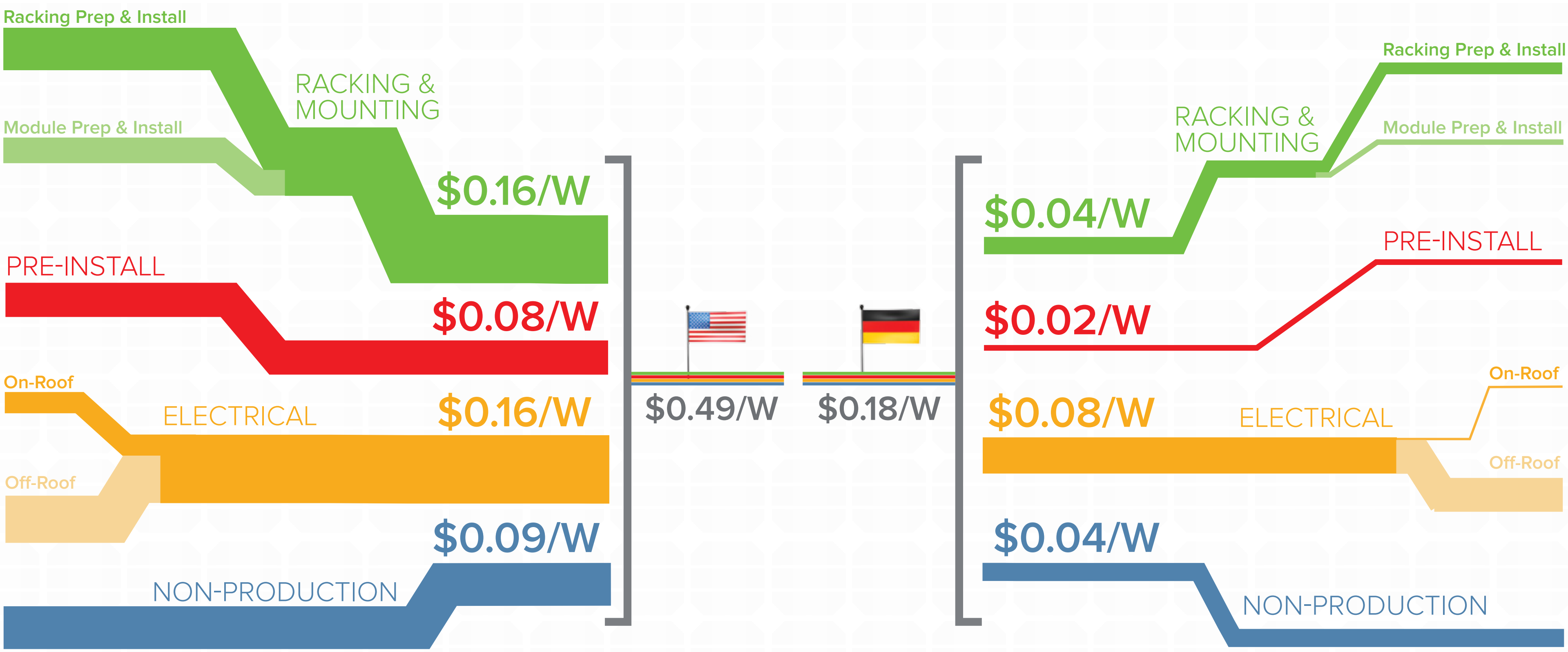
Our initial comparison of U.S. and German installs (see Figure ES1, page 5) using the SIMPLE BoS time and motion methodology highlights even more opportunity for cost reduction than initially suggested by the 2012 LBNL study, with median German SIMPLE BoS installers incurring an installation labor cost of just $0.18/W. The major enabling factors of German efficiency include greatly simplified base installation processes, widespread use of scaffolding and module lifts, task specialization, and uniform residential German architecture.

Preliminary results show that U.S. installers participating in the SIMPLE BoS project incur median installation costs of $0.49/W, compared to $0.91/W for the most expensive single installation benchmarked and $0.30/W for the least expensive (most efficient).

Initial data collection also highlighted a $0.20/W opportunity to identify PV installation best practices within the U.S., not just from benchmarked German installations. Based on our data, a composite "best of the best" virtual U.S. installation that draws upon the fastest observed individual installation activities across all U.S. installations would incur installation costs of only $0.29/W. This is an important finding, as it indicates that some U.S. installers are conducting specific activities near German levels of efficiency.

[1] Lovins, Amory B., and Rocky Mountain Institute. *Reinventing Fire: Bold Business Solutions for the New Energy Era*. Chelsea Green Publishing, 2011.
[2] Wiser et al., Tracking the Sun VI. (LBNL, August 2013): 13–15.
[3] All units in this report reported as per Watt are per Watt-direct current.
[4] Average price estimate from GTM / SEIA Q1 2013 Solar Market Insight. Soft cost estimate based on RMI Analysis of Friedman et al., Second Annual Benchmarking Non-Hardware Balance-of-System (Soft) Costs for U.S. Photovoltaic Systems, Using a Bottom-Up Approach and Installer Survey, (NREL, 2013) Publication forthcoming. Soft costs account for $3.38/W of a typical $4.93/W residential system. This includes $2.16 in installer and integrator margin, sales tax, and other fixed transactional financing costs.

FIGURE ES1: U.S. AND GERMAN ROOFTOP INSTALLATIONS COMPARED



PRE-INSTALL

Travel*
On-Site Prep
Off-Site Prep*

RACKING & MOUNTING

Racking Prep & Install
Base Prep
Rail Prep
Base Attach
Rail Attach
Other Hardware Install

Module Prep & Install
Module Prep
Module Attach

ELECTRICAL

On-Roof
Homerun Install
Grounding Install*
Combiner Box Install*

Off-Roof
Electrical Equipment & Inverter Install
Conduit Install
Disconnect Install*

NON-PRODUCTION

Meals & Breaks
Clean-up
Unavoidable Delay
Avoidable Delay

**denotes U.S. only*

The major opportunities to reduce installation labor costs in the U.S. include:

- adoption of technologies and processes that enable one-day installations,
- overhauling the racking base installation process,
- use of standardized systems that reduce the need for one-off engineering and design work,
- innovating on all AC-related electrical activities, and
- eliminating several non-value-add activities typical to the U.S. installation process.

Several enabling factors from German installers and leading U.S. installers can be disseminated throughout the U.S. market in the near term with varying levels of impact. An additional opportunity exists, and by aggressively pursuing new designs and the most efficient installation practices, U.S. installers could dramatically cut installation labor costs to below those of Germany. Holding hardware and non-installation labor soft costs constant, such drastic changes would reduce soft costs by 30%, lowering the installed costs of a U.S. rooftop residential system by 10% to $4.43/W.

Several opportunities identified by the SIMPLE BoS team can be implemented (or at the very least experimented with) with varying levels of difficulty by installers in the near term and have the potential to reduce installation costs to varying degrees (see Table ES 1).[5]

TABLE ES1: COST REDUCTION OPPORTUNITIES

OPPORTUNITY	APPROXIMATE SAVINGS ($/W)	IMPLEMENTATION DIFFICULTY LEVEL
Design Out Animal Wire	$0.02	Low
On-Ground Rail Preparation	$0.02	Low
Base Installation Redesign	$0.04	Low
One-Day Installations	$0.10	Mid
Integrative Racking: Current Gen	$0.11	Mid
Steep Roof Redesign	$0.10	Mid
Scaffolding / Safety Nets	$0.02	Mid
Conduit Redesign	$0.04	High
Clay Tile Base Revamp	$0.12	High
Integrative Racking: Next Gen	$0.40	High
Process Optimization	$0.17	High
PV-Ready Electrical Circuit	$0.10	High

[5]Work conducted under the SIMPLE BoS project is a direct-project analysis complement to the joint NREL–RMI Soft Cost Roadmap, a survey and secondary research-based report that outlines a pathway to achieving the $1.50/W residential PV system price goal set by the Department of Energy's SunShot Office. Ardani et al. *Non-Hardware ("Soft") Cost-Reduction Roadmap for Residential and Small Commercial Solar Photovoltaics, 2013—2020*, National Renewable Energy Laboratory, August 2013.

INTRODUCTION: THE *REINVENTING FIRE* VISION AND SOLAR ENERGY

02

02: INTRODUCTION: THE *REINVENTING FIRE* VISION AND SOLAR ENERGY

Reinventing Fire, Rocky Mountain Institute's vision of an affordable, resilient, secure, and low-carbon economy for the United States, depicts a future electrical system based on a large amount of distributed renewables, and widespread implementation of energy efficiency measures, demand response programs, electric vehicles, and community-based microgrids. Distributed solar energy plays a particularly important role: RMI estimates that to create this future electricity system, the U.S. will need to deploy over 700 gigawatts of distributed solar photovoltaic capacity—70 times U.S. total installed PV capacity through 2013, according to the Solar Energy Industries Association and GTM Research—between now and 2050.

A number of changes are needed between now and 2050 in order for this vision to become reality, including harmonization of utility business models with distributed renewables, technical advances in the integration and management of large amounts of distributed generation, and expanded access to diverse pools of investment capital. However—and equally critical—the upfront cost[6] of solar must come down in order to deploy this large amount of solar capacity. Between 2008 and 2012, the price of sub-10-kilowatt rooftop systems in the U.S. decreased 37%. However, over 80% of the cost decline is attributable to decreasing solar PV module costs,[7] which has created a skewed residential cost distribution in the U.S. solar market. Of the average $4.93/W cost of a residential rooftop solar system, nearly 70% of the total is attributable to "soft costs," including those associated with installation labor; permitting, inspection, and interconnection; customer acquisition; financing costs; and installer / integrator margin (see Figure 1 on next page).[8]

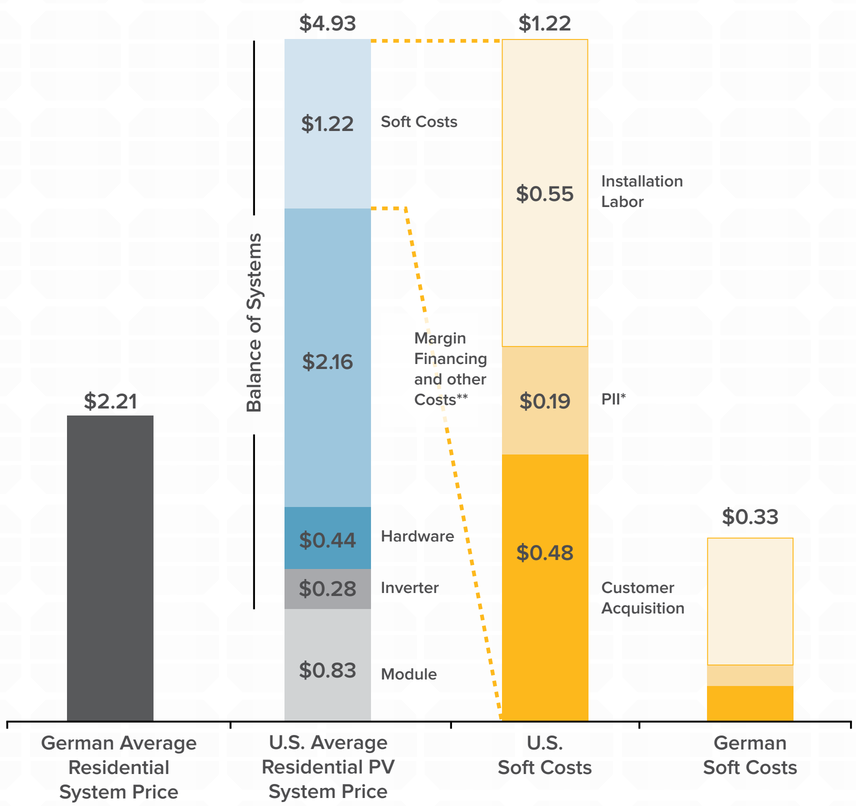
These soft costs must come down in order for the cost of solar systems to meet the aggressive system cost targets set by the Department of Energy's SunShot program. These cost targets—$1.50/W, $1.25/W, and $1.00/W for residential, commercial, and utility-scale systems,[9] respectively—could enable the deployment of cost-competitive solar systems across the U.S. and help the country move closer towards the future electricity system envisioned in *Reinventing Fire*. However, many of these costs, like financial transaction costs, can be difficult to measure consistently across installers and to develop widespread pathways for cost reduction.

In light of these high soft costs in the U.S., RMI has built upon work conducted by Lawrence Berkeley National Laboratory (LBNL) by partnering with the Georgia Tech Research Institute (GTRI) to focus on the large apparent difference in installation labor costs between the U.S. and Germany, the leader of low-cost PV, through our SIMPLE BoS project (Solar Install, Mount, Production, Labor, Equipment, and Balance of System).[10] This partnership was made possible through a funding opportunity from the Department of Energy's SunShot Initiative. This report presents the findings from the first stage of installation labor studies under this partnership.

[6] Upfront cost = overnight capital cost.
[7] Wiser et al. Tracking the Sun VI. (LBNL, August 2013): 13–15.
[8] Average cost estimate from GTM / SEIA Q1 2013 Solar Market Insight. Soft cost estimate based on RMI Analysis of Friedman et al., Second Annual Benchmarking Non-Hardware Balance-of-System (Soft) Costs for U.S. Photovoltaic Systems, Using a Bottom-Up Approach and Installer Survey (NREL. 2013) Publication forthcoming.
[9] Department of Energy Sunshot Initiative Targets are in 2010 U.S. dollars.
[10] Seel et al. "Why Are Residential PV Prices in Germany So Much Lower Than in the United States?" (LBNL, February 2013).

FIGURE 1: **SOLAR PV COSTS IN THE U.S. AND GERMANY**

SOFT COSTS ARE THE MAJOR DRIVER OF COST DIFFERENCES BETWEEN THE U.S. AND GERMANY



*Permitting, inspection, and interconnection costs

** Includes installer and integrator margin, legal fees, professional fees, financing transactional costs, O+M costs, production guarantees, reserves, and warranty costs.

In order to explore this cost divide, help industry reduce installation labor costs, and explore the potential for new racking designs to reduce costs, RMI and GTRI developed a time and motion methodology for tracking installation labor costs on rooftop installations and collected primary data from 26 sites across the U.S. and Germany. To our knowledge, unlike other solar PV cost studies and surveys, this is the first publicly available study of its kind using direct observation to understand root causes of high PV installation costs in the U.S. The time and motion methodology can be applied to residential, commercial, and utility-scale installations. However, given the large apparent installation labor cost reduction opportunity available in the residential PV market, this report focuses on rooftop residential solar systems only.

While not a statistically significant dataset due to the small sample size, preliminary results suggest a significant cost reduction opportunity available to the U.S. solar industry first established by the National Renewable Energy Laboratory (NREL) and LBNL. It is our hope that the preliminary results contained in this report will:

1. Shed light at a very granular level on the cost reduction opportunity available to the U.S. solar industry by exploring cost differences between U.S. and German installers.
2. Identify specific areas ripe for additional innovation by hardware manufacturers to design out costs from rooftop PV systems, enabling broader solar cost competitiveness.
3. Illustrate strategies for near-term cost reduction to U.S. installers and developers.

SIMPLE BoS: A MULTI-YEAR RMI / GTRI / DOE SUNSHOT COLLABORATION

The SIMPLE Balance of System project was made possible through a three-year, $5.8 million research program funded by the Department of Energy's SunShot Initiative. In late 2011—with a project goal to reduce balance of system racking and labor costs by 50% of industry best practice in residential, commercial, and utility-scale photovoltaic applications—multi-disciplinary teams of students and faculty from the Georgia Institute of Technology produced 132 design concepts to meet this aggressive goal.

In order to downselect designs for maximum impact and successful commercialization, they were then evaluated by GTRI, Georgia-based solar companies Suniva and Radiance Solar, testing outfit Intertek, and RMI. To supplement this design work, time and motion studies conducted by RMI and GTRI provided baseline data to evaluate the performance of current technologies, emerging designs, and state-of-the-art installation methodologies. To date, five technologies are being advanced to a 90% pre-commercial design stage with potential cost reductions of >50% for the residential, commercial, and utility-scale markets.

METHODOLOGY AND STUDY OVERVIEW

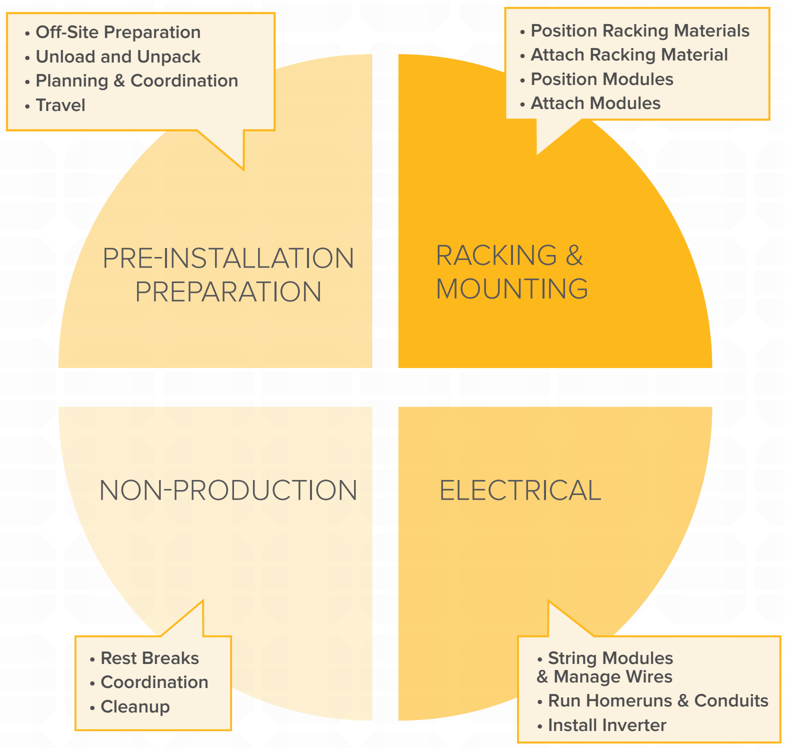
03

03: METHODOLOGY AND STUDY OVERVIEW

For the SIMPLE BoS project, RMI and GTRI developed a time and motion methodology specific to rooftop solar PV installations. The original goal of time and motion studies was to increase productivity while minimizing wasted money and effort.[11] Time and motion study is a proven business efficiency technique that has been used to measure and reduce waste in hundreds of different industries. By directly observing and documenting the timing, physical motion, location, and hardware associated with each step in the PV installation process, studies conducted for SIMPLE BoS are able to identify key drivers of installation efficiency and help industry better understand the benchmarked cost difference between low- and high-performing installers—both in the U.S. and internationally. The time and motion methodology can be used to track utility-, commercial-, and residential-scale installations. This report focuses on installation labor costs in the residential market only.

After developing the SIMPLE BoS time and motion methodology,[12] RMI and GTRI researchers took to the field in the U.S. and Germany to gather primary data on rooftop solar installation processes. Both qualitative and quantitative data were collected and analyzed using time and motion and lean methodologies. Data collection was narrow in scope, focusing only on project-specific construction activities (including off-site preparatory work). Site data was categorized into four primary activity categories: pre-installation preparation, racking and mounting, electrical, and non-production (see Figure 2).

FIGURE 2: **PV INSTALLATION ACTIVITIES**



[11] Niebel, Benjamin W. *Motion and Time Study*. Richard D. Irwin, 1992.
[12] Goodman, J., Nagel, K., Wren, M., & Morris, J. (2014). "Applying lean process principles to improve labor efficiency of solar photovoltaic installations." 2014 Construction Research Congress. Atlanta, GA. In publication.

Each data point was documented with the installation site and contextual parameters, including roof pitch, roof composition, racking design, and module type. The data points included more detailed information on the individual installer's level of training, labor classification (electrician or non-electrician), primary activity, secondary activity (including activities like "attach", "prepare", and "delay"), the location where the activity was performed, the associated hardware, and the amount of time spent on the discrete combination of these variables. We then applied these times to the fully burdened wage rate in the U.S. and Germany based on the labor classification. The SIMPLE BoS team collected data for a wide range of time intervals, ranging from seconds to minutes per data point. An example data point with standard observer protocol coding is illustrated in Table 2.

The data collected during this phase of SIMPLE BoS included time and motion observations of 21 U.S. and 5 German residential installations. In the U.S. 8 different installation companies were observed; in Germany the project team observed 2 installers. In spite of the small number of complete PV installations observed during this phase of SIMPLE BoS, this data set provides interesting, and perhaps telling, observations.

Due to minor variability in installer and observer practices, some post-project time and motion data homogenization was required.[13]

Outside of aggregate site level data as illustrated above, the SIMPLE BoS team captured statistically significant data on a micro-motion scale. This rapid time capture (RTC) data measured the time required to perform a single iteration of a particular work movement, usually involving only one hardware item per data point.[14] For example, module attachment occurs on every site. RTC data records the amount of time (at a granularity of seconds) one or more installers require to attach a single panel to a fully installed racking system, while the higher-level aggregate data would only record the total amount of time all installers spend attaching panels throughout the entire installation process.

[13] This involved re-coding some activities to allow for a more consistent comparison of installer practices.

[14] The SIMPLE BoS team collected approximately 1,500 RTC data points on all racking and mounting activities. This data largely informed the development of several designs under development by the SIMPLE BoS team that are not explicitly discussed in this report.

TABLE 1: EXAMPLE DATA POINT

SITE NAME	SIZE (kW)	ARRAY AREA (M²)	INSTALLER	ELECTRICIAN OR NON-ELECTRICIAN	PRIMARY ACTIVITY	SECONDARY ACTIVITY	LOCATION	HARDWARE	TIME (INSTALLER-MINS)
CO Site 1	5.8	38.7	C	NE	A2: Racking & Modules	0.07 Preparation	L06: Array Area	H02: Module	10

COST REDUCTION OPPORTUNITIES FOR THE U.S. SOLAR INDUSTRY

04

04: COST REDUCTION OPPORTUNITIES FOR THE U.S. SOLAR INDUSTRY

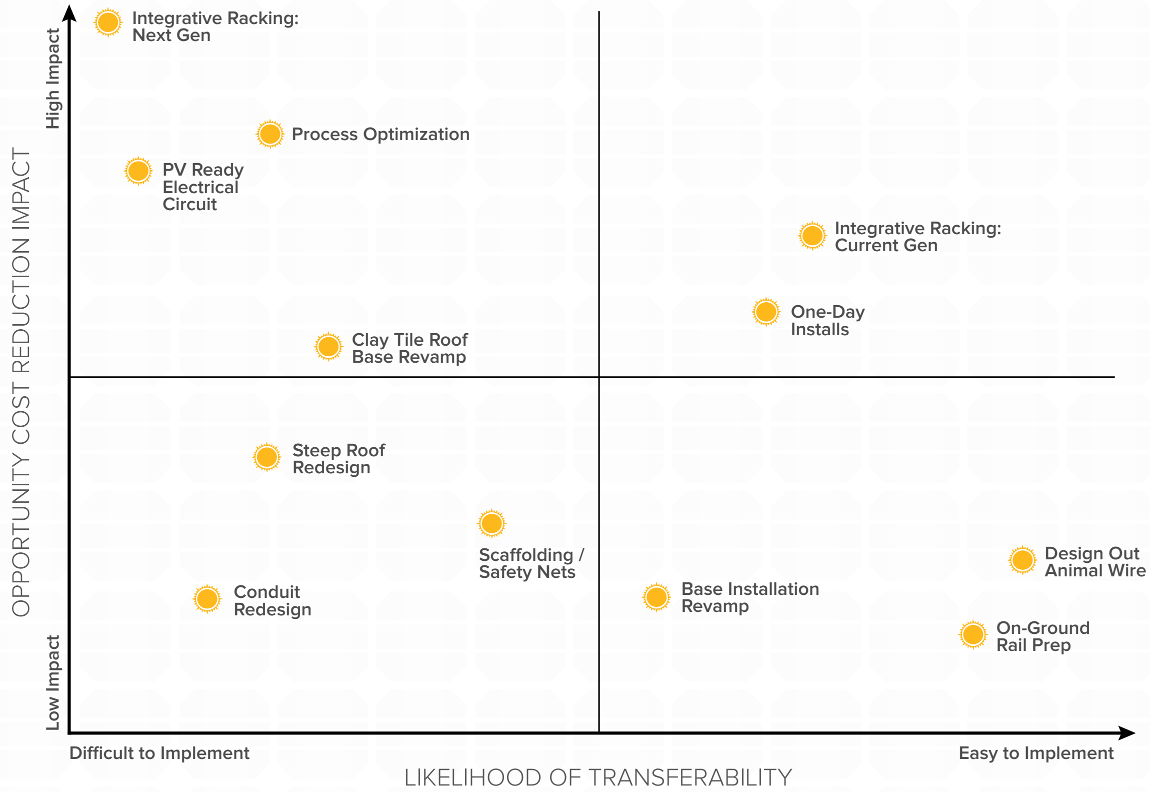
Propagating the efficiency of leading U.S. and German installers throughout the domestic solar industry won't happen overnight. But several efficiency practices and hardware designs observed using our time and motion methodology in both the U.S. and Germany can be readily adopted by U.S. installers, while those that can't provide useful frameworks for new and/or modified hardware designs domestically.

NEAR-TERM OPPORTUNITIES FOR COST REDUCTION

Through analysis of our direct observations and inclusion of anecdotal evidence from installers, the SIMPLE BoS team has highlighted a number of near- and medium-term opportunities for solar installers and hardware manufactures to reduce the installed costs of solar (see Figure 3).

Each of these opportunities has the potential to reduce installation labor costs in the U.S. market with varying levels of impact and difficulty. The next section covers each of these opportunities in more detail.

FIGURE 3: **COST REDUCTION OPPORTUNITIES AND DIFFICULTY OF WIDESPREAD IMPLEMENTATION IN THE U.S.**



LOW-IMPACT, EASY-TO-IMPLEMENT OPPORTUNITIES

Several opportunities identified by the SIMPLE BoS team can be pursued (or at the very least experimented with) by installers in the near term and have the potential to incrementally reduce installation labor costs.

Design Out Animal Wire

U.S. installers using animal wire to prevent PV wire damage and junction box / module replacement incur an average cost of $0.03/W. In some cases, U.S. installers spend more time preparing and attaching animal wire than they do preparing, positioning, and attaching the modules themselves. Several solutions currently exist that can eliminate or reduce animal wire requirements and are worth experimenting with, including:

- Integrated racking solutions (like the Lumos LSX Racking System and SIMPLE BoS designs currently in development) that both ease wire management and prevent animal intrusion
- Repellants like Ro-Pel that are commonly used to protect car systems from rodents—while their longevity is untested and environmental concerns associated with chemical repellants must be evaluated, repellants' success protecting other appliances and wires makes them worthy of further testing for PV applications
- Integrated rail skirts currently available from several racking manufacturers

On-Ground Rail Preparation

A best practice observed in Germany is on-ground rail preparation. This includes splice and fastener attachment to rails before conveying them to the roof. This process is easy to implement and appears to speed the rail installation process.

Base Installation Redesign

U.S. installers participating in SIMPLE BoS spend over $0.05/W installing bases for racking systems. More specifically, for clay tile roof installations, the cost proved four times higher. Reducing the amount of time spent preparing bases can help reduce these costs. Some observed techniques include:

- Visual identification of rafters (when possible) to avoid pre- and/or prospect-drilling, measuring, squaring, base-reinstallation, and removal of excessive tiles on clay tile roofs
- Improved understanding of local wind load requirements to avoid over-engineering base installations
- Racking bases that self-seal or otherwise obviate the need for additional flashing
- Racking bases that require fewer rafter attachments / penetrations
- Pre-assembling bases prior to roof conveyance
- Experimenting with different racking products currently on the market that require fewer roof penetrations

HIGH-IMPACT, EASY-TO-IMPLEMENT OPPORTUNITIES

The following opportunities are proven, as several installers in the U.S. have implemented them with lower-cost results. SIMPLE BoS data suggests cost reduction potential of $0.10/W or more.

One-Day Installations

Moving to one-day installations can significantly decrease installation labor costs by avoiding iterative "fixed" costs that must be incurred for each successive day of a rooftop solar installation, including setup, takedown, all safety-related requirements, travel, and breaks. Several U.S. installers currently complete installations in a single day with modest-sized crews, so this is not a recommendation for installers to descend upon residential installations with more manpower. Instead, installers should focus on increasing efficiency with existing crew sizes in order to complete installations of systems smaller than 10 kW in a single day.

Data collected thus far for SIMPLE BoS is insufficient for the project team to quantitatively illustrate exactly how installers can move to single-day installations from their existing multi-day processes. However, based on anecdotal observations, deep levels of task specialization (discussed later in this report); uniform, universally applicable designs; fully stocked trucks; and satellite imagery (or aerial photography, where available) of the project site appear to help with condensed installation times. However, more data is needed to quantify the impacts of these various strategies. At the very least, it's worth noting that at least two large U.S. solar developers, Vivint and SolarCity, are known to perform single-day residential installations with some regularity.

Integrative Racking: Current Gen

Initial observations suggest currently available integrated rail-less racking solutions decrease overall installation time. Today's rail-less racking solutions still require a lengthy base installation process and hardware may come at an incrementally higher cost, but the overall savings associated with rail-less racking systems are promising.

LOW-IMPACT, DIFFICULT-TO-IMPLEMENT OPPORTUNITIES

The opportunities listed below are likely more challenging to implement than the solutions listed above, but should still be considered as they may be readily implementable for specific installers.

Steep Roof Redesign

Comparing the steepest observed roof pitch to the shallowest highlights a significant cost difference that's largely attributable to the efficiency penalty incurred from working on steep roofs. A design solution that eliminates base preparation work on steep roofs by anchoring into an alternative location (the roof ridge, for example) could produce significant savings for installations on steeper gabled roofs.

Scaffolding / Safety Nets

As observed in Germany, installer use of scaffolding and safety nets in lieu of safety harnesses not only improves on-roof efficiency by allowing installers to move about unhindered, but it also enables simple tool storage and bolt-on solutions like module lifts. However, after preliminary research and discussions with installers, it still remains unclear how scaffolding in lieu of anchored safety harnesses would be evaluated under U.S.

worker safety regulations. Furthermore, many U.S. installation crews are already comfortable working with safety harnesses and anchors on steep-pitch roofs; for them to experiment with a different approach may increase installer cost and risk in the short term. Moving forward, the SIMPLE BoS team will be conducting additional analysis and outreach to further evaluate the potential cost impacts of using scaffolding for residential PV construction projects.

Conduit Redesign

The U.S. National Electrical Code specifies that conduit must envelop all current-carrying PV wires from a PV array to the inverter and electrical panel area. Beyond the National Electric Code, some jurisdictions (or in some cases, customers) may also require additional conduit on the roof between arrays and/or strings.[15] U.S. installers (both electrician and non-electrician) spend a significant amount of time bending, installing, and feeding wire through conduit. Flexible conduit solutions or even pre-wired flexible conduit could enable faster installations, but such hardware solutions are few and far between.

HIGH-IMPACT, DIFFICULT-TO-IMPLEMENT OPPORTUNITIES

Four specific opportunities have the potential to dramatically lower installation labor costs, but implementing them will prove challenging in the near term.

Integrative Racking: Next Gen

Over the past two years, the SIMPLE BoS team has developed a novel racking design for residential rooftop PV applications that should eliminate the majority of base preparation, minimize roof penetration, be applicable to varying roof pitches with no modifications, maintain water-proofing, integrate wire management, and require no conventional rails. The SIMPLE BoS team is working to commercialize this design and expects to deploy pilot installations during calendar year 2014.

Process Optimization

A number of discrete installation activities, as well as different pieces of hardware, actually add little to no value to the end user of solar electricity—the customer (such activities are discussed in detail in the next section). Optimizing the installation process to remove all such non-value-add activities could greatly reduce the installed cost of solar. For an installer to realistically remove all non-value-add activities, however, would require a complete process overhaul as well as investment and experimentation with radically new hardware designs.

[15] National Electric Code (NFPA 70). Article 690.

Clay Tile Base Revamp

As will be discussed in our detailed comparison of U.S. and German installations, German installers working on clay tile roofs are able to fully install bases at very low cost. In contrast, clay tile base installations observed in the U.S. cost four times more than non-clay-tile base installs. Ample opportunity exists in the U.S. market to reduce base installation costs for clay-tile roof systems, but it is unclear exactly how to capture this opportunity as existing racking products entail a lengthy and expensive base installation process.

PV-Ready Electrical Circuits

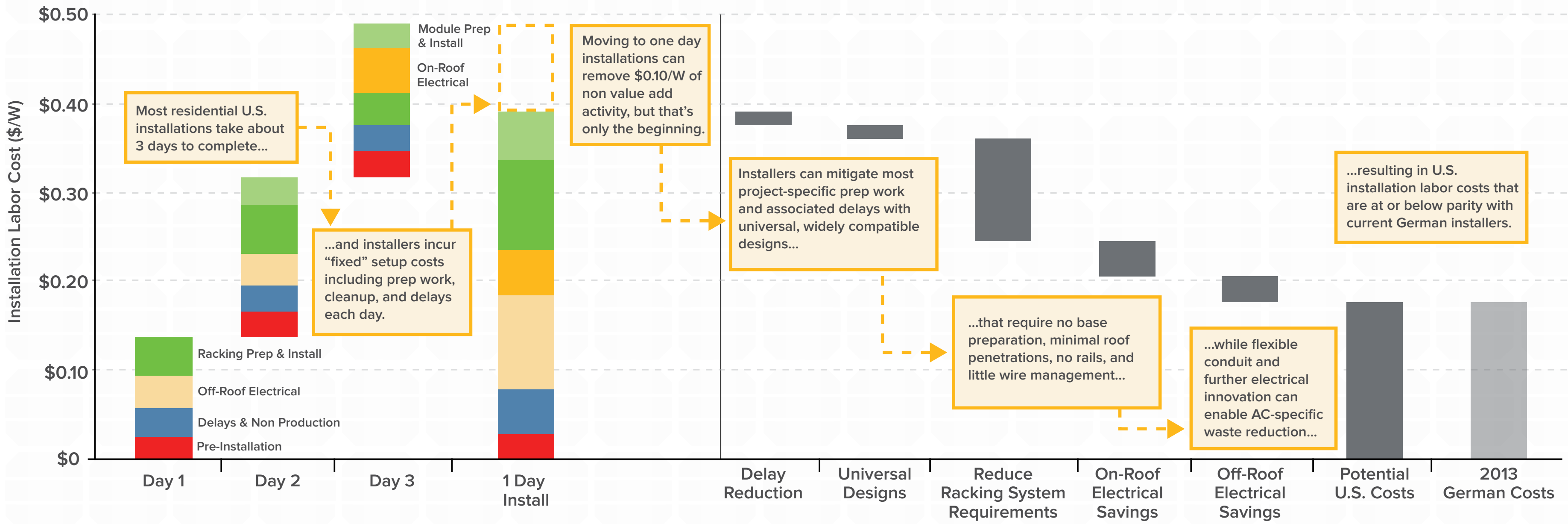
U.S. installers incur $0.11/W for most AC-related activities. A majority of this cost covers electrician-specific work for electrical integration of the PV system into a home's existing electrical system. PV-ready electrical circuits able to accept a single connection from a newly constructed PV system (with either micro or string/centralized inverter configuration) could remove costs from the installation of PV systems—both in the U.S. and Germany. While such offerings have yet to come to market, several efforts, including the Department of Energy's "Plug and Play" initiative, are aimed at the development of such solutions, and our initial data collection effort supports the large apparent cost reduction opportunity available in this area.

PATHWAY TO ACHIEVING GERMAN INSTALLATION COSTS IN THE U.S.

Data collected on U.S. and German installers have allowed our team to highlight, at a detailed level, the large number of non-value-add activities U.S. installers typically carry out. In the context of solar energy, value-add activities are those that directly enable the long-term successful delivery of solar electricity to end users while non-value-add activities (considered different types of waste in "lean manufacturing" parlance) are those that are not inherently required to achieve this goal. Value-add activities include safe, physical attachment of PV modules to a roof, electrical connection of PV modules in series, and electrical integration of a system with a building's electrical system.

Non-value-add activities—which range from installation delays to installation of equipment of parts that could be designed out (e.g., rail installation)—represent a major opportunity for U.S. installers to reduce costs. Unlike the cost reduction opportunity matrix (Figure 3), the deeper cost reductions associated with removing all non-value-add activities are difficult to quantify

FIGURE 4: **PATHWAY TO ACHIEVING GERMAN INSTALLATION LABOR COSTS IN THE U.S.**



and even more difficult to capture. However, illustrating the opportunity and a potential pathway for the U.S. solar industry to capture these cost reductions is a useful first step towards the creation of a residential rooftop installation process in the U.S. that mimics the efficient, waste-light German process.

If the U.S. were to remove all non-value-add activity from the typical residential rooftop PV installation process, installation labor costs could be reduced by 64%, effectively undercutting benchmarked German installation labor costs when differences in country average labor rates are considered. The pathway depicted in Figure 4 (see previous page) is one potential way for industry as a whole to remove most non-value-add activities from the average U.S. installation process using a combination of efficiency measures and new hardware.

First, Move to One-Day Installations

One-day installations are a powerful way for installers to shed cost and remove several non-value-add activities that are regularly incurred during each day of a solar installation. As discussed in detail in the latter half of this report, the current three-day installation process followed by most U.S. installers benchmarked and surveyed under SIMPLE BoS implies fixed setup costs for each successive day of installation. These costs include safety setup, truck unload and load, coordination, delays, and site cleanup. Minimizing the number of days per installation is a powerful near-term opportunity for installers to reduce non-value-add activities and their associated costs by a minimum of 10%.

Second, Implement More Universally Applicable Designs to Avoid On-Site Delays and Prep Work

For the foreseeable future, the U.S. process will likely be subject to several unavoidable delays, including inspection and other jurisdiction-specific requirements that add little to no value to a solar installation. SIMPLE BoS research, however, uncovered several avoidable delays that can still be mitigated through the use of more universally applicable designs. Such designs should allow installers to predictably stock their vehicles for all installations, avoid trips to hardware stores for missing components, and effectively eliminate the need to conduct on- or off-site preparatory work.

Currently, few “universal” racking designs that can be applied irrespective of roof type, pitch, electrical configuration, or module type are available in the U.S. market. In contrast, German installers are able to use a single base type for both clay tile and asphalt shingle installations. Their bases, rails, and fasteners are compatible with a wide variety of modules, and trucks can roll onto any particular site with a standard set of hardware that requires no off-site prep work. Some U.S. installers have begun switching to single racking manufacturers and designs to enable standardized installations and deep specialization with particular products. Such specialization and standardization reduces variability in installation cost and likelihood of system failure, thus reducing investment risk. The switch to more standardized designs is an encouraging development and will help reduce waste in the solar installation process.

Third, Develop Integrated Racking Systems With Dramatically Reduced Requirements

Although the trend towards deep familiarity with specific racking systems is encouraging, existing racking designs still leave a great deal of cost and waste reduction opportunity on the table. Potential exists for manufacturers to deploy fully integrated racking and module solutions with dramatically reduced installation requirements. We estimate that such systems represent the single most powerful way for the solar industry to remove several non-value-add activities from the installation process.

Several manufacturers are aware of the opportunity fully integrated racking systems present, and it's worth noting that a number of currently-available products eliminate some, but not all, non-value-add activities in the process of physically attaching modules to rooftops for electricity generation. For example, rail-less designs available from several companies eliminate an entire piece of hardware and, in some cases, obviate the need for most wire management activities (including grounding). However, such designs still use traditional base installation processes requiring extensive amounts of prep work (squaring, caulking, flashing, and drilling), dozens of roof penetrations, and may require rework due to installer error. Even some of the most innovative hardware on the market requires specialized components to accommodate different roof types and advance planning to ensure stocked components will meet system configurations.

Based on our observations, we encourage racking manufacturers to develop pitched residential rooftop applications that eliminate all pre-installation preparation requirements.[16] The racks would go from truck to rooftop with no modification, need no base preparation work or rails, integrate wire management, and have the ability to be universally installed regardless of roof type and pitch.

Finally, Innovate on the Electrical Side of the PV Installation

Several DC-related electrical activities can be mitigated using existing designs. Self-grounding systems and racking systems that integrate wire management have the ability to eliminate nearly 75% of DC-related costs. Interestingly, removal of DC-related non-value-add activities is not only pertinent to the U.S.; German installers also conduct on-roof DC activities (largely running homeruns prior to module attachment) that could otherwise be eliminated by designs that integrate wire management.

The least-understood area for further innovation with the ability to remove non-value-add activities involves all AC-related activities for PV installations. Detailed data collected in both Germany and the U.S. for AC-related activities during this phase of SIMPLE BoS was limited. However, as illustrated by our comparison of U.S. installers later in this report, electricians in the U.S. spend a great deal of time working with AC-related equipment, including multiple meters, disconnects, small pieces of conduit, and electrical panels. While a general need to eliminate waste and reduce costs in this area is obvious to the SIMPLE BoS team and for most electricians we observed, the path forward for the solar industry to take action is less so. Best-in-class installers have moved to integrated disconnects where permissible in local jurisdictions and have begun pre-mounting AC hardware prior to arrival at the project site. To better understand the potential for further cost reduction in this space, AC-related electrical activities will be a focus of the SIMPLE BoS team moving forward and we hope to have more detailed recommendations and insight on this piece of the installation process in the next year.

[16] The SIMPLE BoS team recognizes the risks inherent to development of new designs, including retooling costs, UL certification cost, and ambiguity in how to design for certification. It is our hope that after commercialization of SIMPLE BoS designs and publication of supporting materials, the SIMPLE BoS design process will help ease some of these barriers and illustrate one possible path to commercialization from which other manufacturers can learn.

TOTAL COST DIFFERENCE BETWEEN THE U.S. AND GERMANY

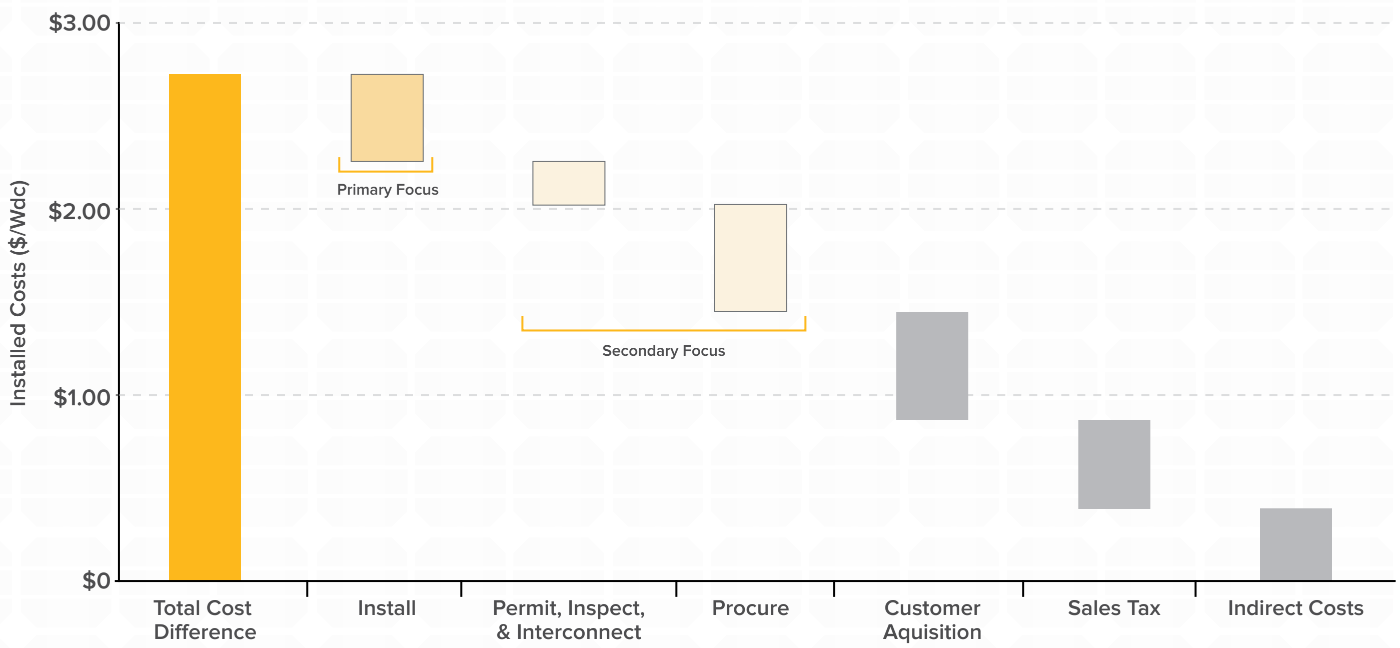
05

05: TOTAL COST DIFFERENCE BETWEEN THE U.S. AND GERMANY

An apparent $2.72/W cost difference exists between the U.S. (average selling price of $4.93/W) and Germany ($2.21/W).[17] As shown in Figure 5, this cost difference is attributable to six primary cost categories. Nearly 80% of the cost difference is attributable to differences in soft costs.

[17] BLOOMBERG NEW ENERGY FINANCE. PV MARKET OUTLOOK: Q2 2013. MAY 13, 2013.

FIGURE 5: **COST DIFFERENCES BETWEEN THE U.S. AND GERMANY**



TOTAL COST DIFFERENCE BETWEEN THE U.S. AND GERMANY. NOTE THAT CHANGES TO INSTALLATION LABOR PRACTICES AND IMPLEMENTATION OF NEW DESIGNS MAY LOWER CUSTOMER ACQUISITION AND SUPPLY CHAIN COSTS, BUT SUCH IMPACTS ARE OUTSIDE THE SCOPE OF THIS REPORT.

SIMPLE BoS FOCUS ON INSTALLATION LABOR

Several organizations, industry trade groups, companies, and government labs are actively involved in efforts to reduce costs within each of the six primary cost categories. However, SIMPLE BoS is focused primarily on the difference in installation labor costs, with a tangential focus on the cost of permitting, inspection, and interconnection (PII) of a system as well as differences in delivered hardware costs between our two countries.

Compared to other soft cost categories, installation labor represents a tangible opportunity to observe, benchmark, and analyze specific installation activities and their associated costs. Such costs are readily comparable, and, as previously noted, many other soft cost categories can be difficult to measure consistently across installers. Installation labor hours and their associated rates, however, can be consistently benchmarked and analyzed across installers both internationally and domestically. Accordingly, customer acquisition costs, differences attributable to sales tax exemptions in Germany, and different “indirect” costs associated with financing in the U.S. will be left outside the scope of this report.

PERMITTING, INSPECTION, AND INTERCONNECTION

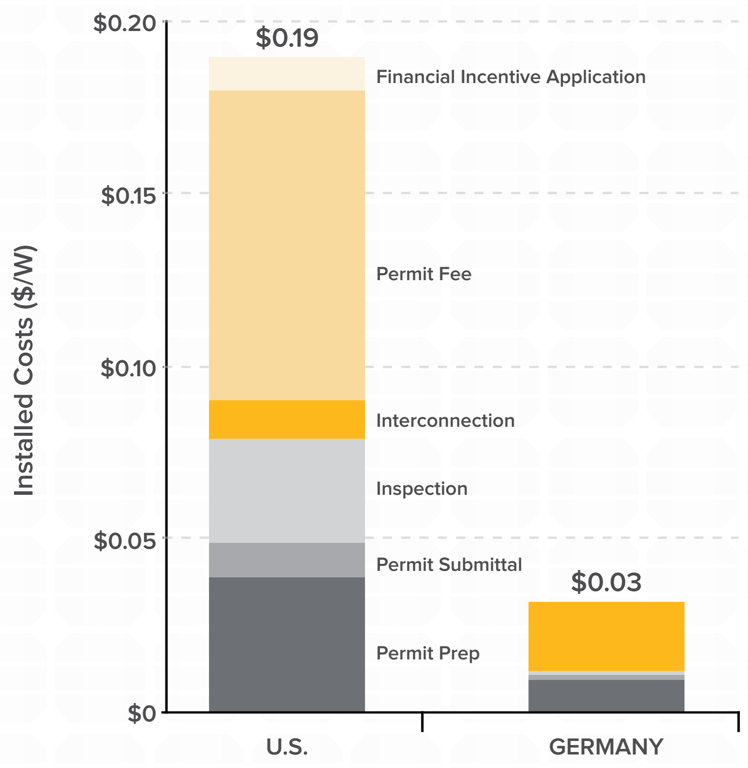
06

06: PERMITTING, INSPECTION, AND INTERCONNECTION

With over 18,000 jurisdictions and over 3,000 utilities in the U.S., it's well known that U.S. installers incur high permitting, inspection, and interconnection (PII) costs around the country—especially when compared to their German peers. Although local governments and utilities are beholden to several state and federal regulations, they are independently responsible for setting the bulk of standards that govern the development of rooftop PV systems. Accordingly, it falls to these local entities to oversee the process of installing and connecting a rooftop PV system to the grid.[18] The U.S.' overlapping network of jurisdictions, utilities, local policies, and standards like the National Electrical Code have created a complicated, expensive landscape for rooftop PV. PII costs are well benchmarked with clear comparisons having been made by LBNL to the German market where PII costs are negligible in the $0.03/W range (see Figure 6).[19]

A number of PII-specific soft cost reduction efforts are underway attempting to close this cost difference. These efforts include Clean Power Finance's partnership with the Department of Energy to establish a National Solar Permitting Database,[20] Vote Solar's crowd sourced "Project Permit" campaign,[21] and various regional efforts funded through the Department of Energy's Rooftop Solar Challenge program such as the joint RMI–Colorado Solar Energy Industry Association's Solar Friendly Communities program, among others.[22]

FIGURE 6: PERMITTING, INSPECTION, AND INTERCONNECTION COSTS IN GERMANY AND THE U.S.

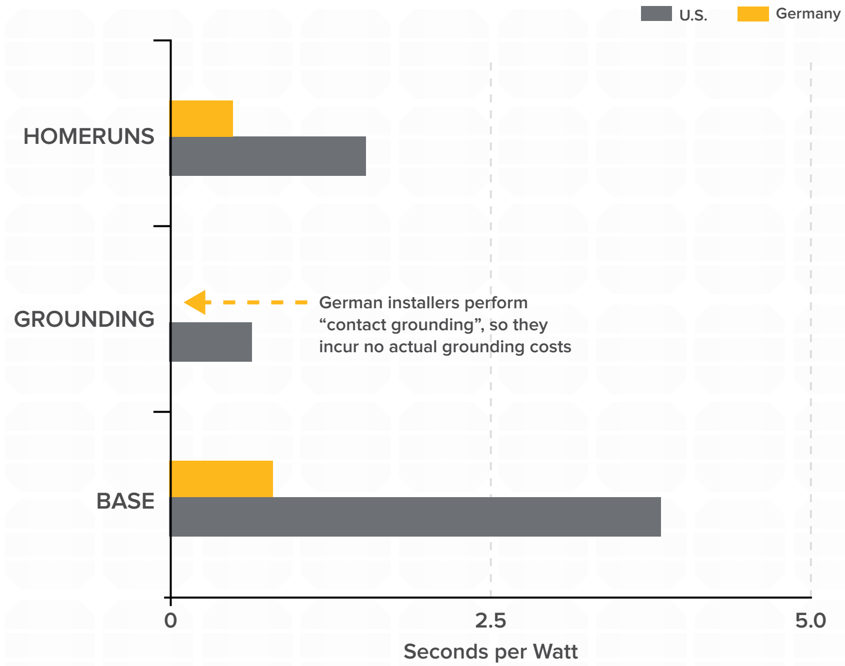


[18] Morris, Jesse. "Developing Solar Friendly Communities: Permitting Interconnection, and Net Metering: An Overview of Model Standards and Policy Design Criteria" (RMI, 2012).
[19] Seel et al. "Why Are Residential PV Prices In Germany So Much Lower Than In The United States?" (LBNL, 2013).
[20] See http://solarpermit.org/ for more information.
[21] See http://projectpermit.org/ for more information.
[22] See http://solarcommunities.org/ for more information.

Encouragingly, recent industry surveys by NREL suggest that PII costs have come down 21% between 2010 and 2012.[23] However, installed cost estimates are just one piece of the PII puzzle as these costs are only being benchmarked in areas where solar installations are currently taking place. Research conducted by Clean Power Finance and others suggests that prohibitive PII requirements cause installers to avoid selling systems in certain jurisdictions altogether, highlighting the need for continued soft cost reduction work in the realm of PII.[24]

Although this phase of SIMPLE BoS was explicitly focused on installation labor, initial data collection efforts did shine some light on PII cost components that are not captured through installer surveys or bottom-up cost analysis. In the U.S., both electrical components (like conduit and grounding) and racking bases are significantly impacted by various PII and regulatory-related requirements. For example, the National Electrical Code largely governs the use of conduit and specifics surrounding AC components in the U.S. while wind-loading regulations and professional engineering stamp requirements (set by local jurisdictions) are primary drivers of base attachment standards. To meet these requirements, U.S. installers spend a disproportionately larger amount of time with specific components than their German counterparts (see Figure 7).

FIGURE 7: **PII-RELATED HARDWARE COMPARISON BETWEEN THE U.S. AND GERMANY**



[23] Friedman et al. *Second Annual Benchmarking Non-Hardware Balance-of-System (Soft) Costs for U.S. Photovoltaic Systems, Using a Bottom-Up Approach and Installer Survey* (NREL, Publication Forthcoming).
[24] Tong, James. "Nationwide Analysis of Solar Permitting and the Implications for Soft Costs" (Clean Power Finance. December 2012).

A good example of these regulatory-related requirements is grounding. Initial analysis suggested that German installers, facing less onerous grounding requirements, can install at a lower cost.[25] However, German installers still actively ground their systems, but the process and associated hardware is quite different than in the U.S.: based on our observations and discussions with German installers, German installers perform "contact grounding" of systems, meaning that once they place a module into a racking system, the system is effectively grounded (albeit at a much different threshold than is required in the United States). In Germany, the natural weight of the module creates a ground path that the Germans have decided is sufficient to deter dangerous levels of voltage in the case of electrical wiring failure. In contrast, U.S. regulation is stricter as it requires an additional wire that physically grounds the entire system.

Data collection efforts in year three of SIMPLE BoS will attempt to draw out more details surrounding these hardware- and process-related PII requirements in order to better inform future rulemaking processes and solar-specific local policymaking.

[25] Seel et al. "Why Are Residential PV Prices in Germany So Much Lower Than in the United States?" (LBNL, February 2013).

PROCUREMENT

07

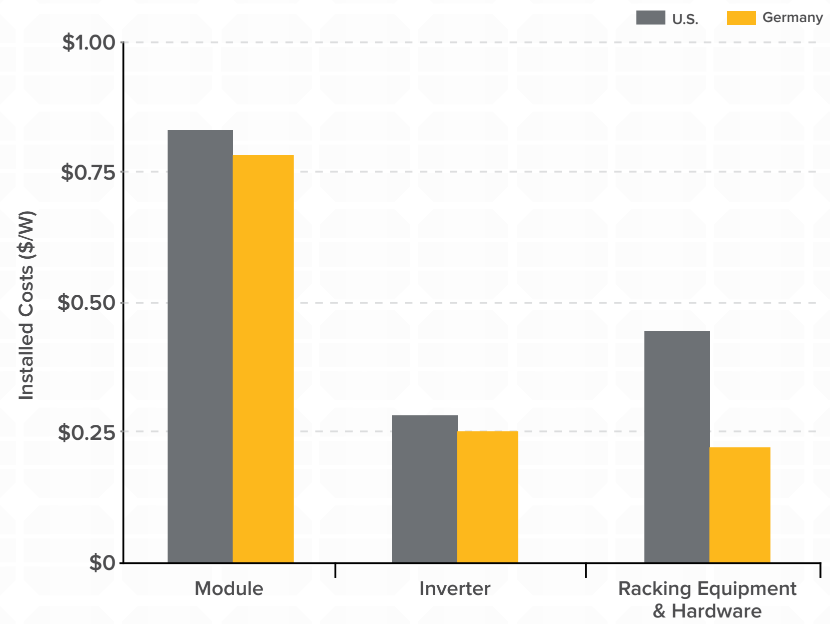
07: PROCUREMENT

Some market analysis firms suggest that the cost of solar PV procurement across countries has largely equalized, meaning that PV equipment costs are standard across national boundaries except for differences in import duties and taxes. Any differences in actual hardware costs across countries, it is hypothesized, are attributable mainly to value-based pricing dynamics in markets across the U.S. Value-based pricing is a common practice in the U.S., where a majority of small PV systems are sold as leases or power purchase agreements supported by transferable federal tax incentives. Instead of pricing systems in terms of expenses plus margin, as is typically performed in other mature construction industries, installers will adjust system pricing and lease/power purchase agreement contracts in order to produce a custom value proposition wherein customers save 5–25% on their electricity bills from the first day their solar system is activated.[26]

Though module and inverter costs tend to be comparable in different international markets, additional equipment and hardware have been shown to have significantly different costs between the U.S. and Germany.[27]

Research suggests an apparent $0.31/W material procurement cost difference between our countries (see Figure 8). The majority of this difference is attributable to significantly different racking equipment, regulatory requirements, and hardware costs. SIMPLE BoS time and motion studies did not focus on specific bill of materials pricing dynamics, and it remains to be seen if this cost delta can be explained by the fact that German installers simply need to buy fewer hardware balance of system components (such as disconnects, grounding wire, and conduit) or if indeed German installers are able to buy similar components at lower costs. Either way, this large ~50% racking equipment and hardware cost difference will be a topic of focus during the next year of SIMPLE BoS, especially if this hardware cost difference holds up under a larger sample set.

FIGURE 8: **HARDWARE PROCUREMENT COST DIFFERENCES BETWEEN THE U.S. AND GERMANY**



[26] Setting prices to meet that savings threshold is a balancing act based on a number of variables, including customer electricity rates, local subsidies, special architectural variables, solar financing costs of capital, and solar irradiance.

[27] Module cost delta based on IHS Solar, November 2012. Inverter delta based on GTM. Global PV Inverter Landscape. 2013: Choose your adventure: manufacturing inverters in the modern PV age. Module cost delta based on Seel et al., "Why are German Residential PV Prices So Low?" (LBNL, February 2013).

INSTALLATION

08

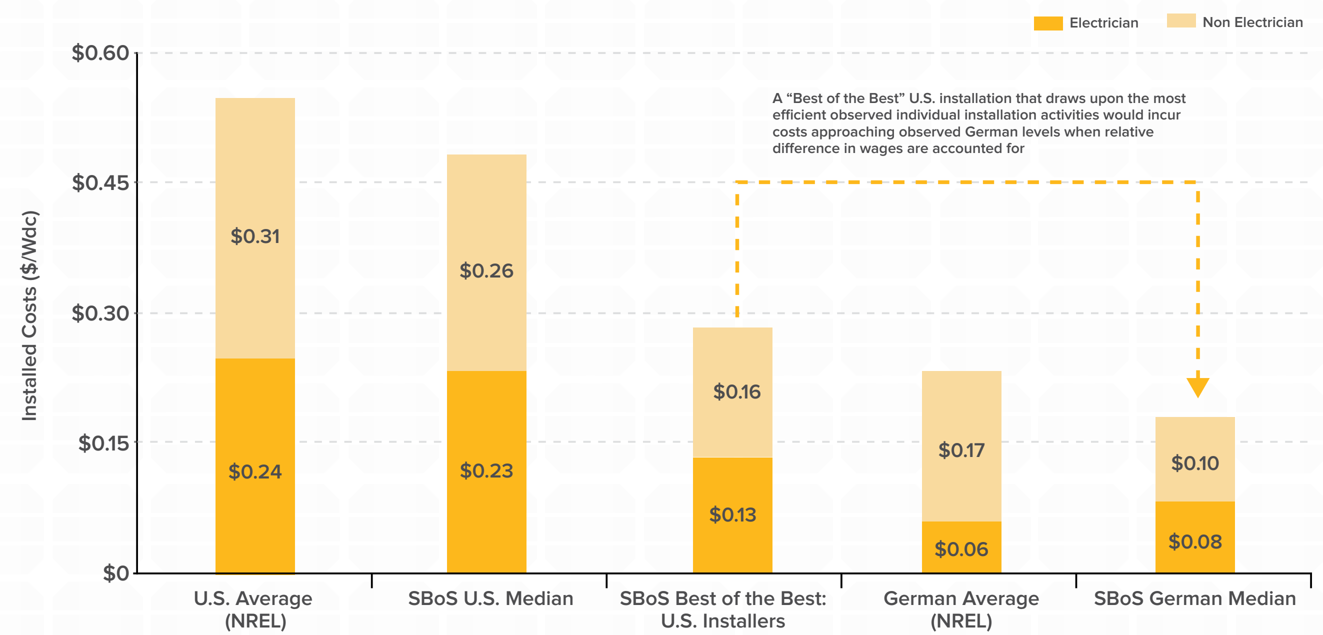
08: INSTALLATION

A number of institutions and reports have benchmarked rooftop solar installation costs over the past several years (see Figure 9). In spite of our small sample size, median installation labor costs for installers observed under SIMPLE BoS time and motion studies ("SBoS" in Figure 9) are within $0.10/W of the 2012 NREL bottom-up cost estimate.[28]

As illustrated in Figure 9, initial survey and analysis by Lawrence Berkeley National Laboratory and NREL suggest that median German installers are able to install rooftop residential systems while incurring installation labor costs nearly 60% lower than those in the U.S.[29] And while it's true that the German market has several intrinsic enablers of this kind of efficiency, German levels of low-cost installation efficiency can be replicated in the U.S. as discussed below.

[28] Friedman et al. Second Annual Benchmarking Non-Hardware Balance-of-System (Soft) Costs for U.S. Photovoltaic Systems, Using a Bottom-Up Approach and Installer Survey (NREL. Publication Forthcoming).
[29] Seel et al. "Why Are Residential PV Prices in Germany So Much Lower Than in the United States?" (LBNL, February 2013).

FIGURE 9: **INSTALLATION LABOR COST COMPARISON: U.S. AND GERMANY**



* This analysis uses the same labor wage rate assumptions for electrician and non-electrician labor as Seel et al. (see footnote 10)

Initial data collection also highlighted a significant opportunity to identify PV installation best practices within the U.S., not just from benchmarked German installations: based on our data, a composite “Best of the Best” virtual U.S. installation that draws upon the fastest observed individual installation activities across all U.S. installations would incur installation costs of only $0.29/W. This is an important finding, as it indicates that some U.S. installers are conducting specific activities approaching German levels of efficiency.

In line with this finding, before illustrating how the U.S. solar industry might replicate German installation efficiency here in the U.S., we first used the SIMPLE BoS data to explore drivers of installation labor costs domestically by comparing installation efficiency among benchmarked U.S. installers.

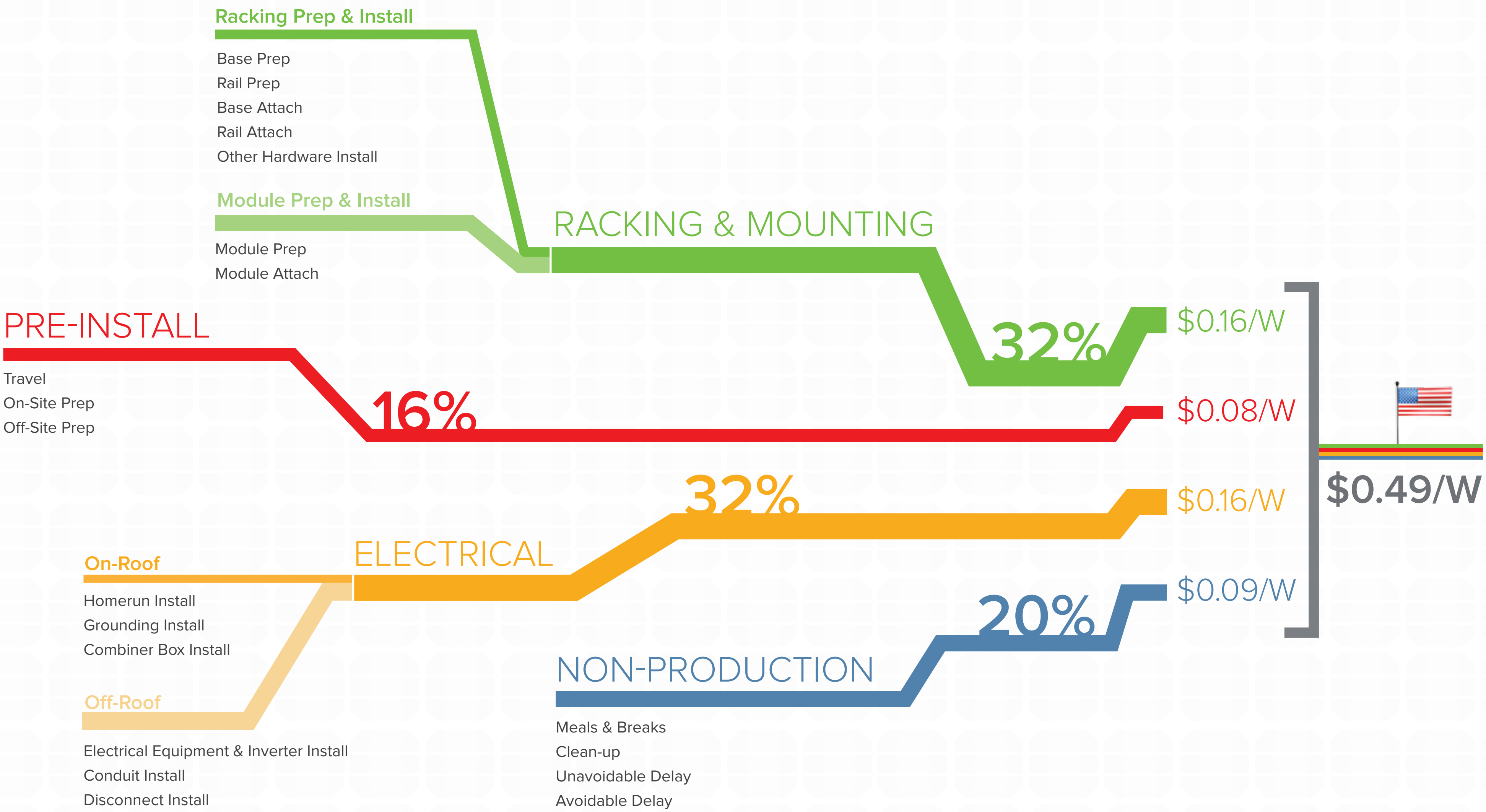
CURRENT STATE: U.S. INSTALLATION LABOR

Designing and building a solar installation in the U.S. is a complex equation with hundreds of variables at play. Individual solar installers employ various processes, design paradigms, PV products, and system configurations. Site-based characteristics like roof pitch and composition affect system configurations, while regional and local dynamics, such as climate and inspection requirements further complicate design and build considerations. Despite the complexity and large number of variables involved in typical rooftop installations, U.S. projects observed for SIMPLE BoS exhibited high similarities. By combining results from observed sites and organizing them according to a generalized residential rooftop installation process, we developed a value stream map to illustrate where and how costs are incurred during a typical rooftop installation process in the U.S. (see Figure 10 on next page).

As illustrated in Figure 10, U.S. installs typically encompass the following activities:

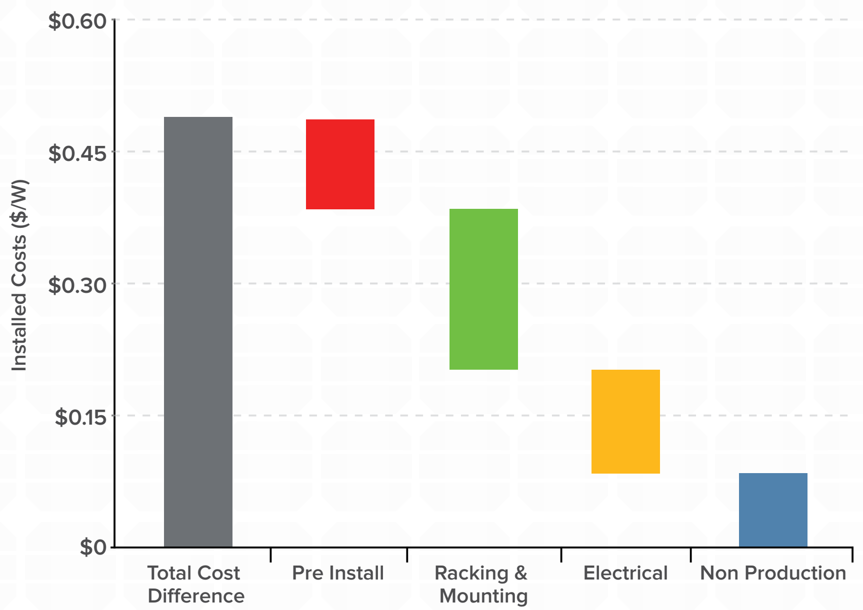
- ***Pre-Installation:*** All activities conducted prior to actual construction, including travel to and from the site, off-site preparatory work, on-site unloading and unpacking of materials, and safety coordination.
- ***Racking Preparation and Attachment:*** The most expensive single installation category in the U.S., this category involves several steps, from preparing the actual roof for base installation (such as pre-drilling holes or removing clay tiles) to physically attaching rails to a fully attached base.
- ***Module Installation:*** Once racking systems have been assembled and installed, modules are typically hoisted onto the roof manually or with lifting systems and physically attached to the installed racking system.
- ***On-Roof Electrical:*** Several electrical-related activities take place on the roof, including connecting modules in series, running homeruns and grounding, installing combiner boxes, and preparing and installing conduit.
- ***Off-Roof Electrical:*** Encompasses most AC-related electrical work during a rooftop solar installation and typically occurs near the building’s electrical panel.
- ***Non-Production:*** Includes all delays, rest breaks, and construction cleanup.

FIGURE 10: **U.S. ROOFTOP INSTALLATIONS: VALUE STREAM MAP**



Though U.S. installers may follow similar installation processes as outlined in Figure 10, variation exists between benchmarked U.S. installers both in terms of the total installed cost of PV systems, as well as at the discrete activity and hardware levels throughout the PV installation process. The total difference in installed costs between the top and bottom 10th percentiles of benchmarked U.S. installation activities is $0.49/W (see Figure 11).

FIGURE 11: **COMPARISON OF U.S. INSTALLERS: 10TH TO 90TH PERCENTILE**

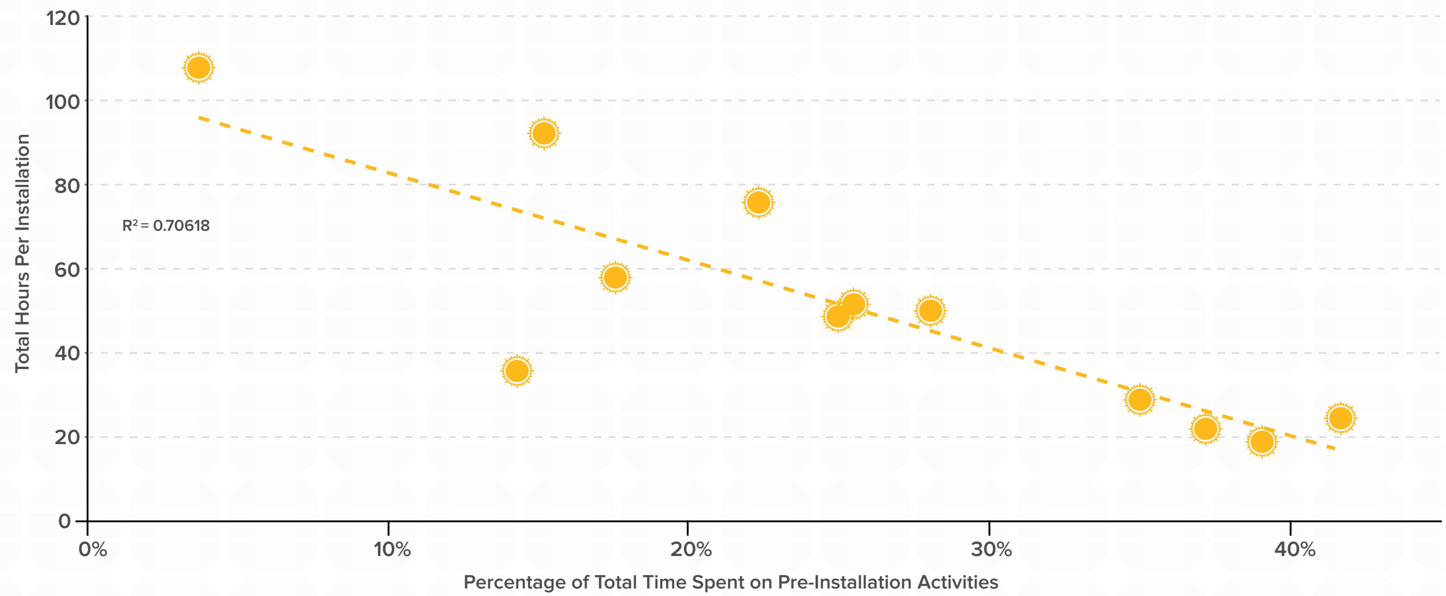


PRE-INSTALLATION

Pre-installation activities accounted for 16% of the total cost of benchmarked PV installation costs in the U.S. The biggest drivers of pre-installation time include off-site preparation work and travel time to and from construction sites, accounting for 69% of total pre-installation cost or 11% of the total U.S. installation labor costs observed. Pre-installation times varied significantly within the study group: the top 10th percentile of installers spent approximately $0.03/W on pre-installation activities, while the bottom 10th percentile of benchmarked installers spent over four times that amount at $0.14/W.

With existing products, however, additional pre-installation time may enable faster overall installation times. In addition to the time and motion studies conducted for SIMPLE BoS, RMI administered an installer survey addressing installation labor costs. Results from the survey (see Figure 12) suggest that as U.S. installers spend an increasing amount of time doing prep work, systems are installed much faster than they would have been otherwise. The survey-based finding is contrasted in the next section against German installation costs, as benchmarked German installers (who use simpler designs with fewer parts and tools that require little preparation) appear to spend little to no time conducting on- or off-site preparatory work and are able to install systems at a significantly lower cost than even the highest performing individual U.S. installer benchmarked under SIMPLE BoS.

FIGURE 12: **TOTAL INSTALLED TIME AND PERCENT OF TIME SPENT ON ALL PRE-INSTALL ACTIVITIES**



RACKING & MOUNTING

Racking and mounting, at $0.16/W, is one of the single largest cost categories for benchmarked rooftop residential installations in the U.S. Racking and mounting activities are dedicated to the physical preparation and attachment of PV racking equipment and modules to the roof. Importantly, significant variation exists among benchmarked U.S. installers, with installers in the top 10th percentile conducting all racking and mounting activities at a cost nearly three times lower than installers in the bottom 10th percentile. This variation is worth a direct comparison to German installers observed under SIMPLE BoS. Figure 13 illustrates installer time spent with discrete pieces of racking and mounting hardware. Though our German dataset is small, significant cost variation is evident in the U.S. compared to relatively consistent costs per project in Germany.

Primary drivers of racking and mounting installation cost in the U.S. include base preparation and attachment, all rail-specific work, and module attachment. The Pareto chart in Figure 14 (see next page) builds upon the distribution analysis in Figure 13 by going one level deeper, breaking apart these specific activities into even more detail.

The next sub-section explores racking and mounting costs by highlighting root causes of high installation times in the U.S. and variations in the U.S. dataset.

FIGURE 13: DIFFERENCES AMONGST U.S. INSTALLERS: RACKING & MOUNTING

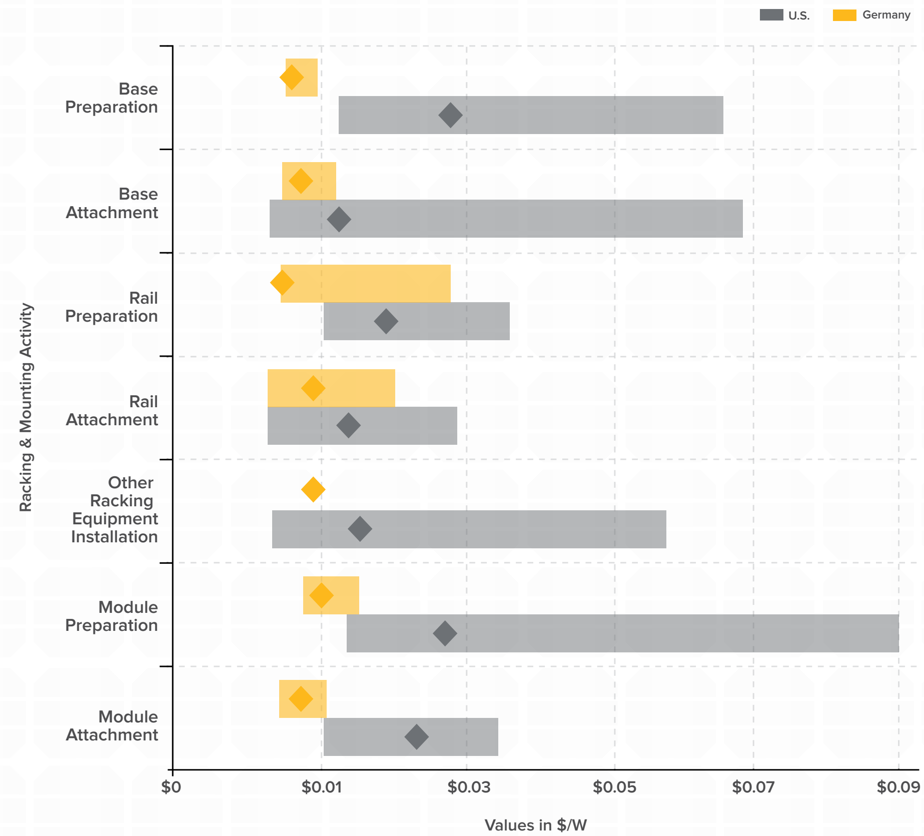
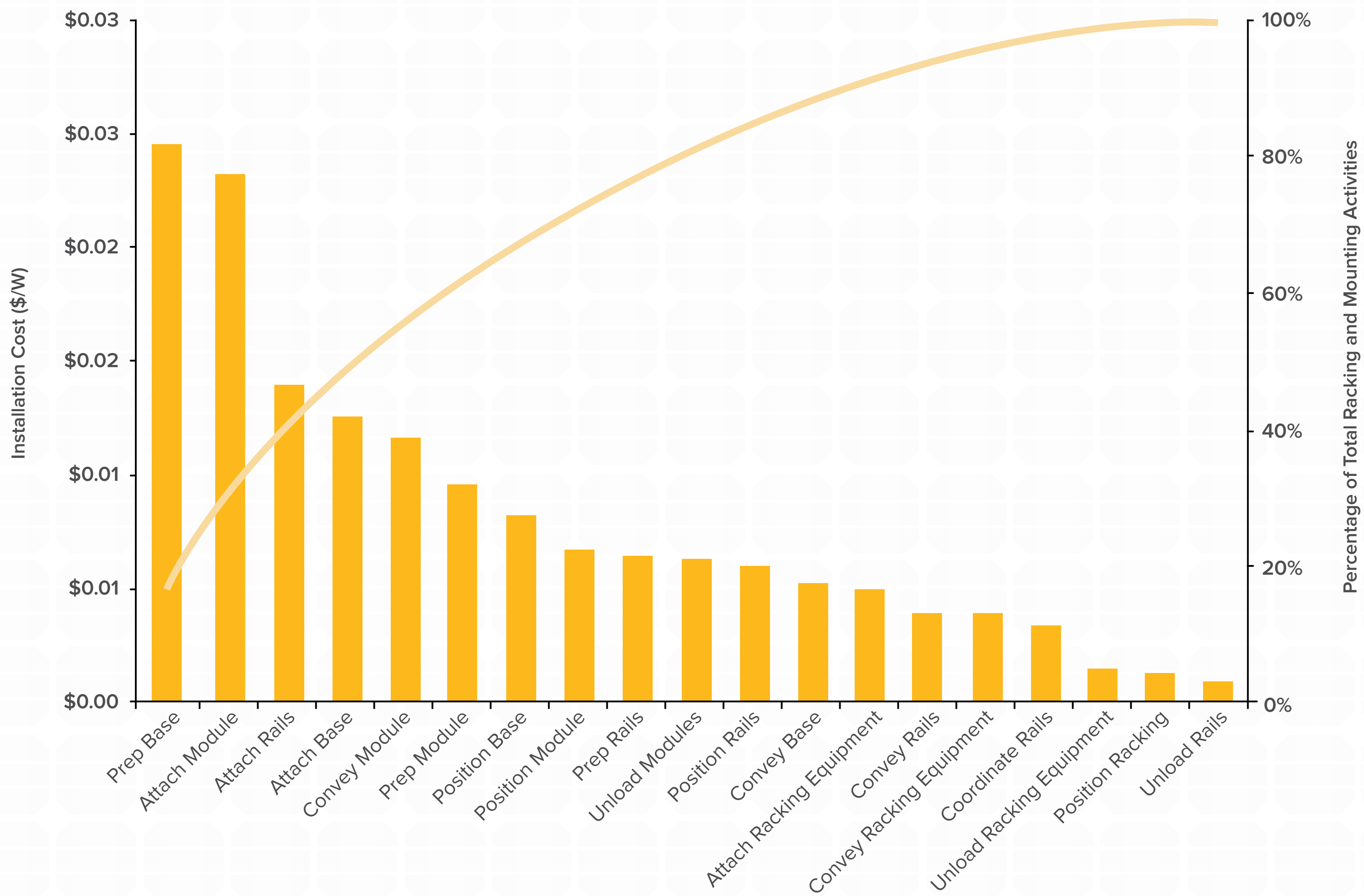


FIGURE 14: **U.S. RACKING & MOUNTING: INSTALLATION COSTS BY SPECIFIC ACTIVITY**



Base Installation Dynamics
As outlined above, two of the largest cost buckets associated with the racking and mounting installation process are the preparation and the attachment of the base. Base preparation alone accounts for 9% of the total cost of installation. A key driver of the cost of base preparation and attachment is exactly how U.S. installers attach bases. Compared to observed German processes, the U.S. base installation process is particularly time consuming in large part due to the need to fully protect against moisture intrusion from roof penetrations.

Our observations and analysis indicate that moisture-barrier-related activities add time to both the base preparation and attachment process. The time and cost impact affected all roof types within the observed U.S. sites. Notably, moisture barrier activities were especially time intensive for all clay tile roof installations observed. As illustrated in Figure 15, the base installation process for clay tile roofs in many instances includes removing and replacing a majority of the roof area in which an array is located. The purpose of this activity is to provide access to the rafters to which the racking equipment is attached and to allow for the placement and attachment of additional moisture protection.

In addition to time spent removing tiles, placing moisture protection, and then replacing tiles, additional base preparation cost comes from installers cutting tiles to fit around the base and base flashing. When comparing this base preparation and installation process to one observed in Germany, there is a distinct emphasis in the U.S. on moisture protection that adds significantly to the total cost of installation. For installers benchmarked under SIMPLE BoS, total base installation activities on clay tile roofs cost nearly $0.15/W, four times more than base installation costs on other roof types, including asphalt shingle and standing seam roofs. Moving forward, additional analysis comparing moisture intrusion and building system failure based on moisture protection processes should inform racking and mounting designs and PV installation processes.

FIGURE 15: U.S. CLAY TILE INSTALLATION

Racking Design

The results of SIMPLE BoS data collection and analysis indicate that racking design and selection can have at least a $0.12/W impact on the total installed cost of PV. The project team observed five different racking types within the SIMPLE BoS sample of PV installations, which varied in total racking and mounting median installation costs from $0.11/W to $0.23/W (see Figure 16). Note that dozens of variables influence total installed labor costs, so it's difficult to draw a direct connection between racking selection and installed costs. However, the SIMPLE BoS team hopes to explore this dynamic further with additional data collection efforts during the next year of the project.

Traditional racking designs (characterized as designs with bases requiring multiple penetrations per base, traditional rails with middle and end clamps, standard grounding requirements, and no integrated array skirts) incurred the highest racking and mounting costs, while rail-less designs were observed to cost installers as little in installation labor costs as flat roof and standing seam installations. In addition, the rail-less installation observed by the SIMPLE BoS team incurred the lowest total installed cost when compared to other racking systems.

The lowest-cost systems focus on either eliminating and/or reducing the total installation time associated with specific activities or hardware components within the racking and mounting installation process. One example of an observed racking design that focuses on reducing hardware components and the associated activities is an integrated rail-less racking system. The combination of a rail-less system and customized modules can eliminate all activities associated with rails, including conveyance, measurement, cutting, positioning,

FIGURE 16: **INSTALLED COSTS BY RACKING SYSTEM ARCHETYPE**

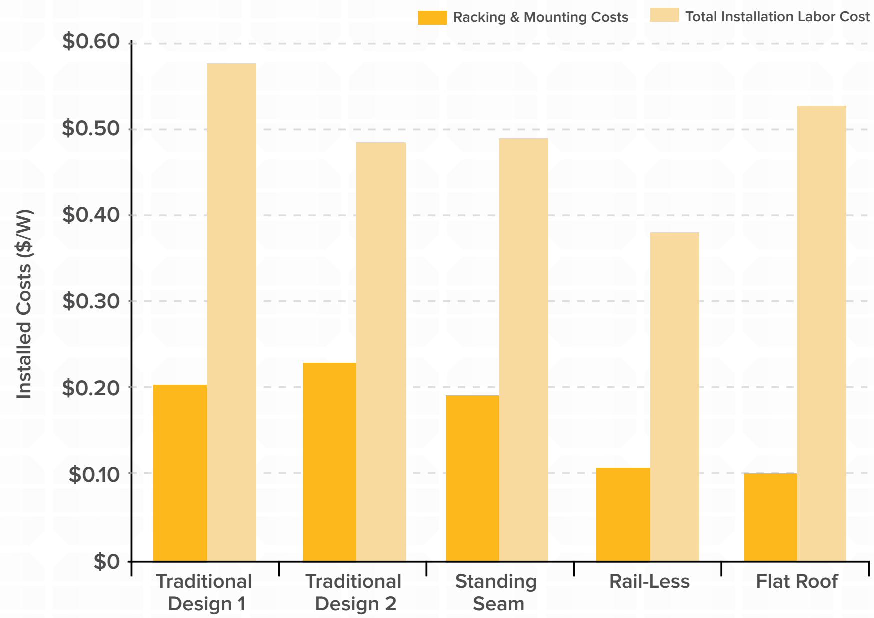


FIGURE 17: RAIL-LESS RACKING INSTALLATION WITH ARRAY SKIRT VISIBLE

and squaring. The system uses a single skirt and the base components to square the array. In addition, the rail-less system incorporates base components that provide the grounding requirement necessary when installing a PV system, thus eliminating all grounding-specific activity. The project team only observed a single installation with an integrated rail-less racking system, thereby limiting a quantitative analysis of the total cost of installation. However, with rail-related activities accounting for 6% of the total cost of installation, systems eliminating the need for rails have the potential to significantly reduce PV installation costs.

Lack of Crew and Individual Specialization

In analyzing PV installation processes, it is clear that there are two primary opportunities to reduce total installation costs:

1. reduce the number of activities or components required during the installation process, and
2. reduce the total time required for a discrete activity or the installation of a component.

The ability of a crew or an individual installer to identify opportunities for specialization within the installation process can be an efficiency driver by reducing the total time required for each activity or component. In our observations, both between different installation crews as well as within the same installation crew, we witnessed the impact of task specialization on the racking and mounting installation process.

Task specialization is particularly well suited for the base installation process, which is comprised of a series of discrete tasks. In one instance, we observed an installer pursuing an assembly-line-like process where the installer drilled each hole for an entire array, then caulked each hole, positioned each base, attached each base, and finally placed flashing over each base. Comparatively, other installers took the time to drill, caulk, position, and attach a base, then place the flashing for a specific base before moving on to the next. The more specialized, assembly-line-like process appears to reduce total racking and mounting installation costs.

Often site factors, and in particular steep roof pitches, can impact the ability to specialize. In conversations with installers, the project team often heard hypotheses of the impact of steep roof pitches, typically on roofs with a pitch greater than 40 degrees, on total installation time. Although the project team only observed a single site with a roof pitch greater than 40 degrees within the U.S. sample, the steep roof pitch affected activities throughout installation process, including the conveyance time to the roof, the number of time installers had to make trips between the roof and the ground, and the ability of installers to move within the array area. These movement limitations on steep roofs therefore make it difficult for installers to perform specialized, assembly-line-like tasks, adding additional time to benchmarked installations.

Animal Wire

FIGURE 18: ANIMAL WIRE

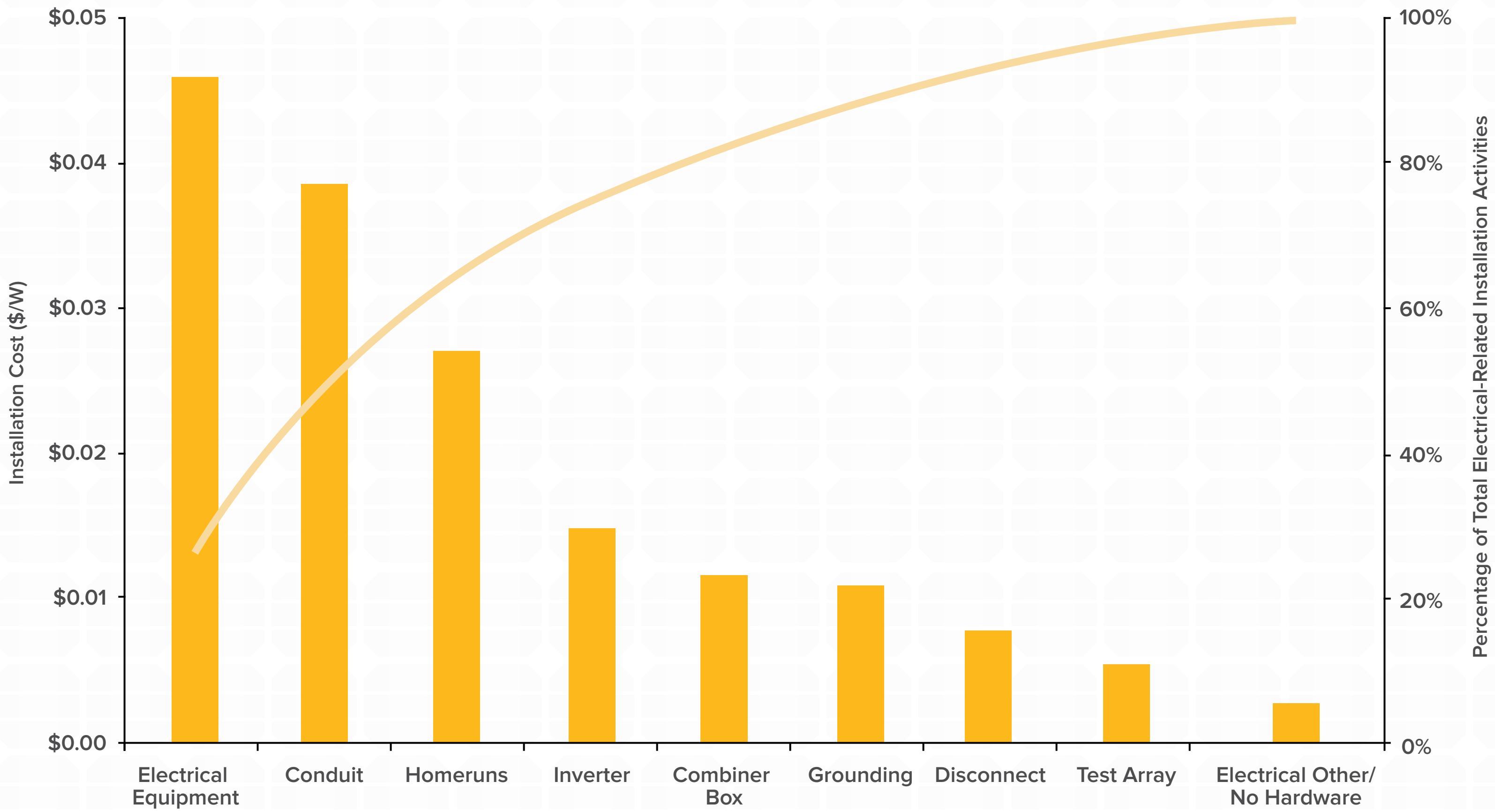
Animal wire is a component of PV systems installed to limit the negative impact squirrels and other rodents can have on system wiring and other components. Animal wire was only observed on PV system installations taking place in Colorado. However, we know from conversations with installers animal wire is used in other states. Our observations indicate that when animal wire is included in the installation, this non-value-add activity contributes 14% of racking and mounting installation costs. In addition, animal wire is an example of an existing process that is not only costly but for which there are cheaper, substitute options currently available in the market.

ELECTRICAL

In the U.S., combined AC and DC electrical activities accounted for $0.16/W, or 32% of total installation cost. Electrical-related PV installation activities are perhaps the area with the most room for near-term innovation from hardware manufacturers interested in helping installers become more efficient at installation. While industry has focused on creating racking and manufacturing designs that reduce installation time and therefore cost within the U.S. market, the same level of effort has yet to be applied to the AC side of PV installations. Instead, the main point of variation between electrical components and processes is the implementation of central vs. micro-inverters. And since electrical activities account for one-third of installation labor costs, there is a distinct opportunity for innovation in addressing both PV electrical system design and installation processes.

The primary electrical cost drivers by hardware category are electrical equipment, conduit, and homeruns, which account for about two-thirds of the total electrical installation cost (see Figure 19 on next page). The electrical equipment category is comprised of a suite of activities associated with assembling and attaching meters, as well as wiring between the meter(s), central inverter(s), and disconnect(s) typically installed in the same general vicinity.

FIGURE 19: **U.S. ELECTRICAL: INSTALLATION COSTS PER ACTIVITY BUCKET**



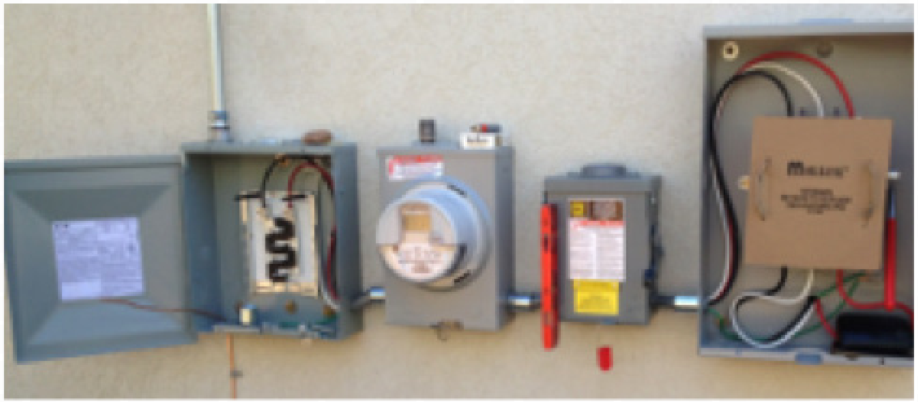
Primary drivers of electrical-related installation time in the U.S. include:

Electrical Panel and Wire Assembly Requirements
Approximately $0.07/W is incurred installing and wiring inverter(s), disconnect(s), and various panels and meters. The panel and meter installation process is time intensive due to the specialized nature of what each jurisdiction, utility, and system require in order to monitor and account for the energy produced by the PV system. For each additional panel, meter, and disconnect added to the system, a licensed electrician attaches the component, installs small runs of rigid conduit, and runs wiring. Collectively this process adds a significant amount of time to the overall electrical installation time. In addition, as electricians typically make higher wages, each additional hour on site has a disproportionately higher impact on the total installed cost of the PV system.

In addition to collecting time data associated with distinct installation activities, SIMPLE BoS team members also gathered qualitative information on each site, the installation company, and the installation crew. One hypothesis regarding the lower installation costs in Germany is that as installation experience increases, the cost of discrete activities, and therefore the system as a whole, will decrease. However, a direct comparison of electrician experience to the cost of electrical installation shows an inverse relationship: anecdotal evidence indicates that each year of additional electrician experience may add $0.02/W to the total cost of installed systems, although more data is needed to draw firmer conclusions around this particular dynamic, particularly frequency (and associated costs) of re-work.

FIGURE 20: DUAL INVERTER CONFIGURATION

FIGURE 21: EXTERIOR ELECTRICAL CONFIGURATION



Conduit Requirements

Conduit installation activities account for over 8% of the total cost of benchmarked PV installations. Conduit generally fell into three primary categories: 1) rigid conduit installed in the inverter area and extending to the point at which it enters the interior of the building, 2) flexible conduit installed in the interior of the home, and 3) rigid conduit installed on the roof (if needed) to reach a combiner box location. The process of installing conduit includes preparation by measuring, cutting, and bending rigid conduit, running flexible conduit inside the building, and attaching the rigid conduit to the exterior of the building. In contrast, the SIMPLE BoS team observed no work with conduit on benchmarked German PV systems.

In the U.S., running flexible conduit inside the home is time and cost consuming. Installers cite customer aesthetic preference as the reasoning behind running conduit through the building rather than straight to the roof from the inverter. Accordingly, the need to support aesthetics has a significant impact on total system cost.

In addition to any aesthetic or installer preferences, installers often reference the National Electric Code for the high cost associated with conduit installation. The U.S. National Electrical Code specifies that conduit must envelop all current-carrying PV wires inside the building.[30] However, local government interpretations of the conduit type required varies widely and might allow plastic, watertight, flexible metal (only indoors), electrical metallic tubing, or rigid conduit which is thicker walled.

Observations and reports from Germany indicate that PV installers use little conduit for wire consolidation and protection, and instead often use wire clips for interior wire organization. Further analysis of the comparative costs and system requirements between the U.S. and Germany are included in the next section.

Electrical System Configuration

The primary hardware component affecting both the configuration of a PV electrical system and the cost of installation is the inverter. Benchmarked U.S. residential PV installations included electrical systems configured with central inverters and micro-inverters. Central inverters comprised 73% of the observed installations, while micro-inverters were used for the remainder. Several factors affect the decision to install a system configured for a central versus micro-inverter, including price, the potential for shading issues, site factors, and third-party financier preferences. In addition to an often higher upfront cost for micro-inverters, the cost of installation for benchmarked U.S. installations is almost $0.03/W higher for micro-inverters than central inverters.

[30] National Electric Code (NFPA 70). Article 690.

NON-PRODUCTION

Non-production activities include cleanup, delays, meals, and rest breaks. Top-performing U.S. installers wasted nine times less time on avoidable delays than the lowest-performing installers. This variation highlights room for improvement at the installer level to reduce time spent on non-production activities—specifically by removing several avoidable delays largely attributable to non-standard racking designs (e.g., installers having to drive to the hardware store to buy missing screws and clips). However, perhaps the highest potential for reducing non-production time rests in moving from a three- or five-day installation to a single-day residential installation. Cleanup, rest breaks, and meals account for 13% of total installation time. As shown earlier in this report (see Figure 4), reducing the number of days per installation limits the impact of non-production on a per job basis, and therefore has a natural cost and time reduction effect.

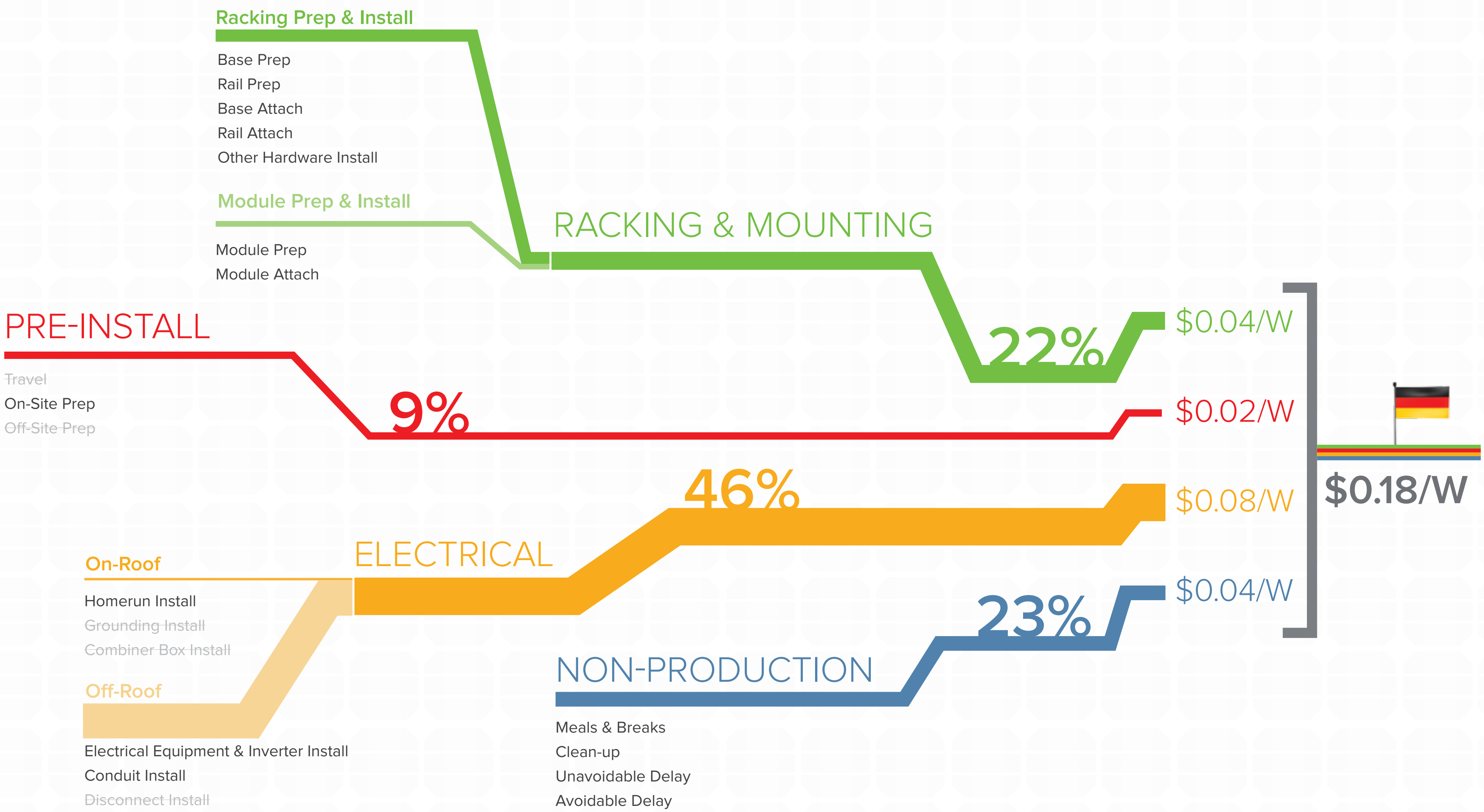
INTERNATIONAL COST COMPARISON

For this phase of SIMPLE BoS, five German installations were observed using the time and motion methodology. Although small, this initial set of data is useful for providing anecdotal comparisons to the U.S. SIMPLE BoS dataset. As with observed U.S. installations, observed German installations generally exhibited a great deal of process homogeneity. By combining results from observed sites and organizing them according to a generalized residential rooftop installation process, we developed a value stream map to illustrate where and how costs are incurred during a typical rooftop installation process in Germany (see Figure 22, next page).

As illustrated in Figure 22, observed German installs comprised the following activities:

- ***Pre-Installation:*** Unlike in the U.S., German installers spent little time conducting warehouse preparatory work. However, three of the five installations observed in Germany employed pre-installation scaffolding crews, comprising well over 90% of median observed German pre-installation activities.
- ***Racking Attachment:*** While fully installed racks look similar to those in the U.S., the construction sequence observed in Germany was drastically simplified. Observed German installers made roof penetrations to install racking bases and manually attach rails to fully installed bases. Several steps present in the U.S. appear to simply not take place in Germany, including most base preparation work (squaring, measuring, flashing, caulking, etc.) and all measurable activities associated with clay / tile roof shingle management.

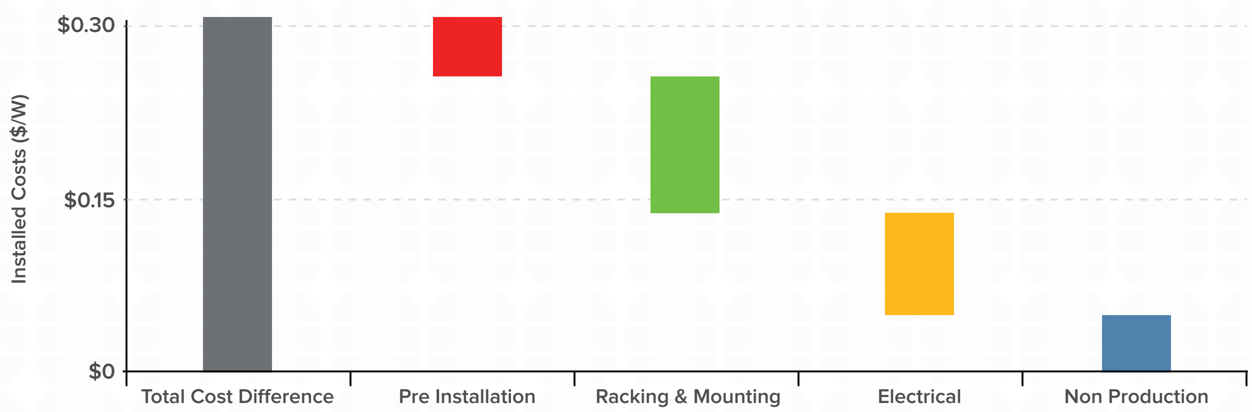
FIGURE 22: GERMAN ROOFTOP INSTALLATIONS: VALUE STREAM MAP



- ***Module Installation:*** Once racking systems have been assembled and installed, modules are hoisted onto the roof using a module lift except in cases of single-story residences where they are manually conveyed to the roof. Many observed German installers extended their module lifts over roof eaves, bringing modules as close to their final position as possible and minimizing the amount of time installers must spend moving modules from lift to rack. Modules were then attached to racking systems using fasteners and tools similar to the U.S. process.
- ***On-Roof Electrical:*** As in the U.S., several electrical-related activities took place on the roof, including connecting modules in series and running homeruns. However, German installers did not use conduit on the roof or combiner boxes, nor do they explicitly ground their systems as U.S. installers do.
- ***Off-Roof Electrical:*** This category encompasses most AC-related electrical work during a rooftop solar installation and typically occurs near the building's electrical panel. This stage of the installation process is similar to the U.S. process, with the notable exception that German installers appear to spend very little time with conduit.
- ***Non-Production:*** Includes all delays, rest breaks, and construction cleanup.

Interestingly, observed German installers spent a proportionately similar amount of time as U.S. installers on the activities listed above. German installers are simply able to do each of these discrete activities two to four times faster than any benchmarked U.S. installer. Benchmarked German installers in SIMPLE BoS installed systems at a cost two and a half times lower than median U.S. installers, at a cost of only $0.18/W (see Figure 23). Furthermore, the most efficient German installation incurred costs 62% lower than the most efficient single U.S. installation observed.

FIGURE 23: **INSTALLATION LABOR COST DIFFERENCES BETWEEN BENCHMARKED U.S. AND GERMAN INSTALLERS**



Several enabling factors allowed observed German installers to install systems safely, efficiently, and at low cost. (Table 3) These factors that differentiate the German and U.S. markets generally fall into three categories: regulatory, legal, and architectural differences; product advantages; and installation best practices.

TABLE 2: BREAKDOWN OF INSTALLATION LABOR COST DIFFERENCES BETWEEN BENCHMARKED U.S. AND GERMAN INSTALLERS

TOTAL COST DIFFERENCE	INSTALLATION ACTIVITY	ACTIVITY COST DIFFERENCE	GERMAN REGULATORY, LEGAL, AND ARCHITECTURAL DIFFERENCES	PRODUCT ADVANTAGES	INSTALLATION BEST PRACTICES
$0.31/W	Pre Installation	$0.06/W	Safety regulations allow scaffolding in lieu of harnesses	Near- identical designs & products are used on every site, enabling efficient truck prep and simple installer training	No off-site prep. Trucks are stocked universally for each site
					Specialized scaffolding crews
	Racking Preparation and Installation	$0.07/W	Scaffolding in lieu of harnesses enables faster movement and easier tool storage	Universal racking bases (roof hooks) can be installed efficiently on all roof types and pitches	Widespread use of equipment lifts
			Fewer warranty-related moisture penetration requirements		On ground rail preparation
					Specialized racking crews
			Uniform German clay tile roofs are “solar ready” and eliminate base prep requirements		Widespread use of single racking system (cross rail)
	Module Preparation and Installation	$0.04/W		No animal wire used on observed installations	Widespread use of equipment lifts
					Bare minimum module packaging
					Specialized module installation crews
	On-Roof Electrical	$0.05/W	Relaxed requirements on homerun management (zipties only sometimes used)		Specialized DC (on-roof) installers
			Minimal grounding requirements		
	Off-Roof Electrical	$0.03/W	Minimal conduit requirements		Specialized AC (off-roof) electricians
	Non Production	$0.05/W	Minimal inspection requirements		One-day installations minimize “fixed” costs (cleanup, meals etc.)

Several enabling factors allowed observed German installers to safely install systems at low cost:

PRE-INSTALLATION

As discussed earlier in the U.S. quartile comparison (Figure 12), a survey administered to U.S. installers participating in SIMPLE BoS suggested a measurable correlation between increased on- and/or off-site preparation time and lower overall installed time. However, observed German installers did not require off-site preparation for high productivity, presumably because the standardized nature of German roof and PV systems enable a well organized and stocked installation truck to reliably supply all of the tools and equipment needed for a particular job. Accordingly, German installers spent only $0.02/W on all pre-installation activities, including travel. While off-site prep work appears to increase efficiency for some U.S. installers, a possible step change in efficiency may be possible in the U.S. by deploying highly standardized systems that eliminate the need for most pre-installation work.

The lion's share of pre-installation work observed in Germany involved scaffolding and safety net setup. National German law requires the use of safety nets along roof edges and mid-roof for long, steep pitches. Initially, this presented a challenge to German installers since such requirements would appear to increase installation labor costs. However, instead of treating such requirements as a cost-adding barrier, industry responded by investing in easily deployable, multi-functional safety equipment that appears to save more time throughout the construction sequence than is incurred in scaffolding setup and breakdown, resulting in a net installation cost savings. In order to make this cost savings as large as possible, German installers have gone so far as to train specialized scaffolding-specific crews that efficiently install scaffolding around project areas (see Figure 24). Scaffolding is used as a tool and materials staging area, work surface, low-fatigue walkway, and break area. Scaffolding configurations also included bolt-on devices like ladders, quick hatches integrated into the scaffolding, and module lifts (see Figure 25 on next page).

FIGURE 24: EXAMPLE SCAFFOLDING ON GERMAN PITCHED ROOF

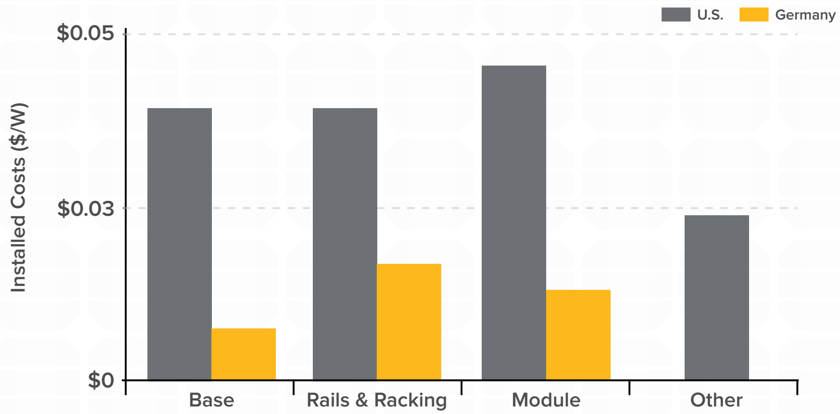
FIGURE 25: SCAFFOLDING WITH INTEGRATED MODULE LIFT

While we have not collected enough data to rigorously test the installation efficiency of projects using scaffolding against those without, using scaffolding for a sloped roof project in the U.S. could seemingly reduce installation costs by $0.01–$0.04/W depending on building size, roof pitch, efficiency gains from simple tool storage, and general efficiency gained from enhanced installer mobility. This estimate includes the additional labor costs associated with setting up scaffolding but does not include any potential savings in terms of rapid module conveyance from integrated lifts.

RACKING & MOUNTING

The distribution of time spent with each major hardware category within the racking and mounting activity bucket is very similar to that of U.S. installers. But, observed German installers have figured out how to install each piece of hardware, including the module, two to three times faster than installers in the U.S. (see Figure 26).

FIGURE 26: **RACKING & MOUNTING HARDWARE COMPARISON BETWEEN THE U.S. AND GERMANY**



Based on initial data collection, the project team has identified several different enablers of efficient German racking and module installation:

Simplified Base Installations

The German residential PV market has evolved to a point where a majority of German installers use a standardized base installation process that is simple, fast, secure, and reliable, allowing German installers to perform base installation at a cost that's three and a half times cheaper than their U.S. counterparts.

One reason for this difference is the presence of virtual "solar-ready homes" in Germany. Before continuing, it's worth noting that these homes were not designed to be solar ready. Instead, a combination of intrinsic architectural characteristics and innovation by PV hardware manufacturers in Germany has created such rooftops and are a primary enabler of German installation efficiency.

Rooftop installations in Germany largely take place on clay tile roofs. Installers reported that most German PV installations take place outside of large cities, where homes commonly have tiled gable roofs with few obstructions. The uniform roof design along with measurement precision of German construction makes tile roofs somewhat solar ready. This uniformity and precision provides for an interesting point of comparison since, as described earlier, clay tile roof installations in the U.S. are expensive, require additional hardware, and in many cases involve removal of 50–75% of existing tiles to accommodate racking base installation. In contrast, German installers and hardware manufacturers have turned the supposed onerous design constraint imposed by clay tile roofs into an efficiency-boosting solution. Standard tile geometry is used throughout the country (see Figure 27), enabling use of satellite imagery and/or on-site observation to measure roof geometry and plan arrays by simply counting tiles.

FIGURE 27: UNIFORM GERMAN CLAY ROOF TILES, EXPOSED FURRING STRIPS

For most German clay tile roofs the construction method is regular and the geometry is reliable. Tiles are hung on lateral “furring strips” (see Figure 27 on previous page) that run on top of a standard roof rafter, waterproofing material, and transverse furring strip assembly. The top furring strips and the rafters underneath them can be easily identified by the gutter hooks (see Figure 28).

To begin an installation, installers use gutter hooks as a visual indicator of where an initial base can be installed. After installing an initial base, installers count tiles to find the next rafter. They then lift or slide out of place individual tiles, visually aligning roof hooks to ensure two to three screw holes overlap with the furring strip. They attach the base with screws that pass through the furring strip and waterproofing material, and into the rafter below. Installers then simply slide the original tile back into place (sometimes after grinding away the tile material for better fit) and the fully installed base is ready for rail attachment (see Figure 29). Each of these roof hook installations on clay tile roofs take roughly 1.8 minutes, compared to 3.2 minutes per full base installation on non-clay tile roofs in the U.S. This discrepancy is important: because of their added complexity, we observed clay tile base installations in the U.S. to be four and a half times more expensive than non-clay tile roof base installations. And yet, observed German installers were able to install bases on clay tile roofs nearly twice as fast as U.S. installers working on supposedly easier to deal with non-clay tile roofs.

By relying on regular roof geometry and following this simple base installation process, German installers avoid all activities associated with base alignment, including measuring, chalking, squaring, and pre-drilling. Furthermore, German installers do not use caulking or flashing as extra protection against water penetration in the clay tile roof installation process.

FIGURE 28: GUTTER HOOKS IMAGE

FIGURE 29: FULLY INSTALLED BASE, WITH & WITHOUT TILE

Rail Design and Preparation

German installers benchmarked for this phase of SIMPLE BoS spend less than half the time U.S. installers do preparing, conveying, and installing rails. All German installations observed by the SIMPLE BoS team used a cross rail system with vertical and horizontal rails running across the roof, as is commonly done in the U.S. German installers typically attach clips and splice bars (when needed to extend rails) on the ground, convey rails to the roof, and attach them with a simple ratcheting wrench (see Figure 30). Some rail cutting observed in Germany was performed on the ground to make short sections, but in general installers trim rails for a flush fit, if needed, on the roof once the racking system is fully installed.

Unlike their German counterparts, U.S. installers observed under SIMPLE BoS typically hoisted rails onto the roof without splicing attachments or clips. U.S. installers also generally added components to rails while on the roof because module attachments are made with discrete clamps that can be dislocated during rail conveyance, whereas observed German installs had clamps integrated into the rails themselves.

National grounding requirements are one factor that accounts for the different technology choices. U.S. codes require a localized ground path that removes non-conductive coatings and high pressure. In contrast, the German industry is comfortable with the safety provided by contact grounding as discussed earlier. This difference in codes has resulted in drastically different rail designs.

FIGURE 30: PREPARING RAILS PRIOR TO CONVEYANCE

Four-Corner Arrays

As in the U.S., outside rails are used to square interior rails with a PV string. This process is most effective on simple rectangular (four-corner) arrays, a characteristic that the uniform German roofs enable. At one German site, the homeowner requested the installer to max out PV capacity, requiring array installation between and around skylights. This configuration increased the complexity of the installation by requiring multiple sub-arrays to accommodate the skylights. This site ended up as a higher cost outlier among the observed German sites, supporting our finding that increasing array complexity, effectively measured by the number of corners in a particular array, increases the overall installation time. Although more data is needed to fully establish a relationship, our limited U.S. and German data indicates some level of correlation between racking and mounting installation time and array complexity, as racking and mounting time appears to increase in accordance with array complexity, as measured by the number of corners in a single installation.

Task Specialization

According to the installation companies benchmarked during this phase of SIMPLE BoS, German solar installation firms deploy highly specialized installation crews. For each site, pre-install teams come in to set up scaffolding and safety nets prior to construction, a different crew performs full base, racking, module, and DC electrical installation (including homerun management), while another electrician-specific crew, often on sub-contract, performs all AC-related work. Within the racking and mounting installation team, a second layer of specialization is commonly present. A lead installer is responsible for critical on-roof activities with one or two assistants, while one to two installers on the ground commonly prepare and convey material and equipment to roof installers. Quality assurance tools like measurement gauges for placing rail clips are often used to significantly decrease the likelihood of installer error among the ground crew.

Many industry experts hypothesize that further specialization within the specific racking and mounting phase of a solar installation can help boost efficiency and lower cost. Some U.S. firms are actively experimenting with this hypothesis: within the racking and mounting subcategory for clay tile roof installations (which in the U.S. are much more complicated than asphalt shingle or metal roof installations), the SIMPLE BoS team observed specialized installation crews deploying racking-specific crews and separate, module-specific installation crews. However, observed German installers combine these activities to deploy combined racking and module installation crews. While our limited dataset makes it difficult to draw definitive conclusions around these dynamics, a direct comparison of German racking and mounting crews and similar teams in the U.S. is useful (see Figure 31 on next page).

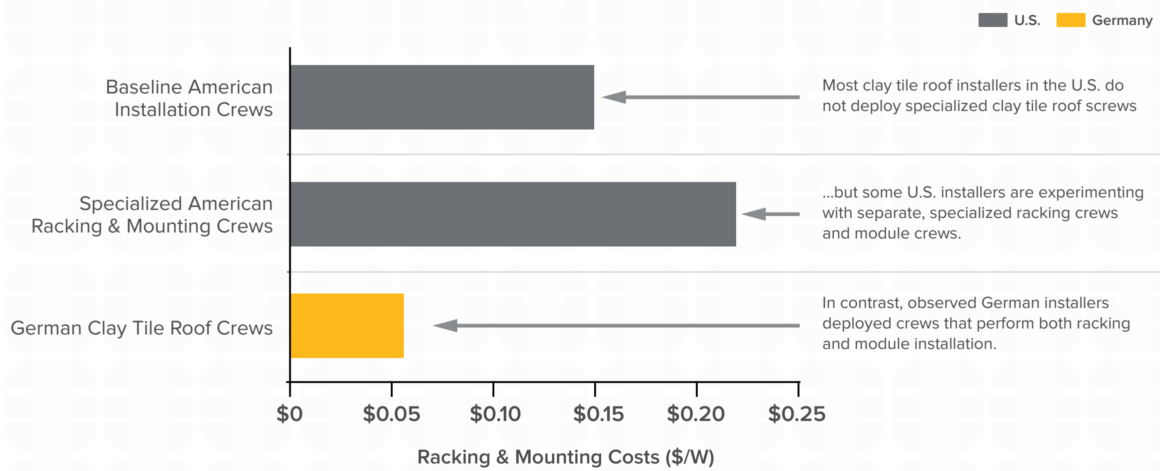
As illustrated in Figure 31, observed U.S. clay tile roof installation crews that deploy specialized teams separately for racking installation and module installation incur over a third higher racking and mounting installation labor costs than normal clay tile roof installation crews. Observed German installers, who combine all racking and module installation activities, incurred over 80%-lower costs than U.S. installers while performing the same activities. Again, our limited dataset cannot be relied upon for deep conclusions on clay tile roof installation efficiency. However, some correlation between installation efficiency and different levels of crew specialization is apparent. This important but little-understood connection warrants additional analysis.

Module Conveyance

Observed German installers incurred a very low module handling and installation cost of only $0.01/W compared to $0.05/W for U.S. installers. This discrepancy is likely attributable to the widespread use of module lifts in Germany and minimal module preparation work prior to conveyance.

As noted earlier, module lifts in Germany are not only used for all installations taller than one story, they are also extended over roof eaves or onto scaffolding, allowing even easier module movement from lift to final racking position. Installer trucks are also configured for simple module unloading with minimal module packaging. In fact, observed German installers organized modules in their trucks so efficiently that the SIMPLE BoS team was unable to measure any significant time being spent unloading, unpacking, or preparing modules. In contrast, U.S. installers spent a median value of $0.01/W conducting such activities.

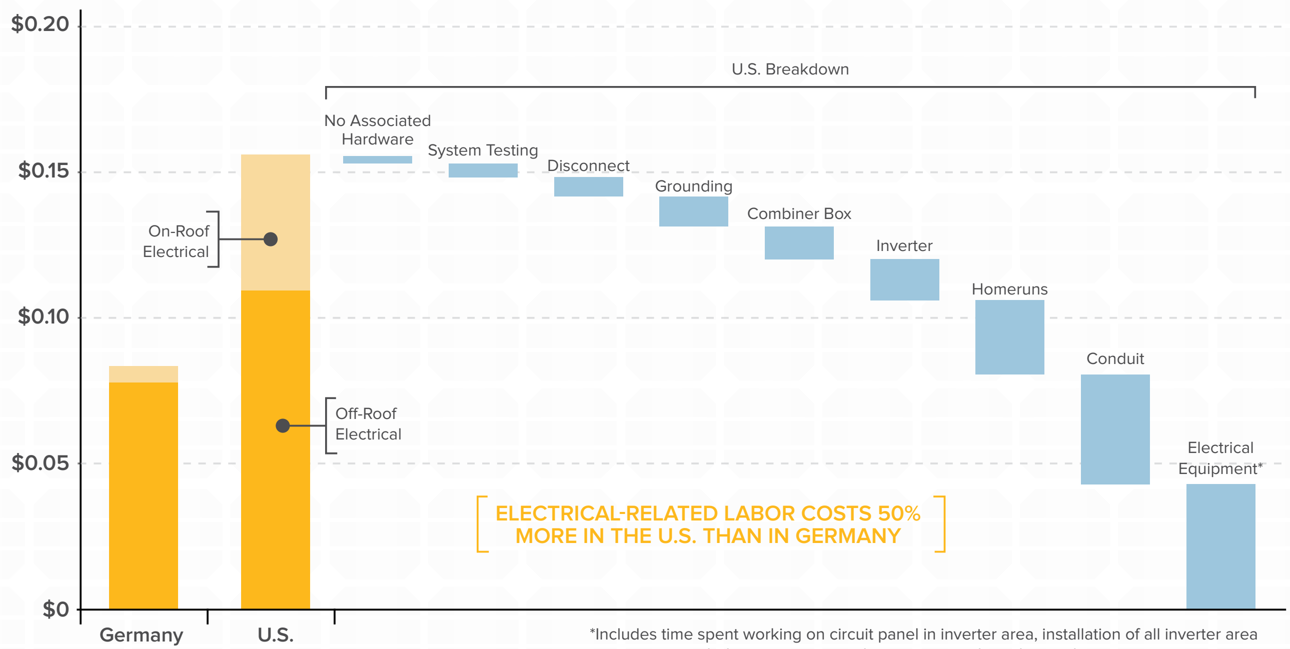
FIGURE 31: **CLAY TILE ROOF RACKING & MOUNTING CREW COMPARISON**



ELECTRICAL

As previously mentioned, many observed German solar installers exhibited a higher degree of crew specialization than U.S. installers: pre-installation crews set up scaffolding, rooftop crews install racking and modules, and electrician crews conduct all AC-related activities. For this phase of SIMPLE BoS, the project team was unable to collect detailed data for all “off-roof” electrical activities (mostly AC), since specialized electrician crews are contracted to complete this work separately from the rest of the solar installation. However, a combination of limited on-site data collection, a survey of German installers conducted by LBNL, and direct installer estimates of AC-related electrical work suggest that German installers complete all electrical activities at roughly half the cost of benchmarked U.S. installers. A majority of electrical related labor can be associated with three major pieces of hardware in the U.S.: homeruns, conduit, and electrical equipment (which includes wire management at the circuit panel, installation of all supplemental inverter area components (meters, extra disconnects etc.), and interior wire runs (see Figure 32)).

FIGURE 32: **ELECTRICAL INSTALLATION LABOR COSTS BY ASSOCIATED COMPONENT**



*Includes time spent working on circuit panel in inverter area, installation of all inverter area components including extra meters, disconnects, and conduit, and interior wire runs

On-Roof Electrical

Systems in Germany have different grounding requirements than in the U.S. and conduit is used sparingly for wire management. Observed German installers sometimes used zip ties to secure homeruns and PV wires on racking systems, but oftentimes installers did not use zip ties and allowed homeruns to hang off of the array (see Figure 33).

Off-Roof Electrical

The SIMPLE BoS team was unable to obtain detailed time and motion data on most off-roof electrical activities. However, an apparent $0.03/W difference exists between U.S. and German installers for all off-roof electrical activities suggesting that some, if not much, room for improvement in terms of electrician-related installation activities exists in the U.S. This small difference may be attributable to conduit requirements for AC wiring and will be an area of focus for SIMPLE BoS moving forward.

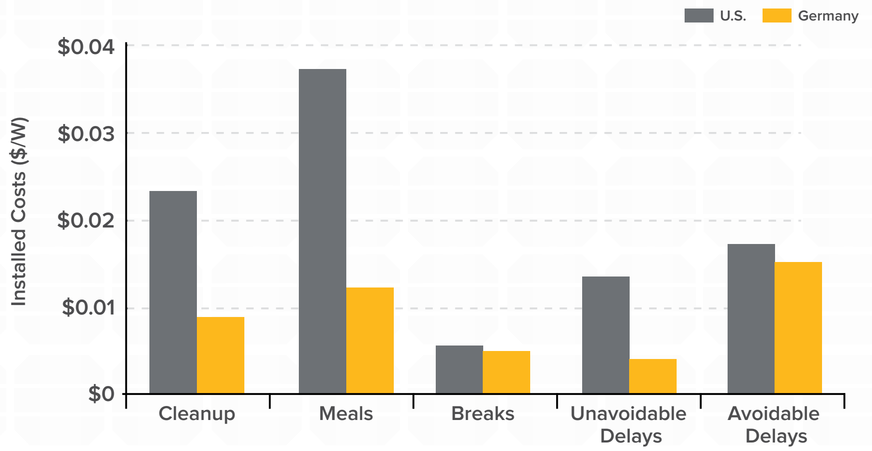
FIGURE 33: ZIP TIES AND WIRE MANAGEMENT

NON-PRODUCTION

Of the four major installation labor activities, non-production time is the least divergent from U.S. installers (see Figure 34).

It's worth noting that observed German installers, like those in the U.S., incur several avoidable delays, suggesting that there is still much room for improvement in the German installation process.

FIGURE 34: **NON-PRODUCTION INSTALLATION COSTS IN THE U.S. AND GERMANY**



CONCLUSIONS AND NEXT STEPS

09

09: CONCLUSIONS AND NEXT STEPS

As solar hardware costs continue to decline, soft costs will become an increasingly potent opportunity for cost reduction. In Germany, installers have relentlessly focused on this issue for several years in the face of decreasing feed-in-tariff levels. Now the U.S. faces a similar situation as installers move beyond traditional regional U.S. solar markets characterized by high electricity prices, good irradiance, and healthy local incentives. New markets with lower electricity prices and a dearth of local incentives put great price pressure on installers. The most tangible way for them to reduce prices and expand their customer base is by focusing on soft cost reductions.

Of those soft costs, installation labor cost reduction represents the single most powerful near-term strategy installers can pursue to offer more attractive prices. Major reasons for increased installation time—and thus, higher costs—in the U.S. include onerous racking installation processes, multi-day installations, limiting options for all AC-electrician-related activities, and a large number of non-value-add activities in the installation process. However, as illustrated by German and leading U.S. installers observed by SIMPLE BoS, these barriers can be overcome by:

- adopting technologies and processes that enable one-day installations,
- using currently available designs that combine discrete installation processes,
- using standardized systems that reduce the need for one-off engineering and design work,
- greatly simplifying racking base installation through design innovation,
- experimenting with scaffolding and module lifts, and
- further specializing installation crews.

Simple changes, like preparing rails with splices and fasteners on the ground, can enable incremental cost savings for installers. Larger but difficult to capture longer-term cost reduction opportunities also exist—especially the removal of most non-value-add activities from the installation process through a combination of efficiency measures and new designs.

Based on the SIMPLE BoS dataset, U.S. installers can leverage proven, currently available, individual solutions to lower costs $0.02–$0.10/W, depending on the solution. But more opportunity exists. By removing all non-value-add activities from the typical installation process, U.S. installers could effectively undercut observed installation labor costs in Germany when differences in wages are taken into account. Holding hardware and non-installation labor soft costs constant, such drastic action would reduce soft costs by 30%, lowering the average installed costs of a U.S. rooftop residential system by 10% to $4.45/W.

This report is only a small piece of the greater SIMPLE BoS effort. In addition to providing updates on this analysis, the SIMPLE BoS team plans to collect additional domestic and international data in order to create a more robust international cost comparison and provide more detailed insight to U.S. installers and manufacturers.

We hope this report and all follow-on work will help the U.S. solar industry continue to reduce soft costs. We look forward to engaging with industry in the future.

Please engage with us by visiting http://www.rmi.org/simple or emailing simple@rmi.org.

GLOSSARY

10

10: GLOSSARY

RACKING AND MODULE EQUIPMENT DEFINITIONS

FULLY INSTALLED ANIMAL WIRE ON ASPHALT SHINGLE ROOF IMAGE

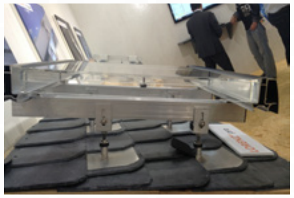
Animal Wire: protective netting to prevent wild animal access to exposed wiring underneath the array.

A FULLY INSTALLED PV ARRAY IMAGE

Array: an arrangement of interconnected photovoltaic modules.

CONCRETE BLOCKS USED AS BALLAST IMAGE

Ballast: weighted anchors utilized to secure arrays in flat-roof applications where roof penetrations are not used to secure a PV system in place.



A FULLY INSTALLED BASE WITH VISIBLE FLASHING IMAGE

Base: the complete assembly that attaches a racking system to a roof. Base components include flashing, furring strip, foot, and ballast (see Glossary entries for these items).

A FASTENER USED TO SECURE MODULES TO RACKING SYSTEM IMAGE

Fasteners: a broad category of components utilized to connect various parts of the racking equipment to the base and the individual components of the base to one another.

Flashing: base flashing comes in several forms, but is often a metal or aluminum piece of hardware that fits over the base plate and is attached to the roof to protect against moisture intrusion through the roof penetration(s) (see Figure G#).

RACKING FOOT ON A STANDING SEAM ROOF IMAGE

Foot: the structural component that connects the racking apparatus to the mount or roof while elevating the racking components above the roof surface.

RACKING FEET COMMON TO GERMANY CLAY TILE AND ASPHALT SHINGLE ROOFS IMAGE

EXPOSED FURRING STRIPS IMAGE

Furring Strip: narrow, water-tight strips situated on top of roof rafters. Base penetrations typically run through furring strips before penetrating rafters.

PV MODULES CONNECTED IN SERIES IMAGE

Module: a packaged, self-contained, connected assembly of solar cells arranged into a panel.

A FULLY INSTALLED CROSS-RAIL RACKING SYSTEM IMAGE

Racking Equipment: the collective equipment utilized to hold, support, and anchor modules in place.

CLOSE-UP OF TYPICAL RAIL IMAGE

Rails: long supports (typically aluminum) that form the matrix upon which modules rest and are secured in a roof-mounted, rack-and-rail system. Splice bars are sometimes used to combine separate rails into a single, longer rail.

ON- AND OFF-ROOF ELECTRICAL EQUIPMENT DEFINITIONS

COMBINER BOX IMAGE

Combiner Box: a closed box where all strings are combined into one electrical output that is then fed to the inverter.

TYPICALLY DISCONNECT INSTALLED IN INVERTER AREA IMAGE

Disconnect: a device used to ensure that an electrical circuit is completely de-energized or isolated for service or maintenance or in the case of over-energization.

INTERIOR CONDUIT USED TO RUN PV WIRES IMAGE

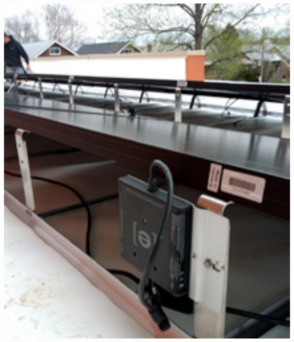
Electrical Conduit: a tubing system used for protection and routing of electrical wiring.

SAMPLE ELECTRICAL EQUIPMENT IMAGE.

Electrical Equipment: the collective equipment utilized to collect, modify, and manage the power provided by the PV array into end-use alternating current. Includes inverters, disconnects, junction boxes, and circuit panels. THIS PHOTO INCLUDES TWO INVERTERS, TWO COMBINER BOXES, AND A JUNCTION BOX AS IS TYPICAL OF INSTALLATIONS THAT USE CENTRAL / STRING INVERTERS IN THE U.S.

GROUNDING WIRE RUNNING ACROSS RAILS

Grounding: an exposed copper wire in contact with each module that provides a common return path for electric current using a direct physical connection to the earth.



AN ENPHASE MICROINVERTER IMAGE

Inverter: an electrical power converter that changes direct current (DC) to alternating current (AC). Some systems utilize microinverters located on each module (see Figure G), while others utilize a central (sometimes called "string") inverter that converts to AC after the current has been aggregated at the combiner box (see Figure G).

HOMERUNS SECURED TO RAILS WITH ZIP TIES IMAGE

Homerun: the main line that runs to connect individual series of panels to the combiner box.

TWO CENTRAL/STRING INVERTERS

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