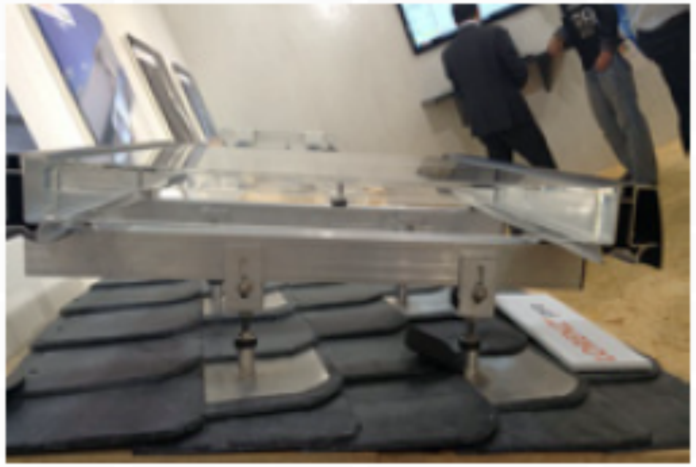
Solar PV Cost Reduction Potential 2016-2030



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).

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.

Morris, J. 2013

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

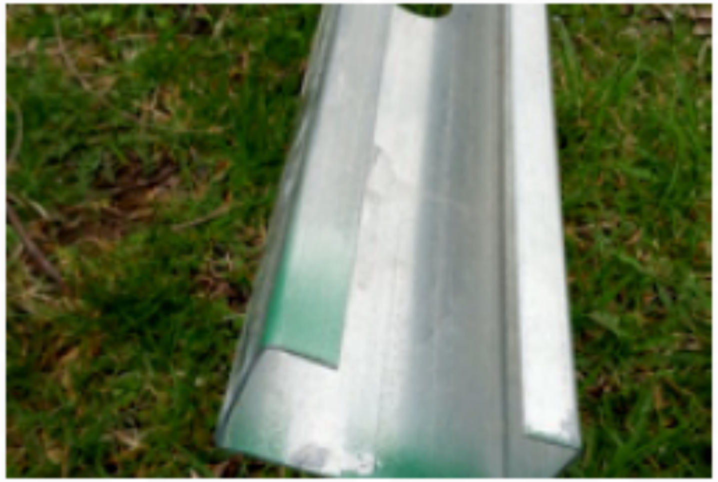
Array: an arrangement of interconnected photovoltaic modules.

Morris, J. 2013

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

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

Morris, J. 2013



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.

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

Morris, J. 2013

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.

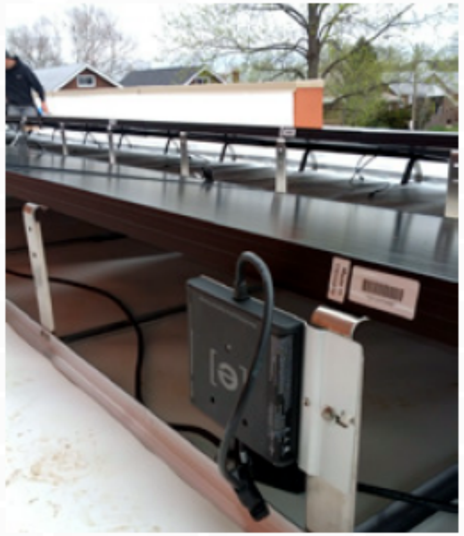
Homerun: the main line that runs to connect individual series of panels to the combiner box.

Morris, J. 2013

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.

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

Morris, J. 2013



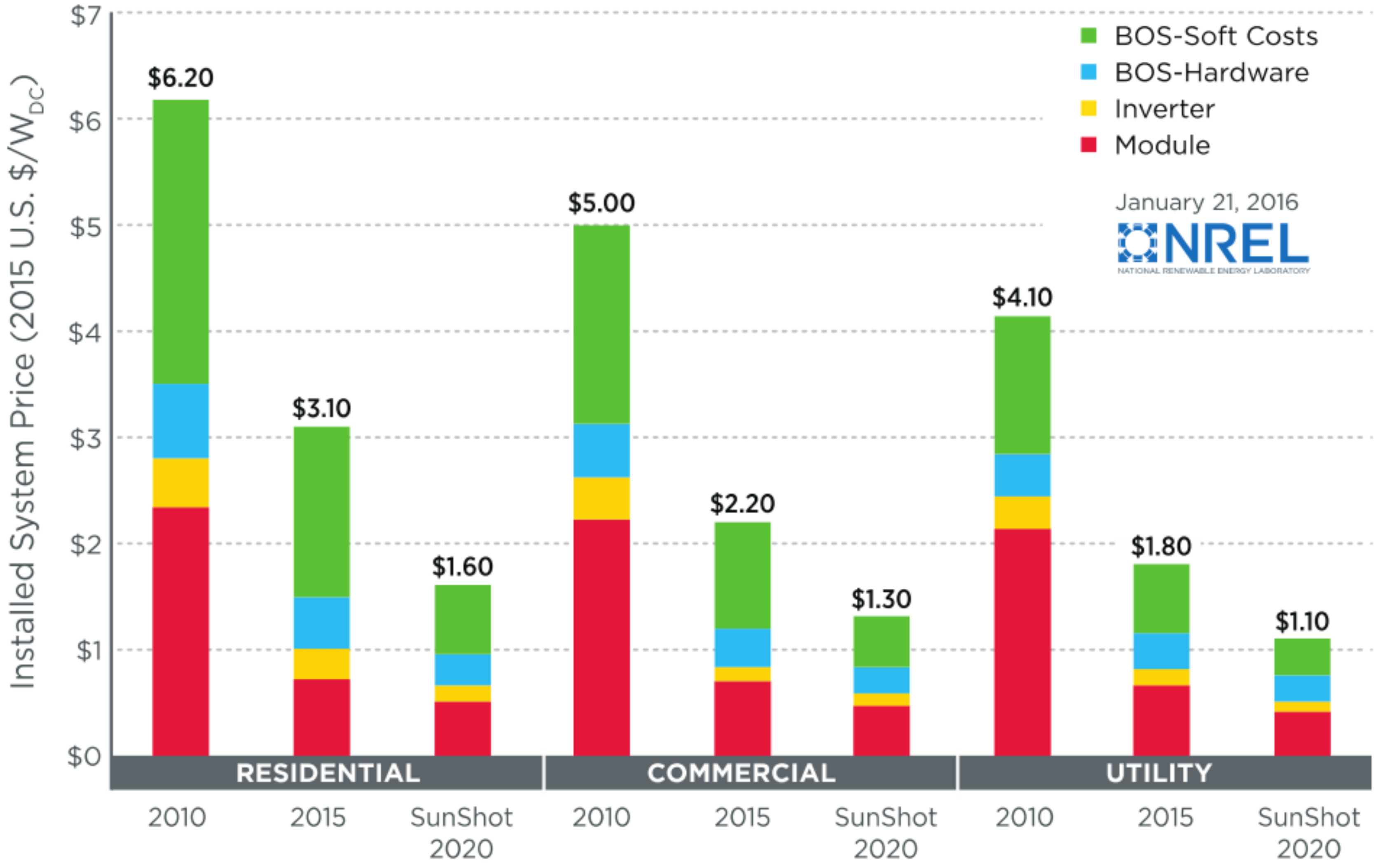
Microinverter

String inverter

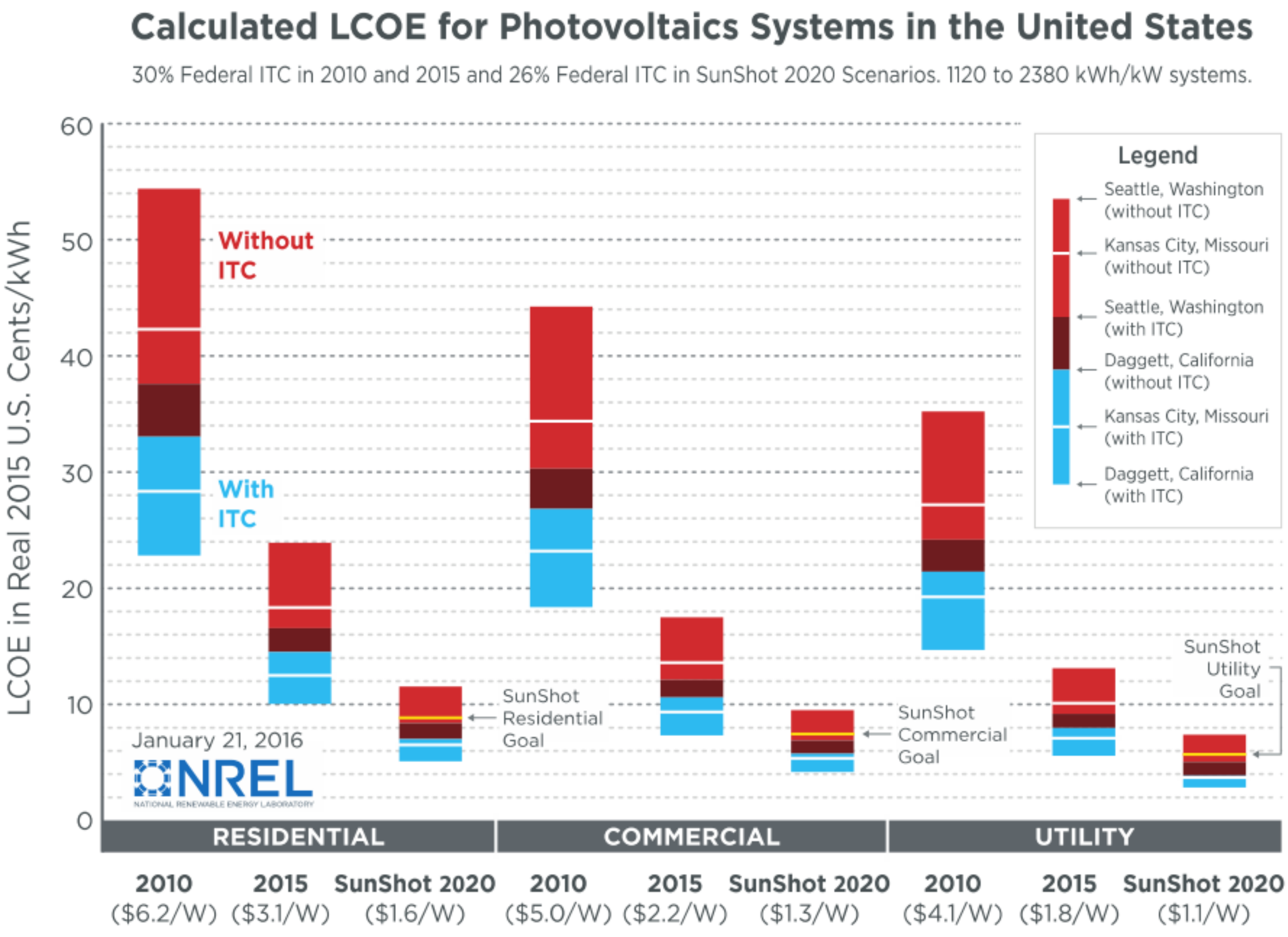
Inverter: an electrical power converter that changes direct current (DC) to alternating current (AC). Some systems utilize microinverters located on each module (see Figure G), while others utilize a central (sometimes called "string") inverter that converts to AC after the current has been aggregated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

Morris, J. 2013

Installed System Price

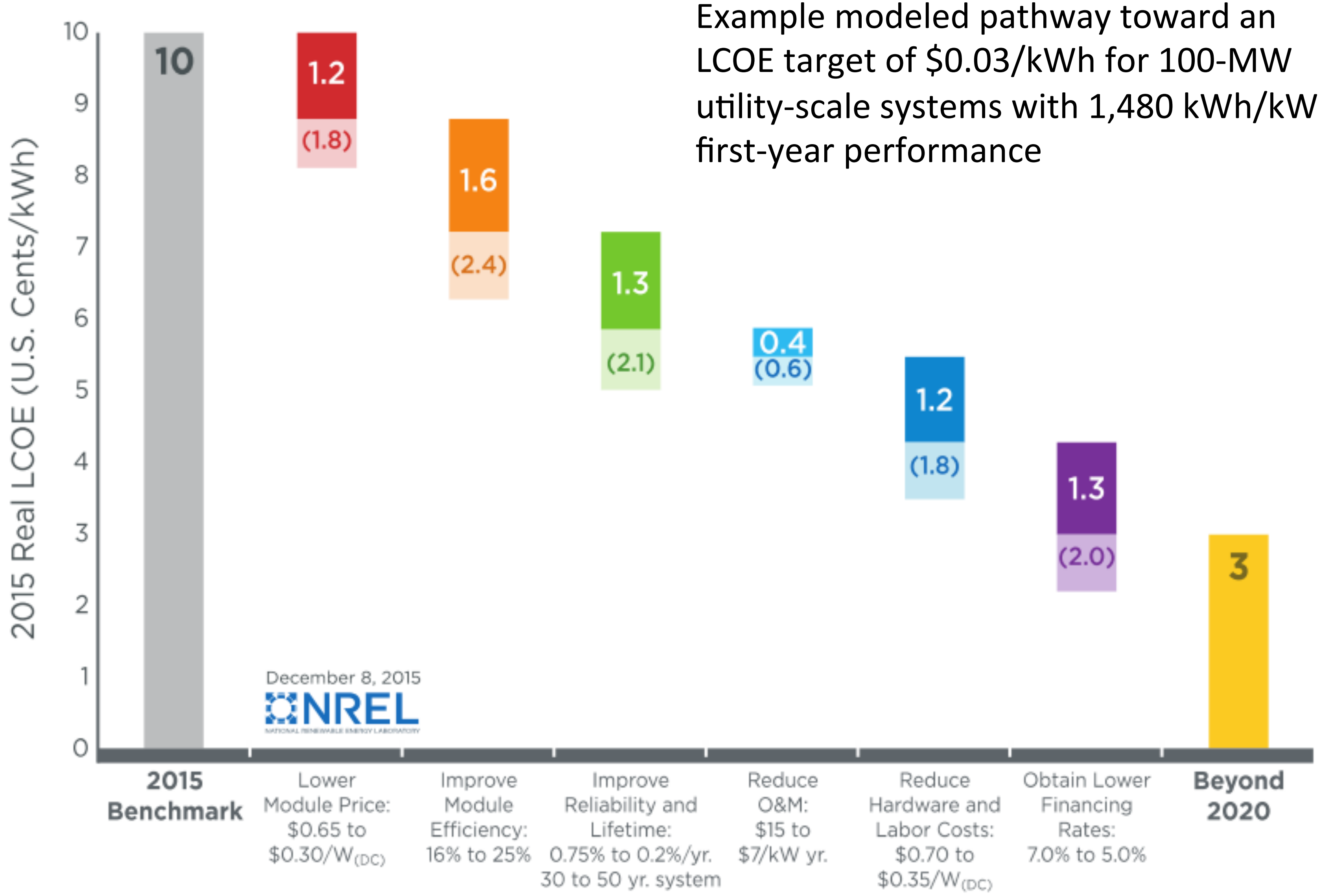


Woodhouse, M. et al. 2016



Woodhouse, M. et al. 2016

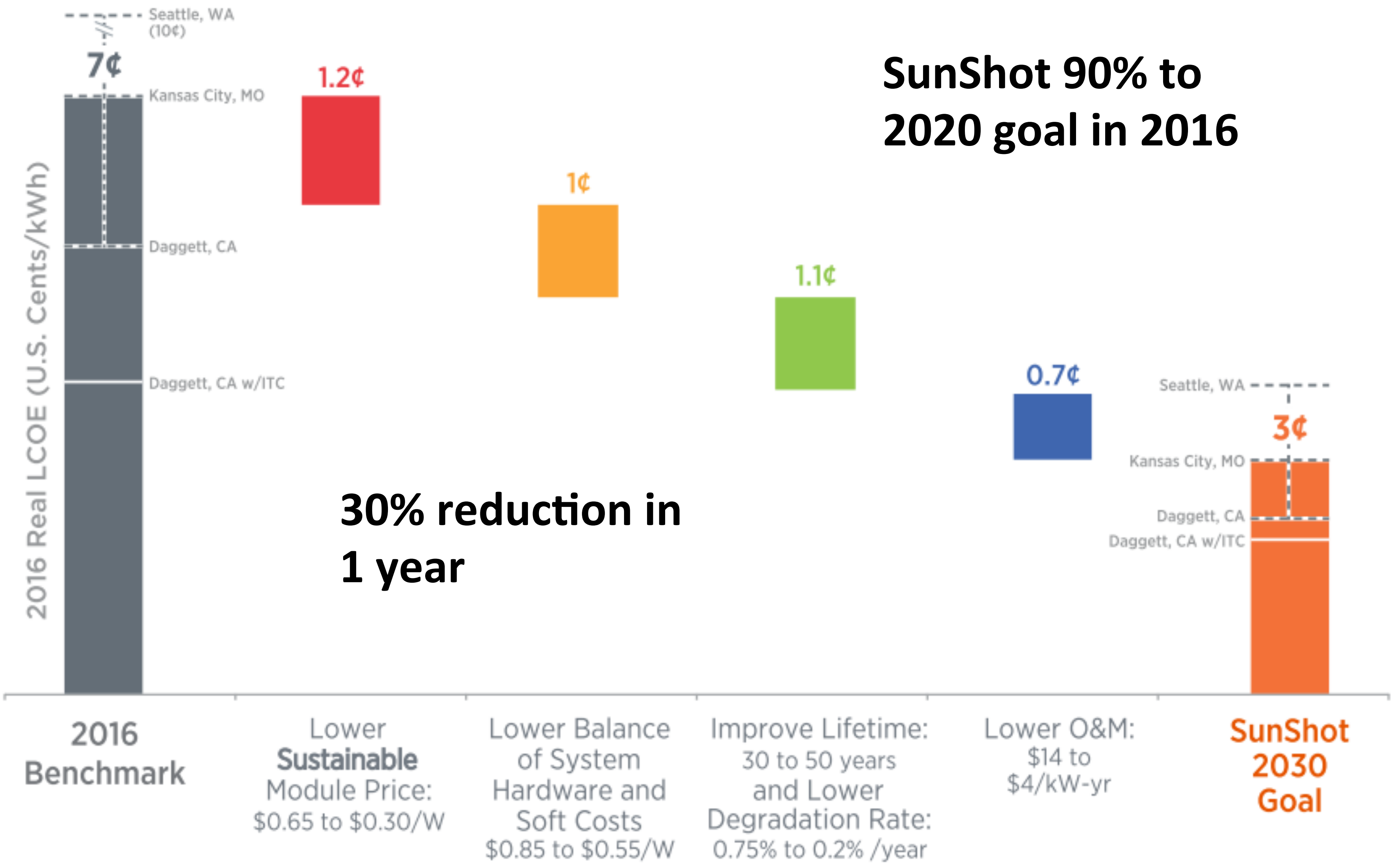
Example modeled pathway toward an LCOE target of $0.03/kWh for 100-MW utility-scale systems with 1,480 kWh/kW first-year performance



Woodhouse, M. et al. 2016

SunShot 90% to 2020 goal in 2016

30% reduction in 1 year



SunShot Initiative 2030 Fact Sheet

Average U.S. Electricity rate was 10.83 ¢/kWh in August 2016, so why is everybody concerned with reducing costs of solar PV?

EIA (2016)

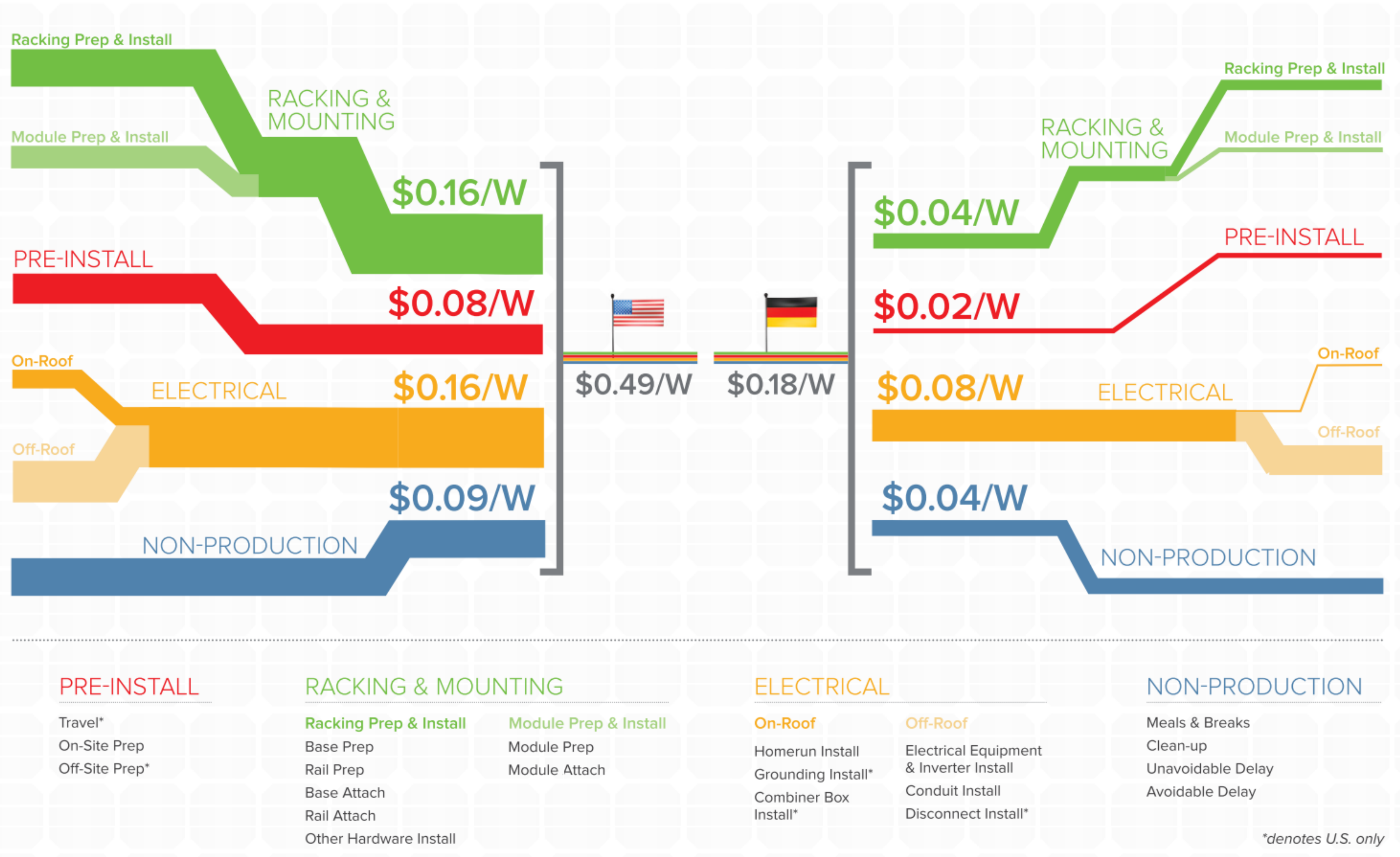
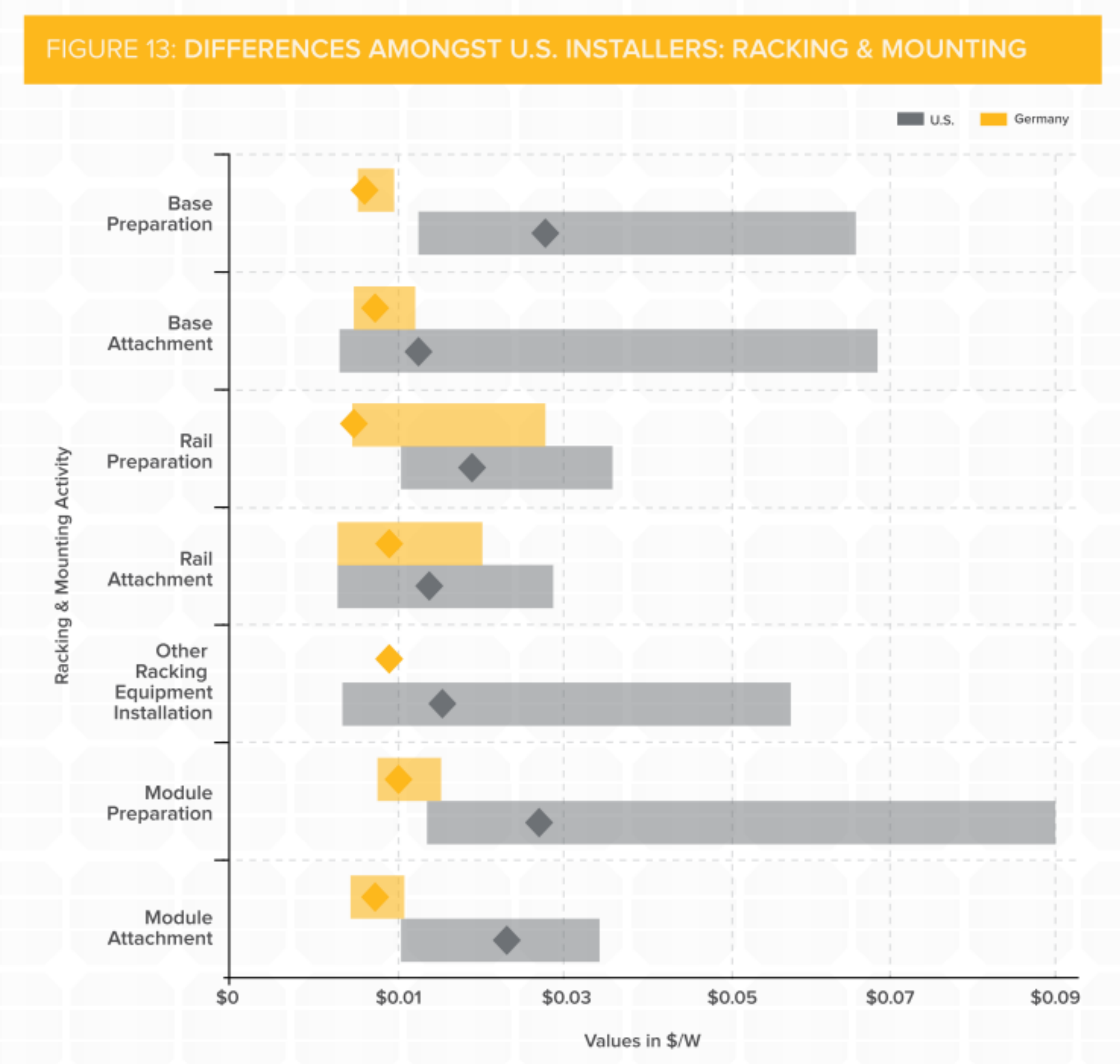


FIGURE ES1: **U.S. AND GERMAN ROOFTOP INSTALLATIONS COMPARED**

Morris, J. 2013



Morris, J. 2013

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

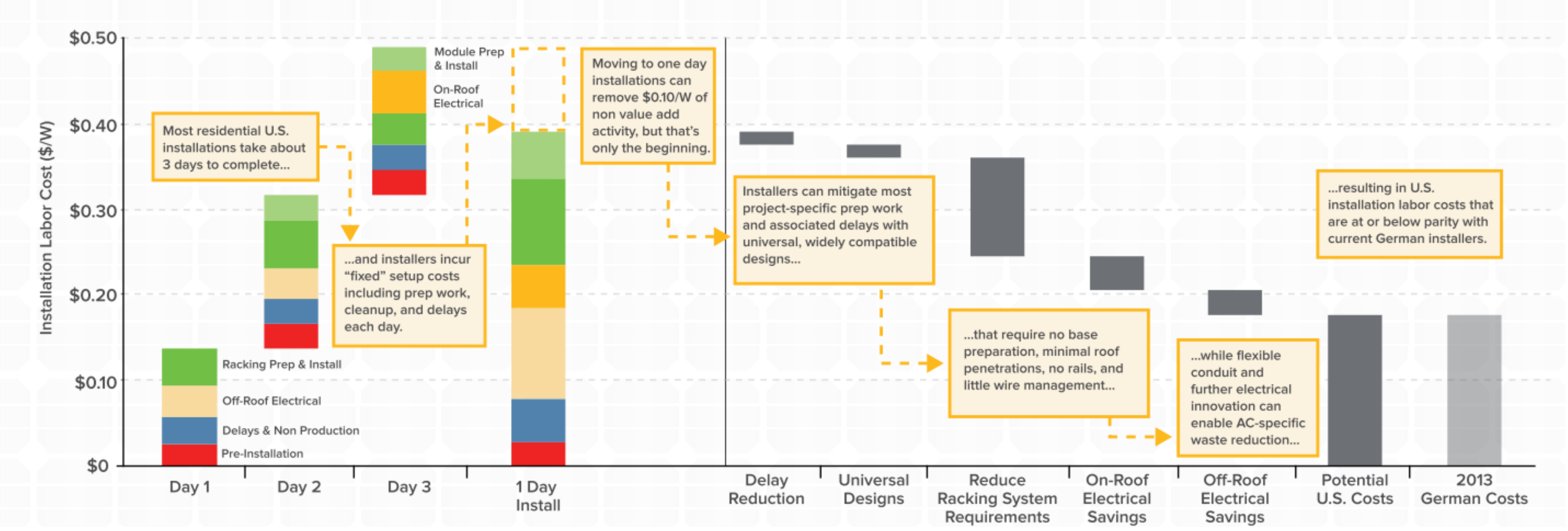
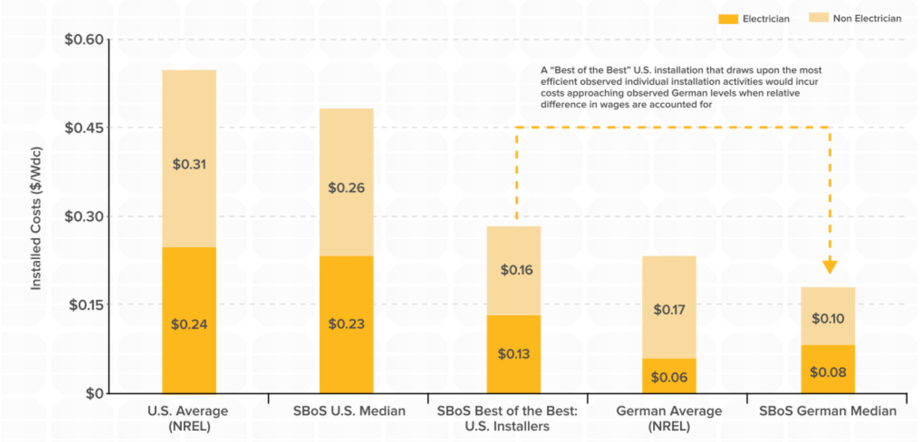
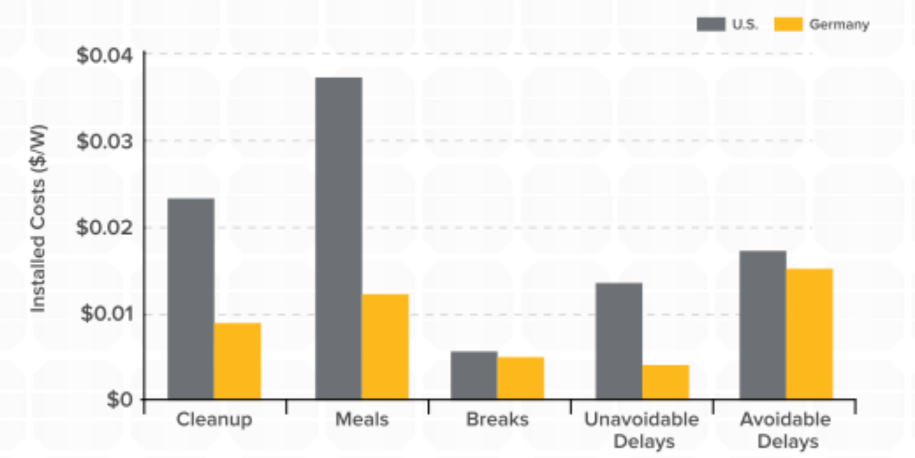


FIGURE 9: INSTALLATION LABOR COST COMPARISON: U.S. AND GERMANY

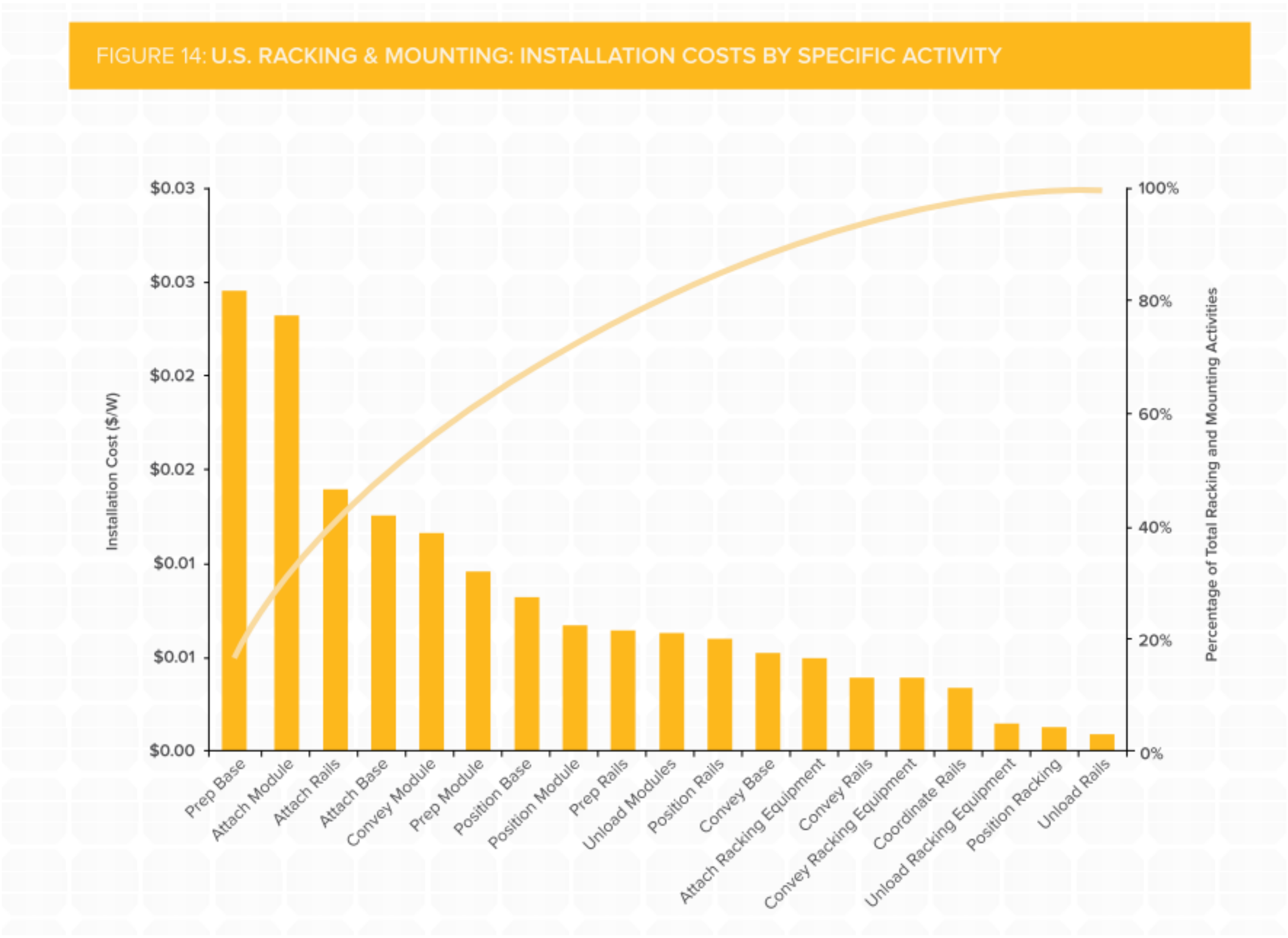


* This analysis uses the same labor wage rate assumptions for electrician and non-electrician labor as Seel et al. (see footnote 10)

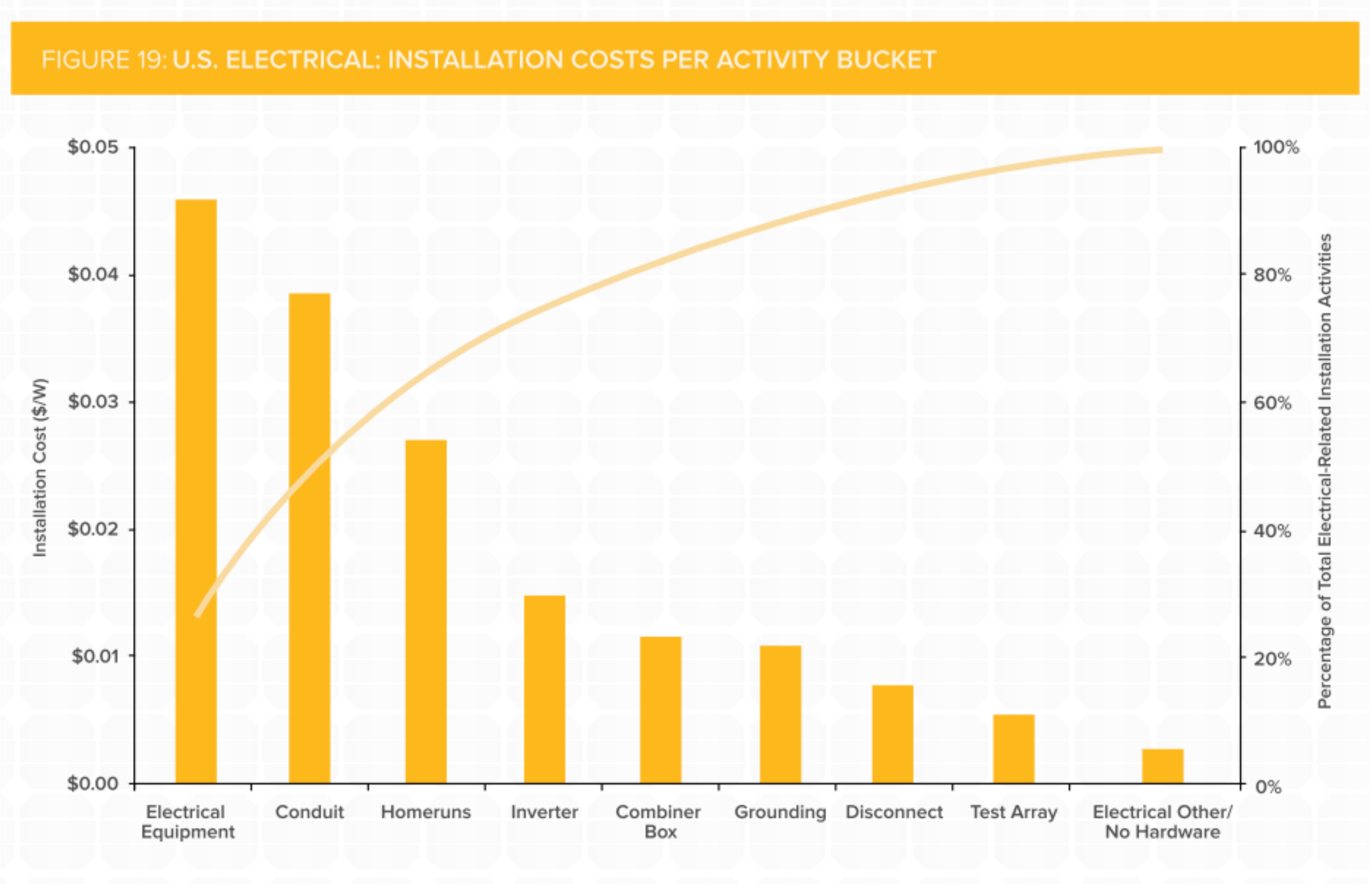
FIGURE 34: NON-PRODUCTION INSTALLATION COSTS IN THE U.S. AND GERMANY



Morris, J. 2013



Morris, J. 2013



Morris, J. 2013

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. (**Vivint and SolarCity, are known to perform single-day residential installations with some regularity**.) 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%.

Steep Roof Redesign

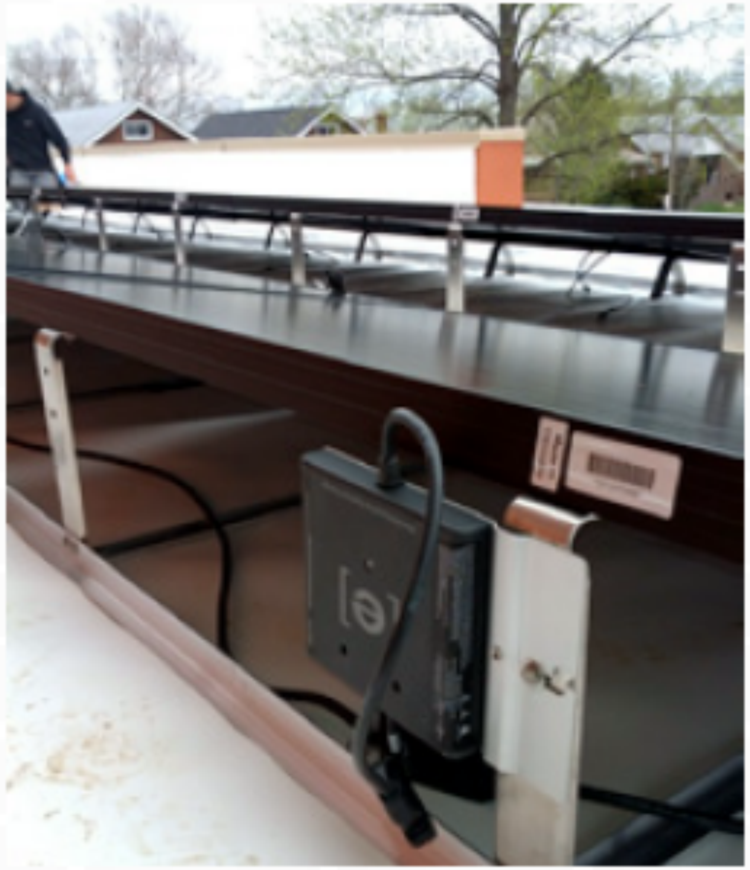
A design solution that eliminates base preparation work on steep roofs by anchoring into an alternative location (the roof ridge, for example) could produce significant savings for installations on steeper gabled roofs.

Conduit Redesign

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

Morris, J. 2013

Morris, J. 2013




Clay Tile Base Revamp

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.

PV-Ready Electrical Circuits

DOE's "plug and play" initiative will make connection of a PV array to the grid much simpler to reduce electrical costs

Base Moisture Protection Layer

Identify strategies to increase the speed of adding moisture protection to base mounts

Scaffolding / Safety Nets

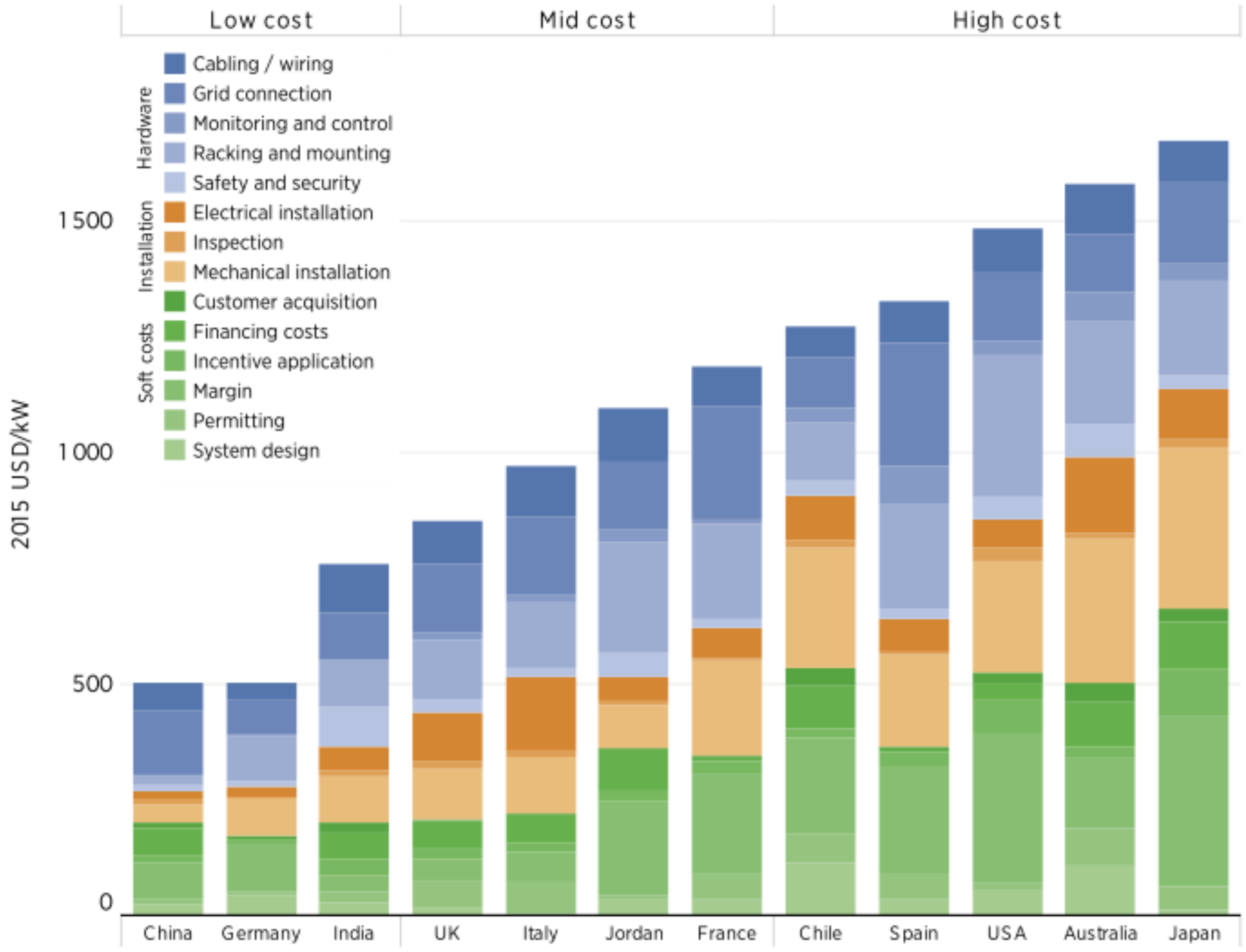
As observed in Germany, installer use of scaffolding and safety nets in lieu of safety harnesses not only improves on-roof efficiency by allowing installers to move about unhindered, but it also enables simple tool storage and bolt-on solutions like module lifts.

Morris, J. 2013

Morris, J. 2013

Morris, J. 2013

PV BoS cost breakdown, 2015



IRENA (2016)

Expected cost reduction of inverter technologies to 2025

Characteristic/Component	Central inverters	String inverters	Micro-inverters
Global price (2015)	~ USD 0.14 USD/W	~ USD 0.18 USD/W	~ USD 0.38 USD/W
Change to 2025	-39%	-33%	-30%
Global price (2025)	~ USD 0.09 USD/W	~ USD 0.12 USD/W	~ USD 0.27 USD/W
Of which:			
Power electronics	0.010	0.012	0.048
Control card	0.001	0.001	0.009
Filters	0.004	0.004	0.007
Distribution board and others	0.016	0.018	0.077
Indirect costs	0.041	0.065	0.082
Margin	0.014	0.020	0.045

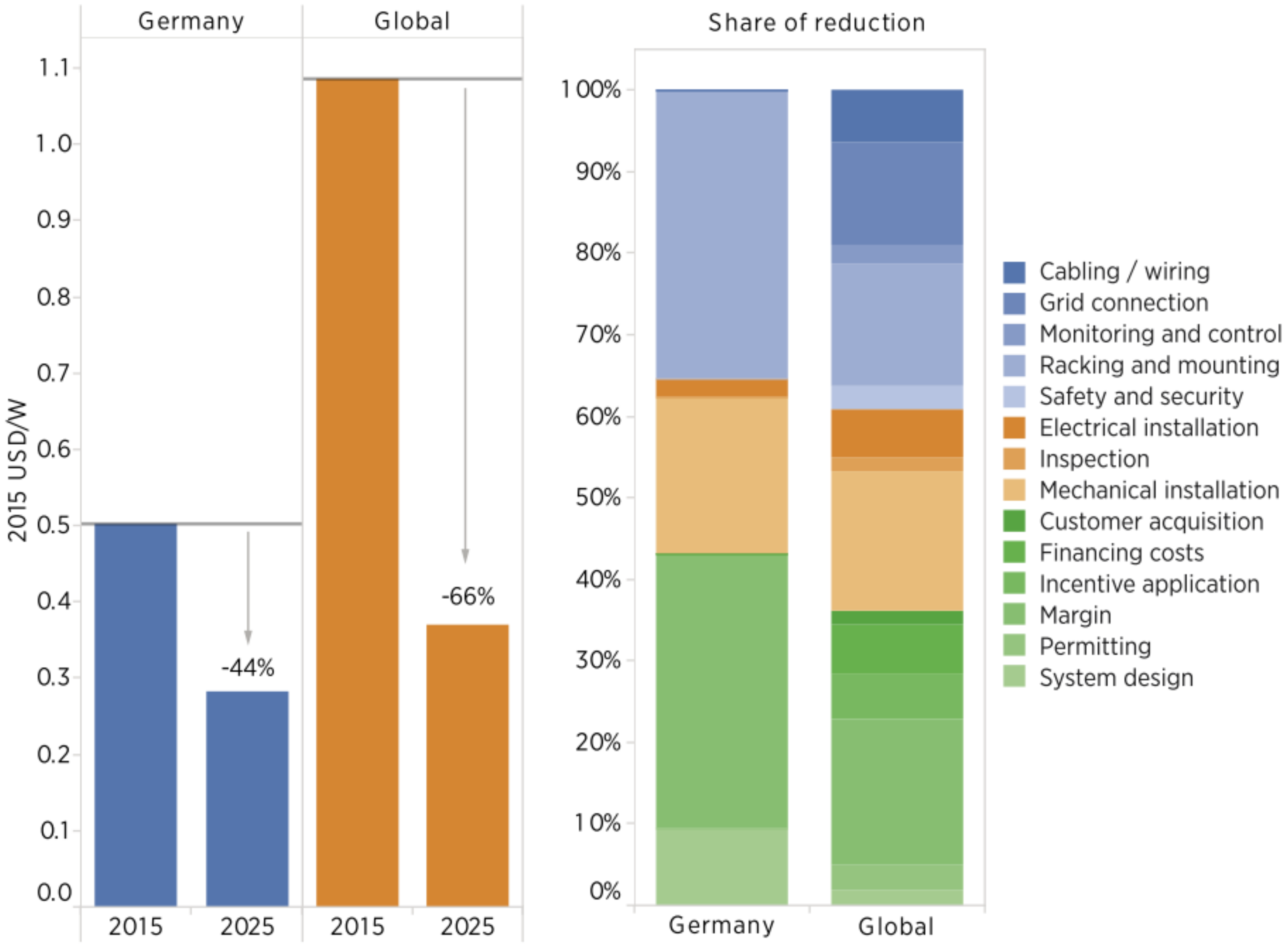
CREARA (2016)

Inverter technology cost trends to 2025

Inverter trend	Key influence
Higher PV module isolation (<1 500 V)	• With little hardware changes, a higher bus DC can be achieved in the PV inverter. This implies a bigger AC connection and a higher power in the inverter (with the same electric current). • This would not only reduce inverter costs but also the amount of transformers and medium voltage cells needed.
Off-grid market (Africa, South America, etc.)	• Manufacturers may be interested in investing in factories where manufacturing costs and transportation may be reduced.
Asian technologies	• Traditionally, inverters installed in Europe have been mainly German, Spanish and Italian, while in the United States, they have been essentially American (although with some European models). However, in recent years there is an increasing presence of low-cost Asian players in international markets.
Other trends	• Adoption of flexible AC transmission systems (FACTS). • Adoption of other sectors' inverters (*e.g.*, wind energy and frequency modifiers). • Adaptation of PV inverters to integrate energy storage.

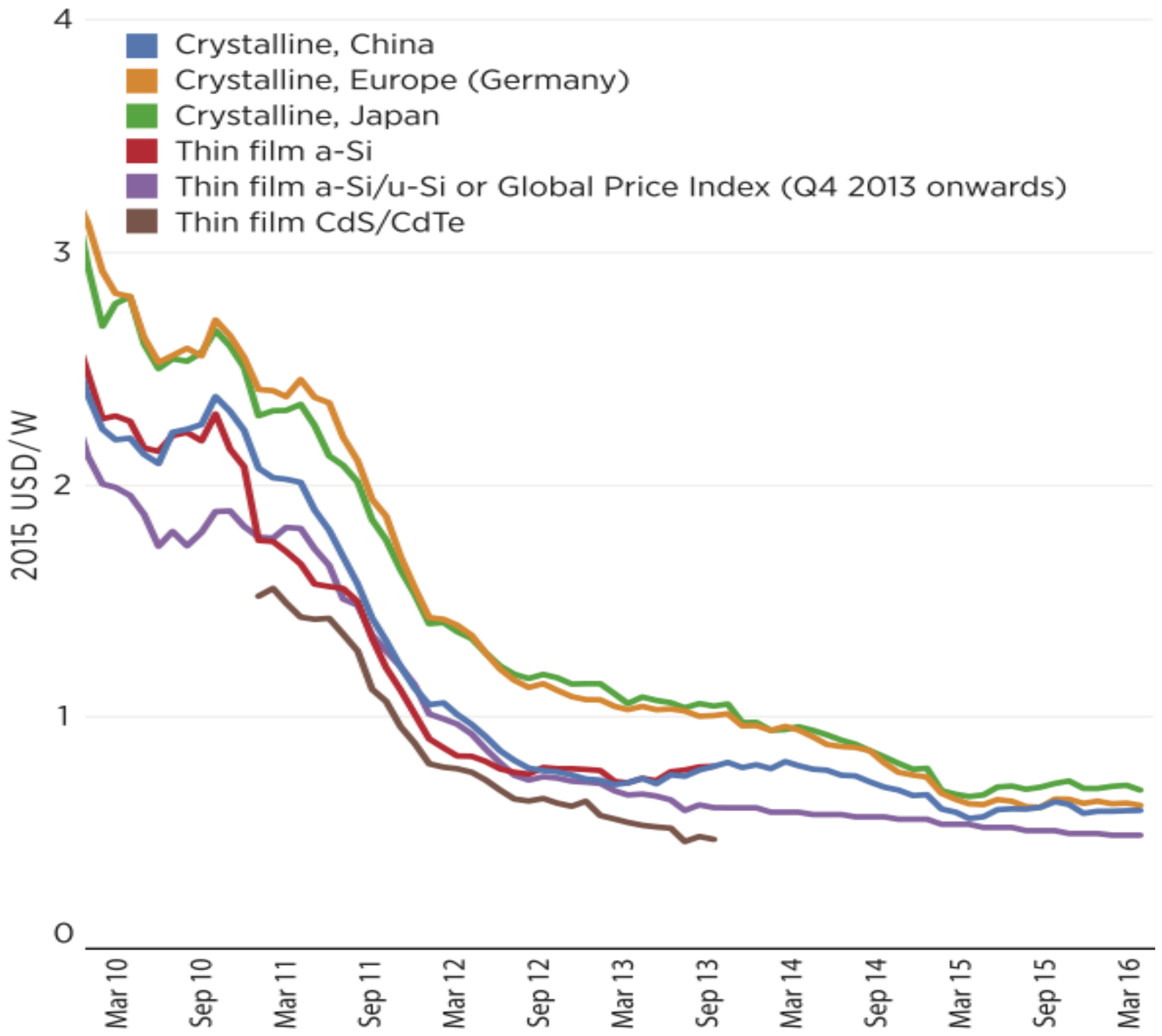
CREARA (2016), IRENA (2016)

BoS cost reduction potential for Germany and globe, 2015-2025



deea. (2016). IRENA (2016)

Global PV module price trends



IRENA (2016), GlobalData. (2014), pvXchange. (2016), Photon Consulting. (2016)

Hanwha Q CELLS overview

- South Korean-based solar module manufacturer
- Flagship company of larger Hanwha Group. Hanwha Group was established in 1952, with over $56B in annual sales
- Module and cell production capacity in excess of 5GW's.
- Bloomberg Tier1 and member of "Silicon Module Super League"

1H 2016 Module prices

- In the first half of 2016, ASP's for c-si modules were above $0.60/watt, on average.
- Module prices varied by format, power density class and manufacturer
  - 60-cell modules were sold at premium prices in mid-to-high $0.60's/watt
  - 72-cell modules were sold at lower prices in the low-$0.60's/watt to the high $0.50's/watt
- Global supply and demand was in general balance

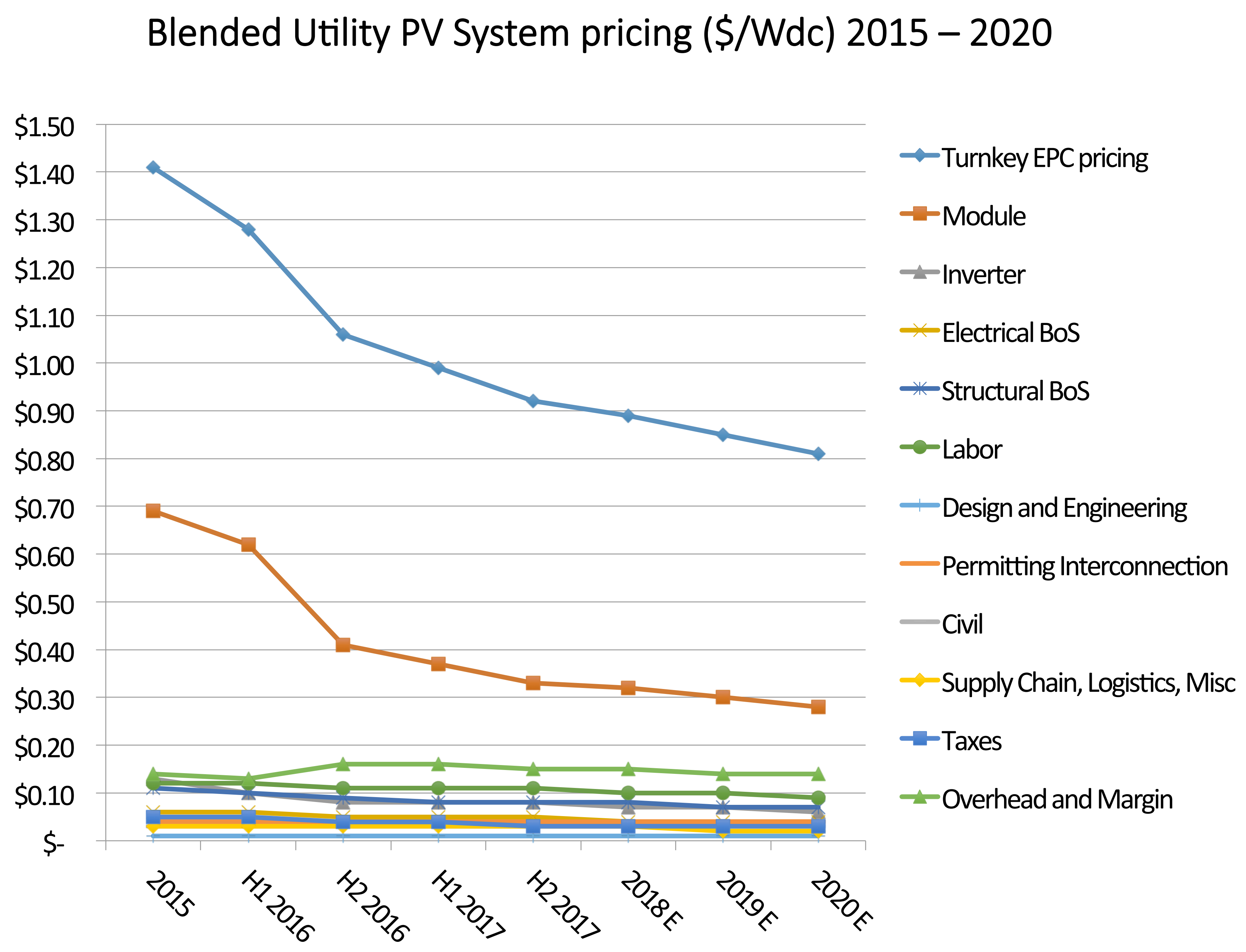
2H 2016 Module prices

- The Chinese market had a FiT incentive decrease that took place after June 2016. The Chinese market is the largest world market. Their demand in H1 2016 was 22GW's, which is expected to decrease to only 6GW's in H2 2016.
- Starting in July 2016, China's sudden decrease in demand led to a global oversupply for solar modules. This oversupplied market led to sudden and sharp declines in c-si module prices
- Module ASP's dropped to the low $0.40's/watt with reports of large project ASP's in the high-to-mid $0.30's/watt
- Module prices are currently stabilizing in the low $0.40's/watt

Blended Utility PV System pricing ($/Wdc) 2015 – 2020

- Pricing example is for U.S. Ground mounted, fixed tilt, 10MW+, c-Si modules
- Turnkey PV System prices fell 16% from H1 2016 to H2 2016, primarily driven by dramatic module price decrease from $0.62/watt DC to an average of $0.41/watt DC.
- Regional prices will differ with soft costs (non equipment), such as labor, permitting, civil, taxes, etc.. In low cost regions, turnkey prices are already below $1.00/watt DC

	2015		H1 2016		H2 2016		H1 2017		H2 2017		2018 E		2019 E		2020 E	
Turnkey EPC pricing	$	1.41	$	1.28	$	1.06	$	0.99	$	0.92	$	0.89	$	0.85	$	0.81
Module	$	0.69	$	0.62	$	0.41	$	0.37	$	0.33	$	0.32	$	0.30	$	0.28
Inverter	$	0.13	$	0.10	$	0.08	$	0.08	$	0.08	$	0.07	$	0.07	$	0.06
Electrical BoS	$	0.06	$	0.06	$	0.05	$	0.05	$	0.05	$	0.04	$	0.04	$	0.04
Structural BoS	$	0.11	$	0.10	$	0.09	$	0.08	$	0.08	$	0.08	$	0.07	$	0.07
Labor	$	0.12	$	0.12	$	0.11	$	0.11	$	0.11	$	0.10	$	0.10	$	0.09
Design and Engineering	$	0.01	$	0.01	$	0.01	$	0.01	$	0.01	$	0.01	$	0.01	$	0.01
Permitting Interconnection	$	0.04	$	0.04	$	0.04	$	0.04	$	0.04	$	0.04	$	0.04	$	0.04
Civil	$	0.03	$	0.03	$	0.03	$	0.03	$	0.03	$	0.03	$	0.03	$	0.03
Supply Chain, Logistics, Misc	$	0.03	$	0.03	$	0.03	$	0.03	$	0.03	$	0.03	$	0.02	$	0.02
Taxes	$	0.05	$	0.05	$	0.04	$	0.04	$	0.03	$	0.03	$	0.03	$	0.03
Overhead and Margin	$	0.14	$	0.13	$	0.16	$	0.16	$	0.15	$	0.15	$	0.14	$	0.14


Blended Utility PV System pricing ($/Wdc) 2015 – 2020
$1.50
$1.40
$1.30
$1.20
$1.10
$1.00
$0.90
$0.80
$0.70
$0.60
$0.50
$0.40
$0.30
$0.20
$0.10
$-
2015
H1 2016
H2 2016
H1 2017
H2 2017
2018 E
2019 E
2020 E
Turnkey EPC pricing
Module
Inverter
Electrical BoS
Structural BoS
Labor
Design and Engineering
Permitting Interconnection
Civil
Supply Chain, Logistics, Misc
Taxes
Overhead and Margin

Thank You

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