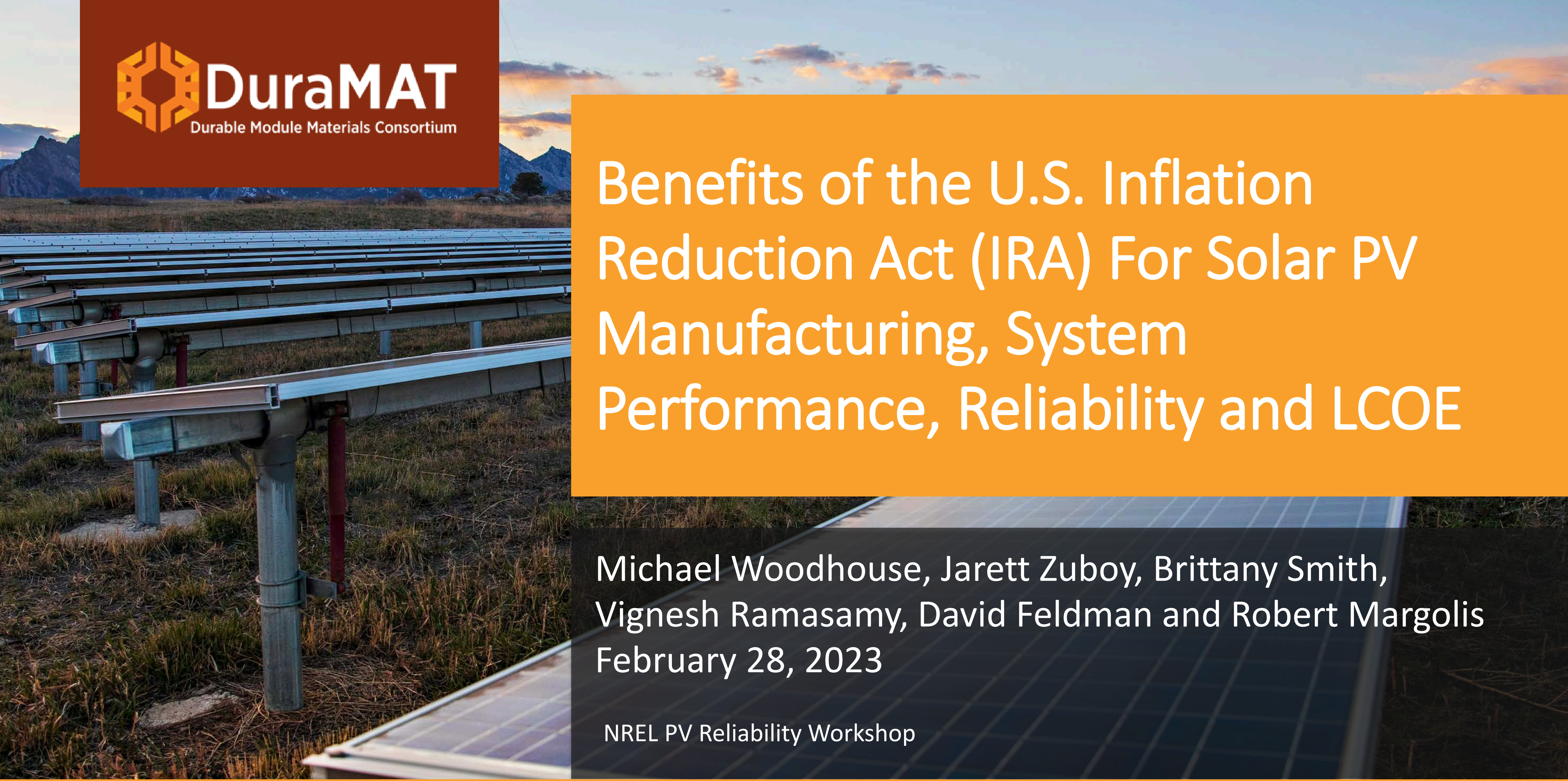

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Benefits of the U.S. Inflation Reduction Act (IRA) For Solar PV Manufacturing, System Performance, Reliability and LCOE

Michael Woodhouse, Jarett Zuboy, Brittany Smith, Vignesh Ramasamy, David Feldman and Robert Margolis
February 28, 2023

NREL PV Reliability Workshop

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Presentation Overview

1. Introduction to the IRA and how it fits into LCOE modeling
2. The case for U.S. PV manufacturing and next steps
3. Energy yield, reliability and LCOE evaluations of historical and upcoming solar technologies including the IRA benefits
4. Conclusions

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Introduction to the IRA

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Investment Tax Credits (ITC) or Production Tax Credits (PTC) in IRA

Manufacturing ITC Section 48C

- Taken from the cost of building, expanding and re-equipping a manufacturing or recycling plant for solar equipment
- 30% credit value if facility meets labor rules (6% if not)
- Credits are also available for projects that qualify under the Defense Production Act (DPA)
- Other considerations including Section 201, Section 301, etc., are relevant for manufacturers but are not part of the ITC

OR

Manufacturing PTC Section 45X

- Credit per unit of a component produced and sold.
- Credits vary by components including polysilicon, wafers, cells, modules, backsheets, inverters, tracker components, tellurium, and batteries (more later)
- Credits are also available for projects that qualify under the Defense Production Act (DPA)
- Other considerations including Section 201, Section 301, etc., are relevant for manufacturers but are not part of the PTC

Deployment ITC Section 48/48E

- Partial refund of the costs for PV systems and standalone storage (new or retrofit)
- Maximum amount: Facilities that meet labor requirements receive 30% of the upfront cost of a project[1]
- Facilities 1 MW and over that do NOT meet labor rules (prevailing wage and apprenticeships) receive 6%
- Additional credits domestic content (+10%), and qualified energy community (+10%)[2]
- Low-income bonus for systems <5 MW (1.8 GW/yr of available credits): 10—20%

OR

Deployment PTC Section 45(d)/45Y

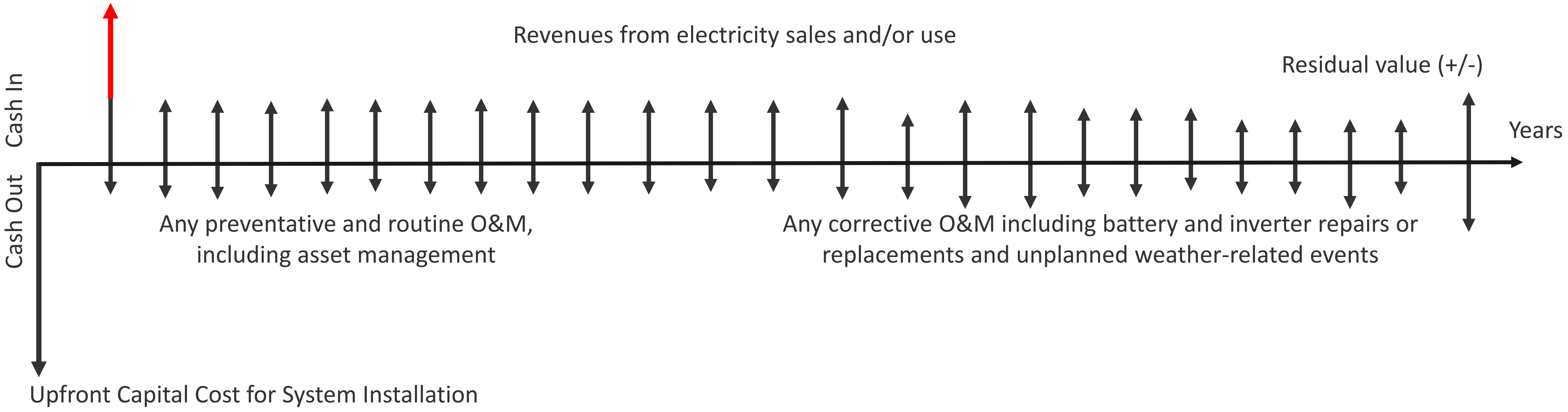
- Credit for the electricity generated over the first ten years of production
- Maximum amount: Facilities <1 MWac *and* that meet labor rules receive 2.75 ¢/kWh for ten years
- Maximum amount: Facilities >1 MWac and that do NOT meet labor rules receive 0.3 ¢/kWh
- Additional credits domestic content bonus (+10%, 0.3 ¢/kWh), and qualified energy community (+10%, 0.3 ¢/kWh)[2]

[1]30% credit also available for residential-owned PV systems
[2]Credits for 1MW+ systems reduced to 1/5 value if they do not meet labor requirements

How the U.S. Inflation Reduction Act (IRA) Applies to Solar Systems

Option 1: Investment Tax Credit (ITC) For Installed Systems

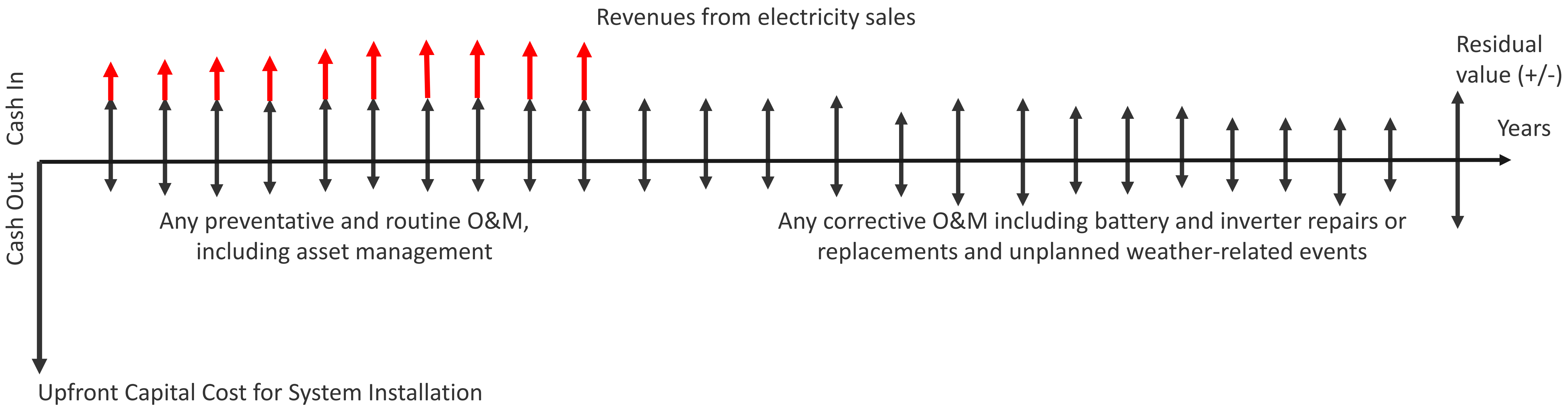
- Monetized as a percentage of original system capital cost after the first full year of operation
- 30% construction ITC until 2033, then stepping down to 22.5% in 2034, 15% in 2035, and 0% in 2036
  - Credit could be extended if greenhouse gas emissions targets are not met.
- As mentioned in previous slide, there are bonus credits for using domestic content, siting in an energy community, or targeting low-income communities.



How the U.S. Inflation Reduction Act (IRA) Applies to Solar Systems

Option 2: Production Tax Credits (PTC) for Installed Systems

- Projects must choose either the ITC or the PTC
- 2.75 cents/kWh from 2023 to 2033, 2.0 cents/kWh in 2034, 1.3 cents/kWh in 2035, ending in 0.0 cents/kWh in 2036. These 2023 reference currency points will be adjusted annually for inflation.
- As mentioned in previous slide, there are bonus credits for using domestic content or siting in an energy community.



Where the ITC or PTC May Be More Favorable and Some Possible Reasons

Favorable Conditions for the ITC (48C Manufacturing Credit, 48/48E for Installations)	Favorable Conditions for the PTC (45X Manufacturing Credit, 45D/45Y for Installations)
Higher upfront capital costs: The rebate is higher, which works to mitigate the higher costs. **Longer timelines to build new capacity:** The ITC can lead to shorter payback times for new investments **Unproven technologies and underperformers:** Unproven technologies and underperforming assets might miss the production goals needed to fully monetize the PTC benefits. Reduced payback time helps to move on from stranded assets. **Domestic content and energy community bonuses:** The relative ability to improve project profitability and lower LCOE is greater for ITC than for PTC	**Higher solar resource areas, systems, or technologies that produce more energy:** More power production (kWh) can be sold and monetized for systems with higher energy yield **Manufacturing projects that can be built quickly:** The PTC provides credits to manufacturers up to 2033 with direct pay options for the first five years. The clock is ticking. **Experienced manufacturers, demonstrated technologies, and shovel-ready projects:** They have more years to monetize the PTC **Potential merchant benefits**

Please see: https://www.energy.gov/eere/solar/federal-solar-tax-credits-businesses and https://www.energy.gov/eere/solar/federal-tax-credits-solar-manufacturers

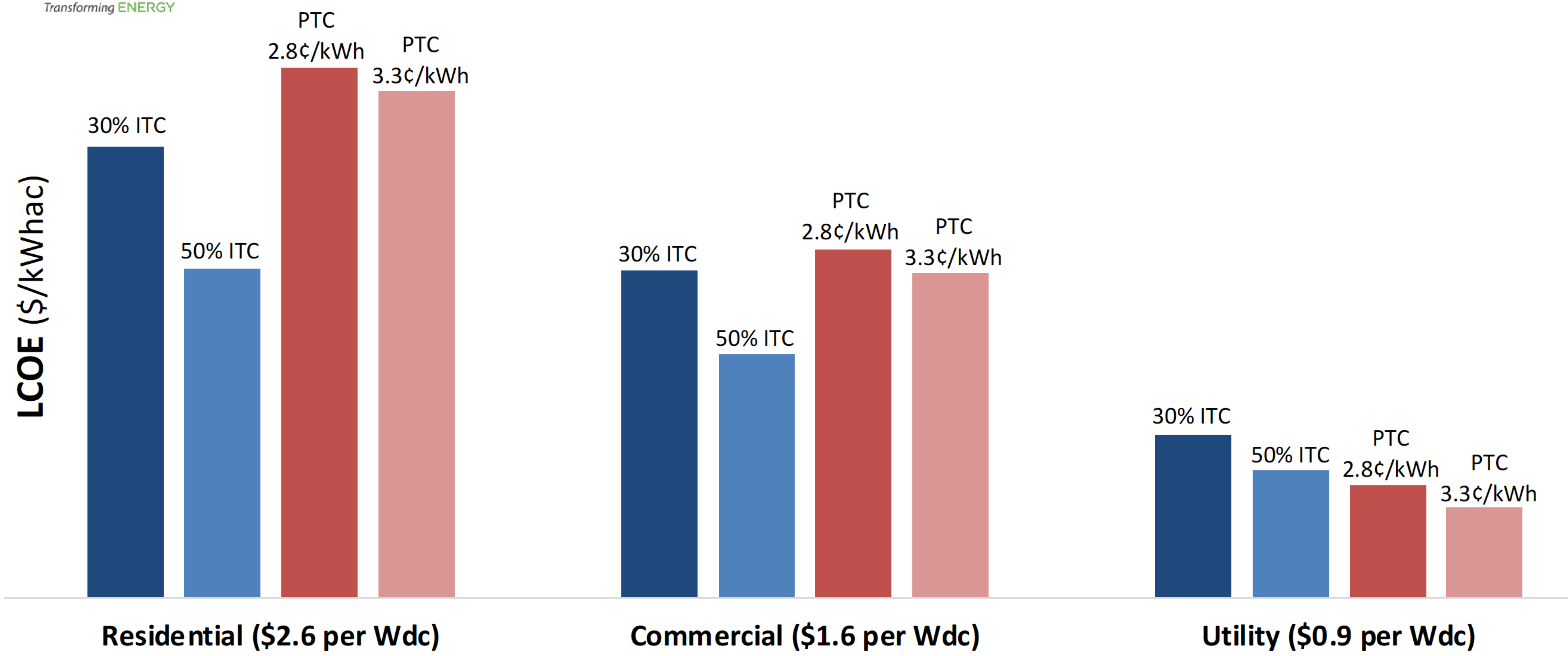
The Additive Possibilities for Solar Projects in the United States

30% ITC or 2.8¢/kWh PTC → 40% ITC or 3.1¢/kWh PTC → ≥50% ITC or 3.4¢/kWh PTC

Up to 30% ITC or 2.8¢/kWh PTC	***Up to 40% ITC or 3.1¢/kWh PTC***	***Up to and beyond 50% ITC or 3.4¢/kWh***
1. Under 1 MW-ac in size or meets prevailing wage and apprenticeship requirements 2. Only 6% ITC or 0.6¢/kWh PTC if prevailing wage and apprenticeship is not met 3. Direct pay options for tax exempt entities (e.g., schools) 4. Credits can be transferred between eligible taxpayers	All requirements are met for 30% ITC or 2.8¢/kWh PTC AND Domestic Content Bonus OR Siting in an Energy Community OR Low- and Moderate-Income (LMI) census tract or on Indian land	All requirements are met for 40% ITC or 3.1¢/kWh PTC AND Domestic Content Bonus AND Siting in an Energy Community AND/OR LMI Community

Please see: https://www.energy.gov/eere/solar/federal-solar-tax-credits-businesses and https://www.energy.gov/eere/solar/federal-tax-credits-solar-manufacturers

Investment Tax Credit (ITC) Or Production Tax Credit (PTC) for PV Systems in the U.S.



Results from the NREL System Advisor Model (https://sam.nrel.gov/). *Benchmark system costs described here*: https://www.nrel.gov/docs/fy22osti/83586.pdf

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The Case for U.S. Photovoltaic Manufacturing and Next Steps

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Inflation Reduction Act (IRA) Credits for Solar Manufacturing

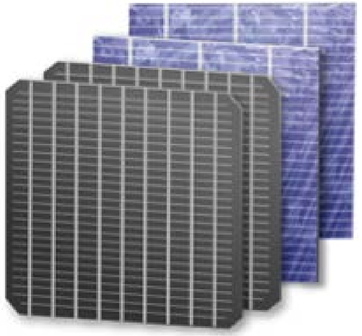
Polysilicon

2022—2029 **$3/kg**
2030—2032 $2.3—0.8/kg
2033 $0/kg

Wafers

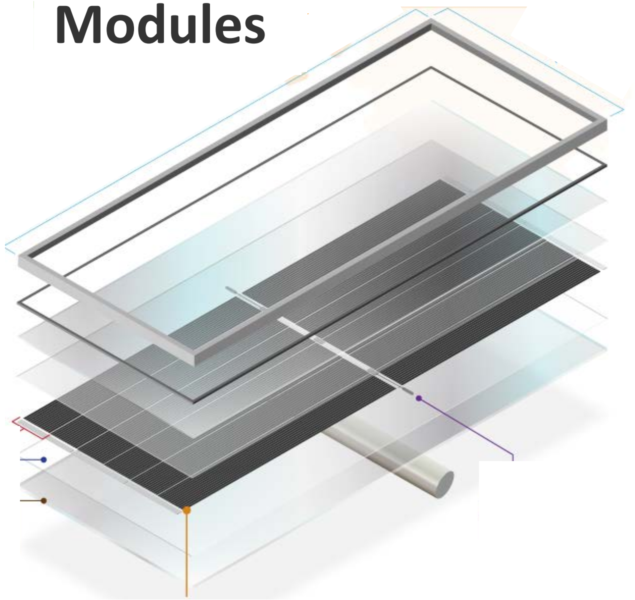
2022—2029 **$12/m^2**
2030—2032 $9—3/m^2
2033 $0/m^2

Solar Cells



2022—2029 **4¢/W**
2030—2032 3—1¢/W
2033 $0/W

Modules

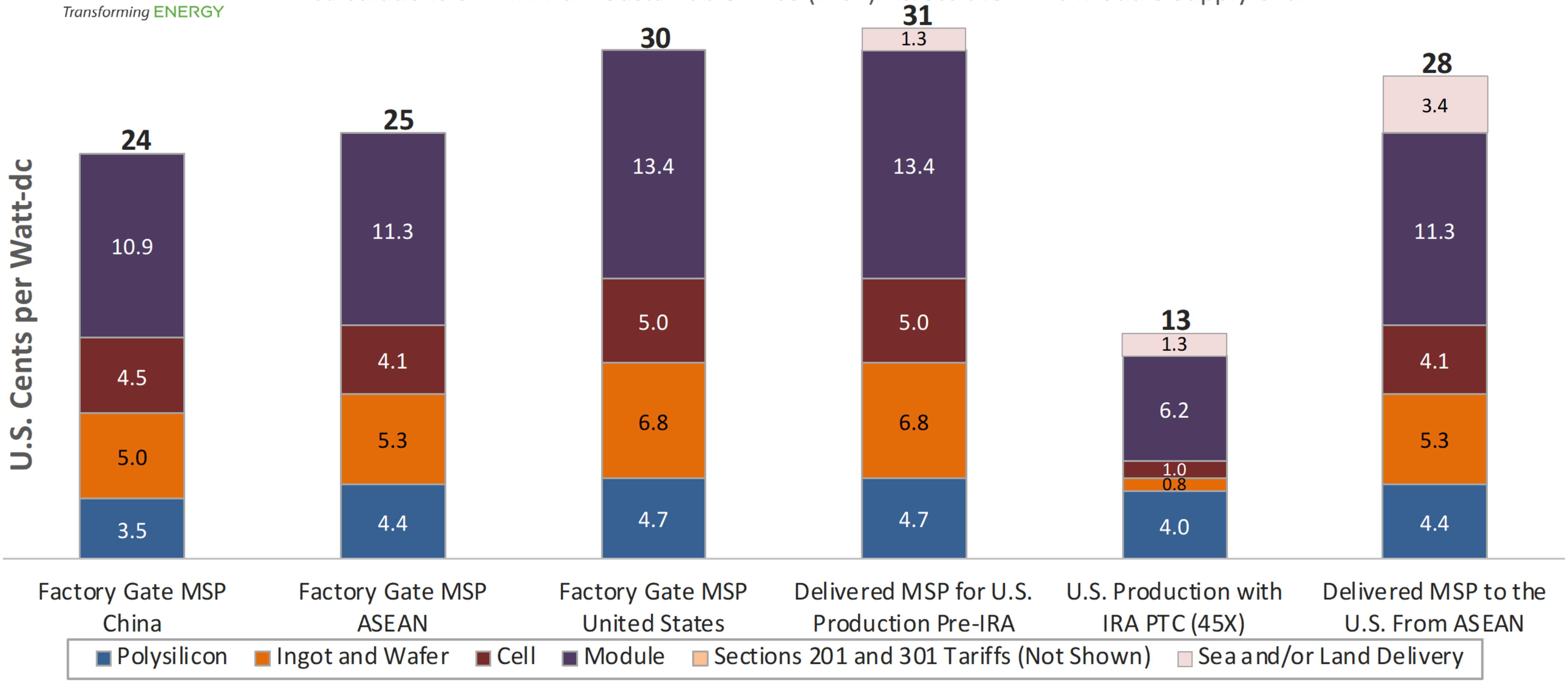


2022—2029 **7¢/W** (+$0.4/m^2 for backsheet)
2030—2032 5.3—1.8¢/W
2033 $0/W

PTC credits (45X) are shown in these tables.
ITC credits (48C) are another option for covering up to 30% of eligible investments.

Solar Photovoltaic (PV) Module Results for Asia and the United States

Calculations of Minimum Sustainable Price (MSP) Across the PERC Module Supply Chain



PTC credits (45X) are shown in these results.
ITC credits (48C) are another option for covering up to 30% of eligible investments.

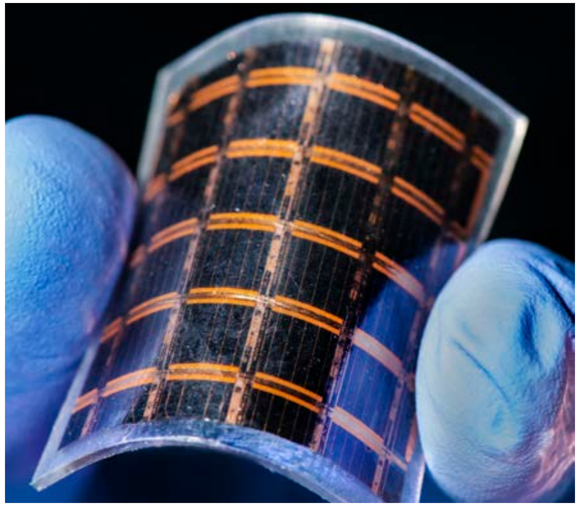
Next Steps for Standing Up New Manufacturing Capacity

Investors

Determine how much capital is available (determines factory size and economies of scale); and the desired margins, returns on investment, and payback time.

Workforce

Determine how the project will attract high quality (and preferably experienced) engineers, operators and supervisors for high efficiency and high yield production across the value chain.



Technology

Determine what technology will be licensed and from whom. Are the investors risk averse or open to higher risk with a newer technology?

Materials and equipment

Determine the availability of manufacturing equipment and materials, and whether they qualify for any incentives (e.g., domestic content bonus). Are there any trade barriers, restrictions or tariffs to consider (e.g., Sec. 301)?

Source of figures: NREL Image Gallery (https://images.nrel.gov/)

Next Steps for Standing Up New Manufacturing Capacity

Initiate Business Plan
- Financing secured
- Key personnel at the executive level have been identified
- Key partners for technology licensing have been established
- Critical workforce needs are on track

Design and Permit Manufacturing Facility
- Work with equipment suppliers to design an appropriate manufacturing facility, which must consider electrical, water and wastewater, and safety codes that vary by region
- Obtain all necessary facility design and construction permits

Execute Sales
- Secure customers that will pay the necessary price and at sufficient volume
- Establish the economic justification to scale production

Nameplate Capacity Achieved
- Debottlenecking completed
- Full staffing of facility in place
- Sales contracts secured

New Entrants Start Here

Experienced Firms

Select Materials and Equipment Suppliers
- Conduct technoeconomic assessments to consider cost-performance tradeoffs for each material and each piece of manufacturing equipment
- Collect engineering-dependent price quotes from equipment suppliers

Execute Supplier Agreements
- Materials and equipment suppliers begin to ramp production for the project at an agreed-upon rate.
- Production, shipment, installation and initial qualification of new manufacturing equipment occurs on a rolling basis.
- Building permits approved and facilitation completed

Achieve Product Qualification
- Modules: Work with independent engineers and submit the product for third-party facility inspection and outdoor reliability testing
- Qualify the product for downstream customers
- Meet ESG requirements (if applicable)

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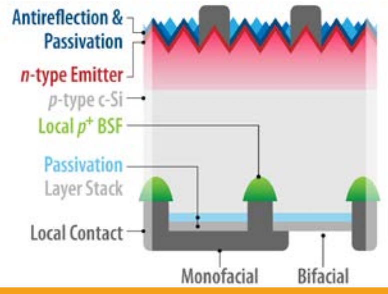
LCOE Evaluation of Technology Options: Reliability Considerations and Energy Yield

Solar Technologies Selected for Energy Yield and LCOE Analysis

p-type

PERC (Passivated Emitter and Rear Cell)



Drivers & Benefits

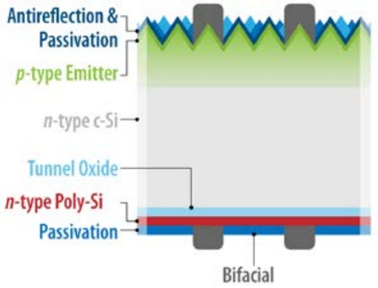
- Largest market share and longest history
- Monofacial and bifacial options
- Industry transitioned from Boron to Gallium doping to mitigate degradation

Potential Risks & Challenges

- Current production cells close to practical efficiency limits - further improvements difficult
- Bifaciality is slightly lower compared to TOPCon/SHJ

n-type

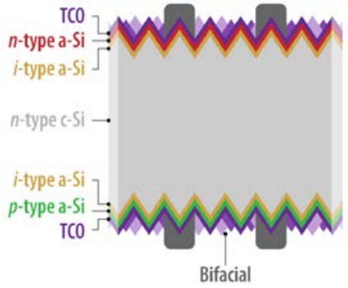
TOPCon (Tunnel Oxide Passivating Contact)



- Inherently bifacial
- Most easily adapted from existing PERC capacity
- Slight efficiency and bifaciality advantage over PERC

- Newer technology than SHJ - less production history, but fundamentally compatible with the conventional Si solar cell production process

SHJ (Silicon hetero-junction solar cell)

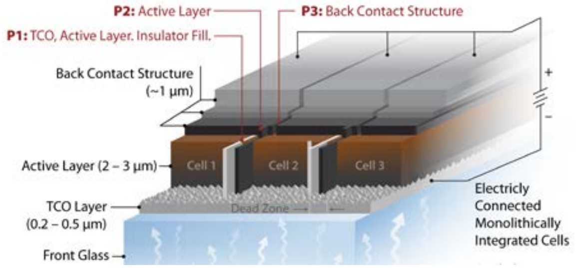


- Superior surface passivation quality improves carrier lifetime and increases cell voltage even further (750 mV)
- Typically, the highest bifaciality and slight efficiency advantage over PERC

- Process temperature limited to <200°C, and this impacts metallization and interconnect technologies and costs
- Substantially different manufacturing process
- Higher tool costs

Thin film

CdTe, CIGS, Perovskites, III-Vs



- CdTe is an established technology leader with a large U.S. manufacturing presence. CIGS has also been developed extensively.
- Next generation technologies including Perovskites may offer lower $\$/m^2$ costs

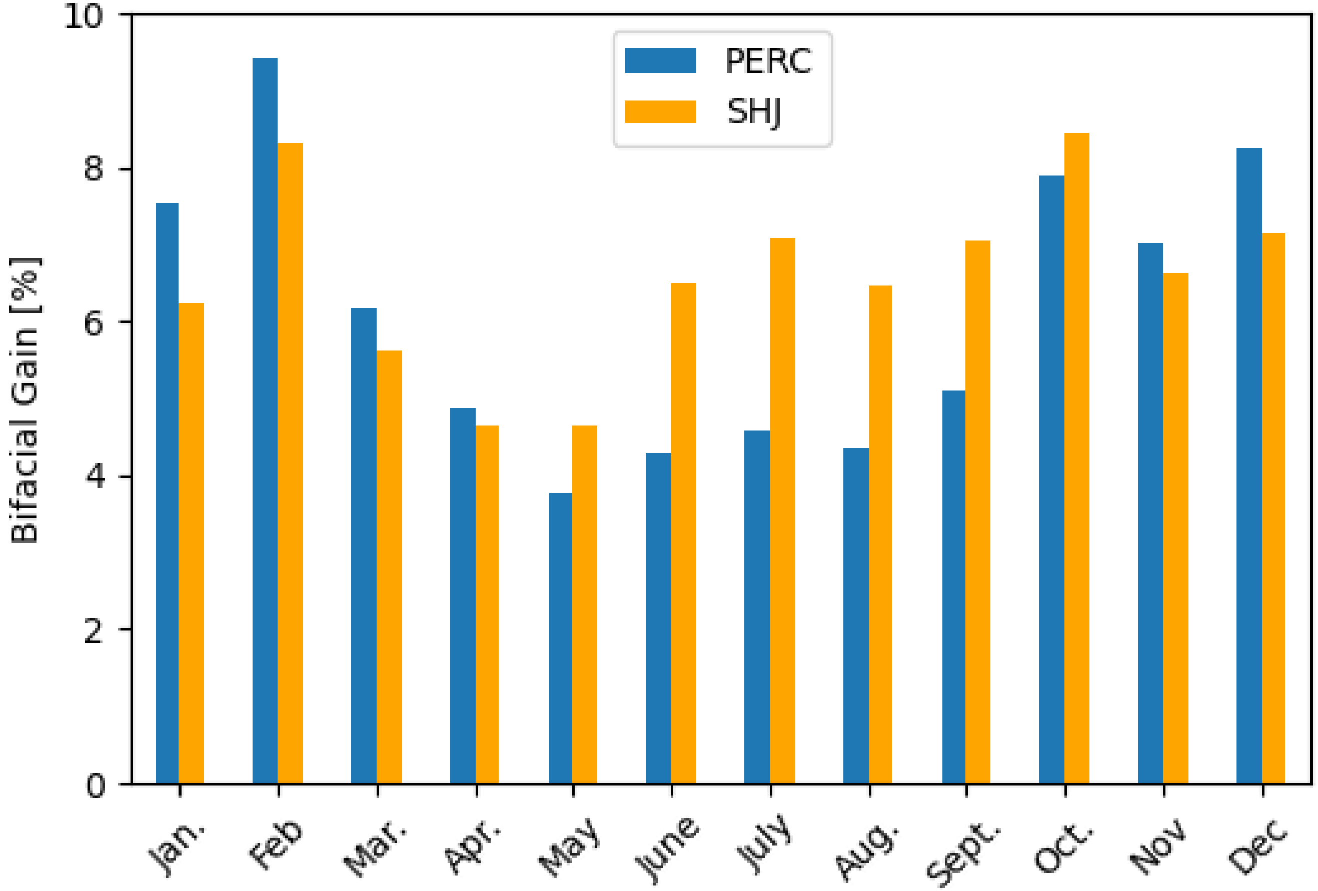
- CdTe is currently the only option produced at scale
- Perovskites are an early-stage technology with varying designs, varying bill of materials and variable reliability characteristics
- III-V cells may have superior performance but are currently prohibitively expensive for mainstream terrestrial PV applications

Energy Yield Measurements from the Field

Source of figures: NREL (Silvana Ovaitt and Chris Deline)

$$Bifacial\ Gain\ (\%) = \frac{Energy\ bifacial}{Energy\ monofacial} - 1$$

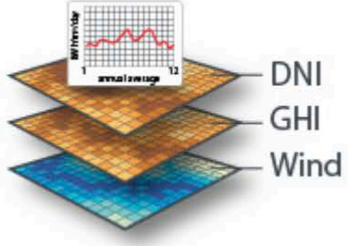
Full Year Results from the NREL Bifacial Test Bed:
PERC bifacial gain: 6.1%, SHJ bifacial gain: 7.6%

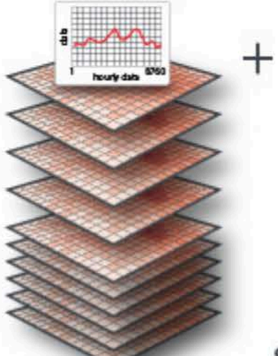


	PERC	CdTe	TOPCon	SHJ	IBC
Bifaciality	0.65—0.80	----	0.85—0.90	0.80—0.95	0.40—0.70
Temperature Coefficient	0.35—0.40 %/°C	0.25—0.35%/°C	0.30—0.35 %/°C	0.25—0.30 %/°C	0.25—0.30 %/°C

Overview of NREL's SAM and Renewable Energy Potential (reV) Capabilities

Resource Data Set → System Generation Modeling → Energy Yield and LCOE





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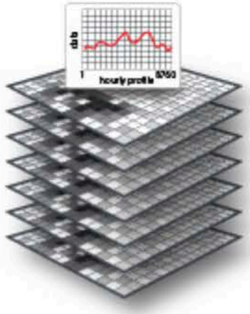
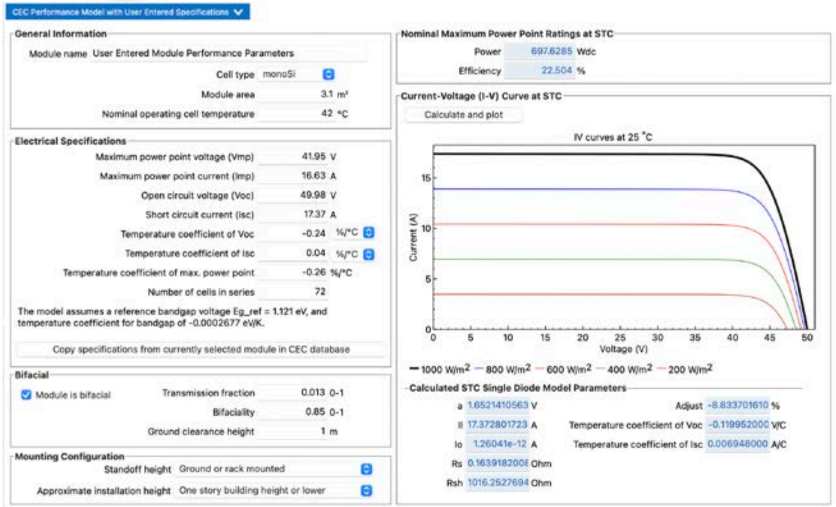


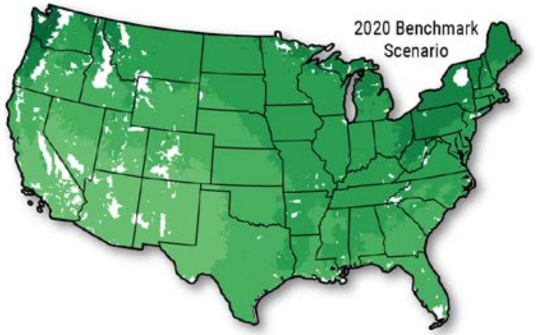
User-Defined
System Specifications

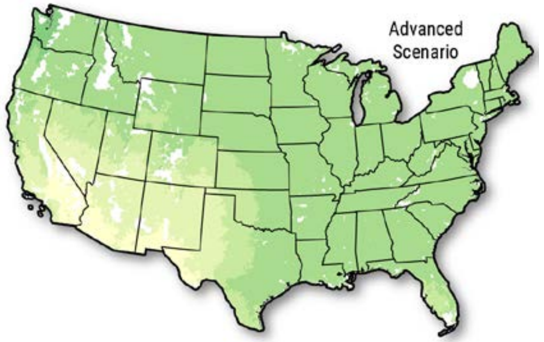


System Advisor Model (SAM)

reV

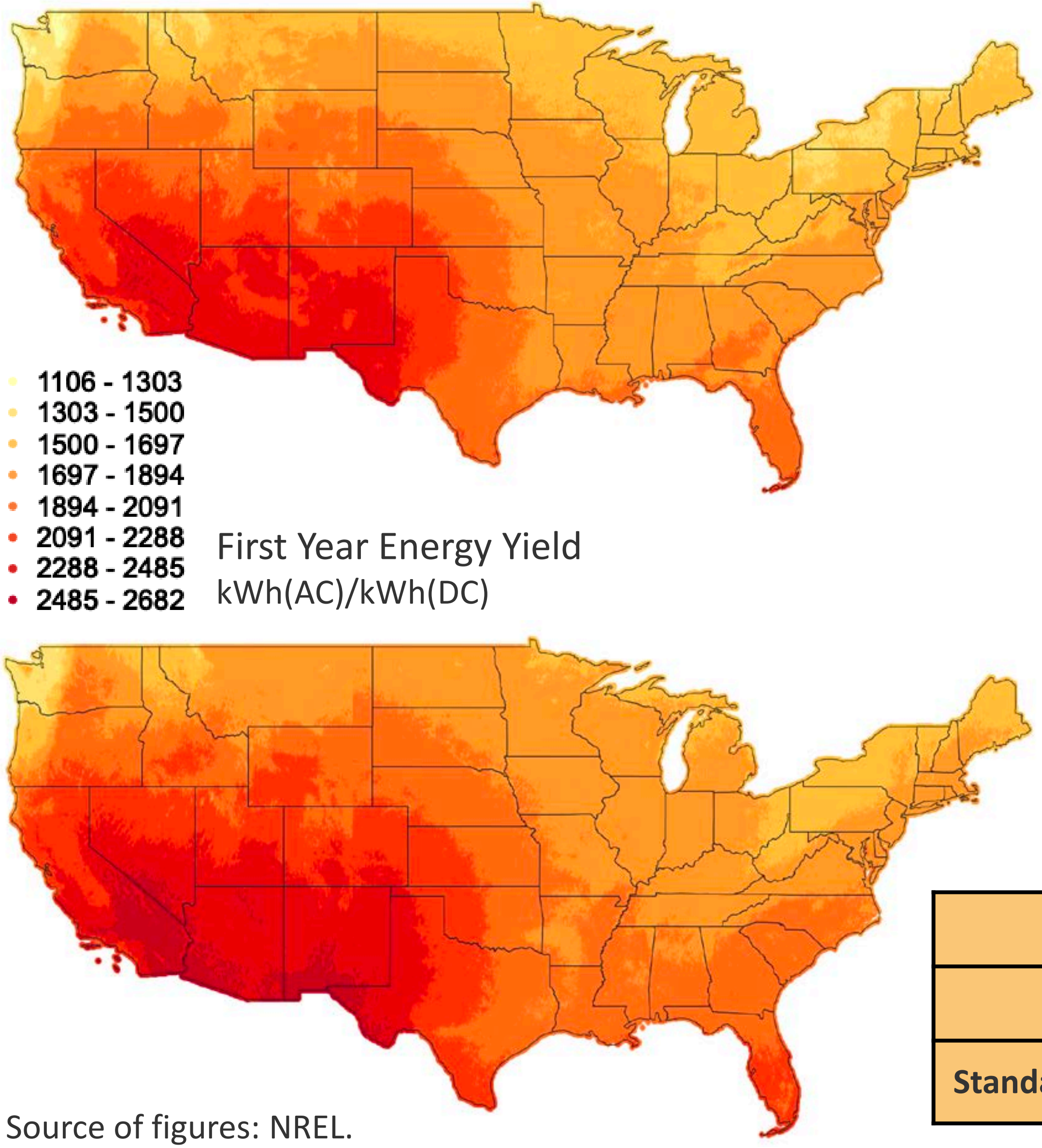
reV work led by Jane Lockshin (NREL)



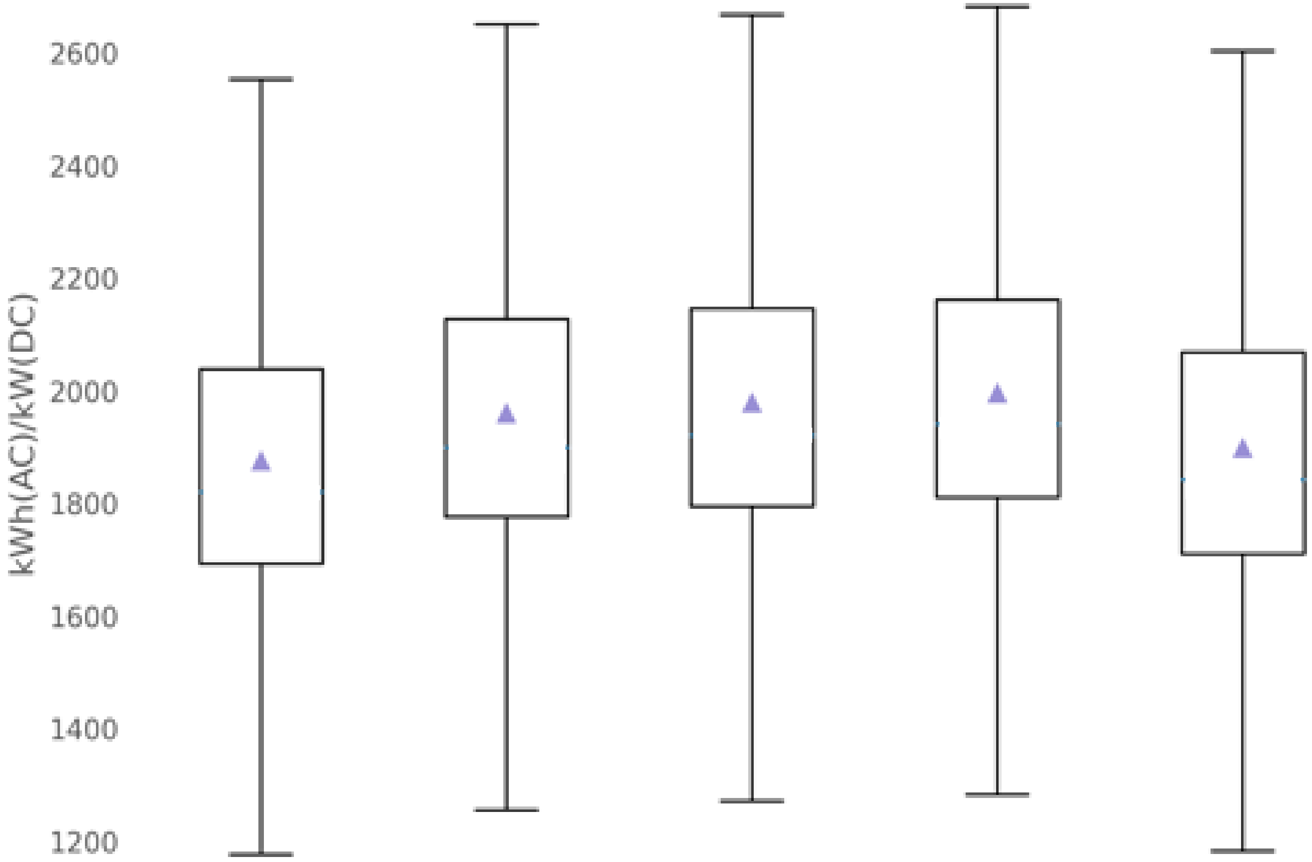


Source of LCOE Figures (Right): "R&D Priorities to Advance Solar Photovoltaic Lifecycle Costs and Performance", DOE Solar Futures Study
For access to the SAM and reV tools, please see https://sam.nrel.gov/ and https://www.nrel.gov/gis/renewable-energy-potential.html

Results from NREL's SAM and Renewable Energy Potential (reV) Models



First Year Energy Yield
kWh(AC)/kWh(DC)

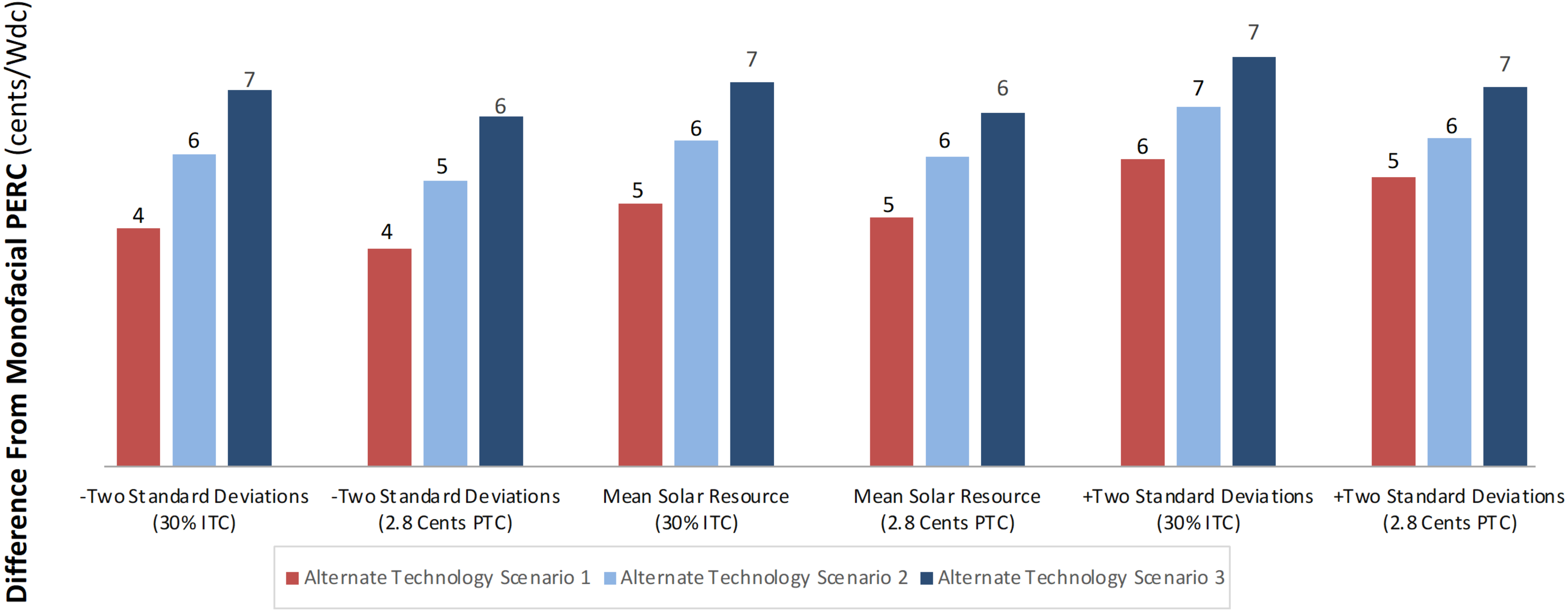


Energy Yield Statistics for the United States (kWhac/kWdc)					
Mean	1,874	1,959	1,978	1,995	1,898
Standard Deviation	248	250	250	249	257

Source of figures: NREL.

Capital Cost Premiums For Breakeven LCOE with Monofacial PERC

Capital Cost Premium Needs to Cover Module Price Plus Procurement Differences Between Technologies



Results from the NREL System Advisor Model (https://sam.nrel.gov/), reV Model, and Online LCOE Calculator (https://www.nrel.gov/pv/lcoe-calculator/)

Reliability Considerations For Breakeven Evaluations

9—12¢/W	6—9¢/W	3—6¢/W	0—3¢/W	0—Negative 3¢/W	Negative 3—6¢/W	Negative 6—9¢/W

ITC	Degradation Rate				
	0.25%/year	0.50%/year	0.75%/year	1.0%/year	1.5%/year
-Two Std Dev					
-One Std Dev					
Mean Solar Resource	9-12 ¢/W	6-9 ¢/W	3-6 ¢/W	0-3 ¢/W	Negative -6 to -9 ¢/W
+One Std Dev					
+Two Std Dev					-3 to -6 ¢/W

PTC	Degradation Rate				
	0.25%/year	0.50%/year	0.75%/year	1.0%/year	1.5%/year
-Two Std Dev					Negative -3 to -6 ¢/W
-One Std Dev					
Mean Solar Resource	6-9 ¢/W		3-6 ¢/W	0-3 ¢/W	0 to Negative -3 ¢/W
+One Std Dev					
+Two Std Dev					

Results from the NREL System Advisor Model (https://sam.nrel.gov/), reV Model, and Online LCOE Calculator (https://www.nrel.gov/pv/lcoe-calculator/)

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Conclusions

Intermediate Conclusions About the IRA

Systems. There are varying considerations where stakeholders will elect for the ITC or PTC. Higher cost systems in low resource areas (e.g., residential PV systems in Seattle) look to benefit more from the ITC. Lower cost systems in high resource areas would seem to benefit more from the PTC on an LCOE basis, but the next-level calculus needs to consider ITC adders, firm preference, curtailment, and local electricity rate structures. There are many markets and conditions for utility PV to prefer ITC.

Manufacturing. The prospects for U.S. PV manufacturing are greatly improved by the IRA. Experienced manufacturing firms could look more at the PTC; while newer technologies, smaller producers, and less experienced manufacturing firms might elect ITC.

Energy yield. Bifacial and thin film technologies are potential candidates to improve energy yield above monofacial PERC. The exact differences that are calculated between CdTe, PERC, SHJ and TOPCon depend upon the specific module datasheets and PAN files that are used.

Reliability and durability. The opportunity and impact of the IRA will be greatest if it is supported by the production and deployment of reliable and resilient components and systems. Reliability is every bit more consequential than the initial cost, initial efficiency and initial energy yield.

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Thank You

www.duramat.org

NREL/PR-7A40-85330

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Vignesh Ramasamy, Jarett Zuboy, Eric O'Shaughnessy, David Feldman, Jal Desai, Michael Woodhouse, Paul Basore, and Robert Margolis. 2022. *U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks with Minimum Sustainable Price Analysis: Q1 2022*. Washington, DC, and Golden, CO: DOE Solar Energy Technologies Office and the National Renewable Energy Laboratory. NREL/TP-7A40-83586. https://www.nrel.gov/docs/fy22osti/83586.pdf

Michael Woodhouse, David Feldman, Vignesh Ramasamy, Brittany Smith, Timothy Silverman, Teresa Barnes, Jarett Zuboy, and Robert Margolis. 2021. *Research and Development Priorities to Advance Solar Photovoltaic Lifecycle Costs and Performance*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-80505. https://www.nrel.gov/docs/fy22osti/80505.pdf.

DOE Resources for Information Pertaining to IRA:

https://www.energy.gov/eere/solar/federal-solar-tax-credits-businesses

https://www.energy.gov/eere/solar/federal-tax-credits-solar-manufacturers

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