

Bifacial Module Market Opportunities, Manufacturing Costs, and Pricing Rationalizations Based Upon Energy Yield

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Variable (cash) cost elements within the cost of goods sold:

- Input materials
- Direct manufacturing labor
- Electricity
- Maintenance of manufacturing equipment and facilities

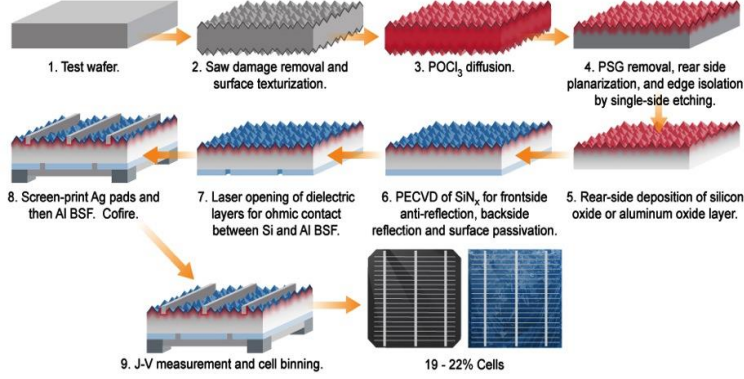
Fixed (non-cash) cost elements within the cost of goods sold:

- Manufacturing equipment
- Building and any facilitation expenses that can be capitalized

Additional fixed (cash or non-cash) cost elements:

- Research and Development (R &D)
- Sales, General, and Administrative (S, G, & A)

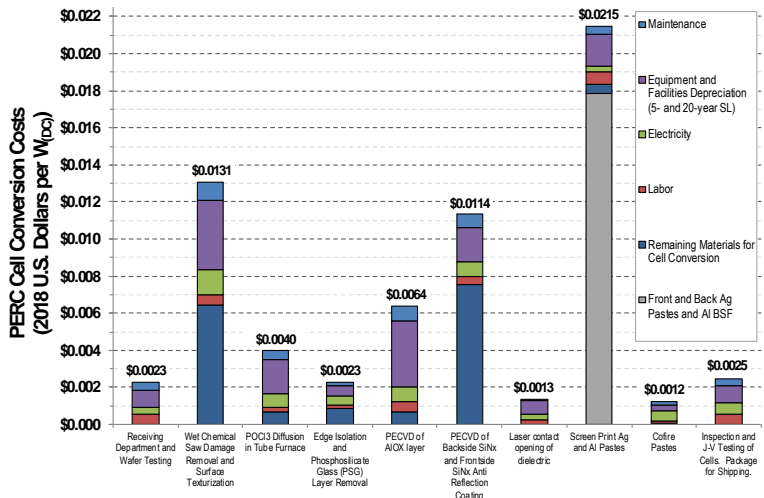
Example Cost Model Results for Cell Conversion (Left) and a Complete Module Supply Chain (Right)



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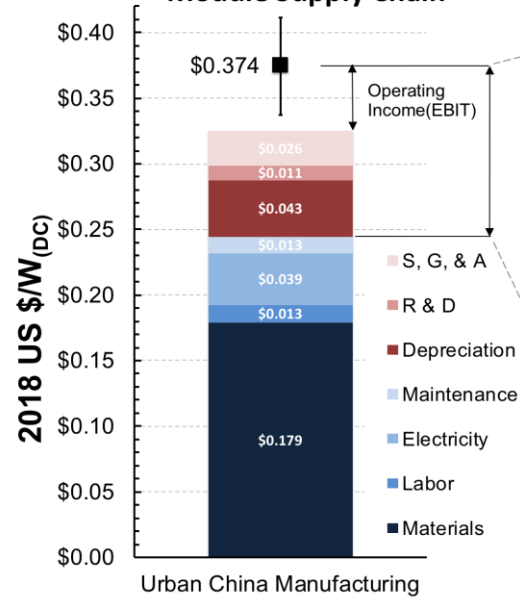
Step Costs for PERC Monocrystalline Silicon Solar Cell Conversion

Greenfield Manufacturing Facility in Urban China. 244 cm² Cells on M2 p-type CzWafers. 21.5% Cell Efficiency

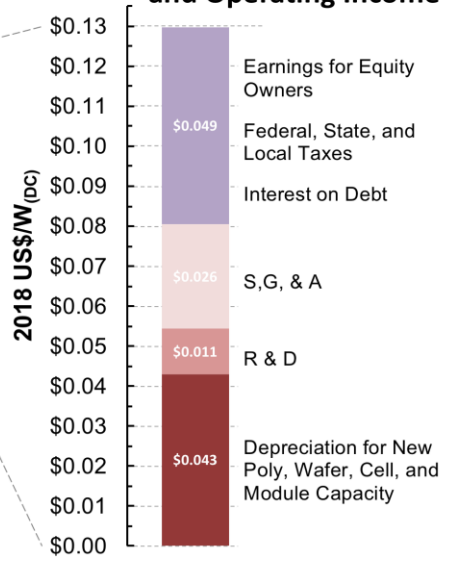


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Mono- PERC Module Supply Chain



Elements of Fixed Costs and Operating Income



Urban China Manufacturing

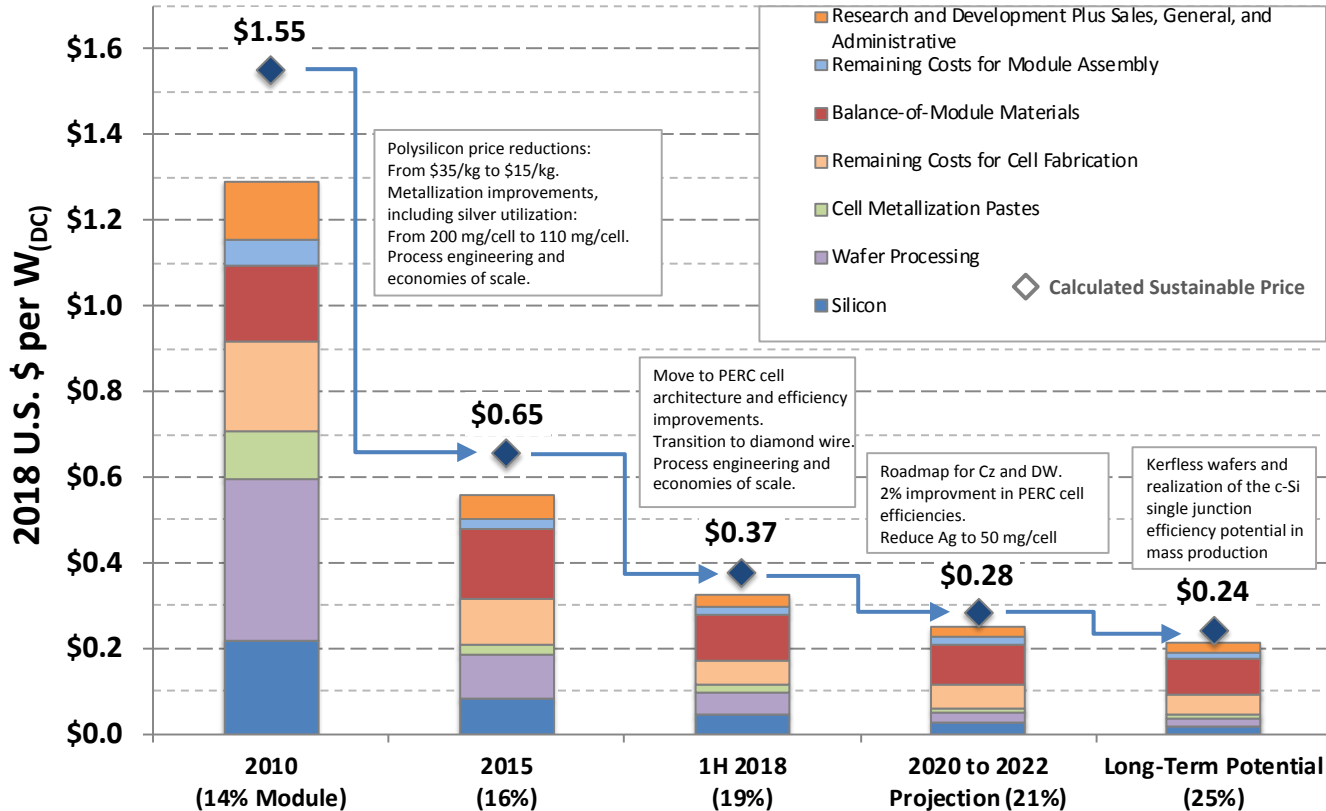
Additional details given in “Economic Factors of Production Affecting Current and Future Crystalline Silicon Photovoltaic Module Manufacturing Costs and Sustainable Pricing”, M Woodhouse, et al., *In Preparation for October 2018 Publication.*

Historical, Current, and Example Roadmap for PERC

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Historical, Current, and Projected Costs and Pricing for c-Si Modules

Input Data Assumes No Tax Exemptions or Tariffs.

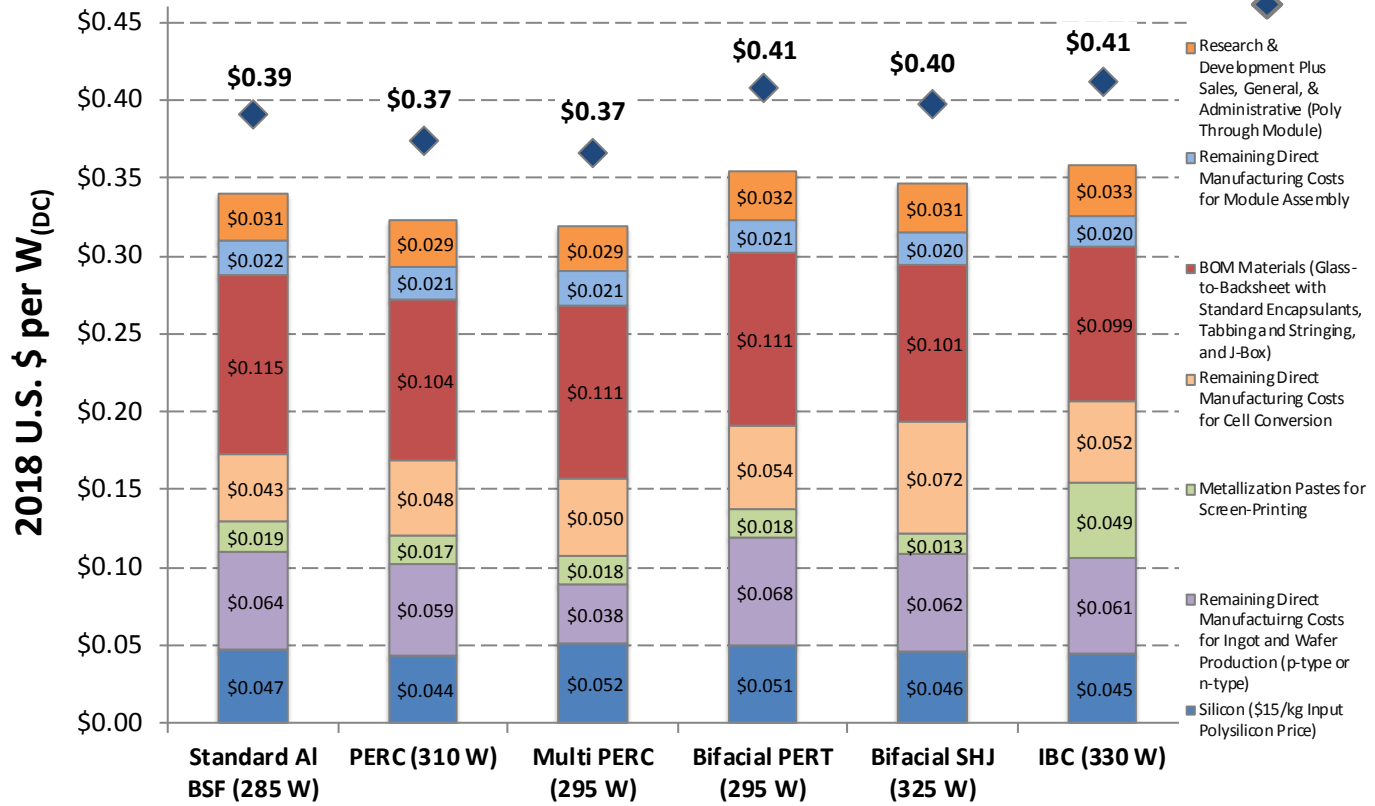


Example Cost Model Results for Different PV Technologies

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Manufacturing Cost Model Results for a Full PV Supply Chain

Results Reflect No Import Tariffs For 60 Cell Modules Shipped From Southeast Asia

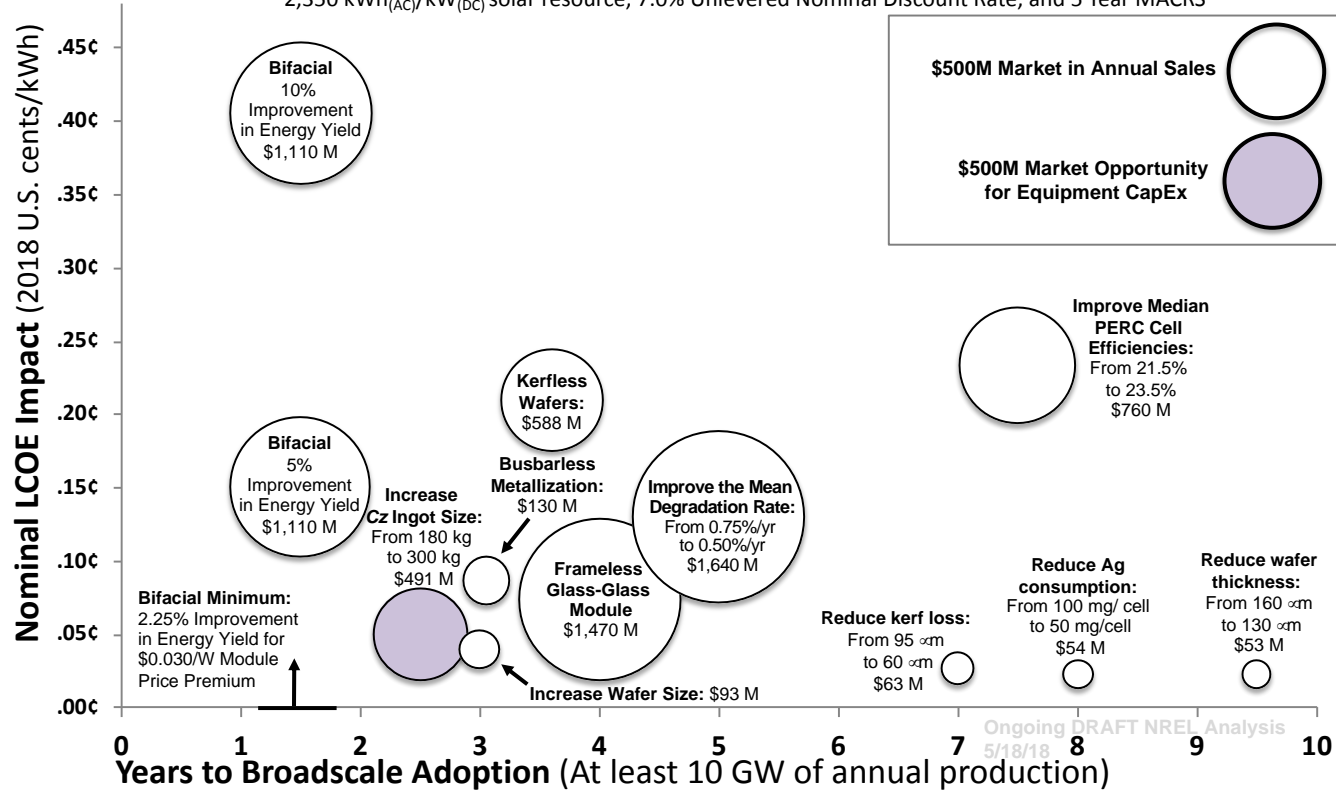


- Higher efficiency benefits \$/W balance of module (BOM) costs
- 10% wafer price premium given for the *n*-type cell architectures PERT, SHJ, and IBC
- Industry median 13% of revenues budgeted for R&D plus S, G, & A
- Minimum sustainable price based upon 15% operating (EBIT) margin
- Additional details given in “Economic Factors of Production Affecting Current and Future Crystalline Silicon Photovoltaic Module Manufacturing Costs and Sustainable Pricing” by M Woodhouse, et al., *In Preparation*.

Calculated LCOE Impacts From Upcoming Technologies

Estimated LCOE Impacts for Upcoming Technologies Within the Crystalline Silicon Supply Chain

2,350 kWh_(AC)/kW_(DC) solar resource, 7.0% Unlevered Nominal Discount Rate, and 5 Year MACRS

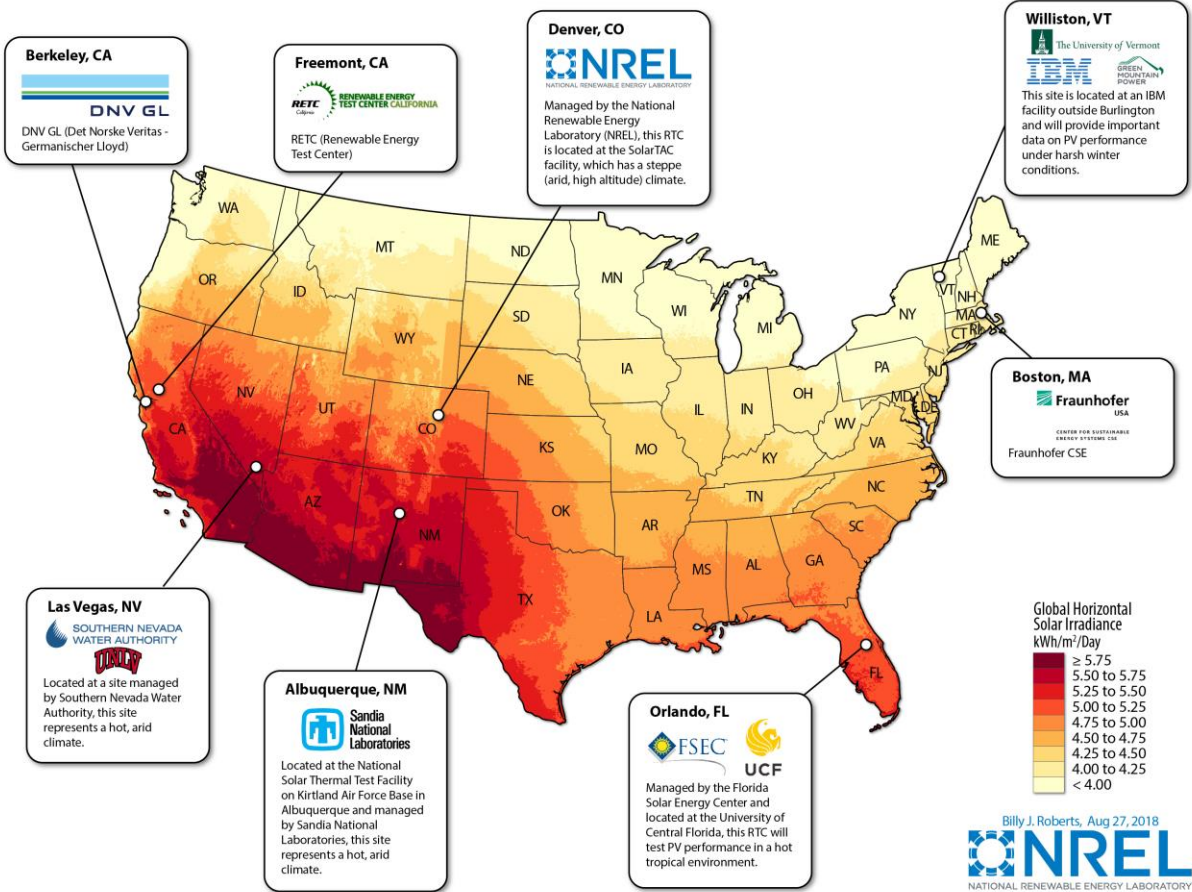


- Years to broadscale adoption for the given technologies are based upon industry survey results compiled for the 2018 International Technology Roadmap for Photovoltaics (ITRPV)

- LCOE impacts are based upon reductions in module cost or improvements in kWh_(AC)/kW_(DC) energy yield

- Additional details about this figure are given in "Economic Factors of Production Affecting Current and Future Crystalline Silicon Photovoltaic Module Manufacturing Costs and Sustainable Pricing" by Woodhouse, et al., *In Preparation*.
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Indoor and Outdoor Testing Sites Within the United States



DOE PV Lifetime and Proving Ground Sites:

- NREL
- Sandia
- Las Vegas, NV
- Orlando, FL
- Williston, VT

Private Independent Testing Labs:

- DNV GL
- RETC
- Fraunhofer CSE

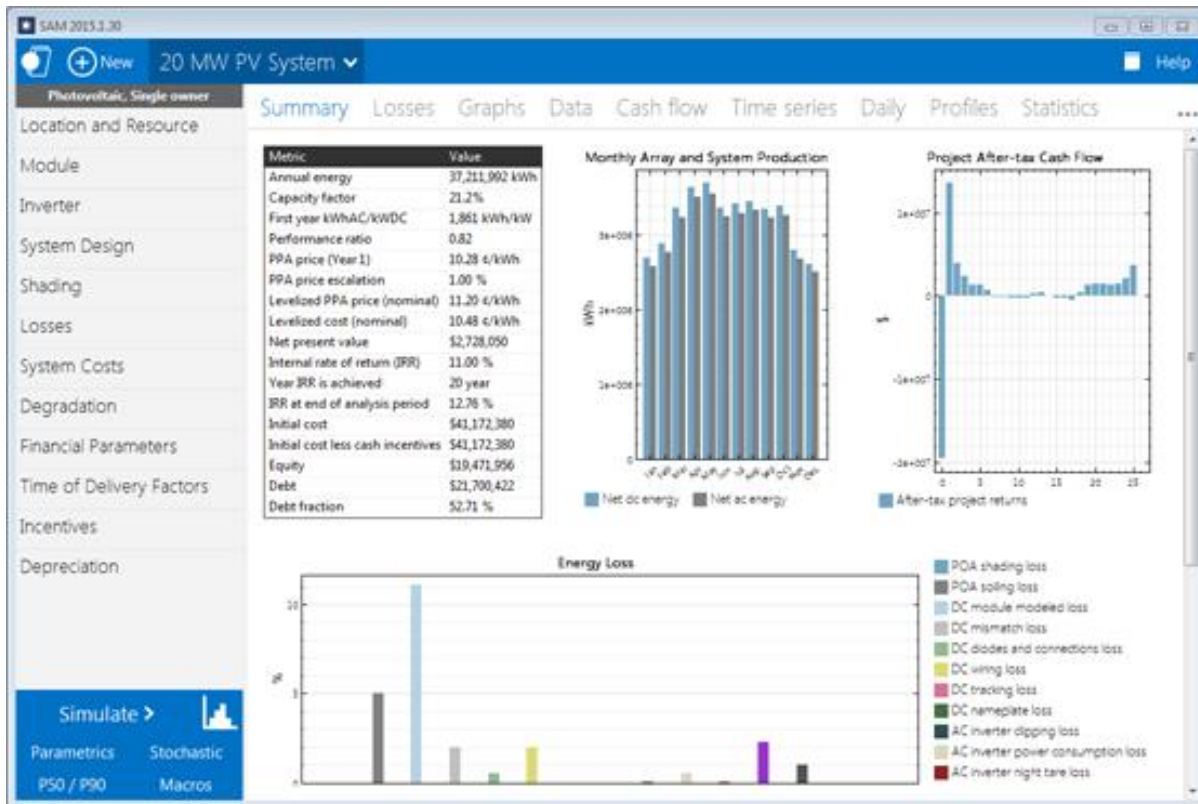
University Testing Labs:

- Arizona State

New Bifacial Performance Modeling Capabilities of SAM

SAM is **free** software available for modeling the performance and economics of renewable energy projects.

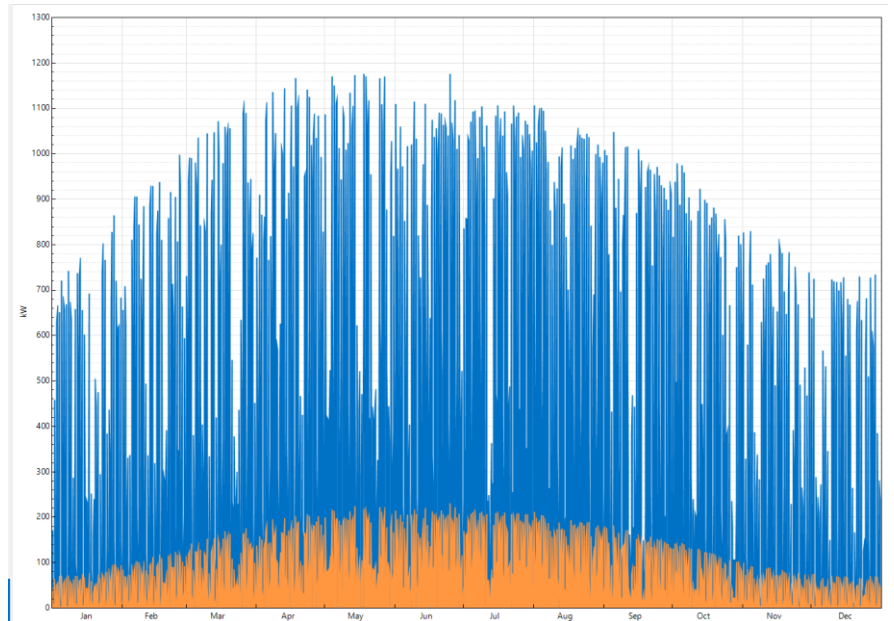
<http://sam.nrel.gov>
github.com/NREL/SAM



- Developed by NREL with funding from DOE
- Windows, OSX, and Linux
- One or two new versions per year
- Software Development Kit (SDK)
- Support
 - Help system
 - Documents on website
 - Online forum
 - Contact form on website

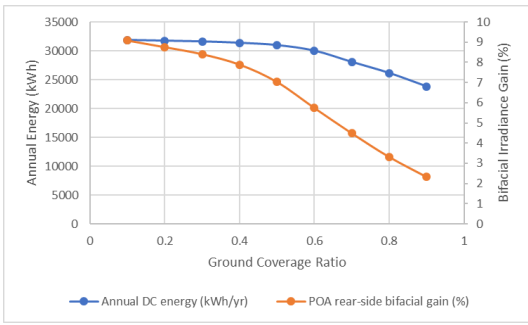
New Bifacial Performance Modeling Capabilities of SAM

Time series outputs for front and rear-side irradiance for each subarray and total array

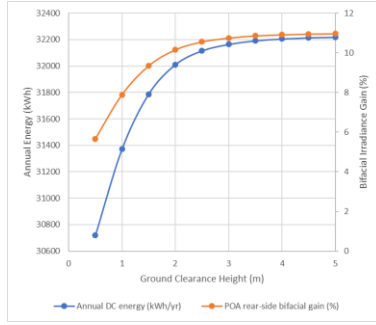


— Hourly Data: Array POA front-side total radiation after cover (kW)
— Hourly Data: Array POA rear-side total radiation after cover (kW)

Ground Coverage Ratio



Ground Clearance Height



Key Variables:

- Ground Clearance Height
- Ground Coverage Ratio (row spacing)
- Albedo
- Tilt

Analysis Disclaimer

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