

Solar and Storage Techno-Economic Analysis Tutorial for the IEEE Photovoltaic Specialist Conference (PVSC)

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## **Introduction of Presenters**









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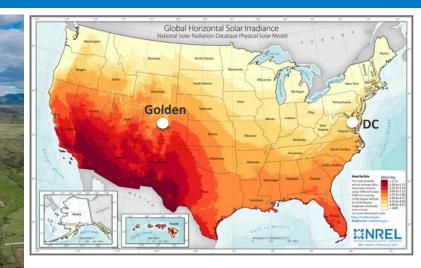
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Introduction and Component Manufacturing Cost Models Levelized Cost of Energy Supply Chain Analysis Levelized Cost of Energy Supply Chain Analysis System Capital Cost Modeling

# **Tutorial Overview**

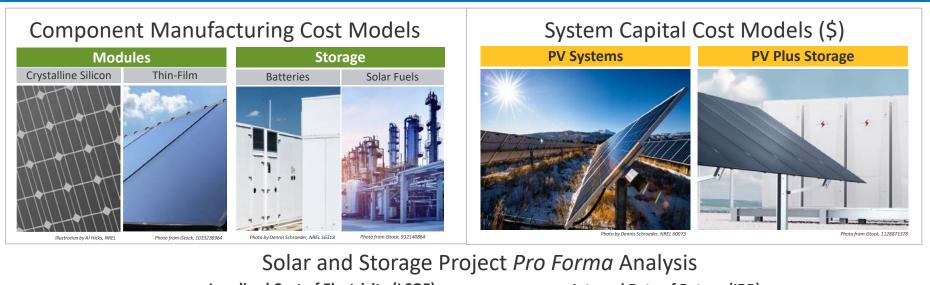
1	Introduction to NREL Solar and Storage Techn
2	Component Manufacturing Cost Modeling
3	System Capital Cost Modeling
4	Levelized Cost of Electricity (LCOE)
5	Supply Chain Analysis
6	Resources for Follow-Up

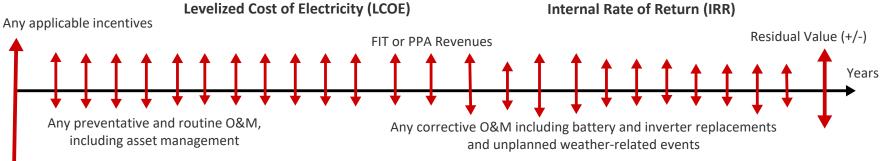
#### Introduction to NREL Main Campus in Golden, Colorado



Main campus for 16 primary research areas including laboratory-level work in solar, storage, and grid integration technologies.

# NREL's Solar + Storage Technoeconomic Analysis (TEA) Portfolio





#### Solar and Storage Technology Topics Covered in This Tutorial



#### Component Manufacturing Cost Modeling

- Review bottom-up cost model templates across the PV supply chain: Thin film and c-Si module assembly, cell conversion, ingot and wafer production, and polysilicon production
- Methodology for calculating direct production costs and overhead (R&D and S,G, &A)
- Provide a framework for assessing potential technology improvements

#### **System Capital Costs**

- Framework to collect system cost model inputs and calculate aggregated results
- Sectors covered: Distributed (Residential and Commercial) and Utility Scale (Fixed Tilt and Tracking)
- Consider changes to utility and distributed generation system design over time and adapt models to novel configurations (BIPV, FPV, PV + Ag, Solar +)



#### Levelized Cost of Energy (LCOE)

- Demonstrate online PV LCOE calculator supported by DuraMAT
- Use SAM Detailed PV models and reV to input technologyand application-specific input parameters that affect energy yield across varying climates
- Link component manufacturing costs models, system capital costs models, O&M models, and financing parameters to benchmark LCOE over time

## **Presentation Overview**

1	Introduction
2	<b>Component Manufacturing Cost Modeling</b>
3	System Capital Costs
4	Levelized Cost of Electricity (LCOE)
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# Solar Technologies and Manufacturing Cost Model Structure

#### CELL AND MODULE TECHNOLOGIES

#### **Crystalline Silicon**

- Polysilicon production
- Ingot and wafering: Czochralski (Cz), directional solidification (DS), kerfless technologies yielding Cz and DS equivalents
- Cell conversion: Monofacial and bifacial PERC, PERT, HJT, and IBC by screenprinting, electroplating, and busbarless
- Module assembly: Standard tabbing and stringing, busbarless, and shingling

#### Thin Film

- CdTe
- CIGS
- III-Vs
- Perovskites

#### **Multi-junction**

- (Two and four terminal)
- All III-Vs and III-Vs on Si
- All Perovskites
- Perovskites on Si

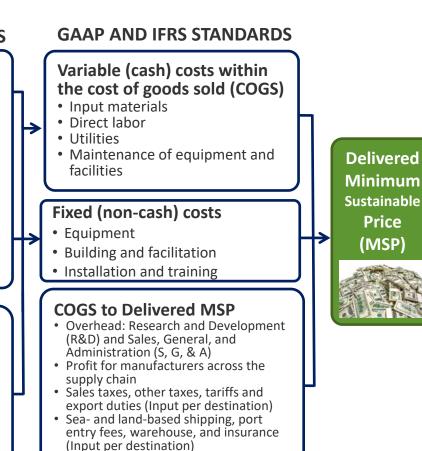
#### STEP-BY-STEP COST OF OWNERSHIP (COO) INPUTS

#### **COO** Format

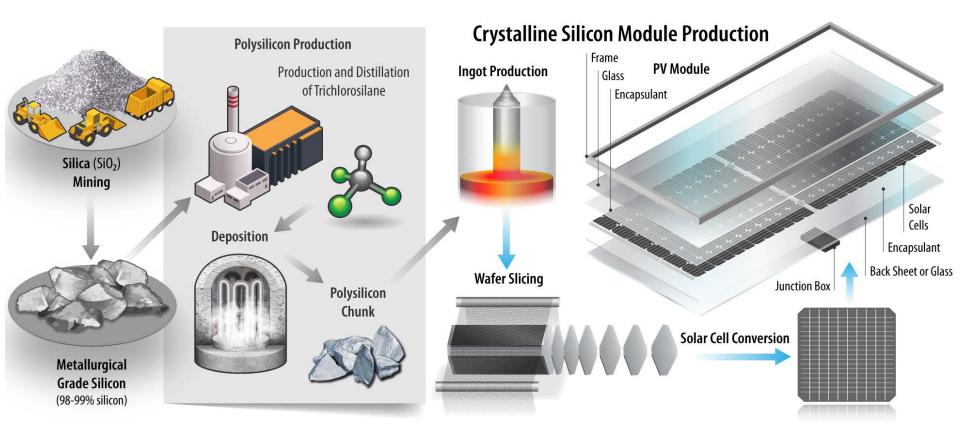
- Tool production and throughput (Uptime and scheduled and unscheduled downtime)
- Depreciation of Equipment
- Depreciation of Facilities
- Materials and consumables
- Utilities (Electricity, water)
- Waste disposal (Wastewater and exhaust air)
- Labor: Direct operators and
- supervisors
- Maintenance
- Account of yield loss

#### **Location Specific Indices**

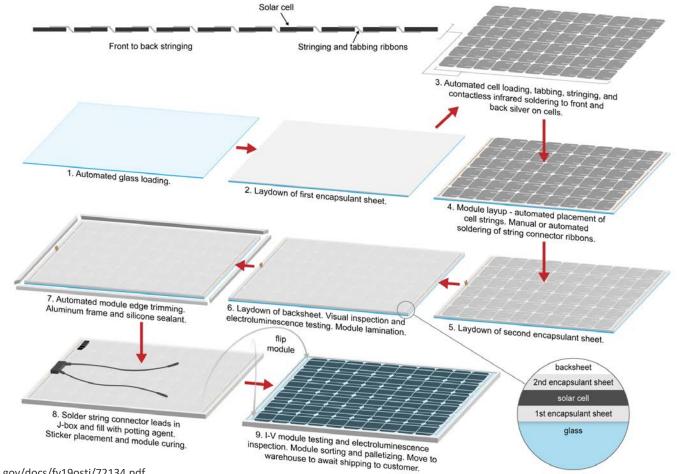
- Local wage rates for direct operators and supervisors
- Local utility rates
- Leasing versus purchasing the building business models
- Local considerations for CapEx and materials expenses relative to the baseline



#### Overview of the Solar PV Module Supply Chain



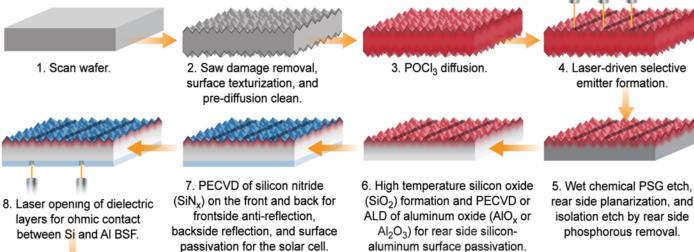
#### Module Assembly Process Flow

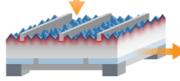


Source of figure: NREL.

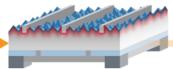
Please see: https://www.nrel.gov/docs/fy19osti/72134.pdf

#### **PERC Cell Process Flow**



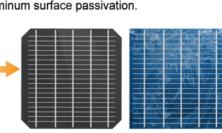


 Screen-print Ag and Al pastes for tabbing and BSF formation, respectively. Screen-print Ag pastes for fingers and optional busbars on front. Cofire.



10. Optional hydrogenation step under illumination (or bias) that improves efficiency and passivates and stabilizes defects responsible for LID.

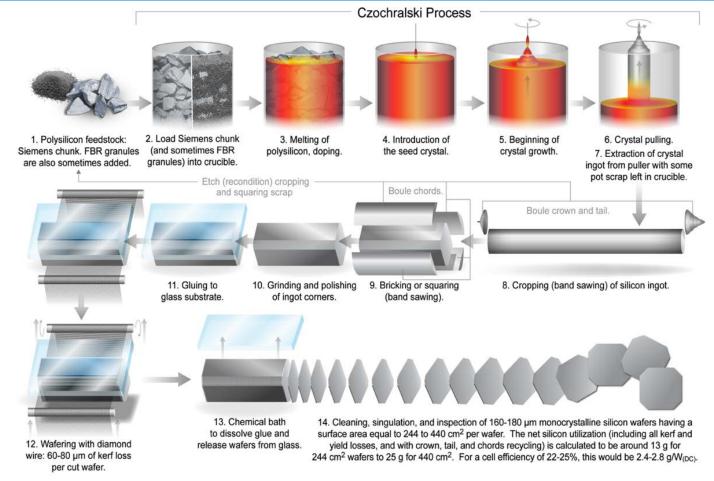
11. J-V measurement, visual inspection, and cell binning.



20 - 24% Cells

Source of figure: NREL. Please see: https://www.nrel.gov/docs/fy19osti/72134.pdf

#### **Process Flow for Ingot and Wafer Production**



Please see: https://www.nrel.gov/docs/fy19osti/72134.pdf

Source of figure: NREL.

#### Equipment and Facilities Costs Drivers for PV Manufacturing

<b>Fixed Costs</b>	X	Investment (\$)	Net Throughput <sup>-1</sup>
Summary	Initial ca	V or \$/unit produced apital expenditure per Watt or per cell, wafer, or kg of annual capacity	per finished unit: Metric tonnes per annum (polysilicon) or wafers, cells and modules per year
Details	Price	e for Manufacturing Tool	Rated Throughput kg, wafers, cells, and modules per hour
		Installation and Training Costs (Manufacturing Equipment)	Uptime Net planned and unplanned downtime
		Footprint and	Account of Yield Loss
		Facilitation Costs (Facility)	Scale is an interdependency. Efficiency impacts \$/W. 3

#### **Capital Investments**

- Range of data collected by NREL from interviews of multiple equipment vendors and manufacturers at each stage.
- Balance-of-plant or factory includes building, facilitation and office space
- CapEx estimates do not include investments for new capacity for supporting materials including glass, encapsulants and back sheets, specialty chemical suppliers, etc..

Fixed Cost		c-Si Sup	ply Chain	
Drivers	Polysilicon	Ingot and Wafer	Cell Conversion	Module Assembly
Initial Capital Expenditure (\$USD per Watt of annual capacity) for equipment: for balance-of-plant or factory	\$0.11-0.14/W (\$40—50/kg, 2.8 g/W) \$0.06—0.08/W \$0.04—0.06/W	\$0.08-0.10/W (\$0.54/wafer, 6.0 W for M6) \$0.06-0.07/W \$0.02-0.03/W	\$0.05-0.13/W (PERC to Advanced technology) \$0.03-0.10/W \$0.02-0.03/W	\$0.05-0.08/W (Standard to Busbarless) \$0.03—0.05/W \$0.02—0.03/W
1 GW <sub>dc</sub> Investment for equipment: for balance-of-plant or factory	\$110—140M \$65—80 M \$45—60 M	\$80—100M \$60—70 M \$20—30 M	\$50—130M \$30—100M \$20—30M	<b>\$50—80M</b> \$30—50M \$20—30M
<b>Time to Build</b> (Engineering to production)	<b>3—4 years</b> (All-new, not retrofit)	1—3 years	1—3 years	1—3 years

Data source for figure: NREL.

Available online: https://www.energy.gov/policy/securing-americas-clean-energy-supply-chain

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#### Labor Costs Drivers for PV Manufacturing

Labor Costs	X	Labor Rate	Labor Intensity
Summary		Burdened \$/hour	Employees per Gigawatt (GW) or Per unit produced
Details		\$/hour direct wage (Direct Operators)	Staffing plan for each station
		\$/hour direct wage (Supervisors)	
		\$/hour direct wage (Engineers)	
	(Cafete	Benefits	Throughput, scale, and yield are interdependencies. Efficiency impacts \$/W.

(Cafeteria, Health Insurance, Retirement, etc.)

#### Labor Costs Drivers

Labor Cost		c-Si Supp	ly Chain		CdTe Module
Drivers	Polysilicon	Ingot and Wafer	Cell Conversion	Module Assembly	Production
Labor Intensity (Direct full-time employees (FTE) per MW <sub>dc</sub> of production)	(40—85 MT per (Labor intensity year per FTE for in U.S or Siemens to FBR Europe to		0.15—0.45 (Advanced technology to PERC)	0.50—0.70 (Advanced technology to PERC)	0.40—0.60
Direct Manufacturing Jobs at 1 GW <sub>dc</sub> Scale	35—70	400—800	150—450	500—700	400—600
Assumed Hourly Labor Rates for Cost Models (\$2020 USD)	Ho \$14.3—22.0 pe	6.2—7.5 per ho using, cafeteria er hour for direc	nour for direct ope ur for first-line sup a, and insurance e t operators in elec States	pervisors in Ch xpenses incluc ctronics assem	ina Jed. bly in the United
		•	r first-line supervisense assumed for		

Source of figure: NREL. Available online: https://www.energy.gov/policy/securing-americas-clean-energy-supply-chain

#### Utilities Costs Drivers for PV Manufacturing

Utilities Costs 🗙	Utility Rate	Utilities Intensity
Summary	\$/year	<b>per finished unit:</b> kWh/kg (polysilicon) kWh/wafer, kWh/cell and kWh/module
		m <sup>3</sup> per finished unit
Details	\$/kWh (Electricity Rate)	per station: kW operating power
	\$/m³ (Water Rate)	m <sup>3</sup> per unit or per hour

Throughput, scale and yield are interdependencies. Efficiency impacts \$/W.

### Going From Direct Cost of Goods Sold (COGS) to Delivered MSP

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# 1. Direct Cost of Goods Sold

- Materials
- Labor and Utilities
- Maintenance
- Equipment and Facilities

### 2. Overhead and Profit

- Research and Development (R&D)
- Sales, General and administration (S, G, &A)
- Gross and Operating Profit
- Other Revenues and Losses (Not Included)

# Factory Gate Minimum Sustainable Price (MSP)

# 3. Taxes and Trade Duties

- Sales, value-added or other taxes
- Customs or other import duties
- Anti-dumping and countervailing duties (AD/CVD)
- Input per source and destination

## 4. Shipping and Delivery

- Sea shipping: Modules per container and shipping container costs
- Land shipping: Miles from port to destination and cost per mile/kilometer
- Insurance, entry bond, shipping fees
- Warehouse
- Input per source and destination

## **Delivered Minimum Sustainable Price (MSP)**

### Monte Carlo Analysis of Multiple Input Variables for a Country

#### Normal Distributions of Multiple Input Variables (500 Samples)

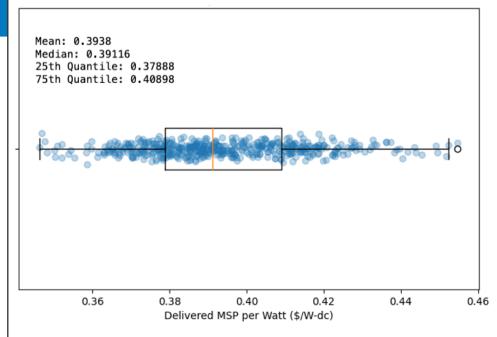
One standard deviation equals +/- 5% change in *cell efficiency (relative)* 

One standard deviation equals +/- 10% change in *CapEx* 

One standard deviation equals +/- 20% change in *labor intensity* 

One standard deviation equals +/- 5% change in *factory uptime* 

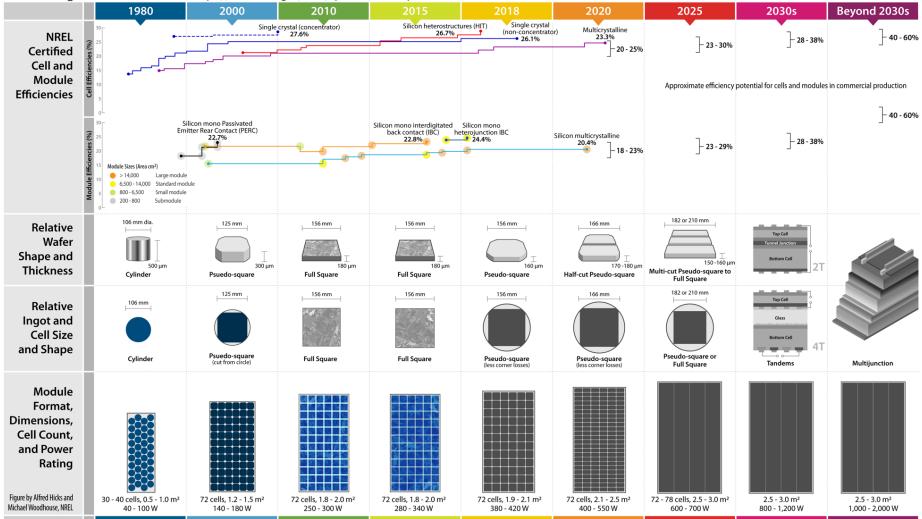
One standard deviation equals +/- 25% change in *factory production volume* 



All input distributions and resultant \$/W calculations are also saved as CSV files

Delivered MSP included around \$0.045/W shipping and delivery costs that were above the factory gate price

Source of figure: NREL. Please see: https://www.nrel.gov/docs/fy22osti/80505.pdf



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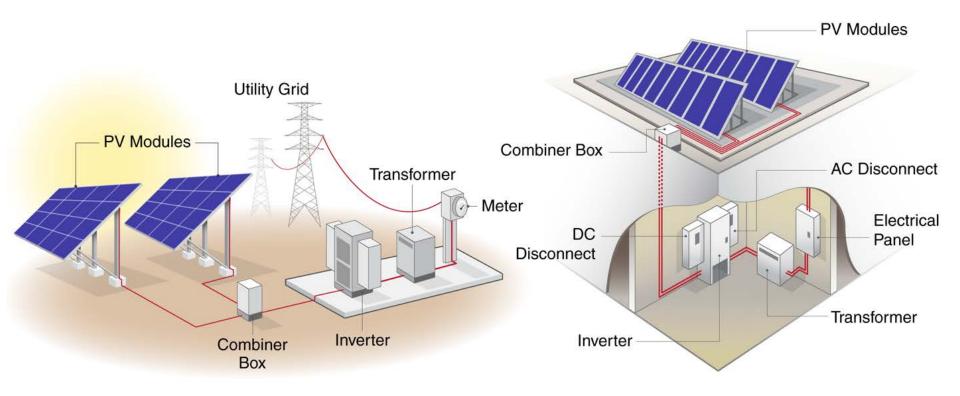
# System Cost Benchmark

**Goal:** Identify cost reduction opportunities, such as the impact of using PV modules with higher efficiency, helping policymakers make future research and development (R&D) decisions etc.,



- NREL has been modeling U.S. photovoltaic (PV) system costs since 2009.
- U.S. solar & storage benchmarks for residential, commercial, and utilityscale systems.
- Bottom-up methodology, accounting for typical system and projectdevelopment costs.
- Model typical installation techniques and business operations from an installed-cost perspective.
- Costs represent the price at which components are purchased by the developer/installer, not accounting for preexisting supply agreements or other contracts.
- Profit the installer/developer receives, as a separate cost category.

### System-Level PV Components



Source of figure: NREL. Available online: https://www.energy.gov/policy/securing-americas-clean-energy-supply-chain

# Key Cost Components

System Cost Components	What is it based of?	\$/unit required
Module/Battery Cabinets	System Size	\$/watt
PV/Battery Inverter	System Size	\$/watt
Structural BOS	Site Preparation, Racking, Mounting Panels, Trenching, Tracking Components, Containers, Inverter & Transformer Housing	Qty & Material-Cost/unit
Electrical BOS	Site Staging, Conduit & Wiring, DC Cabling, Combiner Boxes, Switchgear & Transformers, EMS, Monitoring & Control System.	Qty & Material-Cost/unit
Installation Labor & Equipment	Equipment & Labor Cost Associated with SBOS & EBOS	Qty & Equipment-Cost/unit, Labor Hours/ Activity & Labor Wages/Occupation
Permitting & Interconnection	BLM Cost, Building & Electrical, Interconnection	US Avg.
Sales Tax	By state	%
Overhead	EPC & Developer Overhead by system size	%
Profit Margin	By system size	%

# High Level Framework

<b># Mod</b> Based c Watt/Pa	puts I Location Project Year Project Size Module Efficienc Tracker? MVDC? Overhead/Profit ules/Inverter on Efficiency, unel, System Vdc e string & inverter	%	Load Estim struct	<ul> <li>Labor W</li> <li>Sales Ta</li> </ul>	oh si 'age by ax & Equi ctor alysis 'suppor d on wi	pment	Lab Calc Cons	Construct Index Steel Pri Cum. Ins state in N or Estin ulate Avg. struction la	ction Cost ce Index stallation by MWs	& y
ouloulut			onow		ogion.		uouv			
Category	Activity	Qty	Material \$/unit	Equipment \$/unit or \$/hr	Labor Hours/ Unit	No. of Labors	Labor \$/hr	Material \$	Equipment \$	Labor \$
Structural	Horizontal Support	n1	al	b1	c1	11	m1	=n1*a1	=n1*b1	=n1*c1*l1*m1
BOS	Module Mounting	n2	a2	b2	c2	12	m2	=n2*a2	=b2*c2	=n2*c2*l2*m2
	Trenching	n3	a3	b3	c3	13	m3	=n3*a3	=n3*b3*c3	=n3*c3*l3*m3
Electrical BOS	Conduits & Wiring									
Soft Cost	EPC Overhead %							Material \$ * OH %	Equipment \$ * OH %	

Key Cost Categories	Data Source	Sub-Cost-Components	Values	Units
Module	Woodmac	N	0.34	\$/w
Inverter	Woodmac	N	0.05	\$/w
Site Preparation	<b>RS Means Construction Cost Book</b>	Y		
Site Staging	<b>RS Means Construction Cost Book</b>	Υ		
Structural BOS	<b>RS Means Construction Cost Book</b>	Υ		
Electrical BOS	<b>RS Means Construction Cost Book</b>	Υ		
Install Labor & Equipment	BLS, RS Means Construction Cost Book	Υ		
EPC/Contractor Overhead	Interviews	N	8%	%
Sale Tax (if any)	RS Means Construction Cost Book	N	6%	%
Permitting Fee (if any)	Literature	N	\$ 250,000	\$
Interconnection Fee	Literature	Υ		
Transmission Line (if any)	Literature	Υ		
Contingency	Interviews	N	3%	%
Developer Overhead	Interviews	N	2%	%
EPC/Developer Net Profit	Interviews	N	5%	%

Project Inputs		
System Capacity	100	MWDC
ILR	1.3	#
Inverter Capacity	77	MWAC
PV Module Inputs		
PV Panel Power Rating	390	w
PV Panel Width	77	inches
PV Panel Height	39	inches
PV Panel Weight	60.8	lb

Site Staging	Unit	Qty	Material Cost	Equipment Cost
Preconstruction Surveys	Acre	= 4.56 Acre*100 MW	= 23*Qty	
Access Roads and Parking	S.Y	= 1%*4.56 Acre*100 MW*4840	= 3.39*Qty	
Security Fencing	L.F		- 1	
Temporary Office	#			
Storage Box	#		•	
O & M Building	S.F	•		
Site Preparation				
Site Preparation (Geotechnical Investigation)	Day		·	
Site Preparation (Clearing and Grubbing)	Acre	•	•	= 1675*Qty
Site Preparation (Soil Stripping and stockpiling)	C.Y.			- ,
Site Preparation (Grading)	S.Y.			
Site Preparation (Compaction)	E.C.Y			
Strucural BOS			•	·
Foundation for /inverter/transformer/ PVSC	S.F.			· ·
Trenches	L.F.			
Foundation for Vertical Support	V.L.F.			
Horizontal Support Structures	L.F.	=no.of PV modules*width of pv panel in ft	= 43*Qty	= 29*Qty
Welding or Bolting	Hr			
Modules Mounting	Ea	=no.of PV modules	= 10.53*Qty	
T- Connection	Ea	inclusion of the modules		
Electrical BOS				
Conduit, Wiring	L.F.			
Grounding, DC Cable	C.L.F	·		
Junction/Combiner Boxes	Ea	· ·		· ·
Inverter House	Ea			
On-site Transmission	Ea			.
PV Combining Switchgear (PVCS)	Ea			.
On-site transformer & Substation	Ea			
230kV Transmission Line	_	·	•	.
Tower: Foundation Installation	Hr			.
Tower: Structure Costs	Each		•	.
Tower: Top Assembly	Hr			
Conductor and Cable	C.L.F			
Misc. Assembly Units	%			
Interconnection	-			
Interconnection fee	\$/w	I	•	.
Equipment Upgrade Cost	5/W MW	= 100 MW	= 161,270*Qty	

Site Staging	Unit	Labor Hrs Per Laborer Per Unit	No. of laborers per unit
Preconstruction Surveys	Acre	7.273	1 CL
Access Roads and Parking	S.Y	0.067	3CL
Security Fencing	L.F	0.12	
Temporary Office	#	32	
Storage Box	#	8.89	
O & M Building	S.F	0.06	•
Site Preparation			
Site Preparation (Geotechnical Investigation)	Day	24	1 EO
Site Preparation (Clearing and Grubbing)	Acre	48	1 EO, 2 CL
Site Preparation (Soil Stripping and stockpiling)	C.Y.	0.008	
Site Preparation (Grading)	S.Y.	0.008	
Site Preparation (Compaction)	E.C.Y	0.04	•
Strucural BOS			
Foundation for /inverter/transformer/ PVSC	S.F.	0.137	2 CL
Trenches	L.F.	0.02	2 CL
Foundation for Vertical Support	V.L.F.	0.084	4 CL
Horizontal Support Structures	L.F.	0.966	2 CL, 2 EO
Welding or Bolting	Hr	1	3 CL
Modules Mounting	Ea	0.25	2 CL
T- Connection	Ea	1	2 CL
Electrical BOS			
Conduit, Wiring	L.F.	0.1	2 EL
Grounding, DC Cable	C.L.F	0.8	2 EL
Junction/Combiner Boxes	Ea	8	3 EL
Inverter House	Ea	8	2 EL, 1 CL
On-site Transmission	Ea	8	3 EL, 1 EO, 1CL
PV Combining Switchgear (PVCS)	Ea	16	
On-site transformer & Substation	Ea	80	
230kV Transmission Line			
Tower: Foundation Installation	Hr		
Tower: Structure Costs	Each		
Tower: Top Assembly	Hr		
Conductor and Cable	C.L.F		
Misc. Assembly Units	%		
Interconnection			
Interconnection fee	\$/w		
Equipment Upgrade Cost	MW		

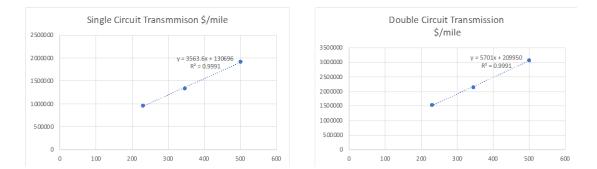
Occupation	\$/hour (nonunion US. Avg)
Electrician (EL)	\$28.87
Construction Laborer (CL)	\$17.38
Equipment Operator (EO)	\$23.25

Total Labor Cost of each activity = Qty\* Labor Hours per unit\* No. of Laborers per unit\* Hourly Labor Wage by specialty

	•	Double Circuit \$/mile (2017 USD)
230	\$959,700	\$153,6400
345	\$1,343,800	\$2,150,300
500	\$1,919,450	\$3,071,750

Transmission Terrain Multiplier						
Dessert	1.05					
Flat	1					
Farmland	1					
Forested	2.25					
Rolling Hill	1.4					
Mountain	1.75					
Wetland	1.2					
Suburban	1.27					
Urban	1.59					

Source: https://energy.utexas.edu/sites/default/files/UTAustin\_FCe\_TransmissionCosts\_2017.pdf



**Transmission Cost, \$** = Single or Double Circuit \$/mile \* transmission miles \* transmission terrain multiplier \* USD adjustment

Key Cost Categories	Data Source	Sub-Cost-Components	Values	Units		Total \$	
Module	Woodmac	N	0.34	1	\$/w	\$	34,000,000
Inverter	Woodmac	N	0.05	5	\$/w	\$	5,000,000
Site Preparation	RS Means Construction Cost Book	Y				\$	1,012,429
Site Staging	RS Means Construction Cost Book	Y				\$	4,822,601
Structural BOS	RS Means Construction Cost Book	Y				\$	14,207,809
Electrical BOS	RS Means Construction Cost Book	Y				\$	8,690,768
Install Labor & Equipment	BLS, RS Means Construction Cost Book	Y				\$	11,157,365
EPC/Contractor Overhead	Interviews	N	8%	5	%	\$	854,892
Sale Tax (if any)	RS Means Construction Cost Book	N	6%	5	%	\$	4,875,936
Permitting Fee (if any)	Literature	N	\$ 250,000		\$	\$	250,000
Interconnection Fee	Literature	Y				\$	3,166,512
Transmission Line (if any)	Literature	Y				\$	1,701,924
Contingency	Interviews	N	3%	5	%	\$	3,029,086
Developer Overhead	Interviews	N	2%	5	%	\$	2,456,780
EPC/Developer Net Profit	Interviews	N	5%	5	%	\$	5,053,980

\$ 100,280,082

#### Q1-2022 Preliminary Modeling Inputs/Assumptions

	Residential	Commercial	Utility	Source
Module Type	Mono-C-Si	Mono-C-Si	Mono-C-Si	CA NEM
Module Power (W)	360	360	405	CA NEM
Module Area (m2)	1.76	1.76	2.01	CA NEM
Module Efficiency %	20.19%	20.19%	20.19%	CA NEM
Module MSP \$/Wdc	0.33	0.33	0.33	PV Module Manufacturing Cost Model
Installer Market Share	Not Updated	NA	NA	Woodmac
Inverter Market Share	Not Updated	Not Updated	NA	Woodmac
Inverter \$/Wac	Not Updated	Not Updated	Not Updated	Woodmac, BNEF

#### Q1-2022 Preliminary Modeling Inputs/Assumptions

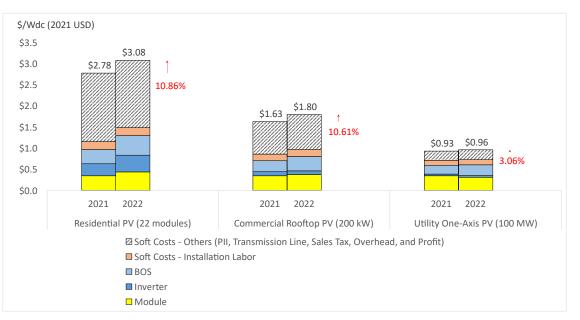
	Residential	Commercial	Utility	Source
SBOS – Material & Equipment \$/unit	Updated	Updated	Updated	Commercial & Utility - RS Means, Residential - Renvu, Ecodirect, RSMeans
Labor Wage - Hrs, \$/Hr	Partially Updated	Partially Updated	Partially Updated	RSMeans, BLS
Cost Indices – Location, Material & Equipment, Steel, CPI	Updated	Updated	Updated	Fred, RSMeans
Soft Costs – Sales Tax, PII, Overhead, Profit	Partially Updated	Partially Updated	Partially Updated	RSMeans, Interviews

# Q1-2022 Utility PV Model Inputs & Assumptions

Category	Modeled Value	Description	Sources
System size	100 MW; range: 5 MW–100 MW	A large utility-scale system capacity	Model assumption
Module efficiency	20.1% (405W, 2.01m2)	Average monocrystalline module efficiency (System Size > 5MW)	CA NEM Q1-2022 (Jan, Feb)
Module price	\$0.33/W <sub>DC</sub>	Module MSP (Duty/Tariff Free)	NREL's PV Module Manufacturing Cost Model
Inverter price	\$0.05/W <sub>AC</sub> (fixed-tilt)	Ex-factory gate (first buyer) price, Tier 1 inverters	Wood Mackenzie and SEIA 2021; Bolinger et al. 2020
	\$0.05/W <sub>AC</sub> (one-axis tracker)	DC-to-AC ratio = 1.31 for fixed-tilt and 1.28 for one-axis tracker	
Structural components (racking)	\$0.13-\$0.22/W <sub>DC</sub> for a 100-MW system	Fixed-tilt racking or one-axis tracking system	MEPS 2019; model assumptions; NREL 2021
Electrical components	$0.08-0.16/W_{DC}$ Varies by system size	$\rm 1,500\text{-}V_{DC}$ system that includes conductors, conduit and fittings, transition boxes, switchgear, panel boards, onsite transmission, and other electrical connections	Model assumptions; NREL 2021; RSMeans 2021
EPC overhead (percentage of equipment costs)	8.67%-13% for equipment and material (except for transmission line costs); 23%-69% for labor costs; varies by system size and labor activity	Costs associated with EPC SG&A, warehousing, shipping, and logistics	NREL 2021
Sales tax	National average: 5.1%	Sales tax on equipment costs	RSMeans 2021
Direct installation labor	Electrician: \$28.9/hour	Modeled labor rate assumes national average nonunionized labor	BLS 2022; NREL 2021
	Construction Laborer: \$18.2/hour		
	Equipment Operator: \$23.3/hour		
Burden rates (percentage of direct labor)	Total nationwide average: 31.7%	Workers' compensation, federal and state unemployment insurance, Federal Insurance Contributions Act, builders' risk, public liability	RSMeans 2021
PII	\$0.02-\$0.04/W <sub>DC</sub>	For construction permits fee, interconnection, testing, and commissioning	NREL 2021
	Varies by system size		
Transmission line (gen-tie line)	\$0.00-\$0.01/W <sub>DC</sub>	System size < 10 MW uses 0 miles for gen-tie line, thus no transmission cost	Model assumptions; NREL 2021
,	Varies by system size		
		System size > 200 MW uses five miles for gen-tie line	
		System size = 10–200 MW uses linear interpolation	
Developer overhead	2%-12%	Includes overhead expenses such as payroll, facilities, travel, legal fees, administrative, business development, finance, and other corporate	Model assumptions; NREL 2021
	Varies by system size (100 MW uses 2%; 5 MW uses 12%)	functions	
Contingency	3%	Estimated as markup on EPC cost	NREL 2021
Profit	5%-8%	Applies a percentage margin to all costs including hardware, installation labor, EPC overhead, and developer overhead	NREL 2021

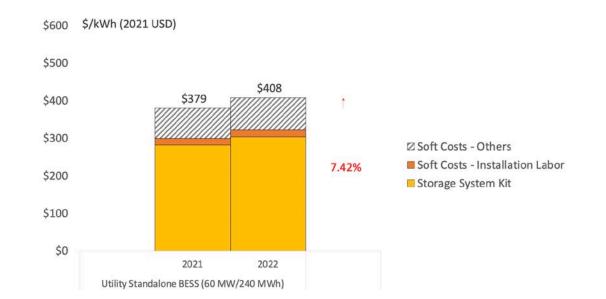
# 2021 vs 2022 PV System Cost Results

- BOS materials cost is the key cost driver
- Drivers of cost increment Balance of System Material/Equipment Rental cost, Hourly Labor Wage.
- Residential PV Cost Weighted average of all inverter types. Includes both small and large installers.



# 2021 vs 2022 Utility BESS System Cost Results

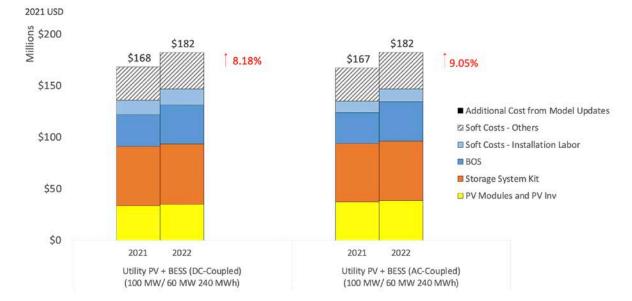
- Increased battery pack cost and electrical material/equipment cost are key cost drivers.
- Storage System Kit includes Li-Ion battery cabinets (battery packs, racking, HVAC, TMS), Inverter, BOS.



# 2021 vs 2022 Utility PV + BESS System Cost Results

### AC Coupled vs. DC Coupled Assumptions

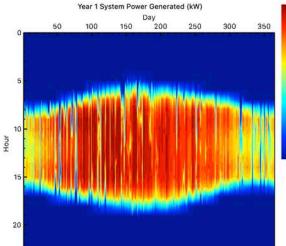
- AC-coupled systems have independent PV and battery systems with separate inverters, this hybrid configuration enables redundancy.
- Number of inverters DC Coupled 1 (bidirectional inverter for battery + DC-DC converters), AC Coupled - 2 (bidirectional inverter for battery plus grid-tied inverter for PV).
- Assumes higher skilled labor work for DC coupled systems.



DRAFT results in support of NREL's 2022 Solar and Storage System Costs Benchmark.

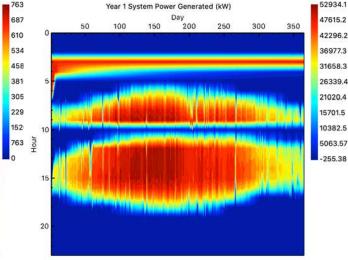
# LCOE of Utility PV & PV + BESS System

Assumptions	PV	PV + BESS
System Size	100 MWdc	100 MWdc + 60 MWdc/240 MWh
Installed Cost	\$0.96	\$1.83
Annual Degradation	0.7%	0.7%
Preinverter Derate	86%	86%
Inverter Efficiency	96%	96%
O&M \$/kW-Yr	\$16	\$28
ILR	1.3	1.3
Analysis Period	30 Years	30 Years
Debt Fraction	71.8%	71.8%
Debt Interest	5%	5%
Debt Term	18 Years	18 Years
Initial Energy Yield (kWh/kWDC)	1,694	1,397
Real LCOE \$/kWh	4.3	7.8



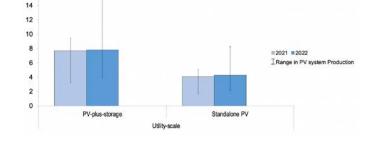
**PV Only Dispatch** 

16



PV + BESS Dispatch

(10% - min SOC, 90% max SOC)



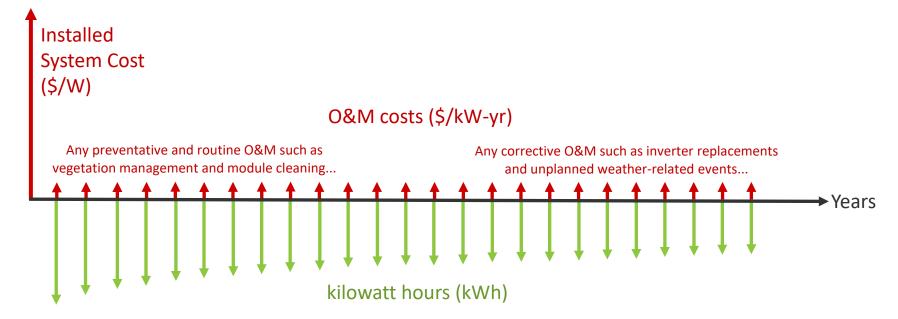
### DRAFT results in support of NREL's 2022 Solar and Storage System Costs Benchmark. NREL | 38

# **Presentation Overview**

1	Introduction
2	<b>Component Manufacturing Cost Modeling</b>
3	System Capital Costs
4	Levelized Cost of Electricity (LCOE)
4 5	Levelized Cost of Electricity (LCOE) Supply Chain Analysis

# Introduction

### LCOE (\$/kWh) = Total Costs over Service Life (\$) Total Energy Produced over Service Life (kWh)



### Drivers of PV System LCOE



Price

- Manufacturer's ability to fulfil the order at the lowest possible price
- Shipping, tariffs (if applicable), insurance, sales or value added taxes, etc., also factor in



- Lower module count to reach nameplate rated capacity equals lower balance of system (BOS) capital costs.
- Higher power rating—by higher efficiency and/or larger physical dimensions equals lower module count
- However, tradeoffs exist once a module reaches a certain size and weight: Tracker requirements, wind design, column spacing, containerizing and handling



### Reliability, Durability, Bankability

- Standardized testing and outdoor field history as a basis for estimating performance.
- Module warranty and warranty profile (Year 1 and subsequent years)
- Assumed useful lifetime of the module, module replacement rates, and associated operations and maintenance (O&M) expenses



### **Energy Yield**

- Temperature coefficient and spectral response
- Bifaciality
- Ability to mitigate DC losses including soiling; cell, module and string mismatch, etc.

# **Tools for Calculating LCOE**

### NREL's System Advisor Model (SAM)

<u>sam.nrel.gov</u>

- Many features, including:
  - More sophisticated financials
  - Many options for modifying specifics of module & system technologies, and designs
  - Ability to pair with storage
- Can be used in detailed site planning or analysis
- Used by NREL team to benchmark LCOE numbers
- Some researchers find SAM has a learning curve; can be difficult to accurately/quickly understand potential impacts of different R&D directions; may introduce confounding variables

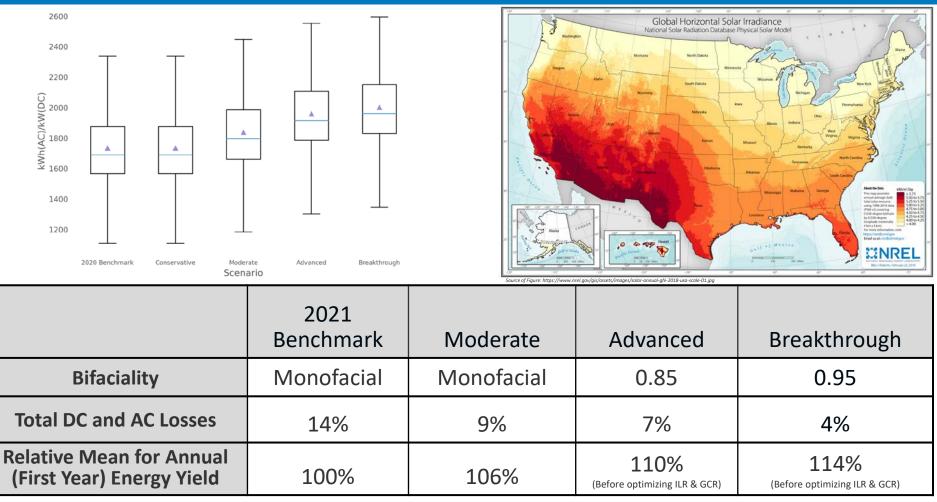
NREL's reV model (Renewable Energy Potential Model) pairs with SAM to create maps on the following slides...

### NREL's Online PV LCOE Calculator

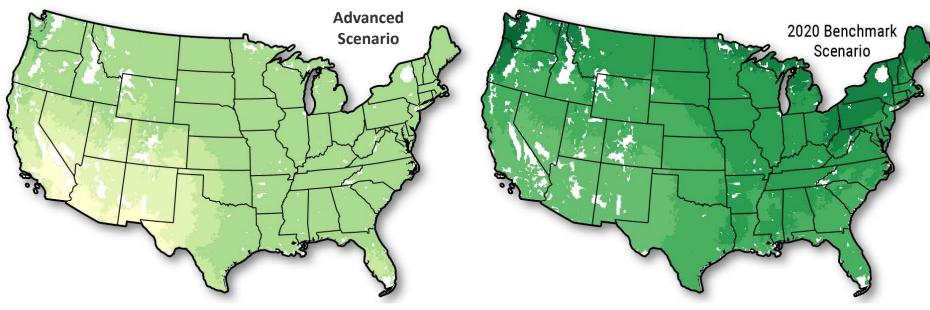
### pvlcoe.nrel.gov

- Simplified online tool targeted at PV researchers who want to quickly explore potential impacts of different high-level R&D directions
- PV-specific, has more detailed breakdown of cost components within a PV module
- Not as accurate or fully featured as SAM, so not a great option for detailed project planning

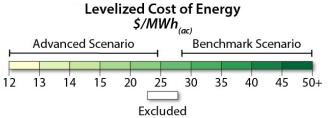
# Energy Yield Statistics from NREL's SAM and reV Tools



# Utility-Scale LCOE Progress Milestones for the United States



	2020 Benchmark	Advanced Scenario
Capital Cost	\$1.0/W	\$0.5/W
O&M (Including land and overhead)	\$17.5/kW-yr	\$8/kW-yr
Degradation Rate	0.7%	0.2%



Source of figure: NREL/DOE Solar Futures Study. Available online.



# Instant, Online, Simplified PV LCOE Calculator Tool

Brittany L. Smith National Renewable Energy Laboratory

Updated under DuraMAT award, August 2021











## **Simplified PV-LCOE Calculator**

- PV technology-specific
- Editable preset fields targeted towards research applications
- Instant comparison of proposed changes to a baseline system

### Calculator access:

- pvlcoe.nrel.gov
- <u>nrel.github.io/PVLCOE/</u>
- github.com/NREL/PVLCOE

Previous Calculator Tutorials:

<u>nrel.gov/docs/fy22osti/80842.pdf</u>

### **Calculator co-architects:**

Tim Silverman Mike Deceglie Sophie Andrews Kelsey Horowitz



### DuraMAT

### SINREL







### **Preset Menus**

#### Presets for Inputs

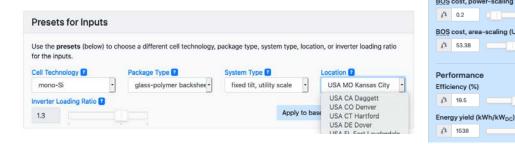
Use the presets (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology 🔽	Package Type 🔞	System Type 👔	Location 😰
√mono-Si multi-Si CdTe	glass-polymer backshee -	fixed tilt, utility scale	USA MO Kansas City
1.3		Apply to ba	aseline Apply to proposed

#### Presets for Inputs

Use the presets (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs.

Cell Technology 김	Package Type 了	System Type ? Locat	ion 😢
mono-Si	- glass-polymer backshe -	✓ fixed tilt, utility scale single-axis tracked, utility scale	MO Kansas City 🔹
Inverter Loading Ratio 김		roof-mounted, residential scale	
1.3		roof-mounted, commercial scale	Apply to proposed
1.0		fixed tilt, commercial scale	



#### Use the presets (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs. Cell Technology 2 Package Type 👔 System Type 🔁 Location 🖬 USA MO Kansas City \* mono-Si glass-polymer backst \* fixed tilt, utility scale Inverter Loading Ratio Apply to baseline Apply to proposed Proposed Baseline Cost Front laver cost (USD/m<sup>2</sup>) Front layer cost (USD/m<sup>2</sup>) i<sup>1</sup> 3.50 i<sup>1</sup> 3.50 Cell cost (USD/m<sup>2</sup>) Cell cost (USD/m<sup>2</sup>) i<sup>1</sup> 22.20 1 22.20 Back layer cost (USD/m<sup>2</sup>) Back layer cost (USD/m<sup>2</sup>) 1 2.40 £1 2.40 Non-cell module cost (USD/m<sup>2</sup>) Non-cell module cost (USD/m<sup>2</sup>) i<sup>1</sup> 13.60 £<sup>1</sup> 13.60 Extra component cost (USD/m<sup>2</sup>) Extra component cost (USD/m<sup>2</sup>) 1 0 1 0 O&M cost (USD/kWpc/year) O&M cost (USD/kWpc/year) i<sup>1</sup> 16.32 £<sup>1</sup> 16.32 BOS cost, power-scaling (USD/W) BOS cost, power-scaling (USD/W) i<sup>1</sup> 0.2 i<sup>1</sup> 0.2 BOS cost, area-scaling (USD/m<sup>2</sup>)



### uraMAT

### ©NREI





Presets for Inputs

1.3

Cost

i<sup>1</sup> 53.38

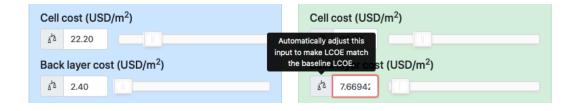
i<sup>1</sup> 19.5

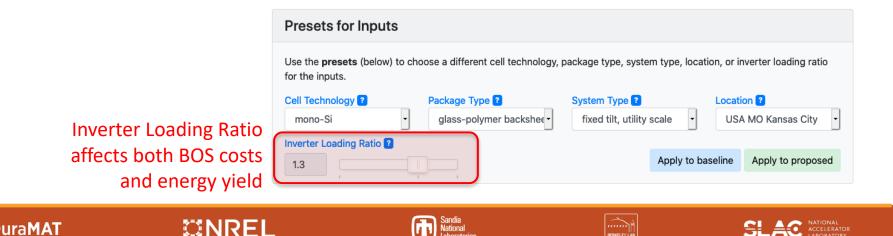
i<sup>1</sup> 1538



### **Updated Calculator Features**

- Breakeven buttons
- Inverter Loading Ratio





### **Results**

DuraMAT

- LCOE
- Module Price ۲
- System Cost ۲

Performance	Performance
Efficiency (%)	Efficiency (%)
<u>لأ</u> ك 19.5	<u>مْ</u> كُمْ 19.5
Energy yield (kWh/kW <sub>DC</sub> )	Energy yield (kWh/kW <sub>DC</sub> )
<u>م</u> <sup>1</sup> 1538	۵٬۵ 1538
Reliability	Reliability
System degradation rate (%/year)	System degradation rate (%/year)
<u>د</u> ه 0.70	<u>δ</u> <sup>t</sup> λ 0.70
Service life (years)	Service life (years)
<u>4</u> <sup>1</sup> 25	<u>مْ</u> كُمْ 25
Financial	Financial
Pinancial Discount rate	Discount rate
6.3	ල් 6.3
Results	
LCOE result	
Baseline LCOE (USD/kWh) 0.0517	Proposed LCOE (USD/kWh) 0.0517
Additional results	
Baseline	Proposed
Module price (USD/W) 0.25	Module price (USD/W) 0.25
Total installed system cost (USD/W) 0.72	Total installed system cost (USD/W) 0.72
Sandia	
Laboratories	

BERKELEY LAB

### **Example use: a hypothetical miracle backsheet**

Baseline	Proposed Copy from Baseline
Cost Front layer cost (USD/m <sup>2</sup> )	Cost Front layer cost (USD/m <sup>2</sup> )
i 3.50	A 3.50
Cell cost (USD/m <sup>2</sup> )	Cell cost (USD/m <sup>2</sup> )
§3 22.20	1 22.20
Back layer cost (USD/m <sup>2</sup> )	Back layer cost (USD/m <sup>2</sup> )
s <sup>ta</sup> 2.40	sta 2.40
Non-cell module cost (USD/m <sup>2</sup> )	Non-cell module cost (USD/m <sup>2</sup> )
<i>s</i> <sup>2</sup> 13.60	13.60
Extra component cost (USD/m <sup>2</sup> )	Extra component cost (USD/m <sup>2</sup> )
Å 0	\$ 0
O&M cost (USD/kW <sub>DC</sub> /year)	O&M cost (USD/kW <sub>DC</sub> /year)
s <sup>3</sup> 18.32	A 15.32
BOS cost, power-scaling (USD/W)	BOS cost, power-scaling (USD/W)
Å 0.2	A 0.2
BOS cost, area-scaling (USD/m <sup>2</sup> )	BOS cost, area-scaling (USD/m <sup>2</sup> )
s <sup>13</sup> 53.38	i <sup>1</sup> 53.38
Performance	Performance
Efficiency (%)	Efficiency (%)
<sup>4</sup> 19.5	ś <sup>1</sup> 19.5
Energy yield (kWh/kW <sub>DC</sub> )	Energy yield (kWh/kW <sub>DC</sub> )
<i>i</i> <sup>2</sup> 1538	1 1538
Reliability	Reliability
System degradation rate (%/year)	System degradation rate (%/year)
1 0.70	s <sup>2</sup> 0.50
Baseline LCOE (USD/kWh) (0.0517)	Proposed LCOE (USD/kWh) 0.0500

ura**MAT** 

Let's say you had a miracle backsheet that somehow created a lower system degradation rate & reduced maintenance costs.

How much could this backsheet cost and still be cost-competitive with the incumbent technology?









### **Breakeven Cost for Hypothetical Backsheet**

Baseline	Proposed Copy from Baseline	Baseline	Proposed Copy from Baseline
Cost Front layer cost (USD/m <sup>2</sup> )	Cost Front layer cost (USD/m <sup>2</sup> ) 2 <sup>th</sup> 3.50	Cost Front layer cost (USD/m <sup>2</sup> )	Cost Front layer cost (USD/m <sup>2</sup> ) 4 <sup>th</sup> 3.50
Cell cost (USD/m <sup>2</sup> )	Cell cost (USD/m <sup>2</sup> ) & 22.20		Cell cost (USD/m <sup>2</sup> ) utomatically adjust this ut to make LCOE match
Back layer cost (USD/m <sup>2</sup> )	Back layer cost (USD/m <sup>2</sup> )	Back layer cost (USD/m <sup>2</sup> )	the baseline LCOE. st (USD/m <sup>2</sup> )
Non-cell module cost (USD/m <sup>2</sup> )	Non-cell module cost (USD/m <sup>2</sup> )	Non-cell module cost (USD/m <sup>2</sup> )	Non-cell module cost (USD/m <sup>2</sup> )
Extra component cost (USD/m <sup>2</sup> )	Extra component cost (USD/m <sup>2</sup> )	Extra component cost (USD/m <sup>2</sup> )	Extra component cost (USD/m²) ຢ່າ 0
O&M cost (USD/kW <sub>DC</sub> /year)	O&M cost (USD/kW <sub>DC</sub> /year) s <sup>4</sup> h 15.32	O&M cost (USD/kWpc/year)	<u>O&amp;M</u> cost (USD/kW <sub>DC</sub> /year) ද් <sup>1</sup> 15.32
BOS cost, power-scaling (USD/W)	BOS cost, power-scaling (USD/W)	BOS cost, power-scaling (USD/W)	BOS cost, power-scaling (USD/W)
BOS cost, area-scaling (USD/m <sup>2</sup> )	BOS cost, area-scaling (USD/m <sup>2</sup> ) <sup>(1)</sup> 53.38	BOS cost, area-scaling (USD/m <sup>2</sup> )	BOS cost, area-scaling (USD/m <sup>2</sup> )
Performance Efficiency (%)	Performance Efficiency (%)	Performance Efficiency (%)	Performance Efficiency (%)
Energy yield (kWh/kW <sub>DC</sub> )	a* 19.5 Energy yield (kWh/kW <sub>DC</sub> ) a* 1538	Energy yield (kWh/kWpc)	Energy yield (kWh/kW <sub>DC</sub> )
Reliability System degradation rate (%/year)	Reliability System degradation rate (%/year) A 0.50 Proposed LCOE (USD/kWh) 0.0500	Reliability System degradation rate (%/year) A 0.70 Baseline LCOE (USD/kWh)	Reliability System degradation rate (%/year) <sup>(A)</sup> 0.50 Proposed LCOE (USD/kWh) 00517
	100000 LOOL (000/KMI)		

### **C**Dura**MAT**

### 







Previously, the calculator relied on a table of energy yield values that was built manually from SAM using the Detailed PV Model: <u>https://sam.nrel.gov/</u>

Now, PySAM package is used by calculator to call SAM directly. Relies on:

– PVWatts model: <u>https://pvwatts.nrel.gov/</u>

uraMAT

– NSRDB weather data: <u>https://nsrdb.nrel.gov/</u>

### **Exponential Relationship:**

$$e_n = e_{yield}(1-r)^{(n-1)}$$

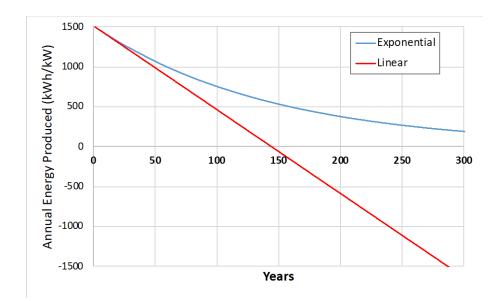
### Linear Relationship:

$$e_n = e_{yield} [1 - r(n-1)]$$

r is the degradation raten is the year of operatione is the energy produced

For a system with:

- 0.7% degradation rate
- 1500 kWh/kW first year energy yield



### **C**Dura**MAT**

### **INREL**







### **Preset Constraints**

Cell	Technology								
effici	echnology affects <b>cell cost</b> , iency, and the available values ackage type and system type.	cho	ose a different cell technology, p	oackage type, syste	em type,	locatio	on, or i	nverter loading ratio	
	Cell Technology ?		Package Type 김	System Type 김			Locat	ion 김	
	mono-Si	•	glass-polymer backshe •	fixed tilt, utility	scale	•	US	A MO Kansas City	•
	Inverter Loading Ratio 김								
	1.3				Apply	to bas	eline	Apply to proposed	ł

Presets for Inputs			
Use the <b>presets</b> (below) to for the inputs.	choose a different cell technology,	package type, system type, location, or i	nverter loading ratio
Cell Technology ?	Package Type 김	System Type 2 Locat	ion 김
mono-Si ·	glass-polymer backshe -	✓ fixed tilt, utility scale single-axis tracked, utility scale	MO Kansas City 🛛
Inverter Loading Ratio ?		roof-mounted, residential scale	
1.3		roof-mounted, commercial scale	Apply to proposed
		fixed tilt, commercial scale	

#### Presets for Inputs Use the presets (below) to choose a different cell technology, package type, system type, location, or inverter loading ratio for the inputs. Cell Technology 💈 Package Type 👔 System Type 👔 Location 2 ✓ fixed tilt, utility scale -CdTe glass-glass **MO Kansas City** single-axis tracked, utility scale Inverter Loading Ratio 👔 roof-mounted, commercial scale fixed tilt, commercial scale Apply to proposed 1.3



### 

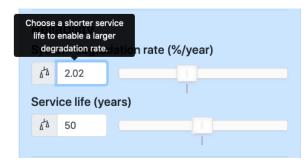






# **Limits on Numerical Ranges**

Restricted service life range & added dead zone to slider to keep energy non-negative and prevent continuous costs on a PV system that does not generate energy.



Physically-motivated limits on:

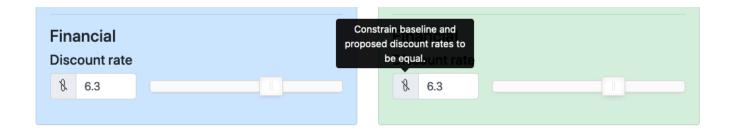
- efficiency (0-100%)
- energy yield > 0
- degradation rate > 0%

### 🕻 Dura MAT









• Sync / unsync discount rates (instead of breakeven button)



©NRE|

Dura**MAT** 







# Equations versus Cash Flow Modeling

# Simplified LCOE relies on an equation with a capital recovery factor:

sLCOE = {(overnight capital cost \* capital recovery factor + fixed O&M cost )/(8760 \*
capacity factor)} + (fuel cost \* heat rate) + variable O&M cost

Equations are efficient for running multiple scenarios over time and looking at the cost impact of a specific input. However, discounted cash flow (DCF) modeling provides a more accurate cost projection and allows for incorporating significant model variations.

### SAM 3021.12.2

New script

Open a project file

#### Welcome

Do you have a guestion or feedback about SAM? Would you like to meet the SAM team? Join us for a SAM Round Table! Registration is free. These 30-minute online sessions are held the last Tuesday of each month at 2:30 pm Mountain time (GMT-6) -- all you need to participate is a computer with an internet connection.

Links to recordings of the 2021 SAM Webinars, including three on the latest battery model features, are available on the SAM website video pages, and on the Events page at https://sam.nrel.gov/events. We will post a new 2022 webinar schedule as soon as it is available.

The Midwest Renewable Energy Association (MREA) offers online SAM courses on modeling PV systems (PV 430) and PV+Storage (PV 431)

To see complete version information for your SAM installation, click About in the lower left corner of this window.

C:\Users\dfeldman\OneDrive - NREL\Desktop\David's Documents\Research\Benchmarks\2021\2021 LCOE Benchmarks-v1.sam C:\Users\dfeldman\OneDrive - NREL\Desktop\David's Documents\Research\Benchmarks\2021\2021 LCOE Benchmarks.sam C:\Users\dfeldman\OneDrive - NREL\Desktop\David's Documents\Research\ATB\2021\Impact of bifacial2.sam

### Start a new project



- D X



<ul> <li>Photovoltaic</li> </ul>	* Fower Purchase Agreement	Since.
Detailed PV Model	Single Owner	
PVWatts High Concentration PV Energy Storage Concentrating Solar Power Marine Energy Wind Fuel Cell - PV - Battery Geothermal Solar Water Heating Biomass Combustion Generic System	Partnership Hip with Debt Partnership Flip without Debt Sale Leaseback P Distributed Merchant Plant LCOE Calculator (FCR Method) No Financial Model	Welcome. NMV reported you must consum this (WM mean) from as for a <u>SAM Training Table</u> ) Reportation is free, a last Tuesday of each streeth at 2000 per Mountain time (EMT-B) — all you must to participate in re, last tuesday of each streeth at 2000 per Mountain time (EMT-B) — all you must to participate in the last tuesday of each streeth at 2000 per Mountain time (EMT-B) — all you must to participate in the last tuesday of each streeth at 2000 per Mountain time (EMT-B) — all you must to participate in the last tuesday of each streeth at 2000 per 2000 per Mountain time (EMT-B) — all you must to participate in the last streeth at 2000 per 2000 pe
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# Choose your technology and financial model

Covoltaic, Single owner	Solar Resource Library	the fit whites								-
ion and Resource	The Solar Resource library is	a list of weather files on your co	mputer. Cho	ose a file fro	m the library a	nd verify the	weather data	information b	elaw.	
lule	The default library comes wit your library. It is available for		o you get sta	ted. Use the	download too	is below to t	ouild a fibrary	of locations yo	ou frequently model. Once you build	
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Input project specifics, including: system design, installation, operation, and financing costs, and how the electricity is sold.

o x

Press "simulate" and the model will calculate a discounted cash flow and output variables.



View the output tabs of the model, including LCOE.

You can also run sensitivity analyses of input variables using the "parametrics" function.

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System Design	Electricity from grid (kWh)		0	-27,812	-27,812		-27,831	-27,83			-27,843	-27,843	-27,849		-27,849	-27,8
e)stern e engri	Electricity to grid net (kWh)		0 1	13,004,672	112,527,744	112,040,928	111,546,152	111,043,55	2 110,533,904	110,016,888	109,494,352	108,966,048	108,431,848	107,892,592	107,350,016	106,802,5
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Losses	PPA price (cents/kWh)		0	4	4.04	and the second sec	4.1212		and the state of t	and the second se	4.28854				4.46267	4.50
Grid Limits	PPA revenue (\$)		0	4,521,300	4,547,244	4,572,854	4,598,192	4,623,25	3 4,648,060	4,672,588	4,696,904	4,720,990	4,744,831	4,768,452	4,791,924	4,815,1
Sho Linits	Curtailment payment revenue (\$)		0	0	0	0	0		0 0	0 0	0	0	0	0	0	
Lifetime and Degradation	Capacity payment revenue (\$)		0	0	0	0	0	i ()	0 0	0 0	0	0	0	0	0	
circuitic on a pegroadion	Salvage value (\$)		0	0	0	0	0	i	0 0	0 0	0	0	0	0	0	
Installation Costs	Total revenue (\$)		0	4,521,300	4,547,244	4,572,854	4,598,192	4,623,25	3 4,648,060	4,672,588	4,696,904	4,720,990	4,744,831	4,768,452	4,791,924	4,815,1
Operating Costs	Property tax net assessed value (\$)	)	0	51,384,532	51,384,532	51,384,532	51,384,532	51,384,53	2 51,384,532	51,384,532	\$1,384,532	51,384,532	\$1,384,532	\$1,384,532	\$1,384,532	51,384,5
Financial Parameters																
Financial Parameters	OPERATING EXPENSES															
Revenue	O&M fixed expense (\$)		0	0	0	0	0	1	0 0	0	0	0	0	0	0	
increase.	O&M production-based expense (	5)	0	0	0	0	0		0 0	0 0	0	0	0	0	0	
Incentives	O&M capacity-based expense (\$)		0	750,033	768,784	788,004	807,704	827,89	6 848,594	869,809	891,554	913,843	936,689	960,106	984,109	1,008,7
Depreciation	Electricity purchase (\$)		0	1,112	1,124	1,135	1,147	1,15	8 1,170	1,182	1,194	1,206	1,218	1,231	1,243	1,2
Depreciation	<	1														>
Electricity Purchases		% of Total Depreciable Basis	Gross Amount Allocated		CBI Reduction	Prior to ITC			of ITC		Basis ITO			C Federal ITC on Reduction		
	DEPRECIATION AND ITC: STATE													-		
	MACRS 5-yr	92,78	49,813,132.00	0	0	49,813,13	49,813,1	132.00	100.00	0	0	0	0	0 6,475,707.50	43,3	37,428.00
	MACRS 15-yr	1.55	830,218.88	0	0	830,210	88.8	0	0	0	0	0	0	0 0	8	30,218.88
	Straight Line 5-yr	0	(	0			0	0	0	0	0	0		0 0		0
Simulate >	Straight Line 15-yr	2.58	1,383,698.12			1,383,690		0	0	0	0	0	0	0 0		83,698.12
Parametrics Stochastic	Straight Line 20-yr	3.09	1,660,437.75	0	0	1,660,43		0	0	0	0	0	0	0 0	1,6	60,437.75
Parametrics Stochastic	Straight Line 39-yr	0		0	0		0	0		0	0	0		0 0		0

To view the DCF model with equations in Excel, go to the "Cash flow" tab and click "Send to Excel with Equations".

# **Basic DCF Inputs and Equations**

Year	YO	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15	Terminal Year
Electricity Production		14,500	14,399	14,298	14,198	14,098	14,000	13,902	13,804	13,708	13,612	13,516	13,422	13,328	13,235	13,142	
Investment	(6,330)																
Buyout																	3,000
PPA Revenue		\$866	\$882	\$897	\$913	\$930	\$946	\$963	\$980	\$998	\$1,015	\$1,033	\$1,052	\$1,071	\$1,090	\$1,109	
Operating Expenses (O&M, Insurance, N	1anagement)	(\$190)	(\$195)	(\$200)	(\$205)	(\$210)	(\$215)	(\$220)	(\$226)	(\$231)	(\$237)	(\$243)	(\$249)	(\$256)	(\$262)	(\$268)	
Interest		(\$347)	(\$329)	(\$311)	(\$293)	(\$273)	(\$253)	(\$232)	(\$210)	(\$187)	(\$164)	(\$139)	(\$113)	(\$87)	(\$59)	(\$30)	
Operating Cash flow		\$329	\$357	\$386	\$416	\$447	\$478	\$511	\$544	\$579	\$615	\$651	\$689	\$729	\$769	\$811	\$3,000
Depreciation		(\$2,220)	(\$3,552)	(\$2,131)	(\$1,277)	(\$1,277)	(\$644)										
Earnings Before Taxes		(\$1,891)	(\$3,195)	(\$1,745)	(\$861)	(\$830)	(\$166)	\$511	\$544	\$579	\$615	\$651	\$689	\$729	\$769	\$811	\$3,000
Taxes		\$510	\$862	\$471	\$232	\$224	\$45	(\$138)	(\$147)	(\$156)	(\$166)	(\$176)	(\$186)	(\$197)	(\$208)	(\$219)	(\$810)
ITC	\$3,900																
Principal		(\$433)	(\$450)	(\$468)	(\$487)	(\$507)	(\$527)	(\$548)	(\$570)	(\$593)	(\$616)	(\$641)	(\$667)	(\$693)	(\$721)	(\$750)	\$0
Net Cash flow	(\$2,430)	\$407	\$769	\$389	\$161	\$164	(\$4)	(\$175)	(\$172)	(\$170)	(\$168)	(\$165)	(\$163)	(\$161)	(\$160)	(\$158)	\$5,190
Present Value of net cash flows	(\$2,250)	(\$1,901)	(\$1,291)	(\$1,005)	(\$895)	(\$792)	(\$794)	(\$889)	(\$975)	(\$1,054)	(\$1,126)	(\$1,191)	(\$1,252)	(\$1,306)	(\$1,357)	(\$1,403)	\$0
IRR	#NUM!	-83%	-35%	-19%	-14%	-10%	-10%	-18%	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	#NUM!	8%
NPV \$0	)																

Each row represents a calculated variable in eventually determining a project's net cash flow. Adjustments can be made to alter (for example): when the cash is received; time periods; additional revenue; additional costs; cash flows from different investors; and important metrics necessary for a project.

An accompanying Excel will calculate this basic model and a more complicated financial structure (partnership-flip).

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# **Presentation Overview**

1	Introduction
2	<b>Component Manufacturing Cost Modeling</b>
3	System Capital Costs
4	Levelized Cost of Electricity (LCOE)
5	Supply Chain Analysis
6	Resources for Follow-Up

# Supply Chain Data Resources

U.S. Imports, Exports, Trade Classifications, Tariffs

- U.S. International Trade Commission (USITC) DataWeb: <u>https://dataweb.usitc.gov/</u>
- Search Harmonized Tariff Schedules (HTS), then
- Search U.S. Energy Information Administration (EIA)

Global Imports/Exports

 UN Comtrade: International Trade Statistics Database: <u>https://comtrade.un.org/</u>

# EIA Data Resources (non-exhaustive)

Source (frequency)	Information	location
Electric Power Monthly and Annual	Electricity generation and capacity by technology, by utility, sector, and state. Sales, Revenue, and Average Price of Electricity.	https://www.eia.gov/electrici ty/monthly/
Form 923 (monthly & annual)	Collects detailed electric power data on electricity generation, fuel consumption, fossil fuel stocks, and receipts at the power plant and prime mover level.	<u>https://www.eia.gov/electrici</u> <u>ty/data/eia923/</u>
Form 860 (monthly & annual)	Generator-specific information for electricity generation projects greater than 1 MW (in-service, planned, and decommissioned). Annually, there is more project specific data, such as technology type, AC/DC capacity, and more.	https://www.eia.gov/electrici ty/data/eia860/
Form 861 (monthly & annual)	Customer focused. Sales, revenue, and customers by utility and state. Small-scale PV capacity and generation. Customer, capacity, and energy sold back to utility of net-metered systems (including PV, storage, distributed wind).	https://www.eia.gov/electrici ty/data/eia861m/
Form 63B (monthly & annual)	U.S. Photovoltaic Module Shipments.	https://www.eia.gov/renewa ble/monthly/solar_photo/
Annual Energy Outlook / International Energy Outlook	Annual cost and deployment regional, national, and international forecasts.	https://www.eia.gov/outlook s/aeo/ https://www.eia.gov/outlook s/ieo/
Wholesale Electricity and Natural Gas Market Data (bi-weekly)	Historical market price and volume data on a selection of markets.	https://www.eia.gov/electrici ty/wholesale/

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# EIA Data Resources (data browser)

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			ľ.	Nov 2021	Dec 2021	Jan 2022	Feb 2022
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Uni	Ied States		6752				
	- Al fuels		2	315,495	339,664	378,997	327,767
	Coal			57,160	59,878	87,506	70,762
	Petroleum liquids			645	912	3,254	1,000
	Petroleum coke			778	564	531	605
	Natural gas		8	122,458	127,169	135,317	115,615
	Other gases			677	689	971	032
	Nuclear		8	62,749	70,720	70,577	61,862
	Conventional hydroelectric		8	20,460	25,650	27,017	23,670
	Other renewables		00				
	Wind		63	36,043	40,678	35,194	38,162
	All utility-acale solar		0	7,874	6,355	8,004	9,203
	Geothermal			1,347	1,454	1,500	1,250
	Biomass (total)			4,304	4,787	4.573	4,320
	Wood and wood-deri	ved fuels	0	2,850	3,189	3,084	2,992
	Other biomass			1,446	1,598	1,489	1,338
	Hydro-electric pumped storage			-377	-445	-493	-412
	Other			978	1,076	1,017	891
	All solar		2	11,137	9,208	11,305	12,848
	Small-scale solar chotovoltaic			3,284	2.853	3.301	3.646

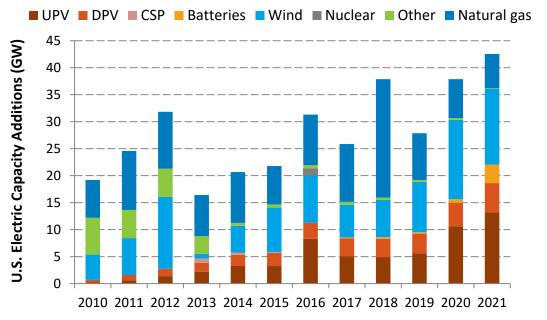
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Ne	t generation v	0	PIC .	Choose a	report		
6	ectricity generation & consumption (EIA-906/EIA-920/EIA-	923)	~				
100	Net generation			Map		? "	ELP DOWNU
	Total consumption						
	Total consumption (Btu)				Feb 202	Annua	I Quarterly Mon
	Consumption for electricity generation					-	
	Consumption for electricity generation (8tu)			v 2021	Dec 2021	Jan 2022	Feb 2022
11	Consumption for useful thermal output			-			
	Consumption for useful thermal output (Utu)						
	Plant level data			115.495	339 664	378.967	327.767
5	ales of electricity (EIA-861/EIA-861M)			57 160	59.070	67.506	70,762
	Retail sales of electricity			BAS	912	3,254	1 000
	Revenue from retail sales of electricity			778	564	531	605
	Average retail price of electricity			22 458	127.169	138 317	115.615
	Number of customer accounts			877	885	0.71	
n	vel quality & receipts (EIA-423/EIA-923)			82,749	70.720	70.577	81 282
	Fossil-fuel stocks for electricity generation			20,460	25 850	27 017	23 670
	Receipts of fossil fuels by electricity plants			20,460	25,650	21,011	23,610
	Receipts of fossil fuels by electricity plants (Dtu)			35.043		38,194	
	Average cost of fossil fuels for electricity generation				40,676		38,162
		-		7.674	0.355	0,004	9,203
	Geothermal			1,347	1,454	1,500	1,250
2.	Biomass (total)			4,304	4,787	4,573	4,328
٠.,	Wood and wood-derived fuels			2,858	3,189	3,084	2,992
÷	Other biomass			1,445	1,598	1,489	1,336
×.,	Hydro-electric pumped storage			-377	-445	-492	-412
٩.,	Other			978	1,076	1,017	291
ħ.,	Al solar	-		11,137	9,208	11,305	12,848
٩. 1	<ul> <li>Small-scale solar photovoltaic</li> </ul>	100		3,264	2,853	3,301	2,646

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	ric pumped alors	ge -			-445	-455	-412	
Other					1.076		891	
Al solar			8	11,137	9,208	11,305	12,848	
- Creat anala	aciar photovoita	6		3,264	2,053	2,301	2,646	



https://www.eia.gov/electricity/data/browser/

# New U.S. Capacity Additions, 2010–2021

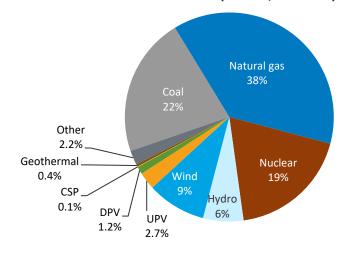


### Example of EIA data

- In 2021, PV represented approximately 44% of new U.S. electric generation capacity (31% UPV, 13% DPV), compared to 4% in 2010.
  - Wind represented 33% of added capacity.
  - Since 2017, PV has represented approximately 35% of new electric generation capacity.
- Over 35 GWac of new installed capacity was either from renewable energy or battery technologies in 2021, surpassing last year's record and nearly matching the total U.S. capacity additions in 2020 and 2018.
- Combined with wind, 77% of all new capacity in 2021 came from renewable sources.
- Battery installations jumped by a factor of 5 from 2020 to 2021; it now represents 8% of capacity additions.

### 2021 U.S. Generation and Capacity

- Renewables are becoming an increasingly large part of the U.S. electric generation mix, representing 27% of capacity and 21% of generation in 2021.
  - Adding nuclear, non-carbon sources represented 35% of capacity and 40% of generation.

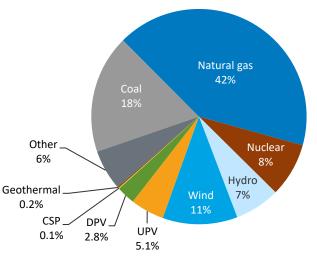


### 2021 U.S. Generation (Total 4,165 TWh)

 Example of EIA data
 percentage
 In 2021, solar represented 8.0% of net summer capacity and 3.9% of annual generation.

• Capacity is not proportional to generation, as certain technologies (e.g., natural gas) have lower capacity factors than others (e.g., nuclear).

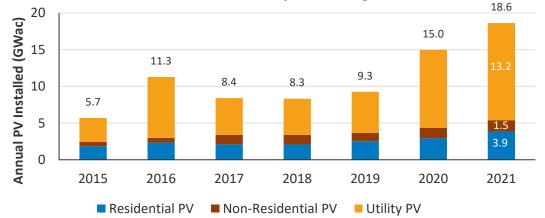
### 2021 U.S. Generation Capacity (Total 1.2 TW)



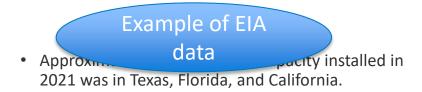
Sources: EIA, "Electric Power Monthly" Tables 6.1, 6.1A, February 2022, "Electricity Data Browser," April 5, 2022.

## U.S. Installation Breakdown Annual: EIA (GWac)

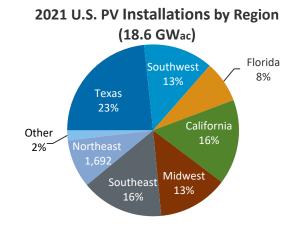
- Despite the impact of the pandemic on the overall economy, the United States installed 18.6 GWac of PV in 2021, its largest total ever—up 24% y/y.
  - Residential (3.9 GWac), C&I (1.5 GWac), and utility-scale PV (13.2 GWac) were up 32%, 5%, and 25%, respectively, in 2021.



#### **U.S. PV Installations by Market Segment**



- Despite a concentration of PV installations in the top three markets, diversification of growth continues across the United States.
  - 19 states had more than 1 GWac of cumulative PV installations at the end of 2021 (New Mexico and Illinois both achieved this distinction for the first time in 2021), and 25 states installed more than 100 MWac in 2021.

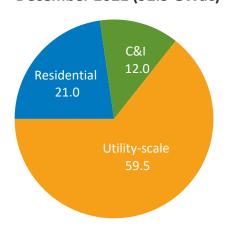


**Note:** EIA reports values in Wac which is standard for utilities. The solar industry has traditionally reported in Wdc. See the next slide for values reported in Wdc. **Sources:** EIA, "Electric Power Monthly," forms EIA-023, EIA-826, and EIA-861 (April 2022, February 2021, February 2019).

# U.S. Installation Breakdown Annual: EIA (GWac)

- At the end of 2021, there were 92.5 GWac of cumulative PV installations.
- EIA reports that at the end of 2021, 64% of U.S. installed PV capacity was from utility-scale PV systems.

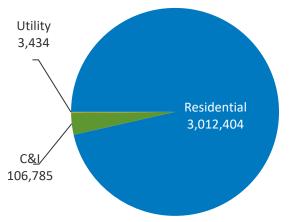
# Cumulative U.S. PV Installations as of December 2021 (92.5 GWac)





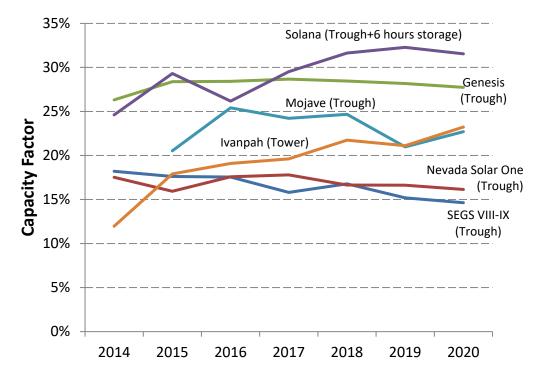
Despite representing only 23% of installed U.S. PV capacity at the end of 2021, 96% of PV systems—over 3 million systems—were residential applications.

# Cumulative U.S. PV Installations as of December 2021 (number)



**Note:** EIA reports values in Wac which is standard for utilities. The solar industry has traditionally reported in Wdc. See the next slide for values reported in Wdc. **Sources:** EIA, "Electric Power Monthly," forms EIA-023, EIA-826, EIA-860, and EIA-861 (April 2022, February 2021, February 2019).

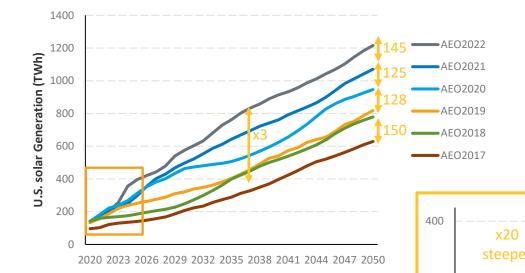
### U.S. CSP Project Generation Performance, 2010–2020



Thor Example of EIA be operation of the data between 2013 and 2015, rour or menniow generally perform better than when they began operation.

- Annual weather variation also caused some of the differences in annual production.
- Plants with newer technology, such as towers and storage, took longer to ramp up than trough plants, which have decades of operating experience.
  - The lone U.S. tower plant with storage, Tonopah, which began operating in 2015, had consistent operating problems, and was shut down for all of 2020 after its PPA was canceled.
- Absolute capacity factor is not necessarily the best metric for performance, as plants can be designed and operated differently.
  - The capacity factors of the SEGS plants have decreased over time as the PPAs of these plants have expired and they have shifted to merchant production.

#### **EIA Projections Over Time**



200

2020

2023

2026

Example of EIA data

- Between EIAST and EIA's AEO2022, PV projections have increased significantly.
  - AEO2022 projects 145 TWh more deployment by 2050 than AEO2021, continuing a trend a of the past few years (except for AEO2018/2019 which gave similar 2050 predictions).
  - Between 2024 and 2034, projections of solar generation nearly tripled between AEO2017 and AEO2022.

 AEO2022 projects a markedly steeper ramp (over 20x faster than that predicted in AEO2017) in solar generation from 2023 to 2024.

# **Presentation Overview**

1	Introduction
2	<b>Component Manufacturing Cost Modeling</b>
3	System Capital Costs
4	Levelized Cost of Electricity (LCOE)
5	Supply Chain Analysis
6	Resources for Follow-up

# **NREL Resources for Follow-Up**

#### NREL Solar-TEA team website

nrel.gov/solar/market-research-analysis/solar-cost-analysis.html

#### All NREL tools

<u>nrel.gov/research/data-tools.html</u>

#### **LCOE tools**

- <u>pvlcoe.nrel.gov</u>
- <u>sam.nrel.gov</u>
- nrel.gov/gis/renewable-energy-potential.html
- nrel.gov/analysis/tech-lcoe.html

# **Other Resources**

#### U.S. Solar Photovoltaic System and Energy Storage Cost Benchmarks: Q1 2021 (2020 USD)

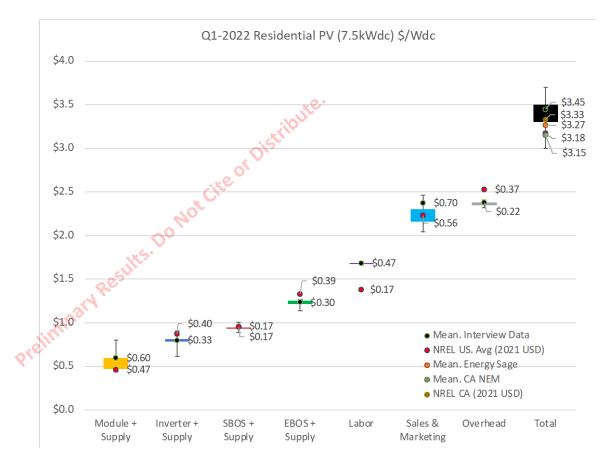
– <u>https://www.nrel.gov/docs/fy22osti/80694.pdf</u>

# Appendix

## Q1-2022 (2021 USD) Residential PV System Cost Results

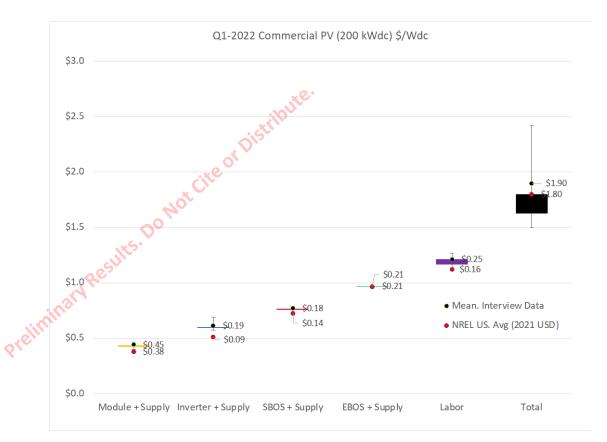
- Standard flush-mounted, pitched-roof racking system.
- Module Imported outside USA
- Inverter Type Micro Inverter
- Installer Type Small Installers
- Module Supply Chain 41% (Inventory, Shipping/Handling, Procurement)
- Inverter Supply Chain 20%
- BOS Supply Chain 15%
- Profit 17%

\$/Wdc (Q1-2022)	Mean	Median
Industry data	\$ 3.45	\$ 3.50
Energy Sage	\$ 3.27	\$ 2.80
CA NEM	\$ 3.15	\$ 3.52



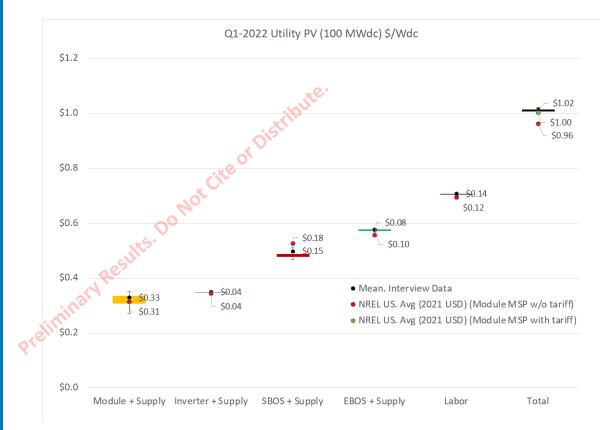
### Q1-2022 (2021 USD) Commercial PV System Cost Results

- 200-kW, 1,000-volt DC (VDC), commercial-scale flat-roof system
- Ballasted Racking
- 21% module supply premium to module cost.
- EPC Overhead 13% (Assumes overhead expenses on materials and equipment rental)
- Developer Overhead 30% (Assumes overhead expenses such as payroll, facilities, travel, legal fees, administrative, business development, finance, and other corporate functions)
- Profit 7%



### Q1-2022 (2021 USD) Utility PV System Cost Results

- 100-MWDC, 1,500-VDC utility-scale PV one-axis tracking system.
- EPC Overhead 8.7% (Assumes overhead expenses on materials and equipment rental)
- Developer Overhead 2% (Assumes overhead expenses such as payroll, facilities, travel, legal fees, administrative, business development, finance, and other corporate functions)
- Profit 5%



#### Utility and Commercial Ground Mount PV BOS Cost Components

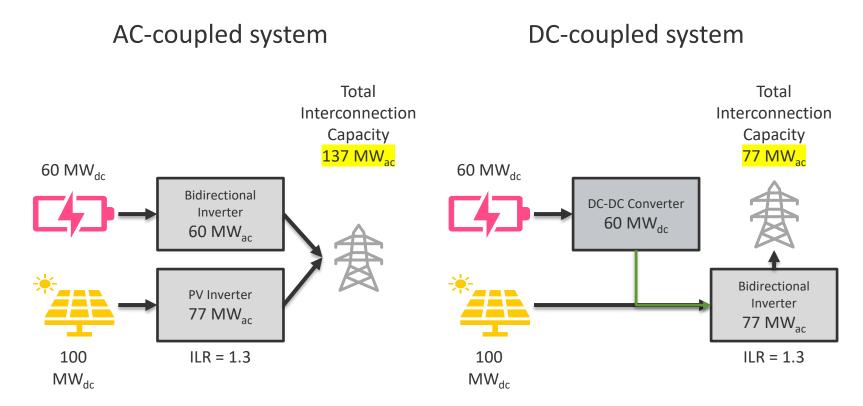
Preconstruction Surveys			
Access Roads and Parking	Staging		
Security Fencing			
Temporary Office			
Storage Box			
O & M Building			
Site Preparation (Geotechnical Investigation)			
Site Preparation (Clearing and Grubbing)	Site Preparation		
Site Preparation (Soil Stripping and stockpiling)			
Site Preparation (Grading)			
Site Preparation (Compaction)			
Foundation for /inverter/transformer/ PVSC			
Trenches			
Foundation for Vertical Support			
Horizontal Support Structures	Structural Work		
Welding or Bolting			
Modules Mounting			
T- Connection			
U-Joint & Driveline			
Slave Gearbox	Tracker		
Motor & Controller Equipment			
Conduit, Wiring			
Grounding, DC Cable	DC Work		
Junction/Combiner Boxes			
Inverter House			
On-site Transmission	A C 14/a-la		
PV Combining Switchgear (PVCS)	AC Work		
On-site transformer & Substation			
Site Preparation (Clearing and Grubbing)	-		
Tower: Foundation Installation			
Tower: Structure Costs	220 kV Transmission line (4 miles). Tower		
Tower: Top Assembly	230 kV Transmission line (4 miles): Tower		
Conductor and Cable			
Misc. Assembly Units			
Site Preparation (Clearing and Grubbing)			
Wood Pole: Foundation Installation	35 kV Distribution line (1 miles): Wood Pole		
Wood Pole: Structure Costs			
Wood Pole: Top Assembly			
Conductor and Cable			
Misc. Assembly Units			

#### Utility and Commercial BESS BOS Cost Components

Battery Cabinet – Battery Pack, Container (including BMS), Thermal Management, Fire Suppression

Foundation for battery/inverter/transformer	
Add battery modules into battery racks	SBOS
Bidirectional Inverter House	
Conduit, Wiring	
DC Cable	
Bidirectional Inverter House	
Energy Management System	EBOS
Switchgear	
1,000 kVA transformer	
Monitors, controls, and communication	

# Q1 2021 Utility AC- and DC-Coupled Battery Energy Storage System (BESS) Configurations



\*Commercial PV plus battery systems follow a similar schematic

# Thank You

# Transforming ENERGY

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