



Recent and Planned Improvements to the System Advisor Model (SAM)

Janine Freeman
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Free software that enable detailed performance and financial analysis for renewable energy systems

The image displays two overlapping screenshots. On the left is the System Advisor Model (SAM) software interface. It features a blue header with 'File', 'Tools', and 'Help' menus. A sidebar on the left lists various simulation parameters such as 'Location and Resource', 'Module', 'Inverter', 'System Design', 'Shading and Snow', 'Losses', 'Lifetime', 'Battery Storage', 'System Costs', 'Financial Parameters', 'Time of Delivery Factors', 'Incentives', and 'Depreciation'. The main window shows a line graph of power output (kW) over a 9-month period (Jan to Sep). The y-axis ranges from -2000 to 20000 kW. The graph shows a seasonal peak in summer months, reaching approximately 18,000 kW, and a minimum in winter months, reaching approximately -2,000 kW. On the right is the PVWatts Calculator website. The header includes the NREL logo and navigation links for 'HELP' and 'FEEDBACK'. A 'Get Started' section has a text input field for 'Enter a Name or Website Address' and a 'GO' button. Below this is a large image of solar panels with the text 'NREL's PVWatts Calculator' and a description: 'Estimates the energy production and cost of energy of grid-connected photovoltaic (PV) energy systems throughout the world. It allows homeowners, small building owners, installers and manufacturers to easily develop estimates of the performance of potential PV installations.' There is also a 'What's New' button and social media links for Twitter, Facebook, LinkedIn, and YouTube.

<http://sam.nrel.gov/download>
<https://pvwatts.nrel.gov>

Multiple ways to access SAM models

- Desktop Application
- Advanced Analysis Features
 - Parametric
 - Stochastic
 - P50/P90
- Built-in Scripting Language
- Macros
- Software Development Kit (SDK)
 - C/C++
 - Matlab
 - **Python ***new & improved!***
 - PHP
 - C#
 - Java
 - VBA
 - iOS / Android
- Web Services API (PVWatts Only)
- Open-source SAM code



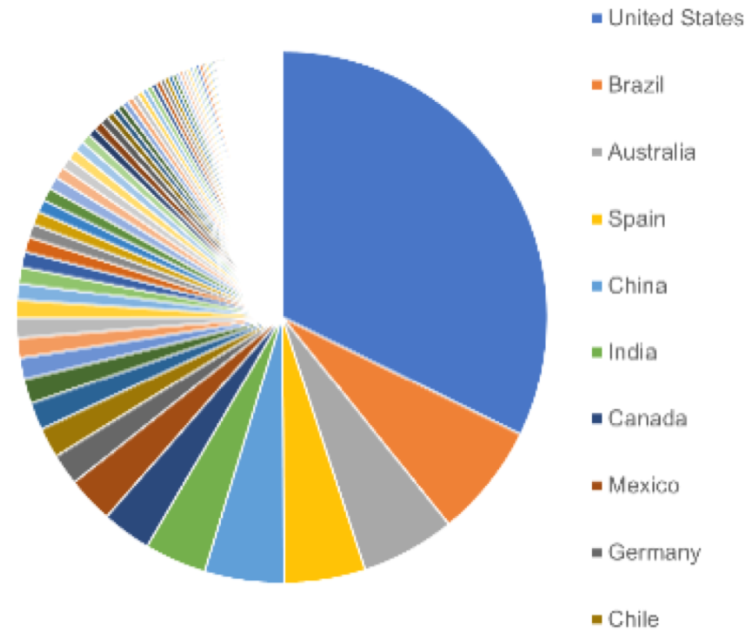
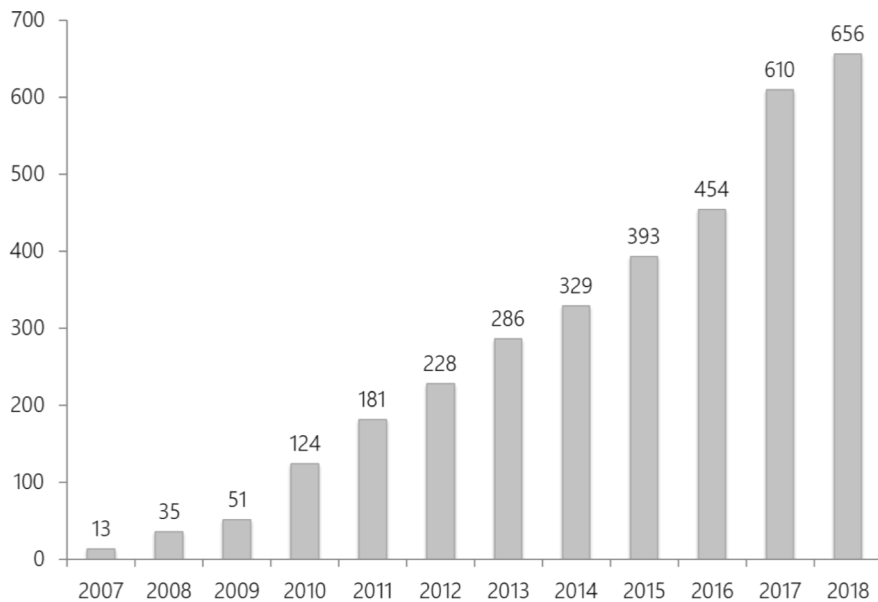
SAM is started **once every 2 minutes**
PVWatts receives over **2 million hits per month**

Over **100,000** users in 190+ countries

90+ webinars with **over 100,000 views**

Users include Sunrun, Enphase, AEP, Southern Company, EPRI, & more

Google Scholar Citations of SAM



Recent Highlights

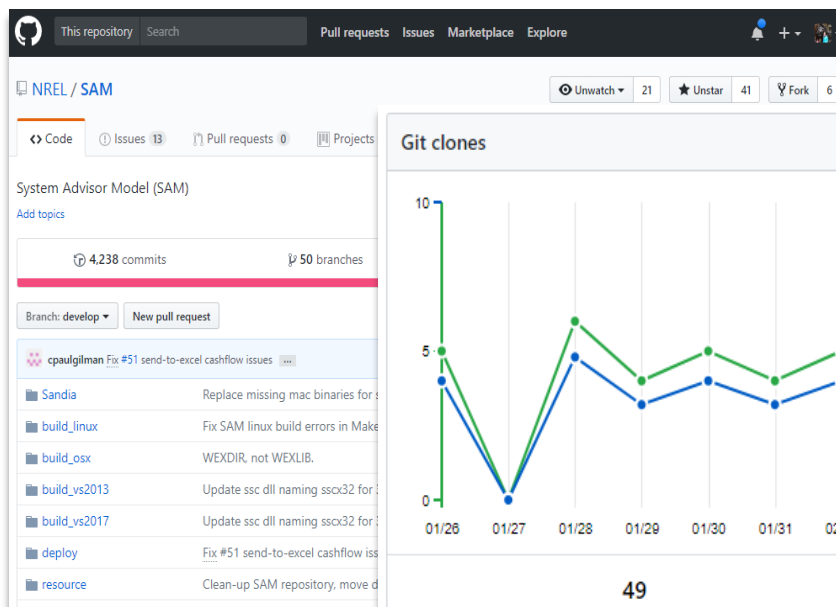


Mermoud-Lejeune module and inverter models added to SDK (Timo Richert, PVYield)

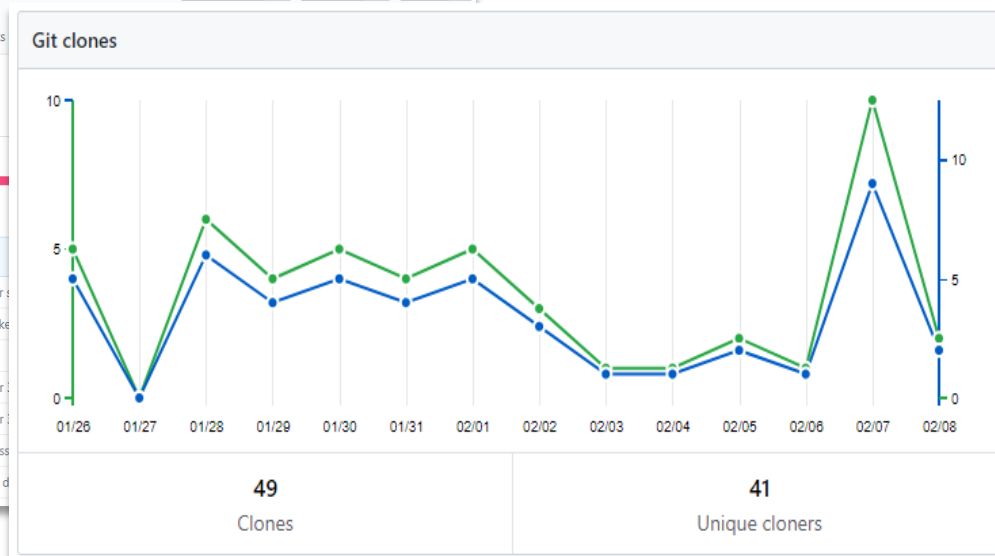
New condenser & cooling system for CSP power towers (Ana Dyreson, University of Wisconsin, Madison)

Bug fixes and new outputs (Casey Zak, Cypress Creek Renewables)

Join us for the SAM Developer's Conference this summer!

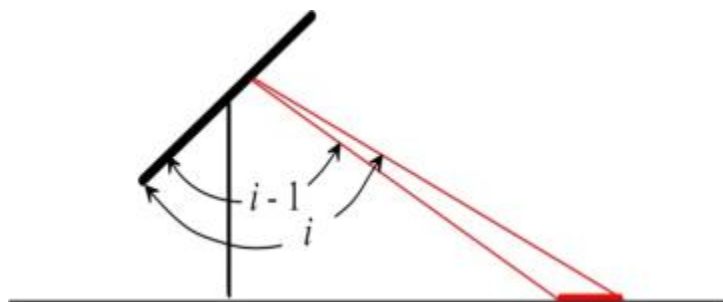


<http://sam.nrel.gov/opensource>





Implemented bifacial model developed by Marion, Deline, et al into main workflow of SAM



“A Practical Irradiance Model for Bifacial PV Modules”, Marion et al, 44th IEEE PVSC, June 2017



Updated SAM Python wrapper to be more intuitive for the many internal and external tools that use the Python SDK

```
batt_pv_dc_forecast
PV dc power forecast [kW], array.
Required if en_batt=1&batt_meter_position=1&batt_dispatch_choice=2.

batt_replacement_capacity
Capacity degradation at which to replace battery [%], number.

batt_replacement_option
Enable battery replacement? [0/1], number.
Constraints: INTEGER,MIN=0,MAX=1

batt_replacement_schedule
Battery bank replacements per year, number.
Required if batt_replacement_option=1

batt_resistance
Internal resistance [Ohm], number.

batt_room_temperature_celsius
Temperature of storage room [C], number.

batt_target_choice
Target power input option [0/1], number.
0=InputMonthlyTarget,1=InputFullTimeSeries; Required if en_batt=1&batt_meter_position=0&batt_dispatch_choice=1

batt_target_power
Grid export [kW], number.
Required if batt_target_choice=0

batt_target_power
Grid import [kW], number.
Required if batt_target_choice=1

batt_target_power
Grid charge [kW], number.
Required if batt_target_choice=2

batt_target_power
Grid discharge [kW], number.
Required if batt_target_choice=3

batt_target_power
Battery calendar choice, number.
0=Use default,1=Use calendar,2=Use matrix

batt_target_power
Battery calendar lifetime matrix, number.
Required if batt_target_choice=2

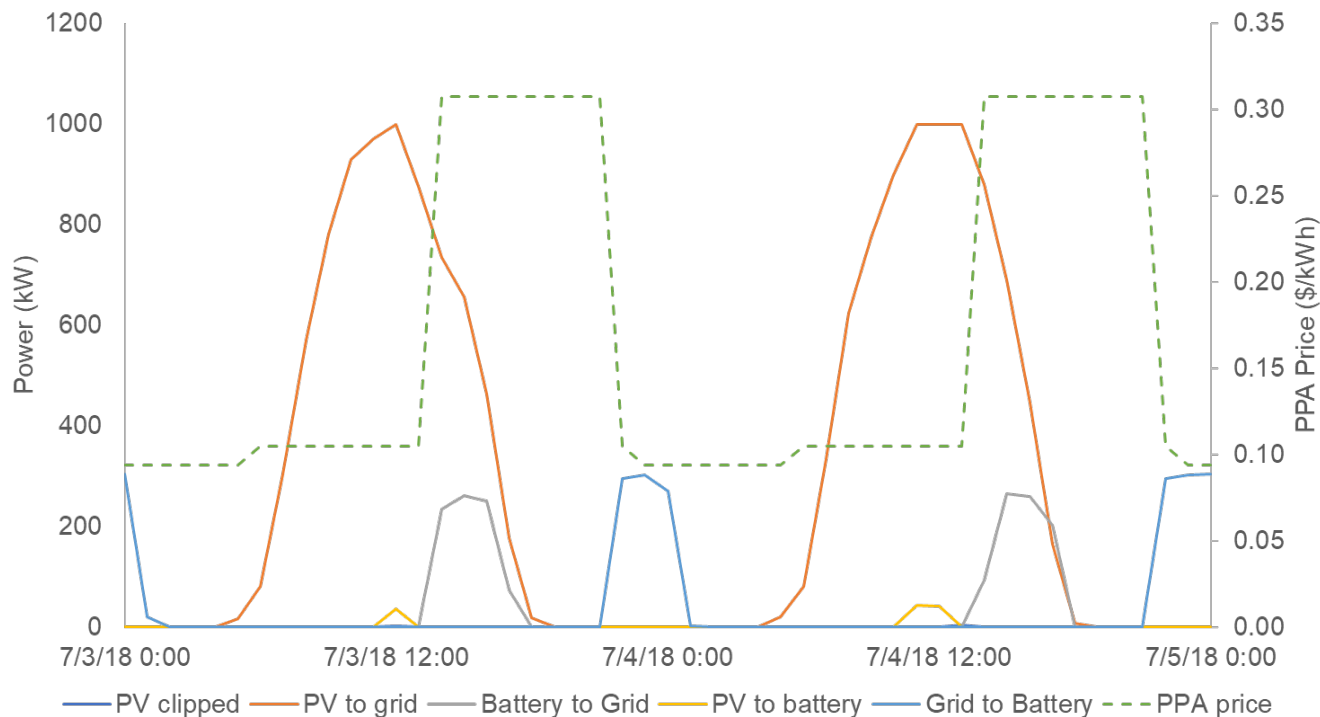
batt_target_power
Battery calendar choice, number.
0=Use default,1=Use calendar,2=Use matrix

batt_target_power
Battery calendar lifetime matrix, number.
Required if batt_target_choice=2
```

```
EnergyMarket = {EnergyMarket} <Pvsamv1.EnergyMarket object>
FuelCell = {FuelCell} <Pvsamv1.FuelCell object>
IEC61853SingleDiodeModel = {IEC61853SingleDiodeModel} <Pvsamv1.IEC61853SingleDiodeModel object>
Inverter = {Inverter} <Pvsamv1.Inverter object>
InverterCECCoefficientGenerator = {InverterCECCoefficientGenerator} <Pvsamv1.InverterCECCoefficientGenerator object>
InverterCECDatabase = {InverterCECDatabase} <Pvsamv1.InverterCECDatabase object>
InverterDatasheet = {InverterDatasheet} <Pvsamv1.InverterDatasheet object>
InverterMermoudLejeuneModel = {InverterMermoudLejeuneModel} <Pvsamv1.InverterMermoudLejeuneModel object>
InverterPartLoadCurve = {InverterPartLoadCurve} <Pvsamv1.InverterPartLoadCurve object>
Layout = {Layout} <Pvsamv1.Layout object>
Lifetime = {Lifetime} <Pvsamv1.Lifetime object>
Losses = {Losses} <Pvsamv1.Losses object>
MermoudLejeuneSingleDiodeModel = {MermoudLejeuneSingleDiodeModel} <Pvsamv1.MermoudLejeuneSingleDiodeModel object>
Module = {Module} <Pvsamv1.Module object>
Outputs = {Outputs} <Pvsamv1.Outputs object>
PV = {PV} <Pvsamv1.PV object at 0x109f08...>
SandiaPVArrayPerformanceModelWithModel = {SandiaPVArrayPerformanceModelWithModel} <Pvsamv1.SandiaPVArrayPerformanceModelWithModel object>
Shading = {Shading} <Pvsamv1.Shading object>
SimpleEfficiencyModuleModel = {SimpleEfficiencyModuleModel} <Pvsamv1.SimpleEfficiencyModuleModel object>
Simulation = {Simulation} <Pvsamv1.Simulation object>
SolarResource = {SolarResource} <Pvsamv1.SolarResource object>
SystemDesign = {SystemDesign} <Pvsamv1.SystemDesign object>
```

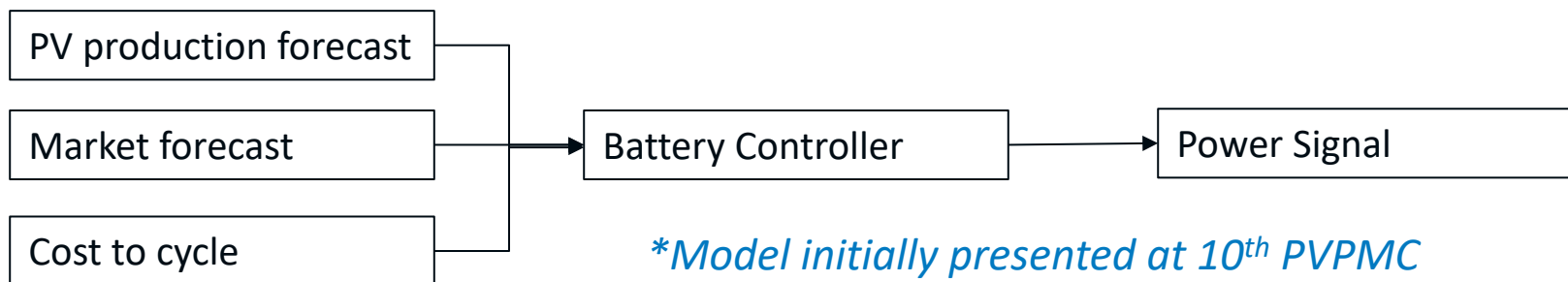



Fixed issues in the economic dispatch model for front-of-meter systems



Issues addressed:

- Consider efficiencies when generating dispatch
- Consider forecast low value period for charging



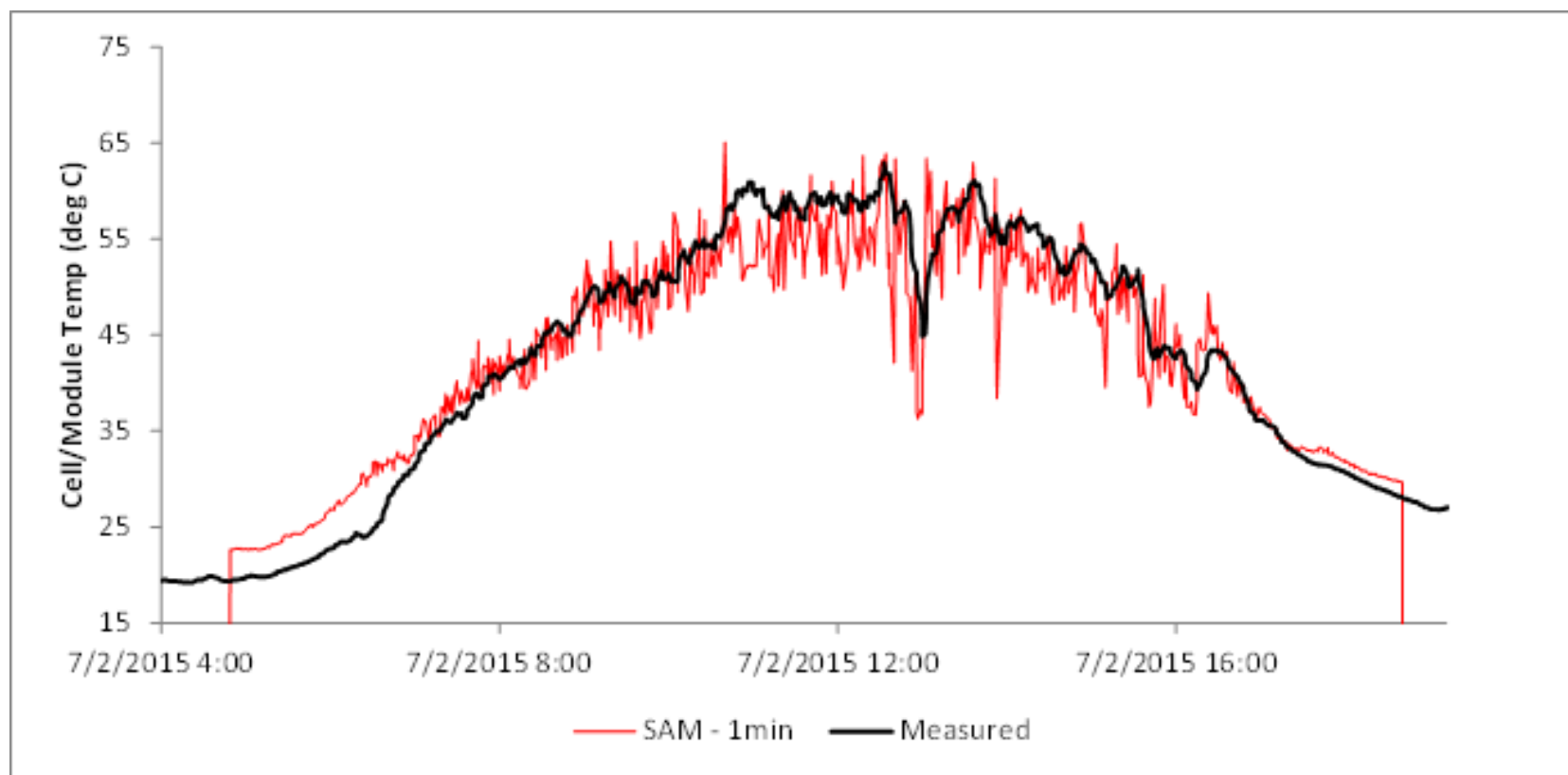


- Download all available data NREL NSRDB data automatically
- Advanced Download capability: easily download multiple years, 30-minute or 60-minute data, multiple locations
- *Coming soon: 5-minute data for Puerto Rico & surrounding areas*

Coming Soon



- Implement moving average transient thermal model being developed by Sandia/ASU, similar to investigations performed by Southern Company with measured data (below)
- Doesn't require many extra inputs






Battery temperature governs available capacity, affects degradation

- Expanded options for battery environment temperature
- Can now model battery with ambient temperature from weather file or input time series

Thermal Behavior



	Temp (C)	Capacity(%)
Import...	-10	60
Export...	0	80
Copy	25	100
Paste	40	100

Rows:

Battery Specific Heat (Cp) J/KgK

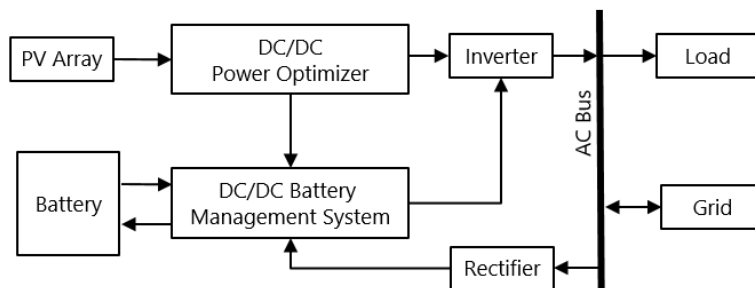
Heat transfer coefficient W/m2K

Choose environment temperature option

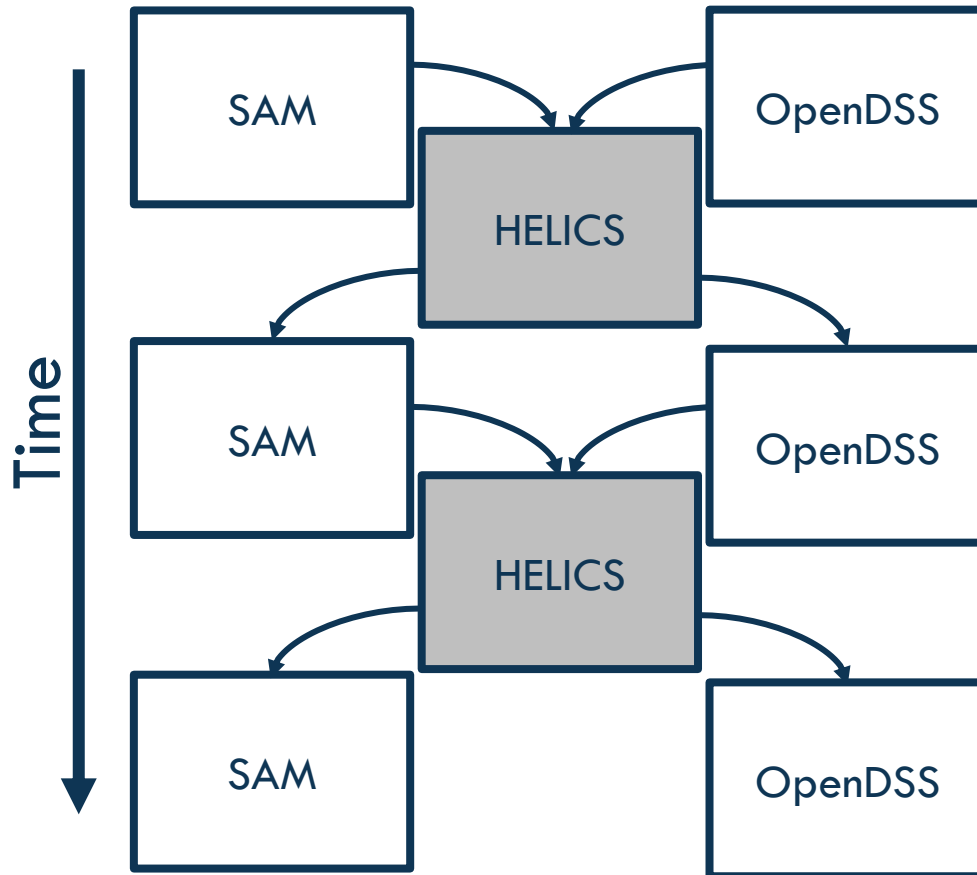
Environment temperature C

Environment temperature C

Model assumes battery with specific heat Cp sits in environment of specified temperature. Heat transfer to room proportional to heat transfer coefficient h



Adding more complex solar + storage layout options, including connecting a battery to a specific inverter input on the DC side



- Co-simulation: multiple models exchanging data as they advance through time
- Allows linking detailed PV+Battery models with large-scale distribution feeder or grid-level simulations
- Requires that PV and Battery models run at a single timestep

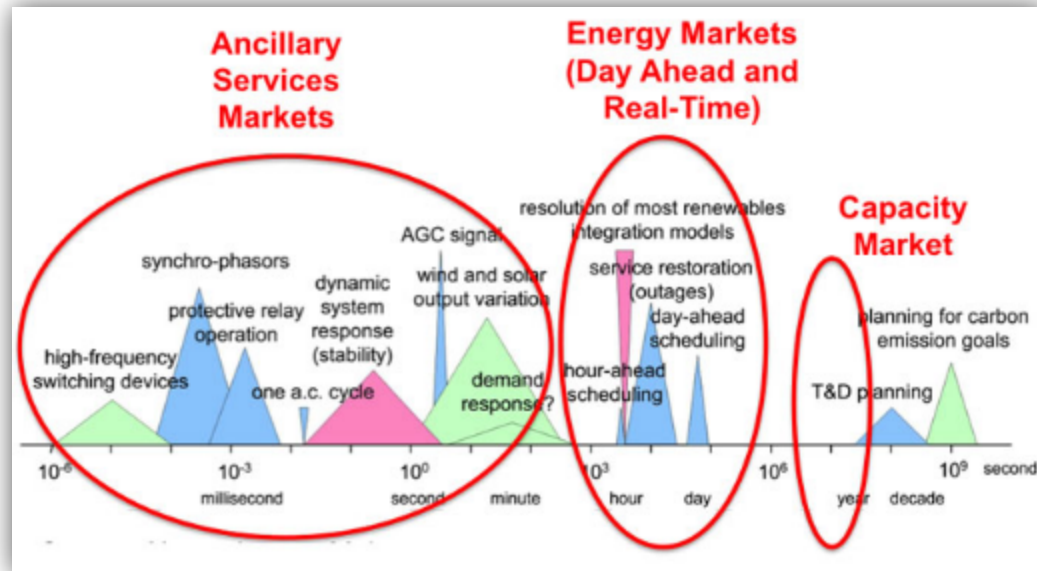


[Image source](#)

Add **resiliency analysis** and metrics, and optimal sizing for resiliency for the PV+Battery models, leveraging the NREL REopt tool



Enable financial models to allow participation in **capacity markets** and allow systems to respond to external price or grid signals and receive compensation for **ancillary services** provided

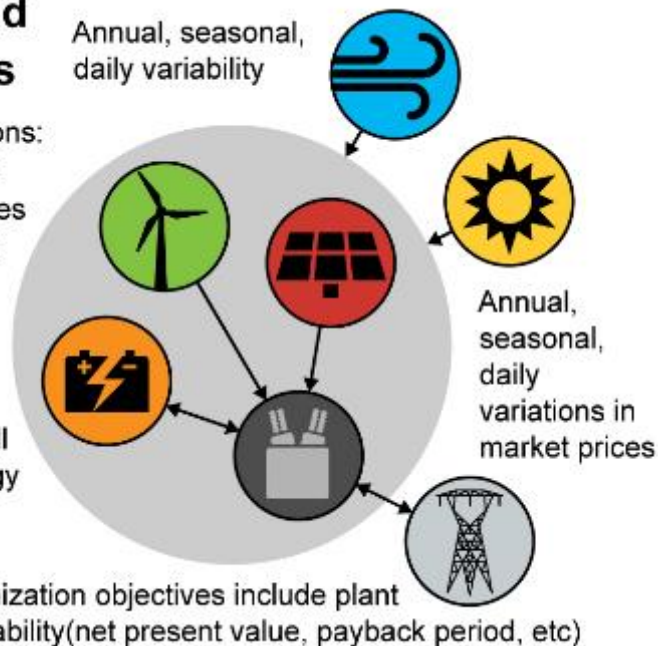


[Image source](#)

Future Hybrid Power Plants

Design Considerations:

- Number, type, and operation of turbines
- Number, type, and operation of solar panels
- Number and type of storage
- Overall layout of all assets and topology and sizing of collection system



Adding capability in SAM to model detailed **wind+solar+storage** systems, leveraging detailed wind system design & optimization of NREL WISDEM tool



Simple calculations for available crop area based on PV system layout and including crop revenue in financial calculations





[Image source](#)

Implementing a
PV+Battery+Fuel Cell model
within SAM

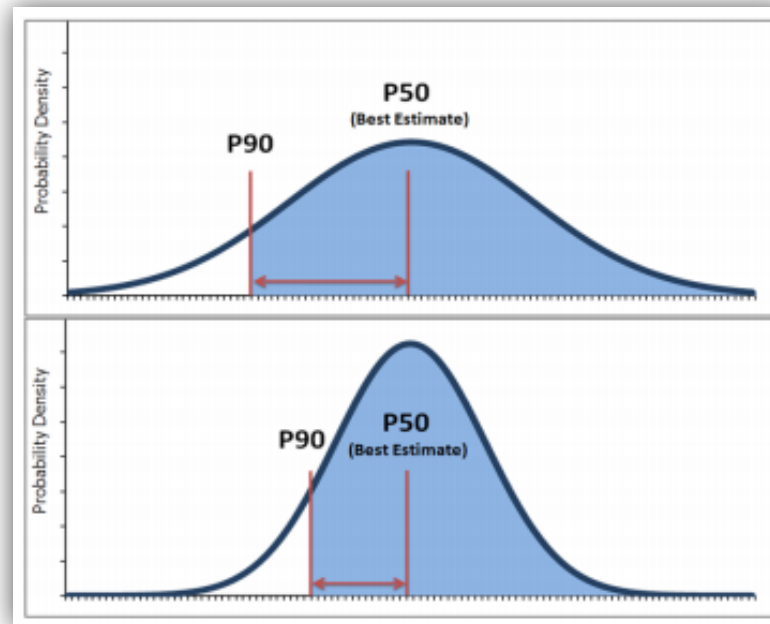
New **Marine Hydrokinetic**
technology model combining
simple performance model and
detailed cost model that can
leverage SAM's existing advanced
features



[Image source](#)



Add detailed **probability of exceedance analysis** framework to SAM wind model, discussing options to add a similar framework to the PV model



[Image source](#)

Project Ideas



- **Crowd-sourced component database**
- Floating PV, BIPV, Transparent/shifted spectrum PV
- Using spectral data from the new spectral NSRDB
- Improved representation of non-linear battery behavior in linear optimization models
- PV+CSP+Battery+Thermal Storage systems

Thank you! Questions?

Janine Freeman - project lead, photovoltaic and wind models

Nick DiOrio - code architecture, battery storage models

Nate Blair - emeritus lead, financials, costs, systems

Darice Guittet – software development, photovoltaic models

Steve Janzou - programming, utility rate structures (subcontractor)

Paul Gilman - user support and documentation (subcontractor)

Ty Neises - concentrating solar power models

Mike Wagner - concentrating solar power models

Matt Boyd- concentrating solar power models

www.nrel.gov

<http://sam.nrel.gov>



Backup Slides



Technologies

- Photovoltaics
 - Detailed & PVWatts
 - Battery Storage
 - Coming soon: Fuel Cell*
 - Wind
 - Concentrating solar power
 - Geothermal
 - Biomass
 - Solar water heating
 - Coming soon: MHK*
-

Financial

- Behind-the-meter
 - residential
 - commercial
 - third-party ownership
- Power purchase agreements
 - single owner
 - equity flips
 - sale-leaseback
- Host/Developer
- Simple LCOE calculator

Other Resources Online

The following information resources about SAM are available.

- [News](#)
- [Webinars](#) (mostly on the SAM YouTube channel)
- [Weather Data](#) (Description of various weather data sources)
- [Sample Files](#) (particularly scripting language examples)
- [Financial Model Documentation](#)
- [Performance Model Documentation](#) (detailed descriptions)
- [System Cost Data](#) (sources and latest cost data discussion)
- [Case Studies and Validation](#) (all data/files from our validations)
- [Libraries and Databases](#) (i.e. module and inverter specs)
- [Source Code](#) (linkages to Open Source code on GitHub)



Built-in parametric, stochastic, probability of exceedance (P50/P90), and scripting features enable complex questions to be answered quickly and easily

Run simulations >

Configure

Input variables: Add... Edit... Remove

Tilt 1 (Normal [20,3])
Azimuth 1 (Normal [180,27])

Correlations: Add... Edit... Remove

Enable weather file analysis DNI Select folder:

Quick setup... Inputs... Outputs... Run simulations >

	subarray_tilt(deg)	subarray_az(deg)	lcoe_real (cents/kWh)
20	200	20	4.84275
21	270	20	5.39946
22	90	30	5.134
23	120	30	4.63881
24	120	30	4.38050
25	108	30	4.17518
26	210	30	4.32793

Run P50/P90 simulations > Select weather file folder: C:\Code\sam-document

	P10	P50	P90
Annual AC energy (kWh)	374402	367119	3541
Inverter clipping loss DC MPPT voltage limits (kWh/yr)	402.66	233.596	114.1
Inverter clipping loss AC power limit (kWh/yr)	1330.57	1044.95	657.2
Inverter power consumption loss (kWh/yr)	597.443	582.173	569.6
Inverter night time loss (kWh/yr)	94.7722	94.6359	94.41
Annual GHI (Wh/m ² /yr)	1.90159e+06	1.85721e+06	1.81115e+06
POA front-side irradiance total nominal (kWh/yr)	2.47032e+06	2.41884e+06	2.33477e+06
POA front-side irradiance beam nominal (kWh/yr)	1.8137e+06	1.751e+06	1.65645e+06
POA front-side irradiance total after shading (kWh/yr)	2.47032e+06	2.41884e+06	2.33477e+06
POA front-side irradiance total after shading and soiling (kWh/yr)	2.3468e+06	2.2979e+06	2.21803e+06
POA front-side irradiance total after cover (kWh/yr)	2.27405e+06	2.2262e+06	2.14926e+06
POA irradiance total after cover (kWh/yr)	2.27405e+06	2.2262e+06	2.14926e+06
POA front-side irradiance beam after shading and soiling (kWh/yr)	1.72301e+06	1.66345e+06	1.57362e+06
Annual DC energy nominal (kWh/yr)	432430	423331	408700

	1.65177e+06	1.54347e+06	1.73167e+06	51579.5	1.73236e+06	1.66624e+06	1.60011e+06
	419033	400764	438995	9051.56	434201	422597	410993

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27



```
New Open Save Save as Find Run >
21 <li> Press 'Run macro' to perform the simulations and create the tornado chart.
22 <li> You can right click on the plot window that pops up to export the data or figure.
23 </ol>
24 @*/
25 // Macro user interface widgets
26 //@ name=inputs;type=inputs;label=Input variables\nto consider;;meta=true;prompt=Specify
27 //@ name=output;type=svoutput;label=Output metric:
28 //@ name=percent;type=number;label=% adjustment;;value=10
29 //@ show_save_load_buttons=true
30
31
32 if ( typeof(macro) == 'unknown' ) {
33     msgbox('This macro must be run from within
34         exit;
35 }
36
37 outvar = macro.output;
38 percent = macro.percent;
39 vars = macro.inputs;
40 if ( #vars == 0 )
41 {
42     msgbox('No input variables selected.');
```

Append Snow Data

Subarray Layout Optimization

System Sizing

Download Electric Load

Value of RE System

Combine Cases

Create a Tornado Chart

Download Weather Files

Siting Considerations

Solar Resource File Checker

Solar Resource File Converter

Solar Resource Interpolation

Run macro >

Create a Tornado Chart

Tornado charts can be a helpful way to visualize sensitivities of a model to various inputs. Creating a tornado chart involves running several simulations decreased and increased independently to see how much a particular output metric changes.

This macro creates a tornado chart like this one based on input ranges you specify:

Instructions:

1. Using the interface at the right, select one or more input variables to consider.
2. Select an output metric to plot on the tornado chart.
3. Specify the percentage change (decrease and increase) to apply to each input variable.

If you wish to specify different adjustments to each input variable, double click the variable or press Edit. In the popup dialog, you may enter:

- A custom percentage decrease and increase, such as "10%" or "23%"
- A custom absolute change, such as "5". If the base case input has a value of 30, values of 25 and 35 will be used.
- A custom absolute changes in both directions, such as "4, 7". If the base case input has a value of 30, values used will be 26 and 37.

4. Press 'Run macro' to perform the simulations and create the tornado chart.
5. You can right click on the plot window that pops up to export the data or figure.

Flexible, lightweight scripting language built in to the SAM desktop tool, allowing users to quickly run custom analyses and read/write to other files

Detailed Cash Flow Financial Models



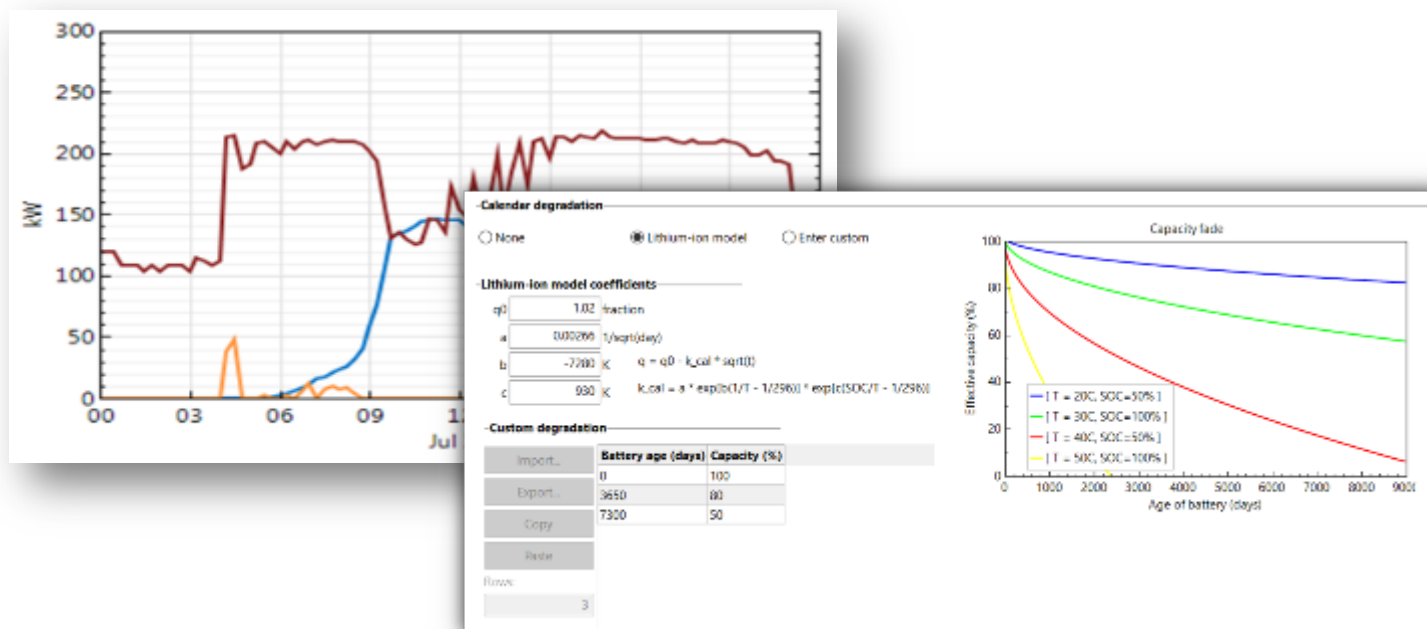
No other tool provides detailed, *time-based* financial modeling across multiple market sectors, including complex utility rates, combined with detailed performance modeling

The screenshot displays the System Advisor Model interface. On the left, a 'TOD factors' panel lists nine periods with values ranging from 0.7036 to 1.4514. Below this is a calendar grid for January to December, with each day's TOD factor color-coded. A time-series chart at the bottom left shows a highly volatile signal. The main window displays a financial summary table with columns for years 0 through 8. The table includes sections for 'PRODUCTION (AC/WH)', 'REVENUES', 'PROPERTY INCOME/EXPENSES', 'OPERATING EXPENSES', and 'DEPRECIATION AND COSTS'. A sidebar on the right lists various model components like 'Photovoltaic Single cover', 'Local and Resource', 'Module', 'Inverter', 'Shading and Layout', 'Losses', 'Lifetime', 'Battery Storage', 'System Costs', 'Financial Parameters', 'Time of Delivery Factors', 'Incentives', 'Depreciation', and 'Electricity Rates'. At the bottom, there are buttons for 'Simulate', 'Parameters', 'Stochastic', and 'PS0 / PS0 Models'.

	0	1	2	3	4	5	6	7	8
PRODUCTION (AC/WH)									
Energy (MWh)	0	21,740,894	22,054,000	22,699,815	23,049,313	23,591,348	24,312,518	24,992	25,992
REVENUES									
PPA price (cents/kWh)	0	6.6673	6.1348	6.8323	6.8701	6.5325	7.0925	7.6725	7.74
PPA revenue (\$)	0	2,485,276	2,481,577	2,507,424	2,526,203	2,532,514	2,543,252	2,577,651	2,570
plus FBT (if available for debt service)									
Subprocessor (\$)	0	0	0	0	0	0	0	0	0
Total revenue (\$)	0	2,485,276	2,481,577	2,507,424	2,526,203	2,532,514	2,543,252	2,577,651	2,570
Property Income/expense value (\$)									
Property Income/expense value (\$)	0	15,764,618	15,764,618	15,764,618	15,764,618	15,764,618	15,764,618	15,764,618	15,764
OPERATING EXPENSES									
O&M fixed expense (\$)	0	0	0	0	0	0	0	0	0
O&M production-based expense (\$)	0	0	0	0	0	0	0	0	0
O&M capacity-based expense (\$)	0	180,000	184,500	185,121	120,000	105,000	205,000	256,154	270
Property tax expense (\$)	0	0	0	0	0	0	0	0	0
Insurance expense (\$)	0	165,000	186,715	185,765	115,483	114,000	119,125	126,857	125
Total operating expenses (\$)	0	265,000	280,615	290,886	235,483	219,000	324,125	382,811	295
DEPRECIATION AND COSTS									
MACRS 5-yr	22,712	25,425,774.00	0	0	20,428,774.00	25,425,774.00	100.00	0	
MACRS 15-yr	110	68,168.75	0	0	58,268.75	0	0	0	
Straight Line 5-yr	0	0	0	0	0	0	0	0	
Straight Line 15-yr	233	267,418.28	0	0	267,418.28	0	0	0	
Straight Line 20-yr	619	68,168.75	0	0	68,168.75	0	0	0	
Straight Line 41-yr	0	0	0	0	0	0	0	0	



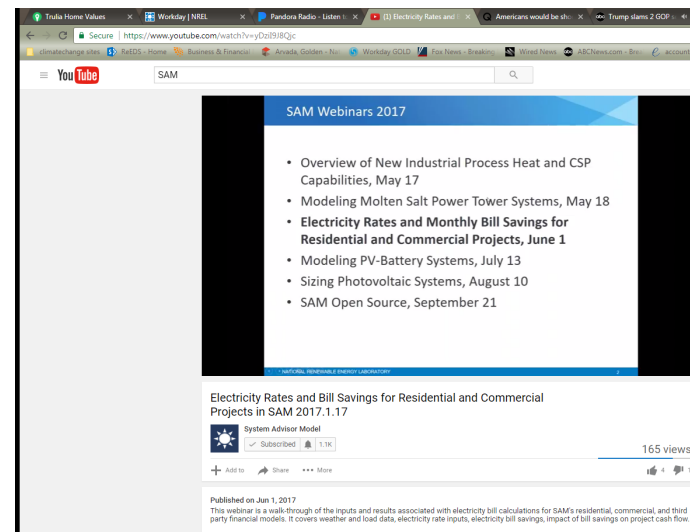
Only publicly available tool with detailed battery model that accounts for voltage characteristics, calendar and cycle degradation, etc



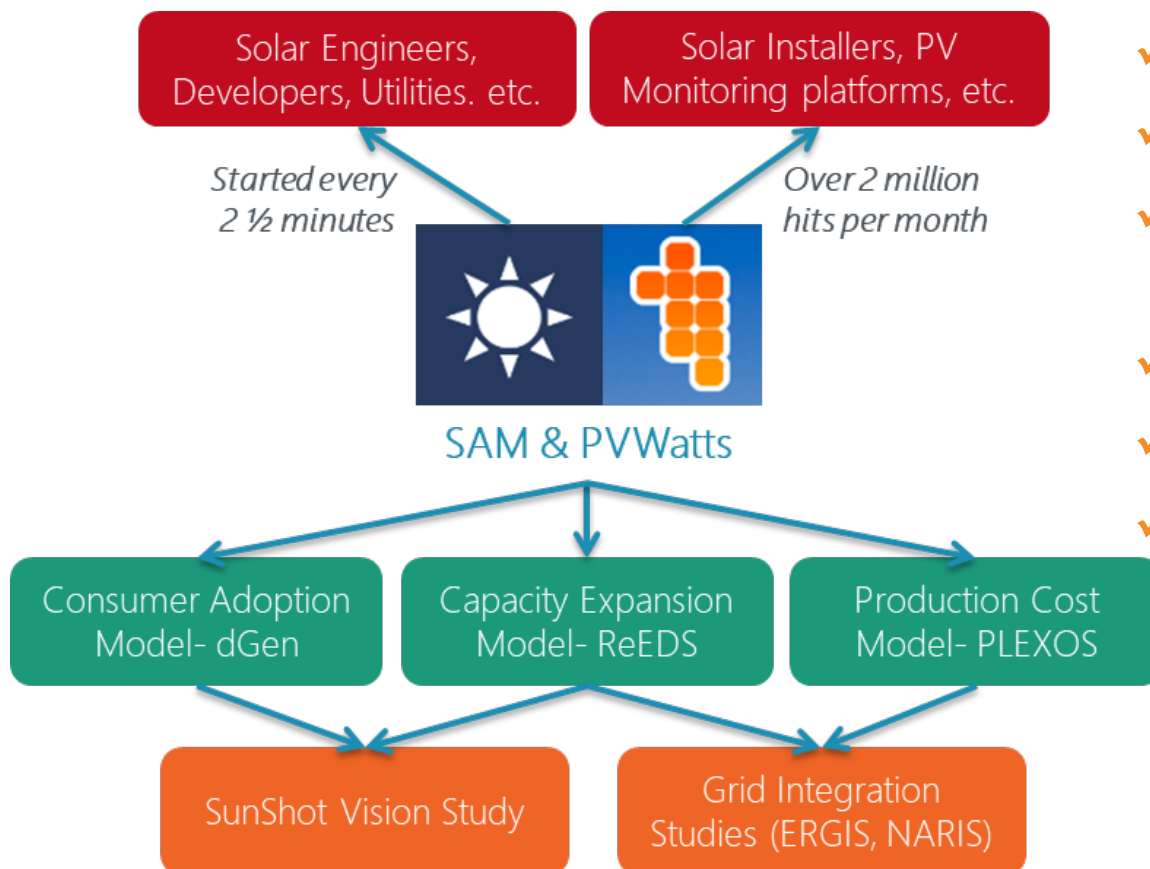
- ✓ Currently integrated with PV and “Generic System” model
- ✓ Available on DC or AC side of PV system
- ✓ Multiple automated dispatch strategies for different markets
- ✓ Behind-the-meter or front-of-the-meter operation

Extensive Help Documentation

- Website – <http://sam.nrel.gov>
 - Support Forum – Ask your question!
 - General info/ online help file / contact info
- YouTube Channel
 - <https://www.youtube.com/user/SAMDemoVideos>
 - All prior webinars and seminars
- Bi-Monthly Round Table sessions
 - SAM team asks questions live and interactively
- Email Support
 - SAM support can provide email support if question/bug is involved



How does SAM fit in at NREL and externally?



- ✓ Grid integration studies
- ✓ Renewable energy futures
- ✓ LCOE of breakthrough technologies
- ✓ Policy and utility rate design
- ✓ Technical potential studies
- ✓ Commercial applications (e.g. Southern Company, AEP, Sunrun)