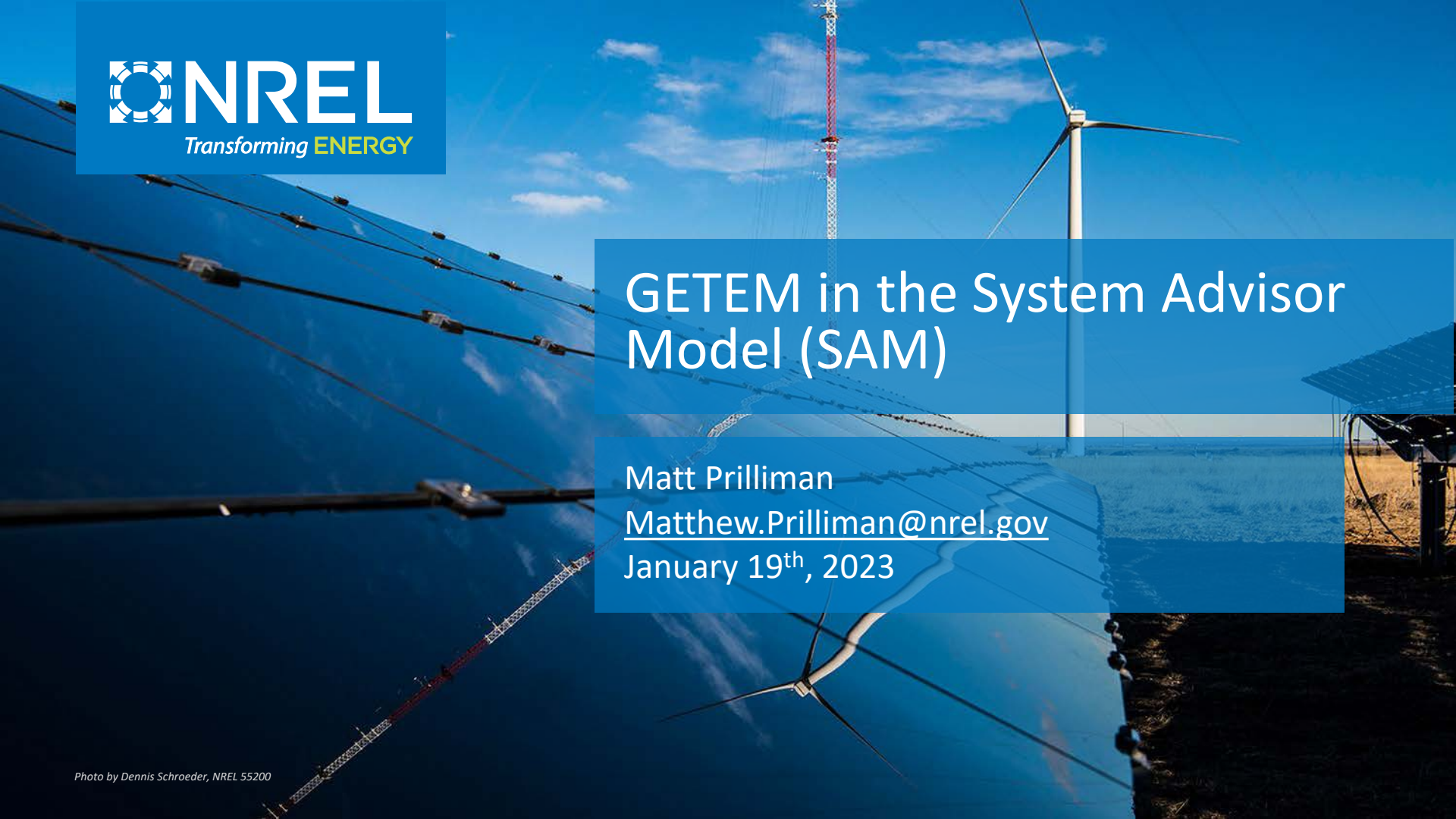


GETEM in the System Advisor Model (SAM)

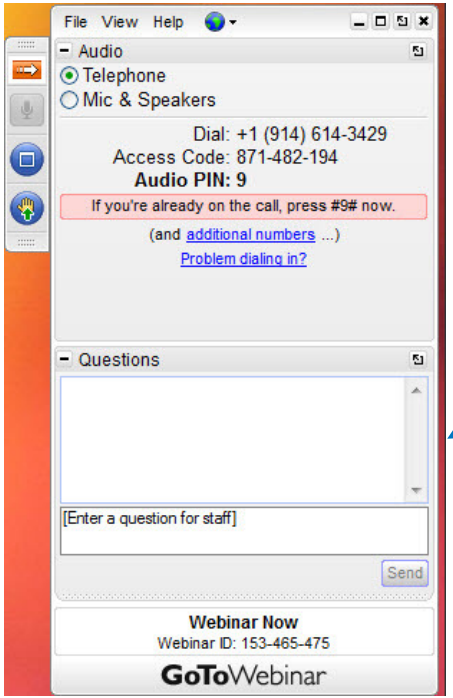
Matt Prilliman
Matthew.Prilliman@nrel.gov
January 19th, 2023

Photo by Dennis Schroeder, NREL 55200

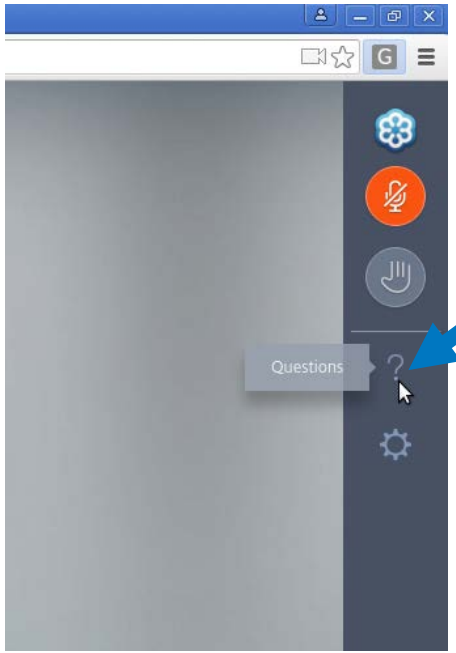
Agenda

1. Introduction to SAM
2. Who uses SAM?
3. Advanced SAM features
4. Introduction to GETEM
5. SAM GETEM inputs and outputs
6. Live SAM Demonstration
7. Q&A

Questions and Answers



Desktop application



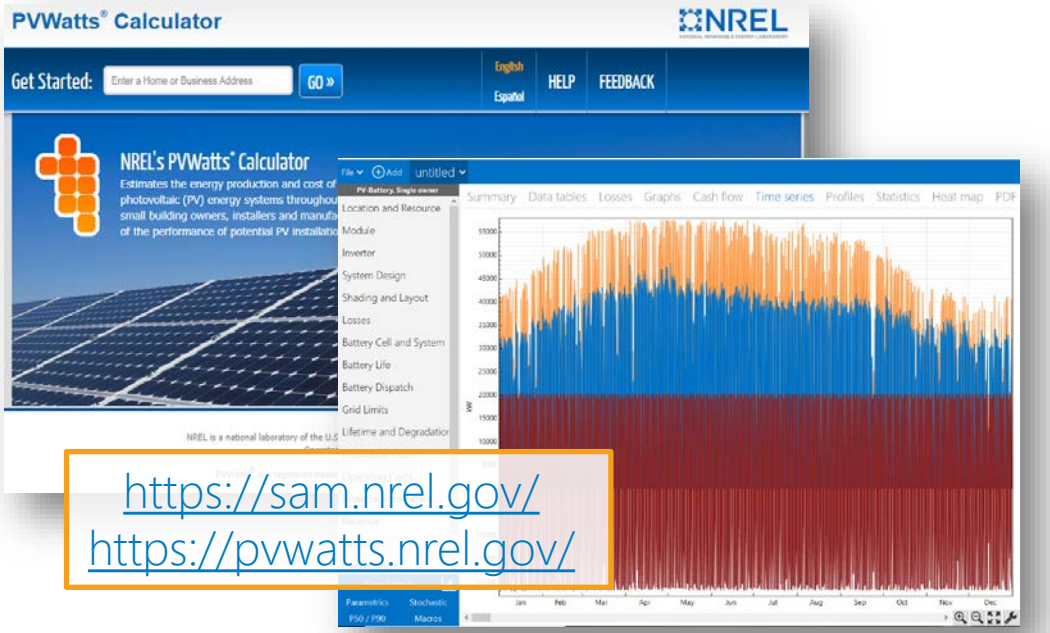
Instant Join Viewer

We will either type an answer to your question or answer it at the end of the presentation.

Find webinar recordings at https://sam.nrel.gov/

System Advisor Model (SAM) & PVWatts

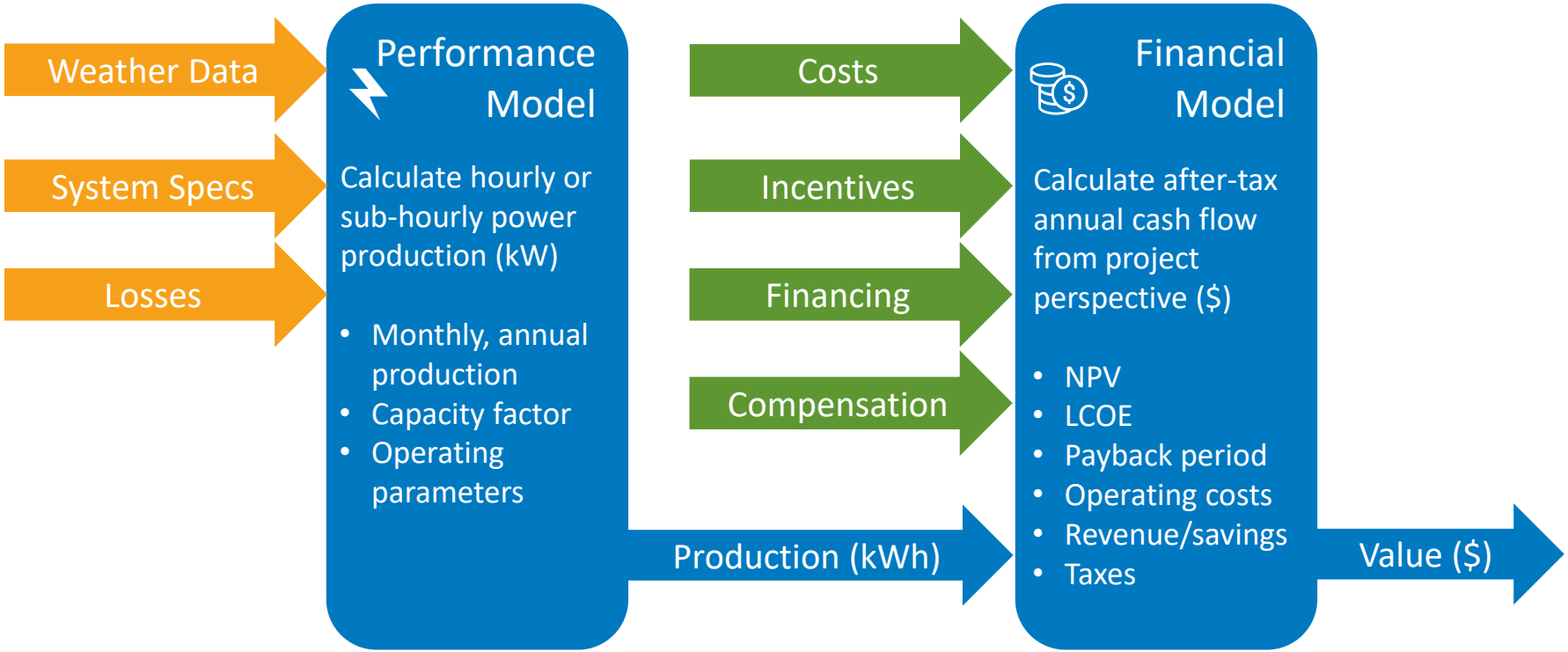
Free software that enable detailed performance and financial analysis for renewable energy systems



https://sam.nrel.gov/
https://pvwatts.nrel.gov/

- ✓ Desktop application
- ✓ PVWatts web tool & API
- ✓ Software development kit
- ✓ PySAM Python package
- ✓ Open source code
- ✓ Extensive documentation
- ✓ User support

Model Structure



Technologies

- Photovoltaic
- Energy storage
  - Electric battery
  - Electric thermal storage
- Concentrating solar power
- Industrial process heat
- Marine energy
- Wind power
- Fuel cell
- Geothermal power
- Solar water heating
- Biomass combustion
- Generic system

Financial Models

- Power purchase agreements
  - Single owner
  - Partnership flips
  - Sale leaseback
- Residential
- Commercial
- Third party ownership
- Merchant plant
- Community solar
- Simple LCOE calculator

History

Developed by

- Department of Energy
- National Renewable Energy Laboratory
- Sandia National Laboratories

Original vision in 2004

- Allow DOE to make R&D choices based on analysis of the entire system including costs
- Model different renewable energy projects in a single platform
- Facilitate technology comparison by handling performance, costs and financing consistently across technologies

Some Applications

- Feasibility studies, benchmarking for other models, research projects, plant acceptance testing, evaluation of grant proposals

SAM Users

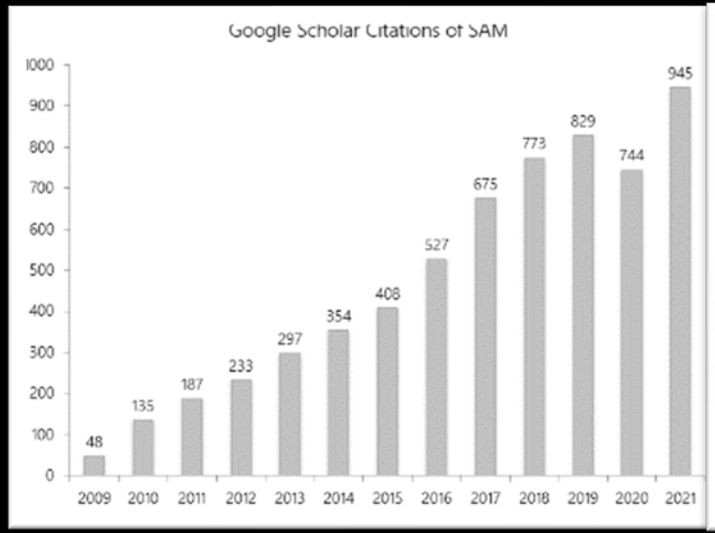
SAM is started **once every 1.4 minutes**

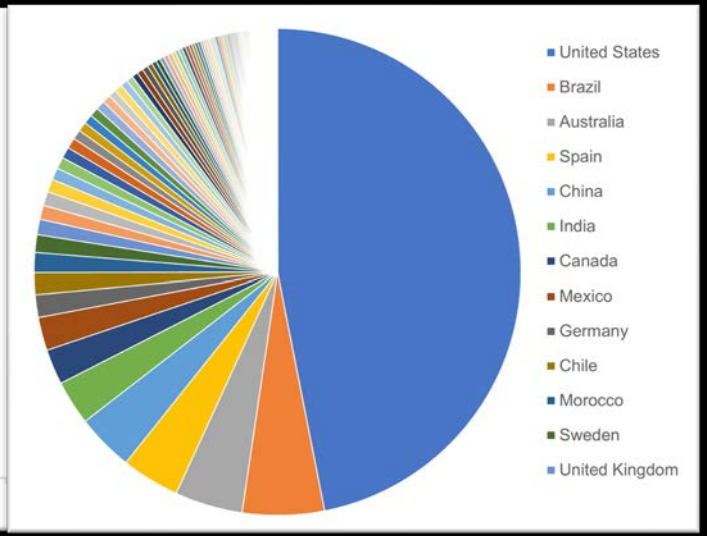
PVWatts receives over **17.5 million hits per month**

Over **150,000** users in 190+ countries

120+ webinars with **over 280,000 views**

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

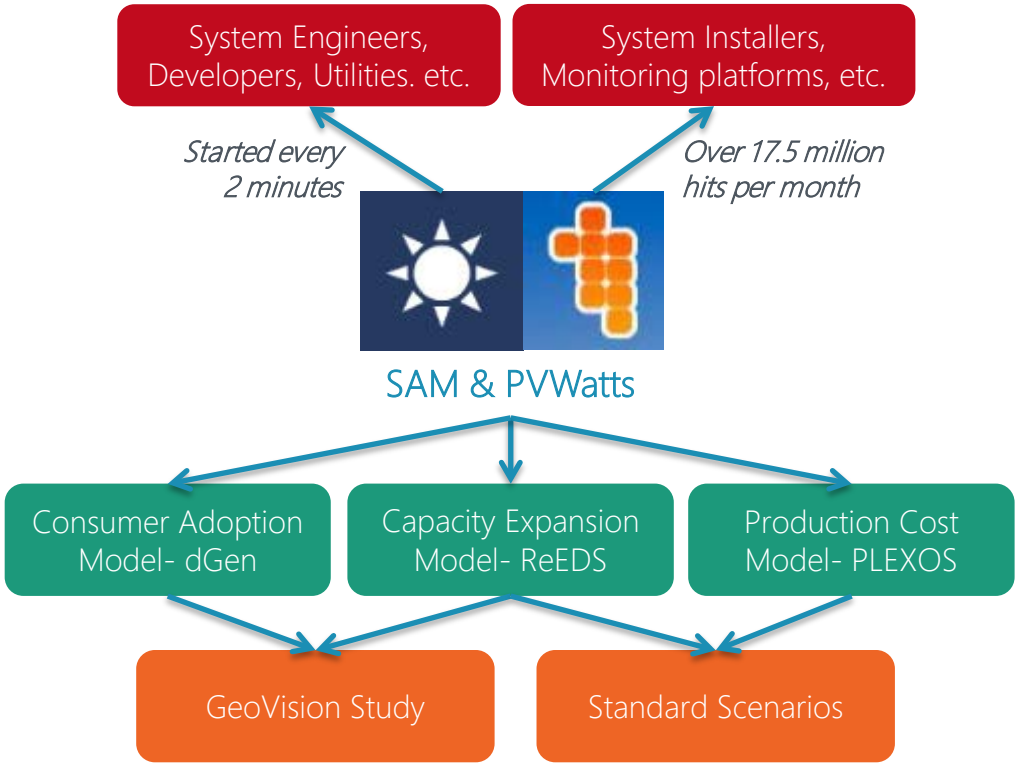




Who Uses SAM? Why?

- **Lawmakers and Utilities**
  … to study how a policy would affect the economics of a typical system
  … to analyze different types of utility rate structures for renewables
- **Developers and Engineers**
  … to compare technologies, sites, or configurations
  … to estimate the Levelized Cost of Energy for a system
- **Researchers**
  … to examine how an innovative concept might be able to lower the Levelized Cost of Energy
  … to estimate the technical potential of a technology in a region
- **Students**
  … to learn about renewable energy
  … to explore financing structures for renewable energy

How SAM Fits in at NREL and Externally

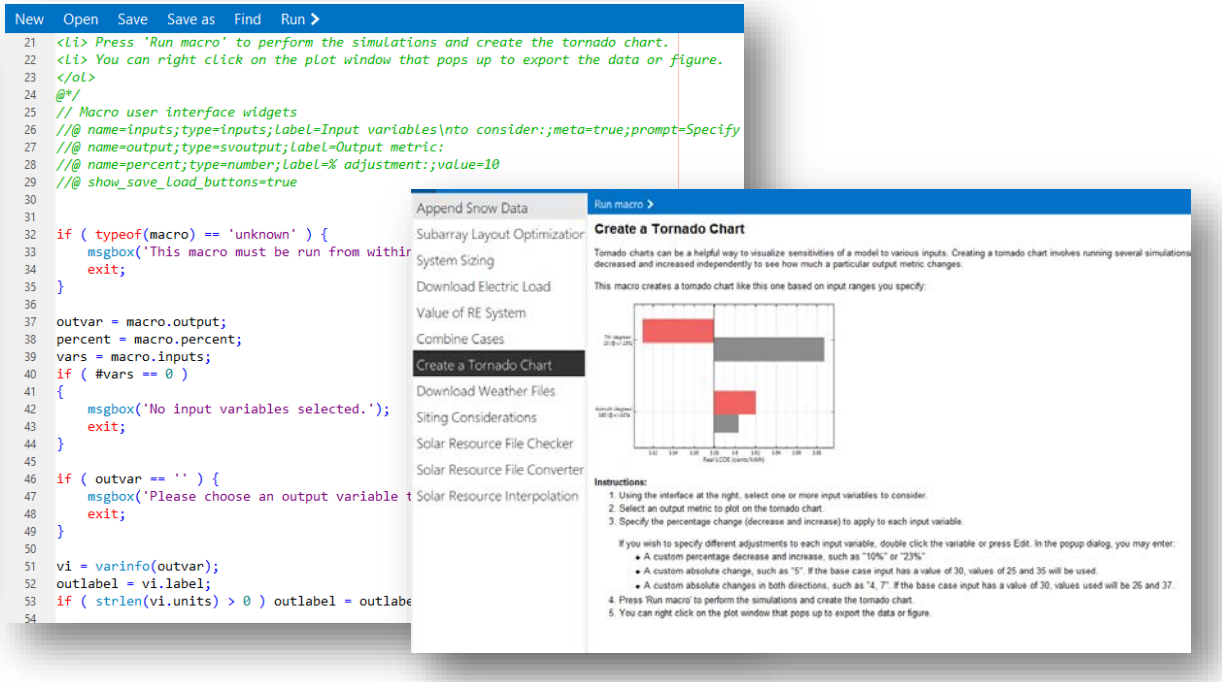


- ✓ Grid integration studies
- ✓ Renewable energy futures
- ✓ LCOE of breakthrough technologies
- ✓ Policy and utility rate design
- ✓ Technical potential studies
- ✓ Commercial applications (e.g. Southern Company, AEP, Sunrun)

How can you access SAM models?

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

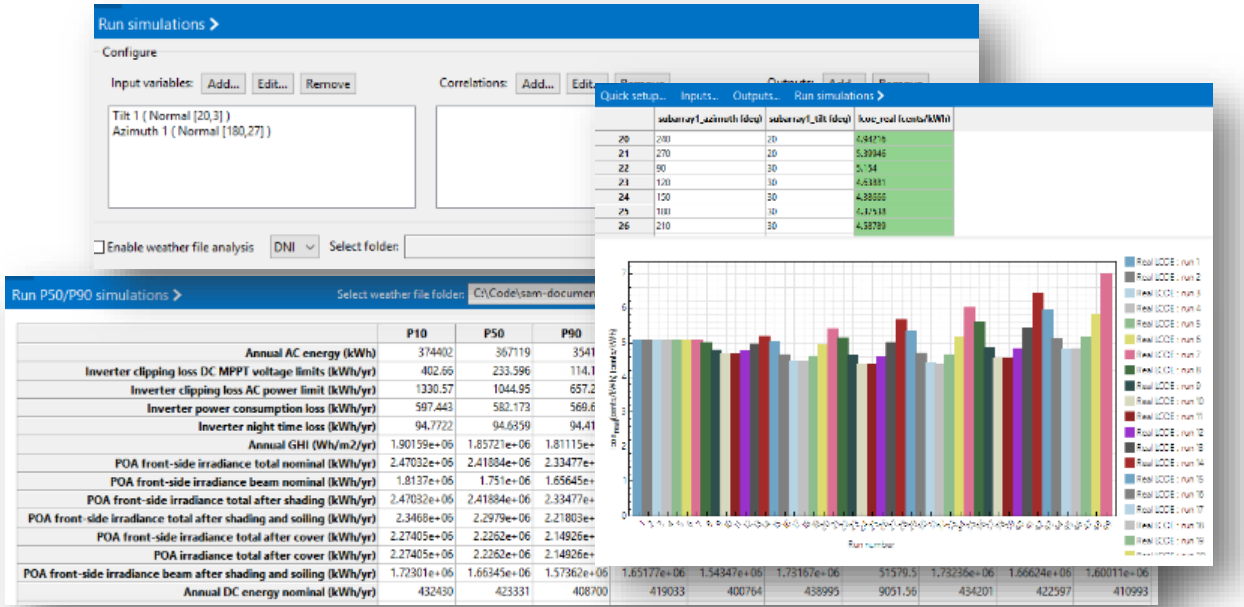
Built in Scripting Language and Macros



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

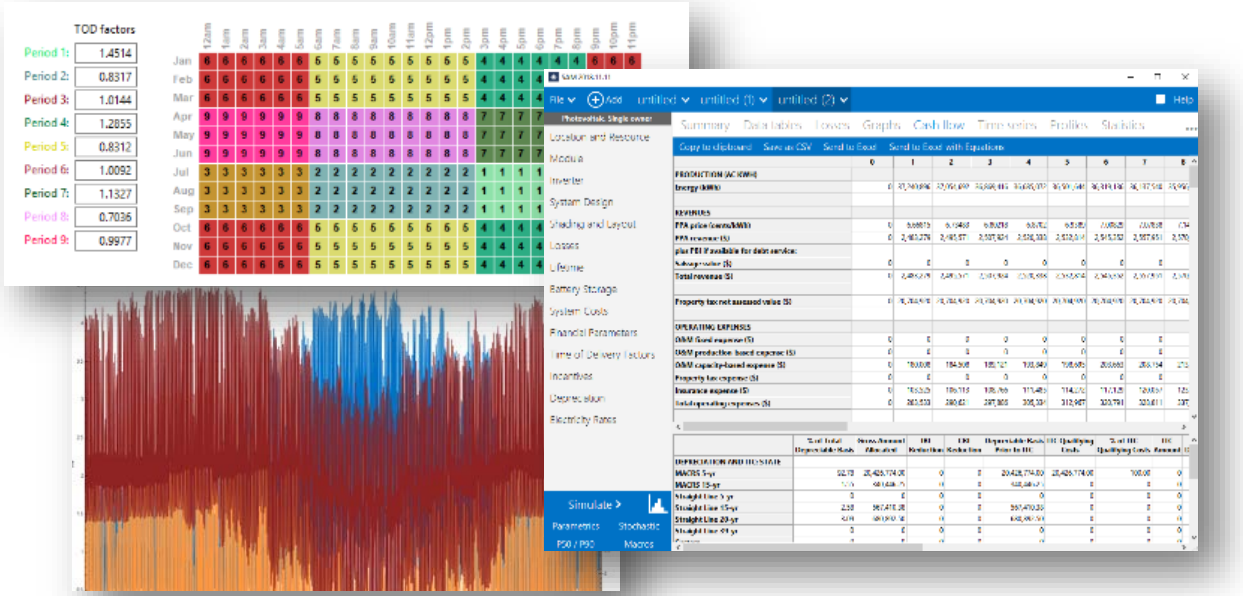
Advanced Analysis Features

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

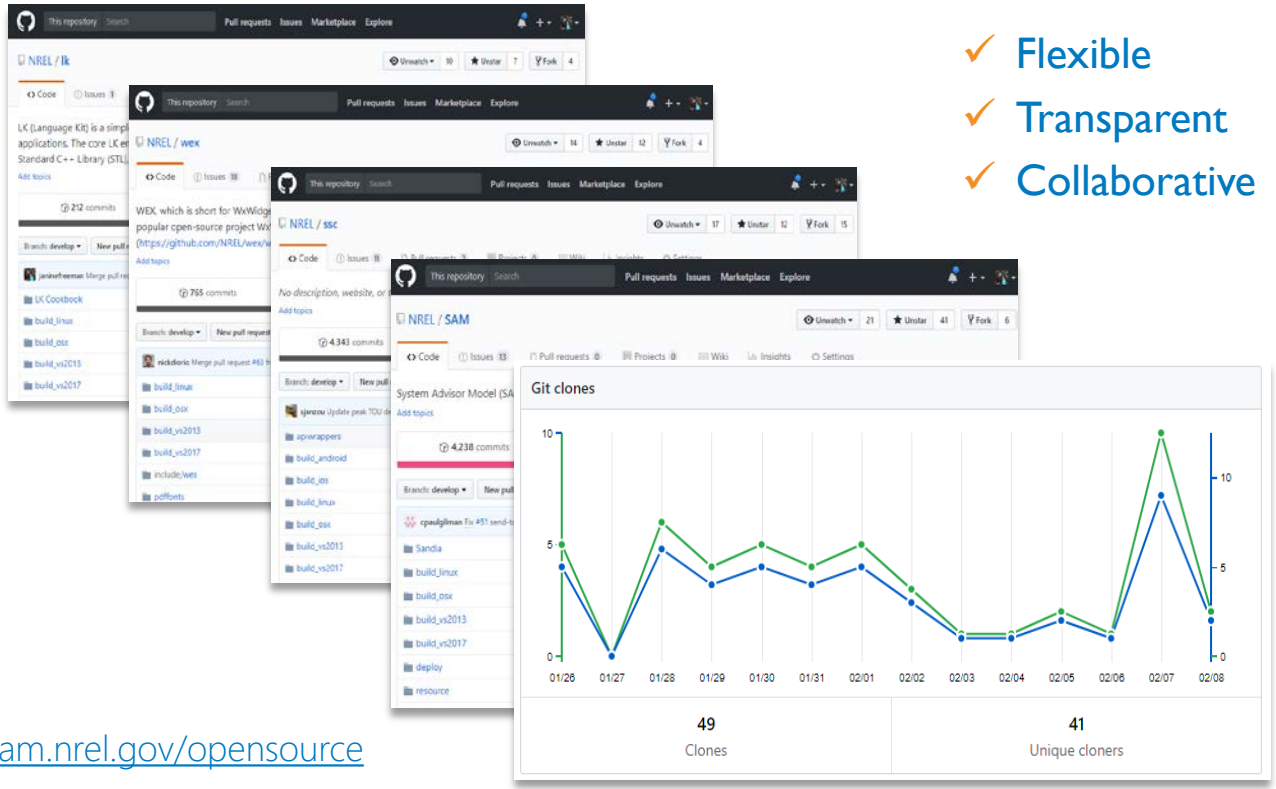


Detailed Cash Flow Financial Models

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



Open Source Code

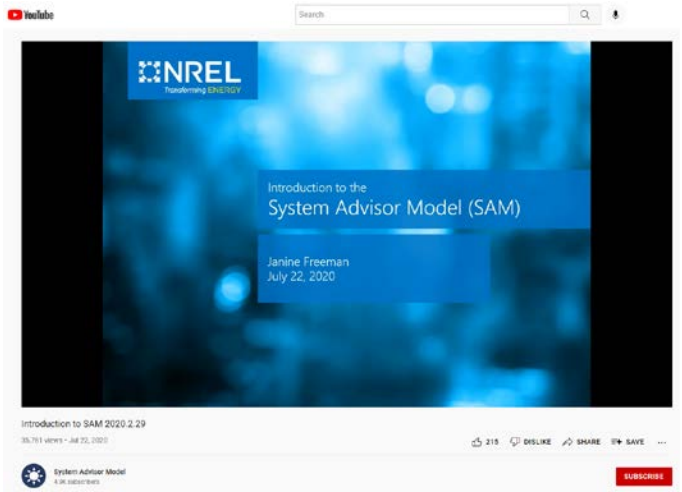


- ✓ Flexible
- ✓ Transparent
- ✓ Collaborative

http://sam.nrel.gov/opensource

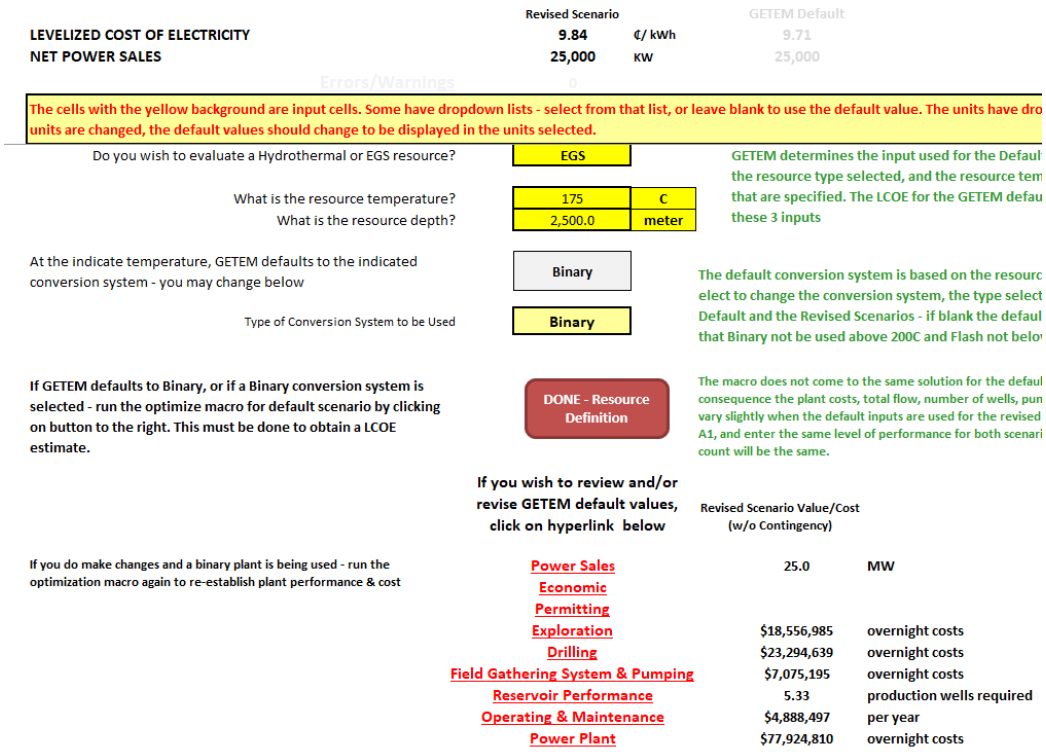
Extensive Help Documentation

- 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



Geothermal Electricity Technology Evaluation Model

- Performance and Financial calculations for geothermal power projects
- Excel model with LCOE calculations
- Greenfield and Brownfield projects
- Developed by Greg Mines (INL)



	Revised Scenario		GETEM Default
LEVELIZED COST OF ELECTRICITY	9.84	¢/ kWh	9.71
NET POWER SALES	25,000	kW	25,000
Errors/Warnings	0		

The cells with the yellow background are input cells. Some have dropdown lists - select from that list, or leave blank to use the default value. The units have dro
units are changed, the default values should change to be displayed in the units selected.

Do you wish to evaluate a Hydrothermal or EGS resource?	EGS	
What is the resource temperature?	175	C
What is the resource depth?	2,500.0	meter
At the indicate temperature, GETEM defaults to the indicated conversion system - you may change below	Binary	
Type of Conversion System to be Used	Binary	

GETEM determines the input used for the Defaul
the resource type selected, and the resource tem
that are specified. The LCOE for the GETEM defau
these 3 inputs

The default conversion system is based on the resourc
elect to change the conversion system, the type select
Default and the Revised Scenarios - if blank the defaul
that Binary not be used above 200C and Flash not belo

If GETEM defaults to Binary, or if a Binary conversion system is selected - run the optimize macro for default scenario by clicking on button to the right. This must be done to obtain a LCOE estimate.

DONE - Resource Definition

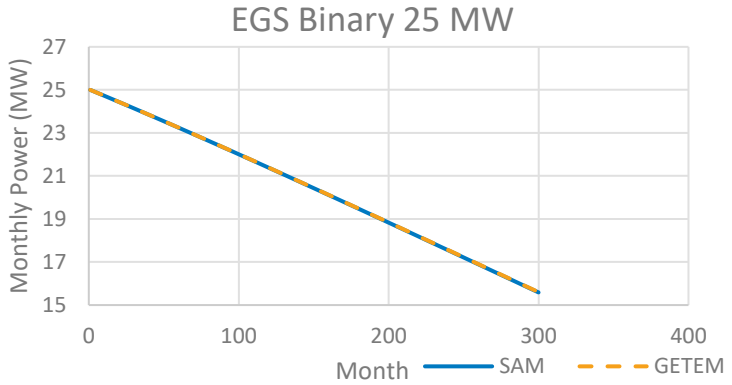
The macro does not come to the same solution for the defaul
consequence the plant costs, total flow, number of wells, pun
vary slightly when the default inputs are used for the revised
A1, and enter the same level of performance for both scenari
count will be the same.

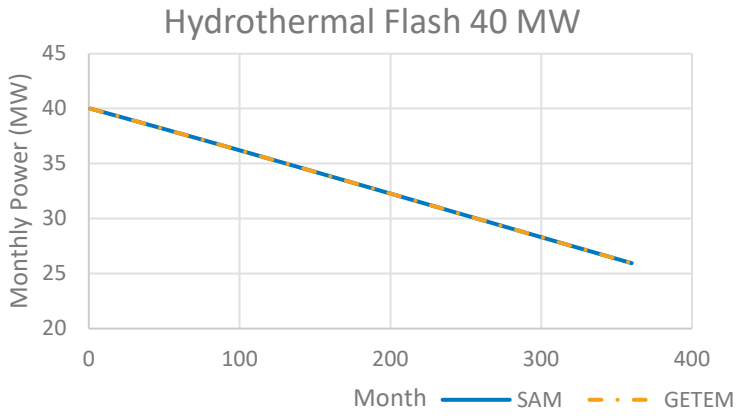
If you do make changes and a binary plant is being used - run the optimization macro again to re-establish plant performance & cost

If you wish to review and/or revise GETEM default values, click on hyperlink below	Revised Scenario Value/Cost (w/o Contingency)	
Power Sales	25.0	MW
Economic		
Permitting		
Exploration	$18,556,985	overnight costs
Drilling	$23,294,639	overnight costs
Field Gathering System & Pumping	$7,075,195	overnight costs
Reservoir Performance	5.33	production wells required
Operating & Maintenance	$4,888,497	per year
Power Plant	$77,924,810	overnight costs

GETEM in SAM

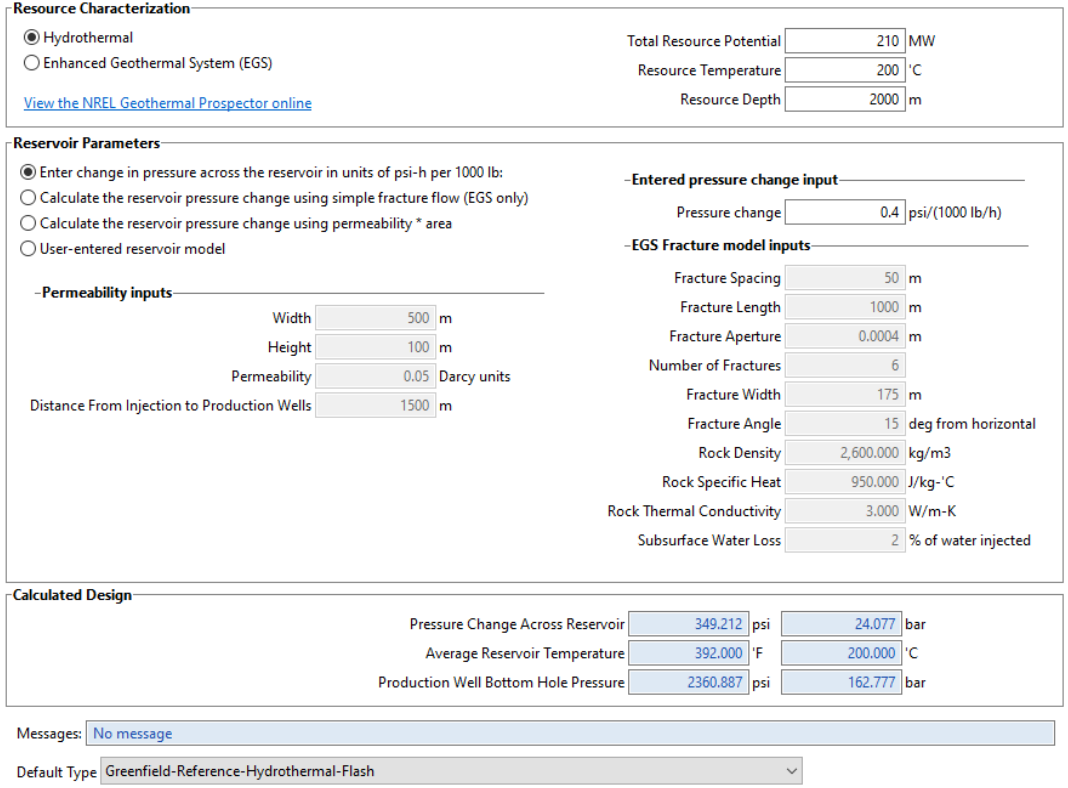
- GETEM implemented in SAM for technoeconomic analysis
- Updated in 2021-2022 to latest version of Excel model
  - Pump work calculations
  - User-defined reservoir model
  - Temperature loss in well bore
- Potential for future development
- Validated for power output in key example cases





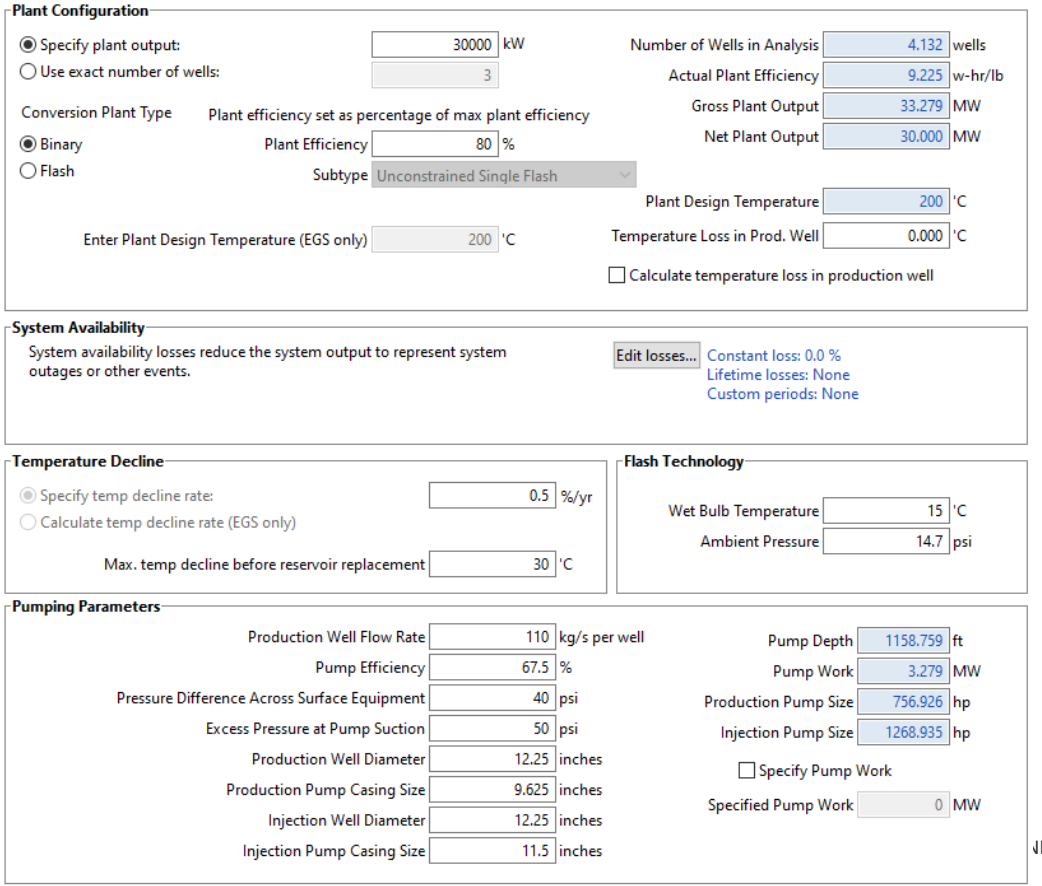
GETEM SAM – Geothermal Resource

- Define geothermal reservoir
- Pressure, temperature changes in reservoir
- Hydrothermal or EGS resource
- New: User-entered reservoir tables
- New: Default system spec dropdown list



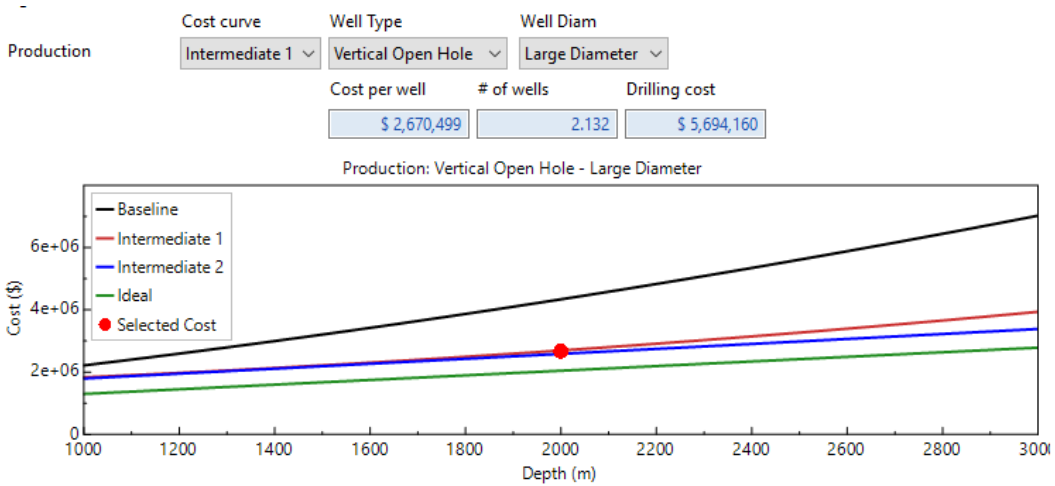
GETEM SAM – Plant and Equipment

- Binary and Flash technologies
- Specified plant output
- Thermal decline
- Pumping requirements (parasitic loads)
- New: equation for temperature loss in production well



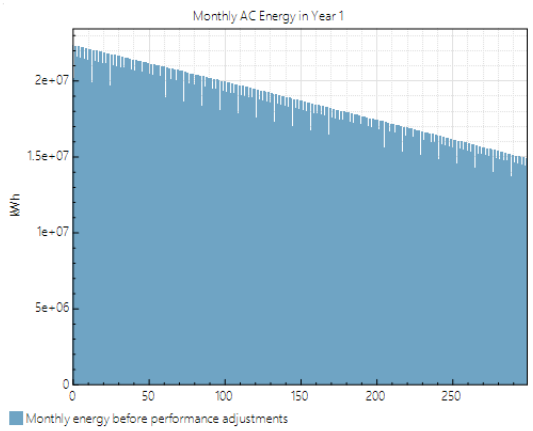
GETEM SAM – Costs

- Production and Injection drilling cost curves
- Plant cost calculator
- PPI Indices
- Drilling cost curves: generated from the Well Cost Simplified (WCS) model developed by Sandia
- GeoVision Reservoir Maintenance and Development taskforce report (https://doi.org/10.2172/1394062)



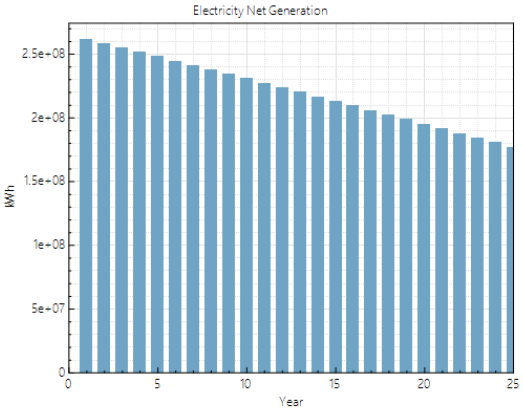
GETEM SAM – Energy Outputs

- Performance metrics: annual, monthly, hourly energy output
- Graph time series outputs, export data to csv or image files



Lifetime Monthly Data

	Monthly avg resource temperature (C)	Monthly power (kW)
1	200	30000
2	199.917	29969
3	199.833	29937.9
4	199.75	29906.8
5	199.667	29875.7
6	199.584	29844.6
7	199.501	29813.4
8	199.417	29782.2
9	199.334	29751
10	199.251	29719.7
11	199.168	29688.5
12	199.085	29657.2
13	199.002	29625.8
14	198.919	29594.5
15	198.836	29563.1
16	198.754	29531.7
17	198.671	29500.3
18	198.588	29468.9
19	198.505	29437.4
20	198.423	29405.9
21	198.34	29374.4
22	198.257	29342.8
23	198.175	29311.3
24	198.092	29279.7
25	198.01	29248.1
26	197.927	29216.4
27	197.845	29184.8
28	197.762	29153.1
29	197.68	29121.4
30	197.597	29089.6
31	197.515	29057.9
32	197.433	29026.1
33	197.35	28994.3
34	197.268	28962.5
35	197.186	28930.6
36	197.104	28898.7
37	197.022	28866.8



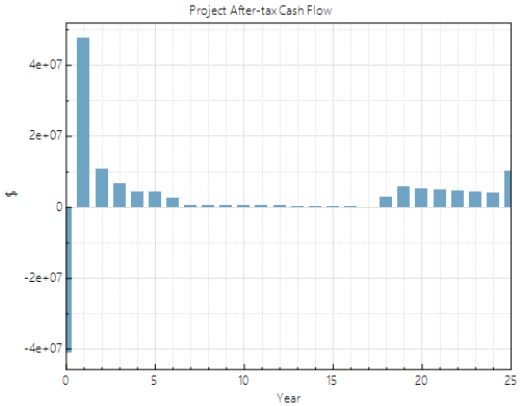
GETEM SAM – Financial Outputs

- Key metrics such as LCOE, NPV, IRR, etc…
- Detailed annual cash flows

Copy to clipboard | Save as CSV | Send to Excel | Send to Excel with Equations

	0	1	2	3	4	5	6	7
Property tax net assessed value ($)	0	126,031,312	126,031,312	126,031,312	126,031,312	126,031,312	126,031,312	126,031,312
OPERATING EXPENSES								
O&M fixed expense ($)	0	0	0	0	0	0	0	0
O&M production-based expense ($)	0	0	0	0	0	0	0	0
O&M capacity-based expense ($)	0	5,823,764	5,969,358	6,118,592	6,271,556	6,428,346	6,589,054	6,753,780
Electricity purchase ($)	0	0	0	0	0	0	0	0
Property tax expense ($)	0	1,260,313	1,260,313	1,260,313	1,260,313	1,260,313	1,260,313	1,260,313
Insurance expense ($)	0	630,157	645,910	662,058	678,610	695,575	712,964	730,788
Total operating expenses ($)	0	7,714,234	7,875,582	8,040,963	8,210,479	8,384,234	8,562,331	8,744,882
EBITDA ($)	0	13,189,235	12,970,898	12,742,768	12,504,747	12,256,733	11,998,622	11,730,310
OPERATING ACTIVITIES								
EBITDA ($)	0	13,189,235	12,970,898	12,742,768	12,504,747	12,256,733	11,998,622	11,730,310
Interest earned on reserves ($)	0	111,624	111,582	111,519	111,434	111,328	111,200	111,051
plus PBI if not available for debt service:								
Federal PBI income ($)	0	0	0	0	0	0	0	0

Metric	Value
Annual AC energy (year 1)	261,293,360 kWh
Capacity factor (year 1)	99.4%
PPA price in Year 1	8.00 ¢/kWh
PPA price escalation	1.00 %/year
LPPA Levelized PPA price nominal	8.61 ¢/kWh
LPPA Levelized PPA price real	6.95 ¢/kWh
LCOE Levelized cost of energy nominal	7.23 ¢/kWh
LCOE Levelized cost of energy real	5.83 ¢/kWh
NPV Net present value	$31,716,692
IRR Internal rate of return	47.12 %
Year IRR is achieved	20
IRR at end of project	47.13 %
Net capital cost	$150,127,072
Equity	$41,219,976
Size of debt	$108,907,088
Debt percent	72.54%



Live SAM Demo

www.nrel.gov

Photo from iStock-627281636

NREL Transforming ENERGY

45Th anniversary

NREL Transforming ENERGY | 45Th anniversary

Thank you! Questions?

Janine (Freeman) Keith – project lead, photovoltaic and wind models
Nate Blair – emeritus lead, financials, costs, systems
Darice Guittet – software development, battery models
Brian Mirletz – software development, costs, battery models
Matt Prilliman – photovoltaic, geothermal, and marine energy models
Steve Janzou – programming, utility rates, financials (subcontractor)
Paul Gilman – user support and documentation (subcontractor)
Ty Neises – concentrating solar power models
Matt Boyd – concentrating solar power models

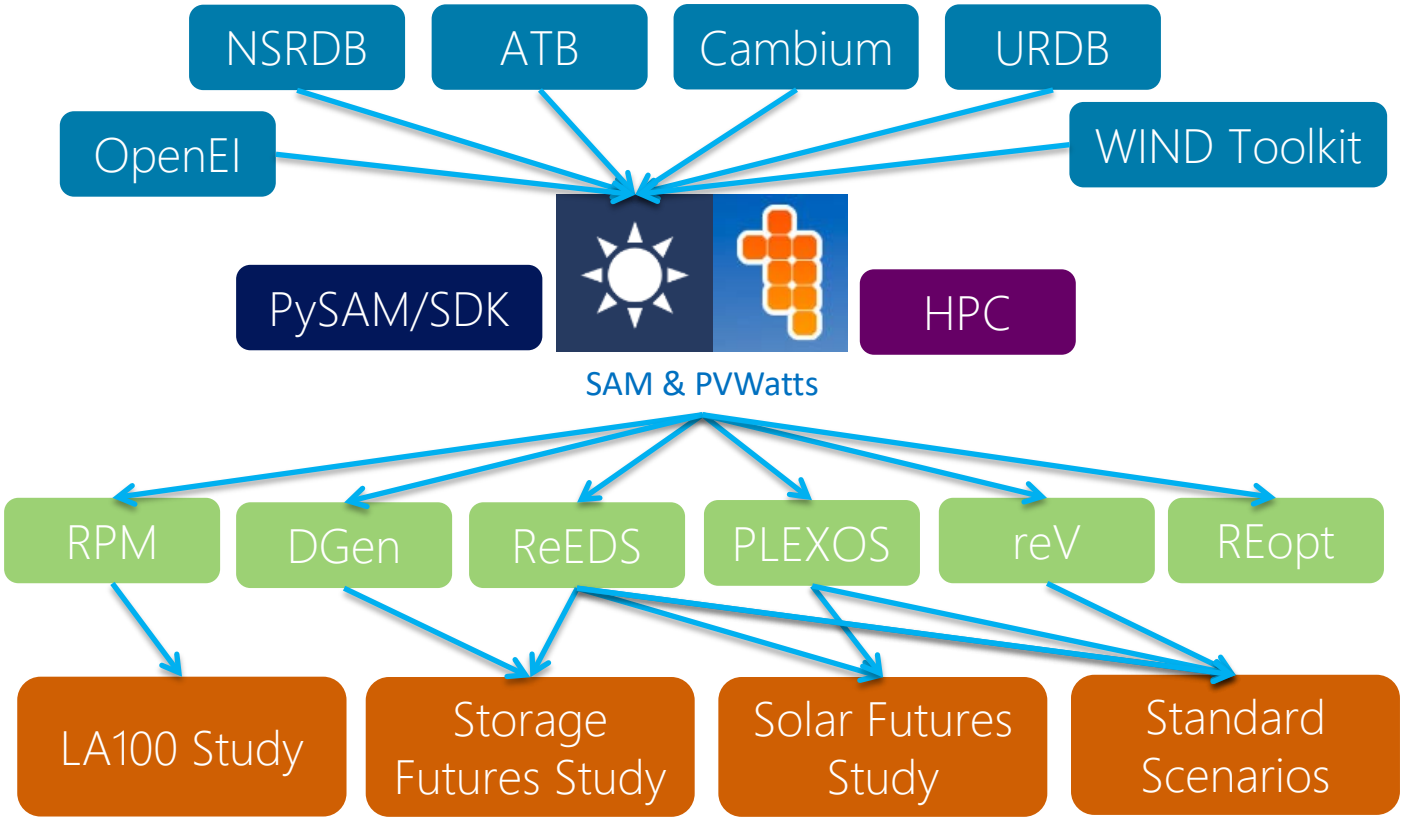
Photo from iStock-627281636

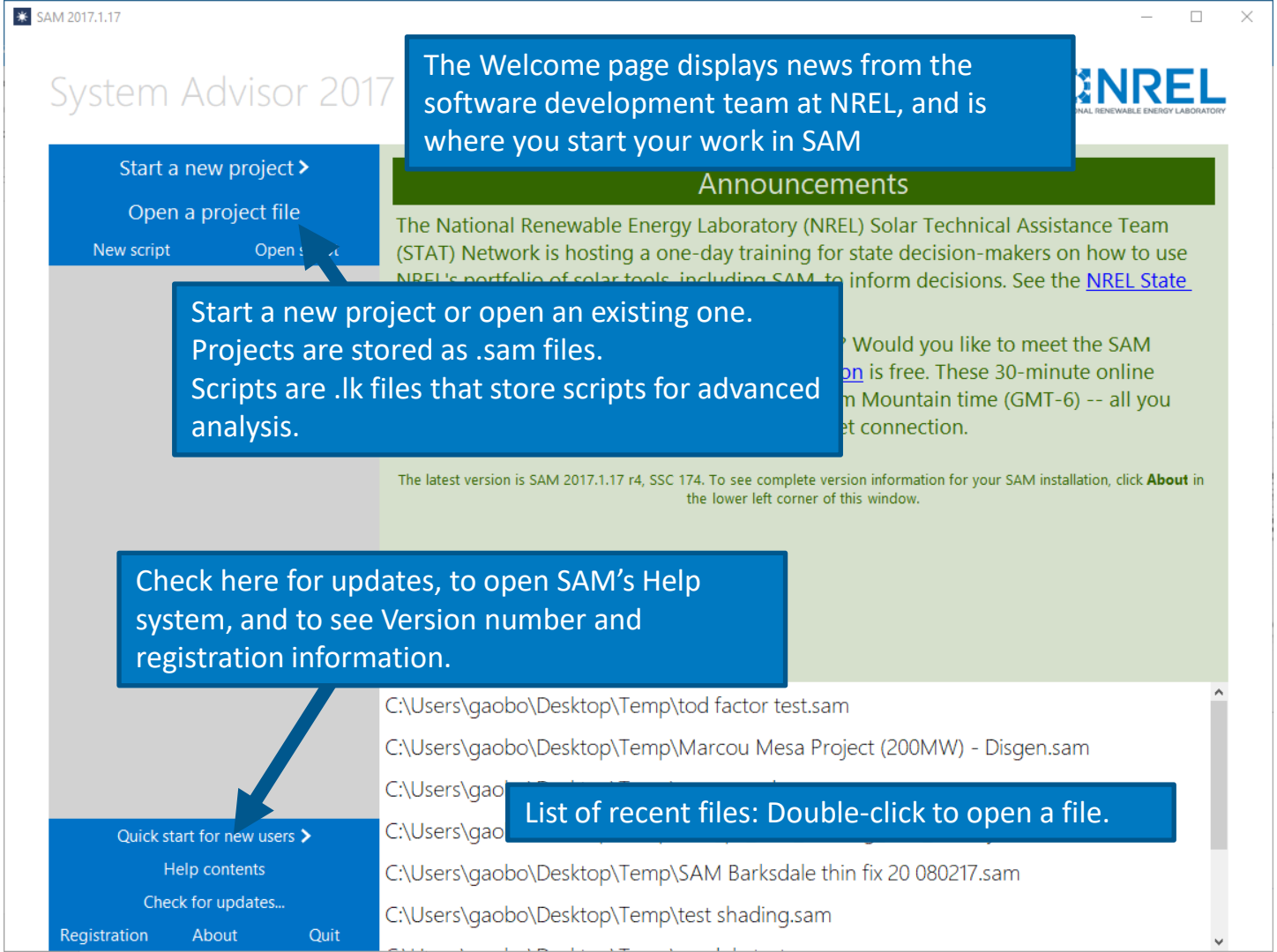
Other Resources Online

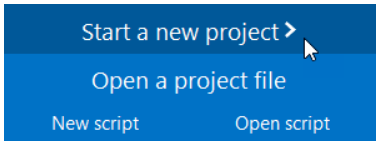
The following information resources about SAM are available.

- 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)

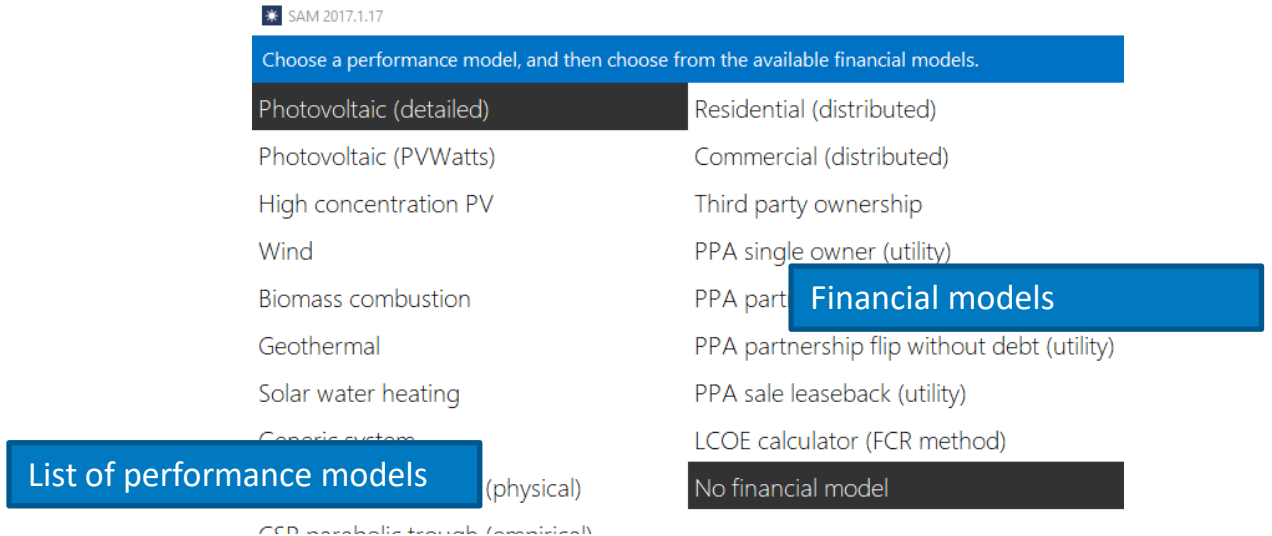
A Partial Web of NREL Data & Tools



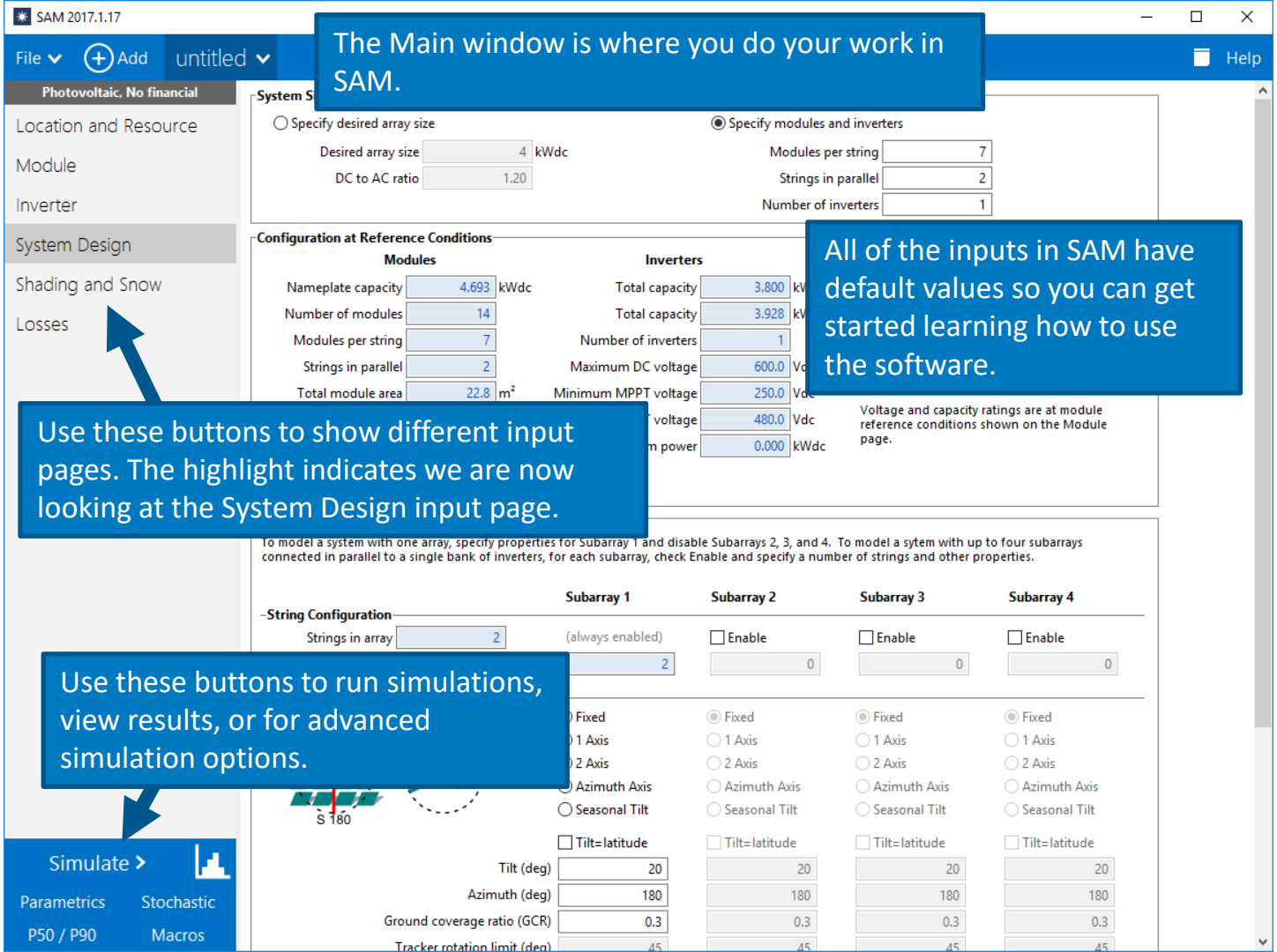

SAM 2017.1.17
System Advisor 2017
NREL
The Welcome page displays news from the software development team at NREL, and is where you start your work in SAM
Start a new project
Open a project file
New script
Open
Announcements
The National Renewable Energy Laboratory (NREL) Solar Technical Assistance Team (STAT) Network is hosting a one-day training for state decision-makers on how to use
to inform decisions. See the NREL State
Would you like to meet the SAM
is free. These 30-minute online
Mountain time (GMT-6) -- all you
connection.
Start a new project or open an existing one.
Projects are stored as .sam files.
Scripts are .lk files that store scripts for advanced analysis.
The latest version is SAM 2017.1.17 r4, SSC 174. To see complete version information for your SAM installation, click About in the lower left corner of this window.
Check here for updates, to open SAM's Help system, and to see Version number and registration information.
C:\Users\gaobo\Desktop\Temp\tod factor test.sam
C:\Users\gaobo\Desktop\Temp\Marcou Mesa Project (200MW) - Disgen.sam
List of recent files: Double-click to open a file.
C:\Users\gaobo\Desktop\Temp\SAM Barksdale thin fix 20 080217.sam
C:\Users\gaobo\Desktop\Temp\test shading.sam
Quick start for new users
Help contents
Check for updates...
Registration
About
Quit



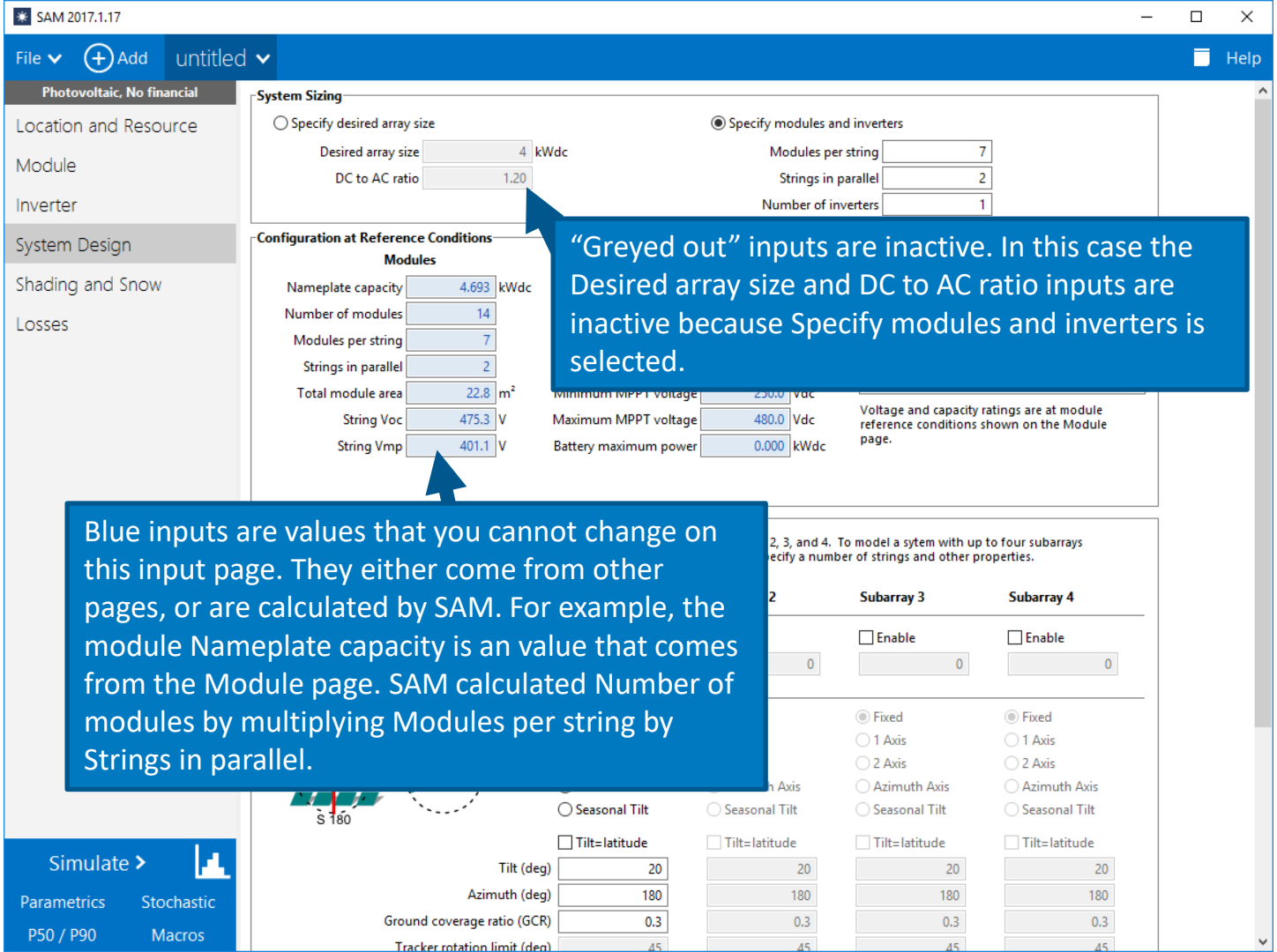
To create a new project, click Start a new project in the Welcome window, and then choose a performance model and financial model for your analysis.

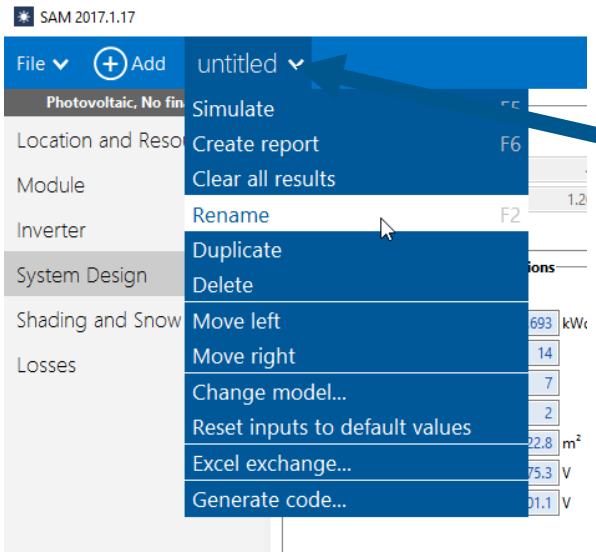


Source:


SAM 2017.1.17
File
Add
untitled
Help
The Main window is where you do your work in SAM.
Photovoltaic, No financial
Location and Resource
Module
Inverter
System Design
Shading and Snow
Losses
Specify desired array size
Specify modules and inverters
Desired array size
4
kWdc
DC to AC ratio
1.20
Modules per string
7
Strings in parallel
2
Number of inverters
1
Configuration at Reference Conditions
Modules
Inverters
Nameplate capacity
4.693
kWdc
Number of modules
14
Modules per string
7
Strings in parallel
2
Total module area
22.8
m²
Total capacity
3.800
Total capacity
3.928
Number of inverters
1
Maximum DC voltage
600.0
Minimum MPPT voltage
250.0
voltage
480.0
Vdc
m power
0.000
kWdc
Voltage and capacity ratings are at module reference conditions shown on the Module page.
All of the inputs in SAM have default values so you can get started learning how to use the software.
Use these buttons to show different input pages. The highlight indicates we are now looking at the System Design input page.
To model a system with one array, specify properties for Subarray 1 and disable Subarrays 2, 3, and 4. To model a sytem with up to four subarrays connected in parallel to a single bank of inverters, for each subarray, check Enable and specify a number of strings and other properties.
String Configuration
Strings in array
2
Subarray 1
Subarray 2
Subarray 3
Subarray 4
(always enabled)
Enable
Enable
Enable
2
0
0
0
Fixed
1 Axis
2 Axis
Azimuth Axis
Seasonal Tilt
S 180
Use these buttons to run simulations, view results, or for advanced simulation options.
Tilt=latitude
Tilt (deg)
20
Azimuth (deg)
180
Ground coverage ratio (GCR)
0.3
Simulate
Parametrics
Stochastic
P50 / P90
Macros

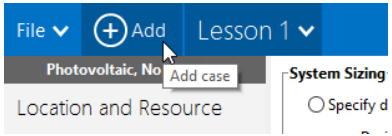
Source:

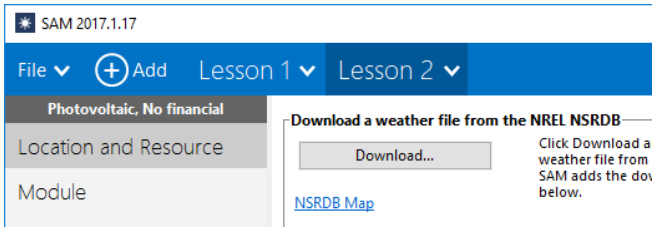

SAM 2017.1.17
File
Add
untitled
Help
Photovoltaic, No financial
Location and Resource
Module
Inverter
System Design
Shading and Snow
Losses
System Sizing
Specify desired array size
Desired array size 4 kWdc
DC to AC ratio 1.20
Specify modules and inverters
Modules per string 7
Strings in parallel 2
Number of inverters 1
Configuration at Reference Conditions
Modules
Nameplate capacity 4.693 kWdc
Number of modules 14
Modules per string 7
Strings in parallel 2
Total module area 22.8 m²
String Voc 475.3 V
String Vmp 401.1 V
Maximum MPPT voltage 480.0 Vdc
Battery maximum power 0.000 kWdc
Voltage and capacity ratings are at module reference conditions shown on the Module page.
"Greyed out" inputs are inactive. In this case the Desired array size and DC to AC ratio inputs are inactive because Specify modules and inverters is selected.
Blue inputs are values that you cannot change on this input page. They either come from other pages, or are calculated by SAM. For example, the module Nameplate capacity is an value that comes from the Module page. SAM calculated Number of modules by multiplying Modules per string by Strings in parallel.
2, 3, and 4. To model a sytem with up to four subarrays
ecify a number of strings and other properties.
Subarray 3
Subarray 4
Enable
Enable
Fixed
1 Axis
2 Axis
Azimuth Axis
Seasonal Tilt
Tilt=latitude
Tilt (deg) 20
Azimuth (deg) 180
Ground coverage ratio (GCR) 0.3
S 180
Simulate
Parametrics
Stochastic
P50 / P90
Macros



The Case menu lists commands for the current case. Click v to see the menu.

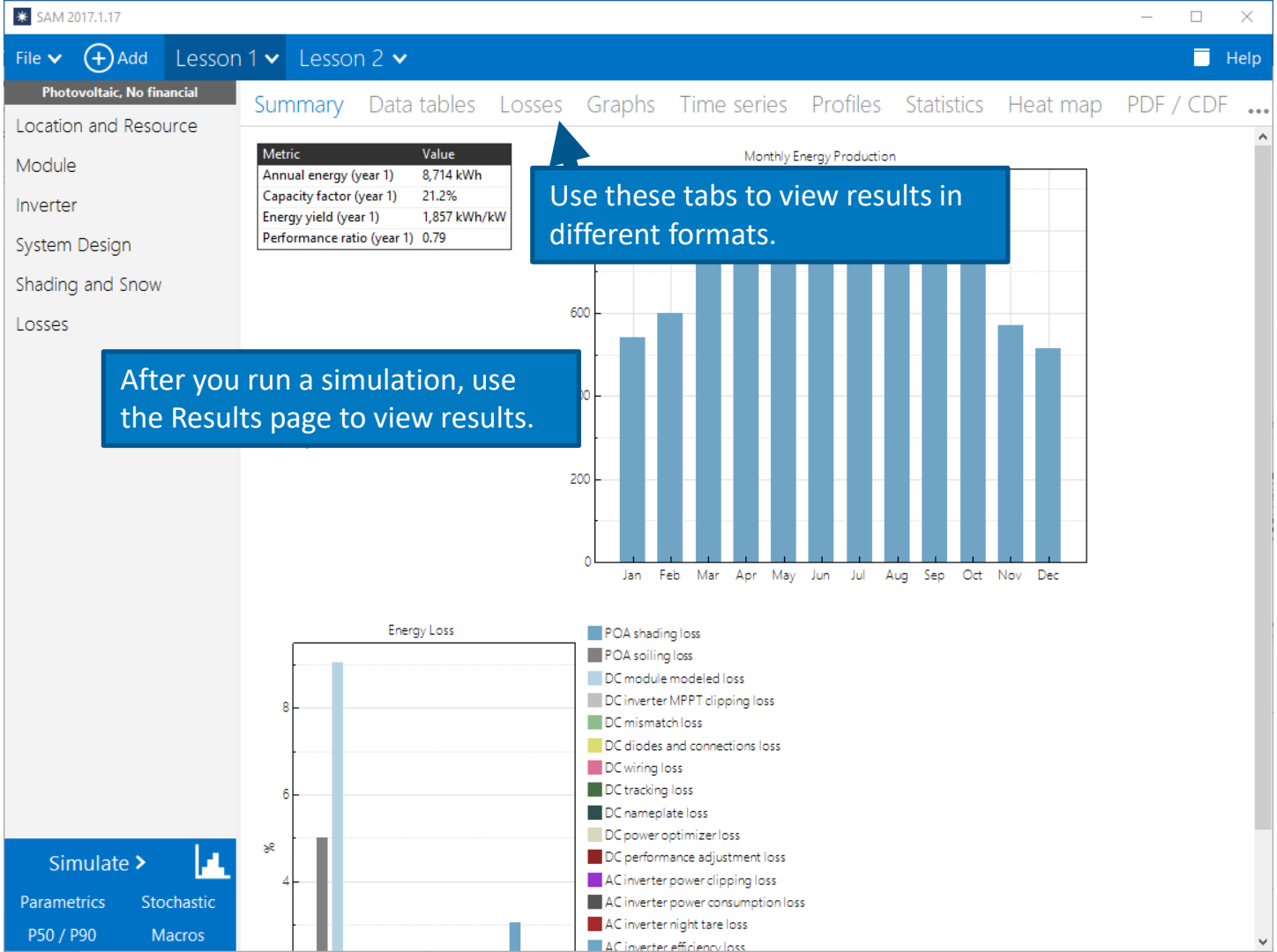
A case is like a worksheet in an Excel workbook, it is a complete set of inputs and results. A project can have one or more cases.

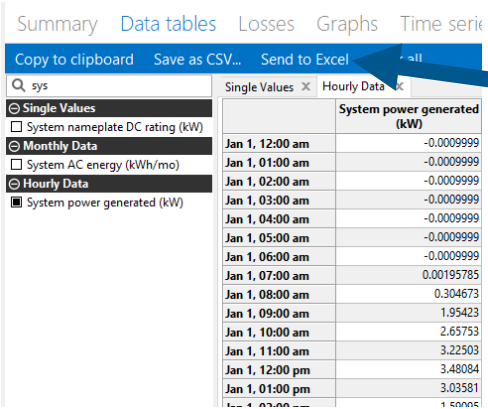




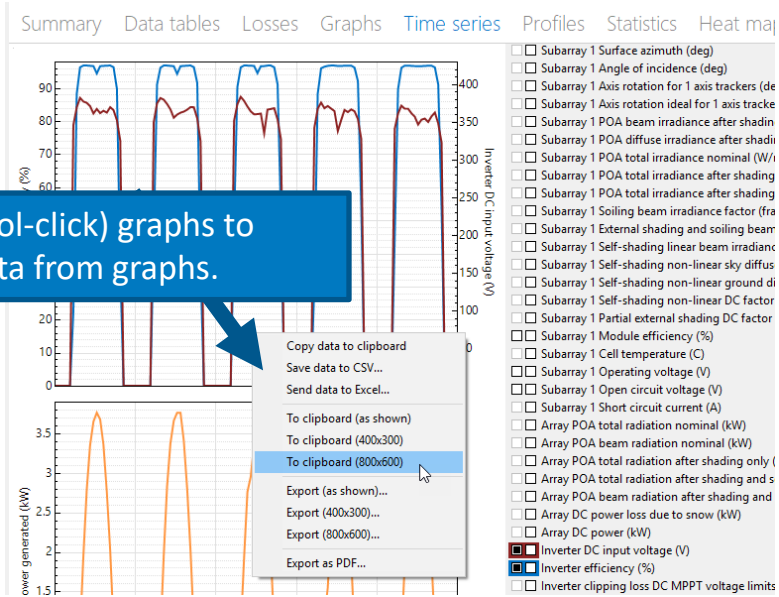
Click Add to add a case to your project. You can use multiple cases for comparison or to model a complex system.

Source:


SAM 2017.1.17
File
Add
Lesson 1
Lesson 2
Help
Photovoltaic, No financial
Location and Resource
Module
Inverter
System Design
Shading and Snow
Losses
Simulate
Parametrics
Stochastic
P50 / P90
Macros
Summary
Data tables
Losses
Graphs
Time series
Profiles
Statistics
Heat map
PDF / CDF
Metric
Value
Annual energy (year 1)
8,714 kWh
Capacity factor (year 1)
21.2%
Energy yield (year 1)
1,857 kWh/kW
Performance ratio (year 1)
0.79
Use these tabs to view results in different formats.
After you run a simulation, use the Results page to view results.
Monthly Energy Production
600
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Energy Loss
8
6
4
%
POA shading loss
POA soiling loss
DC module modeled loss
DC inverter MPPT clipping loss
DC mismatch loss
DC diodes and connections loss
DC wiring loss
DC tracking loss
DC nameplate loss
DC power optimizer loss
DC performance adjustment loss
AC inverter power clipping loss
AC inverter power consumption loss
AC inverter night tare loss

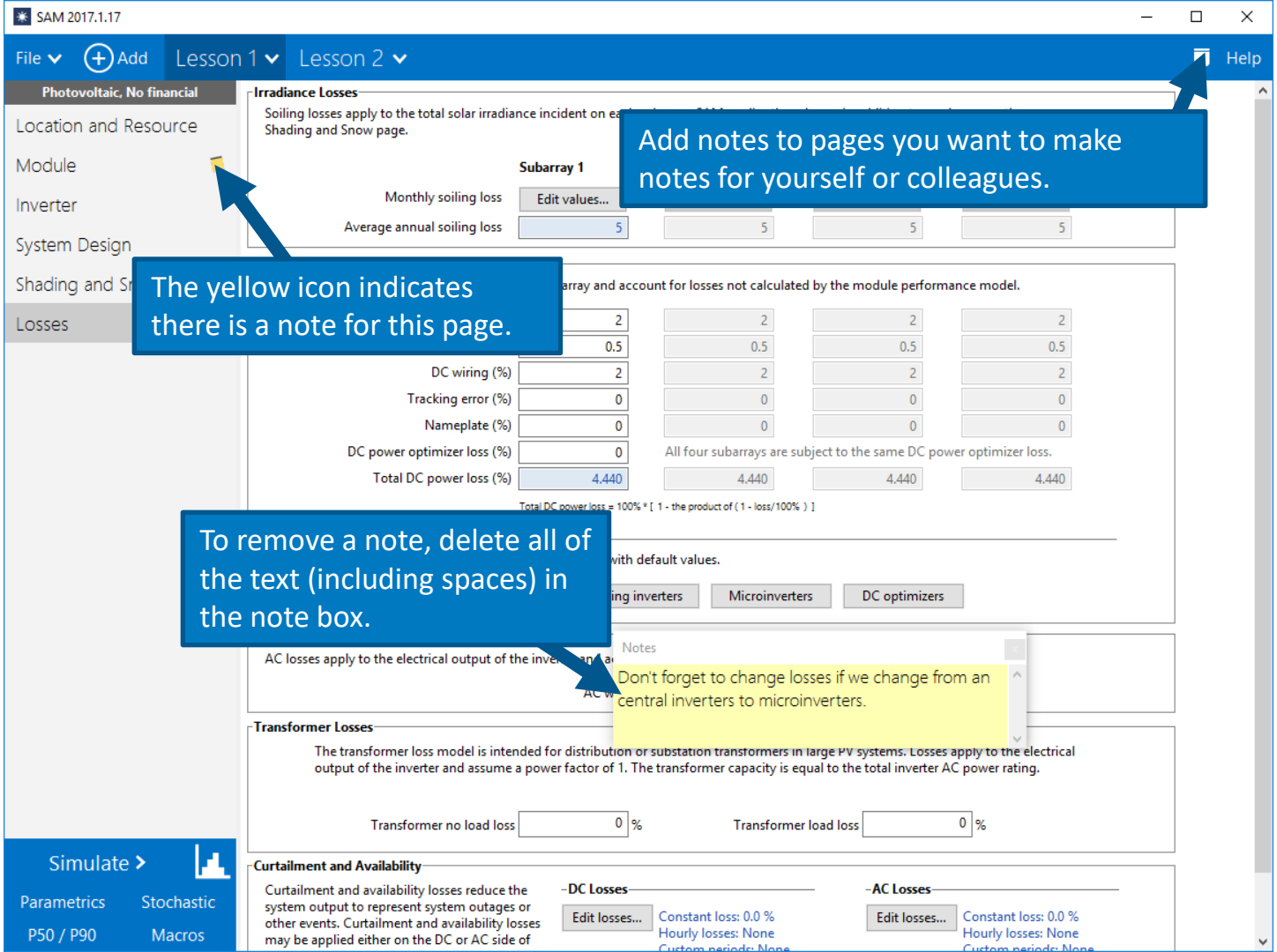


Use these buttons to export data from tables to your documents.



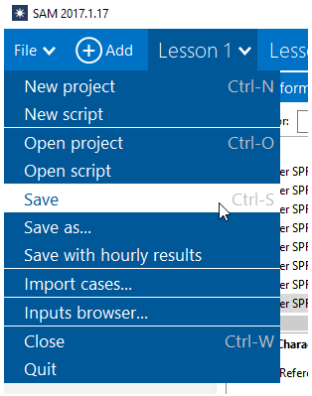
Right-click (or Control-click) graphs to export images or data from graphs.

Source:


SAM 2017.1.17
File
Add
Lesson 1
Lesson 2
Help
Photovoltaic, No financial
Location and Resource
Module
Inverter
System Design
Shading and Sr
Losses
Simulate
Parametrics
Stochastic
P50 / P90
Macros
Irradiance Losses
Soiling losses apply to the total solar irradiance incident on ea
Shading and Snow page.
Subarray 1
Monthly soiling loss
Edit values...
Average annual soiling loss
5
5
5
5
Add notes to pages you want to make notes for yourself or colleagues.
The yellow icon indicates there is a note for this page.
array and account for losses not calculated by the module performance model.
2
2
2
2
0.5
0.5
0.5
0.5
DC wiring (%)
2
2
2
2
Tracking error (%)
0
0
0
0
Nameplate (%)
0
0
0
0
DC power optimizer loss (%)
0
All four subarrays are subject to the same DC power optimizer loss.
Total DC power loss (%)
4.440
4.440
4.440
4.440
Total DC power loss = 100% * [1 - the product of (1 - loss/100%)]
To remove a note, delete all of the text (including spaces) in the note box.
with default values.
ing inverters
Microinverters
DC optimizers
Notes
Don't forget to change losses if we change from an central inverters to microinverters.
AC losses apply to the electrical output of the inve
Transformer Losses
The transformer loss model is intended for distribution or substation transformers in large PV systems. Losses apply to the electrical output of the inverter and assume a power factor of 1. The transformer capacity is equal to the total inverter AC power rating.
Transformer no load loss
0
%
Transformer load loss
0
%
Curtailment and Availability
Curtailment and availability losses reduce the system output to represent system outages or other events. Curtailment and availability losses may be applied either on the DC or AC side of
DC Losses
Edit losses...
Constant loss: 0.0 %
Hourly losses: None
AC Losses
Edit losses...
Constant loss: 0.0 %
Hourly losses: None

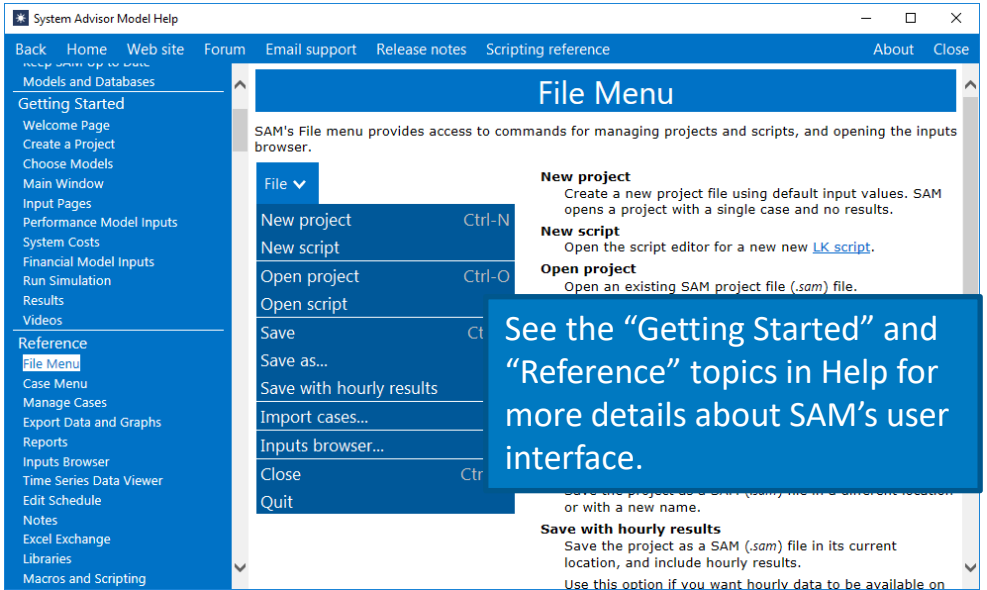
Source:


SAM 2017.1.17
File
Add
Lesson 1
Lesson 2
Help
Photovoltaic, No financial
Location and Resource
Module
Inverter
System Design
Shading and Sr
Losses
CEC Performance Model with Module Database
Search for:
Name
Click Help, or press the F1 key to display help.
System Advisor Model Help
Back
Home
Web site
Forum
Email support
Release notes
Scripting reference
About
Close
Excel Exchange
Libraries
Macros and Scripting
Software Development Kit
File Formats
Software Installation
Registration
Web Access and Proxies
Simulation
Parametric Simulations
Stochastic Simulations
P50/P90 Simulations
Optimization
Weather Data
Folders and Libraries
Download Weather File
Weather File Formats
Weather Data Elements
Typical and Single Year
Time and Sun Position
Photovoltaic Systems
Location and Resource
PV System Costs
Edit Shading Data
Detailed Photovoltaic Model
Module
Module
The Module page allows you to choose a model to represent the photovoltaic module's performance. For each time step of the simulation, the module model calculates the DC electrical output of a single module based on the design parameters and the incident solar radiation (plane-of-array irradiance) calculated from data in the weather file.
SAM assumes that the system is made up of an array of identical modules, which can be wired into up to four DC subarrays. The photovoltaic array's electric output depends on the number of modules in the system and the orientation, tracking, shading, and other parameters on the System Design page, and any losses you specify on the Shading and Snow and Losses pages. The array's electrical output is fed to a bank of one or more inverters, whose characteristics appear on the Inverter page.
SAM displays the name of the active module model at the top of the Module page. Click the model name to choose a different model:
CEC Performance Model with Module Database
Simple Efficiency Module Model
CEC Performance Model with Module Database
CEC Performance Model with User Entered Specifications
Sandia PV Array Performance Model with Module Database
IEC61853 Single Diode Model
You can choose from five different module performance models:
Simple Efficiency Module Model is a simple representation of module performance that requires you to provide the module area, a set of conversion efficiency values, and temperature correction parameters. The simple efficiency model is the least accurate of the three models for predicting the performance of specific modules, but is useful for analyses involving explorations of the relationship between module efficiency and the system's performance and cost of energy because it allows you to
Simulate
Parametrics
Stochastic
P50 / P90
Macros
Heat transfer dimensions
Module Dimensions
Mounting structure orientation
Structures do not impede flow underneath module
Module width
1
m
Columns of modules in array
10
Temperature behind the module
20
°C



Use the File menu to save your project files as .sam files.

If your project has more than one case, use the inputs browser to compare inputs.



See the “Getting Started” and “Reference” topics in Help for more details about SAM’s user interface.