



System Advisor Model, SAM 2011.12.2: General Description

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

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Executive Summary

This document describes the capabilities of the U.S. Department of Energy and National Renewable Energy Laboratory's System Advisor Model (SAM), Version 2011.12.2, released on December 2, 2011. SAM is software that models the cost and performance of renewable energy systems. Project developers, policy makers, equipment manufacturers, and researchers use graphs and tables of SAM results in the process of evaluating financial, technology, and incentive options for renewable energy projects. SAM simulates the performance of solar, wind, geothermal, biomass, and conventional power systems. The financial model can represent financing structures for projects that either buy and sell electricity at retail rates (residential and commercial) or sell electricity at a price determined in a power purchase agreement (utility). Advanced analysis options facilitate parametric, sensitivity, and statistical analyses, and allow for interfacing SAM with Microsoft Excel or with other computer programs. SAM is available as a free download at <http://sam.nrel.gov>. Technical support and more information about the software are available on the website.

Table of Contents

- Executive Summary iii
- Table of Contents iv
- List of Figures v
- 1 Overview 1**
- 2 Results: Tables, Graphs, and Reports 3**
- 3 Performance Model 5**
- 4 Financial Model..... 6**
 - 4.1 Residential and Commercial Projects6
 - 4.2 Power Purchase Agreement (PPA) Projects6
 - 4.3 Levelized Cost of Energy and Cash Flow.....7
 - 4.4 Incentives8
- 5 Advanced Options 9**
- 6 Software Development History and Users 10**
- 7 Downloading SAM and User Support..... 11**

List of Figures

| | |
|--|----|
| Figure 1. SAM's main window shows monthly electricity generation for a 250-kilowatt PV system in Phoenix, Arizona. | 1 |
| Figure 2. Graphs and Charts on the Results page displays graphs of results that you can easily export to your documents. | 3 |
| Figure 3. The reports generator allows you to create fully customizable reports with text, images, graphs, and tables. | 4 |
| Figure 4. This example of a Time Series graph on the Results page shows hourly electricity generation for a 100 MW parabolic trough system with 6 hours of storage in Blythe, California. | 5 |
| Figure 5. In this screenshot, you can see several rows of the cash flow table for a 10-megawatt utility-scale project with a two-partner flip financial structure. | 7 |
| Figure 6. SAM's website at http://sam.nrel.gov includes software descriptions, links to publications about SAM and other resources. | 11 |
| Figure 7. SAM's help system includes detailed descriptions of the user interface, modeling options, and results. | 12 |

1 Overview

The System Advisor Model (SAM) is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry:

- Project managers and engineers
- Incentive program designers
- Technology developers
- Researchers.

SAM makes performance predictions and cost-of-energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that you specify as inputs to the model.

Projects can be either on the customer side of the utility meter, buying and selling electricity at retail rates, or on the utility side of the meter, selling electricity at a price negotiated through a power purchase agreement (PPA).

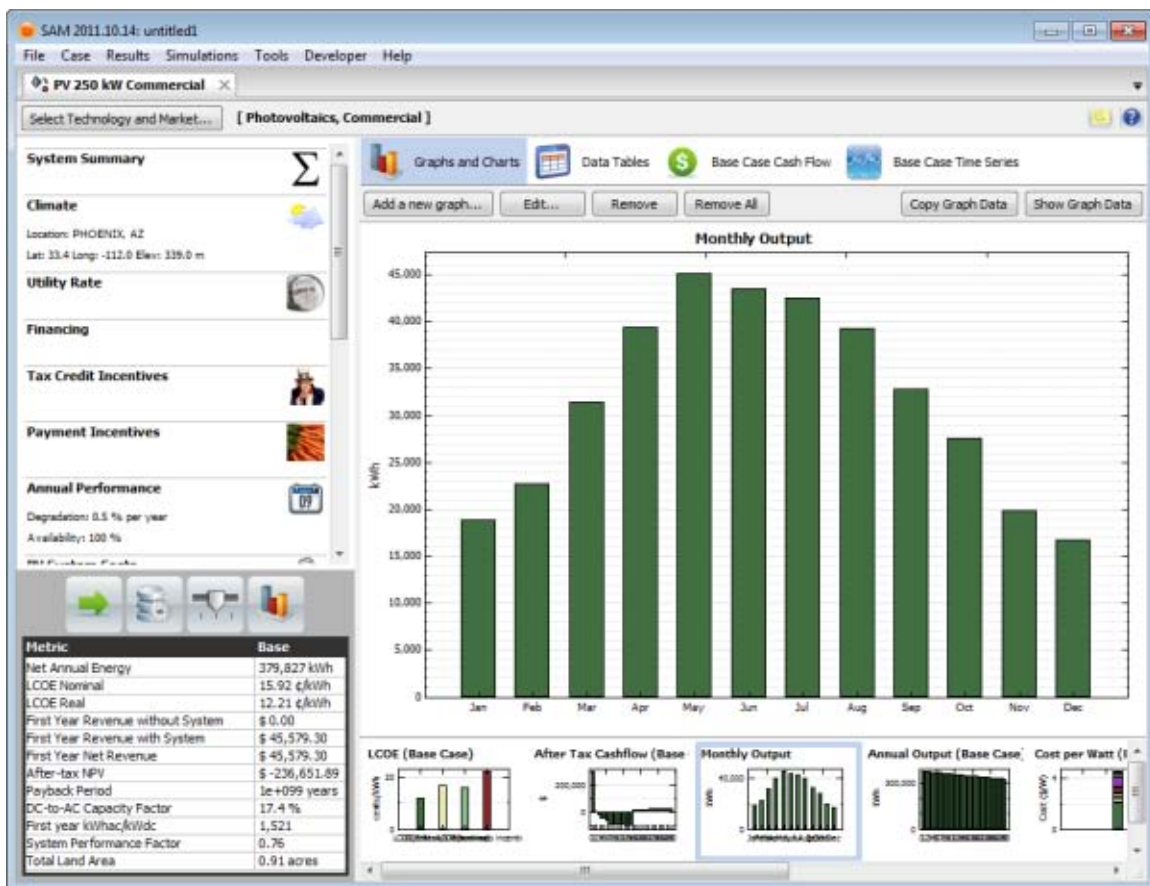


Figure 1. SAM's main window shows monthly electricity generation for a 250-kilowatt PV system in Phoenix, Arizona.

The first step in creating a SAM file is to choose a technology and financing option for your project. SAM automatically populates input variables with a set of default values for the type of project. It is your responsibility as an analyst to review and modify all of the input data as appropriate for each analysis.

Next, you provide information about a project's location, the type of equipment in the system, the cost of installing and operating the system, and financial and incentives assumptions.

SAM includes several databases of performance data and coefficients for system components such as photovoltaic modules and inverters, parabolic trough receivers and collectors, or biopower combustion systems. For those components, you simply choose an option from a list. SAM can also automatically download data from an online database of retail electricity rates and structures for U.S. utilities.

For the remaining input variables, you either use the default value or change its value. Some examples of input variables are:

- Installation costs, including those for equipment purchases, labor, and engineering; other project expenditures; land; and operation and maintenance.
- Numbers of modules and inverters, tracking type, and derating factors for photovoltaic systems.
- Collector and receiver type, solar multiple, storage capacity, and power block capacity for parabolic trough systems.
- Analysis period, real discount rate, inflation rate, tax rates, and internal rate of return target or power purchase price for utility financing models.
- Building load and time-of-use retail rates for commercial and residential financing models.
- Tax credit and payment incentives amounts and rates.

Running the model also requires a weather file for your project's location in one of three formats: TMY2, TMY3, or EPW. Files for many locations in the United States and around the world are available in those formats for free on different websites. SAM includes the complete set of TMY2 files for U.S. locations, a tool for automatically downloading weather files from the National Renewable Energy Laboratory (NREL) weather file databases using a project site's address or geographic coordinates, and a tool for creating weather files with your own weather data.

Once you are satisfied with the input variable values, you run simulations, and then examine results. A typical analysis involves running simulations, examining results, revising inputs, and repeating that process until you understand and have confidence in the results.

2 Results: Tables, Graphs, and Reports

SAM displays modeling results in tables and graphs, ranging from the metrics table displaying levelized cost of energy (LCOE), first year annual production, and other single-value metrics, to the detailed annual cash flow and hourly performance data that can be viewed in tabular or graphical form.

A built-in graphing tool displays a set of default graphs and allows for creation of custom graphs. Graph sliders make it easy to visually examine the effect of changing input values in graphs and tables without changing values on the input pages. All graphs and tables can be exported in various formats for inclusion in reports and presentations, and also for further analysis with spreadsheet or other software.



Figure 2. Graphs and Charts on the Results page displays graphs of results that you can easily export to your documents.

SAM's report generator allows you to create custom report templates to include SAM results in your project proposals and other documents.

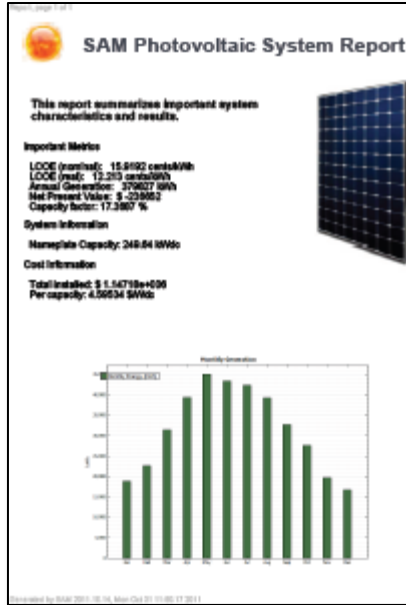


Figure 3. The reports generator allows you to create fully customizable reports with text, images, graphs, and tables.

3 Performance Model

SAM's performance model makes hour-by-hour calculations of a power system's electric output, generating a set of 8,760 hourly values that represent the system's electricity production over a single year. You can explore the system's performance characteristics in detail by viewing tables and graphs of the hourly and monthly performance data, or use performance metrics such as the system's total annual output and capacity factor for more general performance evaluations.

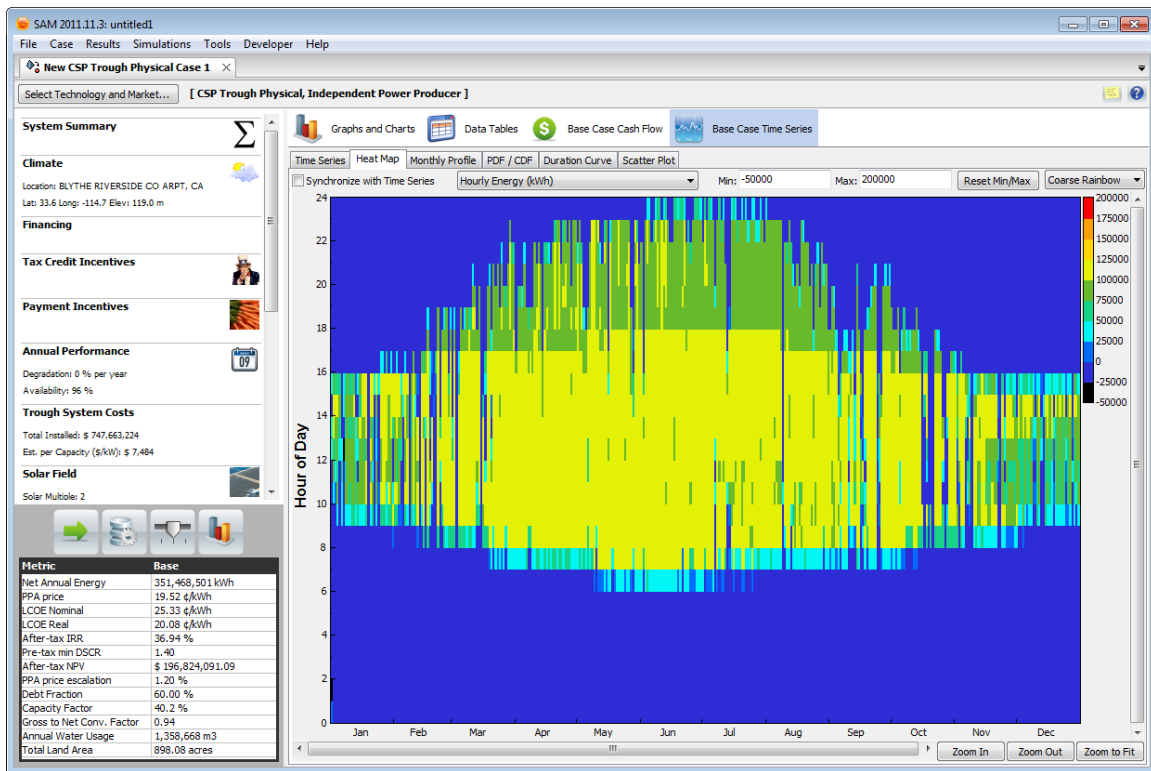


Figure 4. This example of a Time Series graph on the Results page shows hourly electricity generation for a 100 MW parabolic trough system with 6 hours of storage in Blythe, California.

The current version of SAM includes performance models for the following technologies:

- Photovoltaic systems (flat-plate and concentrating)
- Parabolic trough concentrating solar power systems
- Power tower concentrating solar power systems (molten salt and direct steam)
- Linear Fresnel concentrating solar power systems
- Dish-Stirling concentrating solar power systems
- Conventional fossil-fuel thermal systems
- Solar water heating for residential or commercial buildings
- Large and small wind power projects
- Geothermal power and geothermal co-production
- Biomass power.

4 Financial Model

SAM's financial model calculates financial metrics for various kinds of power projects based on a project's cash flows over an analysis period that you specify. The financial model uses the system's electrical output calculated by the performance model to calculate the series of annual cash flows.

SAM includes financial models for the following kinds of projects:

- Residential rooftop (retail electricity rates)
- Commercial rooftop (retail rates or power purchase agreement)
- Utility-scale (power purchase agreement):
 - Single owner
 - Leveraged partnership flip
 - All equity partnership flip
 - Sale leaseback.

4.1 Residential and Commercial Projects

Residential and commercial projects are financed through either a loan or cash payment, and recover investment costs by selling electricity through either a net metering or time-of-use pricing agreement. For these projects, SAM reports the following financial metrics:

- LCOE
- Revenue with and without renewable energy system
- After-tax net present value
- Payback Period.

4.2 Power Purchase Agreement (PPA) Projects

Utility and commercial PPA projects are assumed to sell electricity through a power purchase agreement at a fixed price with optional annual escalation and time-of-delivery adjustment factors. For these projects, SAM calculates:

- LCOE
- PPA price (electricity sales price)
- Internal rate of return
- Net present value
- Debt fraction or debt service coverage ratio.

SAM can either calculate the internal rate of return based on a power price you specify, or calculate the power price based on the rate of return you specify.

4.3 Levelized Cost of Energy and Cash Flow

SAM calculates the LCOE after-tax cash flows for projects using retail electricity rates, and from the revenue cash flow for projects selling electricity under a power purchase agreement.

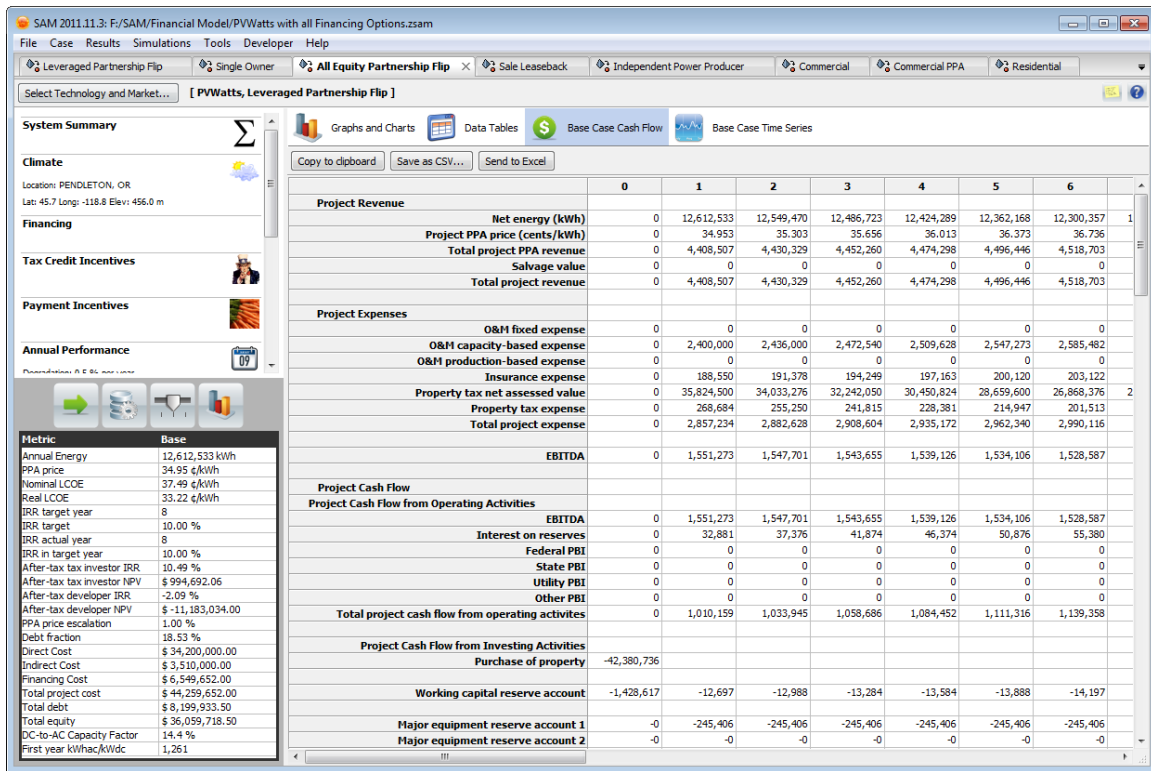


Figure 5. In this screenshot, you can see several rows of the cash flow table for a 10-megawatt utility-scale project with a two-partner flip financial structure.

The project annual cash flows include:

- Revenues from electricity sales and incentive payments
- Installation costs
- Operating, maintenance, and replacement costs
- Loan principal and interest payments
- Tax benefits and liabilities (accounting for any tax credits for which the project is eligible)
- Incentive payments
- Project and partner's internal rate of return requirements (for PPA projects).

4.4 Incentives

The financial model can account for a wide range of incentive payments and tax credits:

- Investment-based incentives (IBI)
- Capacity-based incentives (CBI)
- Production-based incentives (PBI)
- Investment tax credits (ITC)
- Production tax credits (PTC)
- Depreciation (MACRS, Straight-line, custom).

5 Advanced Options

Advanced modeling options allow for studies involving multiple simulations, linking SAM inputs to a Microsoft Excel workbook, and working with custom simulation modules.

The following options are for analyses that investigate impacts of variations and uncertainty in assumptions about weather, performance, cost, and financial parameters on model results:

- **Parametric Analysis**—Assign multiple values to input variables to create graphs and tables showing the value of output metrics for each value of the input variable.
- **Sensitivity Analysis**—Create tornado graphs by specifying a range of values for input variables as a percentage.
- **Optimization**—Find the value of input variables that result in either a maximum or minimum value of an output metric.
- **Statistical**—Create histograms showing the sensitivity of output metrics to variations in input values.
- **P50/P90**—For locations with weather data available for many years, calculate the probability that the system's total annual output will exceed a certain value.

For files with multiple cases, the Multiple Subsystems option allows you to model a project that combines systems from the cases, assuming that the system's total electrical output is the sum of the output of the systems modeled in each case, and applies the financing model from one case to this total output.

SAM also makes it possible to work with external models developed in Excel or the TRNSYS simulation platform:

- **Excel Exchange**—Use Excel to calculate the value of input variables, and automatically pass values of input variables between SAM and Excel.
- **User Variables**—Create your own input variables for use with Excel Exchange or a custom TRNSYS deck.
- **Simulator Options**—Change the simulation time step, or run SAM with your own simulation modules developed in the TRNSYS modeling platform.

Finally, SAM's scripting language SamUL allows you to write your own programs within the SAM user interface to control simulations, change values of input variables, and write data to text files. You can also use SAM's code generation feature to automatically generate code that controls SAM from your programs written in Excel VBA, Python, C, or MATLAB.

6 Software Development History and Users

SAM, originally called the "Solar Advisor Model" was developed by NREL in collaboration with Sandia National Laboratories (Sandia) in 2005, and at first was used internally by the U.S. Department of Energy's (DOE) Solar Energy Technologies Program for systems-based analysis of solar technology improvement opportunities within the program. The first public version was released in August 2007 as Version 1, making it possible for solar energy professionals to analyze photovoltaic systems and concentrating solar power parabolic trough systems in the same modeling platform using consistent financial assumptions. Since 2007, two new versions have been released each year, adding new technologies and financing options. In 2010, the name changed to "System Advisor Model" to reflect the addition of non-solar technologies.

The DOE, NREL, and Sandia continue to use the model for program planning and grant programs. Since the first public release, more than 35,000 people representing manufacturers, project developers, academic researchers, and policy makers have downloaded the software. Manufacturers are using the model to evaluate the impact of efficiency improvements or cost reductions in their products on the cost of energy from installed systems. Project developers use SAM to evaluate different system configurations to maximize earnings from electricity sales. Policy makers and designers use the model to experiment with different incentive structures.

7 Downloading SAM and User Support

SAM runs on both Windows and Mac OS. It requires about 470 MB of storage space on your computer.

SAM is available for free download at <http://sam.nrel.gov>. To download the software, you must register for an account on the website. After registering, you will receive an email with your account information.

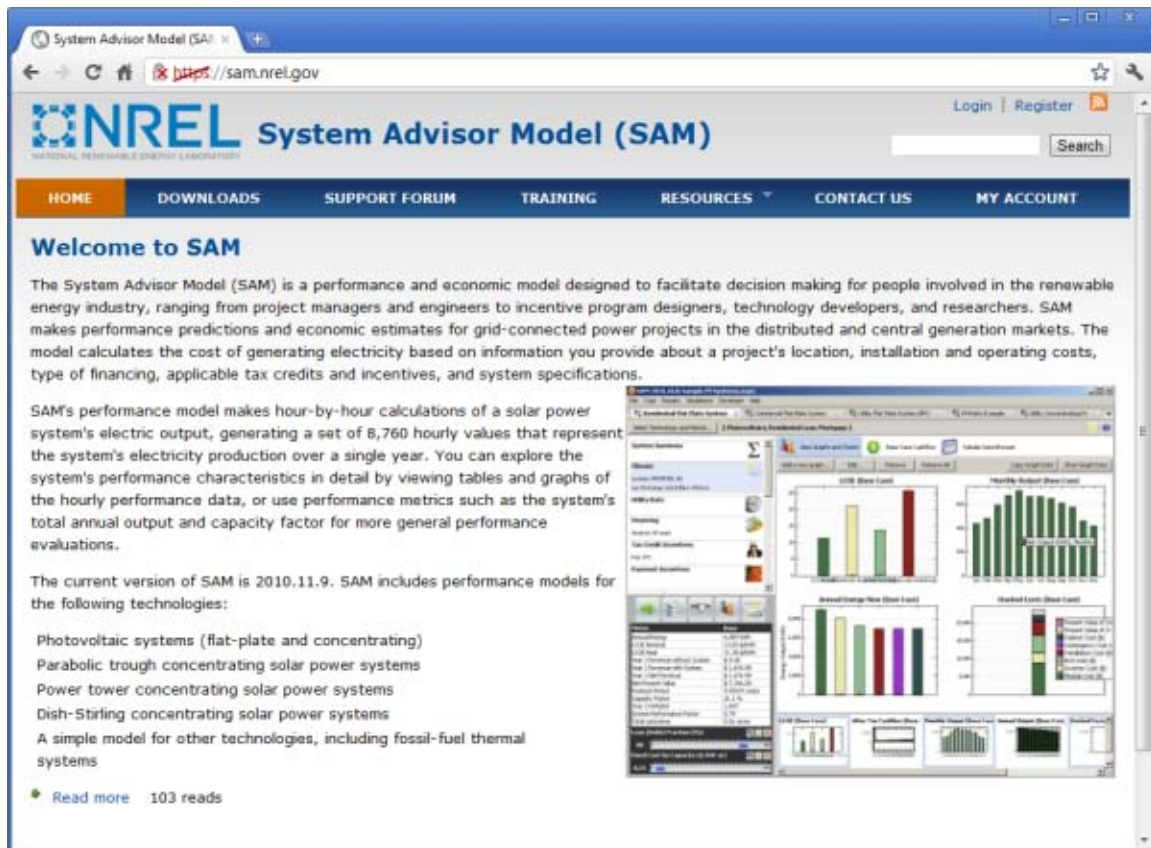


Figure 6. SAM's website at <http://sam.nrel.gov> includes software descriptions, links to publications about SAM and other resources.

The following resources are available for learning to use SAM and for getting help with your analyses:

- Help system
- User support forum: <https://sam.nrel.gov/forums/support-forum>
- Video recordings and webinar announcements: <https://sam.nrel.gov/content/resources-learning-sam>

You can contact the SAM support team by emailing sam.support@nrel.gov.

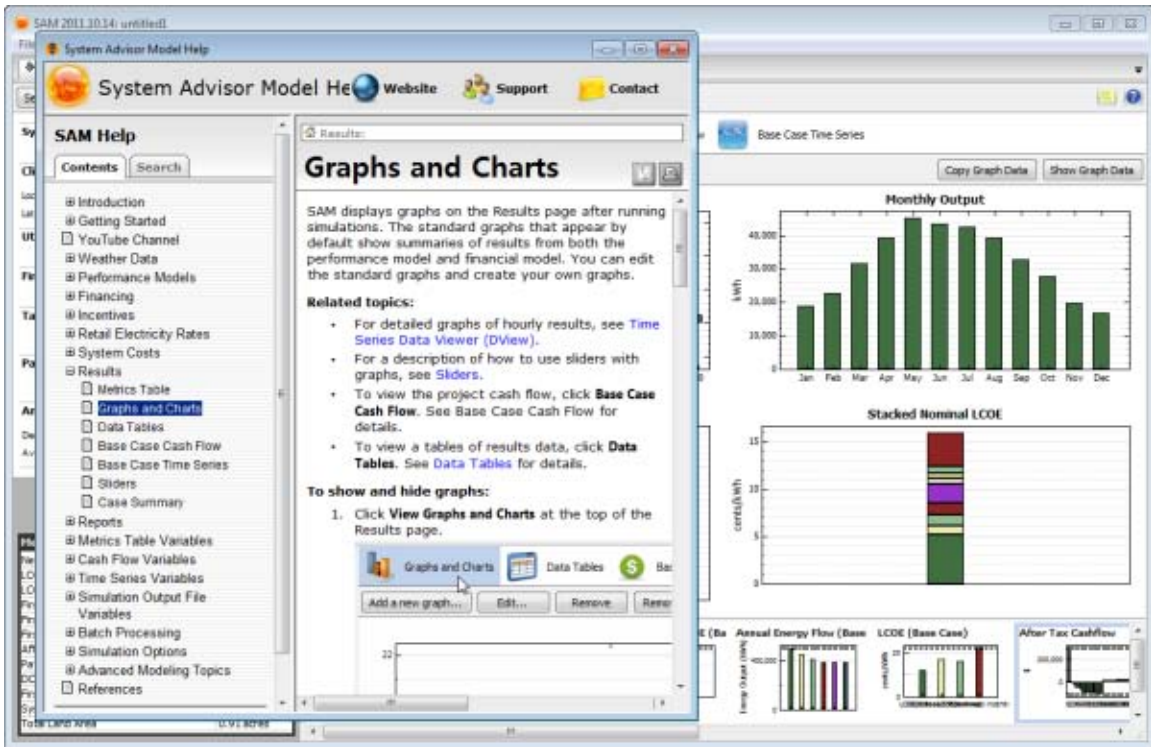


Figure 7. SAM's help system includes detailed descriptions of the user interface, modeling options, and results.