System Advisor Model: An Introduction

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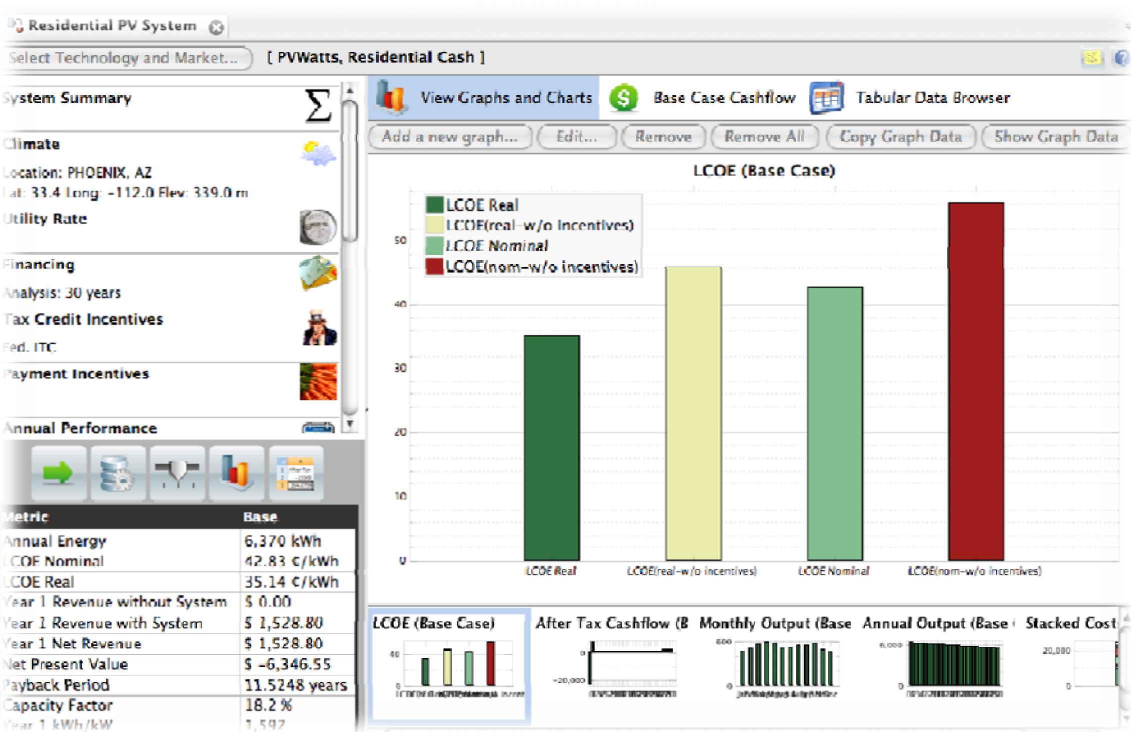
What is SAM?

The System Advisor Model (SAM) is a free computer program that **calculates a renewable energy system's hourly energy output** over a single year, and **calculates the cost of energy** for a renewable energy project over the life of the project.

These calculations are done using detailed performance models, a detailed cash flow finance model, and a library of reasonable default values for each technology and target market.



What can you do with SAM?

- Model solar, wind, and geothermal power systems in a single, user-friendly application
- Access high-quality performance and economic models developed by NREL, Sandia, and other partners
- Evaluate and compare options using consistent models across technologies
- Calculate economic metrics such as LCOE, NPV, payback for projects in different markets
- Perform parametric and uncertainty analyses
- Present modeling results in graphs and tables

Technologies & Markets

- Photovoltaics
- Concentrating Solar Power
  - Parabolic Troughs
  - Power Towers
  - Dish-Stirling
- Solar Water Heating
- Wind turbines and farms
- Geothermal power plants

Key outputs

- Hourly energy production (kWh)
- Capacity factor

- Residential, commercial, and utility-scale projects
- Installation and operating costs
- Tax credit and payment incentives
- Complex electric utility rates

Key outputs

- Levelized Cost of Electricity (LCOE)
- Payback
- Net present value
- Multi-year cash flow

Background

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

Other Contributors

Photovoltaics

- Sandia Laboratories
  - Development of Sandia PV Array Performance Model and Performance Model for Grid-Connected PV Inverters (David King et. al.)
  - Parameter data for Sandia PV and inverter models
- University of Wisconsin
  - Development of CEC Performance Model (Five-parameter module model)
- California Energy Commission (CEC)
  - Parameter data for CEC Performance Model

Concentrating Solar Power

- NREL
  - Parabolic trough model (Hank Price et. al.)
- University of Wisconsin (with funding from NREL)
  - Dish-Stirling model, power tower model, PV model enhancements

Financial modeling

- Lawrence Berkeley National laboratory: Validation
- WorleyParsons: Parabolic trough cost model
- Deacon Harbor Financial: general consulting and utility-scale model development

Users and Applications

Feasibility studies

- Project developers, Federal Energy Management Program

Use as benchmark for other models

- System integrators and utilities

Research projects

- Universities and engineering firms

Plant acceptance testing for parabolic trough systems

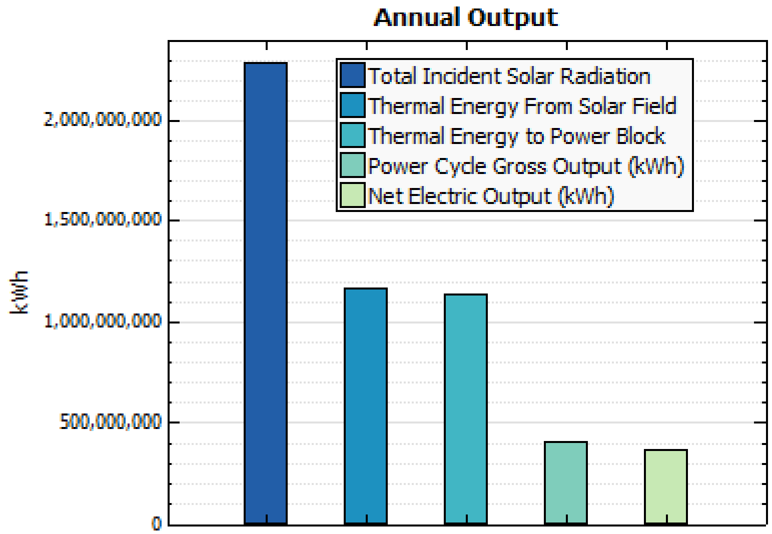
Evaluate technology research opportunities and grant proposals

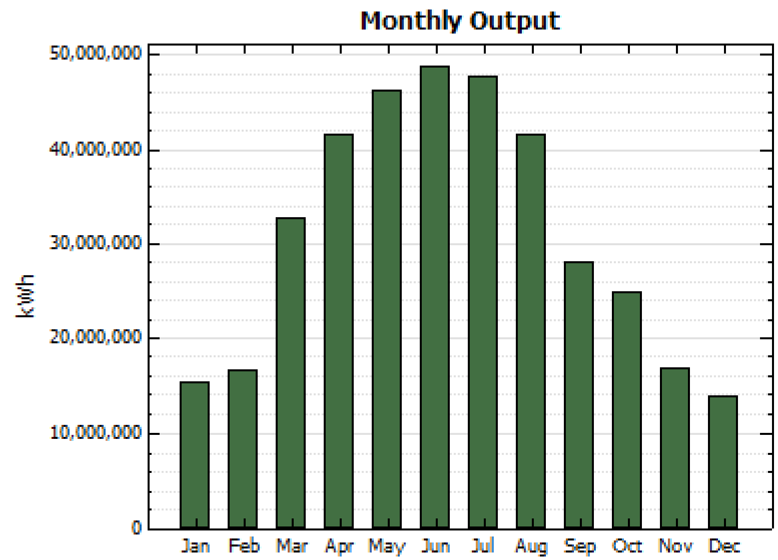
- Department of Energy

20,000+ Downloads

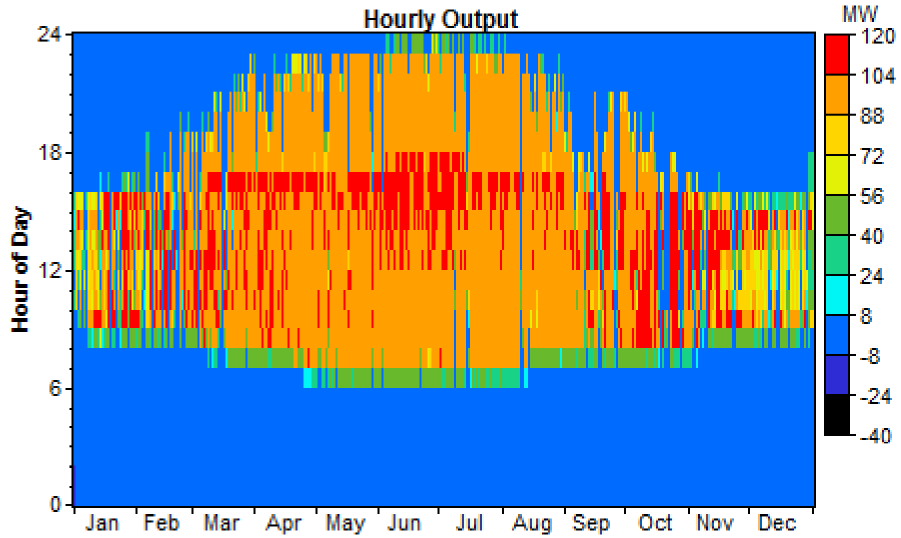
Manufacturers
Engineering Firms
Consultants
Developers
Venture Capitalists
Policy Analysts

Predict System Energy Output

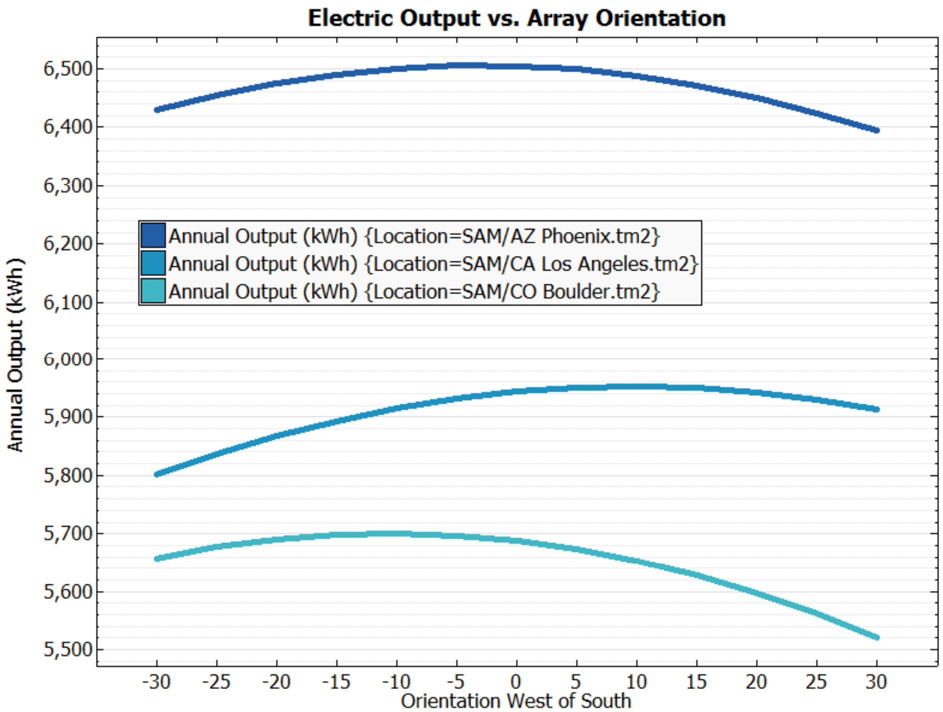




Example: 100 MW Parabolic trough system with 6 hours of storage



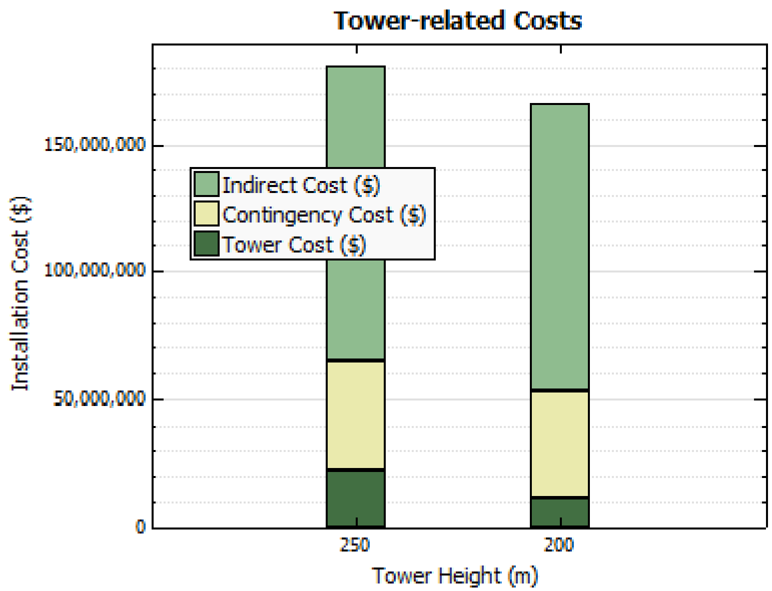
Optimize Design Parameters



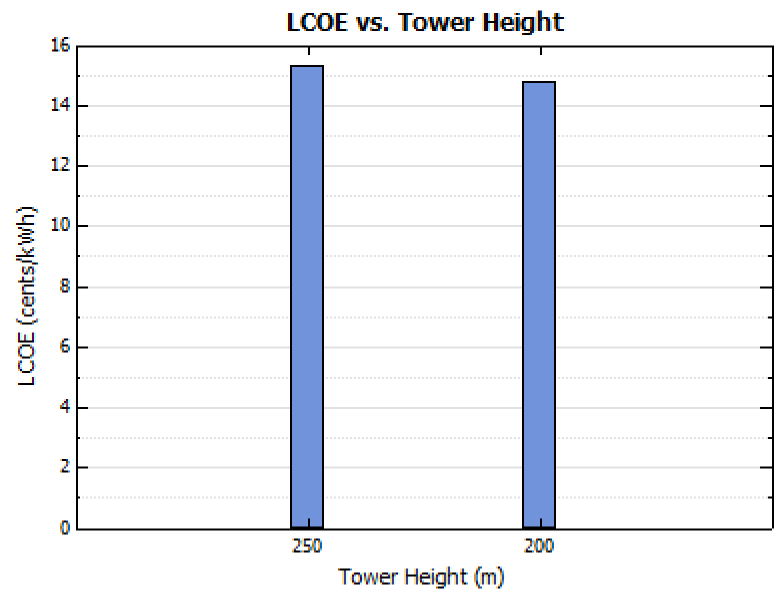
- For Boulder, CO, orient array slightly eastward to avoid summer afternoon thunderclouds over mountains
- For Los Angeles, CA, orient array slightly westward to avoid morning fog
- For Phoenix, AZ, orient array due south

Example: Explore optimal array tilt and azimuth angles for a 3 kW residential photovoltaic system in three different locations

Analyze Project Costs

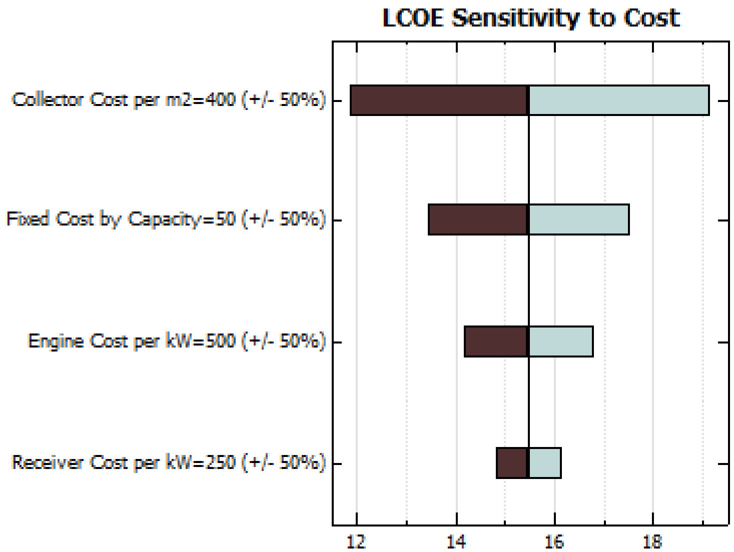


Decreasing tower height by 50 m decreases installation costs by 2.5% and levelized cost of energy (LCOE) by 4.0%



Example: 100 MW power tower system with 6 hours of storage

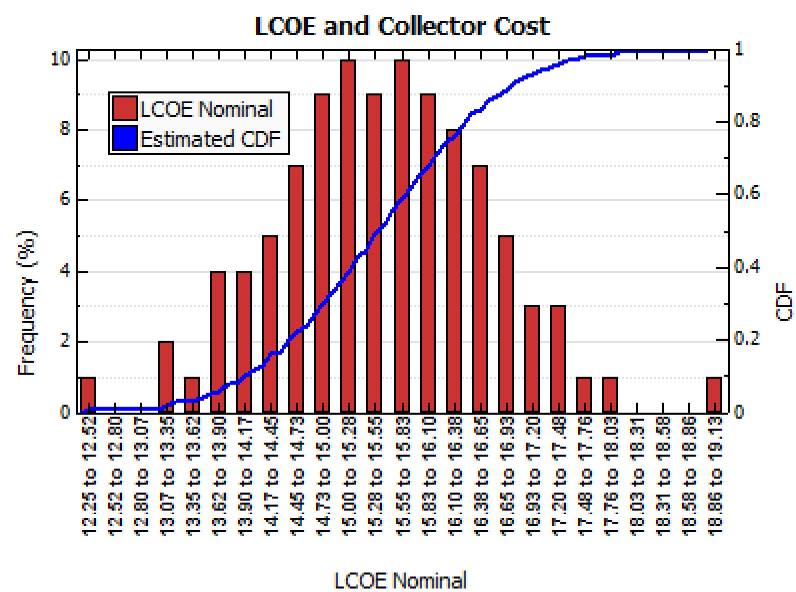
Assess Uncertainties



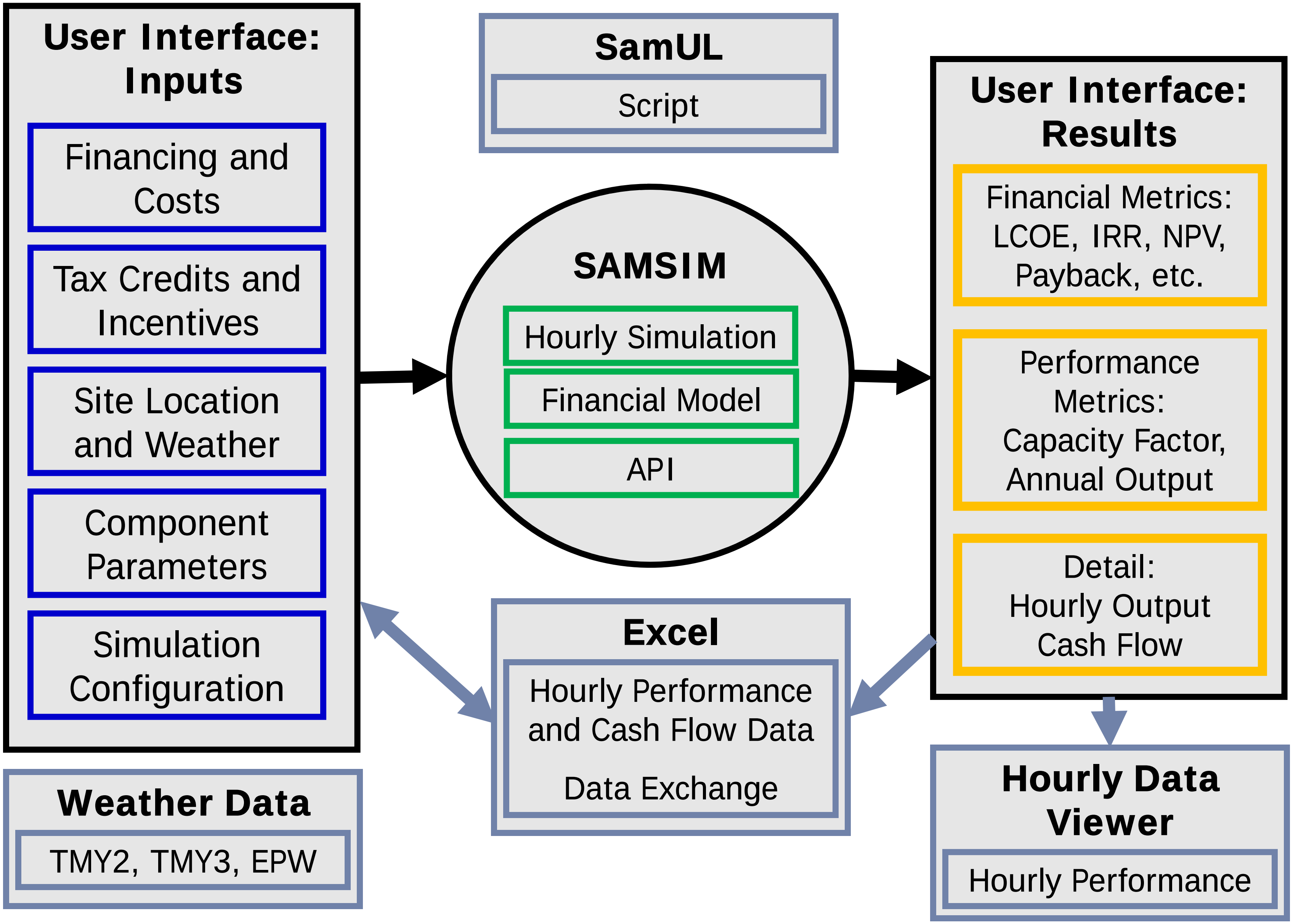
Sensitivity analysis: LCOE is most sensitive to collector cost

Statistical analysis: Shows degree of uncertainty

Example: 25 kW dish-stirling system



Program Structure



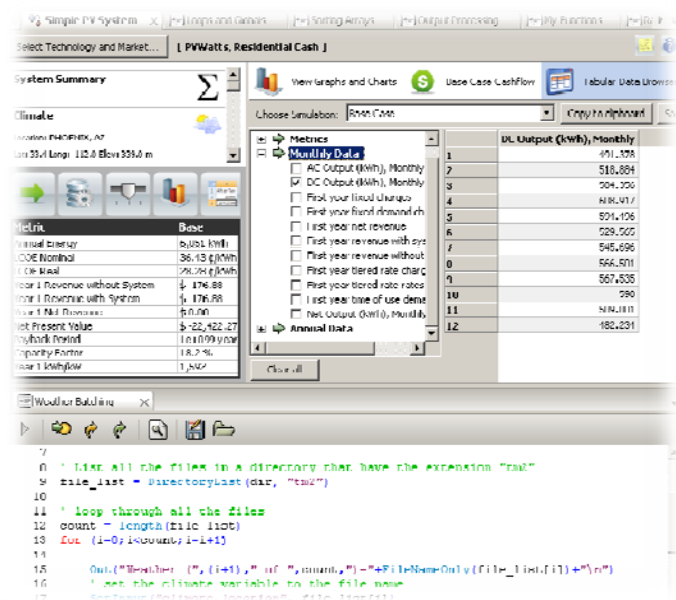
Extending SAM

Interoperability with Excel/VBA, Matlab, Python, C, others

- SAM simulations can be configured and run from other tools without opening the SAM application
- Allows other tool developers to directly integrate SAM calculations into their tools

SAM User Language (SamUL)

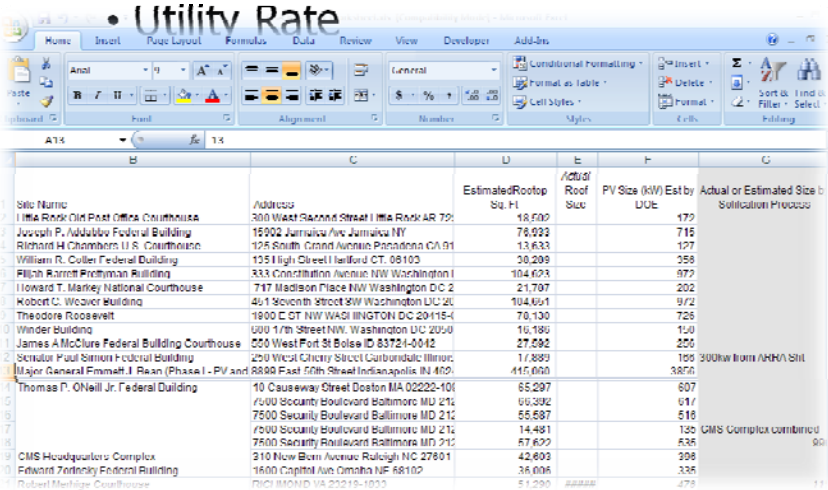
- Built-in scripting language to automate complex analysis tasks
- Allows developers to extend the core functionality of SAM to suit their needs



Example of Extending SAM via SamUL

Input: spreadsheet of 30 GSA buildings with PV

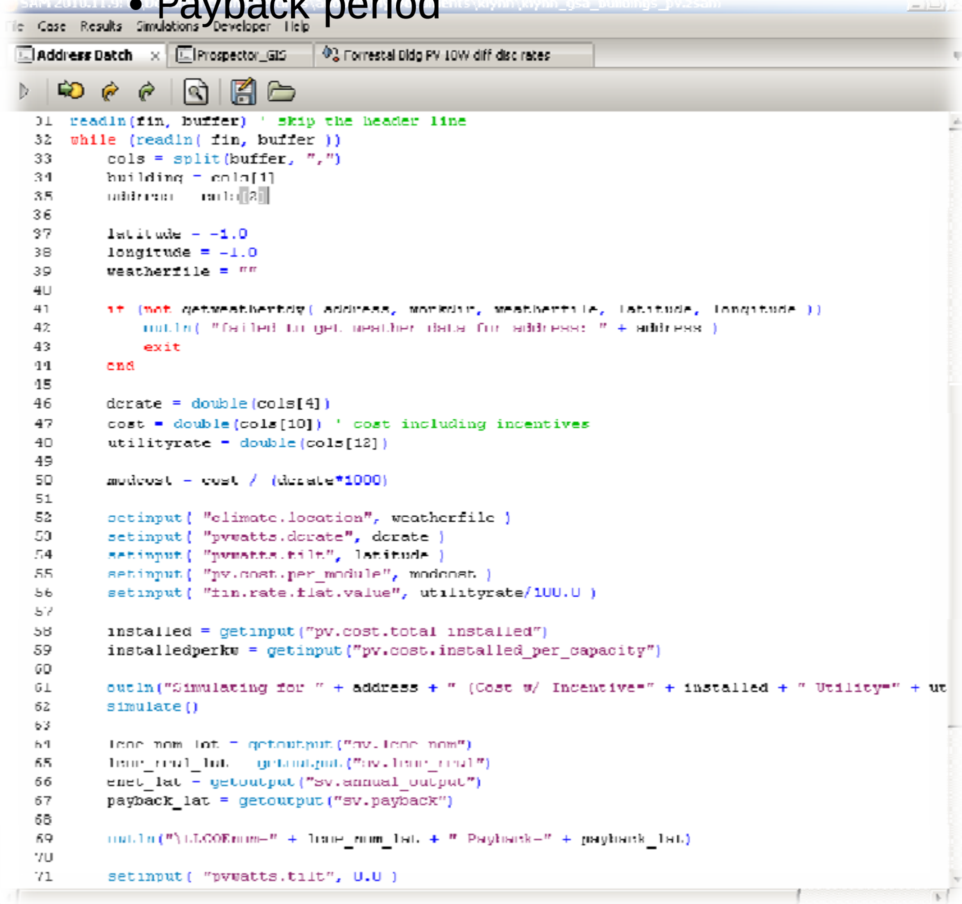
- Street address
- PV system size
- Cost
- Utility Rate



Site Name	Address	EstimatedRooftop Sq. Ft	Actual Roof Size	PV Size (kW) Est by DOE	Actual or Estimated Size b Solicitation Process
Little Rock Old Post Office Courthouse	300 West Second Street Little Rock AR 72	18,502		172	
Joseph P. Addabbo Federal Building	15902 Jamaica Ave Jamaica NY	76,933		715	
Richard H Chambers U.S. Courthouse	125 South Grand Avenue Pasadena CA 91	13,633		127	
William R. Cotter Federal Building	135 High Street Hartford CT. 06103	30,209		358	
Elijah Barrett Prettyman Building	333 Constitution Avenue NW Washington I	104,623		972	
Howard T. Markey National Courthouse	717 Madison Place NW Washington DC 2	21,707		202	
Robert C. Weaver Building	451 Seventh Street SW Washington DC 20	104,651		972	
Theodore Roosevelt	1900 E ST NW WASHINGTON DC 20415-	78,130		726	
Winder Building	600 17th Street NW. Washington DC 2050	16,186		150	
James A McClure Federal Building Courthouse	550 West Fort St Boise ID 83724-0042	27,592		256	
Senator Paul Simon Federal Building	250 West Cherry Street Carbondale Illinoi	17,889		166	300kw from ARRA Sol
Major General Emmett J. Bean (Phase I - PV and	8899 East 56th Street Indianapolis IN 462	415,060		3856	
Thomas P. ONeill Jr. Federal Building	10 Causeway Street Boston MA 02222-10	65,297		607	
	7500 Security Boulevard Baltimore MD 212	66,392		617	
	7500 Security Boulevard Baltimore MD 212	55,587		516	
	7500 Security Boulevard Baltimore MD 212	14,481		135	CMS Complex combined
	7500 Security Boulevard Baltimore MD 212	57,622		535	99
CMS Headquarters Complex	310 New Bern Avenue Raleigh NC 27601	42,603		396	
Edward Zorinsky Federal Building	1600 Capitol Ave Omaha NE 68102	36,006		335	
Robert Merhige Courthouse	RICHMOND VA 23219-1033	51,290	#####	478	11

Output: spreadsheet with results for each system

- LCOE real & nominal
- Annual system output
- Payback period

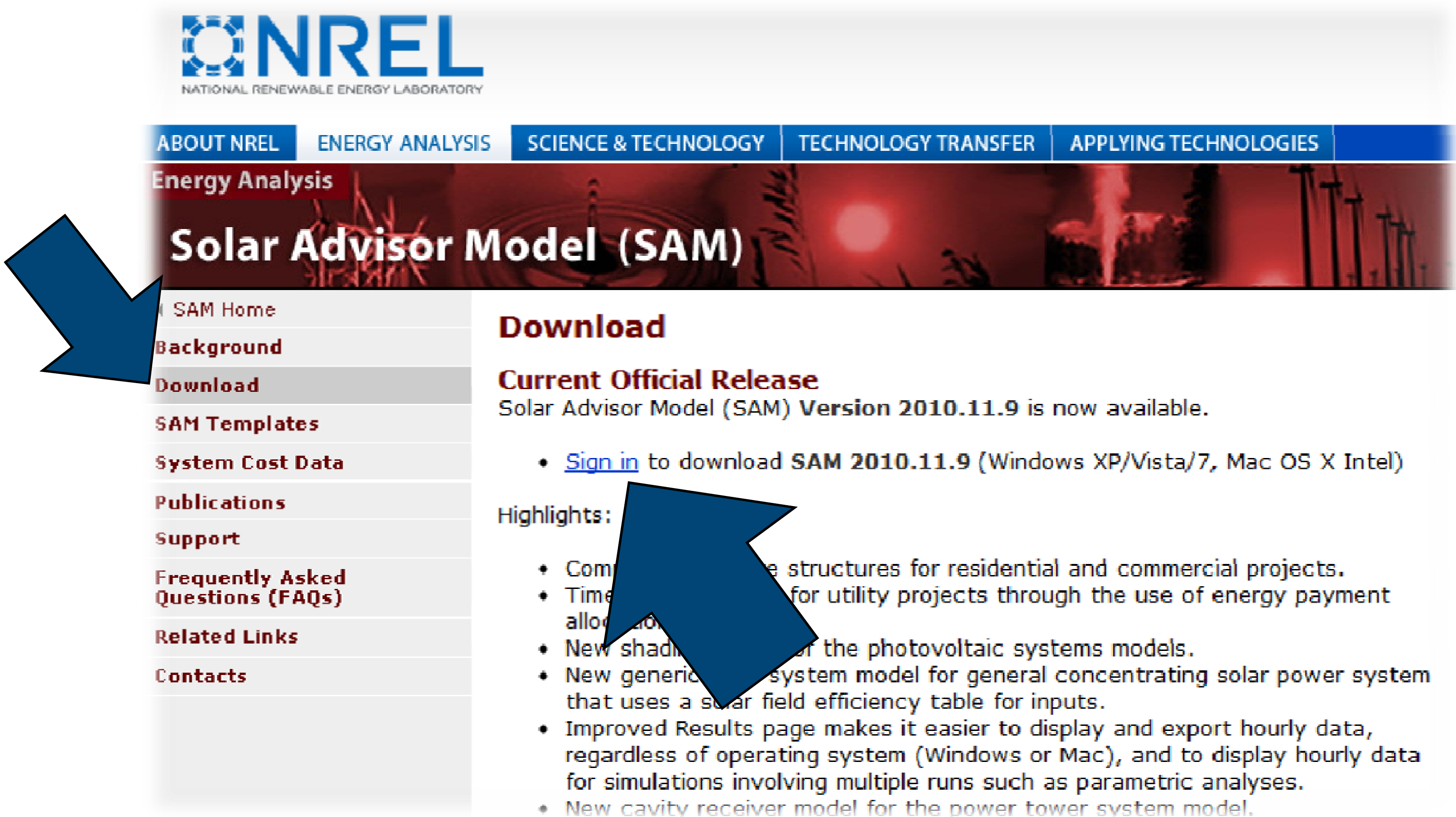


Result: In 85 lines of script code, the whole simulation process was automated for each building. Weather data was automatically downloaded for each address from Solar Prospector, and the simulation results were written to a CSV file. SAM's capabilities were extended in a project-specific way, and thus avoided a lot of tedious and error-prone work.

Obtaining SAM

http://www.nrel.gov/analysis/sam

1) Click 'Sign in' 2) Complete registration form 3) Download



Other Workshop Questions Answered

Do you add environmental implications and benefits into the levelized cost of electricity calculations?
Not at this time. These could be calculated outside the model and added in.

What are the sources of the cost drivers, escalation assumptions and generation characterizations that are used as inputs to your levelized cost of electricity calculations?
The default values are taken from technology experts at NREL and usually reference published reports.

What is the frequency for updating the modeling inputs information?
Typically, we review the model inputs (costs in particular) with each release (twice annually).

Are future cost projections included, and if so, what is the basis for these projections and what in-service years are included?
Future projections are not included.

What is the relationship between your resulting levelized cost estimates and expected market prices?
While real-world LCOEs are subject to a variety of impacts, current comparison efforts have resulted in good agreement with real-world LCOE values (especially for CSP plants while PV is more volatile and wind and geothermal are newly added technologies).

Thank You

QUICK DEMO OF PV SYSTEM

SAM Overview

EXTRA SLIDES

Getting Help

Online Help and User Guide

– Help menu and buttons

SAM Website

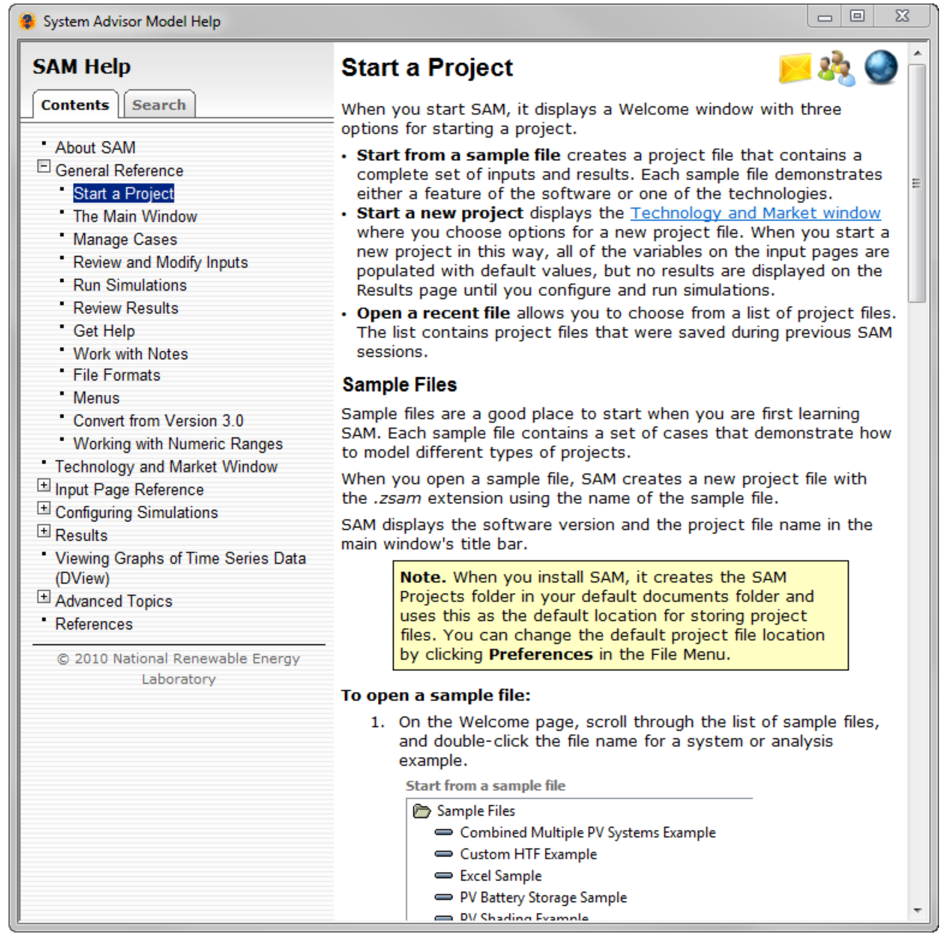
– http://www.nrel.gov/analysis/sam

Google Groups

– http://groups.google.com/group/sam-user-group

Email User Support

– solar.advisor.support@nrel.gov



Current Development Team

Management

- Nate Blair, NREL

Programming

- Aron Dobos, NREL
- Steven Janzou, NREL*

PV Model Validation

- Chris Cameron, Sandia

Photovoltaics

- Bolko von Roedern, NREL

* Contractors

Concentrating Solar Power

- Mark Mehos, NREL
- Craig Turchi, NREL

Water Heating

- Jay Burch, NREL
- Craig Christensen, NREL

Documentation and User Support

- Paul Gilman, NREL*

SAM Overview

PV MODELING OPTIONS

PV modeling features

Grid-connected systems only

No storage

No size limit

Model options

- Simpler PVWatts model represents entire system using a single derate factor
- More detailed represents system using separate module and inverter model with derate factors

Electric load for residential and commercial systems with TOU rates

Advanced PV modeling features

Array shading and self shading

System can made up of multiple sub-systems

PV module performance models

- Sandia PV Array Performance Model
  - Database of commercially-available modules
  - Parameters based on test data
  - Database maintained by Sandia National Laboratories
- CEC / U of Wisconsin five-parameter model
  - Database of commercially-available modules
  - Parameters based on manufacturer specifications
  - Database maintained by California Energy Commission
- PVWatts model
  - Specify a single derate factor to model entire system
  - Adapted from NREL's web-based model
- Simple efficiency model with temperature correction
  - Specify module area, efficiencies for different radiation levels, temperature coefficient, and module structure
  - Allows for parametric analysis on module efficiency and temperature coefficients

CPV Modeling Options

Simple efficiency model for concentrating PV

- Specify module area, efficiencies for different radiation levels, temperature coefficient, and module structure
- Allows for parametric analysis on module efficiency and temperature coefficients
- Assumes module only converts direct component of incident radiation
- No modeling of active or passive cooling devices

CPV modules in Sandia database

- Current version includes a single CPV module: Entech 22x, more to come in future versions

PV inverter performance models

Sandia Inverter Performance Model

- Database of commercially-available inverters
- Parameters based on field test data

Single-point efficiency inverter model

- Specify an inverter capacity and average DC-to-AC conversion efficiency
- Allows for parametric studies on inverter efficiency

PV input requirements

- Hourly weather file in TMY3, TMY2, or EPW format
- Financial assumptions
  - Loan parameters for all projects
  - Target IRR for utility projects
  - Utility rate for residential and commercial projects
  - Incentives and tax credits
- System costs: Installation and operating costs
- System nameplate capacity
  - Module and inverter make and model for component models

SAM Overview

PARABOLIC TROUGH MODELING OPTIONS

PV Performance Models

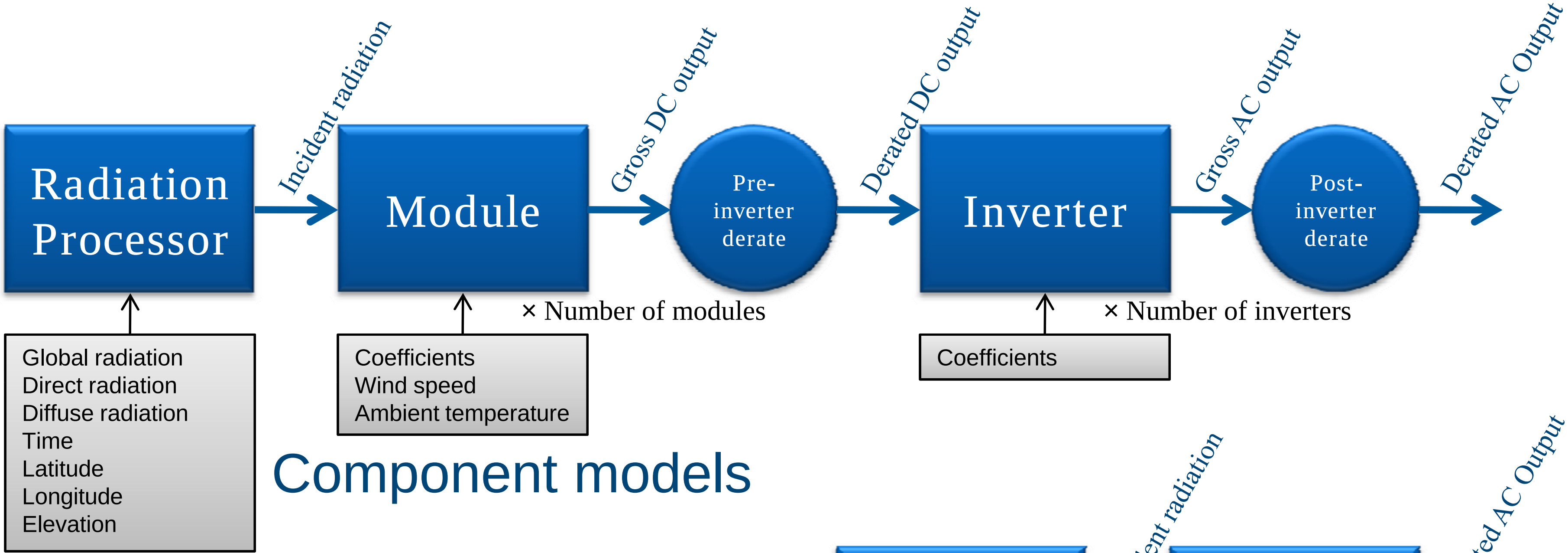
Component models

- Inverter and module as separate models
- Shading
- Electric load for residential and commercial projects

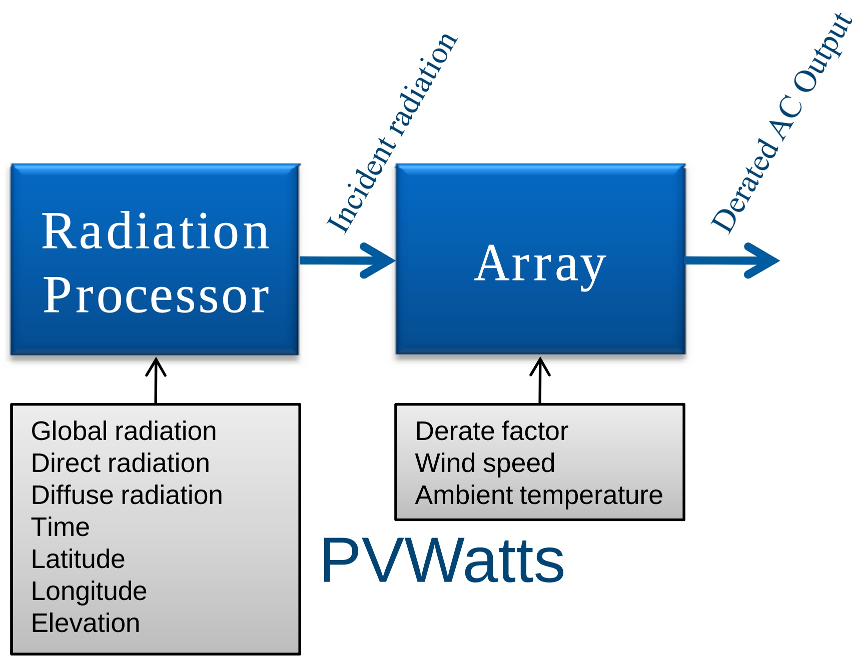
PVWatts

- Single derate factor for entire system
- Shading
- Electric load for residential and commercial projects

PV Performance Models



Component models



PVWatts

PV Shading

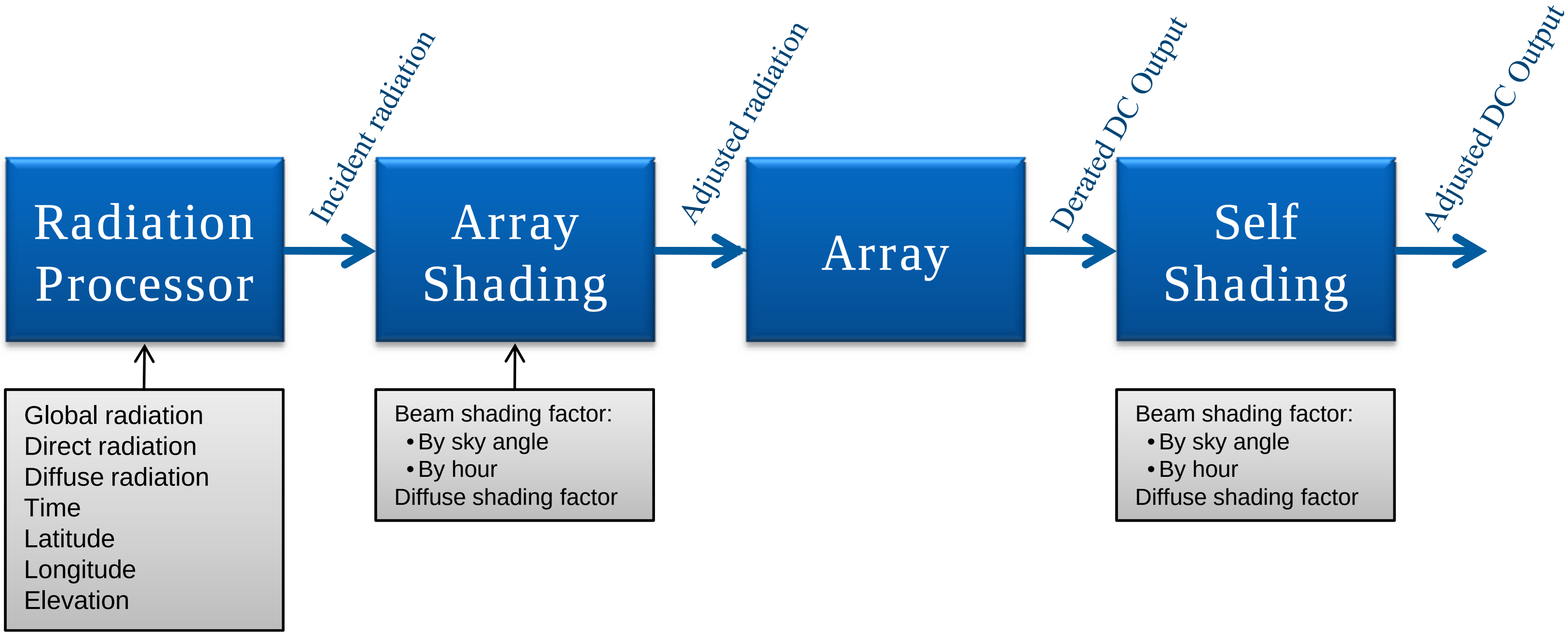
Array shading

- Beam shading factors reduce incident direct radiation
- Diffuse shading factor reduces incident diffuse radiation
- Import shading factors from PVsyst and SunEye

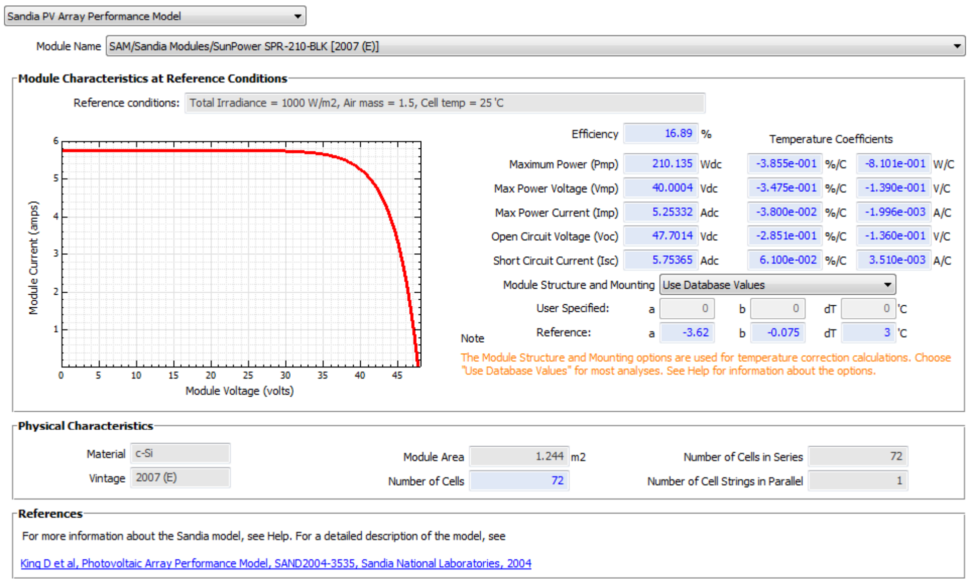
Self-shading

- Calculates hourly DC derates factor to approximate effect of row-to-row shading
- Requires information about cell layout and number of diodes in module

PV Shading


Radiation Processor
Incident radiation
Array Shading
Adjusted radiation
Array
Derated DC Output
Self Shading
Adjusted DC Output
Global radiation
Direct radiation
Diffuse radiation
Time
Latitude
Longitude
Elevation
Beam shading factor:
• By sky angle
• By hour
Diffuse shading factor
Beam shading factor:
• By sky angle
• By hour
Diffuse shading factor

Sandia PV Array Performance Model



Steps:

1. Choose a module from the list
2. Choose a module structure and mounting option

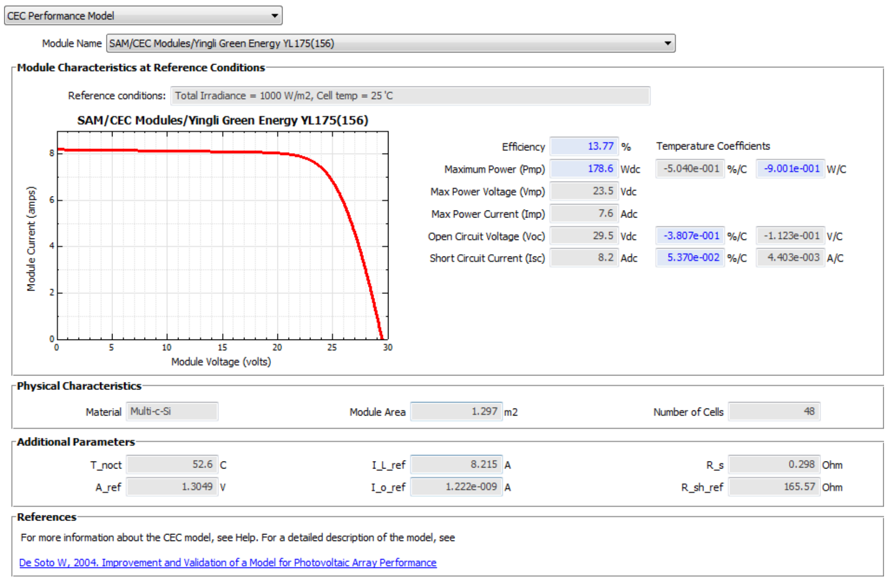
Calculates hourly module efficiency values based on incident radiation, ambient temperature, and module coefficients

Characterizes module using Sandia empirical model and coefficients derived from field test measurements

Recommended model for modules available in database

Module database updated with each new version of SAM

CEC Performance Model



Steps:

1. Choose a module from the list
2. Choose a module structure and mounting options

Calculates hourly module efficiency values based on incident radiation, ambient temperature, and module coefficients

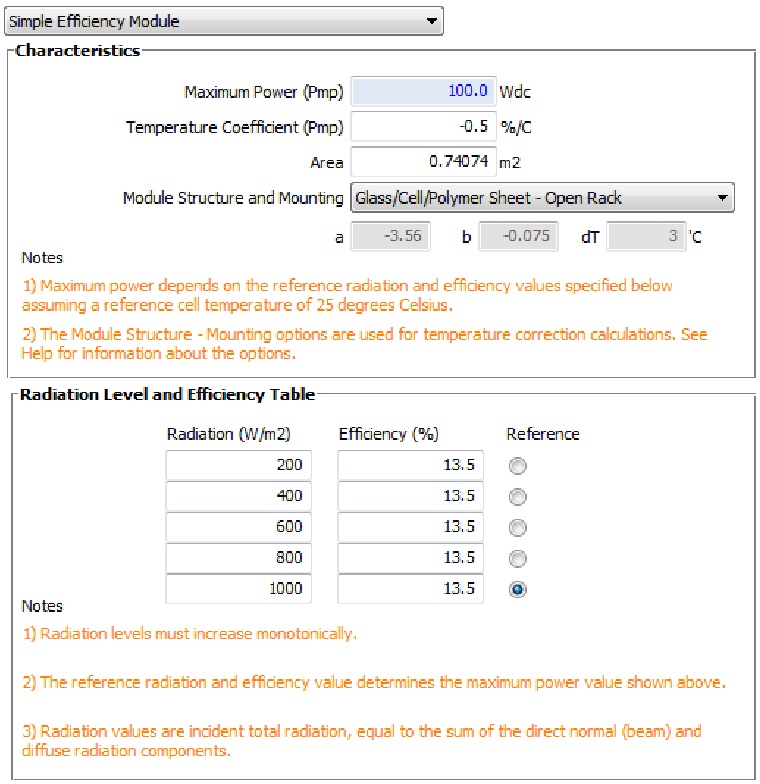
Characterizes module using University of Wisconsin five-parameter theoretical model and coefficients derived from manufacturer's specifications

Recommended when module is not available in Sandia database

Module database maintained by CEC for New Solar Homes Partnership program

Five-parameter model may not represent thin film performance accurately

Simple Efficiency Module



Steps:
1. Specify module area
2. Specify module efficiency for one or up to five incident radiation levels
3. Choose a reference radiation value
4. Specify a temperature coefficient of power
5. Choose a module structure

Calculates hourly efficiency values using the efficiency curve you specify

Includes the temperature correction algorithm from the Sandia model

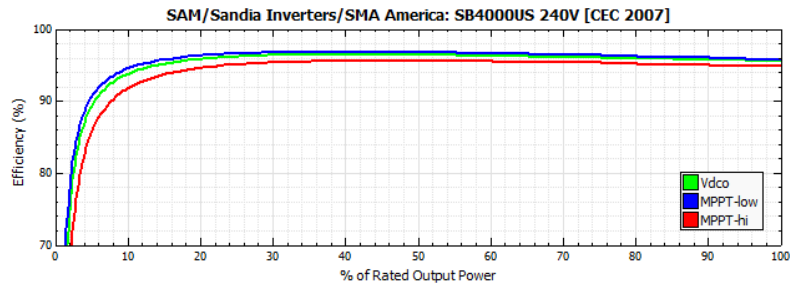
Recommended for parametric studies on module efficiency and temperature coefficient, or when a module is not available in either the Sandia or CEC databases

Sandia Performance Model for Grid Connected PV Inverters

Sandia Performance Model for Grid Connected PV Inverter

Sandia Inverter: SAM/Sandia Inverters/SMA America: SB4000US 240V [CEC 2007]

Efficiency Curve



Inverter Characteristics

AC Voltage	240	V	Coefficient 0	-6.57929e-006	1/V
Power ACo	4000	Wac	Coefficient 1	4.72925e-005	1/V
Power DCo	4186	Wdc	Coefficient 2	0.00202195	1/V
PowerSo	19.7391	W	Coefficient 3	0.000285321	1/V
PowerNTare	0.17	W	MPPT_low	250	V
Vdcmax	0	V	Vdco	310.67	V
Idcmax	0	A	MPPT_hi	480	V

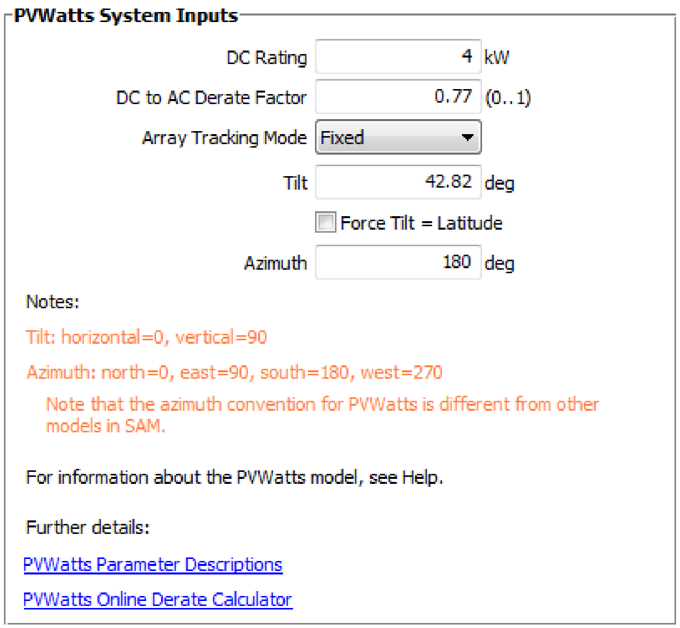
SAM can model systems with this inverter. However, because the parameter database for this inverter does not include its rated voltage limits, SAM will not be able to perform the pre-simulation check to verify that the array voltage falls within the inverter's minimum and maximum voltage ratings. If you use this inverter in SAM, please check with the inverter manufacturer specifications to verify that the array open circuit voltage value displayed on the Array page is not above or below the inverter's minimum and maximum voltage ratings. Please see the Inverter page's help topic for details.

Steps:

1. Choose an inverter from the list

- Calculates hourly inverter efficiency values as a function of model coefficients and array's DC output
- Characterizes inverter using Sandia empirical model and coefficients derived from field test measurements
- Database of coefficients for commercially-available inverters maintained by Sandia and CEC

PVWatts



Steps:

1. Specify a system capacity in DC kW
2. Specify a DC to AC derate factor

Calculates hourly system AC output by applying a single derate factor to the hourly total incident radiation value

Calculates an hourly temperature correction factor based on ambient temperature and wind speed