

# System Advisor Model: An Introduction



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May 2011

**DOCKET**

11-IEP-1D

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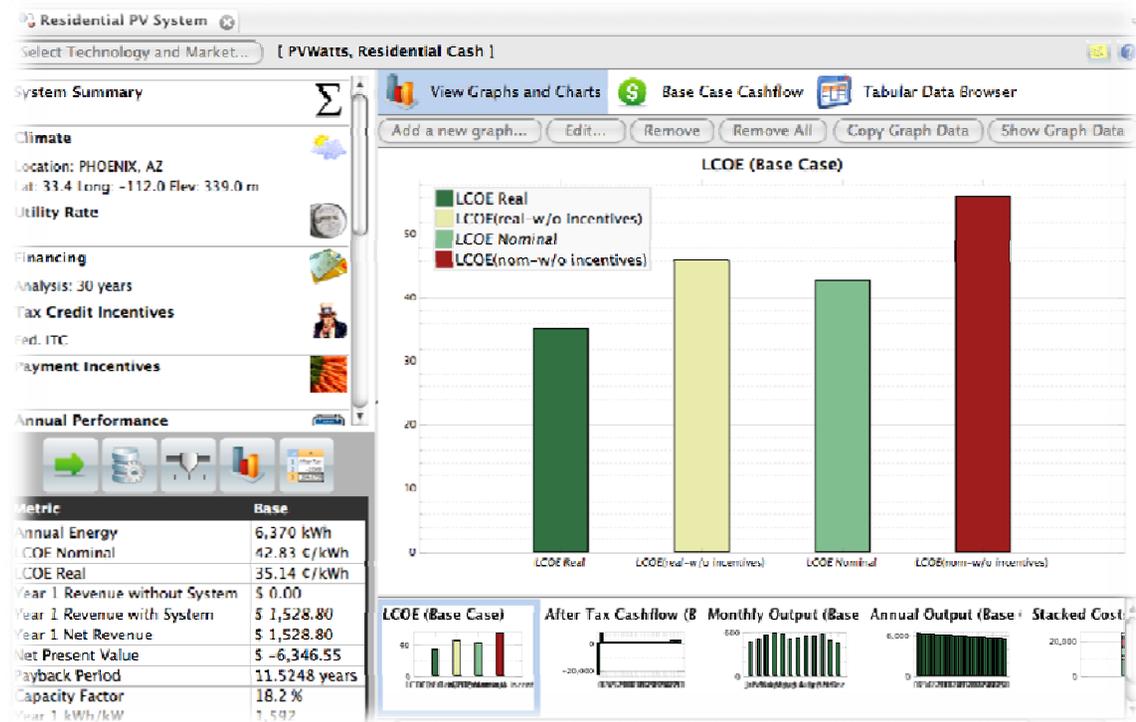
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# What is SAM?



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?

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- 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



**WorleyParsons**  
resources & energy

# 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

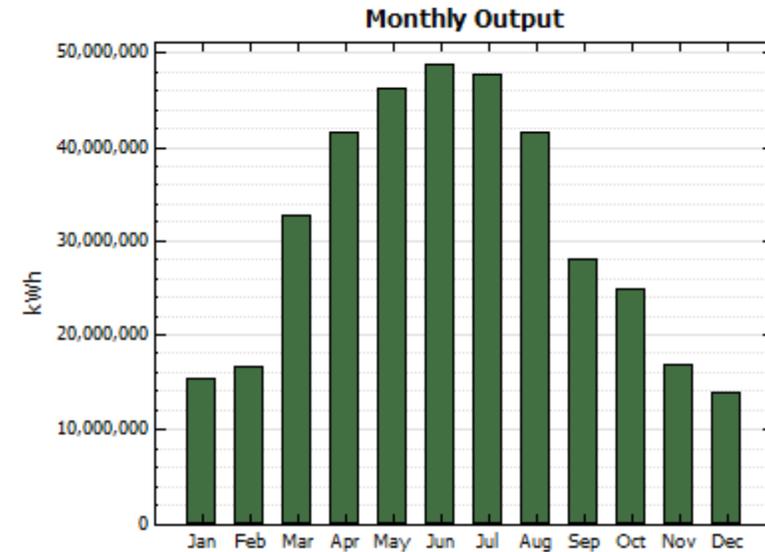
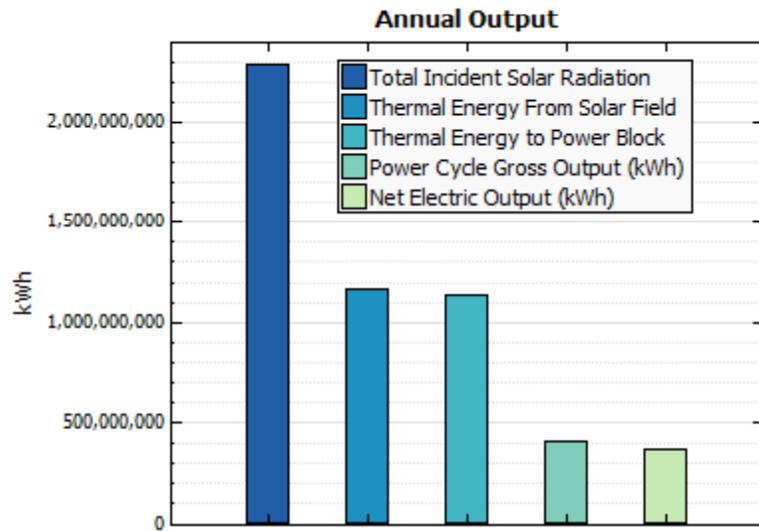
## Evaluate technology research opportunities and grant proposals

- Department of Energy

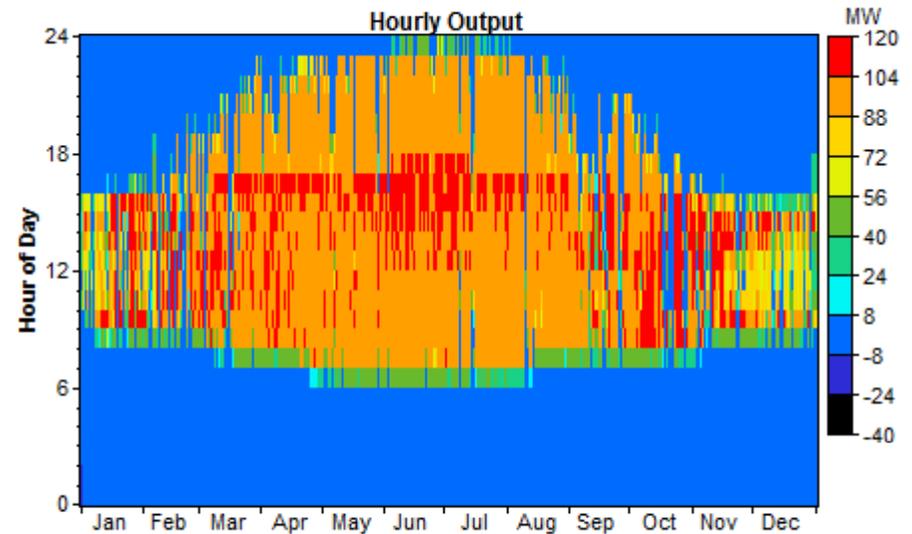
**20,000+ Downloads**

Manufacturers  
Engineering Firms  
Consultants  
Developers  
Venture Capitalists  
Policy Analysts

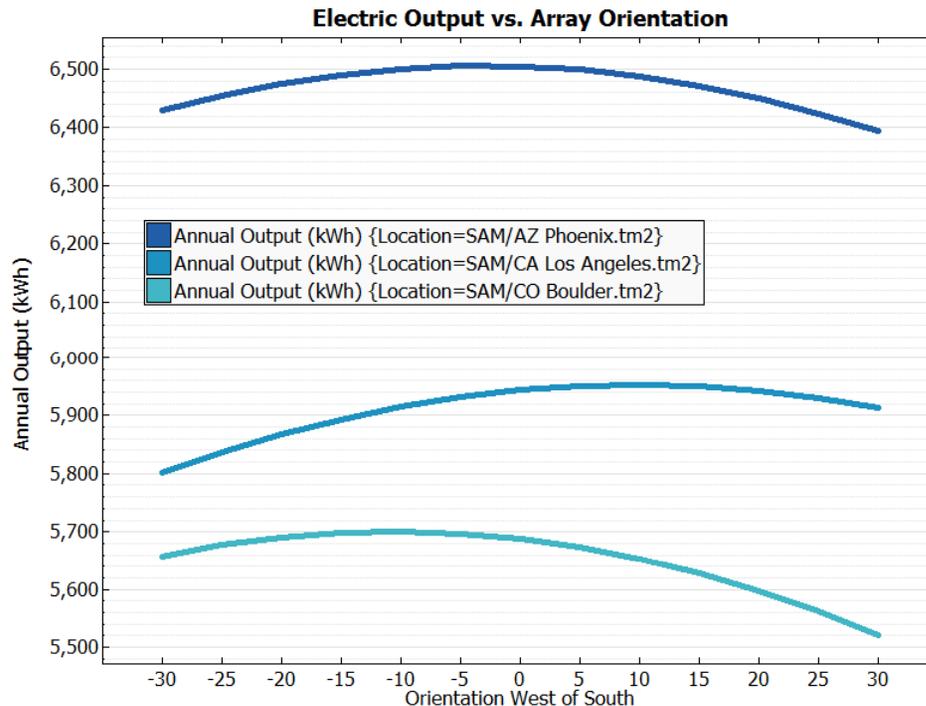
# Predict System Energy Output



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



# Optimize Design Parameters

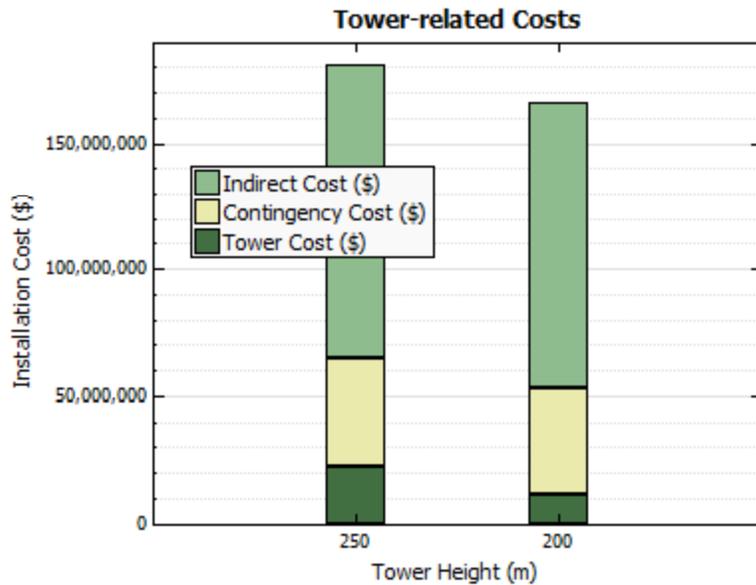


- For Boulder, CO, orient array slightly eastward to avoid summer afternoon thunderclouds over mountains
- For Los Angeles, CA, orient array slightly westward to avoid morning fog
- For Phoenix, AZ, orient array due south

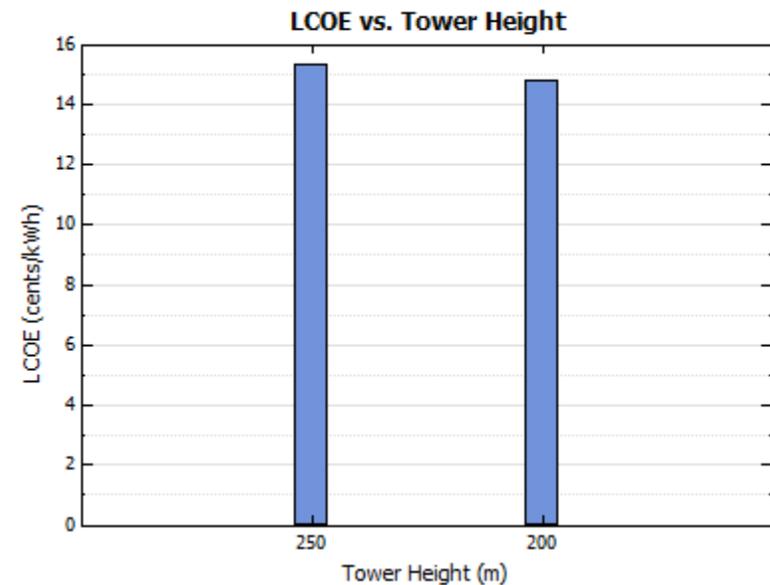
Example: Explore optimal array tilt and azimuth angles for a 3 kW residential photovoltaic system in three different locations



# Analyze Project Costs



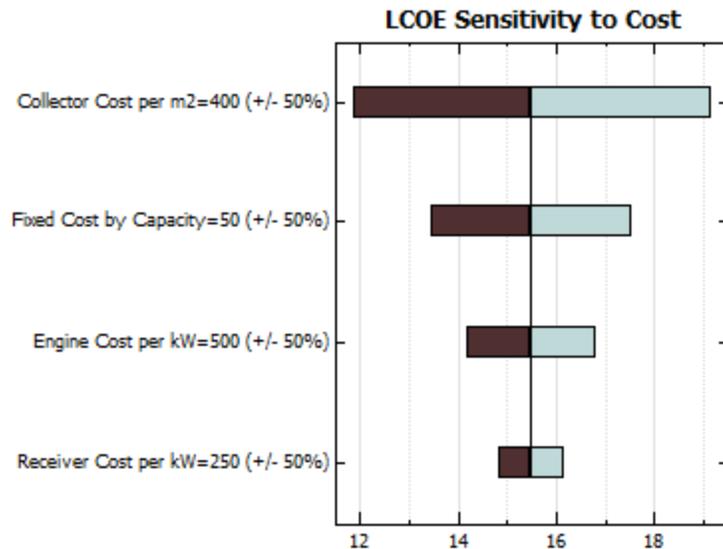
Decreasing tower height by 50 m decreases installation costs by 2.5% and levelized cost of energy (LCOE) by 4.0%



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



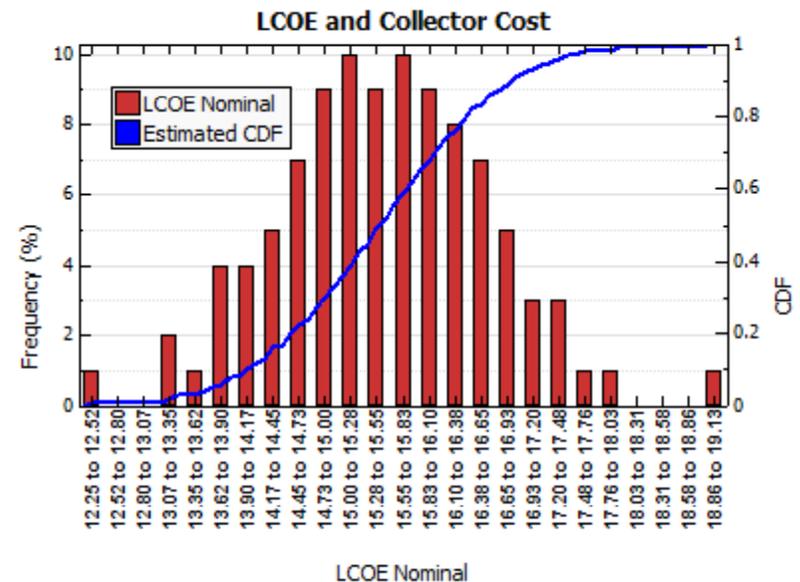
# Assess Uncertainties



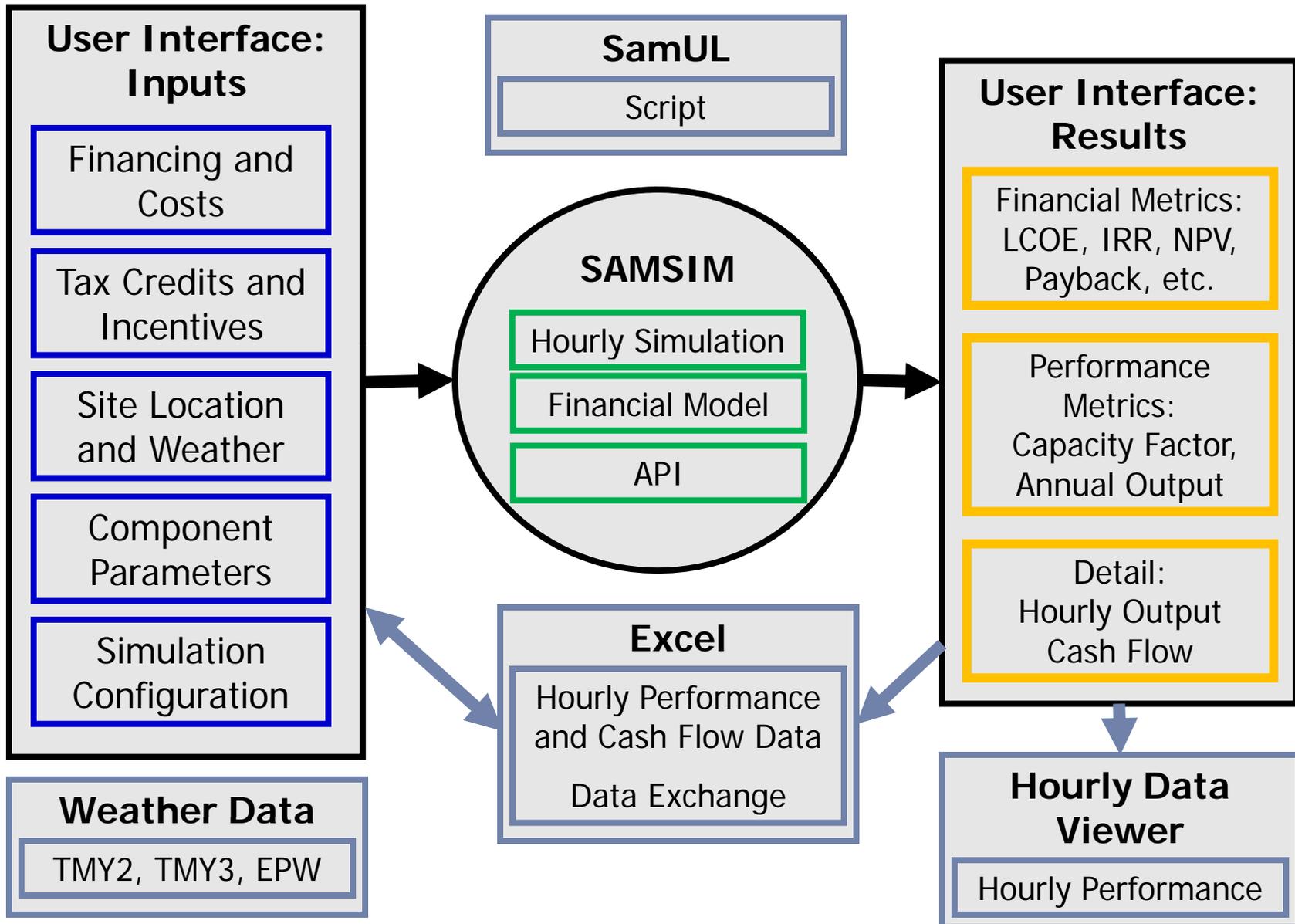
Sensitivity analysis: LCOE is most sensitive to collector cost

Statistical analysis: Shows degree of uncertainty

Example: 25 kW dish-stirling system



# Program Structure





# Extending SAM

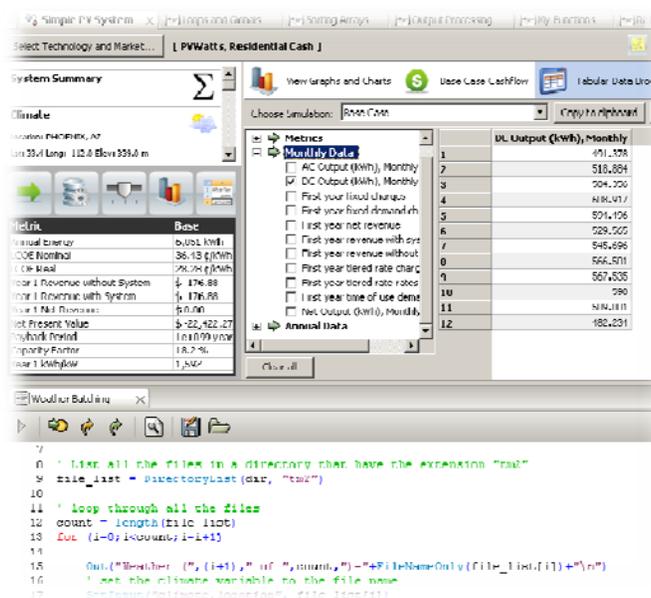
## Interoperability with Excel/VBA, Matlab, Python, C, others

- 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)

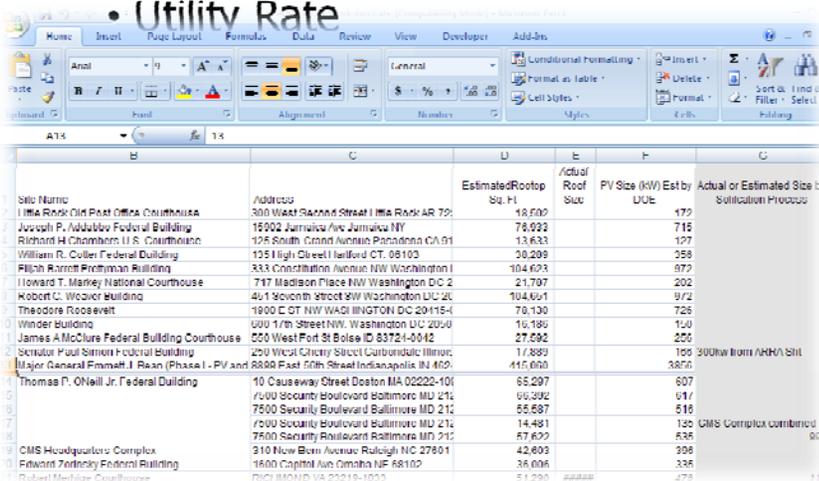
- Built-in scripting language to automate complex analysis tasks
- Allows developers to extend the core functionality of SAM to suit their needs



# Example of Extending SAM via SamUL

**Input:** spreadsheet of 30 GSA buildings with PV

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

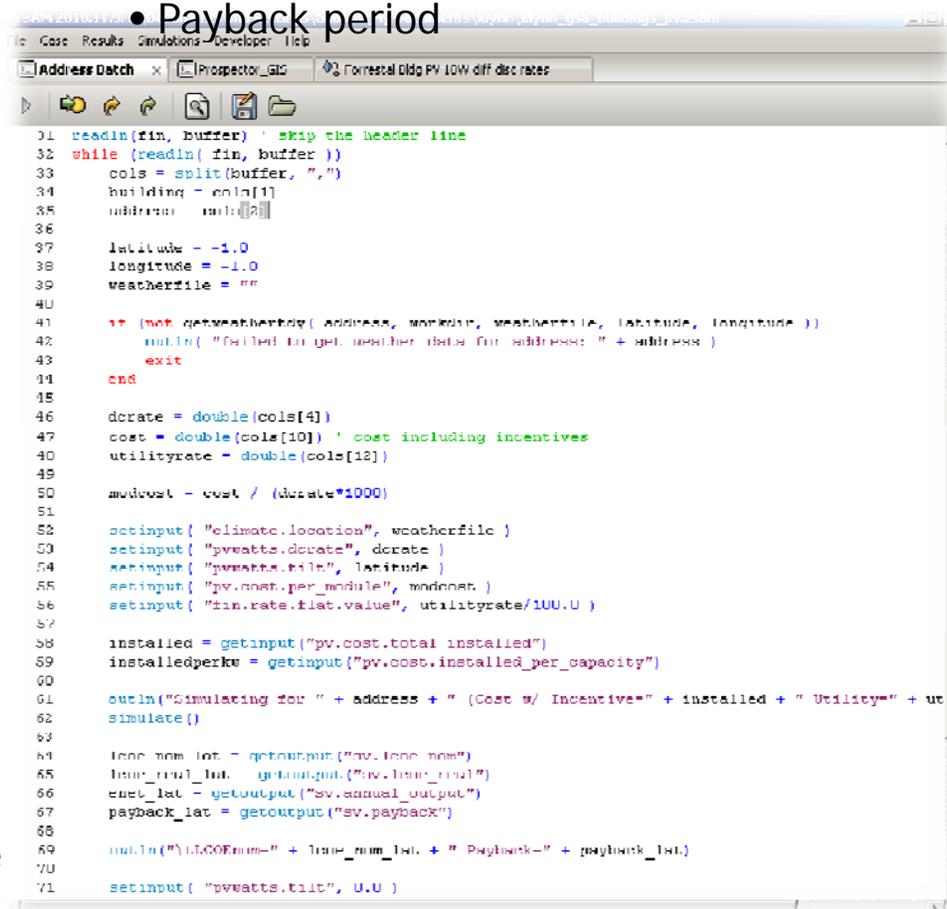


| Name   | Address                                   | Estimated Rooftop Size (ft <sup>2</sup> ) | Actual Roof Size (ft <sup>2</sup> ) | PV Size (kW) Est (DU) | Actual or Estimated Size (DU) |
|--|---|---|-------------------------------------|-----------------------|-------------------------------|
| Wm Rankin Post Office Courthouse               | 300 West Second Street   Wm Rankin TN 370 | 18,600                                    | 179                                 |                       |                               |
| Joseph P. Addabbo Federal Building             | 15002 Jamaica Ave Jamaica NY              | 78,922                                    | 715                                 |                       |                               |
| Richard H. Chambers U.S. Courthouse            | 125 South Grand Avenue Pasadena CA 91     | 13,833                                    | 197                                 |                       |                               |
| William R. Collier Federal Building            | 125 High Street Hartford CT 06103         | 30,209                                    | 258                                 |                       |                               |
| Ellis Ruffin Prothman Building                 | 333 Constitution Avenue NW Washington D   | 104,623                                   | 972                                 |                       |                               |
| Howard T. Markey National Courthouse           | 717 Madison Place NW Washington DC 2      | 21,707                                    | 202                                 |                       |                               |
| Robert C. Weaver Building                      | 461 Seventh Street SW Washington DC 20    | 104,601                                   | 972                                 |                       |                               |
| Theodore Roosevelt                             | 1800 C ST NW WASHINGTON DC 20115-4        | 70,130                                    | 728                                 |                       |                               |
| Winder Building                                | 600 17th Street NW, Washington DC 2000    | 16,180                                    | 150                                 |                       |                               |
| James A. McClure Federal Building Courthouse   | 550 West Fort St Boise ID 83721-0042      | 27,592                                    | 255                                 |                       |                               |
| Scrivner Post-Simons Federal Building          | 250 West Canyon Street Columbus Illinoi   | 17,889                                    | 169                                 | 300lbs from AEM's Sit |                               |
| Major General Emmett J. Bean (Phase I - PV and | 8200 East 50th Street Indianapolis IN 462 | 415,600                                   | 3870                                |                       |                               |
| Thomas P. O'Neill Jr. Federal Building         | 10 Causeway Street Boston MA 02222-101    | 55,297                                    | 507                                 |                       |                               |
|  | 7500 Security Boulevard Baltimore MD 212  | 66,392                                    | 617                                 |                       |                               |
|  | 7500 Security Boulevard Baltimore MD 212  | 55,587                                    | 518                                 |                       |                               |
|  | 7500 Security Boulevard Baltimore MD 212  | 14,481                                    | 135                                 | CMS Complex combined  |                               |
|  | 7500 Security Boulevard Baltimore MD 212  | 67,602                                    | 636                                 |                       |                               |
| CMS Headquarters Complex                       | 310 New Bern Avenue Raleigh NC 27601      | 42,603                                    | 398                                 |                       |                               |
| Edward Zerkley Federal Building                | 1800 Capital Ave Omaha NE 68102           | 36,606                                    | 336                                 |                       |                               |
| Robert Hefner Courthouse                       | 7000 Blount Dr VA 23219-1035              | 51,200                                    | 478                                 |                       |                               |

**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.

**Output:** spreadsheet with results for each system

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



```
31 readln(fin, buffer) ' skip the header line
32 while (readln( fin, buffer ))
33 cols = split(buffer, ",")
34 building = cols[1]
35 address = cols[2]
36
37 latitude = -1.0
38 longitude = -1.0
39 weatherfile = ""
40
41 if (not getweatherfile( address, weatherfile, latitude, longitude ))
42     writeln( "failed to get weather data for address: " + address )
43     exit
44 end
45
46 dcrate = double(cols[4])
47 cost = double(cols[10]) ' cost including incentives
48 utilityrate = double(cols[12])
49
50 mducost = cost / (dcrate*1000)
51
52 setinput( "climate.location", weatherfile )
53 setinput( "pvatts.dcrate", dcrate )
54 setinput( "pvatts.lat", latitude )
55 setinput( "pv.const.per_module", mducost )
56 setinput( "fin.rate.fiat.value", utilityrate/100.0 )
57
58 installed = getinput("pv.cost.total installed")
59 installedperkw = getinput("pv.cost.installed_per_capacity")
60
61 outln("Simulating for " + address + " (Cost w/ Incentive=" + installed + " Utility=" + ut
62 simulate()
63
64 lcoe_nom_lat = getoutput("pv.lcoe_nom")
65 lcoe_nom_lat = getoutput("pv.lcoe_nom")
66 annl_lat = getoutput("sv.annual_output")
67 payback_lat = getoutput("sv.payback")
68
69 writeln("LCOENom=" + lcoe_nom_lat + " Payback=" + payback_lat)
70
71 setinput( "pvatts.tait", 0.0 )
```

# Obtaining SAM



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

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

**NREL**  
NATIONAL RENEWABLE ENERGY LABORATORY

ABOUT NREL | ENERGY ANALYSIS | SCIENCE & TECHNOLOGY | TECHNOLOGY TRANSFER | APPLYING TECHNOLOGIES

Energy Analysis

## Solar Advisor Model (SAM)

- SAM Home
- Background
- Download**
- SAM Templates
- System Cost Data
- Publications
- Support
- Frequently Asked Questions (FAQs)
- Related Links
- Contacts

### Download

#### Current Official Release

Solar Advisor Model (SAM) Version 2010.11.9 is now available.

- [Sign in](#) to download SAM 2010.11.9 (Windows XP/Vista/7, Mac OS X Intel)

Highlights:

- Complete system structures for residential and commercial projects.
- Time-based pricing for utility projects through the use of energy payment allocation.
- New shading model for the photovoltaic systems models.
- New generic system model for general concentrating solar power system that uses a solar field efficiency table for inputs.
- Improved Results page makes it easier to display and export hourly data, regardless of operating system (Windows or Mac), and to display hourly data for simulations involving multiple runs such as parametric analyses.
- New cavity receiver model for the power tower system model.

# Other Workshop Questions Answered

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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).*

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Thank You

# QUICK DEMO OF PV SYSTEM



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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](mailto:solar.advisor.support@nrel.gov)

The screenshot shows the 'System Advisor Model Help' window. The left pane contains a table of contents with 'Start a Project' highlighted under 'General Reference'. The right pane displays the 'Start a Project' help text, which includes instructions on how to start a project, a note about the SAM Projects folder, and a list of sample files to open.

**SAM Help**

Contents Search

- About SAM
- ▣ General Reference
  - **Start a Project**
  - The Main Window
  - Manage Cases
  - Review and Modify Inputs
  - Run Simulations
  - Review Results
  - Get Help
  - Work with Notes
  - File Formats
  - Menus
  - Convert from Version 3.0
  - Working with Numeric Ranges
- Technology and Market Window
- ▣ Input Page Reference
- ▣ Configuring Simulations
- ▣ Results
  - Viewing Graphs of Time Series Data (DView)
- ▣ Advanced Topics
- References

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### Start a Project

When you start SAM, it displays a Welcome window with three options for starting a project.

- **Start from a sample file** creates a project file that contains a complete set of inputs and results. Each sample file demonstrates either a feature of the software or one of the technologies.
- **Start a new project** displays the [Technology and Market window](#) where you choose options for a new project file. When you start a new project in this way, all of the variables on the input pages are populated with default values, but no results are displayed on the Results page until you configure and run simulations.
- **Open a recent file** allows you to choose from a list of project files. The list contains project files that were saved during previous SAM sessions.

### Sample Files

Sample files are a good place to start when you are first learning SAM. Each sample file contains a set of cases that demonstrate how to model different types of projects.

When you open a sample file, SAM creates a new project file with the `.sam` extension using the name of the sample file.

SAM displays the software version and the project file name in the main window's title bar.

**Note.** When you install SAM, it creates the SAM Projects folder in your default documents folder and uses this as the default location for storing project files. You can change the default project file location by clicking **Preferences** in the File Menu.

### To open a sample file:

1. On the Welcome page, scroll through the list of sample files, and double-click the file name for a system or analysis example.

Start from a sample file

- ▣ Sample Files
  - ▣ Combined Multiple PV Systems Example
  - ▣ Custom HTF Example
  - ▣ Excel Sample
  - ▣ PV Battery Storage Sample
  - ▣ PV Shading Example

# Current Development Team

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## 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\*



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SAM Overview

# PV MODELING OPTIONS

# PV modeling features

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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

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Array shading and self shading

System can be made up of multiple sub-systems

# PV module performance models

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## 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

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## 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

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## 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

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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



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SAM Overview

# PARABOLIC TROUGH MODELING OPTIONS

# PV Performance Models

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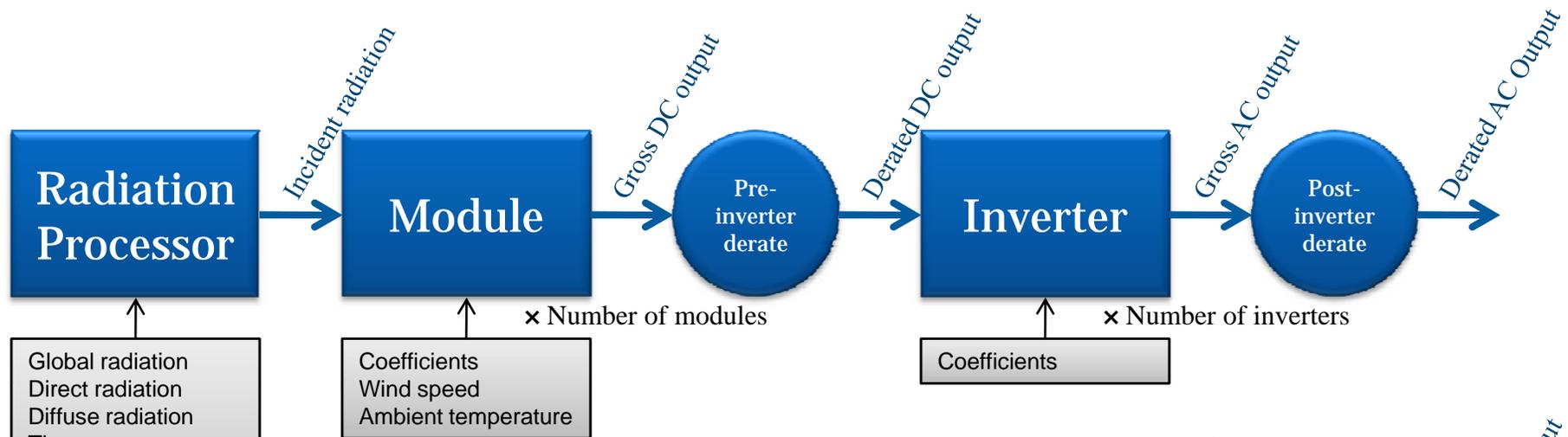
## Component models

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

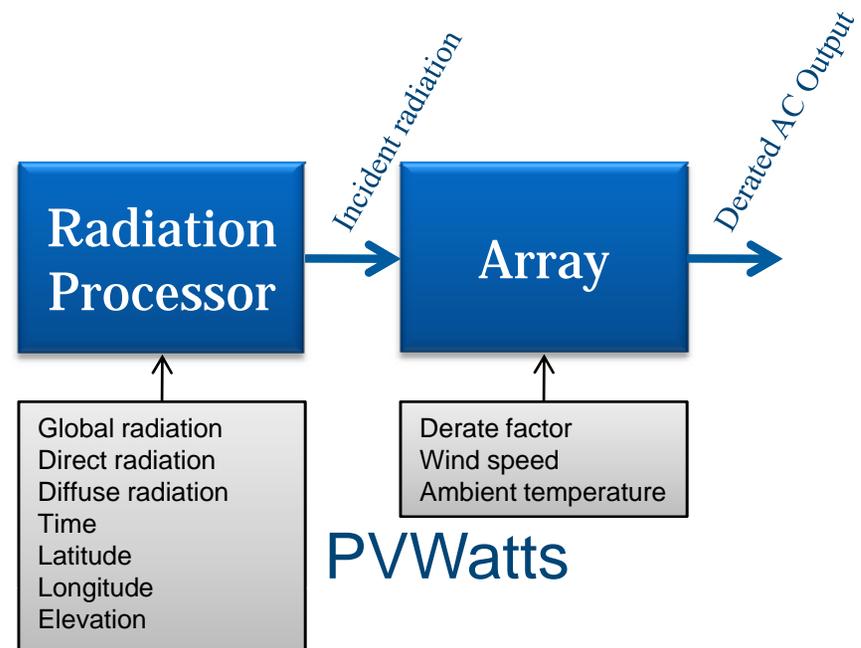
## PVWatts

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

# PV Performance Models



## Component models



## PVWatts



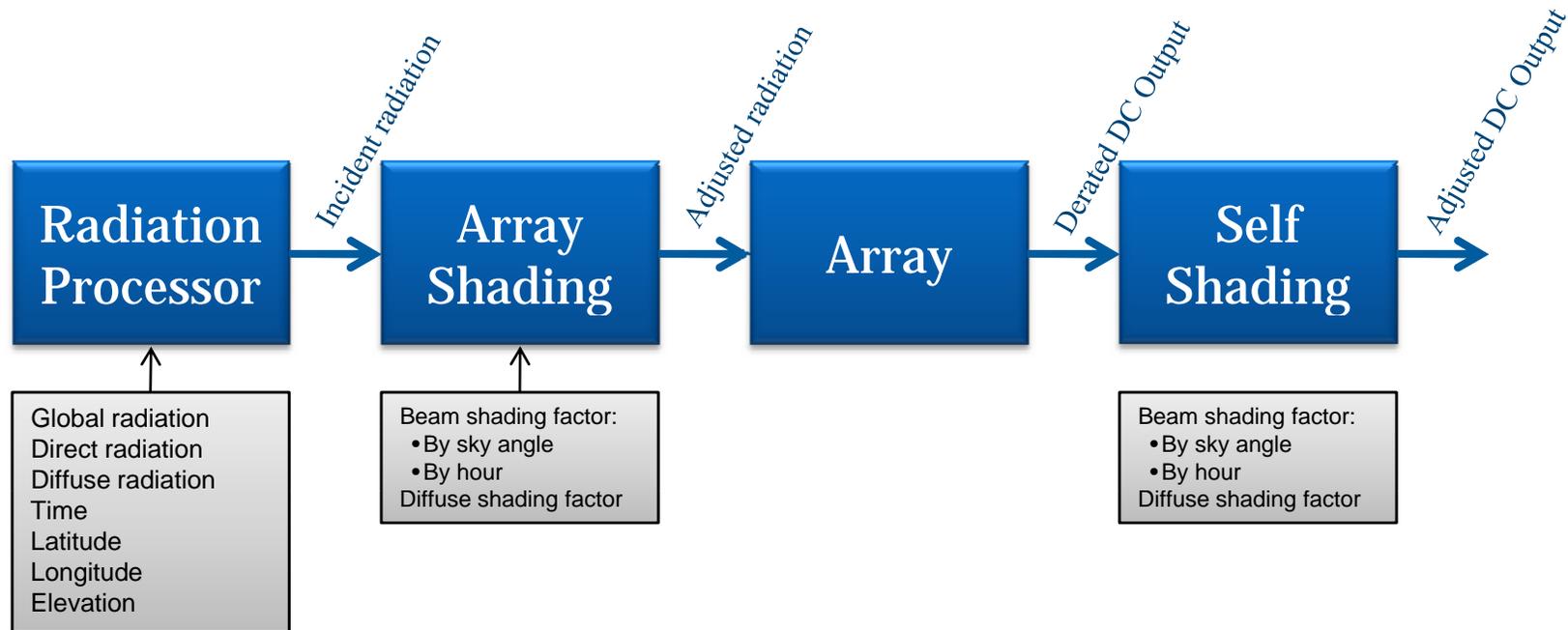
## Array shading

- 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



# Sandia PV Array Performance Model



## Steps:

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

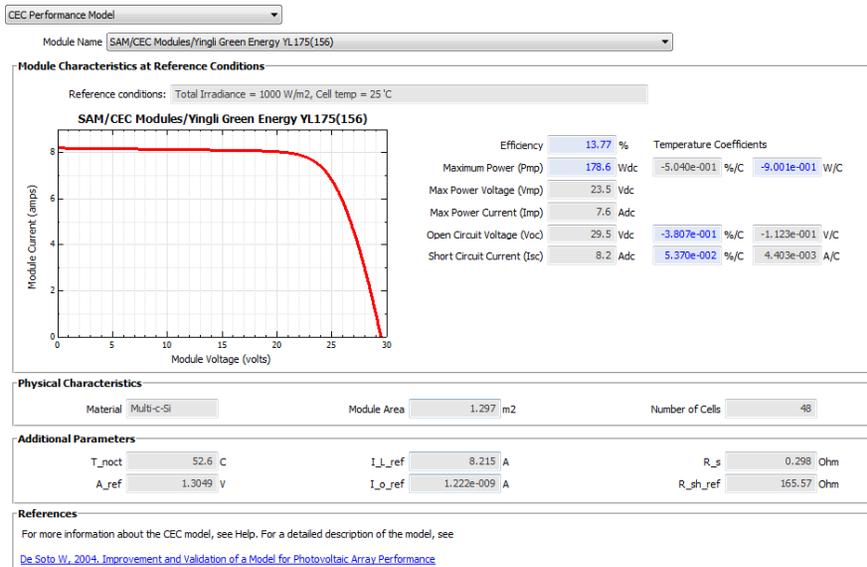
Calculates hourly module efficiency values based on incident radiation, ambient temperature, and module coefficients

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



Simple Efficiency Module

**Characteristics**

Maximum Power (Pmp)  Wdc

Temperature Coefficient (Pmp)  %/C

Area  m<sup>2</sup>

Module Structure and Mounting

a  b  dT  °C

**Notes**

1) Maximum power depends on the reference radiation and efficiency values specified below assuming a reference cell temperature of 25 degrees Celsius.

2) The Module Structure - Mounting options are used for temperature correction calculations. See Help for information about the options.

**Radiation Level and Efficiency Table**

| Radiation (W/m <sup>2</sup> )     | Efficiency (%)                    | Reference                        |
|-----------------------------------|-----------------------------------|----------------------------------|
| <input type="text" value="200"/>  | <input type="text" value="13.5"/> | <input type="radio"/>            |
| <input type="text" value="400"/>  | <input type="text" value="13.5"/> | <input type="radio"/>            |
| <input type="text" value="600"/>  | <input type="text" value="13.5"/> | <input type="radio"/>            |
| <input type="text" value="800"/>  | <input type="text" value="13.5"/> | <input type="radio"/>            |
| <input type="text" value="1000"/> | <input type="text" value="13.5"/> | <input checked="" type="radio"/> |

**Notes**

1) Radiation levels must increase monotonically.

2) The reference radiation and efficiency value determines the maximum power value shown above.

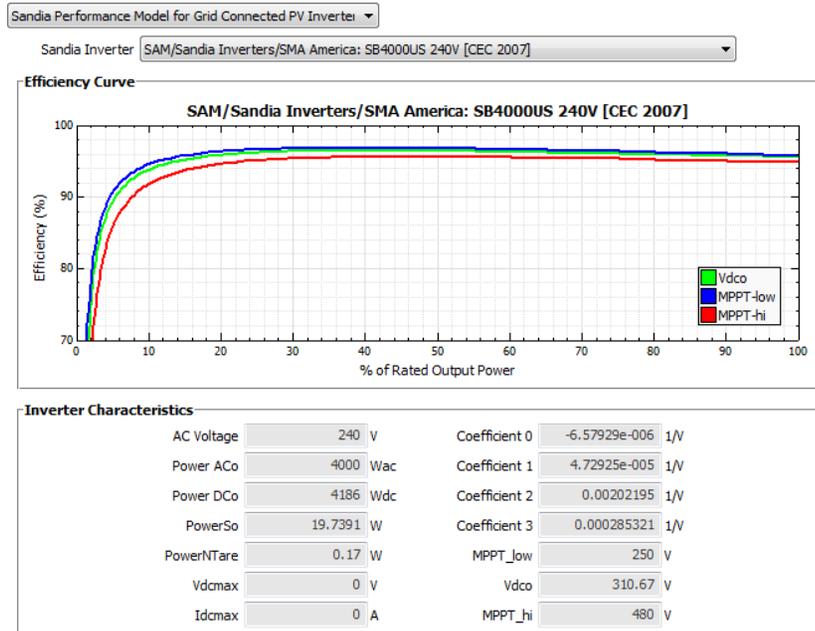
3) Radiation values are incident total radiation, equal to the sum of the direct normal (beam) and diffuse radiation components.

## 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



**Steps:**  
1. Choose an inverter from the list

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.

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 System Inputs**

DC Rating  kW

DC to AC Derate Factor  (0..1)

Array Tracking Mode

Tilt  deg

Force Tilt = Latitude

Azimuth  deg

Notes:

Tilt: horizontal=0, vertical=90

Azimuth: north=0, east=90, south=180, west=270

Note that the azimuth convention for PVWatts is different from other models in SAM.

For information about the PVWatts model, see Help.

Further details:

[PVWatts Parameter Descriptions](#)

[PVWatts Online Derate Calculator](#)

## 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