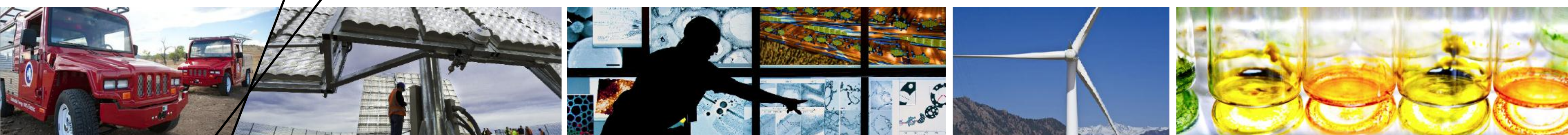
PV Modeling in SAM



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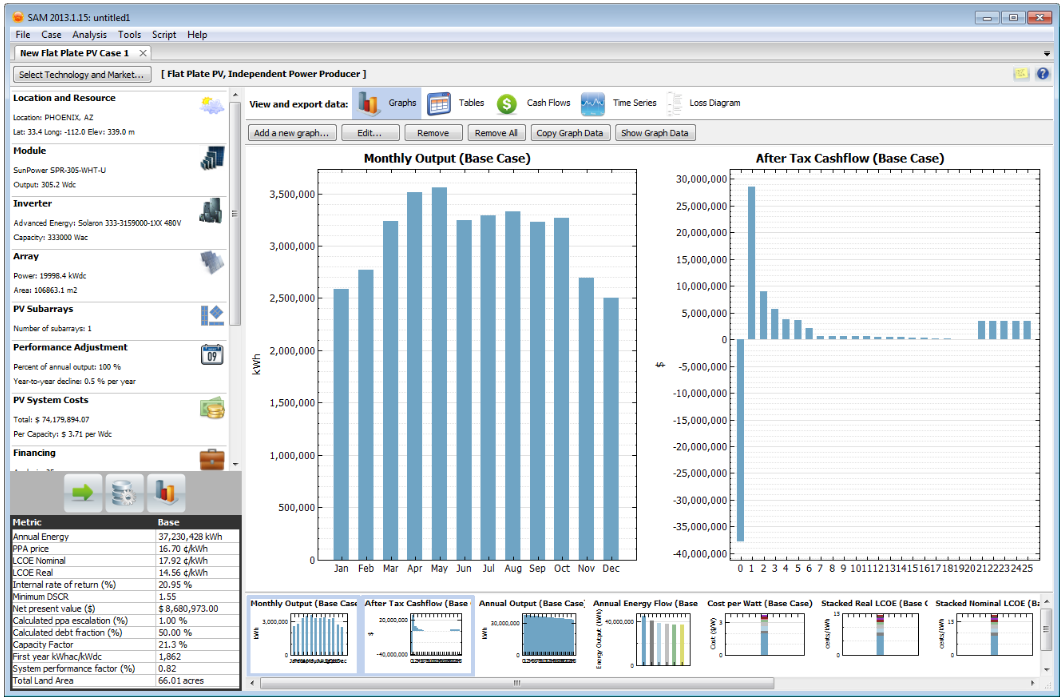
System Advisor Model (SAM)

- **Performance models calculate a renewable energy system's hourly energy output over a single year**
- **Financial models calculate the cost of energy for a renewable energy project over many years of operation**



Find out more and download the software free at http://sam.nrel.gov

Technologies in SAM

Photovoltaics

Concentrating PV

Solar Water Heating

Geothermal

Parabolic Trough

Power Tower

Linear Fresnel

Dish-Stirling

Small Wind

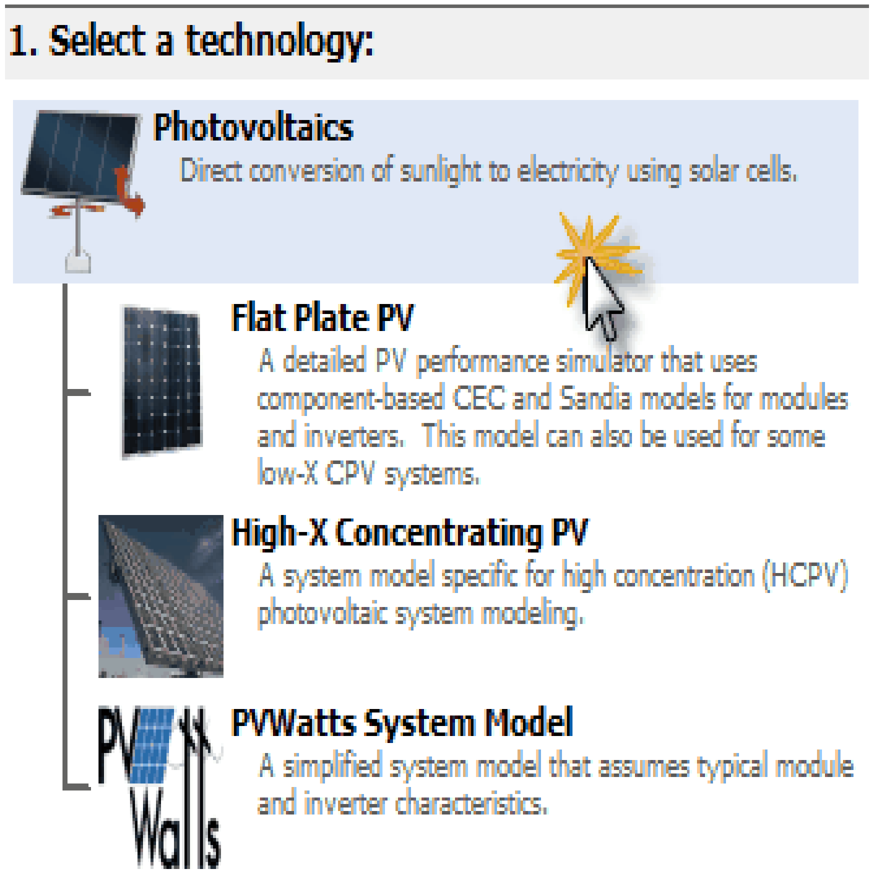
Utility-scale Wind

Biomass Power

Conventional

High-Level Options for PV Modeling

- SAM offers three options for modeling a photovoltaic system:
- PVWatts System model is an implementation of NREL's online photovoltaic calculator
- Flat Plate PV model combines separate, user-selectable component models for the module and inverter with a set of parameters describing the array layout to represent the system
- High-X Concentrating PV model is for concentrating PV (CPV) systems.



Commonalities Among All Models

- A radiation processor to calculate incident radiation on the array using TM2, TMY3 or EPW formatted data
- The irradiance processor may use one of three different tilted surface algorithms (Isotropic, HDKR, Perez)
- All use a set of user-specified shading factors that adjust the incident irradiance
- All use a set of performance adjustment factors to represent availability, degradation, curtailment, outages, etc.
- All have derate values that adjust output for non-modeled factors like wiring losses, tracking losses and inefficiencies.
- SAM runs an hourly simulation model for all cases

Summary of SAM's Photovoltaic Models

	Flat Plate	PVWatts	High-X CPV
Array DC output	•	•	•
Inverter AC output	•	•	•
Temperature effects	•	•	•
Array shading	•	•	•
Tracking options	•	•	2-axis only
Row-to-row shading	•		
Backtracking	•		
Mounting options	•		
Multiple subarrays	•		

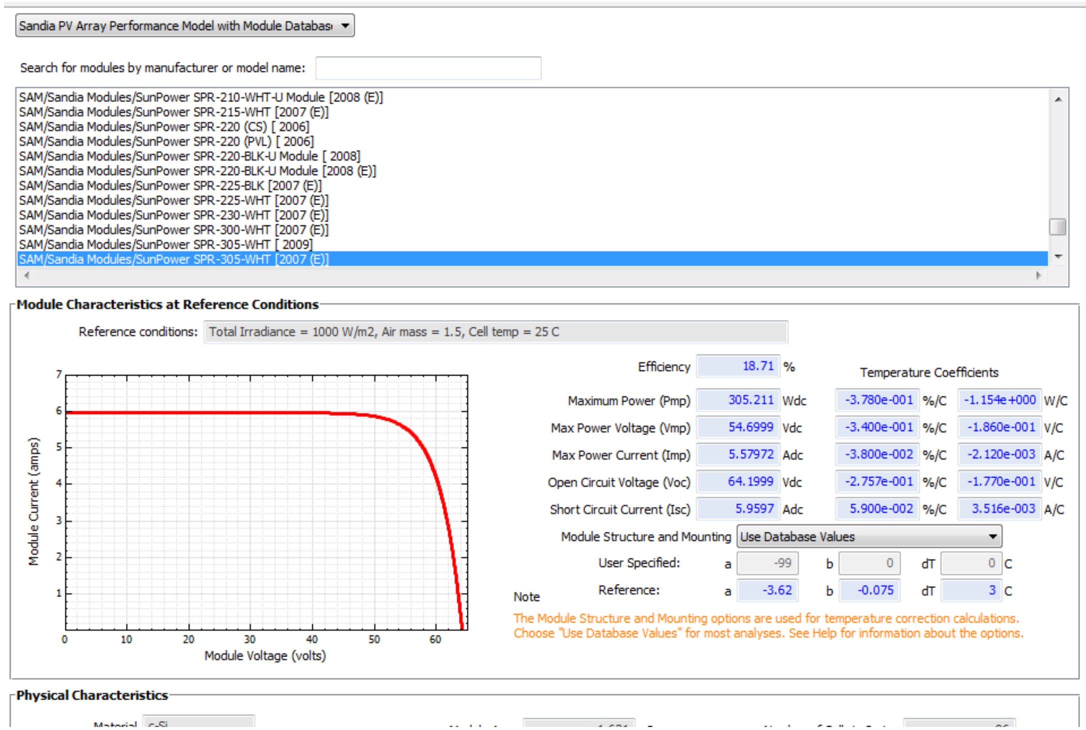
Flat Plate Modeling Option Overview

- **Module Models:**
  - the Sandia Module Model, CEC module model and the Simple Efficiency module model
- **Inverter Models:**
  - the Sandia Inverter Model and the Single-Point efficiency model..
- **Subarray characteristics (up to 4 different subarrays):**
  - Specific module and inverter constant across entire system
  - Defines # of modules/string and # of strings in parallel
  - Different orientation for each
  - Shading and soiling factors for each
  - DC derate factors for each
  - Module mismatch losses in each subarray can be represented using a DC derate factor.
  - SAM can calculate subarray mismatch losses caused by subarrays with different maximum power point voltages (only with CEC module model)
- **Subarray Assumptions**
  - Assumes that each sub-array operates at its maximum power point.
  - Assumes that the modules in each subarray operate uniformly at the same cell temperature and maximum power point.
  - Assumes that all inverters have the same hourly conversion efficiency.

Sandia PV Array Performance Model

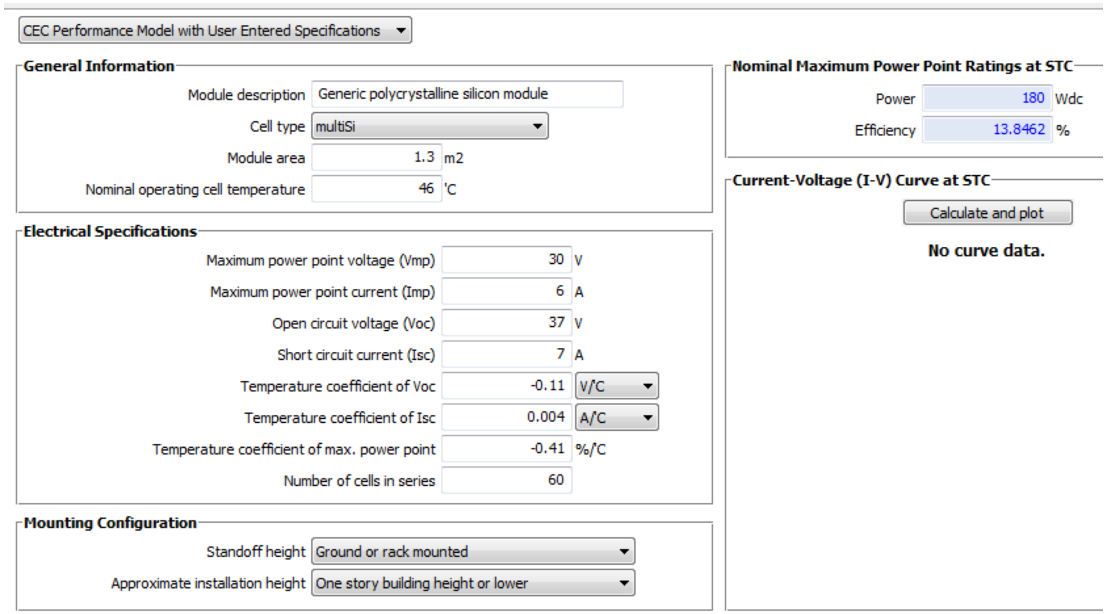
- **Calculates module output using a set of equations and 40 coefficients calculated from multi-day measurements at a certified outdoor test facility.**
- **SAM stores a library of module coefficients**
  - currently 514 modules
  - Includes modules with thin-film cells, including amorphous silicon, CIS, CdTe, and HIT.

- **Because the Sandia model coefficients are based on measured data, it may more accurately represent the performance of thin-film modules at low light levels than the CEC and simple efficiency models.**



CEC/5-parameter Module Model

- **Uses a variant of the five-parameter model developed by the UW-Madison**
- **It is a single diode model whose parameters can be calculated from the manufacturers datasheet specs.**
- **Uses a CEC-maintained database of module characteristics (10,000+ entries)**
- **SAM allows the user to enter their own spec sheet data.**
- **The CEC module model offers two temperature correction algorithms**
  - The NOCT cell temperature algorithm (from the original model)
  - the mounting-specific cell temp model is a first-principles heat transfer algorithm.

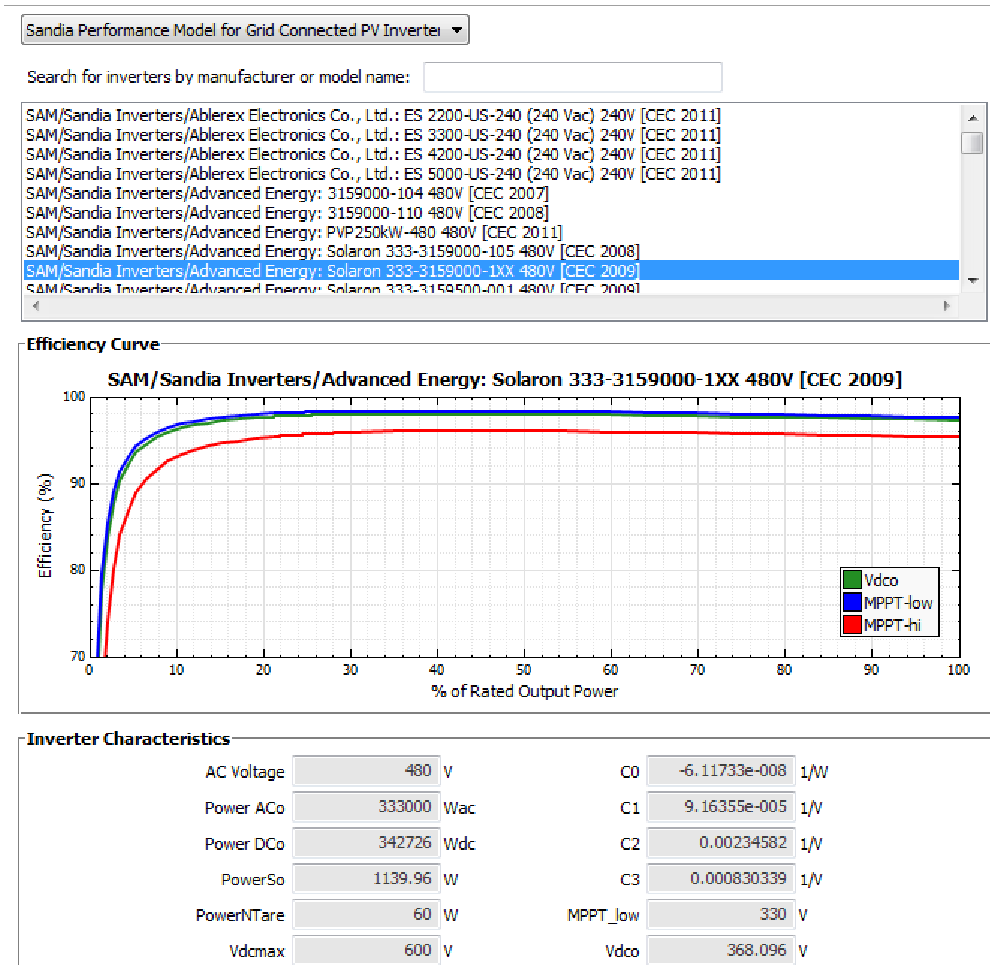


Inverter Models

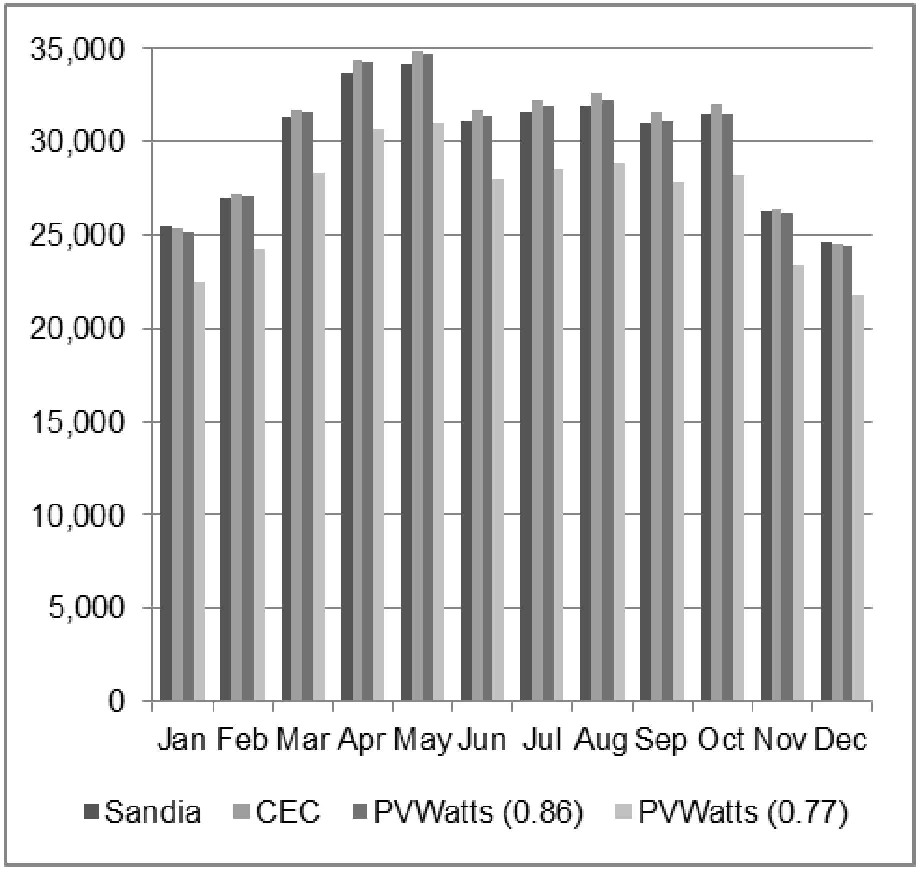
- The Sandia Model for Grid-connected Inverters calculates the inverter's efficiency using coefficients from a library of inverters (currently 1157 entries) developed from manufacturer specifications and field test data.

- The Single Point Efficiency Model uses two user-specified inputs, the rated AC power in Watts, and rated DC-to-AC conversion efficiency (which is constant)

- The PVWatts model represents the inverter using an internal algorithm without separate inputs for the module and inverter algorithms.



Comparison of Module Models



- **Hypothetical 200 kW PV system**
- **The Sandia and CEC models use coefficients for the SunPower SPR-210-WHT-U module**
- **Other inputs are SAM defaults for commercial system and a SMA America 36 kW inverter.**
- **For the PVWatts cases, the system was modeled with two DC-to-AC derate factors, 0.77 and 0.86.**

- **The Sandia and CEC module models are in close agreement with monthly values within 2%.**
- **The PVWatts derate factor of 0.86 more closely matches the other model results than the default value of 0.77.**

Comparison Annual Results

	Annual Output (kWh/yr)	LCOE (¢/kWh)
Sandia Module	360,000	11.8
CEC Module	365,000	11.7
PVWatts (.86)	361,000	11.8
PVWatts (.77)	323,000	13.2

- **The Sandia, CEC, and PVWatts with 0.86 derate factor models are in close agreement, while the PVWatts with 0.77 predicts a lower annual output and higher LCOE.**

- **For the TMY2 weather data used, the differences between results is within the weather data uncertainty.**

- **The LCOE differences are within the uncertainty of the various assumptions. This suggests that any of the three model options are suitable for estimates of a PV system's output or cost.**

Conclusions and Future Work

- SAM's implements several different photovoltaic models, which each use different algorithms and databases
- Different models are best for different use scenarios
- For a typical system with crystalline silicon modules, the Flat Plate PV CEC and Sandia module models and the PVWatts System Model predict total monthly AC output values within 2.0% of each other, and for a financial analysis using SAM's commercial financing model with default values, an LCOE within 0.1 cent/kWhr
- NREL has developed case studies comparing SAM results to data measured from installed systems
- Current major efforts to validate model results against measured data for residential, commercial and utility-scale systems.
- See the SAM website for more info on planned improvements.