System Advisor Model (SAM) Work Plan

January 2014

This document is adapted from NREL's Statement of Project Objectives (SOPO) submitted by NREL to the U.S. Department of Energy's Solar Energy Technologies Program. It describes the NREL Systems Integration program's System Modeling activity entitled "Improvement and Validation of Solar Systems Modeling Algorithms and Tools" and is the plan for NREL's work on SAM in fiscal years 2014 and 2015.

NREL is making this document available to the public on the SAM website to help keep SAM users and other interested parties informed about its plans for future work on the model.

The goals of the System Modeling activity are to improve system modeling accuracy and risk assessment via research into improved data and algorithms. We will make robust models available to various audiences – thereby improving the industry characterization of risk and improving bankability across all markets (residential, commercial and utility).

Our ongoing value to the community at a high level is to **enable and accelerate research and analysis of solar technologies** through the development and dissemination of cutting-edge solar and finance modeling. The research and analysis includes four equally valuable types:

- Our (EERE) own public research that is published for the wider community
- Our own analysis to inform research dollar investment decisions
- Research at academic institutions
- Analysis by independent engineers, solar installers, and utility participants.

Solar System Modeling Algorithms and Tools for Reducing Uncertainty and Risk

Project Overview

While needing more basic modeling research to improve their accuracy, these tools have a proven track record of success and are staffed by a talented team as described further below.

To secure competitive financing for a photovoltaic (PV) system, the economic risks associated with variability, technology maturity, and system design must be quantified and minimized. Since a PV system’s economic viability depends directly on its energy yield, the performance of a proposed system must be accurately characterized over various measures such as the time horizon, size and climate to ensure that financial institutions are confident in the technology and system design. To be accessible by the financial community, the impact of variations in energy yield must also flow through to economic metrics such as the LCOE, ROI, etc.

There are several shortcomings in the current state-of-the-art utility-scale solar modeling area with respect to risk and uncertainty and the ability of the financial community to ascertain the risk of a solar investment. Current tools including the System Advisor Model (SAM), PVWatts, PVsyst, etc. are not sufficiently validated across a broad range of systems, markets and geographical locations to provide the financial and independent engineering community with sufficient acceptance of these models. Additionally, there continue to underlying modeling gaps with regards to derates, emerging technologies and the unique characteristics of very large systems. These modeling gaps means that financiers are not adequately equipped with tuned performance predictions to make large investment decisions. This proposal addresses the issue of acceptance for SAM and PVWatts by focusing on validation of the models with extensive real data, a stakeholder engagement plan, inter-model comparisons and validation of underlying data. Additionally, we intend to increase the value of SAM to the community by creating new algorithms and methods to improve the fidelity and accuracy of modeled results and translating this to the broader community via accessible tools. The success of this project will therefore provide the PV and financial community a rigorous scientific underpinning for best-in-class modeling algorithms to accurately predict PV system performance, thereby reducing the economic uncertainties involved.

We will make robust models available to various audiences – thereby improving the industry characterization of risk and improving bankability across all markets (residential, commercial and utility).

Technical Work Plan: Fiscal Year 2014 (12 months)

In FY 2014, our efforts from budget period 1 (2013) will continue as we build on the knowledge learned in year 1. In Year 1, the LPDP review committee recommended strongly that we have a SAM Technical Review Committee (TRC). We did this and received good representation from the PV modeling community particularly people using tools to model large systems. Based on the output of the SAM (And PVWatts to a lesser degree) TRC meeting, we have revamped the activities in Year 2 and Year 3. Additionally for year 2, we have been responsive to recent DOE feedback to accelerate the SAM validation work and PVWatts development into Year 2 from Year 3.

Task 1 - Validation of SAM and PVWatts

To have any of the typical suite of PV performance modeling tools accepted by the solar industry (including financiers), these tools and the aggregate system modeling outputs need to be validated against actual systems. Therefore, to improve acceptance by the solar industry, gather valuable information about issues to improve, and interact with a technical review committee of users and potential users.

This task is focused on the validation of SAM and PVWatts across technologies and markets but with an emphasis on commercial and utility-scale PV systems. These validation activities will hopefully create a much higher level of acceptance of SAM outputs (and understanding of additional areas of improvement) in the community and also dramatically reduce the uncertainty. This activity builds on a variety of existing validation activities from the many validation efforts that have been performed for sub-components within PV (and CSP) systems.

Problem Statement

To date, there has been no public validation of the key PV performance tools in the marketplace that considers the PV system specifications and model assumptions in an end-to-end fashion. While various validation studies have been conducted at the component level (module performance vs. module model, etc.), the efforts to capture the question of "will a system perform as modeled?" has seldom been answered and never comprehensively by a National Laboratory.

Value Proposition

These validation activities will hopefully create a much higher level of acceptance of SAM outputs (and understanding of additional areas of improvement) in the community and also dramatically reduce the uncertainty. This activity builds on a variety of existing validation activities from the many validation efforts that have been performed for sub-components within solar systems. For example, the intermodal comparisons enable the market to determine the level of confidence in modeled results using different tools.

Approach

The approach we take in budget year 2 will build on the extensive work done in Year 1 to compare actual system performance data against modeled data from SAM and the establishment of a SAM/PVWatts TRC of independent engineers. Note that based on feedback from the SI team last month, we have accelerated this task to essentially be completed in Budget Year 2.

Subtask 1.1 SAM Interaction with the Userbase

We will be querying the SAM user base (and potential users as possible) to gather information about current and potential use of the SAM and PVWatts tools. We would also be gathering additional feedback on near-term thoughts for improvements and issues they feel we should be researching. We will be summarizing these survey results and sharing them on the SAM website and with DOE. We will work with DOE to determine the best survey questions to ask.

In parallel to the abbreviated PV TRC, NREL will conduct a survey of users of CSP technologies in SAM from industry, government, and academia to learn about current models and areas for improvement. The result and deliverable of this task is a memo detailing how stakeholders use SAM CSP models, what features they find useful and which are hard-to-use and recommendations for developments and future improvements.

Subtask 1.2 SAM Roadmap Exercise

Separate from subtask 1.1, we will be working with survey responses and key stakeholders as well as a much broader range of stakeholders via interactive webinars, surveys, phone calls and travel to a modelers workshop (Sandia currently plans to hold this), create a five year roadmap for the SAM model and system modeling in general. While subtask 1.1 focuses on the near term, this subtask focuses much more on a multi-year plan going out five years. The primary output of this would be a viable roadmap for the next five years which indicates what SAM's (and relatedly PVWatts) desired capabilities are, what SAM's desired "boundaries" are and how it's likely we will share the tool, code and effort (open source, license, full support, support by private firm, etc.). Additionally, this activity will work through the process of claiming the IP of SAM source code for DOE and NREL completely (prior versions have been compromised by inclusion of code developed by Universities under subcontract). This likely will be a protracted effort through the NREL and DOE legal offices. Finally, we anticipate sharing the roadmap specifically with other firms in this space via a separate "modeler's forum" half day meeting at the larger Sandia modeling workshop. This will help us to craft a roadmap that doesn't impinge on the plans (and not just what's released) of private software development firms. The primary costs associated with this activity are team effort to coordinate conversations, draft the roadmap, circulate and get comments on the roadmap via web meetings, attend the Sandia Modeling Workshop in CA (likely 2 people), survey the broader user base and publish the final roadmap.

Subtask 1.2 Intermodel Comparison

Problem Statement: There are several "industry standard" PV performance models produced by different vendors in common use throughout the PV industry worldwide: SAM, PVsyst, and PV*SOL. Each model makes different assumptions about loss factors and how they are applied, models module IV curves differently, has different approaches to shading, and allows different degrees of flexibility for configuring inverters and overall system operation. Given the cleaned measured performance data and specifications of nine geographically diverse systems used to validate the SAM model in FY13, we will apply the same approach to determine how these other models fare relative to measured performance data. This analysis will uncover in a systematic way key differences between and specific limitations of each model, and will lead to a better understanding in the solar industry of how much trust can be placed in the estimates produced by various PV performance models.

Value Proposition: Estimating PV system energy production is an essential part of developing projects. Since several PV performance models are used by the industry, it is important for the project developers and financiers to have an understanding of how well each tool is able to match a specific system against measured data. Since our approach does not explicitly "tune" model assumptions to the actual system beyond choosing the module and inverter types, the results will be indicative of how accurately each model functions as a predictive tool. Previous informal blind studies by Sandia in 2010 have shown that even experienced modelers with the same set of input criteria yielded a wide range of estimates. Annual estimates varied up to 25 % from the average between different models, and up to +/-17% for one model with different users running it. This data shows that there is significant variation between models and the assumptions experienced engineers use. Thus it is of high value to the industry to do a careful comparison of each model to actual data to confirm or disprove whether this level of variability in estimates is representative of what the models are capable of. If the differences between the newest versions of these tools using individual vendor assumptions can be shown to be less than 5% and the annual estimate error relative to measured data for 9 systems also less than 5%, then the financial community may not worry about which particular tool a project developer used for their projections.

Preliminary results of this comparison effort as of December 2013 suggest that while differences between model predictions for fixed systems are less than 5 %, predictions for one-axis tracking systems range up to 20% between models.

Approach: Building on the test suite of 9 systems that we used for validation in FY13, select a set of typical systems (across all scales from residential, commercial, and utility) for which we have measured performance data and which exercise various aspects of the models. This will build on the existing datasets we have from FY13 so that we can also compare results from the January-2013 version with updated versions of SAM as part of this activity. This comparison after the model has been improved is helpful to the development cycle. We will then exercise several models (including PVSyst and PV*SOL) through this test bed in addition to SAM. While all 9 systems plus other available datasets will be used internally, difficulties in publishing the FY13 validation report indicate that not all real data sets will be able to be published. Therefore, the commitment is only for the actual NREL systems (although both Sunpower and SunEdison need to be consulted for these systems). All internal results for all systems will be shared with DOE.

Subtask 1.3 PV Module Database Comparisons

Problem Statement: All industry standard PV performance models include databases of module parameters for often thousands of modules. The data sources for module parameters such as Pmp, Imp, Voc, Isc, temperature coefficients, and others is frequently not known, and may result from published datasheet specifications, independent tests, or manufacturer provided values. In addition, different model formulations require additional model-specific parameters to calculate module performance in different irradiance and temperature conditions. For example, the SunPower SPR-210-BLK-U module is listed in the California Energy Commission (CEC) module database as a 215.25 W Pmp, while the Sandia Module Database for the exact same model name lists of 210.135 W Pmp: the discrepancy is in the specified maximum power voltage (Vmp). This is approximately a 2.4% difference simply in nameplate rating for the same module between two heavily used module databases. The proposed work will systematically quantify these types of differences for many standard parameters for common modules across databases so that the PV stakeholder community can decide how much confidence to place in the default module parameters distributed with tools.

Value Proposition: Successful completion of this subtask will enable the market to determine the level of confidence in using established module databases and quantify the relative differences in predicted output among the models. From a validation perspective, this separates inconsistencies with the databases of module coefficients (inputs essentially) from the actual mathematics of the model. Errors for module models have not historically separated these potential causes of error. Using the single example provided above for a common crystalline silicon module, it may be the case that up to 2-3% of the differences in model predictions (characterized in Subtask 1.2 above) are attributable to module database discrepancies between the tools. Such a result would strongly suggest the need for more rigorous processes and standards for including module parameters in databases so that they can be used by the stakeholder community with confidence.

Approach: Perform a detailed comparison of PV module databases (CEC, Sandia, PVSyst, PV*Sol or others as possible) to determine variation in model parameters and performance estimates using default provided data for the modules. The various databases might contain the same module manufacturer and model number but because the underlying models ask for different inputs, it is insufficient to simply compare the datasheet parameters. While we will start by comparing the spec sheet data, we will go further and compare the representative points on calculated I-V curves at different operating conditions. We can then determine what percentage of the overall system error between models (Task 1.2) is due to variations in these databases.

Task 2: Augment the popular DOE-sponsored System Advisor Model (SAM) tool for growing industry needs, inter-annual variability risk assessment, and grid integration modeling

The System Advisor Model (SAM) tool is a project that aims to make available to the widest possible audience the best-in-class solar technology system performance models integrated directly with detailed market-specific financial, incentive, utility rate, and cost analysis. The tool supports analysis of key industry and DOE metrics, most notably the levelized cost of electricity (LCOE), and others, using a technology-agnostic cross-cutting framework. By providing this modeling platform, DOE has reduced the risk and improved communication about both performance and cost between project stakeholders (Developers, utilities, regulators, etc.). In the LPDP review process in Summer 2012, the key feedback our agreement received from the review panel was to make SAM the premier PV performance modeling tool available. To that end, we propose the categories of work below to continue and build upon the core value that SAM provides to the solar community:

- Inter-annual variability and risk analysis
- Modeling capability enhancements for independent engineers
- Documentation, communication, support, outreach

- Research and enhancements for grid integration studies and utility-scale modeling

Problem Statement

Many excellent algorithms and models are developed within the academic and lab research community for solar technologies including by our own solar modeling team. However, publication of these models into a journal or technical report is often inadequate to promote adoption of these cutting-edge models by the R&D communities that we seek to enable. Additionally, to measure the true cost-effectiveness of a technology (especially an emerging technology), an analyst needs to effectively combine detailed system performance with detailed financial and cost modeling. Finally, for DOE SETP to even track progress against the Sunshot goals, a complex techno-economic tool and package needs to be available and be standardized to calculate the progress.

Value Proposition

Therefore, to enable and accelerate research and project development, NREL has worked diligently over the years to create the SAM (and PVWatts and IMBY) tools. NREL has created a suite of products in an attempt to serve a broad range of stakeholders all trying to do techno-economic analysis of solar technologies.

Approach

For this budget period (FY14), we have grouped the detailed tasks into four subtasks. Each one will be discussed separately.

Subtask 2.1 Interannual variability and risk analysis

Subtask 2.1.1 We will release a robust long term dataset of 239 locations in the US for interannual variability analysis. This new dataset means that the existing P50/P90 exceedance probability calculation capabilities that exist within SAM will be viable for many more locations than currently by providing a ready-to-use and validated dataset. To date, a serially complete solar and weather dataset for 1961-1990 does not exist for all locations (a handful of locations due have perfect datasets), making it impossible to run long-term simulations in modeling tools. This subtask uses established data filling algorithms developed by the solar resource assessment group at NREL to fill missing data for temperature, relative humidity, wind speed, wind direction, and pressure with representative and consistent values so that SAM (and other modeling tools) can run simulations using models that require this data and yield appropriate estimates for annual energy yield for systems. Currently, the solar radiation data is complete for all historical periods but the met data often has gaps. This data set was singled out by the original LPDP committee as being of high value for them. This activity is also enhanced by the fact that the NCDC no longer charges money for this historical data and we can share it more freely through the SAM tool.

Subtask 2.1.2 Establish a new standard flexible SAM weather file format and integrated import tool in SAM. The FY13 TRC strongly indicated that the ability to import one's own measured weather and solar data is a key need among the modeling community, and we have anecdotally received this feedback also from users. Current standard weather data file formats (TMY2, TMY3, EPW) are rigidly formatted data files that are not easily editable in common tools and contain superfluous data that is not needed for modeling. We will design a simple, flexible, Microsoft Excel-editable weather file format and provide all of the TMY2, TMY3, international, and historical (see Subtask 2.1.1) weather data in this new format. The format will be accompanied by robust documentation, software tools integrated in SAM to convert weather data to this format, and will be the standard format used by the SAM models.

Subtask 2.2 Documentation, communication, support, outreach

This subtask seeks to convert potential users who have downloaded our free modeling software into people who can effectively and correctly perform analysis with it. Modeling software for renewable energy systems like SAM is necessarily somewhat complex with a moderately steep learning curve, and to enable users to use established methods correctly to yield reliable estimates of energy production and economic value, we provide direct user support via our educational website and forum, extensive software and technical model documentation, email support, free training webinars, and general outreach to our stakeholders.

Subtask 2.2.1 We will deliver 6 free public webinars on different aspects of SAM modeling: weather data, PV shading modeling, CSP trough modeling, SAM validation results, new features in latest version, and complex utility rate modeling. Each webinar lasts one hour, allows participants to ask questions, and we subsequently post a video of the webinar and associated training materials on the SAM website.

Subtask 2.2.2 Create a recorded VIDEO Tutorial training for SAM and post/upload online so that users can learn online at any time of the day. This task provides value to the greater solar community It is very important that engineers and other solar industry practitioners are able to use complex tools correctly so that the projected energy production estimates they provide to banks are as accurate as possible. Delivering a targeted training session is a proactive way to reduce model prediction errors by ensuring that people use the software appropriately.

Subtask 2.2.3 Complete writing the SAM PV Performance Models Technical Manual started in Summer 2013. It's anticipated to be approximately 50 pages and incorporate all relevant equations and process calculations for the several PV modeling options within SAM. This document was requested by the SAM TRC to improve transparency.

Subtask 2.2.4 Online user support and SAM website maintenance and website improvements (a website infrastructure upgrade was started in FY13 and has been primarily completed in FY14 Q1). We hope to, for example, add a section that facilitates information sharing of SAM scripts as well as the use of SAM in the classroom.

Subtask 2.2.5 Complete the SAM model user documentation (primarily within the model but also as a stand-alone PDF) of new features including the IEC 61853 PV Module model, shading improvements and visualization, new weather file formats and general changes to the interface. This is made available as web pages on the SAM website, downloadable with the desktop tool and a small subset of the documentation is run through the NREL publications team.

Subtask 2.2.6 Establish a new capability to track SAM usage in real time over the internet by issuing free "license keys" and collect data to inform statistics on SAM users, usage patterns and most used/never used features. This data can help inform prioritization of future work as appropriate.

This task requires working with NREL Information Services to establish an SQL database on a stable NREL server, design the data schema, write server-side PHP code to manipulate the database, and make modifications to the SAM software framework to connect to the NREL server to synchronize the free license key. The online user database management must also be linked to this task.

Subtask 2.2.7 Complete an extensive upgrade to the core SAM software framework and to the PV system design input pages to simplify the current complex user interface. This task involves two major efforts: 1) upgrading the core SAM code to utilize the latest C++ software libraries, and 2) revise confusing input pages and other user interface elements to reduce modeling errors.

1) The current SAM codebase was developed over five years ago in C++ using wxWidgets 2.8, a well-known open-source cross-platform (Windows, OSX) toolkit for writing graphical user interfaces. Since

then, wxWidgets 3.0 has been released, and provides many improvements including Unicode text support, better graphics, improved speed, and a long list of other enhancements. To keep SAM viable into the future, it is very important to stay up-to-date with the latest software libraries and development tools so that the codebase does not become obsolete. The process of upgrading the SAM core will involve porting existing code to be compatible with the new wxWidgets, as well as in places writing new code (particularly in the area of graphics) to leverage the newest technologies made available. This will also allow us to easily produce 64-bit versions of SAM for Windows that will enable larger simulation runs and avoid current problems with 32-bit SAM running out of available memory. The code reorganization will also leverage improvements that we have made in the past five years to other components such as the built-in scripting language used for automating batch-mode tasks within SAM.

2) The current user interface has grown "organically" over the past several years and has become difficult to use effectively. This is feedback we have received from numerous users, both new and advanced, from both outside and within NREL. An unnecessarily complex user interface introduces error and uncertainty in the modeling process, and we will mitigate this by simplifying the user interface and providing better error and warning messages to the user. Specifically, the complexity of providing 4 PV module model options, 3 PV inverter model options, more than ten different derate and loss factor options, 4 shading factor input options, and 2 self-shading options has resulted in a very flexible model structure, but the user interface is very complex and can be simplified to reduce user confusion and error. Similarly, there are numerous ways to browse outputs, but they are not grouped very logically or intuitively in the current version – again, due to the constantly evolving needs and additions over the last five years. A revamp of the user interface will put SAM in a robust position to absorb additional enhancements in the future in a logical and user-friendly way.

Subtask 2.2.8 Maintain and support the solar web services (primarily the PVWatts web service) that run on the SAM engine (SDK) and are available at http://developer.nrel.gov These activities generally are in supporting users of the web services (of which we have many including SunRun and others) as well as improvements in documentation and capabilities. Additionally, when new capabilities or changes are made to the online PVWatts tool, related changes will likely need to be made to the underlying web service that drives both the PVWatts online tool as well as tools for other companies. Finally, NREL is the subject of significant cyber attacks and ongoing updates for infrastructure and security changes consumes some minimal resources as well.

Subtask 2.3 Modeling capability enhancements for utility-scale system analysis

While some tasks (such as utilizing the 61853 standard in a model) would work across markets (residential included) but the primary focus of this subtask is to improve the model that is generally very useful for utility-scale system analysis. Grid integration modeling, CSP modeling, more complex module and inverter modeling all would be used by analysts and researchers investigating utility-scale systems. Some of the specific activities within this subtask include:

Subtask 2.3.1 We will research methods to create a backwards-compatible extension of the standard 5 parameter single-diode PV module model that uses additional parameters to more accurately model PV module performance. There are several steps required to successfully establish a new capability in the SAM tool:

1. Measure current model error in the 5 parameter single-diode model relative to IEC 61853 data. The reference data set will be comprised of actual measured IEC 61853 data from Bill Marion's MPERT activity and other TBD datasets, as well as a comprehensive synthesized dataset generated via the Sandia Model.
2. Analyze 5 parameter model errors and regress them with respect to the various parameters to determine which auxiliary model equations need to be modified to improve model prediction.
3. We will then consider new parameters and forms of the auxiliary model equations to reduce maximum power point power prediction error.
4. For a subset of the modules in the reference dataset, we will manually estimate the new auxiliary model parameters and reassess the errors of the "extended" *N*-parameter model.
5. Once we are satisfied that the additional model equation parameters adequately reduce the model prediction error, we will develop automated algorithms to remove the manual process of estimating model parameters. This will make the model useful to a large number of people who have IEC 61853 test data results and wish to use those data in a model in a robust fashion.
6. Test our "automated" parameter estimation method across one thousand synthesized IEC 61853 test data sets to determine how reliably it generates the parameters

7. Comprehensively document the methodology, auxiliary equations, and additional model parameters to establish transparency and credibility in the technique.

The IEC 61853 standard is an emerging standard in the industry, yet to date no model exists that utilizes all of the test data to reduce errors in predicted module model performance.

There is a parallel effort at Sandia National Laboratories to utilize IEC 61853 test data to inform PV module models. Although our approach is distinct from Sandia's in several ways, we have coordinated directly with our Sandia colleagues to define parallel pathways to improving model predictions in this very important area. In particular, we have shared our proposed methods and seek to use common validation datasets and metrics to assess these advances.

- The NREL approach seeks to utilize ONLY the Pmp, Voc, Isc, and Imp data provided in the IEC 61853 module test matrix at various temperature and irradiance conditions, and we propose to make a robust tool built into SAM ready for end-users to take advantage of
- The Sandia approach uses all of the points on the I-V curve data at each temperature and irradiance, and will publicize their methodology in reports and journal articles

From this it may be inferred that the Sandia approach might give more accurate predictions, but will require many more data points than readily available. On the other hand, the NREL approach may have more difficulty numerically converging on a solution for parameters due to the limited dataset. We strongly believe that both of these approaches to utilizing IEC 61853 test data are complementary and will be extremely valuable to the PV community to improve PV module model predictions.

Subtask 2.3.2 Proper sizing of PV array DC nameplate to inverter capacity is a complex optimization problem that depends on numerous factors including solar resource, expected module degradation rates, and other factors. We will develop a step-by-step "wizard" in the SAM user interface that performs many intermediate calculations to help users properly size their arrays and inverters given certain performance criteria.

Subtask 2.3.3 Currently, the SAM PV models are only able to run hourly for one whole year. We will establish a new capability to run the SAM PV model engine (the SDK) for non-annual simulations such as performing a yield calculation at single timestep up to a few months at a time. This capability has been vigorously requested by users of the SDK and enables forecasting simulations as well as easier interaction with grid integration tools.

We will require several iterations on this capability to ensure that stakeholder needs have been met. Additionally, significant testing is necessary so that the subhourly simulations are correct given many different data sources. Various users have been asking for this and we anticipate them using this capability in a variety of ways which all need to be tested.

Subtask 2.3.4 Implement CSP model enhancements.

In FY13 internal and external users identified various deficiencies and inconsistencies in existing CSP models. Additionally, opportunities to streamline model performance and convergence were identified during FY13's code conversion task. Each of these distinct issues requires between a few days and a week to resolve, depending on complexity and scope. This task resolves these issues by thoroughly addressing the original deficiencies. Additionally, this task will cover similar problems identified in FY14. The current set of planned FY14 improvements is listed below for reference. Each of these individual projects requires coding, testing, documentation, and comparison against the old model to inform users about the resulting changes in predicted output and to justify them accordingly.

1. Improvements and bug fixes in code for thermodynamic properties of water/steam need to be implemented
2. The cavity receiver sub-model for power tower technologies currently uses an incorrect approach in calculating radiative loss. We have worked with Univ. of Wisconsin through a Master's project to develop a corrected radiation model and to allow user-selection of the convective loss correlation. This funding is required to implement this reformulation in SAM. Although initial guidance from DOE suggests canceling this task, we submit that it is worth pursuing specifically because the research work has already been done at U. Wisconsin and the funding allocation here is simply to integrate the results of that research into the SAM model to make the CSP model more realistic and flexible.
3. The direct steam Linear Fresnel model has an error in how the heat transfer coefficient is calculated in the superheater section for the evacuated tube receiver model. This results in an underestimate of thermal loss for this modeling configuration.
4. Piping thermal losses in the power tower models have several issues:
    a. The estimate of thermal loss at 10.2 kWt/m is based on findings from Solar Two, but the given number is on the same order of magnitude as thermal loss from an uninsulated header pipe. This indicates that the current number is probably incorrect. We would like to perform limited piping thermal loss calculations to

determine a more appropriate number or to develop a better model and implement it in the tower models.

b. The piping thermal loss is applied subsequently to all of the receiver performance calculations as an equivalent electrical parasitic. Thus, piping losses are treated exclusively using first law principles while actual piping losses should be accounted for in both first and second law treatments of the system. Furthermore, the application of thermal loss as an equivalent electrical parasitic is not only technically incorrect (and was only ever intended as a temporary fix), but it is often a source of confusion for model users.

Subtask 2.3.5 Complete self-shading model enhancements for 1-axis trackers. This will be completed in collaboration with Chris Deline (NREL staff working in Bill Marion's team and located organizationally within the National Center for Photovoltaics (NCPV). Currently, SAM only includes estimation of non-linear losses due to self-shading for fixed arrays, but these equations can be extended to apply to one axis tracked arrays.

Subtask 2.3.6 Implement new capability to automatically parallelize all simulations using the core SSC/TCS model framework (certain CSP technologies have developed this capability in FY13 but outside of the SAM interface). Note here that we will need to integrate and test on many different operating systems and this will involve extensive testing (Windows 7 32/64bit, Windows 8 32/64bit, OSX 10.6, 10.7, 10.8).

Subtask 2.4 Modeling capability enhancements for residential and commercial-scale analysis

While some tasks (such as 3D shading analysis and visualization) would work across markets (utility-scale included), the primary focus of this subtask is to improve the model that is generally very useful for smaller-scale system analysis. Solar aggregators, installers, NREL distributed PV analysis (even on the supercomputer) all will be improved by these improvements to SAM.

Subtask 2.4.1 We will establish a new capability for 3D shading calculation and visualization that enables robust analysis around shading, as described in the SAM Shading Model Roadmap document submitted to DOE in September 2013. This capability will allow a user to interactively create and visualize a 3D scene consisting of crude buildings and trees, place PV panels, and calculate a beam irradiance shading factor for any sun position. The calculation will yield a hourly set of beam irradiance shading factors that can be utilized directly in the current SAM PV model engine. No such capability currently exists in SAM, and while the ability to import shading data from other tools does exist, the 2013 SAM Technical Review Committee emphatically declared that this was the single most important improvement to be made to the SAM tool.

Subtask 2.4.2 Implement changes in SAM to reflect updates to incentives and utility rates web services. This subtask reflects updates made to those data sets and web services that SAM accesses by other projects and is needed to maintain SAM's capability to easily model complex utility rates and state/local incentives.

In FY13, it took several months to update SAM to reflect changes in the utility rate database. We anticipate that this will be not as significant in FY14 but still will need to handle minor updates (occurring outside of our control) because the utility rate code is exceptionally complex to program and test given the 500+ unique variables that are required to fully define a utility rate.

Subtask 2.4.3 Implement the building load estimator that was developed by an intern in FY13. To appropriately account for net metering impacts and the value of PV production within complex utility rates, it's important to have a building load that uses the same outside weather and radiation values as the underlying PV module so supply and demand are co-incident.

Technical Plan: Fiscal Year 2015 (12 months)

In FY 2015, our efforts from budget period 1 and 2 will form the foundation for what is done but new activities will be started. DOE requested we accelerate SAM validation and PVWatts development into Year 2 so we are now not extensively working on these tasks (although we anticipate some minimal activities in both areas). SAM continues to be developed and we anticipate incorporating other results (data, models, insights) from the other 3 year LPDP projects within this year.

Task 2: Improve the System Advisor Model (SAM) tool for growing industry needs, inter-annual variability risk assessment, and grid integration modeling

The System Advisor Model (SAM) tool is a project that aims to make available to the widest possible audience the best-in-class solar technology system performance models integrated directly with detailed market-specific financial, incentive, utility rate, and cost analysis. The tool supports analysis of key industry and DOE metrics, most notably the levelized cost of electricity (LCOE), and others, using a technology-agnostic cross-cutting framework. By providing this modeling platform, DOE has reduced the risk and improved communication about both performance and cost between project stakeholders (Developers, utilities, regulators, etc.). We propose the categories of work below to continue and build upon the core value that SAM provides to the solar community.

Problem Statement

Many, many excellent algorithms and models are developed within the academic and lab research community for solar technologies including by our own solar modeling team. However, publication of these models into a journal or technical report is often inadequate to promote adoption of these cutting-edge models by the R&D communities that we seek to enable. Additionally, to measure the true cost-effectiveness of a technology (especially an emerging technology), an analyst needs to effectively combine detailed system performance with detailed financial and cost modeling. Finally, for DOE SETP to even track progress against the Sunshot goals, a complex techno-economic tool and package needs to be available and be standardized to calculate the progress.

Value Proposition

Therefore, to enable and accelerate research and project development, NREL has worked diligently over the years to create the SAM (and PVWatts and IMBY) tools. NREL has created a suite of products in an attempt to serve a broad range of stakeholders all trying to do techno-economic analysis of solar technologies.

Approach

Subtask 2.1 Integrate stochastic analysis capabilities (using Latin Hypercube Sampling) with weather variability analysis using improved weather dataset developed in FY14. This allows for Monte Carlo analysis that includes weather variability as another stochastic input. Thus the user is able to convolute the weather uncertainty with cost or performance inputs. No other modeling framework supports this for solar technologies currently and this would be useful for dealing with uncertain research projects. This task has been requested by certain national lab analysts in the past for specific analyses. Additionally, we think that combined with the complete list of locations that have adequate datasets for P50/P90 analyses, more users will be able to access this capability and start to use it more extensively.

Subtask 2.2 Establish a new capability within the 3D shading model developed in FY14 to calculate diffuse radiation view factor reductions for any arbitrary obstruction geometry. The treatment of diffuse radiation reduction is cutting-edge and no commercial models currently model this effectively.

Subtask 2.3 Establish a new capability to characterize AC modules and DC/DC converters in SAM. Thereby allow users to evaluate the monetary value of the performance improvement due to these technologies. This requires integration of our R&D efforts with efforts in "Emerging Technology Characterization" (ETC) being done by Chris Deline (NREL staff working in Bill Marion's team and located organizationally within the National Center for Photovoltaics (NCPV). The work in the ETC agreement is primarily to develop datasets and equations to represent the operational behavior of module-level power electronics. This subtask will build on that work and determine the best way to integrate the improved models in the SAM tool. For example, to correctly represent the potential benefit of module level power electronics, it is necessary to actually model the nonlinear power losses due to irregular shading on a module-by-module basis. Only then can the improved electrical performance of a DC-DC optimizer be determined, once a full electrical simulation is done. However, SAM does not currently perform a full electrical simulation of each module – so we will need to develop regressions to estimate the power loss/gain due to module-level electronics, similar to the current approach in SAM for regular fixed-array self shading impact estimation.

Subtask 2.4 Deliver six free webinars on a variety of SAM modeling topics as well as new features. This will be done in FY14 as well and we can reassess the value of these after FY14 is mostly complete. One of these webinars will be on the SAM roadmap finalized in FY14.

Subtask 2.5 Research methods to disaggregate PV array representation in SAM to explicitly model non-linear electrical effects in arrays with significant obstruction shading. (enabled by FY14 task to implement 3D shading representation) This is a significant activity that requires potentially rewriting the modeling code in SAM that calculates PV module power output so that each module or shaded array sub-section is treated independently. If a different approach is taken (similar to the reduced-form regression model for nonlinear shading impacts that is currently used for regularly-spaced fixed arrays), then it will be a significant research effort to implement and validate generalized regression forms that will estimate the nonlinear power losses due to irregular obstruction shading.

Subtask 2.6 User support and SAM website and online user forum maintenance.

Subtask 2.7 Towards the end of FY15, resurvey the stakeholders that assisted with the SAM roadmap creation via phone, webinar and email. Communicate progress to them and elicit updated feedback on the plan as well as initial implementation at the end of FY14 and early FY15. This can likely be augmented with participation in the Sandia modeling work shop (assuming it's held in FY15).

NREL will again survey the users of CSP technologies in SAM as in FY14 to review progress and discuss current models and areas for improvement. The result and deliverable of this task is a memo detailing updates to the SAM model and reflections on the Roadmap as well as suggestions/needs for future improvements.

To be clear, this subtask will be conducted without paying any participants or paying for their travel to NREL. Our team will travel to the modeling workshop if held.

Subtask 2.8 SAM user documentation updates to reflect changes in the tool

Subtask 2.9 Establish new capability to model appropriate financing of third party leased systems to determine their economic benefit and answer additional relevant questions. Specifically, while SAM can currently calculate the PPA price that a third-party-owner could offer a homeowner, it currently requires detailed knowledge of the internal financing of Solarcity or similar third-party owner. In reality, a commercial or residential building owner really would like to know (1) how buying a system themselves would compare to a PPA offer, or (2) if buying the lease up front (a common option) would be better and (3) how these relative scenarios would change if different assumptions regarding discount rates, net metering or electricity price escalation were used.

The tasks associated with this activity include: working with the financial experts and other solar analysts at NREL (some working this issue under related agreements) to validate the relevant questions (above), programmatically modify the underlying cash flow models in SAM to perform needed new calculations, modify programmatically the SAM financing interface for residential and commercial systems to reflect the new calculation and new outputs and then test, and document this new capability. We will also validate against actual third-party system financial data from datasets we currently have.

Subtask 2.10 Completely enable the SAM user interface and simulation engine to allow more than 4 PV sub-arrays. This is a limitation that prevents proper modeling of many systems – including the DOE Forrestal rooftop system. This has been reported by several users as a limitation although we originally thought that 4 sub-arrays would be adequate.

Subtask 2.11 Implement CSP model enhancements. In FY15, we anticipate internal and external users will identify various deficiencies and inconsistencies in existing CSP models. Each of these distinct issues requires between a few days and a week to resolve, depending on complexity and scope. This task resolves these issues by thoroughly addressing the original deficiencies. In addition to model errors that are reported through the usual user support channels, the modeling team will address the following known errors and difficulties with using the CSP performance models in their current forms:

1. Error catching is currently insufficient. Simulations with calculation errors often cause SAM to crash, and feedback to the user does not enable quick user debugging. This results in more frequent use of the SAM help staff and technology experts.
2. Arrangement and organization of inputs on technology input pages causes confusion among users. Reorganizing inputs will help alleviate common usage mistakes and misinterpretation of model capabilities.
3. Hourly and tabular outputs in SAM are not consistent across technologies. Standard naming and unit conventions should be applied to reduce user confusion.
4. Key output values are not defined consistently across technologies. For example, in some technologies, energy from the solar field includes absorber reflective loss and in others it does not.
5. Correct the over-simplification of the wet cooling HR model that results in inaccuracies in predicted performance and water use. The wet cooling heat rejection model adjusts for part load behavior using a simple energy balance model that ignores actual changes in heat exchanger off-design performance. This simplification has a minor impact on annual power cycle performance and a significant impact on calculated water usage throughout the year. We developed a more accurate model prior to the current LPDP's, but did not receive funding to implement the model in SAM.
6. Header losses calculated in the Physical Trough model disagree with more detailed vendor models. We would like to correct the model to better match new data

Subtask 2.12 Update default values for financial assumptions and component costs to reflect the most up-to-date market trends and analysis.

Subtask 2.13 Update SAM PV model technical manual to include technical documentation of new capabilities added in FY14 and FY15 in shading, subarrays, IEC modeling among others.

Subtask 2.14 Create new set of SAM SDK example programs in multiple languages (including VBA) to demonstrate programmatic use of new PV and CSP modeling capabilities added in year 2 and 3.

Subtask 2.15 Organize and hold the SAM virtual conference to enable stakeholder engagement and interaction with the SAM development team and showcase use scenarios of SAM software. The goal of this activity is to enable SAM users to share best practices which even the development team is not always aware of. This works towards the roadmap of enabling a community of experts.

Subtask 2.16 Improve the solution methods used to extract IEC 61853 module parameters from test matrix data based on research in FY14. Due to the coupled highly nonlinear model equations that need to be solved simultaneously to determine model parameters some of which are of different orders of magnitude, the solver does not always converge and produce a reliable set of parameters for a particular module. This subtask proposes to research improved solution methods so that the numerical convergence is improved and that the methodology is robust and readily useful for a wider range of module test data.

Subtask 2.18 Finalize implementation of snow cover effects within SAM and PVWatts by doing the following: Take all the hourly data for all years that go into the TMY2 sites (For which we have nightly snow fall totals). Then, calculate the average monthly loss due to snow for all years and all sites using the model developed last year by Bill Marion and team. Publish that information and incorporate it by default into PVWatts. Recent feedback from DOE indicates that there is not much appetite for snow-data analysis.