SAM Five Year Solar Technologies Roadmap

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Executive Summary

As the System Advisor Model has now been an active effort for ten years and a public tool for close to eight years, there is a need to develop a long term, five year roadmap for how the SAM tool will be modified, updated, distributed and positioned to have the greatest impact on the techno-economic analysis community. To this end, several key activities in each of these areas are discussed. The decade-long history of the SAM is presented leading to the current set of goals for the model as well as what the goals can be in the future and building on past successes. A discussion of specific business model questions is presented. Finally, a year-by-year breakdown of tasks are presented that lead toward these goals.

SAM was originally developed by the National Renewable Energy Laboratory in collaboration with Sandia National Laboratories. It launched in 2005, and at first was used internally by the U.S. Department of Energy's Solar Energy Technologies Program for systems-based analysis of solar technology improvement opportunities within the program. The first public version was released in August 2007 as the ***Solar*** **Advisor Model** Version 1, making it possible for solar energy professionals to analyze photovoltaic systems and concentrating solar power parabolic trough systems in the same modeling platform using consistent financial assumptions. Since 2007, two new versions have been released each year, adding new technologies and financing options. In 2010, the name changed to "System Advisor Model" to reflect the addition of non-solar technologies. As of the fall of 2013, NREL began releasing one new version per year with periodic updates as needed.

Note that SAM is cross-technology in nature – modeling wind, geothermal, biopower and solar water heating in addition to the PV and CSP technologies discussed here. This roadmap has been requested by the DOE SunShot program and therefore is focused on solar technologies only.

However, one may presume that the goals and vision for solar could generally work across all technologies in SAM.

Note also that the DOE Solar "Systems Modeling" agreement encompasses more than just our work on the SAM model itself. We have spent significant effort on validation of SAM and other models, developed fundamental new models (such as the new module model that uses IEC 61853 standard test data) and tools (such as our new shading tool) and, importantly, have worked vigorously in FY13 and FY14 to updating the online PVWatts tool as well.

History

The System Advisor model had it start via a request from Ray Satula of the DOE Solar Program in 2003. He had identified a need within the solar program to compare the technologies within the solar program, which included at the time several PV technologies (crystalline silicon, solar hot water and heating, various CSP technologies, CPV, solar hybrid lighting, etc.). The cost and performance estimates varied widely between these technologies and the assessments were not done in the same way. Therefore, a platform to compare the different technologies with identical financial and other assumptions was needed to make informed R&D investment decisions. It was launched in 2005 after two years of internal development, and at first it was used internally by the U.S. Department of Energy's Solar Energy Technologies Program for systems-based analysis of solar technology improvement opportunities within the program.

Following this initial period, the DOE Solar Program indicated to NREL that the tool, which was being used and gathering users, should be shared as a tool to support the solar industry at large. Therefore, NREL released a free, public version of the SAM tool starting in 2007. DOE and NREL continued to invest in the project developing new capabilities and new models for technologies that, had not had an accurate, detailed hourly model available previously. In part because SAM was running the TRNSYS software[1] for many technologies, NREL teamed with Prof. Sandy Klein and the University of Wisconsin-Madison and support eight different Master's and PhD students. From this collaboration, several PV and CSP technologies were modeled robustly for the first time and were incorporated into the SAM interface and shared publicly.

In 2009, NREL released a new version of SAM which had been rebuilt almost completely from the ground up and had a new, more intuitive interface and significantly improved backend framework. In this same year, NREL received funds from EERE Corporate Analysis to add non-solar technologies to SAM. These initially included utility-scale wind and utility-scale geothermal technologies. Eventually, additional NREL-internal funds were used to add biopower modeling to SAM as well.

[1] http://www.trnsys.com

In 2012, NREL updated the PVWatts web service with the SAM "engine" being used behind the scenes. This was an important software development as it demonstrated significant code consolidation at NREL such that almost all PV and CSP performance modeling occurs using the same code base. You do not get one answer from one of our tools and a different answer with a different tool.

In 2013, NREL released the SAM Software Development Kit (SDK), as a free download package, which allowed the public to harness the algorithms of the SAM engine without going through the SAM user interface. This is an important milestone in the SAM product line as companies can now run either the PVWatts, detailed flat plate or other models within the SAM engine on their own systems being called from their own code. The SDK is a collection of developer tools for creating renewable energy system models using the SSC library. SAM is a desktop application that provides a user-friendly front end for the SSC library. The SDK allows you to create your own applications using the SSC library.

In 2014, the final major step in the SAM core development is being completed. The SAM front-end is being rewritten to work in a more integrated way with the SAM SSC engine. This rebuilding completes the removal of all FORTRAN engineering code, the TRNSYS core (used with permission from the Univ. of WI-Madison throughout the history of SAM), and the interface layer between SSC and the SAM user interface. SAM now will be completely free of IP constraints as well as have several advantages including better code organization, more interface capabilities, better ability to add new technologies, parallelization, improved speed, and reduced system resource utilization.

In summary, we have reached the point where we have a suite of products that can meet different needs for different users. See Figure 1 below for a graphical representation of these options (both for models and for methods to access those models). A great deal of thought and planning has gone into streamlining these activities and making sure that the redundancy and inefficiency in the code is as minimal as possible. This has precipitated the developments to the core in 2014. One of the key questions this roadmap will address below is how this product line should move forward over the next five years. Should models be retired? Should other models be added? Do additional products need to be offered to increase the impact of the software?

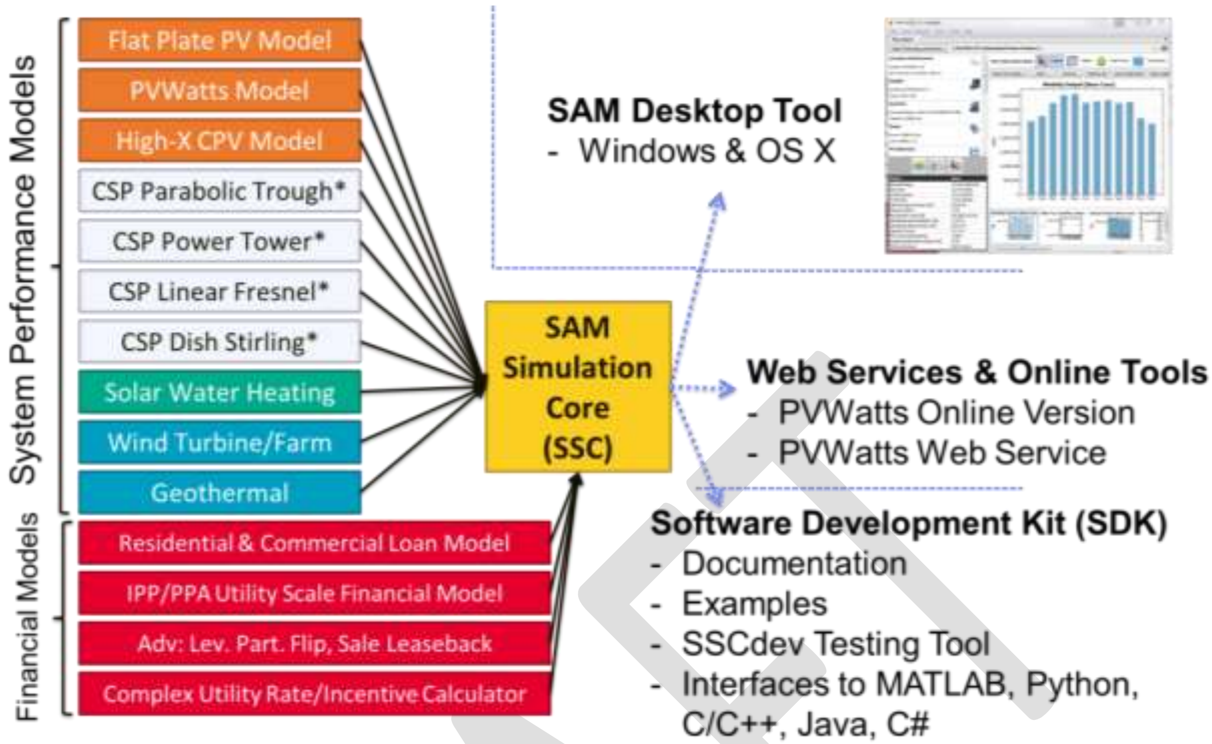

Figure 1: SAM Product Line Details and Relationships

Previous Successes

As stated in the introduction, SAM has been used extensively for many years by a variety of users. The DOE, NREL, and Sandia continue to use the model for program planning and grant programs. Since the first public release, over 40,000 people representing manufacturers, project developers, academic researchers, and policy makers have downloaded the software. Manufacturers are using the model to evaluate the impact of efficiency improvements or cost reductions in their products on the cost of energy from installed systems. Project developers use SAM to evaluate different system configurations to maximize earnings from electricity sales. Policy makers and designers use the model to experiment with different incentive structures.

It is less well-known that SAM has been used historically for several Solar Program Funding Opportunity Announcements. With the focus (pre-SunShot) on the levelized cost of energy and the impact of research on that cost metric, SAM was required by all applicants as they attempted to show how their research would drive down the LCOE significantly in the future. The ability to share the information contained in SAM and have a technical conversation based on that information (while not revealing the detailed proprietary information) was critical in establishing the value of each proposal and the relative impact of the research.

Additionally, we have heard anecdotes throughout the last five years indicating that communication between developers, bankers and EPC contractors happened with SAM in the CSP industry (particularly in Spain where many more plants were being deployed). While each of these entities had models tailored to their specific plants and needs, they were able to agree to use SAM to communicate as well as to set the performance guarantee without sharing any proprietary information while having enough detail that it was not a complete black box to each other.

SAM has also been used extensively by the researchers at the National Renewable Energy Laboratory as well. From the publications of the SAM research team to a part in landmark studies like the Renewable Electricity Futures study[2], SAM and sometimes the PVWatts implementation within SAM have been used extensively. This has been especially true with the detailed residential modeling of PV systems that are enabled by SAM through the combination of detailed utility rate data, building load data options, incentives data and financing. This allows for a detailed analysis of the economics of these systems.

Finally, we measure the value of SAM in terms of the other publications that have been published using SAM to accelerate the research as stated in our goals. One easy metric to track is the number of SAM citations in Google Scholar. While not perfect, this capability has been a recent large step forward in being able to easily track who is using SAM to create academic publications (Figure 2 below). Note that while SAM has been publicly available since 2006, usage for academic papers has increased dramatically in recent years due to improved capabilities in SAM.

[2] REF Reference

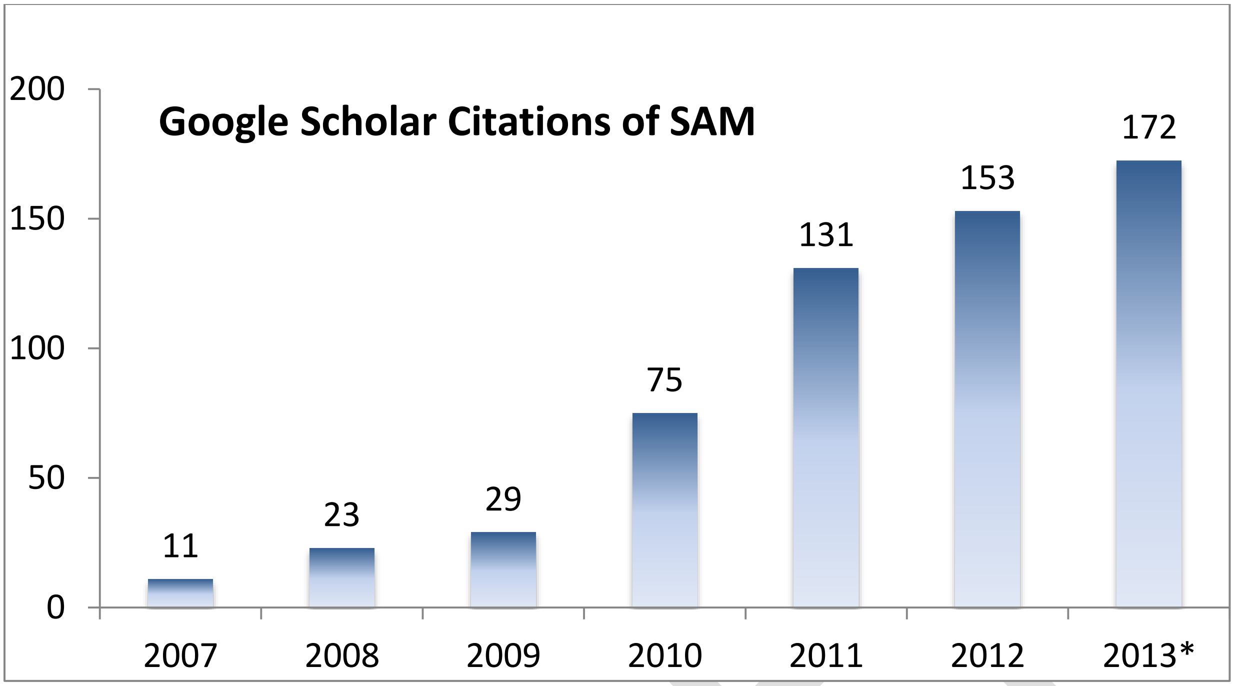

Figure 2: Google Scholar Citations of SAM

We also have several other metrics that we track including recent downloads of the SAM desktop tool as well. These include website visits, SAM desktop downloads and SDK downloads as well as PVWatts website visits (Which uses the SAM engine on the back-end).

SAM Recent Website Visits and Downloads

	FY2013	FY2014	FY2014	Change (%)
	Q4	Q1	Q2	
Unique Visitors	19,235	19,484	24,588	+ 26
Page Views	88,723	93,188	113,994	+ 22
Downloads				
Windows	1,381	2,089	2,168	+4
Mac	150	162	199	+23
SDK	28	66	41	-38

PVWatts Recent Visits and Downloads

Tool Name	January	February	March
PVWatts Version 1	14,722	12,506	16,638
PVWatts Version 2/Viewer	7,180	7,537	6,102
IMBY	1,868	2,086	2,127
PVWatts (Beta)	15,515	16,130	39,555

Figure 3: SAM and PVWatts Online Statistics

Finally, a large part of our success can be attributed to our technical support for SAM. We provide a host of technical support options which, over the years, we have refined to minimize cost and maximize value. We educate and train both on an individual or corporate (for a fee often) level as well as providing extensive online resources. This support has led to many users adopting SAM with less effort, improved the accuracy of the outcomes and helped the final analyses to take advantage of all the capabilities of SAM. Some of the technical support options we offer include:

- Extensive online help system that is context sensitive within SAM. This entire help system is also replicated on the SAM website (so you can have that open while working with SAM)[3]. This includes a "Getting Started" section for new users and strung together is over 800 pages of text.
- Over a dozen YouTube videos on specific SAM features or as a general introduction. These videos are often a bi-product of SAM webinars. They are available at the SAM YouTube channel.[4]
- An online Support Forum.[5] This has proven to be a significant reduction in tech support email help questions. There are now over 830 questions on the SAM support forum which have been answered by the SAM Team and/or other users. New users can search this forum for their question (and the answer) before emailing our tech support staff. This has reduced the number of tech support emails significantly.
- Documentation of the underlying Models: In addition to the model documentation help system, we have produced a number of stand-alone documents describing the technical PV models, CSP models and wind models. These include the detailed algorithms that are used and the flow of the algorithms.[6]
- Spreadsheet Versions of the Financial Models: For the cashflow models in SAM, we have spreadsheet versions as well so that users can, if they want, dig into the details of the cashflow equations.[7]
- Email Support: Lastly, we provide email support via sam.support@nrel.gov email address for questions and issues that can't be addressed in other ways. These questions are usually answered by our technical support contractor, Paul Gilman, but he also escalates some questions to other modelers if needed.

Other products in our space

There are a variety of tools that can be used to do the type of techno-economic analysis that SAM enables for its users. Frankly, the most commonly used tool is likely Microsoft Excel. A

[3] https://www.nrel.gov/analysis/sam/help/html-php/
[4] https://www.youtube.com/user/SAMDemoVideos/
[5] https://sam.nrel.gov/forums/support-forum
[6] https://sam.nrel.gov/reference
[7] https://sam.nrel.gov/financial

researcher reads a paper, grabs the algorithm and attempts to code it into Excel while providing the appropriate data. Another way to think about the goal of SAM is to short-circuit that path for industry (who likely aren't reading the latest journal papers anyway) and move the best models into the industry. However, we also have a mandate as a National Lab not to provide unnecessary competition to other products in the industry. From our perspective, we don't want to spend our time nor tax dollars reinventing the wheel. This area is understandably grey as no products are identical nor is the implementation of capabilities consistently robust across products.

Having said that, SAM has several products that are in this space, particularly in the area of PV modeling. In fact, the SAM team has just completed a major inter-model comparison effort between several tools including PVsyst[8], PV*SOL[9] and RETScreen[10]. It should be noted that these other tools are all non-US products. The inter-model comparison found several interesting issues but also was the first documented comparison of all these tools to actual deployed systems. See Figure 4 for an example of the type of variation that we found.

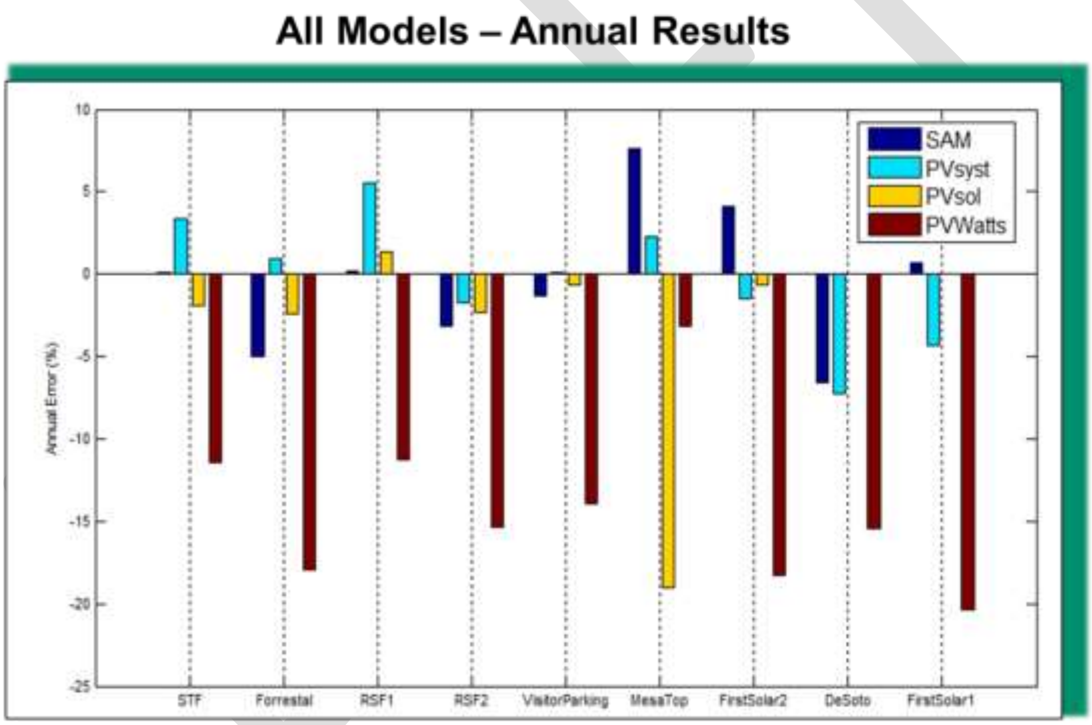

Figure 4: Results across Models for nine real systems

While several of these tools provide very detailed (and in some cases more detailed) PV performance modeling, none of them have the other capabilities on the economic side that SAM does. They might have some simple cost data included and even calculate a simplified LCOE but they do not have detailed incentives, etc. that we have. PVsyst is the industry default for PV

8 http://www.pvsyst.com
9 http://www.valentin-software.com/en/products/photovoltaics/55/pvsol
10 http://www.retscreen.net/

system performance modeling, Helioscope is new module-by-module model, PVSOL has existing user base, many tools coming up that attack some piece of the puzzle or provide a framework for installers to build a business on. Still, no one has the same mix of performance, costs and financing that SAM has.

For CSP technologies, there is one tool that has both the detailed performance models and the financial analysis that SAM encompasses. This tool is Greenius[11] and is offered by the German DLR. This tool has not been validated against SAM so we can't speak to its accuracy at this time. Additionally, we continue to work with DOE and private entities to add and incorporate several technologies that are the focus of CSP research even if they aren't being deployed at this time. To our knowledge, SAM is significantly more powerful in its ability to support complex analyses of interest to the labs and to DOE (parametrics, uncertainty, integration with detailed cost models). SAM integrates with resource datasets currently supported within the U.S. (e.g. through use of the solar prospector tool). This in turn supports DOE with additional analyses of interest such as high-resolution grid-integration studies necessary for proper valuation CSP-generated energy.

Goals of the Model

As stated above, the goals of the model have changed somewhat through the history of the model from a firm focus on internal DOE analysis to supporting industry and academia to now enabling other tools via the SAM SDK and other capabilities. The recent three-year planning process that we went through with DOE in summer 2012 (the "LPDP process") sheds some significant detail on this. From this process, we consolidated the goals for this modeling agreement as:

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.*

[11] http://freegreenius.dlr.de/

From this process, we received detailed feedback from a panel of outside advisors representing the solar industry, academia, DOE and the financial community. The high level feedback that we received is included below. One should note that the first point of feedback indicates that the primary guidance is that SAM should be a *world class PV performance model that is highly validated*. We have been therefore working towards that and other goals for the last two years.

Reviewer Comments

- ***The primary focus should be to develop SAM into a world class PV performance model. The reviewers felt that model validation was critical to acceptance by the broader PV community. To make that happen, NREL needs to do the following:***
    - ***SAM should create a TRC that includes all the IE's to guide SAM towards acceptance as the premier PV performance model.***
    - ***Focus on validation of the model.***
- *Why is utility scale being proposed as a separate model? While this work is important, it was not considered the highest priority. NREL should focus more on validation of the current model.*
- *PV Watts should incorporate the results of Chris DeLine's work so the benefits of DC optimizers can be captured for rebates.*
- *The difference between NREL and Sandia's work on module mismatch and temperature variation across PV plants was not discernible from the proposals. This needs to be coordinated.*

The current client within the DOE SunShot program has asked for a roadmap as they seek to get the greatest value from this project. However, we continue to steer our activities generally towards becoming the premier PV (and CSP) modeling tool.

What are the goals for SAM in the future? Being the premier free PV modeling tool is not necessarily our end goal, but a useful starting point perhaps. As stated above, having the best impact on the mission of the laboratory and the DOE SunShot program is our end goal. We do want to be part of taking system modeling to the next level – greater accuracy and fewer "losses" terms. We want to enable both beginners and advance users to effectively get valuable answers from the tool.

Vision of the Future for SAM

What should the suite of SAM tools become in the next five years and beyond? How do we build on the work that's already been invested and utilize the team that's become experts in this type of modeling?

Even with all the capabilities of SAM and other tools, there remain 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 completely 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 even though we have made strides in that direction over the last few years. Additionally, there continue to be underlying modeling gaps with regards to losses, 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.

As we move forward over the next five years, to maintain the cutting edge in several areas, we want to include and use the very best weather data, the best models (such as the new IEC 61853 model currently being developed), make the user interface as intuitive as possible and create the best methods for interacting with the user interface and the models. The bottom line will be quick, easy, accurate, objective and credible analysis results for all users from the most introductory to the most advanced users.

From an application perspective, we think that the key research and analysis areas to support are:

- Grid Integration: From short timesteps to linkages with tools like OpenDSS and Gridlab-D, the ability to provide robust and realistic PV and CSP output profiles (And perhaps time-synchronous load profiles) in an accessible manner by the various teams looking at the operational impacts of high levels of PV and CSP penetration on the grid is critical.
- Utility-scale plants: As utility-scale plants continue to increase in market penetration, [12] the SAM tool has focused on this somewhat during this three year AOP cycle but this is a growing area with a remaining significant number of modeling efforts including such items as heat-island effects, self-shading and backtracking for one-axis systems (including such things as topography which aren't effectively modeled now) and the value of two-axis tracking, etc.
- "Loss terms": The often glossed-over factor in PV and CSP modeling is that there are physical mechanisms for which either the models or the data doesn't exist – or at least hasn't yet been examined including shading, soiling, snow, mismatch during aging, etc. This is a key role for a national laboratory to continue to address both through data and modeling. We have been working on these, in conjunction with others, but there is significant work to be done.
- Financing: As modules continue to decrease in cost and third-party ownership and other mechanisms penetrate the market (with SolarCity currently deploying over a third of all systems in the US), the need for understanding the NPV of a residential or commercial

[12] Footnote that says that there are more utility plants now than 5 years ago – duhh… (perhaps it goes without saying)

system on all these various financing options is important for the analysis community to convey to the general public as well as the implications if the future is not as today (higher inflation, lower growth in electricity prices than expected, etc.)

- CSP Technology: Finally, with the excitement both by the industry and DOE around PV, the modeling of various important and emerging CSP technology trends (hybrid plants, supercritical CO2 cycles, advanced heliostat designs, etc.) have been modeled but significant additional work could be done in this area.

Key new Features for Development

There is an extensive list of capabilities that could be added to SAM over the next five years. However, as we think through the needs of the users for all technologies, and particularly for PV and CSP, the needs and wants of the user base for SAM will likely change faster than we can predict effectively. For example, who would have known five years ago that the price of batteries would have dropped 80% in the last five years resulting in a great need for analysis of integrated battery storage even for grid-connected systems? Additionally, SAM continues to garner more and more attention from international audiences for both PV and CSP technologies. Recent data indicates that while the US still is the vast majority of users, there are many very active international users of SAM. Their needs also change quickly.

However, we think it's important to include a concrete list of potential improvements to SAM in the next five years. We think this is important because to the casual observer it may seem like the SAM toolset is complete. We model most all of the critical PV and CSP standard configurations (flat plate PV, HCPV, CSP troughs, CSP towers, CSP dish Stirling, PV simple efficiency, etc.). However, that assessment masks both the changing needs as well as the various assumptions that are currently used not just by SAM but by all solar performance tools that could be improved.

The new features can be divided into several categories including improved inputs and data, improved user interface and visualization, extension of new models and finally back-end improvements to the core of SAM. Some major and minor examples of each area are given below to communicate what we feel goes in each category.

Improved Inputs and Data

- Integration of new robust resource datasets
- Integration with IRENA international cost and system data effectively.
- Integration of "Green Button" data into SAM (to enable installers to effectively get data from users that can enable accurate economic analysis)
- Continued integration of 61853 data and push to have that data provided by manufacturers.

- Create a set of libraries for data that is currently extracted from the internet in case it goes away: incentives, utility rates, sample loads, etc.
- Dramatically improved soiling data for typical systems around the country.
- Improved snow losses data for emerging markets with significant winter snow.
- Perhaps through partnership, better assess the value of mismatch and wiring losses on typical systems at all scales.
- Improved and standardized assessment of shading. Our initial foray into having a shading tool associated with SAM has led to an initial conclusion that while many tools and individuals assess shading on a system, that information is neither consistent nor validated. That can lead to significant deviations for real systems.

Back-End Improvements to the SAM Core

- PV modeling at any time step paired with sub-hourly solar data
- Access to engineering equations/C++ code for everyone via an open source license. Note that this is an extension of the SDK concept but implies significantly more knowledge from the user as well as the ability to compile the C++ code.

Extension of New Models

- Integration of electrical storage
- CSP modeling of options for hybrid systems
- Enable output metrics and financial methods to enable analysis for the latest financing option (third-party ownership). This is being funded by DOE for FY15.

Improved user interface and visualization

- Simple Systems or wizards implemented in the new SAM scripting language and calling the SDK.
- Ability to modify the user interface without having the code for the user interface. This is something that we've proposed in conjunction with allowing users to modify and add to the engineering code. This would allow a small group of committed developers to modify SAM in a way that would enable them to essentially create their own version of SAM but without having all the SAM source code.
- What is the most expensive part of the PV system that can be improved via software – the soft cost of a system?
    - How do we enable analytics that drive down that cost?
    - Automatic reports for regulatory agencies and pushing regulators to adopt a DOE-supported standard template.
    - Servicing of needs for installers in emerging markets (i.e. not California)

- Improved graphical outputs including parametric specific charts (i.e. maps if multiple locations are selected, surface plots if 2D parametric space examined)

Business Plan

Building software over a long period of time is not something that our funders are typically focused on doing or something that they really expect from a national lab. In fact, the more typical activity is to come up with a project, pose it to the national lab research team and they eventually write one or more peer-reviewed journal articles about this project. Both types of projects are completely viable and impactful on the mission of NREL. However, because software development is atypical, there is a need for a long-term plan to understand how such tools are being developed and what the long-term goal is for the tool. Will NREL/DOE continue to fund the tool forever? As indicated above, there are a plethora of improvements to make that could take several years. Should private industry solely build these tools?

In reality, the assessment of our team is that the true and best answer lies somewhere in the middle of the extremes. While there is an ongoing constant need for improved performance and financial models, NREL/DOE does not need to fund the development of all industry-facing tools. NREL/DOE can, in fact, potentially focus on building the algorithms. However, there will always be important stakeholders that cannot afford expensive industry tools and sometimes it isn't easy to know if an algorithm is working until it's actually placed in a framework in which it can be effectively used and tested.

As we go forward, our test for the best software business model is to focus on the activity that will make the best use of tax dollars to have the largest impact and enable the most research and analysis to happen quickly. As a result, we have several questions that the SAM team has been asked during several recent reviews that we will respond to from that lens.

- What to do about licensing?

  NREL and DOE have not been highly successful in the past at licensing software code to private companies to see them take off. We've licensed about a dozen copies of the original PVWatts source code but conversely have hundreds of users including dozens of major firms using the PVWatts web service. The seemingly most effective licensing of code was of the Homer software code which was licensed by the NREL staff person originally responsible who left the lab to take over the code. In our opinion, the majority of codes built at NREL are meant to solve several problems but not necessarily with the goal of being profitable and the market of renewable energy analysts is small. Typically, software is combined with services and consulting to create a winning business model.

Additionally, there are restrictions on licensing the code of a tool that is still in development. The license is for a very specific version of the source code which is problematic since the licensee has to come back 6 months later to get the new updated code via a new license agreement. Our SDK method is a solution to this problem as the user can just download a new SDK and all updates are immediately available (but perhaps with some minimal recoding to access new inputs and outputs).

Finally, NREL's general licensing position is that we would like to enable a company to have a business advantage by licensing source code to a single entity at least for some pre-determined period of time. Therefore, the licensing of SAM should be constructed such that someone outside of NREL could potentially make money by having an exclusive license to the tool.

Having said this, we get periodic requests to have both the entire SAM code base (both for the "engineering code" or SSC as well as to the entire desktop-version user interface code).

Now (in 2014) that we have completely replaced all code written by subcontract Universities within the SAM engine, we have the opportunity to potentially share the entire engineering code base as an open source project. That would include everything necessary to build the SAM Solution Core (SSC). We intend to move in this direction pending funding, though it should be noted that it will take *more* funding to support an open source version of the source code than it does to support the existing closed-source SDK package.

Alternatively, we would like to see the downloadable version of the full SAM tool with the user interface live on past significant DOE funding to the point that we would want to offer the complete user interface code base for a significant sum (like $50,000) to a single entity planning to make SAM publicly available (if not free) in a way that continues to support research, etc. in a way compatible with our goals. It would be a very significant investment for any firm to license the code, get up to speed on how it works (although that will be easier with the new code organization and update in 2014) and then learn to use it and improve it going forward.

Our goals are to continue to advance and improve SAM while another entity takes over the costs of technical support, website, etc. We would continue, pending funding, make updates to the engineering code and even perhaps the user interface for NREL/DOE needs which we would hopefully find a way to share with the outside entity in a positive synergistic relationship. Note that this would likely mean that there would not be a free version of SAM available outside of NREL (to academics, etc.) but hopefully we could structure the license such that academic users pay a manageable fee.

- What to do about web services?

The SAM team offers only one public web service which is the PVWatts Version 4 (and soon updated to Version 5) web service. However, SAM makes use of roughly 10 other web services within NREL to get inputs the Solar Prospector data, geothermal and biopower resource data, detailed local incentives, and complex utility tariff data, among others. We have also worked with others to build two other web services that are for a third party and not publicly available.

In general, we think now that for data provisioning, web services are very valuable. However, for analytical capabilities, creating NREL web services is a significant effort that can be, in most cases, more easily replicated through the onsite implementation of the SAM SDK. Additionally, the resources need to create and maintain the web services are significant for each year.

Therefore, we do not anticipate, in the next five years, making significant investments into providing additional public web services other than the basic PVWatts web service (which our online version of PVWatts also uses).

- What to do about competition?

As mentioned previously, there are several other foreign private companies that offer tools with some similar capabilities to SAM. While DOE has pushed us recently to be the premier PV modeling tool, we still do not want to spend time replicating other tools capabilities generally. We think that by focusing on validation, standards and creating cutting-edge models, we can continue to push these other tools to adopt better models and thereby “raise all boats”.

The open source release of the SAM engineering code might also help this in that other companies could implement the same algorithms into their tools quickly.

Another factor that we’ve found to be important is to continue to inform companies in this space of the planned feature additions quickly and early so that no parallel developments are done in isolation.

Again, our goal is not to waste our time or resources but work with others to improve all tools and point to the future to provide the most accurate and effective tools possible.

- Should some models be retired and should some be added?

The answer to the question of - if models should be added to SAM - in general is yes. Models get added when requested by users (either internal or external) or clients (DOE or others such as EPRI) and when we perceive that the models will be relatively broadly useful to justify long-term support. That’s often the real question – long-term support. All models require periodic maintenance to keep up-to-date with infrastructure changes, updated default values, technical support, etc. Therefore, there are examples of where we were concerned that long-term funding would not be forthcoming to support technologies such as desalination with CSP or PV, and so we did not pursue adding those technologies to SAM.

As alluded to, the question of whether models should be retired is difficult to answer. First, there are often many existing users who have old project files that use some of these technologies and we would like to allow them to upgrade to the latest SAM version. Second, just because a technology is not being installed significantly in the marketplace doesn't mean that modeling and research isn't being done for that technology in universities around the globe. However, certain technologies or implementations of them have been superseded (such as the empirical trough model being superseded by the physical trough model) that raise the question of if these technologies should be included. Also, if funding for a particular technology option (such as wind or geothermal) is not funded, the SAM team cannot update or do maintenance on those technologies with funds from the solar program so they might languish.

As we go forward in time, the updates to the code infrastructure that we are making in 2014 will enable us to minimize the maintenance and upkeep for existing models which should hopefully mitigate the need to question the inclusion of existing models.

- What will SAM not be?

  The SAM tool will not end up being focused too specifically on a particular sector of the solar industry as you might expect for other tools. Many tools either focus on residential/commercial systems or utility-scale systems. With the interest by the DOE SunShot program on all sectors, we will continue to address all sectors and technologies resulting in several difficult interface issues that as a business we would not need to address.

  Additionally, we will not work towards a model just for the market of today nor a specific company's product. We want to remain generic and focused on a longer time horizon.

  Finally, the SAM tool will generally be always focused on enabling research and analysis in an objective way. Our default values and assumptions are based on the most realistic if not conservative data that is available.

  The SAM tool will continue to emphasize the mix of performance and financing issues that characterize all systems. While we have focused at various times much more or less on either performance models or finance models, we consistently work on both types of modeling.

Year by Year Roadmap

In this section, we attempt to capture what we feel would be a good set of major projects that would lead the SAM tool to accomplish the goals described above. While each year has a core of technical support, updates, and publications, the key research areas and focal areas shift from year to year. In fact, we are advocating not even releasing a new version of SAM in each year necessarily although typically we want to get out new capabilities or are requested to release if users hear about it. Furthermore, ongoing bug fixes as reported by users typically require at least one release each year. The year by year staging of projects below should hopefully give an idea about our prioritization as well as the rhythm of development leading to deployment leading to iterative improvements on the capability as well as the periodic need to refresh various parts of the tool in response to market changes. This staging also assumes a resource level of roughly two developers, support staff, modeling expertise and management totally roughly four FTEs per year.

During each year, there are a number of funded activities that are really critical to the value of SAM to the users as indicated above. We've summarized these items here but we are not going to mention them for each year of work.

- Technical support – we've had a contractor working with the SAM user base answering many email questions per week and monitoring our online support forum. This contractor, Paul Gilman, also is available for onsite training for SAM as requested and coordinates much of our outreach such as webinars, user surveys and our YouTube channel.
- Documentation – One of the most valued parts of SAM according to user surveys is the documentation of the model. Our contractor Paul also tracks much of that and composes much of it as well with support from the rest of the team writing up the parts that they have worked on.
- Updating and maintaining default values and assumptions – each year we coordinate with solar, wind and geothermal technology experts at NREL and elsewhere to get the very best cost and performance data assumptions. This includes adding to the sub-component libraries (modules and inverters), improvements in typical system design and updates to outside data sources.
- Communications and Web Site – each year we typically have multiple conference papers and technical reports that need to be reviewed and edited by NREL communications for which the project gets charged. Also, the SAM website consistently needs time each year to update, upgrade and then augment as the information we want to share changes and as NREL infrastructure evolves.
- Bug Fixing – While we often discuss the key enhancements to SAM, we also spend significant time tracking down bugs and issues either that the team finds or that are

reported by users. Occasionally bugs are determined to be severe enough to necessitate an updated release, or at a minimum a software patch, which can be a time consuming process, particularly since multiple platforms are supported (Windows 32/64 bit, OSX 64bit).

- Reacting to Changes in Markets and Data – For example, we are currently updating SAM to use the updated utility rate database API (Version 3) which was an unexpected update. Even minor changes to one of the several API's that we use (solar data, wind data, geothermal data, biomass resource, incentives, utility rates, etc.) can cause significant redevelopment on our end.
- Back-end updates: While SAM is written in C++, there are various libraries and links that we use within the code. Periodically, those are updated and modifications to use those updates are required within SAM.
- Note that we do this not just for the SAM desktop application but also the SAM SDK, the PVWatts web service and relatedly the PVWatts online application.

Year 1

For FY15, we have already worked through a plan of development and release with the DOE Solar program as well as the DOE Wind program. The key items are:

- Integrate stochastic analysis capabilities (using Latin Hypercube Sampling) with weather variability analysis using improved weather dataset developed in FY14.
- Establish a new capability within the 3D shading model developed in FY14 to calculate diffuse radiation view factor reductions for any arbitrary obstruction geometry.
- 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.
- 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.
- 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.

- Completely enable the SAM user interface and simulation engine to allow more than 4 PV sub-arrays.
- Improve the solution methods used to extract IEC 61853 module parameters from test matrix data based on research in FY14.
- 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.

Additionally, we have asked for more funds to integrate battery storage into SAM. That requires additional efforts at modeling hour-by-hour all the years of the lifetime of the system and really requires enhanced dispatch capabilities to really be useful to the grid integration modeling community as well as the SAM community. We won't know about the status of funding for this project until the end of FY14. If this project doesn't happen in Year 1, we will continue to propose it as a top priority and move it into one of the out years. With the resource reductions expected already, we will have the bandwidth on the team to complete this task. A quick synopsis of this project is:

> *Approach: The research activity will commence with a literature review of battery storage modeling techniques, commercially available batteries, charge controllers, storage-integrated inverters, and related topics. Consultation with NREL and external energy storage experts will naturally be included. Once the model requirements for various timescales are defined, a model will be coded in C++ and integrated into the SAM PV system performance model. The SAM simulation engine will also be modified to model the whole lifetime of the PV+storage system, so that the interplay between PV module degradation, battery degradation, component failure and replacement, and system sizing (DC/AC capacity ratio) can be accurately analyzed.*
>
> *Value Proposition: The integrated approach taken in this project is unique because it integrates battery storage into a first-class PV performance and economic analysis model. This enables robust end-to-end analysis of the economic value of battery storage systems. Furthermore, because SAM is freely available to the public, it will enable other researchers and members of the solar industry to leverage NREL/DOE dollars and expertise to build unique market offerings to bring down the cost of these technologies and enable greater penetration of solar into the distribution grid.*

Year 2 Focus on Shading and Modifiable User Interface

In 2014, we have released a 3D shading tool associated with the SAM model (both stand-alone and integrated into SAM). This tool allows us and researchers to investigate 3D shading in a simplified way.

This is not meant to replace AutoCAD or other tools. Subsequently, we think that there are several tasks that should be completed in the future related to this tool including:

- Detailed Inter-comparison of 3D shading tools: In particular, we have observed large (~30%) discrepancies between the shading loss predictions by the three most commonly used PV modeling tools (SAM, PVsyst, PV*SOL), and no third-party validation data or analysis exists.
- Standard file format for shading geometries to allow all shading tools to interoperate. Right now, there is no seeming standard other than the defacto standard of using "Sketchup" from Google. However, that is inadequate for the needs of most tools for passing obstruction information between other tools. We would like to examine what the options are, propose and refine a shading standard and communicate that to the solar industry and the alrger building modeling industry.
- 3D shading tool enhancements coming from beta test – We are currently underway in a long-term beta test and have received a few comments from outside and inside users. Once the 3D shading tool is incorporated into the official SAM Beta release in the next month, this will also result in significant feedback from users on its usefulness and content.
- Support for tracking systems in the 3D shading tool. This would be particularly useful for layout of systems with two axis tracking, such as HCPV.
- Scripting support in the 3D shading tool to allow programmatic generation of obstructions, objects, and PV active surface segments.

Relatedly, we would like to continue working on meeting the needs of our more advanced users – as well as with the 3D shading tool – to start allowing them to modify SAM input pages and add in their own C++ functions to the SAM SDK engine. There will be a small number of users (several within the DOE lab complex) that would benefit from being able to modify the SAM user interface and engine. However, this could be a very significant feature for those interested. The new SAM (released in late 2014) has an improved user interface with a significantly improved ability to modify the interface via scripting and non-compiled code.

The entire point of this activity is to allow users to add features and perhaps even full technologies that DOE and/or NREL would not want to support over the long-term as a SAM feature but that would be very valuable for a specific analysis. This effort would start in Year 1 but certainly wouldn't be completed until later in this five year plan.

In addition to these focus areas, other development items we think would be good to complete during Year 2 include:

- Create a set of libraries for data that currently is extracted from the internet in case it goes away: incentives, utility rates, sample loads, etc.
- Create a version of the CSP trough technology that does not automatically include a power block. We get various requests to understand only the thermal output from a trough solar field for both industrial process heat analyses as well as CSP-fossil hybrid analysis.

Year 3 Year of Grid Integration

The prime focus in Year 3 would be on continuing to enable and focusing on the work being done in grid integration. If the currently proposed work on integrating battery storage into SAM isn't funded, we would work in Year 3 ahead to reacquire funds for this activity and the related activity of optimizing the PV/battery controls to create the most value for the user based on the utility rates and resource data for that location. Additionally, we would want to do this for CSP technologies as well. We currently enable some simplistic controls of the CSP plant based on time-of-dispatch inputs but the outputs is neither optimized over the entire period or even a 12 or 48 hour window ahead. Finally, while we have started to allow sub-hourly data to be processed by SAM and creating PV and CSP output at that scale, this would be the year in which we really examined if the profiles that we generated were appropriate and, if not, how to improve the representation of variability in these profiles. This could be very important for grid integration as they continue to represent shorter and shorter timesteps in more complex systems with significantly more PV and wind on the grid.

Finally, we would like to get funded a project actually suggested by DOE – a linkage between OpenDSS and SAM (as well as updated linkages to GridLab-D). The project can be broken down into three stages. First, a linkage between the OpenDSS and SAM software tools will be demonstrated. This will involve developing expertise with the OpenDSS code base to determine how best to connect with the SAM software development kit (SDK). This may require further changes to the SAM SDK to enable integration. Second, the OpenDSS+SAM linkage will be used to model a prototypical distribution system with several PV generators, and the result will be compared with using stock PV profiles. The analysis is intended to show that integrating these tools improves the fidelity of model predictions. Finally, using real-world data from the SMUD system, attempt to replicate the real-world performance of installed PV systems using the new OpenDSS+SAM hybrid. This work will result in a publication showing the value of this new capability.

Relatedly, allow for greater configurability of the inverter models. Currently, SAM only supports one bank of inverters, but large systems frequently have many banks of inverters. Additionally, modern inverters often have multiple MPPT inputs, which SAM does not model currently. Advancing the inverter capability to support multiple banks and MPPT inputs that can be connected to different subarrays would greatly extend SAM's ability to model real systems as they are built.

In addition to these development activities specifically focused on grid integration research, there are several other activities which should occur in this timeframe including:

- The SAM technical review committee hopefully will be funded for a deep-dive on the newest version at the end of year two. They likely will suggest a variety of development activities which we can work through in Year 3.

- Research the feasibility of directly using POA data as an input to PV modeling. The deliverable for this would most likely be a white paper, research article, or similar. Would involve an extensive literature review, coordinating with other teams (Sarah Kurtz, resource assessment team, Sandia, other PV models, IEs?), and potentially some case studies with available measured POA, GHI, DNI, DHI data. Currently, no PV modeling tools can effectively use POA irradiation as an input. However, the measurement is a fairly common one to take in the industry. Furthermore, the error of the transposition model from horizontal to POA is widely thought to be one of the largest sources of uncertainty in PV modeling. Eliminating this step would greatly reduce PV modeling error. See 2014 IEEE paper by Kurtz et al to help make a case for the need for this research.
- Generic thermal storage system. This would provide a storage module that extracts and provides energy and exergy from/to the HTF. The tool is needed to evaluate phase-change and thermochemical storage systems that DOE is funding. We'll need to think more about the boundaries of such a system.
- Continued integration of 61853 data and push to have that data provided by manufacturers.
- Dramatically improved soiling data for typical systems around the country.
- Improved snow losses data for emerging markets with significant winter snow.
- Perhaps through partnership, better assess the value of mismatch and wiring losses on typical systems at all scales.

Year 4 Year of Financing and Additional Customization

In Year 4, we will revisit the variety of financing options available to the SAM user. While currently third-party ownership models are growing significantly in interest, it might be that even other financing options will have emerged by this point in the future. Ongoing reductions in costs might precipitate even more typical home-improvement type loans to have PV installed. Additionally, in the utility market, the methods for financing large utility-scale plants continue to evolve as do the incentives that drive that marketplace.

Relatedly, we would want to attempt to integrate the use by users of "Green Button" data from utilities to enable installers to effectively get data from users that can enable accurate economic analysis.

Secondly, we want to continue to allow users to customize SAM. This could be through the open-source sharing of the engineering code, licensing of the UI code (both with appropriate support) or through additional customization of the interface without having the source code. WE've had several ideas on this front. Some of them are:

- Create a Scripting Library for users. We have many useful scripts already, so this might start with collecting scripts, standardizing the format, and providing additional documentation and commenting. Later we could take requests for new scripting capabilities. The library would also provide useful examples for people to learn more about scripting.
- IEC 61853 PV model: 28 test conditions are too onerous and test labs aren't doing them. Goal is to find out exactly which test conditions are needed to inform the model and maintain accuracy- perhaps only 8 or 12 test conditions would be needed. This would extend the IEC-61853 model to allow a variable number of test conditions to be specified, and the model would adapt as best as possible.
- SAM Excel Applets. Building on the type of work done by John Nangle and others, setting up some simple Excel example templates that call the SAM SDK to (1) get solar data (2) do PVWatts calculations (3) do an LCOE calculation might be very useful to a broad analysis audience.
- Continue to improve the previously developed ability to modify the user interface and link in additional engineering C++ code into the SAM core.

In addition to these development activities specifically focused on financing and customization, there are several other activities which should occur in this timeframe including:

- Include Spectrum Effects in 1-Diode Model: Extend single diode model(s) to utilize precipitable water vapor and aerosol optical depth in weather data files to predict spectrum and allow the calculation of light current from a spectral response curve entered by the user. This would allow physics-based evaluation of spectral effects in thin-film and/or CPV modules that currently are not available in any modeling tool. This could be an additional "expert" option to using the air-mass modifier based approach. This capability would also enable analysis of future potential technology improvements with respect to spectral response: i.e. if the spectral response is improved by X amount, what is the energy harvest and LCOE impact.

Year 5 Year of International Support and an Electrical PV Model

The final year in this plan will be focused on a nod to our international users among other improvements. We have many international users of SAM and many US users working on international projects. While we don't intend to have SAM in many languages (As is true of tools like RETScreen from NRCan), we do intend to confirm and make sure that it's use in these other contries of interest are appropriate for those countries. This would build by the as yet uncompleted (in Year 0) international hourly gridded data set being created by NASA currently. The publication of a publicly available gridded dataset of typical hourly values for the entire planet would be a huge boon to all tools, not just SAM, but we would look forward to being the tool that shows how this data can be accessed and used by all. We would hope to work with the broad SAM user community (as we have done with users in Australia already) to confirm that SAM performance models as well as financial models are appropriate for these countries. IRENA continues to work towards a dataset of international cost and system data and we would like to integrate SAM with that dataset as well.

Secondly, we intend to focus on creating and integrating (assuming this is possible which would be the first stage-gate) a full electrical model into SAM. This electrical model would track not only the power working through the system but also the voltage, current and reactive current, etc. that can be so important for various activities. This would be a significant development for the SAM model but, assuming it's still needed in five years, would be a very useful tool and help capture the benefit of PV systems to the larger electrical grid.

Finally, in addition to these key focus areas, there are other activities that we think could be done appropriate (and assuming typical past budgets) in Year 5 that will come out of ongoing feedback from our user base, reaction to developments in the intervening years as well as from an ongoing technical research council.

Conclusion

There are several conclusions that can be drawn from this document. These are summarized here but can broadly be categorized in that a significant investment has been made in this tool and additional effort over the next five years can significantly improve and enhance the ability and usefulness of the entire SAM tool suite. The specific conclusions from this document include:

- SAM has a ten year history of providing value both to the DOE system, NREL specifically, the solar (and other technologies not addressed here) industry and academia.
- The goals and vision for SAM have changed significantly over the last ten years as have the desired capabilities depending on the audience.
- There are a large and significant number of activities that could be funded to reach the long-term vision for SAM.
- There are a variety of products that could easily be augmented and even offered for license to others.
- The creation of SAM has provided an end-point for many different resources and analysis and an entry point for industry to access NREL products. These include the Solar Prospector, the Utility Rate Database, the DSIRE incentive data web service, typical system cost defaults, etc.

- While SAM started as a desktop tool, the suite of products now offered (from the SDK to associated financial spreadsheets) are far more impactful to a wider variety of stakeholders and needs.
- The five year plan provides a broad and rich set of capabilities that will significantly impact the solar industry and research community.