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Performance and Cost Model for Solar Energy Technologies in Support of the Systems-Driven Approach

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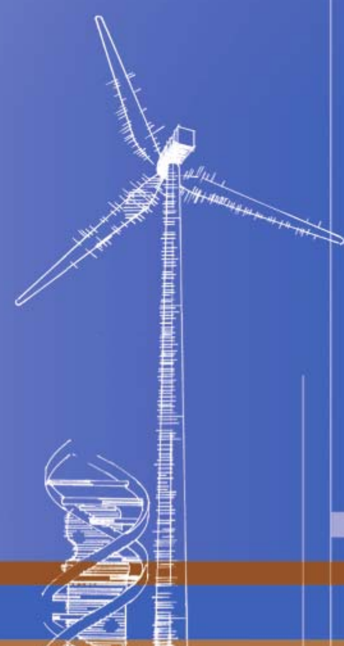

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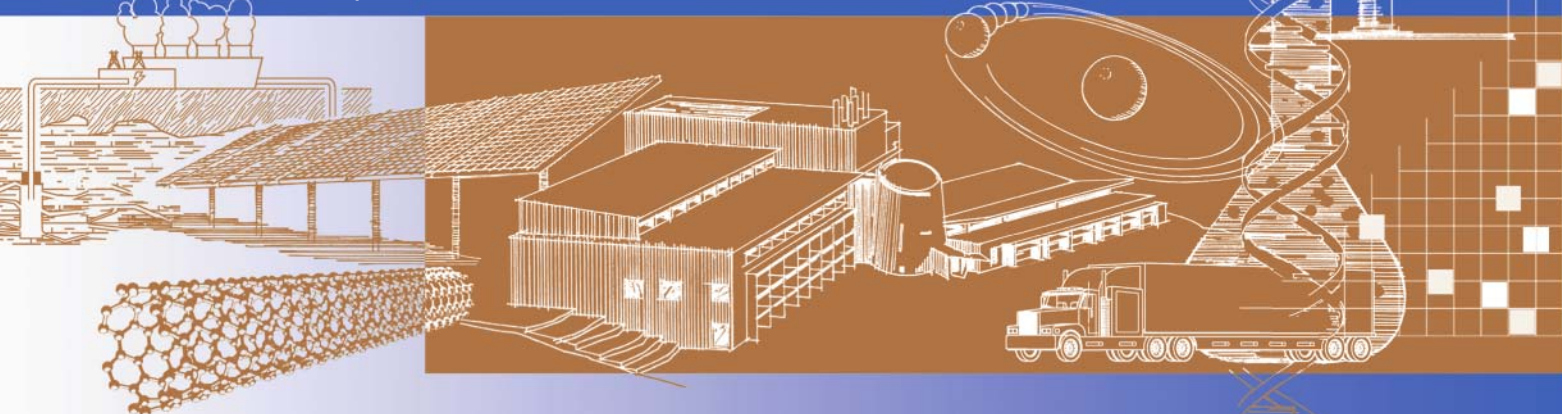

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ABSTRACT

A comprehensive solar technology systems analysis model is being developed to support the implementation of the systems driven approach to program planning for the U.S. Department of Energy's Solar Energy Technologies Program (SETP). Use of this systems model, together with technology and cost benchmarking, market penetration analysis, and other relevant considerations, will support the development of program priorities and direction, and the subsequent investment needed to support R&D activities.

1. Objectives

The primary function of the model is to allow users to investigate the impact of variations in physical, cost, and financial parameters to better understand their impact on key figures of merit. Figures of merit related to the cost and performance of these systems include, but aren't limited to, system output, peak and annual system efficiency, levelized cost of electricity, and system capital and O&M costs. The model is intended for use by DOE and laboratory management and research staff. The model may be used by members of the solar industry to inform internal R&D direction and to estimate systems cost and performance.

2. Technical Approach

The model will ultimately allow for analysis of the full portfolio of technologies currently funded by the Solar Energy Technologies Program, including photovoltaic, concentrating solar power, and solar heating and lighting systems. Because detailed systems analysis models have already been developed for concentrating solar power and solar domestic hot water systems, the initial focus of the development effort is on flat-plate photovoltaic systems.

Particular emphasis was placed upfront on the design of a user interface that could meet the needs of a diverse set of users. User profiles were developed to provide a general description of DOE, laboratory, and industry users and their motivation for using the modeling tool. A mockup of the user interface was developed and a series of usability sessions were conducted to provide feedback on the initial interface design. This feedback was used to refine the interface used for the working version of the model.

The working model consists of a user interface module for selecting and providing input data on the system configuration and operating environment, a system performance module which simulates the hour-by-hour output of the selected system for the lifetime of a project, a cost input module for providing simple or detailed cost inputs for system components, and a financial analysis module for calculating system economics. The modules work in concert to generate the physical and financial figures of merit relevant to the particular user. Specifics of each module are provided in the following section.

3. Results and Accomplishments

3.1 User-interface module

The user-interface module allows the user to access various default configurations of solar energy systems. Default system configurations, performance, and cost parameters are provided but can be changed to evaluate the impact of these parameters on key results. Drop-down menus provide in-depth access to component-level inputs. Standard graphical and tabular results are available, or data can be exported to other software packages, such as Excel or PowerPoint.

While the current interface allows access to standard configurations for all systems funded through the SETP, its functionality is currently limited to residential and commercial PV systems. The functionality will grow from this limited capability to include a broader set of technologies and capabilities, as driven by user needs.

3.2 System performance module

The system performance simulation module calculates the transient, generally hour-by-hour, performance of a collection of components configured into an overall system design. These calculations are done in the background and not visible to the user. To predict PV module performance, the user will initially have the option to model performance based on NREL's PVWATTS or Sandia's "King" methodologies [i,ii]. Currently, the PVWATTS option is coded into MatLab, while the King model is accessible from within TRNSYS [iii], which will be the transient simulation solver for the model that fully integrates all the solar technologies. TRNSYS was chosen in part to make available to the user the extensive, existing library of system components relevant to the SETP.

Because the model will ultimately be used for analysis of thermal, as well as photovoltaic systems, a generalized description of component and configuration input options are provided in the user interface. Options include the collector (PV module), converter (PV inverter), array/field (module configuration), storage (battery), and balance of system.

3.3 Cost input module

Expanding on the current, simple cost model, future versions of the cost input module will include a detailed component and systems level capital costs, as well as a component and systems level O&M costs model as part of the default systems. These cost parameters will be accessible for modification by the user. Costs can be entered through the user interface or derived from a more detailed cost model implemented within a Microsoft Excel® environment. As is the case with other portions of the model, the user will be able to not only modify default values, but to redefine the model itself. Such user-defined models will allow for sophisticated rollup of materials and labor costs, with varying relationships to system size and capacity, to meet the user's specific needs.

3.4 Financial analysis module

The financial module calculates the system cost and revenue streams for a given configuration, its associated input data, energy production, and various project-specific financial input assumptions. Based on this information, the module will be used to calculate information of interest to the user, such as project earnings, detailed cash flows, debt payments, equity income, levelized cost-of-electricity, after-tax internal rate of return (IRR), and debt service coverage ratio.

An important feature of the finance module is that it will offer a variety of standard schemes for financing solar-related projects. The user will be allowed to select financing mechanisms related to the project at hand, e.g. mortgage, commercial loan financed systems, or standard power project debt/equity financing. Default financial parameters are provided. However, the user is allowed to vary the financial parameters to address project-specific requirements or to assess the sensitivity of output parameters to financing assumptions.

3.5 Preliminary results

Preliminary results have been generated for the default 2.3 kW grid-tied residential PV system. To begin to assess the functionality of the PV performance, cost, and financial models, five of the more than 70 model parameters included in the model for this default system have been varied to allow the user to explore sensitivities. These variables include system lifetime, inverter efficiency, module efficiency, inverter cost, and inverter lifetime. While extensive validation must still be undertaken to gain further confidence in the model's input and output accuracies, these preliminary results are informative in demonstrating the types of analyses that the model will enable. Figure 1 below shows one of these results.

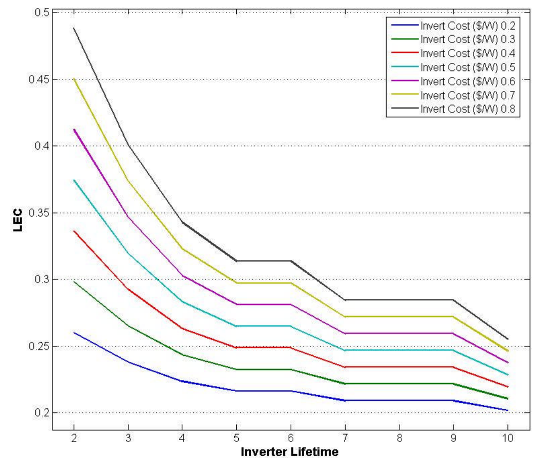

Figure 1. A plot of the impact of inverter lifetime on levelized energy cost for a range of inverter prices.

In the example plot, the user can readily see that to achieve a given LEC, a variety of combinations of inverter lifetime and inverter costs are possible. The model will help reveal and quantify these and other combinations. This information, along with other relevant considerations, will help inform researchers and program managers in determining the R&D path to targets that represent the most cost-effective and lowest-risk combination to achieve the target LEC.

4. Conclusions

Substantial progress has been made in the development of a performance, cost, and financial modeling tool for supporting and informing R&D investment decisions. Initial development of an intuitive, graphical user interface is complete, and preliminary functionality for modeling the performance, costs, and financial parameters of a residential grid-tied PV system has been established. Preliminary results offer encouraging insights into the utility of the tool.

Next steps in this effort will include releasing the beta model to a wider audience to begin a more thorough vetting process while continuing to add functionality for PV modeling and incorporating existing models for concentrating solar power and solar heating and lighting.

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[i] http://rredc.nrel.gov/solar/codes_algs/PVWATTS/
[ii] King et al., "Photovoltaic Array Performance Model," SAND2004-3535.
[iii] Klein et al., 2000. TRNSYS 15, A Transient Simulation Program. Solar Energy Laboratory, University of Wisconsin, Madison, Wisconsin, WI.

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