November 17, 2016

Mr. Jeremy Rand
Manager, Business Development
First Solar, Inc.
350 West Washington Street
Tempe, AZ 85281

Subject: **Review of First Solar's PlantPredict Photovoltaic Simulation Software - Final Report**

Dear Mr. Rand:

Introduction

Leidos Engineering, LLC ("Leidos") has completed a review of a software tool and associated methodology called PlantPredict ("PlantPredict") developed by First Solar, Inc. ("FSLR") for use in performance modeling of photovoltaic ("PV") plants. PlantPredict takes inputs relating to the solar resource, climate, key PV plant equipment and PV plant design to estimate a PV plant's performance over its operational life. Access to PlantPredict is provided through a web-based log-on to a cloud-based portal. This Letter Report presents the results of this review.

This work was undertaken under a Task Order effective August 5, 2016 pursuant to the Technical Services Agreement between Leidos and FSLR dated April 2, 2014. This Letter Report is solely for the information of and assistance to FSLR and should not be used for any other purpose or by any other party, except for those parties who have entered into a third party use of work products agreement with Leidos. This Letter Report has been developed based on the specific needs of FSLR and the level of information included reflects the knowledge of the issues gained by FSLR through the course of our review. To the extent that other readers of this Letter Report have not been involved over the course of our review, the information contained herein could be misunderstood or incomplete.

Certain statements included in this Letter Report constitute forward-looking statements. The achievement of certain results or other expectations contained in such forward-looking statements involve known and unknown risks, uncertainties and other factors which may cause actual results, performance, or achievements described in the Letter Report to be materially different from any future results, performance or achievements expressed or implied by such forward-looking statements. We do not plan to issue any updates or revisions to the forward-looking statements if or when changes to our expectations, or events, conditions or circumstances on which such statements are based, occur. No warranty, guarantee, or promise, express or implied, related to any future results, performance, or achievements associated with such forward-looking statements is provided.

Background

Accurate and repeatable modeling of a PV system is a crucial requirement in the development of PV generation plants. The task requires detailed information of the solar resource, the plant configuration, and the PV equipment performance. Research, modeling improvements, testing, and verification of these components and their interaction with the environment has evolved over a period of many decades into a generally accepted set of parameterized calculations that can be used on a routine basis by developers and engineers. Performance predictions can be compared with data from actual operating plants to further inform and refine the modeling. Modeling requires reasonably complex software which utilizes a large number of inputs, to be used in a series of calculations or algorithms which each capture individual parts of the plant operation, which are then combined to simulate the overall plant performance. The PV plant equipment is described as a series of parts (modules, inverters, and transformers) connected into a system that produces AC electricity at the plant's point of common coupling ("PCC") to the electricity grid. Modern software includes databases which contain a wide variety of detailed equipment performance specifications as provided by manufacturers. The software calculates performance at each time interval according to the equipment's performance at the specific environmental conditions of each time interval.

PVsyst ("PVsyst") is a commonly used software package, widely accepted in the PV industry. PVsyst was originally produced by the University of Geneva and is now supported by PVsyst SA. It is widely used by developers of utility and commercial-scale PV systems to model annual electricity production and has undergone multiple revisions, with the latest available being Version 6.47; the analysis within this Letter Report has employed Version 6.38. PVsyst is locally installed on individual computers, under a paid license, and is supported through help files and an on-line forum.

PlantPredict has been developed by FSLR to estimate the performance of utility-scale PV plants employing FSLR modules and design methods as well as any other industry standard modules, including silicon and other thin film technologies made by other manufacturers. It is designed to be a complete and user-friendly software tool that includes within it all the modeling steps required to describe a utility-scale project. The software is offered through a cloud-based service, and available free of charge, with a user registration; corporate accounts with multiple individual users can also be arranged.

Broadly, accurate modeling can be broken down into four major tasks: (1) irradiance modeling; (2) effective irradiance on PV cells; (3) direct current ("DC") system modeling; and (4) alternating current ("AC") system modeling. Each of these major tasks rely on a set of sub-tasks or modeling algorithms that are used in conjunction with user inputs and model selection, with output results of one algorithm being used by the next algorithm.

In this Report, the software tool PlantPredict was assessed in relation to its modeling algorithms and implementations, in comparison to PVsyst and operational data. This review is undertaken based on: (1) a series of papers provided by FSLR that document PlantPredict's modeling algorithms, (2) FSLR's comparative studies of the tool against PVsyst and operational data, and (3) Leidos' independent use of PlantPredict to simulate FSLR and non-FSLR plants in comparison to PVsyst and operational data.

The versions of PlantPredict that were used during our evaluation are 3.6.0 and 3.7.0 (an update occurred during our review). The tool was run in "full plant description" mode. The "indicative model," application programming interface ("API") functions, and parametric analysis tools were not assessed.

Table 1
List of Key Papers

File No. [(1)]	Document	Author Affiliation	Description of Main Content
Benchmarking of PlantPredict			
(1)	B. Littman et al., "PlantPredict: Utility-scale PV modelling software for solar project life-cycle assessment," PV-Tech Magazine May, 2015, (5 pages).	FSLR	Overview of software.
(A)	*FSLR, "PlantPredict Algorithm Requirements"* internal MSWord document, (81 pages).	FSLR	Internal FSLR document which provides detailed description of all algorithms, (no validation included).
(B)	L. Ngan et al., *"PlantPredict Performance Model Fleet Benchmarking for 2013 Energy Prediction Guidance Parameters,"* FSLR report, Aug. 26, 2016, (51 pages).	FSLR	Detailed study of PlantPredict versus 20 operational plants.
(C)	K. Passow et al., *"Accuracy of Energy Assessments in Utility Scale PV Power Plant using PlantPredict,"* IEEE Photovoltaics Specialist Conf. Proc., June 2015, (6 pages).	FSLR	Study of PlantPredict versus 20 operational plants, AND analysis of two advanced algorithms (Hayes thermal model, spectral shift model).
(3)	L. Ngan et al., *"Performance Characterization of Cadmium Telluride Modules Validated by Utility-Scale and Test Systems,"* IEEE Photovoltaics Specialist Conf. Proc., June 2014, (6 pages).	FSLR and NREL [(2)]	Detailed study of PlantPredict versus 1 operational plant AND summary statistics of PlantPredict versus 54 operational plants.
General in the Field			
(2)	A.F. Panchula, et al., *"First Year Performance of a 20MWac Power Plant,"* IEEE J. Photovolt, July 2012, (5 pages).	FSLR	Comparison of 1 plant operational data versus PVsyst, examining areas of disagreements between the two.
Assessment of Particular Algorithms			
(8)	D. G. Eras, et al., "Estimation of the Diffuse Radiation Fraction for Hourly, Daily, and Monthly-Average Global Radiation," Solar En. 28(4), 1982, (10 pages).	Other	Highly cited journal paper that provides the basis for industry standard models of plane of array ("POA").
(10)	M. Lave et al., *"Evaluation of Global Horizontal Irradiance to Plane of Array Irradiance Models at Locations across the United States,"* J. Photovolt., March 2015, (9 pages).	FSLR and Sandia [(3)]	Detailed evaluation of decomposition and transposition models for accuracy versus ground measurements from 11 stations in the United States ("U.S.").
(6)	FSLR, "Application Note - System Parameter Specifications for PVSYST1 Simulations of PV Systems Constructed with FS Series 2, FS Series 3, FS Series 3 Black, or FS Series 3 Black Plus PV Modules," (4 pages).	FSLR	This reference, relating spectral correction factors, was reviewed separately by Leidos in another project.
(7)	L. Nelson, et al., "Changes in Cadmium Telluride Photovoltaic System Performance due to Spectrum," IEEE J. Photovolt. Jan. 2013, (6 pages).	FSLR	This reference, relating spectral correction factors, was reviewed separately by Leidos in another project.
(13)	W. Hayes et al., "A Time Dependent Model for CdTe PV Module Temperature in Utility Scale Systems," IEEE J. Photovolt. Jan. 2015, (6 pages).	FSLR	Analysis of thermal models of operating PV modules.
(11)	W. Hayes et al., "Thermal Modeling Accuracy of Hourly Averaged Data for Large Free Field Cadmium Telluride PV Arrays," IEEE Photovoltaics Specialist Conf. Proc., June 2012, (4 pages).	FSLR	PV module thermal models.
(12)	K. Passow et al., *"Self-Reported Field Efficiency of Utility Scale Inverters,"* IEEE Photovoltaics Specialist Conf. Proc., June 2014, (6 pages).	FSLR	Estimates inverter model inaccuracies of ~ 0.9 percent.

(1) The file number is the number assigned by FSLR in the set of documents they provided, or the letter that we have assigned in the instances where the file did not have number. These numbers will be used when documents are referred to within this Letter Report.
(2) U.S. National Renewable Energy Laboratory ("NREL").
(3) Sandia National Laboratories ("Sandia").

Description of PlantPredict

The following table contains a brief summary of the most relevant *functional* differences that we noted in the PlantPredict software tool in comparison to the PVsyst tool.

Table 2
Comparison of Key Features of PlantPredict to Other Software

	PlantPredict	PVsyst	Comment on PlantPredict
Access	Usage by invitation to cloud-based portal.	Purchase of license for downloadable software. All files reside on user's computer.	A potential concern in security and privacy to the user in their modeling efforts, and to version control. Both can and need to be managed in a professional manner.
Solar Radiation Files	Includes access to satellite services and TMY files.	Provides tool for importing data to create a "MET" file.	PlantPredict's direct access to multiple sources can be an advantage in time and thoroughness of the analysis.
Other Useful Tools	Separate stage for creating new module and inverter files.	A few tools for quality checking and quick processing of irradiance data.	
Project Structure	Is a collection of one or more designs and one or more weather file inputs.	Is based on a single weather file and one or more system design variants.	Plant Predict can more easily compare the same design in different locations with different weather inputs. Reusable subsections can potentially simplify project creation.
Plant Description	A collection of "DC Fields", "Inverters," "Arrays," and "Blocks," that are connected hierarchically, including multiple stages of AC transformers.	A collection of up to 8 "Sub-Arrays" containing modules and inverters, with a central transformer.	PlantPredict can replicate a complex plant, and can provide production predictions of the plant subsections.
Equipment Specifications	Select number of manufacturer datasheets available, or user can import or copy and edit.	Wide number of manufacturer issued datasheets available, or user can import or copy and edit.	No difference in functionality.
Time Step	Variable from one minute to hourly.	Hourly only.	Modeling with small time steps can be advantageous for some applications.
Period of Time to be Simulated	Any length.	One full year only.	PlantPredict can be more easily used for ongoing comparison to measured operational performance.

Comments on Terms of Usage by Industry

FSLR has explained that they developed PlantPredict to undertake a complete job of all modeling and computing aspects for the energy production assessment of a utility-scale project, thereby avoiding certain short-comings of other current products on the market. This will be assessed in detail in this Report. FSLR's intent is to continue to offer the product free of charge to users, thereby helping industry players improve their modeling capability.

In a broad industry context, three issues should be considered when using PlantPredict to model non-First Solar projects. The first is that clients who are independently developing projects may require assurance that uploaded data is not accessible by any other party, including FSLR. First Solar has indicated an intent to manage this in a professional manner including potentially (in the near future) the engagement of a third party host. Terms of service should be accessed on-line. The second issue is that the tool is developed to model utility-scale projects - certain capabilities that may be required to model other types of projects or novel technologies may not be included. FSLR has indicated a plan for continuous improvement of the product and to be receptive to user needs, though there could be instances where business interests do not align. The third is that the tool is updated on a regular basis (FSLR's present processes provide an update every two weeks) and that only the latest codes are available to the user. FSLR has stated that they undertake regression testing for any update to ensure that results are reproducible to previous versions, but because of the cloud interface, it is not feasible for them to offer all historic versions through the interface. It could be a concern to some users to not have software version control, in particular if updates materially affected their calculations, though FSLR has indicated to us they wish to work to support clients and they can rebuild an older version of the application in a separate cloud environment, should such an occasion arise.

Review of User Interface and Structure

The PlantPredict user interface is relatively well laid-out and it guides the user through each of the main modeling development tasks. It should be generally straightforward for those experienced in modeling of PV systems to learn how to develop a realistic model. The PlantPredict user interface provides access to four libraries: (1) the "Project Library," (2) the "Weather Library," (3) the "Inverter Library," and (4) the "Module Library." Each library provides several filters as well as a "search" field to aid the user in locating files. Each library allows files to be imported although the project, inverter, and module imports are limited to files created in PlantPredict. New inverter and module files may be created from scratch or by "cloning" and editing an existing file.

Creation of a new project begins with identifying the geographical location of the project using a search field to enter key words (e.g., city, zip code, or point of interest) or by entering specific latitude and longitude coordinates. Once the geographical location of the project has been defined, all of the components necessary to estimate the project's energy generation are selected in what FSLR calls a "Prediction." A Prediction is comprised of four major categories: (1) weather data; (2) modules, inverters, and medium-voltage transformers; (3) substation transformer, transmission, and interconnection equipment; and (4) modeling options such as transposition model, spectral method, and degradation method.

Before selecting weather data for the project, it must be available or defined in the Weather Library. Weather data available for a Prediction is presented both in list form and on a map so that its proximity to the project location may be viewed graphically. Settings for albedo, soiling losses, spectral losses, and a horizon scene are located in the weather data category.

For those with experience using PVsyst for modeling PV systems, PlantPredict's construction of a power plant may seem "back to front;" while PVsyst models are built by first defining sub-arrays comprised of modules and inverters, PlantPredict models start at the energy meter or "Block" then the medium-voltage transformers or "Arrays" within the Block are defined. Once an Array has been defined, the inverters that connect to that medium-voltage transformer may be defined. For each inverter a "DC Field" is then defined by selecting a module type, the number of modules in series, and the number of parallel strings connected to that inverter.

The definition of a DC Field includes the module specifications, string length and number, module-related losses, DC wiring loss, and description of mounting arrangement. We note that PlantPredict uses the common definition of due south as 180 degree azimuth and includes a visual element to help orient the user. Each DC field of a project can be independently defined in terms of any of the parameters mentioned above. Each DC Field is connected into an inverter and one or more inverters are connected to a first stage transformer to make up an Array. Each Block contains one or more Arrays, and this Block structure can serve to define zones of a big project that are sub-metered, or phases of a project that are built and connected at different start dates. At each substructure, settings specific to that equipment may be defined, and other parallel-connected units may have different settings and different sub-components. The advantage of this approach is that a plant can be described in the tool in the same manner that it is built, with no restriction on the number of variants, unlike PVsyst, which is limited to 8 sub-arrays. Furthermore, energy predictions can be obtained for the substructures, which can be compared with equivalent data streams available from operating plants.

The cloning feature allows a user to replicate any of the above structures and the "Quick Edit" feature allows certain parameters for all Blocks, Arrays, Inverters, and DC Fields to be viewed and edited in table form. Both can be helpful when building up a large plant from a series of smaller sub-elements, though a new user is likely to experience an initial learning curve for how to efficiently use these two features.

The third category in the creation of a Prediction is the definition of the substation transformer(s) and associated losses (if applicable), of the transmission line, and the interconnection. This is where a point of interconnection limit may be set.

The final category of Prediction options comprises "Simulation Settings" including timeframe and model choices for solar irradiance decomposition and transposition, module temperature, incidence angle, spectral effects, soiling and degradation. It can be noted that this is where main on/off toggles for several modeling options exist, although the detailed inputs for module incident angle modifier curve parameters and spectral correction factors are contained in the module specifications. Uncertainty analysis options are also available in this category.

Once a Prediction has been completely defined the simulation may be generated by clicking on a "Run Prediction" button. Results may then be viewed; to export them to a report format the Prediction status must be changed from a "draft" setting to a "read-only" state; this prevents model changes once a prediction report has been issued. Leidos is suggesting that a "draft report" also be included as an available option, to allow for preliminary review of draft designs with audiences/clients in a nicely formatted report.

<u>Review of Algorithms Used in PlantPredict</u>

File (A) entitled *"PlantPredict Algorithm Requirements"* provides a detailed account of the equations for each algorithm, with appropriate references to the literature, and how the algorithms inputs and outputs flow. This detailed text is also included in the Resource Centre of the on-line tool, broken down into six main sections. We found this to be an improvement over PVsyst help files, which do not always provide a seamless and clear explanation about how parameters are derived, and generally do not include equations. This is relevant to those skilled in the field, who need to understand the detailed modeling assumptions.

In general, the functionality and flow of the modeling algorithms in PlantPredict is similar to other software packages used in the industry, including PVsyst. The algorithms in the tools are generally based on models that are cited in published scientific literature. Leidos has completed a limited comparison of implemented modeling algorithms in PlantPredict versus PVsyst, including comparative tables and discussion of any areas of particular note; the results are summarized in the following pages.

<u>Irradiance Modeling</u>

Modeling of a system starts with the use of a time series weather dataset containing environmental conditions. Most often, this is accomplished using a one-year solar and weather input file (MET file) containing hourly data for the location of interest, which is meant to represent a year at a specific location. A time series dataset can also be formed of time steps less than one hour, and be representative of a period of time shorter or longer than a year. The physical orientation and layout of the PV modules in the Array are required to determine the amount of solar radiation reaching the module. Modeling algorithms are required to convert the global horizontal radiation from the input file into the net irradiance that reaches the modules. A detailed approach includes calculating how much light reaches the POA of the modules, both from the sky and through reflections from the ground. The following modeling algorithms accomplish these calculations.

Table 3
Comparison of Irradiance Modeling Algorithms

Modeling Algorithm	Inputs => Outputs	PlantPredict	PVsyst
Solar Position	Time => zenith and azimuth angle of sun, air mass	NREL's SPA [(1)] ± 0.0003°	Simplified expressions ± 0.05°
Air Mass	Zenith angle => air mass	Bird/Hulstrom or Kasten/Sandia	n/a
Beam Incidence Angle (from Array configuration)	Array orientation => collector angle for each hour	Fixed, seasonal tilt, or single-axis trackers (only N-S with 0 degree pitch angle).	Fixed, seasonal tilt or sunshields, and most types of tracking
Clear Sky Irradiance	Zenith, GHI => K_T	Bird & Hulstrom	Unclear
Decomposition Model	GHI, K_T => direct and diffuse	Erbs or Reindl or DIRINT	Erbs
Transposition Model	Anisotropic diffuse and reflected beam => POA	Hay & Davies or Perez	Hay & Davies or Perez
Option to Use Measured DNI or POA	n/a	DNI-Yes (POA anticipated in future)	No

(1) Solar Position Algorithm ("SPA").

Solar Position

Calculations for solar position are well understood and documented. PlantPredict has opted to employ higher accuracy equations, which may be particularly advantageous for sub-hourly calculations of the product.

Air Mass

Air mass is closely related to the solar position, and is used in PlantPredict for spectral correction modifiers implemented at later stages of the code. PlantPredict implements a detailed equation that is generally acknowledged to provide good accuracy, including correction due to barometric pressure.

Beam Incident Angle

This parameter is a geometric calculation between the sun position and the module orientation, undertaken at every timestamp. The calculation itself is straightforward and assumed to be equivalent to the models used in PVsyst. The type of Array configurations that can be calculated appears to be more limited in PlantPredict than PVsyst, but the tracker styles commonly employed in FSLR-designed plants are included. A single-axis tracker model is presently limited to 0° pitch (i.e., flat ground); FSLR expects to add sloped surfaces in future versions. Backtracking functionality is included as an option in all software.

Clear Sky Irradiance

Calculation of the extraterrestrial irradiance and clearness index are straightforward, though they can be defined differently, thus the documentation of the equations by PlantPredict is good practice.

Decomposition and Transposition Models

The conversion of global horizontal irradiance ("GHI") into POA requires a two-step process: decomposition of GHI into diffuse and direct normal irradiation ("DNI") components, followed by transposition of each component onto the plane of the modules. In general, the uncertainty of decomposition and transposition models can be significant to the overall modeling accuracy of a plant performance prediction, on the order of several percent, thus implementation of new models that can reduce this error are of interest. For the decomposition modeling, PlantPredict has opted to include two additional models not available in PVsyst: Reindl and DIRINT – which have been reported to provide improved performance in certain studies. For the transposition modeling, PlantPredict and PVsyst offer the same two choices: Hays/Davies and Perez. FSLR and Sandia published a detailed study in the "*Journal of Photovoltaics*" in 2015 (File #10) which tests the accuracy of a number of model choices against ground-measured irradiance, and which provides a good basis for their selection of any of the above, including their minor modification to the Reindl model. Presently, there is no industry consensus on which models are optimal.

Option to Use Measured DNI or POA Data Inputs

When the development of a project can access local ground-measured DNI and diffuse, its use in simulations avoids the need to use a decomposition model; furthermore, when local ground-measured POA is available, its direct use in simulations avoids the need of both the decomposition and transposition models. Since this circumvents modeling steps that are known to have an impactful modeling error, this approach may be preferred when the data is of a high quality. PVsyst modeling forces the use of GHI data and decomposition; though it is possible, with an added tool they provide, to use measured DNI and diffuse or POA to produce a GHI dataset for input (reverse decomposition), this clearly is an added and inconvenient step. Overall, with respect to the irradiance modeling algorithms, those implemented in PlantPredict appear to be reasonable, and to be equal to or improved upon PVsyst for accuracy and uncertainty in the modeling of the irradiance on the modules.

Effective Irradiance on PV Cell

The construction of the Array and its environment also has an influence on the irradiance reaching the front surface of the modules. The additional modeling algorithms of this section account for shadowing, soiling, incidence angle modifier ("IAM") and spectral correction.

Table 4
Comparison of Effective Irradiance on Cell Modeling Algorithms

Modeling Algorithm	Inputs => Outputs	PlantPredict	PVsyst
Horizon Shading	Description of horizon => shading loss factor	Far shading reduces beam component only	Far shading reduces beam and diffuse components
Near Shadings (Beam)	Array geometry, time => direct shading loss factor	Per timestamp simplified calculation	Detailed 3D scene, look-up table of shading factors
Near Shadings (Diffuse Sky and Ground Reflected)	Array geometry => diffuse shading loss factor	Single value	Single value
Incidence Angle Modifier	User input => decreased light on cell versus angle	ASHRAE (1) model, Sandia (2), or user tabular input	ASHRAE model or user tabular input
Albedo	User input => adjusts magnitude of reflected component	User input monthly values	User input monthly values
Spectral correction	User input => modifies light on cell	1 and 2 Parameter (PW, AM) (3) corrections options or user input monthly values	Not included directly
Soiling	User input => decreased light on cell	User input monthly values	User input monthly values

(1) American Society of Heating Refrigerating, and Air Conditioning Engineer ("ASHRAE").
(2) Sandia National Laboratories ("Sandia").
(3) Precipitable water and air mass ("PW, AM").

Horizon Shading

Losses due to far objects and geographic features (ridgelines, mountains, etc.) are treated as a loss factor that applies to the entire plant. Both PlantPredict and PVsyst adjust the beam portion of light in consideration of when the sun is behind the horizon, but PlantPredict calculates a fractional value between 0 and 1 for each timestamp based on the percentage of time the sun was below the horizon within that timestamp interval, whereas PVsyst does a single calculation at the middle of the hour and sets the loss factor to 0 or 1 for the whole hour. The PlantPredict approach will have a better accuracy on timescales of less than or equal to one hour, which is of relevance for comparisons of modeled versus operation data during plant monitoring, but it would be expected, over a full one-year simulation, that the difference will average out and have little impact on the yearly sums. A second difference is that PVsyst also considers the reduction of the horizon to the hemisphere of the diffuse sky dome – they use an isotropic sky model and develop a single correction factor applied for all hours throughout a year. The PVsyst approach is more precise, but for relatively flat sites, such as is typical for utility-scale plants, the horizon shading is typically minimal, and in which case diffuse horizon shading is negligible.

Near Shading (Beam)

Near shading represents losses due to nearby objects (including trees and buildings), and self-shading of one row on another, which require geometrical calculations for each hour or each sun position. But, complete, hour-by-hour calculations for different positions in the Array are computationally intensive, so certain approximations are generally used. The PlantPredict algorithm derivation considers a large Array and simplifies the scene into a two-dimensional geometry problem looking at rows from the side, and examines the shadow length in the direction perpendicular to rows. This assumes that the row-to-row shading is dominant over edge-effects including shadows by nearby objects; both of these assumptions are reasonable simplifications for large Arrays. The algorithm would be error-prone in other circumstances, such as smaller systems with many row ends and roof-mount systems. In contrast, PVsyst is capable of calculating shading of a complex three-dimensional ("3D") scene, and in fact, even for only row-to-row shading, but requires the description of the exact geometry of the PV field and its environment, in the

3D space or “global scene.” The default method in PVsyst is to precompute, using the 3D scene, as a shading factor table for 190 sun positions covering all possible sun angles, and during simulation to interpolate between this data.

Near Shading (Diffuse Sky)

Light from the diffuse sky dome that is blocked by other rows should be taken into account for an accurate evaluation, and is a relatively newer augmentation to plant modeling. Both tools consider, for this modeling, an isotropic sky model for these complex geometrical calculations, and both in the end determine a single diffuse shading factor (for the system, constant throughout the year).

Near Shading (Ground Reflected)

This factor is a further minor correction that considers that shadows on the ground will reduce the amount of light that is reflected up and onto the modules. In PVsyst, this is called “Shading Treatment of Albedo.” As per above, both tools determine a single correction factor for this.

Near Shading (All)

For both the diffuse sky and ground reflected corrections, the concepts of both tools are similar if not the same (documentation in both PlantPredict and PVsyst are complex and incomplete, making exact direct and full comparisons intractable) and are reasonable models that are expected to provide adjustments for typical systems that are reasonably accurate given their relatively small impact. There are two noted differences in the treatments of the three shading corrections:

1. PlantPredict includes the IAM factor (further explained below) in its calculations, but since the IAM losses are small, and the shading factors for most systems small to begin with, the high “accuracy” of the PlantPredict model will generally be of negligible consequence. There is a lack of validation data and scientific study to rule any one approach as more accurate.

2. In PlantPredict, the shading factor on the module is implemented as a linear geometric correction, while PVsyst can also be operated with inclusion of so called “electrical” effects whereby the string design of the module is taken into account (a single shaded cell in a string will reduce the output of the whole string in a non-linear manner, with details user adjustable). However, the latter is a complicating factor and Leidos’ common practice is to select the geometric factor calculation for shading.

Incidence Angle Modifier (IAM)

Plant Predict provides two modeling options in the same manner as PVsyst: an ASHRAE equation in which the user can adjust the b0 value, or user tabular input. In addition, PlantPredict also provides a modified version of the Sandia 5th order polynomial approximation, where the modification is a reasonable fix to the artificial (unphysical) dip of the polynomial at low angles. The variation in results between these models is generally small, and the industry has not yet demonstrated one model to be better than another, nor have the input parameters for any one model been studied conclusively.

Albedo

Describes the reflectivity of the ground and is a factor used in the calculation of magnitude of direct and diffuse light that is reflected onto the module surface. Both tools take in monthly user input values and use the factors in the same manner.

Spectral Correction

The spectral shift factor is representative of how much the performance of a PV system will vary from nameplate due to differences in outdoor spectrum from flash spectrum defined in the American Society for Testing and Materials (“ASTM”) Standard G173. The factor varies over time and can be positive (a gain) or negative (a loss), dependent on the actual solar spectrum at each instant in time, which in turn is dependent on the sun’s position and the constituents of the atmosphere at that time. It has been shown in several references, for example File (7), that the spectral correction factor of cadmium telluride ("CdTe") modules depends more strongly on precipitable water content in the atmosphere, of the order of -1 to +2 percent on an annualized basis for continental U.S. locations, while crystalline silicon modules have a spectral correction that is less significant and dependent instead on air mass, with values of the order of 0 to 1 percent. These values are annualized and dependent on the site's climate; instantaneous and monthly correction factors can be larger. In PVsyst, there is no direct means of correcting for spectral dependence, whereas in PlantPredict multiple correction algorithms are provided. Selecting the one-parameter model, PlantPredict automatically selects the Sandia one-parameter air mass correction model for silicon and the one-parameter precipitable water model for CdTe modules. The user can also choose a model that depends on both of these parameters, or input static monthly correction factors. It should be noted that the model coefficients must be defined in the module files for the calculations to function, unless you use the monthly values, but the selection of which model to use in a Prediction is at the project level, and thus will be universal to the entire project.

Leidos has separately provided a detailed review of FSLR's research and algorithms with respect to the above default algorithm for spectral shifts, and determined that "their method for adjusting PV facility production estimates for the varying spectral content of solar radiation and the different spectral response curves of crystalline silicon and CdTe solar modules is reasonable" and that use of these models "is likely to yield annual energy production estimates that are generally closer to field performance."

It is worth noting that FSLR has also developed a recommended approach for including spectral correction within PVsyst. The user first employs a standalone FSLR tool to produce monthly spectral correction factors, and then includes these factors into PVsyst soiling terms.

Soiling

Both tools implement soiling loss factors, which can be set at a fixed annual value or as monthly values. It should be noted that losses due to snow are accommodated in both PlantPredict and PVsyst within the monthly soiling term. No model for predicting snow losses is included in either. This approach may be sufficient for regions with little snow, but for climates that experience higher levels of snow, where there will be a combination of days with 100 percent loss due to snow with days without any loss, Leidos' approach is to separately calculate losses using daily weather records. We note that the industry has not reached any consensus on how to accurately model losses due to soiling or snow cover.

<u>DC System Modeling</u>

The DC portion of the electrical system is a series of modules connected into inverters. The performance is calculated using equipment specifications from module and inverter files, but with a small number of user inputs and software tool algorithms required to properly describe the complete system in the project location.

Table 5
Comparison of DC System Modeling Algorithms

Modeling Algorithm	Inputs => Outputs	PlantPredict	PVsyst
Module Temperature	Ambient temperature and POA => module surface temperature	Simple heat balance OR Hayes model	Simple heat balance
PV Module IV Curve	Module specifications => IV curve	1-diode model	1-diode model
Mismatch, Module Quality, and LID (1)	Loss factor applied to DC field	User set	User set
DC Wiring	Effective resistance of DC Array => DC losses	Percentage losses	Ohmic or percentage losses
Degradation Model	User selected degradation rate	Multiple model options	Not included

(1) Light Induced Degradation ("LID").

Module Temperature

PlantPredict and PVsyst provide a model called the simple energy balance model, which undertakes a linear adjustment of cell temperature dependent on incoming irradiance and thermal loss factor. It is a static model if the wind-dependent convective coefficient is set to zero, as is often done. For the constant thermal loss factor, PVsyst defaults are 29.0, while FSLR studies recommend using values of 30.7 for their FSLR CdTe modules and 29.0 for silicon modules. We do note that FSLR modules have a glass backing, which has a higher insulating value than the plastic film backings more common in silicon modules. PlantPredict further offers the choice of using the Sandia model.

Module Diode Model

Both tools use a one-diode model with temperature correction, with most inputs coming from the module specifications. A detailed review of the algorithms' equations and the exact implementation of each of the many parameters is beyond the scope of this study, but are assumed to be effectively similar.

Module Quality, LID, Mismatch, DC Wiring

These user defined loss factors appear to be implemented identically in both tools. In PlantPredict they must be defined within the DC Field – and can thus vary across multiple Arrays – whereas in PVsyst they are system-wide settings. It can be noted, that PVsyst also provides tools for the user to help calculate suitable inputs for module mismatch and DC wiring from more comprehensive analyses.

Degradation

PVsyst does not include any long-term degradation ("LTD") calculations, thus users have to do post-processing outside of PVsyst to study plant performance over life. PlantPredict provides several reasonable modeling options for module degradation: DC linear, AC linear and AC stepped. The DC linear is likely the most commonly used in the industry, (though none have been proven in the industry to be superior to another at present). LTD is an important effect to include in the evaluation of plant performance over life and thus is a useful addition to have integrated into the tool.

AC System Modeling and Plant Performance

The output from the DC Arrays is fed into inverters, which are then connected to two or more stages of AC transformers and AC lines prior to the plant energy meter.

Table 6
Comparison of AC System Modeling Algorithms

Modeling Algorithm	Inputs => Outputs	PlantPredict	PVsyst
Inverter Set Point	Inverter specs or user => maximum AC output per inverter	Set as the "power factor" in inverter	Not adjustable, except by changing OND file
Transformer and AC Losses	User input	Multiple pieces of equipment	Partial, restrictive model
Auxiliary Loads	User input	W	W
Availability	User input	Not included	Percent loss

Inverter Set Point

In the field, inverters are commonly software limited for a set maximum AC output power, below their maximum potential output power. In operation, if power available from the PV array is higher than this set point, the inverter moves the string off its maximum power point by adjusting the DC voltage either higher or lower. PVsyst will operate an inverter at the rating interpreted from the inverter description file ("OND" file); to implement a software limit this file must be edited. PlantPredict includes an inverter software limit directly within the tool.

Transformer and AC Losses

PVsyst can model the losses of a single transformer and of one segment of AC lines – this is insufficient for most large and utility-scale projects, and Leidos has developed its own post-PVsyst processing tool to model this part of a facility. PlantPredict has included loss algorithms for AC components that seem appropriate, and generally parallels Leidos' common practices. At the Array level, there are modeling algorithms for one transformer and one segment of AC line losses (as a percentage value). There is also the option for the user to include additional (multiple) transformers and transmission line lengths at the plant level.

Auxiliary Losses

At the Array level, PlantPredict allows the user to enter two kinds of auxiliary losses: data acquisition systems and shelter cooling losses, in units of Watts of power consumption. For the latter, we believe it would be more appropriate, for some projects, to allow for monthly values of heating/cooling loads, as they vary strongly throughout the year in some climates.

Availability

The version of PlantPredict we reviewed did not provide an opportunity to include losses due to estimated plant downtime, whereas PVsyst does. FSLR has indicated that they have added this feature upon our request in a later release, but our review was not inclusive of this feature. Since lack of availability is, by nature, unpredictable some industry participants prefer to manage it outside of a performance model (e.g., in post-processing or in a financial analysis).

Summary of the Review of Algorithms

FSLR has predominantly followed common industry practices in their implementation. In many instances, they provide the user with more model choices than are currently available in PVsyst. The added choices have been from either their own published and peer-reviewed work or from institutions such as NREL and Sandia. There are five notable additional capabilities that are not present in PVsyst and that can be useful to users:

- Spectral correction models;
- Ability to include multiple AC transformers and line segments;
- Degradation over life;

- The capability to model at time steps shorter than one hour and different periods than one year; and
- The capability to describe the plant hierarchically similarly to how it is actually built, with no apparent limit to the number of different Blocks, Arrays, Inverters, or DC Fields.

Other areas where added modeling choice is provided include: ability to use DNI input; more choices for decomposition models, IAM, module temperature and soiling; and adjustable inverter set point.

There are a few notable places where the algorithms are different than PVsyst and the changes appear justified because PlantPredict is developed specifically for simulation of utility-scale systems. In particular, the options for tracker configurations are more limited in PlantPredict, and the shading calculations are undertaken with the assumption of large arrays where edge effects are minimal.

In terms of the clarity of the algorithms implementation, FSLR has provided us with a detailed 81-page document, File (A), which describes in substantial detail the sequential flow of algorithms that are employed. The document is reasonably thorough and can be generally understood by experienced personnel. In contrast, we are not aware of such a document for PVsyst, and its help files are inconsistent with providing the sequential set of equations used in the algorithms, resulting in less clarity.

In summary, the selection of the algorithms in PlantPredict is reasonable and it is expected to enable one skilled in the modeling of solar plants to produce a plant performance model that has an uncertainty similar to that when such modeling is undertaken in other established tools.

<u>Overall Strategy for Case Studies</u>

It is important to consider that a modeling tool which has many user-adjustable inputs can easily be manipulated to provide good agreement of a single valued output (such as yearly energy production) with another source. A key aspect of our critical analysis was to assess not just: (1) gross agreement of annual production estimates, but also (2) the use of reasonable and equivalent inputs to the modeling; (3) agreement of intermediate modeling outputs; and (4) agreement over a range of operating conditions. In the following sections, at least two of these conditions are confirmed within any particular case study, and all conditions are confirmed across the collection of case studies.

<u>Review of Case Studies Done by FSLR</u>

FSLR: PlantPredict versus PVsyst

FSLR has completed a benchmarking exercise of PlantPredict against PVsyst simulations for a larger collection of projects, including 51 FSLR projects using CdTe modules and 12 projects using Si modules. FSLR provided a summary table of these studies, which listed the following key characteristics: the general climate and location, whether the project had tracking or fixed mounting, the inverter brand and size, the module type, the nameplate megawatts ("MW")-AC and MW-DC rating, the version of PVsyst that was used in the simulation, the PlantPredict estimated energy production, and the percent difference in predictions between the two software tools. We can confirm these 63 projects include a good variety across each characteristic, within what is reasonable for utility-scale projects. We can further confirm that there are no discernable trends against any one characteristic, including in particular CdTe and Si modules. The statistics when including all 63 project simulations results together indicate that PlantPredict estimated 0.02 percent higher than PVsyst, with a standard deviation of 0.46 percent; overall PlantPredict estimates ranged between -1.6 percent and +0.9 percent compared to PVsyst. We note that these statistics are slightly different than values published in File (1) for the same 51 CdTe projects; FSLR reports that the minor differences relate to the use of an earlier version of PlantPredict in that publication.

It should be noted that a direct "apples-to-apples" comparison between PlantPredict and PVsyst is challenged by the fact that PVsyst does not allow for implementation of detailed dual-stage transformer AC system and various auxiliary losses, such as tracker motors and data acquisition losses ("AC Losses"). This missing ability has led both First Solar and Leidos to develop proprietary post-processing methods based on the hourly output files from PVsyst.

To further evaluate the above benchmark study, including the post-processing step that was employed by FSLR, Leidos selected two FSLR projects from the list to examine in more detail. We did not undertake an exhaustive review of their post-processing calculations, but we did review the modeling inputs and outputs from files provided by FSLR.

When examining the detailed outputs, we found that there were minor differences in certain calculated output losses, but these were of a magnitude of less than 0.5 percent and could often be traced back to minor differences in the input values. Overall, from this review, it should be emphasized that the intermediate outputs contained in the detailed system losses were in good agreement between the two tools, as follows:

- The agreement was excellent (less than 0.1 percent difference), when the algorithms employed should be identical: transposition on POA, module temperature loss, module quality loss, module mismatch loss, DC wiring loss, inverter efficiency loss, and inverter limitation loss;
- The agreement was strong (less than 0.3 percent difference), and within reason, given the small but reasonable differences in the algorithms of the two tools (Near Shading Loss, IAM Factor Loss);
- The agreement was sufficient (0.26 and 0.30 percent difference) for Module Irradiance Losses and Spectral Loss, and;
- The modeling of the AC Losses was the most difficult to compare directly, and we could not necessarily discern the reason for the differences in inputs or outputs when they did occur, which relates to FSLR's selection of inputs in each model and their post-processing tool for use with PVsyst (which we did not review). The agreement was reasonable, but not zero, and we observe a net difference for AC Loss between the two modeling of 0.55 and 0.87 percent, respectively for the two projects.

The net result of FSLR's comparison for these two projects, as reported in their benchmarking exercise summary list, were predicted production differences of +0.45 percent and +0.17 percent, and we can confirm that the files we reviewed indicated net differences of +0.44 percent and +0.14 percent (with PlantPredict yielding the higher values in all cases). These numbers are the same to within the expected margin of error. Leidos also considered an alternate approach to adding a net post-process AC Loss to the PVsyst values, by applying PlantPredict's net AC Losses directly to the PVsyst inverter output value, which we believe could potentially be closer to an apples-to-apples comparison. We found slightly different values of predicted output, resulting in differences of +0.9 percent and +0.64 percent.

In all the cases examined here, the statistical differences between the two software tools are smaller than the generally expected uncertainty for PV simulations in comparison to actual performance.

FSLR: PlantPredict versus Operational Data

FSLR has published several papers that summarize analysis of the agreement between PlantPredict and operating data; in particular, File (3) provides a detailed comparison of PlantPredict to operational data for one plant in the U.S. southwest with approximately 15 months of plant operation, and File (B) is an extensive FSLR document which provides a similar detailed study for a selection of 21 operational plants. File (3) analyses the statistical agreement of the hourly values of the one plant, while File (B) studies the statistical agreement of annual values of all of the plants. For both, the studies examine intermediate modeling outputs of POA, module temperature, inverter DC voltage, current and power, inverter efficiency, inverter AC output, and plant metered output. File (3) also contains a simple compilation of the final outputs of similar comparisons for a fleet of 54 PV systems, including systems that have an average operational life of five years, including four systems with lifespans of nine years.

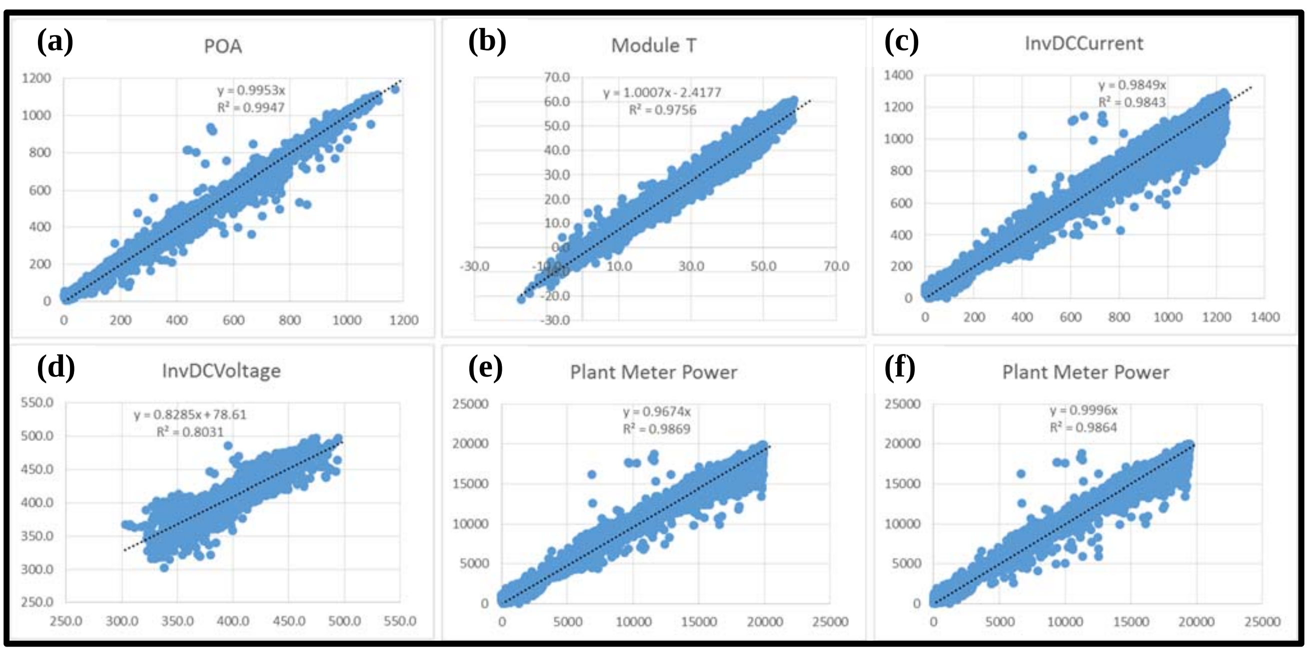
In File (3), all figures show a mean bias difference (over/under prediction) within 2 percent and a low root mean squared error ("RMSE") less than 5 percent (the scatter of all hourly results relative to the mean). In File (B), the annual plant production estimates showed a mean difference of 0.1 percent over operational results, with a standard deviation of 2.0 percent, and the maximum disagreement of 4 percent occurred for the oldest (2009) plant. Thus, it appears that PlantPredict is able to closely match measured operational data, over a wide range of operating conditions, for both intermediate outputs and final plant energy production estimates. File (B) includes discussion by FSLR on where differences have minor trends, relating to season, system age and climate. Leidos has not attempted to review in detail each of these 21 simulation comparisons, and thus we cannot confirm these statistics, but instead we reviewed the methodology undertaken and examined two case studies to confirm that our observations are in keeping with their more detailed and extensive work.

Detailed descriptions of the methodologies, in particular the filtering methodology, employed by FSLR in the above benchmarking exercise are contained in File (B). These methodologies are generally in keeping with the principals employed in scientific literature, in combination with some unique but reasonable filtering stages relating to the data streams available from their plants. It can be noted that some filtering criteria are not very aggressive, i.e., most data would pass, which could cause scatter in the comparison, yet the graphs in Files (3) that include all data points (e.g., measured versus predicted) have very low RMSE values, and no major outlier data appears, indicating the filtering has been sufficient and modeling and operational data are generally agreeing well.

Leidos completed a brief analysis of simulation results for two of the projects in the above benchmarking exercise. In our analysis of two case studies, a detailed review of the modeling inputs was not undertaken, but it is noted that modeling inputs are listed in File (B) Page 29 and stated as following FSLR guidance, and understood to be the same for all simulations.

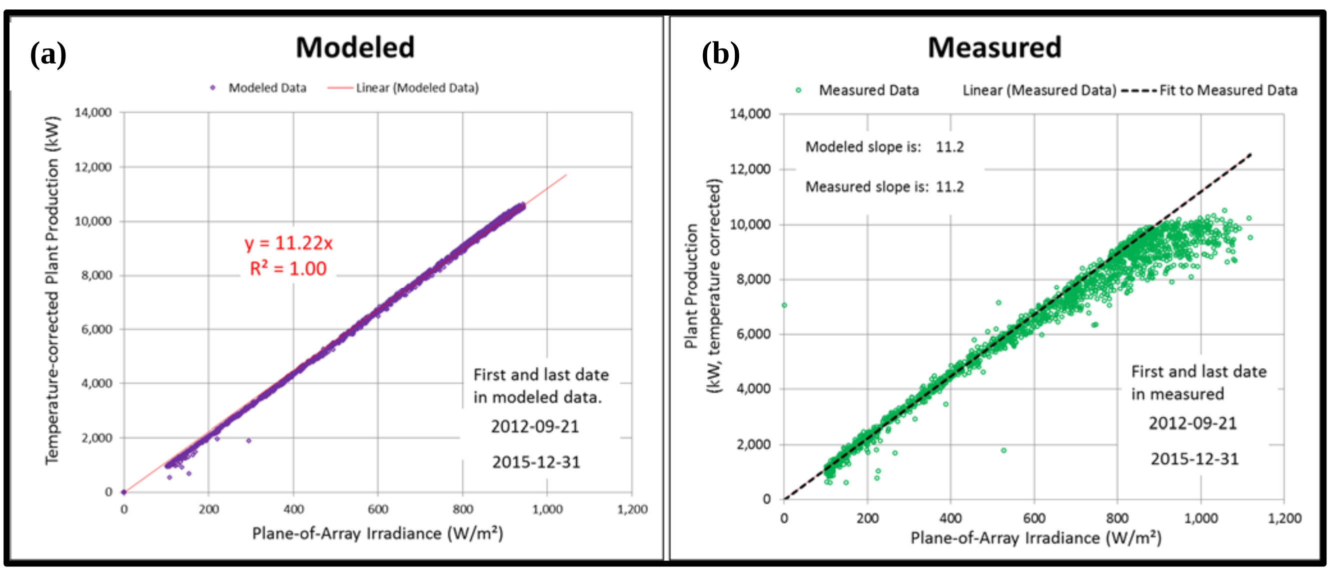
For the first project we examined the general agreement of the intermediate hourly outputs by creating scatter plots of predicted versus measured. In this exercise, the data is filtered using FSLR flags pertaining to their above-mentioned filtering methods, which were included in the files received. Figure 1, shows that, for a subset of five of the intermediate outputs, as well as the final plant energy, there is good agreement, with R squared fit metrics of 0.97 or better. The only noted exception was inverter voltage. The offset of -2.4 degrees for module temperature is because the operational sensor measures back-of-module temperature, which is expected to have a small offset from the cell temperature value calculated by the software. There are approximately 10,000 valid data points in each graph, spanning a period of three years. The slope fit of the final plant production estimate in this case study, in Figure 1 (f), is 0.9996, indicating agreement between PlantPredict and operational data to within 0.1 percent.

Figure 1
PlantPredict versus Measured Operational Data: First Solar Measured versus PlantPredict Values for Six Select Intermediate Hourly Outputs, (a)-(e), and the Net Hourly Plant Meter Output (f) from Three Years of Data at One Project



As a second approach to confirming agreement, and with a second project, we have imported data from FSLR files into a Leidos analysis tool. In particular, the complete set of hourly values for POA, module temperature and plant energy from both PlantPredict and operational data were used. The method for comparing performance models to match measured data is based on the ASTM Standard E2848-13, titled *"Standard Test Method for Reporting Photovoltaic Non-Concentrator System Performance"* ("E2848"), which fits temperature-corrected plant performance as a linear function of the POA irradiance. The analysis involves employing the methodology of E2848 on both the data from a model of plant performance and on field measurements, and then comparing the results. In order to remove extraneous data before calculating plant performance, inappropriate data is filtered out. First, the data was filtered for periods when the POA irradiance exceeded 100 Watts per meter squared ("W/m²") and when the plant operation was less stable (i.e., when output was changing at a rate in excess of 5 percent of plant nameplate per time-step, presumably because of changing insolation, but also possibly due to operator interventions). Similarly, periods when the plant was operating within 5 percent of its maximum AC capacity were filtered out, when one or more inverters may be clipping. Figure 2(a) displays the PlantPredict modeled data after filtering, and with a linear fit (red line). Figure 2(b) similarly displays the operational data, including a linear fit in the region without clipping (black line), which shows excellent agreement with the red line linear fit of the modeled data. The operational data does seem to indicate some occasional or partial clipping, curtailment or other phenomenon at plant output levels up to 30 percent below capacity, but which related to operational conditions which have not been filtered out in this analysis. Subjective analysis of the best fit slope to the linear portion of the operational data seems to indicate slopes of 11.2 ± 0.1 are a reasonable fit, which equates to 0.0 ± 0.9 percent agreement between modeling and operational results.

Figure 2
PlantPredict versus Measured Operational Data: Leidos (a) PlantPredict Hourly Modeling Estimates and (b) Hourly Operating Data for a Fixed-Tilt Plant Against POA Values, both Temperature Corrected and Filtered



We conclude from our analysis of these two case studies that PlantPredict, along with the modeling inputs recommended by FSLR, has provided strong agreement between predicted production estimates and operating plants.

<u>Independent Case Study</u>

We have performed an independent assessment of PlantPredict by utilizing it to simulate a non-FSLR plant. The results of the PlantPredict production estimates were compared to both operational data and production estimates generated by PVsyst.

Plant Description

The facility considered is a single-axis tracking system in California with polycrystalline silicon modules. The general parameters of the system are described below in Table 7.

Table 7
Description of the Operation Facility

Parameter	Description
AC Capacity (MW-AC)	14.4
DC Capacity (MC-DC)	20.42
Configuration	Single-Axis Tracker
Azimuth	South
Location	Southern California

The system was modeled using 800 kilowatt (“kW”) inverters and a combination of 300 W and 305 W polycrystalline silicon modules as found at the facility. The exact details of the plant and configuration are proprietary and therefore will not be discussed. All models are representative of the facility and are consistent with each other.

Operational data for the facility from January 1 to December 31, 2015 were used for analysis. The data included facility power, POA, module temperature, cell temperature and per inverter power on and a 15-minute timescale.

Solar Resource

We used subscription-based “SolarAnywhere” data from the satellite data firm, Clean Power Research (“CPR”). CPR provides hourly meteorological data from 1998 to the present for a grid of 10 kilometers (“km”) by 10 km pixels within the continental U.S. and Hawaii. CPR data is based on algorithms for processing satellite data as developed by Dr. Richard Perez of the State University of New York, at Albany. Data from the CPR tile containing the location of the Facility was downloaded. The models were run using one-hour time-series data from January 1 to December 15, 2015.

Models and Process Description

The inputs for the models in PlantPredict and PVsyst were developed to be as identical as possible given the limitations of each tool. For PlantPredict and PVsyst, the same inverter and modules were imported and used in the simulation.

Modeling assumptions followed those we typically use and others specific to the site as discussed below.

The facility site has a low horizon. Our estimate of horizon shading is based on the horizon profile developed from Google Earth™. The horizon profile was imported into PVsyst with the same points manually input into PlantPredict on the ‘Parameters’ tab in the Environmental Conditions section. Near shading losses are based on a row-to-row spacing of 5.87 meters (“m”) used in both models.

Module quality losses were calculated to include the effects of binning, module quality losses, LID, imperfect maximum power point tracking, and the first year of degradation. Module mismatch losses resulting from installation activities were also considered. Monthly soiling losses were considered in the models, based on the conditions specific to the facility.

Other loss factors, including DC line losses, AC line losses, and transformer losses were based on information provided on the design of the facility. PlantPredict has the ability to input losses for medium voltage transformers and the main transformer separately and the losses were input as such. PVsyst does not provide the ability for multiple stages for transformers, therefore, in the PVsyst model, we combined the expected transformer losses into one effective transformer.

Auxiliary losses, including the data acquisition system, heating/cooling and tracker motor losses were not included in either model, because the ability to input them are not consistent between PlantPredict and PVsyst. Availability losses were also not included.

A summary of the inputs relating to annual losses is shown in Table 8.

Table 8
Input Annual Loss Factors

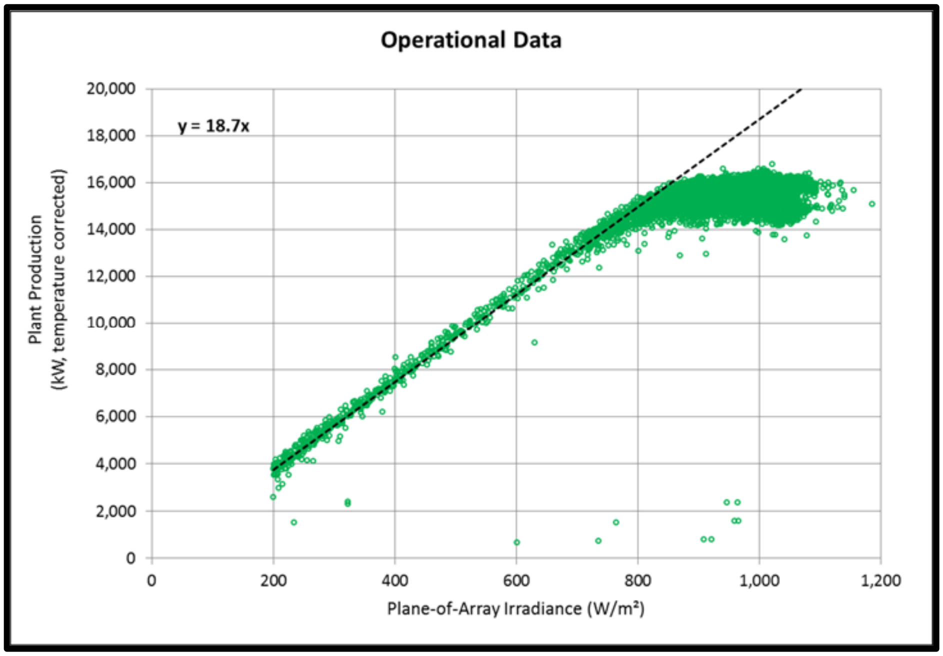
Factor	Loss Percentage
Soiling	3.6
Module Quality Loss (Not Including MPPT)	-0.15
LID Loss	1.5
Module Mismatch	0.5
DC Wiring	1.36
AC Wiring and Daytime Transformer Losses	0.38
Medium-Voltage Transformer No Load Losses	0.2
Medium-Voltage Transformer Full Load Losses	1.0
Main Transformer No Load Losses	0.1
Main Transformer Full Load Losses	0.5

(1) Maximum power point tracking (“MPPT”).

Analysis

Figure 3 displays the production of the Facility versus POA, corrected for module temperature. The black dotted line with a slope of 18.7 represents a line of best fit through the data when the POA is under 800 W/m². Above approximately 800 W/m² clipping of the facility output is common.

Figure 3
Operational Data for Model Plant
Operational Data for Calendar Year 2015 with a Linear Fit to the Region Without Clipping Effects



Figures 4 and 5 are plots of the hourly estimated production of the facility versus hourly POA, corrected for module temperature, for PlantPredict and PVsyst, respectively. Once again the black dotted line represents the line of best fit through the data when POA is below 800 W/m². For both PlantPredict and PVsyst, the slope of the line is 17.8, and it can also be noted that both simulated datasets exhibit the same shape as the operational data, which is indicative of clipping. These observations indicate very good agreement over a wide range of operating conditions between PlantPredict, PVsyst and operational data. The difference in the slopes between the estimates from both simulation tools and the operational data is 3.7 percent (slopes of 17.8 versus 18.5) which indicates that one or more modeling inputs were chosen too conservatively in both simulations. Possible user-selectable parameters that have a linear impact include module quality (which may also include LID and first year degradation), module mismatch, and soiling. Leidos' practice would be to "tune" the models by increasing module quality until the slope of the modeled matched that of the measured. It appears that the same tuning procedure could be undertaken with both PlantPredict and PVsyst.

Figure 4
PlantPredict Predictions for Model Plant
PlantPredict Estimated Hourly Power Production using CPR 2015 Solar Resource

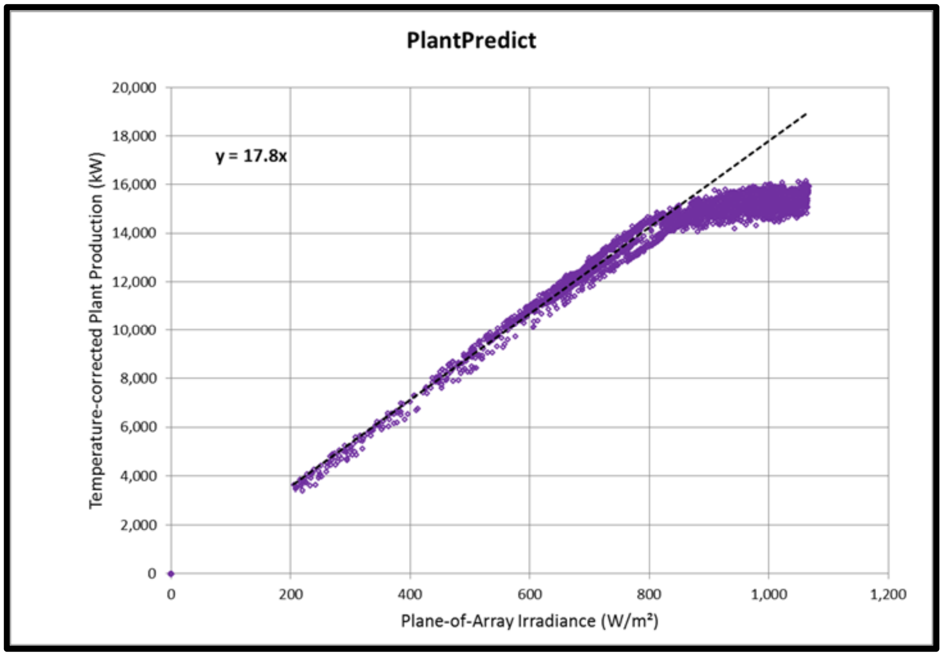
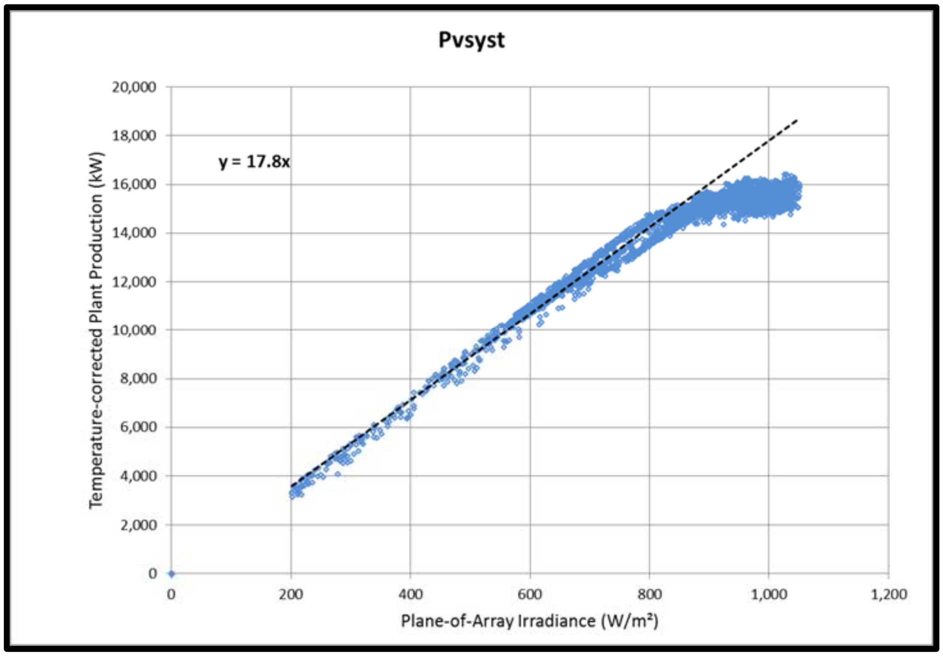


Figure 5
PVsyst Predictions for Model Plant
PVsyst Estimated Hourly Power Production using CPR 2015 Solar Resource



As a final comparison, Figure 6 provides a plot of the difference in the hourly production estimates between PlantPredict and PVsyst over the course of an entire year, filtered for POA values larger than 200 W/m^2. The data clearly shows a very low difference, and the linear regression fit to the data is a horizontal line at a value of zero. Similarly, the statistical analysis, contained in Table 9, exhibits good agreement. The relative mean bias difference error indicates that, on average, PlantPredict produced values 0.7 percent higher than PVsyst in this case study; this parameter is in line with the levels of agreement for annual energy predictions in the earlier discussed case studies. The relative root mean square error is an indication of the scatter in the agreement when examining it on an hourly basis, and the value of 4.3 percent is a small value, indicating strong agreement at any timescale.

Figure 6

**PlantPredict versus PVsyst Predictions for Model Plant
Difference Between PlantPredict and PVsyst Estimated Hourly Power Production using CPR 2015 Solar Resource**

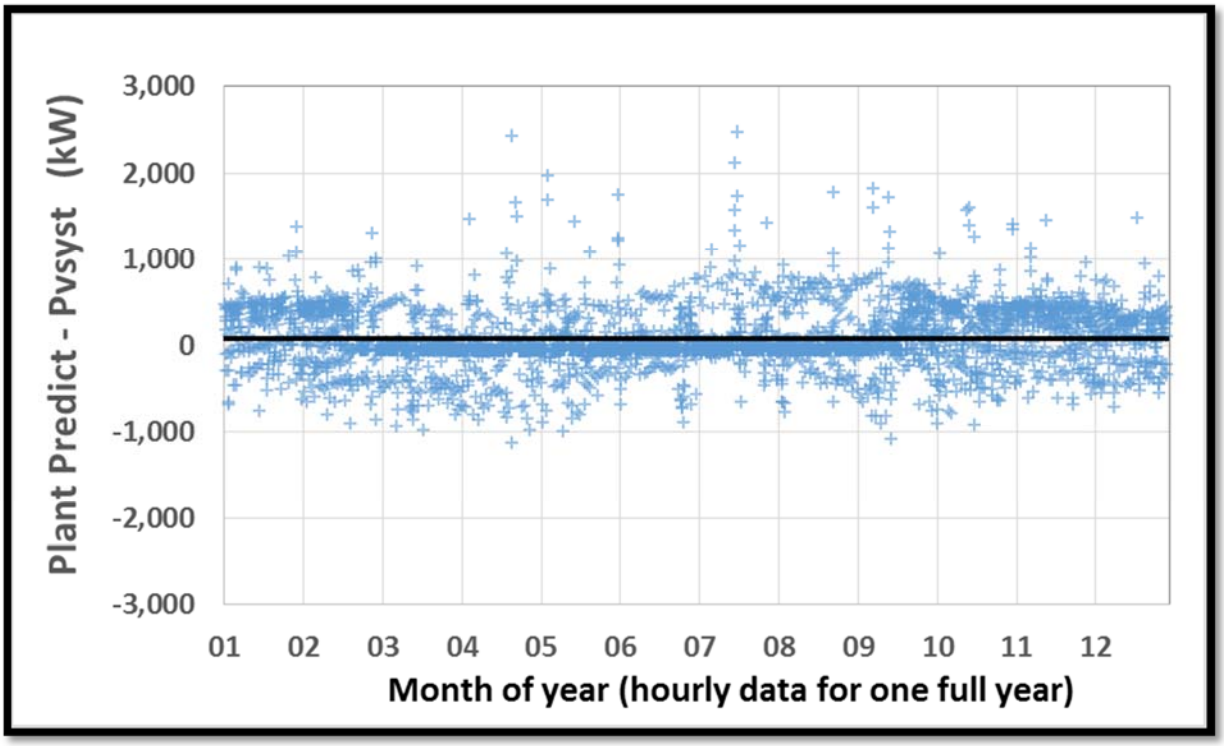


Table 9
Statistical Agreement between PlantPredict and PVsyst for a Model Plant (filtered for POA values greater than 200 W/m^2)

Parameter	Value	Units
Mean Bias Error	71	kW
Relative Mean Bias Error	0.7	percent
Root Mean Squared Error	346	kW
Relative Root Mean Squared Error	4.3	percent

Summary of Review of Case Studies

We have reviewed multiple case studies of PlantPredict versus PVsyst, and PlantPredict versus operational data, and in all cases, for both intermediate values and final yearly energy results, found a high degree of agreement between the two tools, as would be anticipated given that they are built using nearly the same modeling algorithms. The agreement between PlantPredict and operational data was found to be within the typical uncertainty of any PV plant simulation. In all cases, no bias or error in calculation was found. Table 10 provides a brief summary of this work.

Table 10
Summary of Analysis Results of Case Studies

Study	Number of Projects	Result	Notes
FSLR Benchmarking Exercise versus PVsyst	63	Average difference of 0.02 percent with standard deviation of 0.46 percent	Covered a broad range of site climates, CdTe and Si modules, fixed and tracking systems
FSLR Case Studies PlantPredict versus PVsyst	2	Both case studies had differences of < 1 percent	Agreement of intermediate outputs was also confirmed
FSLR Case Studies PlantPredict versus Operating Data	2	Both case studies had differences of < 0.1 percent	Agreement of intermediate outputs was also confirmed, with data covered multiple years of operation.
Leidos Case Study PlantPredict versus PVsyst	1	Average difference of 0.7 percent	Excellent hourly agreement also confirmed.

Summary

The structure and the implementation in PlantPredict are in keeping with common industry practice. For the most part, the modeling algorithms include the same selections as in PVsyst, but also include several alternative models. New augmentations are provided, including algorithms for spectral correction and multi-stage AC equipment descriptions; these may provide advantages in ease of use and modeling accuracy. Two differences that exist are (1) tracker configuration and shading calculations in Plant Predict are limited to modeling relevant to utility-scale projects, and (2) PlantPredict is able to calculate on time steps of less than one hour and for time periods of other than one year, which may be an advantage for plant performance tracking.

FSLR has undertaken an extensive campaign to review PlantPredict simulations against both PVsyst and operational data and has found a high degree of agreement in those studies. Leidos has not attempted to repeat or validate all values in those works, but has reviewed the methodologies employed and has conducted spot analyses of a few of the simulation files, and find that the methodologies employed are reasonable, and sample calculations are in keeping with the overall conclusions.

Leidos has also undertaken an independent modeling of one plant with silicon modules, and found that the PlantPredict and PVsyst simulations produced nearly identical performance estimates, and that both simulations were in keeping with the plant's measured operational data.

In summary, PlantPredict appears to be well-constructed for the use of simulations and energy production estimates of utility-scale PV plants, and appears to be able to provide a modeling accuracy equivalent to other commonly used industry software tools for utility-scale projects; in certain cases where spectral correction is required, the modeling accuracy of PlantPredict may surpass other tools.

Questions regarding this Letter Report can be addressed to Joan Haysom at 613-683-3298 or via e-mail at haysomj@leidos.ca.

Respectfully submitted,

LEIDOS ENGINEERING, LLC