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PV Systems Optimization Through Improvements in Laboratory and Field Characterization, Modeling, and Analysis

Charles Hanley

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Sandia National Laboratories

Relevance/Objective

- FY06 AOP: "develop, validate and apply new testing procedures based on energy production to optimize the performance of multiple components in fully integrated PV systems, providing the basis for system performance modeling and testing standards.
- MYPP milestone links:
  - Determine PV configurations for government procurements and hardware certification programs (2008)
  - Extend Solar Advisor Model (SAM) capabilities as a predictive energy model (2009)
  - Demonstrate factory-integrated residential and commercial PV systems (2011)
- Links to other program areas:
  - Inverter and balance-of-system development
  - Module and array manufacturing and reliability studies
  - Systems analysis, including baselines and tracking of TPPs in SAI
  - SAI testing, evaluation, and technical support

Overview of PV Systems Optimization Laboratory (PVSOL)

Controlled side-by-side array and system characterization

- *Energy production comparison versus module design*
- *Inverter in-situ performance testing*
- *Soiling effects for different glasses and coatings*

Comprehensive Data Acquisition Systems

- *All ac and dc data*
- *Meteorological data*
- *Continuous archive*
- *Protocols for others*

Inverters, combiners, disconnects – all reconfigurable

Part of the PVSOL Module Setup

Budget History

SNL Project Areas:	FY06 ($k)	FY07 ($k)
Inverter/BOS Development, Manufacturing R&D, and Testing	380	1000
System Performance Optimization, Modeling, and Benchmarking	835	850
Module, Array, and System Manufacturing, Reliability, Test and Evaluation	300	1500

This materials in this presentation are covered in the line highlighted in yellow above.

Summary of Activities/ Accomplishments

1. Draft system test protocol completed for use in SAI evaluations
2. Empirical inverter model completed
3. Complete system performance model updated for inclusion in SAM
4. Further characterization of new products in partnership with U.S. industry leaders.

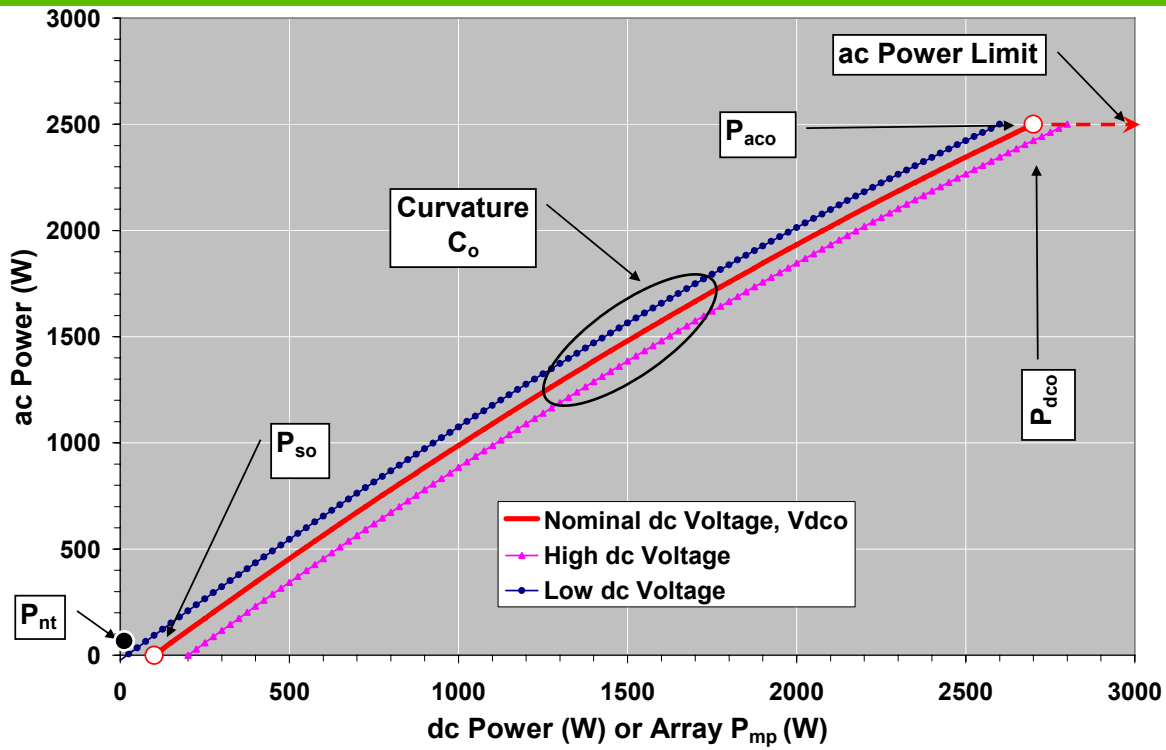
Table 1. Some of SNL's PV Systems Partners

Advent Solar	Powerlight	Sun Edison
BP Solar	Sanyo	SunPower
CSG Solar	Sharp	SunWize
Evergreen Solar	SMUD	Tucson Electric
PV Powered	Solectria	Xantrex

1. System Test Protocol

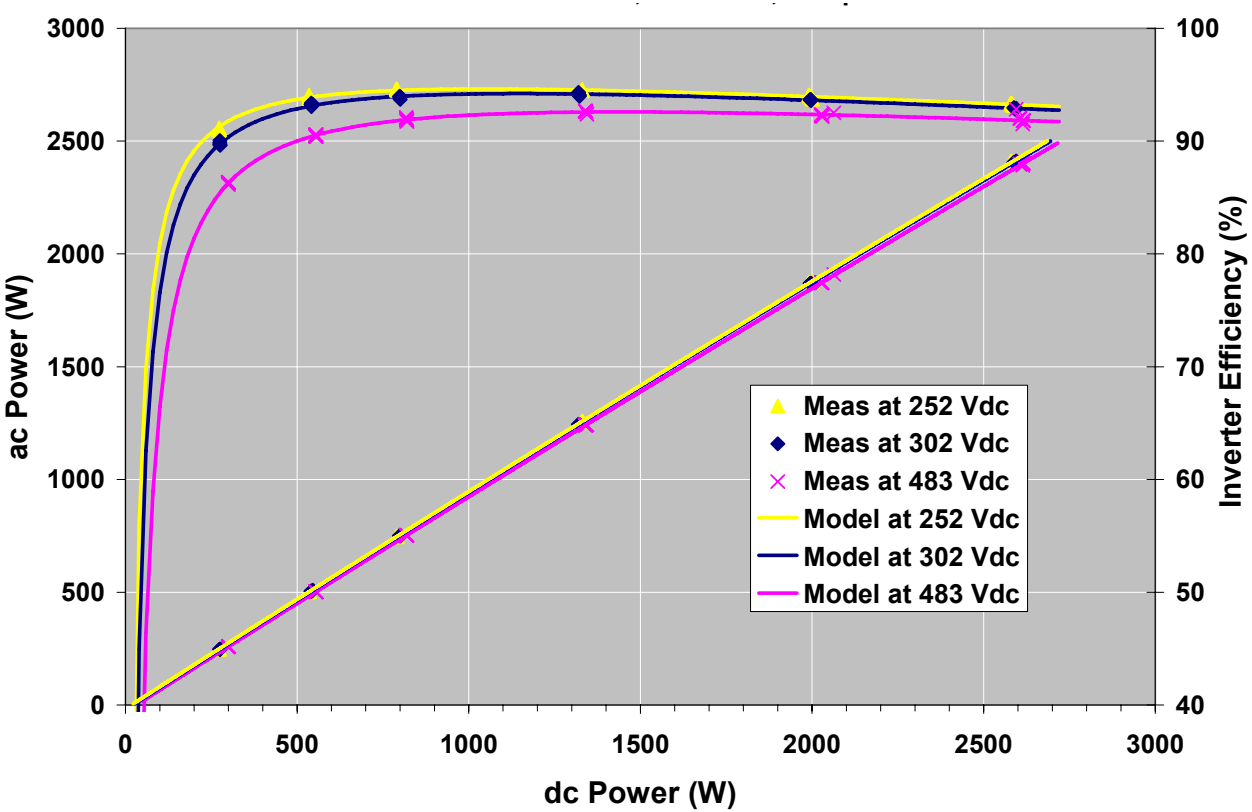
- Developed in partnership with USDA/Rural Utility Service
- Documented and structured approach for components and systems
- Support SAI objectives and activities
  - Establishing technology baselines
  - Tracking program progress
  - Stage gate evaluations
- Current Status: undergoing review by RUS; under revision by inter-lab Test & Evaluation team.

2. Inverter Model Parameters



- Model determines AC power based on DC power and DC voltage inputs
- Employs up to 8 parameters, depending on information available
  - 5 parameters shown in figure above, others are empirical coefficients
  - Defaults come from manufacturers' specification sheets
  - Current CEC inverter tests/database provide all parameters for model

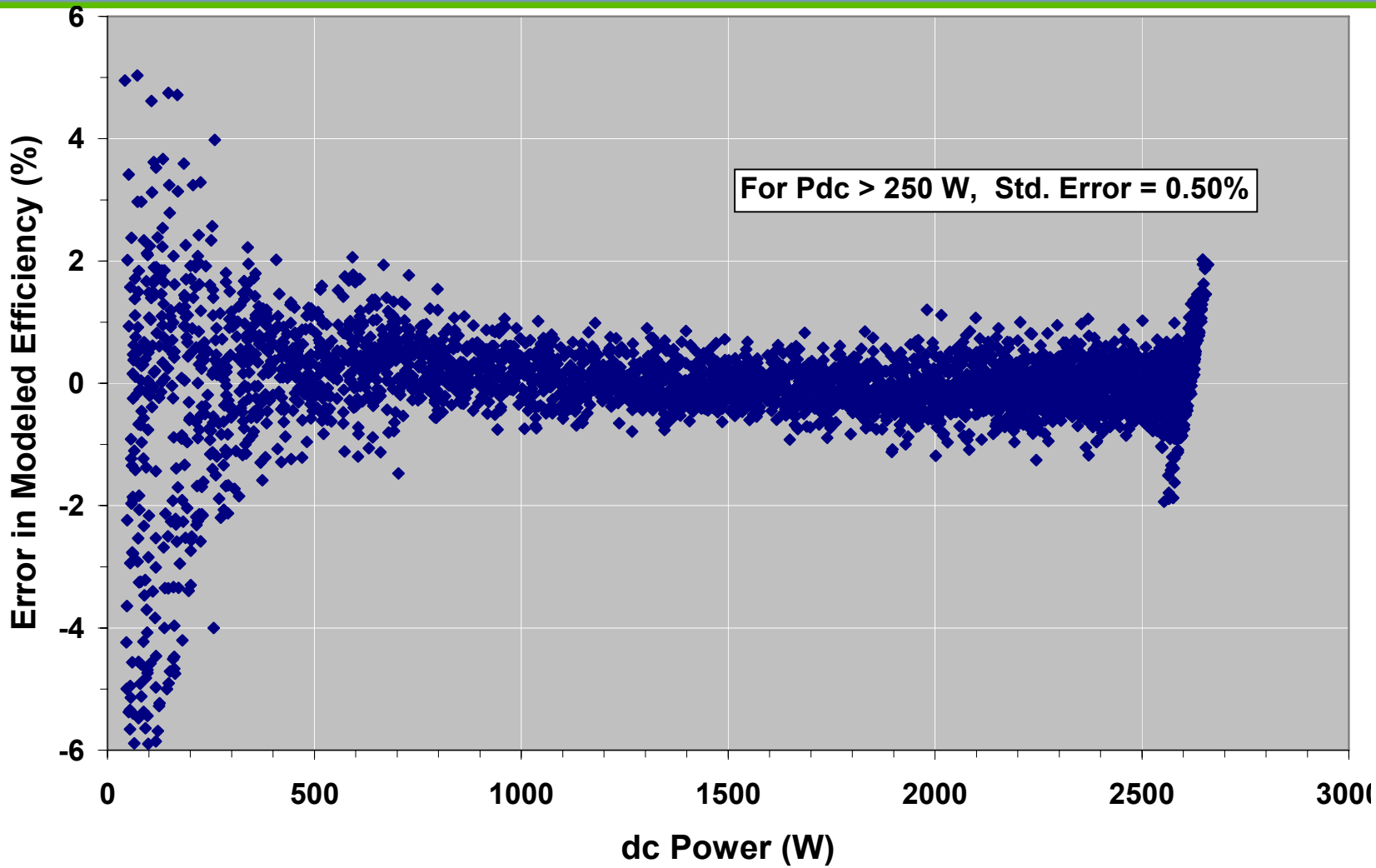
Inverter model maps output across full range of inputs



Comparison of Sandia inverter performance model (lines) and CEC measurements (dots).

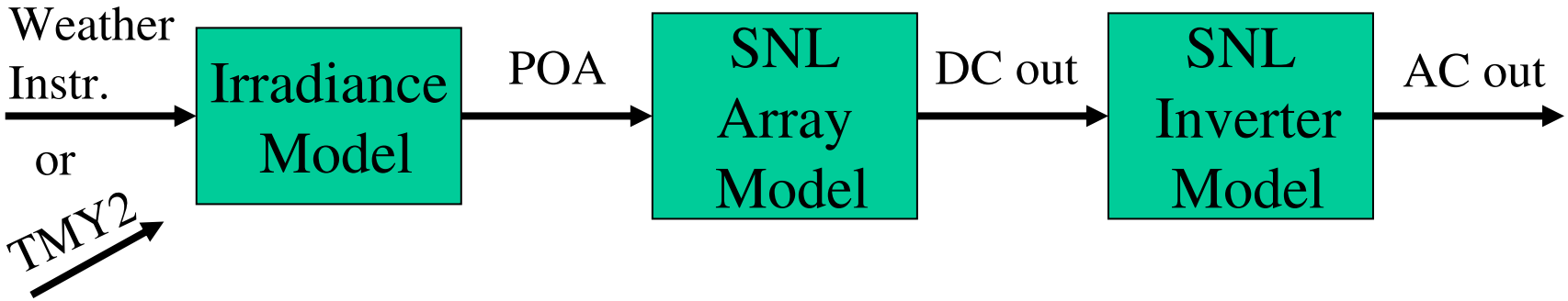
- Ready for inclusion in Solar Advisor Model (SAM)
- Database contains parameters for 47 inverter/voltage combinations, based on SNL tests, CEC inverter database, and manufacturers' spec sheets.

Inverter model closely tracks real-world measurements



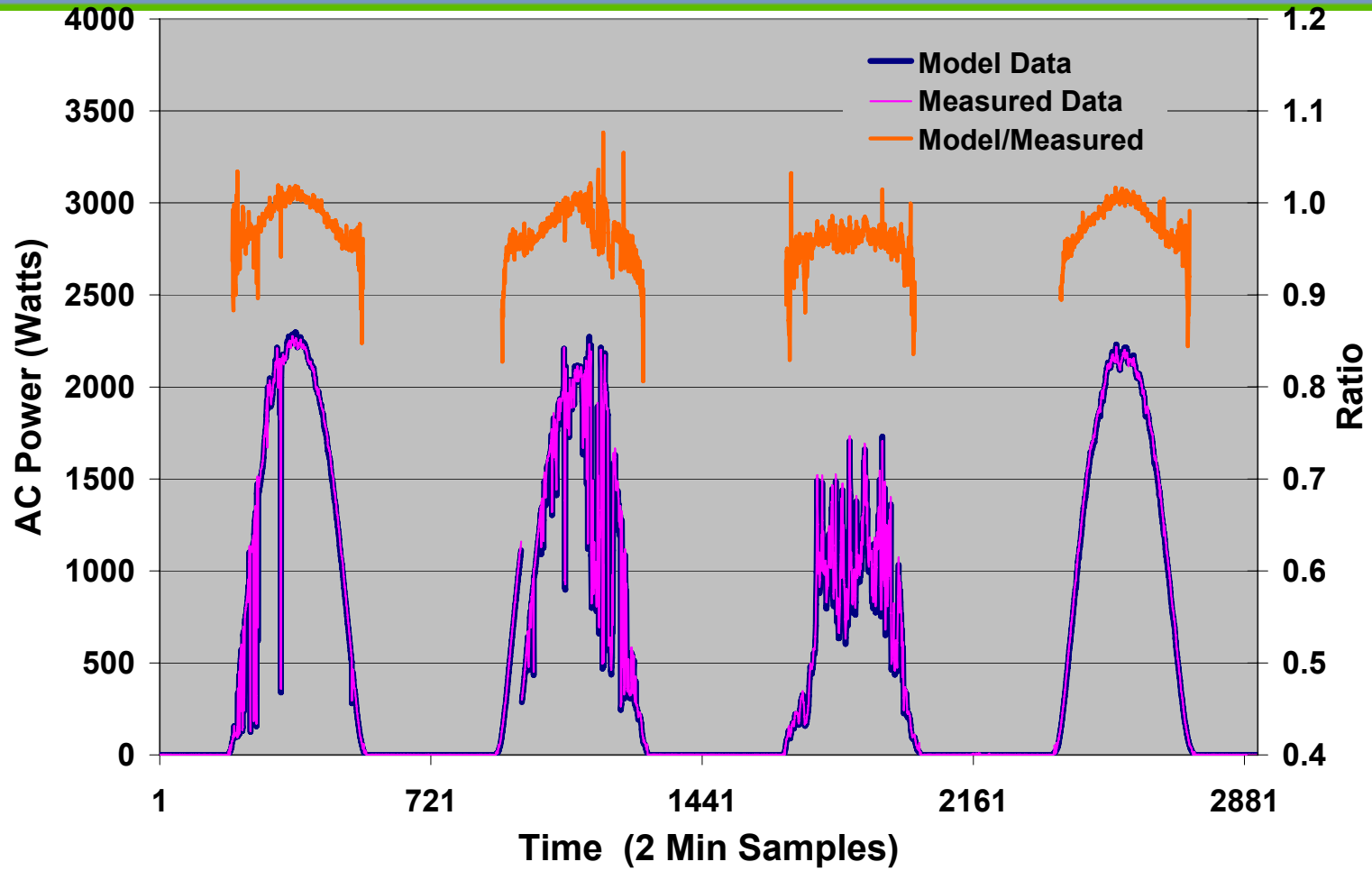
Error in modeled vs. field measurements of a 2500W inverter over a 13-day period.

3. Integration of Overall System Performance Model



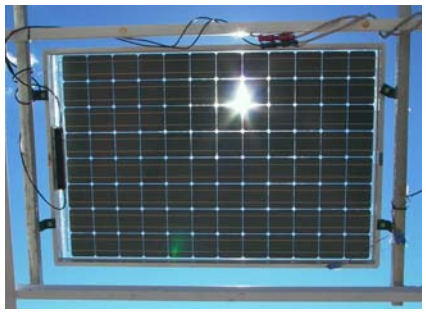
- Linkage of inverter model with previously-developed module/array model
- Covers a variety of climatic conditions, technology configurations, and installation conditions
- *Predictive* value: determine expected AC energy production for a particular system configuration
- *Real-time* value: monitor changes in output to determine system performance, identify faults.

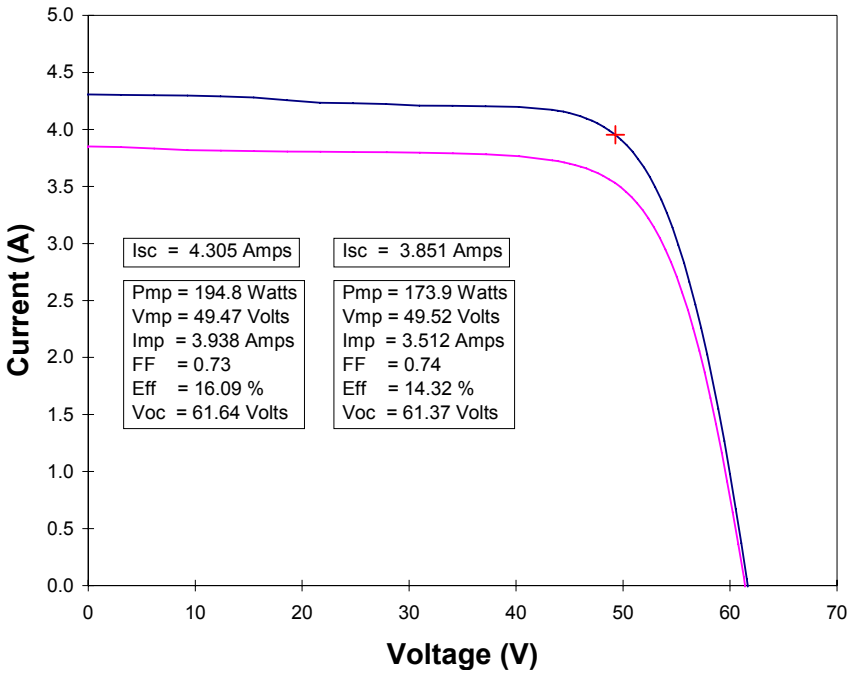
System performance model closely tracks measured output



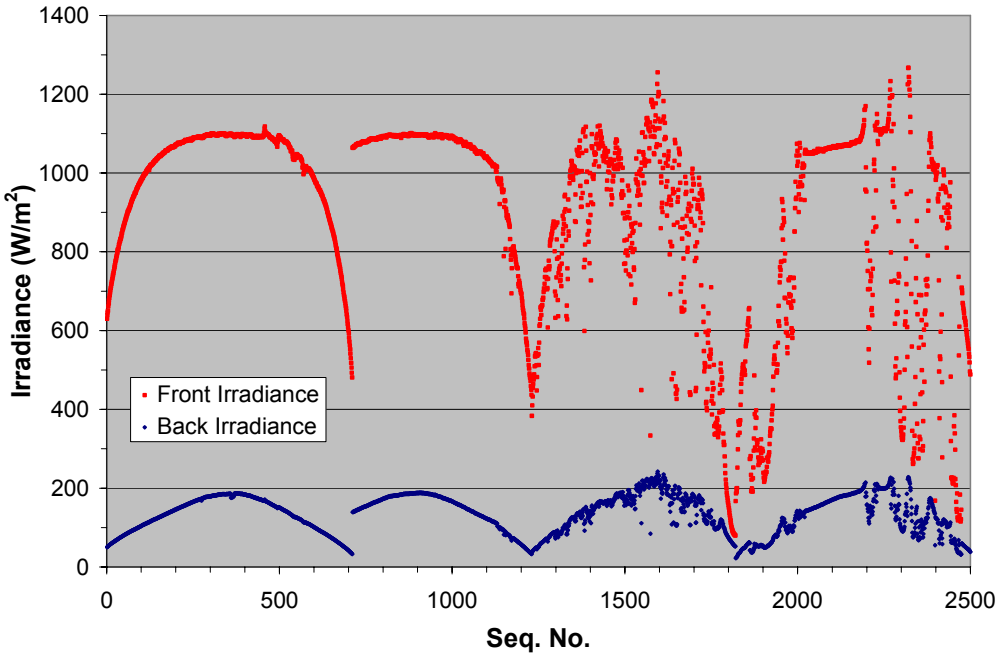
- 4-Day comparison of modeled and measured system performance at PVSOL
- Accurate match even in changing weather conditions

4. Characterizing New Products: e.g., Bifacial Modules





IV curves empirically obtained – dependent on installation conditions, such as ground reflectance.



Solar irradiance on front and back of bifacial modules for two clear and two cloudy days.

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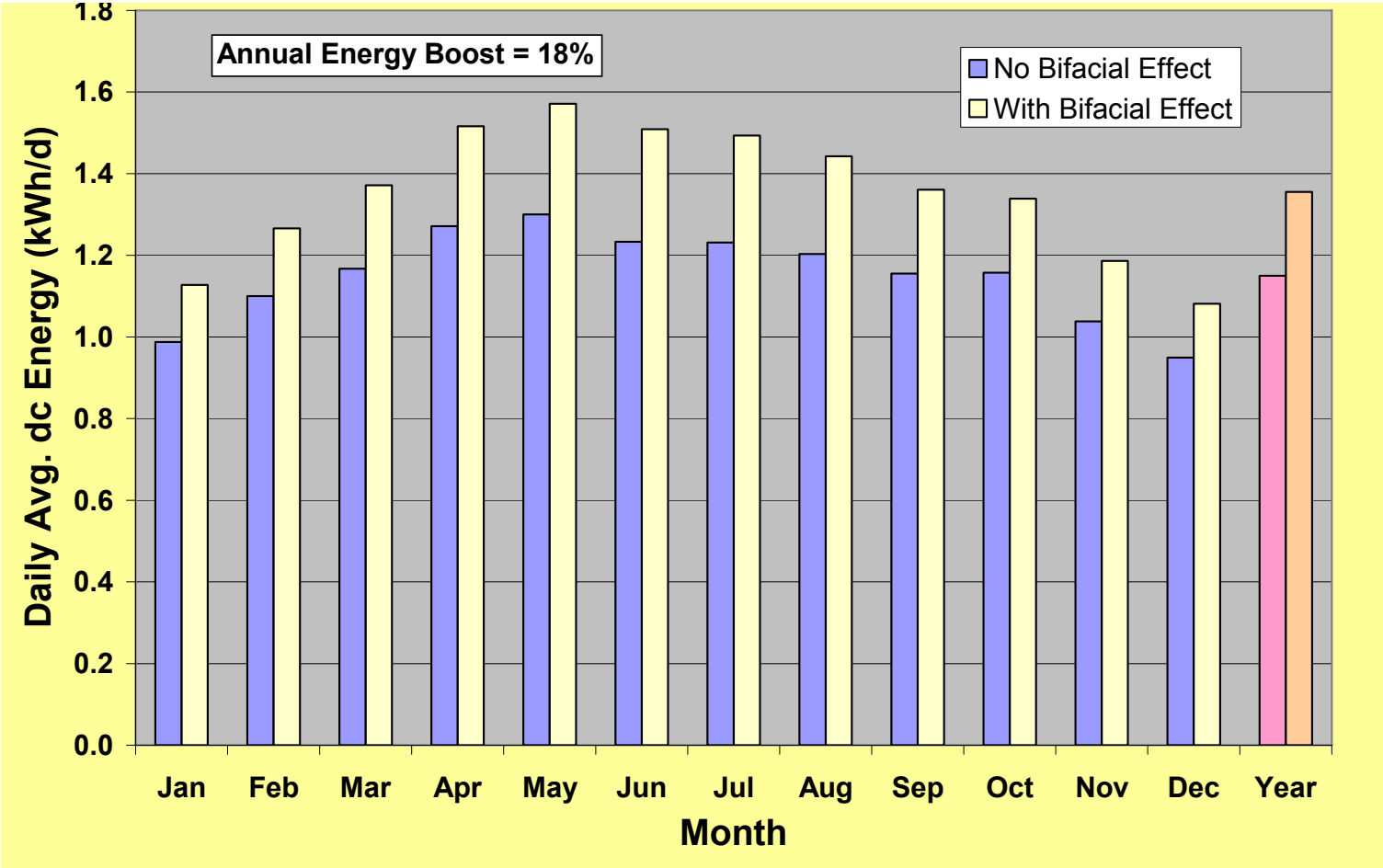
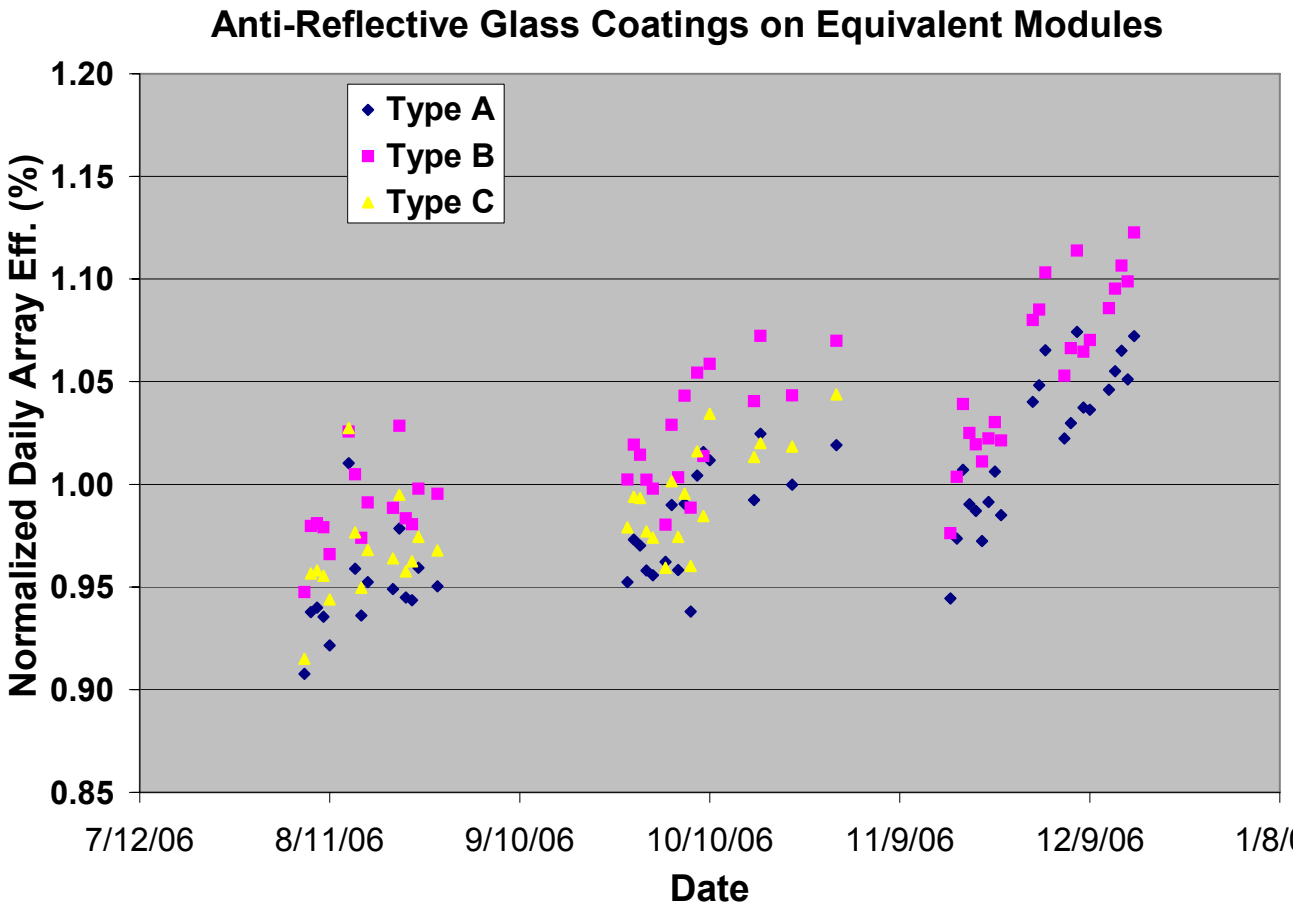
Bifacial modules: modeling annual output



Result: empirical model predicts 18% boost in annual energy!

4. Characterizing New Products: e.g., Anti-Reflective Coatings

- Partnered characterization effort with U.S. manufacturer
- Statistical analysis of time-series data shows marked differences (3-4%) in energy production
- System model parameters developed and utilized for overall comparisons
- Visual inspections showed different rates on soiling of panels



Major Milestones

FY06 Program Milestones:

- *Demonstrate and document a new benchmark for accuracy in characterizing, modeling, and analyzing energy-based performance of PV systems and components (inverters) in SNL systems optimization lab (PVSOL).*
  - **Result: Models integrated to calculate overall system efficiency; letter report sent to DOE describing proposed system-level metric.**
- *Through comprehensive interactions with component manufacturers and system integrators, demonstrate and promote specific technology pathways in PV system integration/manufacturing/deployment that will achieve DOE and industry goals for levelized energy cost.*
  - **Result: Reports to industry partners covering specifics of all technologies and pathways investigated, including those examples described herein.**

FY07 Program Milestones:

- *Documentation of field-testing protocol for array, inverter, system performance for SAI/TPP participants.*
- *Document performance metrics for multiple array/inverter combinations in PVSOL providing validation of testing and modeling protocols.*
- *Initiate new method for accelerated array field-aging for SAI/TPP participants.*
  - Result: All milestones on track for FY07; several links to other milestones in test & evaluation, inverters &BOS, systems analysis, and SAI market transformation.

Future Directions

Specific follow-on activities include:

- Refining models to address issues such as tracking and shading, reliability, derates, different weather models, and other lifetime-related variables.
- Establish, validate, and implement accelerated testing protocols for PV components and systems (corrosion, packaging, interconnection, system reliability, etc.)
- Execution of test & evaluation activities in support of SAI, including lab and field measurements to refine analyses, establishing SAI baselines, and tracking program progress.
- Continuation of partnered investigations with industry on new materials, components, and systems integration methods.