

# 2008 Solar Annual Review Meeting



## Session: Test and Evaluation

## Company or Organization: NREL and SNL

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# Overall Goals

- Provide test and evaluation of PV cells/modules/ systems to TPP participants, other PV industry, labs, and universities in support of technology optimization efforts sponsored by DOE's Solar Program and the SAI.
- Support commercial and emerging technology development.
- Provide component and system performance data to improve and validate system performance models
- Provide T&E support for Reliability activities.
- Priority is placed on TPP's and other solicitations.



# Impact on Progress of Technology

- Provides benchmarks for assessing improvements in technologies.
- Provides performance characteristics and other information for comparing competing technologies.
- Identifies areas needing improvements to meet cost and performance goals.



# Budget

NREL			
Project Beginning Date	FY07 Budget (\$M)	FY08 Budget (\$M)	Total Budget (\$M)
Ongoing	0.8	1.6	2.4

SNL		
Project Name	FY07 \$k	FY08 \$k
Module/Array Testing	550	840 (notes 1,2)
PV Systems T&E	950	
Inverter/BOS T&E	1,050	775 (note 1)

- Notes:
1. As Sandia ramped up its activities in reliability in FY08, we proposed a significant reduction in T&E budgets.
  2. In FY08, the module, array, and systems T&E activities were combined.

# NREL Project Specific Information



## Performance and Energy Ratings Testbed (PERT):



1. Technical details – Operate testbed for outdoor testing of prototype and commercial PV modules (I-V curves and energy production).
2. Milestone (5/07) – Refurbish PERT data acquisition systems; completed, 45 module capacity, replaced and upgraded wiring, etc.
3. Milestone (9/07) - Report on feasibility of using PERT data for IEC module energy ratings; completed, NREL Test Report says “yes”.
4. FY08 – Added additional modules (4) per manufacturers’ requests.
5. FY08 To-Do: Add spectroradiometer and dark I-V curve capability; continue PERT operation and maintenance; on-track.
6. Issues – Some PV module designs exceed PERT voltage limit of 240V (a CIGS module  $V_{oc}=280$  V; a CPV module  $V_{oc} = 290$  V).

# NREL Project Specific Information (cont)



## Energy Ratings

### Method Validations:



1. Technical details – Validation studies of proposed energy rating methodologies, and development of techniques and models for use in energy rating methods and standards.
2. FY08 Accomplishments – Two energy ratings related papers were completed for 2008 IEEE PVSC that contain: (A) analysis and metrics for a-Si winter-summer degradation-recovery cycles, (B) an accurate model for power that requires only 3 parameters: power at SRC, power temperature coefficient, power at 200 W/m<sup>2</sup>
3. Milestone (9/08) - Validation of proposed IEC 61853 energy rating standard procedures related to PV module irradiance and temperature dependencies; on going and on track.

# NREL Project Specific Information (cont)



## Two-Axis Tracking Testbed :

1. Technical details – Extend capabilities for testing two-axis tracking flat-plate and concentrating PV modules (SAI and other products).
2. FY08 Accomplishments: (A) Removed extraneous tracker equipment (shown in figure), (B) Purchased a direct normal spectroradiometer, (C) Borrowed a tracking error monitor from Sandia, (D) Identified controller options.
3. FY08 To-Do: (A) Purchase and install improved controller, (B) Evaluate tracking accuracy, (C) Purchase and install data acquisition system (DAS) for I-V curve measurements.
4. Milestone (9/08) - A two-axis tracking test bed completed for testing flat-plate and concentrating PV modules; on track.

# NREL Project Specific Information (cont)



## BIPV Performance :

1. Technical details – Evaluate elevated operating temperature environment of BIPV system and the impact on performance.
2. FY08 Accomplishments: (A) Reviewed available BIPV modules, (B) Consulted with NIST on module selection, (C) Began dismantling existing PV array (shown in figure).
3. FY08 To-Do: (A) Install BIPV array on test shed, (B) Install DAS and inverter, (C) Evaluate temperature and energy performance.
4. Milestone (9/08) - Technical report with recommendations for modeling BIPV system elevated temperature losses and for modeling PV system shading losses; on-track.

Note: In FY09, the array will be replaced with an SAI deliverable.

# NREL Project Specific Information (cont)



## Shading Losses :

1. Technical details – Develop improved method for accounting for energy losses from shading and partial shading of PV arrays.
2. FY08 Accomplishments: (A) Purchased inverter and DAS equipment, (B) Began reconfiguring PV array as a grid-connected system and DAS for individual PV module voltage measurements.
3. FY08 To-Do: (A) Complete PV system and DAS installation, (B) Analyze performance and develop guidelines for shade analysis and accounting for shading losses.
4. Milestone (9/08) - Technical report with recommendations for modeling BIPV system elevated temperature losses and for modeling PV system shading losses; on-track.

# NREL Project Specific Information (cont)



## PV Summary Information

### Reporting :



1. Technical details – Summary information determined for PV modules and systems to compare and contrast the performance of various technologies or manufacturer's product at NREL's location.
2. FY08 Accomplishments: (A) Compiled index list of modules at NREL dating to 1993, and associated data files, (B) Identified appropriate IEC 61724 metrics, (C) Began software development.
3. FY08 To-Do: (A) Complete software development, (B) Produce summary information for modules and systems at NREL.
4. Milestone (9/08) - Procedures and software completed for producing summary performance information for PV modules and systems at NREL using IEC 61724 metrics; on-track.

# NREL Project Specific Information (cont)



## Field Based Testing and Evaluation:

1. Technical details – Provide support to meet industry requests for PV related equipment field testing and other assistance.
2. Accomplishments: (A) Provided assistance with measurement of solar radiation and meteorological parameters for Black & Veatch performance assessment of 8.2 MW PV plant constructed by SunEdison (Alamosa, CO, August 27-30, and December 10-17, 2007, Stoffel, Wilcox, McNutt).



# NREL Project Specific Information (cont)

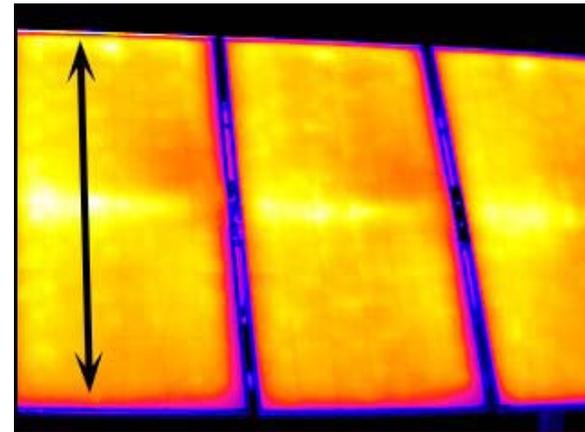


## Field Based Testing and Evaluation: (cont)

(B) Demonstrated to SunEdison personnel use of IR camera for PV system diagnostics. →

FY08 To-Do: Provide other industry assistance as requested.

Milestone (9/08) - Summary report listing activities related to providing field-based support to industry and for DOE solicitations; on-track.



Infrared



Visible

## Sandia Technical Details:

# Module, Array, System T&E (PV Systems Evaluation Lab) Inverters & BOS T&E (Distributed Energy Technologies Lab)



- SAI test & evaluation working group
  - Prepare for stage-gate evaluations of TPPs and other SAI partners; develop protocols for new systems evaluations; execute industry-supportive T&E*
- System-level model development/validation
  - Incorporate full system model into SAM; conduct validation of inverter model through enhanced data collection*
- Industry support through developmental assistance
  - Assure industry access to lab technical strengths to improve performance, reliability of new and near-commercial products*
- Performance, failure assessment through long-term exposure
  - Re-invigorate Module Long-Term Exposure activity; assess inverter long-term performance through controlled activities*

# SNL: SAI test & evaluation working group

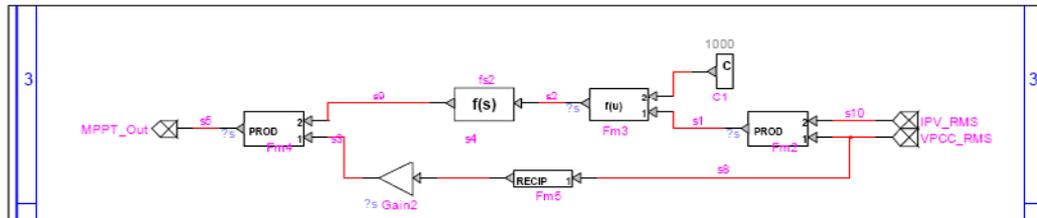


- Collaboration with NREL, SWRES, SERES
- Developed detailed T&E requirements from winning TPP proposals
  - Tool used by DOE in contract negotiations to determine lab level-of-effort*
- Initiated development of protocols for field testing of integrated PV systems
  - Two-day workshop held at SNL, follow-up to include on-site measurements with large systems*
- Measurement, analysis procedures established for new concentrating PV configurations
  - TPPs offer several configurations; lab data collection underway, field measurements planned for late April*
- Several TPP baseline and developmental evaluations have already been conducted
  - Module performance parameters determined; inverter topologies assessed; integrated CPV modules evaluated.*

# SNL: System-level model development/validation



- Inverter performance model completed; fully integrated into system model  
*Empirical model based on measured parameters; can also utilize spec-sheet data*
- Inverter model incorporated into Solar Advisor Model  
*Improved accuracy over single-point efficiency*
- Growing database of inverter performance parameters, based on SNL evaluations and CEC database  
*Leveraging CEC requirements allows inclusion of more than 100 inverter models*
- Matlab/Simulink developmental inverter model complete  
*In-depth tool for assessing hardware, algorithm improvements in inverter design*
- Validation a continual process, with in-lab measurements  
*All in-house inverter evaluations provide data for model validation*

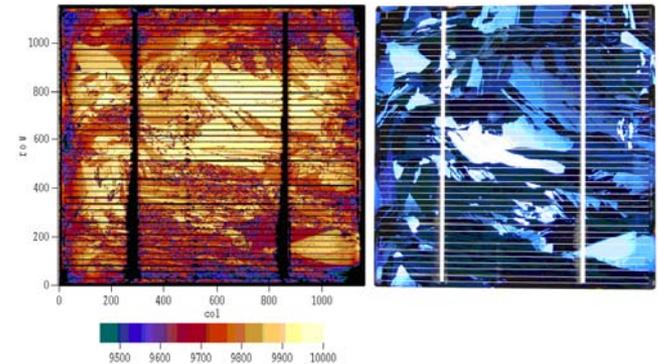


Inverter Development Model: Max Power Point Tracking algorithm implemented in Matlab.

# SNL: Industry support through developmental assistance



- Cell characterization efforts support broader systems activities
  - *Laser Beam-Induced Current (LBIC) tests completed with several manufacturers to highlight cell flaws*
- Module-level characterizations of several anti-reflectance schemes
- Initiation of CPV cell and system baselines with manufacturers
  - *New 2-axis tracker and controller in place*
  - *Developing high-accuracy tracker error monitors*
- Inverter evaluations on a new Inverter design from Xantrex
  - *30kW Bi-polar beta unit evaluations revealed anti-islanding issues and MPPT issues. Unit ready for re-evaluation.*
  - *5kW GT Series inverter has L-N voltage measurement issues under noisy conditions*
- EMTEC Black box energy management system evaluation.
  - *Precursor to SEGIS deliverables*

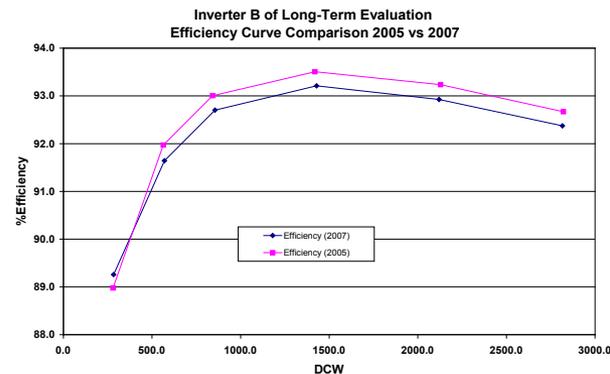
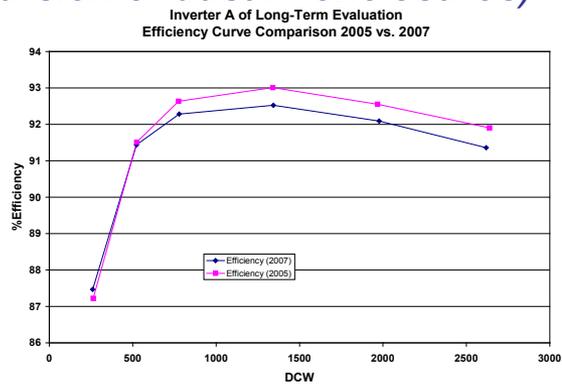


Sample LBIC scan for micro-crack detection

# Performance, failure assessment through long-term exposure evaluations



- Reinvigoration of Module Long-term Exposure regimen on track
  - *Work initiated in 1992 was seminal in determining c-Si degradation rates over time*
  - *Based on strong industry show of interest at FY07 workshops*
  - *Evaluation process in place; modules under test by end of FY08*
- Re-characterization of the long-term inverter operation test bed
  - *Designed to assess long-term performance issues of inverters*
  - *Collaboration with New Mexico State Univ., Florida Solar Energy Center*
  - *Efficiency and maximum continuous power rating evaluations*
  - *Early results show operational impacts on inverter performance (possibly due to incursion of dust in enclosures)*



# T&E efforts are vital to our industry partners



(Examples of active collaborations during the last year...)

## Modules, Arrays, Systems:

- Advent - full suite of cell, module, system evaluations
- **Amonix** – develop field test sequence; plans to execute in April/May
- **Boeing** – early development of test sequence for new SAI products
- **Dow** - planning reliability tests of new products
- Emcore – full suite of cell-to-system developmental tests for CPV
- Evergreen – assessments of different module designs
- **GreenRay** – module characterization for micro-inverter development
- Sanyo – module characterizations
- **Soliant** – system evaluations
- SunEdison – large-field modeling support; field characterization planned
- **SunPower** – assessments of different module materials; modeling support

## Inverters & BOS:

- EMTEC – evaluation of load controller
- Fronius – long-term characterization
- **GE** – development of microgrid control components
- **GreenRay** – TPP design review; baseline characterization, preliminary IR imaging
- PVPowered 4800 – thermal imaging, baseline performance
- PVPowered 30kW –baseline performance and MPPT evaluation
- SMA – long-term characterizations
- **SunPower** – reliability improvements through design assessment
- Xantrex – long-term characterization; microgrid evaluations

**TPPs are indicated in bold**

# Key plans for rest of FY08



## Important SAI needs in the near future

- Finalize evaluation procedure for SAI stage-gate reviews
- Conduct evaluation of stage-gate deliverables
- Provide baseline evaluations of PV components and systems associated with SAI stage-gates

## Field evaluations of large PV systems:

- Complete protocols and test protocols through field activities
  - Fielded CPV system with Amonix
  - Nellis AFB – both PV system and distribution feeder
  - Utility-scale PV systems in Napa Valley, Alamosa, others
  - Residential systems in AZ
- Link to Grid-Integration activities: distribution system impacts of high penetration PV

## Completion of an inter-lab facility strategic plan

<b>Data Set:</b>	SNL PSEL Radiation and Weather Data
<b>Laboratory:</b>	PV Systems Evaluation Laboratory (PSEL)
<b>Location:</b>	SNL
<b>POC:</b>	Bill Boyson
<b>Web Site:</b>	<a href="http://photovoltaics.sandia.gov/weather/Weather.htm">http://photovoltaics.sandia.gov/weather/Weather.htm</a>
<b>Test Platform:</b>	Weather Station
<b>Interval:</b>	Instantaneous values measured every 3-4 seconds. Values below sent to other users 1/minute. Averaged over 10 minutes and archived.
<b>Duration:</b>	Archived since 1989
<b>Data</b>	Direct Normal Radiation Diffuse Horizontal Radiation Total Horizontal Radiation Total Radiation at Latitude Tilt (35.05) Total Horizontal Infrared (less beam) Dry Bulb Temperature Wet Bulb Temperature Wind Speed (5 min avg) Wind Direction (5 min avg) Peak Wind Speed (20 min) Atmospheric Pressure Precipitation
<b>Diagnostics:</b>	not applicable
<b>Test Objective:</b>	not applicable
<b>Reference:</b>	
<b>Standards:</b>	Various ASTM and SNL Primary Standards Laboratory
<b>Procedures:</b>	
<b>Uncertainty:</b>	
<b>Notes:</b>	
<b>Turn Around Time</b>	Data available in real time
<b>CPS Agreement ID</b>	17065
<b>CPS Agreement:</b>	Module, Array & Systems T&E - SNL
<b>Agreement Funding:</b>	\$50k of \$745
<b>Other Funds</b>	
<b>Customers</b>	1-minute data is web-accessible and used by SNL T&E Tasks, Emcore, and the local community. Monthly averages since 1989 are also accessible on the web. Detailed historical data is made available on request (recently requested by Amonix).

Info sheets of test capabilities are being completed for all NREL/SNL facilities to support strategic planning.

# Looking Forward



*Plans for the coming year:*

- New CPV capabilities from cell through system
- Fully operational T&E working group, with field-tested protocols for system assessment
- Prepare Distributed Energy Technologies Laboratory and protocols for SEGIS deliverables, much broadened from inverters to system controllers

*These plans are in AOP, however:*

- Current AOP only covers next 6 months
- Expected *significant* increase in SAI activity in FY09 (TPPs, SEGIS, etc)

# Looking Forward (cont)



- Significant concerns:
  - Satisfactory funding for facility upgrades to meet planned needs
  - Knowledge of SAI T&E needs are dispersed across organizational lines, creating uncertainty in the extent of T&E support needed
  - T&E needs may be impacted by stage-gate reviews; either by change in research direction, or down selection.
- Major upcoming decisions/events: FY09 and FY10 AOP planning

# Systems Engineering Considerations



DOE PV Program has an evolving focus on systems solutions:

- *Systems Driven Approach (2002)*
- *Solar America Initiative (2006)*
- *Renewable Systems Interconnection (2007)*
- *Solar Energy system Grid Integration Systems (SEGIS) (2008)*

All of this leads to identification of new systems-level needs...

- *Integrated storage systems*
- *Advanced controls*
  - *Microgrids*
  - *Load management*
- *Communications infrastructure*
- *New standards for new technology integrations/applications*

... And the necessary capabilities to look beyond tomorrow's needs

- *Large (250kW+) PV array simulator*
- *System-level HALT chambers*
- *Integrated microelectronics (inverters, controllers, sensors) for full plug-n-play capability*

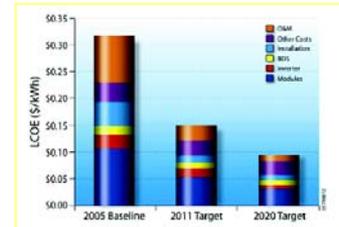


Fig. 3.1.6-5 Component contributions to LCOE for c-Si residential reference system - shown for 2005 benchmark and 2011/2020 targets.

$\$/W \rightarrow \text{¢}/kWh$

