Brookhaven National Laboratory Solar Energy and Smarter Grid Research Update

Presented to BNL CAC

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Office of Science
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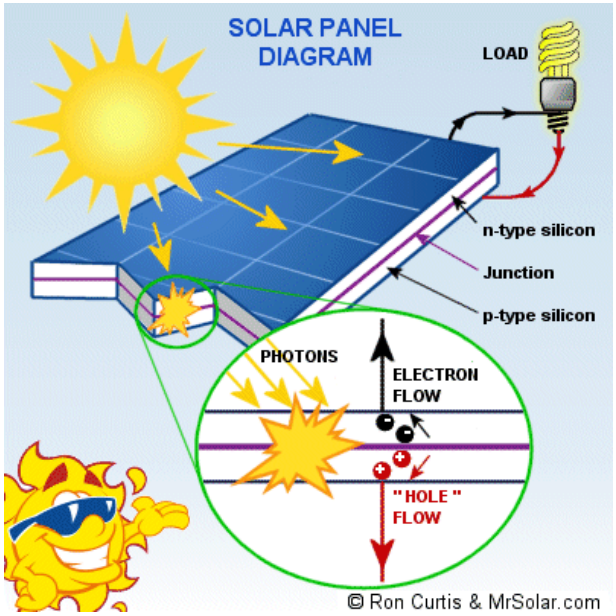
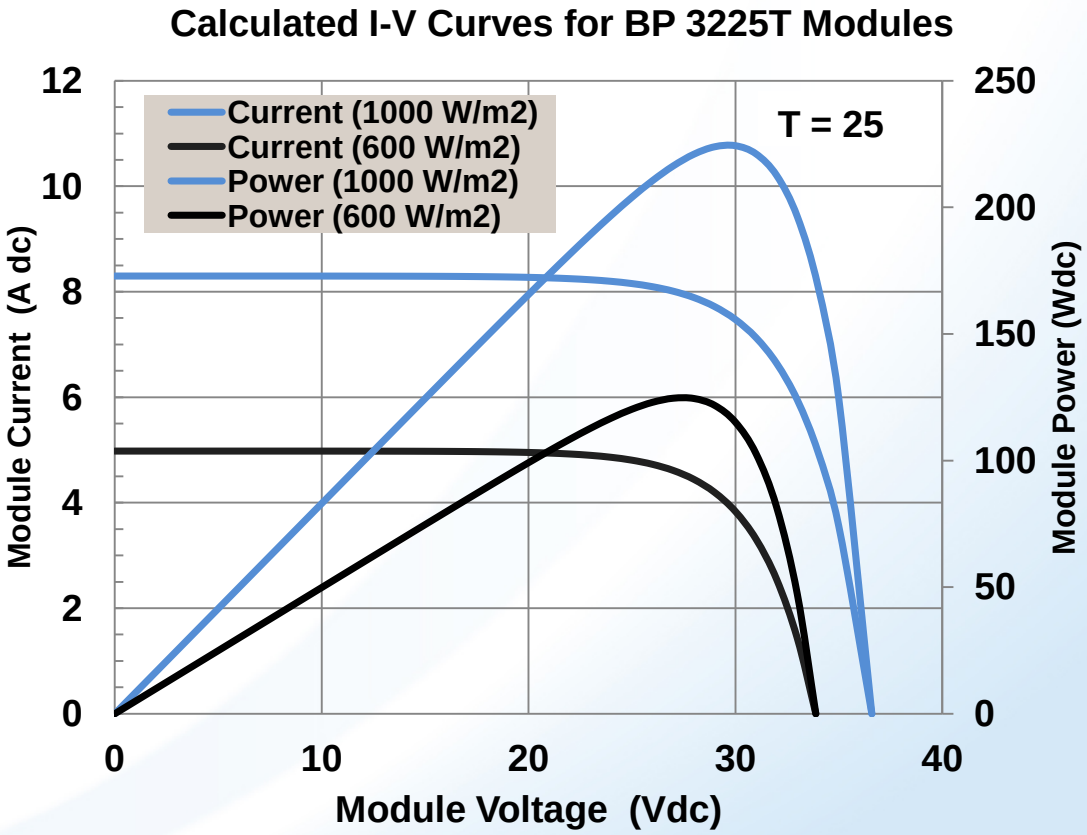
Quick Introduction to Solar Power

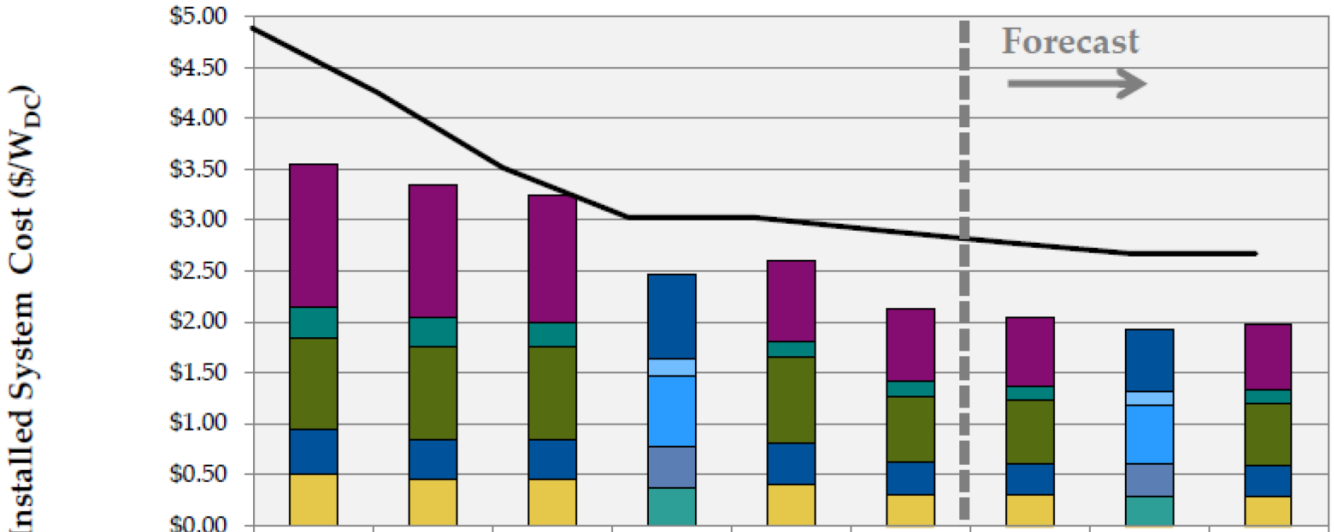




Solar Research Focuses on Market Barriers

Design: 164,312 Si Mods./25 Inverters @ 1.25MW/27º Fixed Tilt
Reliability: 80% @ 25 Yrs (0.8%/yr)
Power: 32 MWe/44 GWh annually
Land: 200 acres/20 Year Easement
Utility Cost, Contract: 20 Year PPA/ Total $298M/~$0.30 kW
Financing: METLife
Permitting, Construction: Three Years from Proposal to Completion

Solar Research Focuses on Market Barriers



	Tracking 2009	Tracking 2010	Tracking 2011	Fixed 2012	Tracking 2012	Tracking Q1 2013	Tracking 2014	Fixed 2015	Tracking 2015
% Change from Q3 2012	0%	0%	0%	0%	0%	-11%	-13%	-11%	-10%
Total - Commercial	4.90	4.30	3.60	3.14	3.14	3.02	2.91	2.80	2.80
Total - Utility	3.55	3.35	3.25	2.46	2.60	2.13	2.04	1.92	1.97
Module	1.40	1.30	1.25	0.83	0.80	0.71	0.67	0.61	0.64
Inverter	0.30	0.30	0.25	0.16	0.15	0.15	0.14	0.14	0.14
Racking & BOS	0.90	0.90	0.90	0.70	0.85	0.65	0.63	0.56	0.61
Labor	0.45	0.40	0.40	0.40	0.40	0.32	0.31	0.32	0.30
Margin & OH	0.50	0.45	0.45	0.37	0.40	0.30	0.29	0.29	0.29

Figure 5: US Utility Scale PV System Prices - Tracking and Fixed Tilt, 2009-2015

Sources: Navigant estimate based on industry interviews, market reports, and primary market research Dec. 2011 – March 2013.

Notes: Utility scale plant sizes are estimated to be >10MW; Commercial scale plants are estimated to be >250 kW; Fixed tilt system refer only to thin-film technology; Tracking systems refer to c-Si 1-axis tracking systems; Margin & Overhead include interconnection, permitting, and development costs among others; Racking & BOS costs include the racking, foundations, tracking hardware (if needed), wiring, roads, and security among others.

From: SEPA Centralized Solar Projects Update Bulletin, May 2013

BNL's research agenda for solar energy and smarter electric grid focuses on two key areas

- Advancement of Solar Energy Generation in Northeast
  - Characterization of renewable generation
  - Impact of renewables on the grid
  - Role of storage to enhance benefits/mitigate the impacts of renewable
  - New technologies, such as advanced inverter controls, improve grid control

- Smarter Electric Grid Development
  - Advanced simulation of distribution networks and systems (e.g. graph trace analysis using iterators)
  - Modeling & advanced sensors to inform decisions on grid operation, validate/improve simulations
  - Evaluation of new technologies and control strategies for improved efficiency and reliability
  - Automated demand response, particularly in high density urban applications
  - Micro-grid concepts for improved reliance, resiliency

A key motivation for pursuing solar energy research at BNL is access to the Long Island Solar Farm …

- **32 MWac grid-connected solar photovoltaic plant being built at BNL**
  - **Owned by Long Island Solar Farm, LLC (company partially owned by BP Solar)**
  - **Purpose is to sell power to LIPA under a PPA**
  - **Commercial operation initiated Nov. 1, 2011**
- **Located on 195 acres on BNL campus under an easement from DOE**
  - **Consideration (in-kind funds) provided to DOE**
  - **BNL can instrument and collect data from the array for research purposes**
- **BNL installed research instruments to collect data for research**
  - **High-resolution, time synchronized data sets**

LISF is complete and is generating power!

Commercial operation November 1, 2011

BNL installed research instruments in the LISF
Collecting Time Synchronized, High Resolution (1sec.) Data Sets

- **Solar Resource Data**
  - Field Instruments: pyranometers 32 pairs @ 25 locations to measure direct and diffuse irradiance
  - Base Station Instruments: Solar tracker, rotating shadowband radiometer for precision measurements
- **Meteorological Data**
  - Two Met Towers (85m & 10m)
    - Air Temp/Barometric Pressure
    - Wind speed and direction
  - Array Field Instruments
    - Temperature (air , panel, soil)
    - Relative Humidity
  - Total Sky Imagers – Cloud images
- **Electrical Performance Data**
  - Power Quality: all inverters, collection substation
  - Power Quality: Utility feeders to BNL
  - String Level: DC currents and voltages


Rotating Shadowband Radiometer


Field Pyranometer


Power Quality Monitor

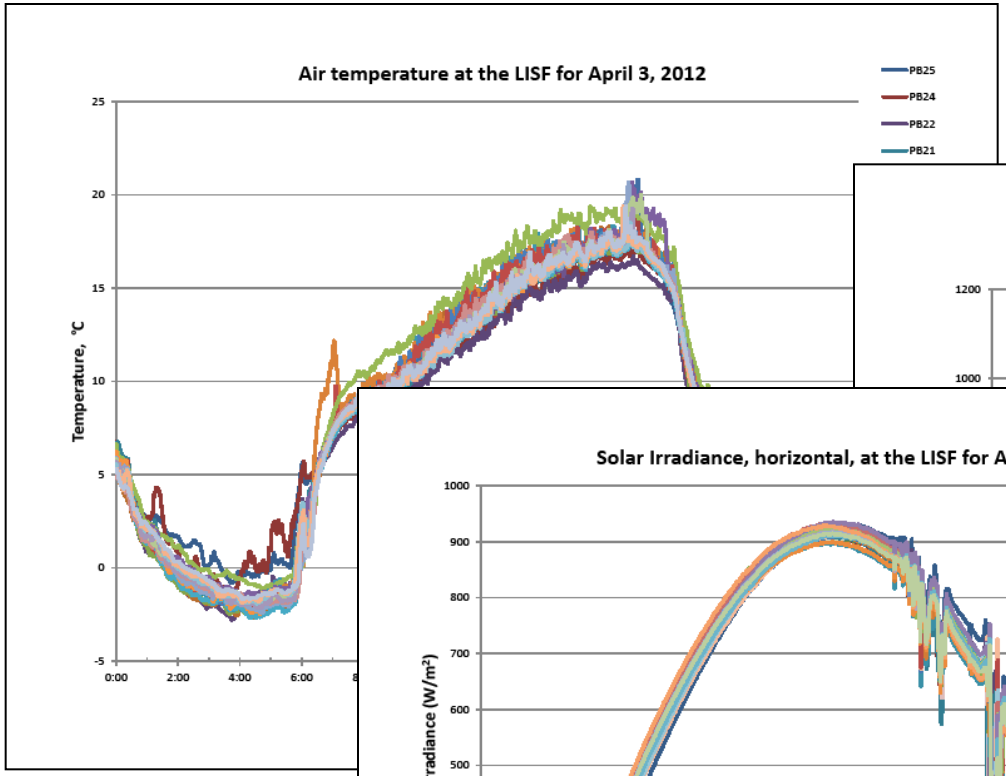

Pyrheliometer

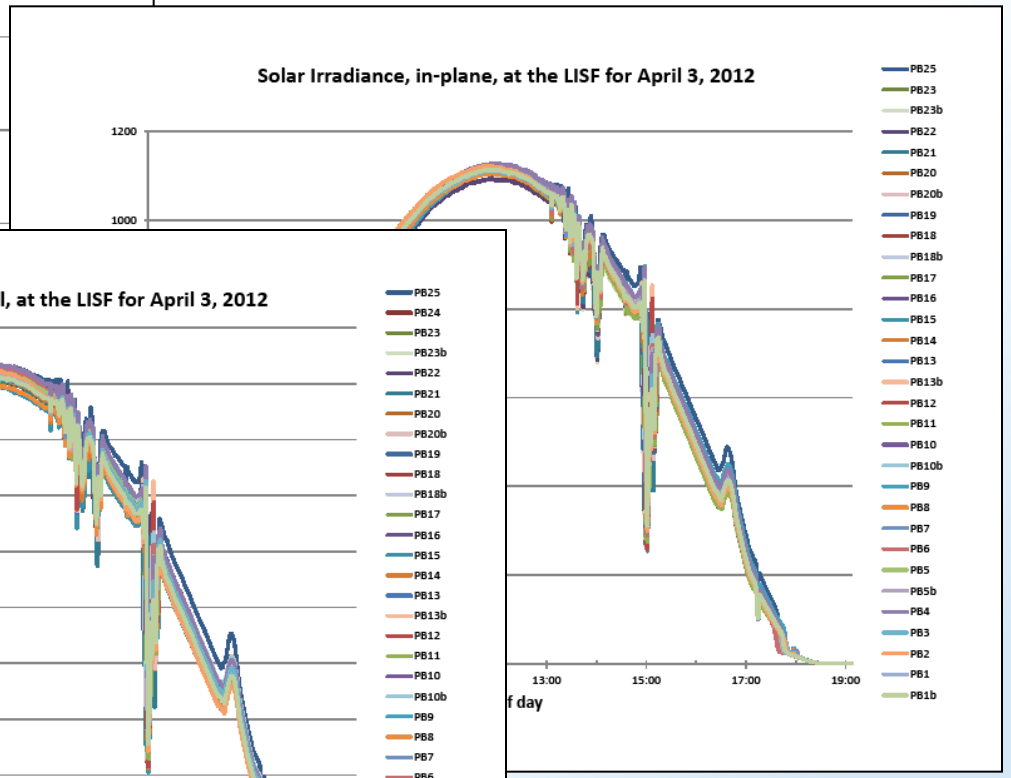

Pyrgeometer

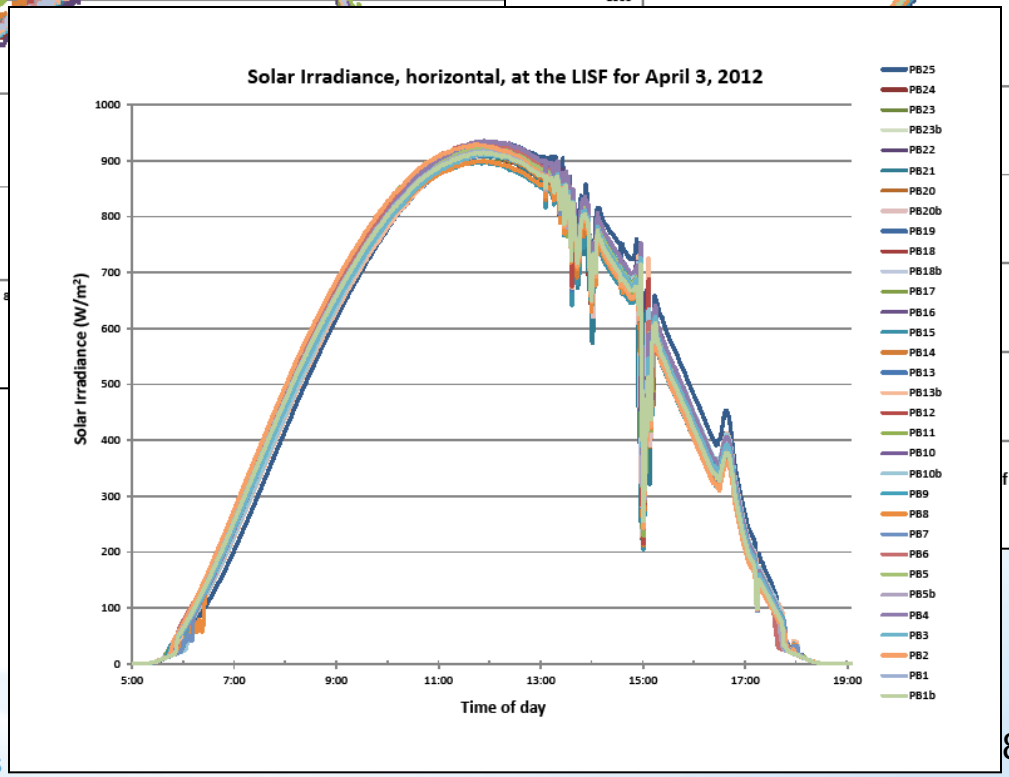

Sun tracker with sensors for global, diffuse and direct irradiance.


Total Sky Imager

BNL is collecting and storing LISF data
Data will be made available for research purposes



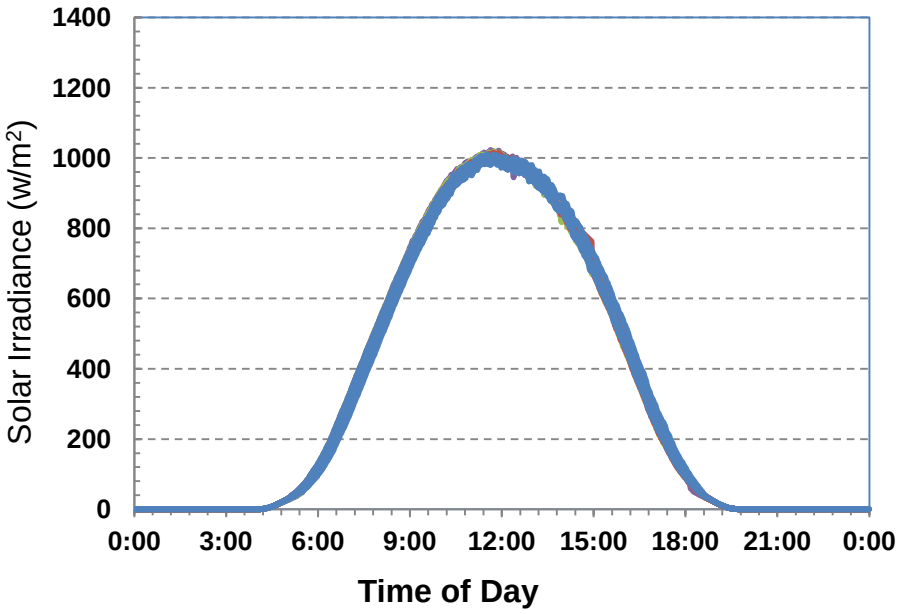




Solar Irradiance Comparison for Sunny vs. Cloudy Day

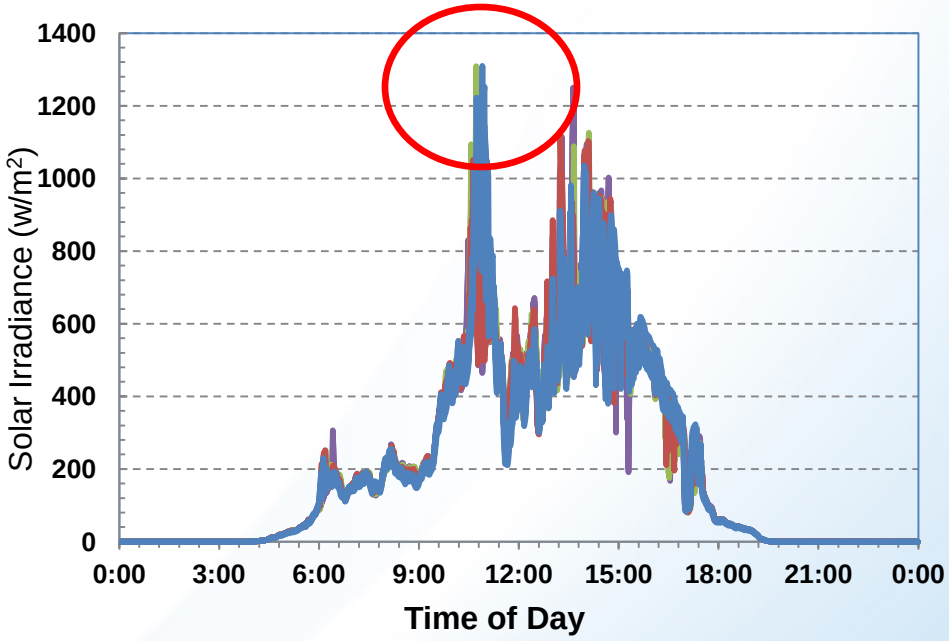
(Pyranometer data from 25 LISF power blocks)

In-plane solar irradiance – sunny day



Irradiance on sunny day peaks at approx. 1000W/m^2

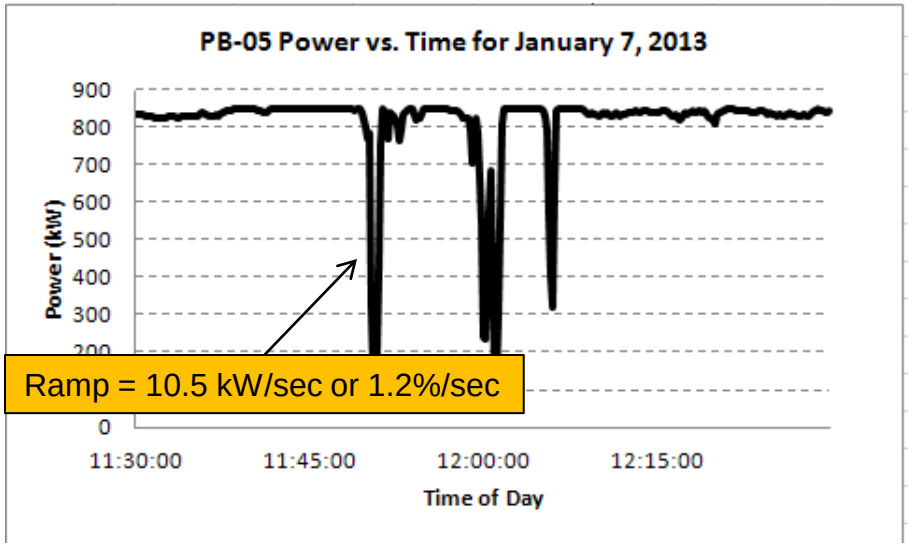
In-plane solar irradiance – cloudy day

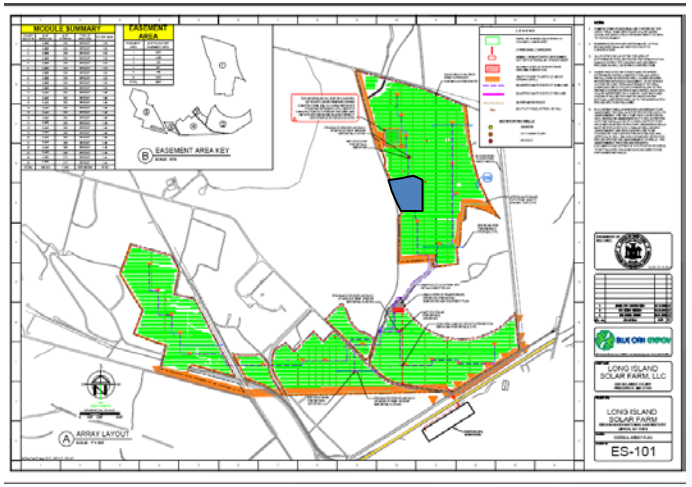


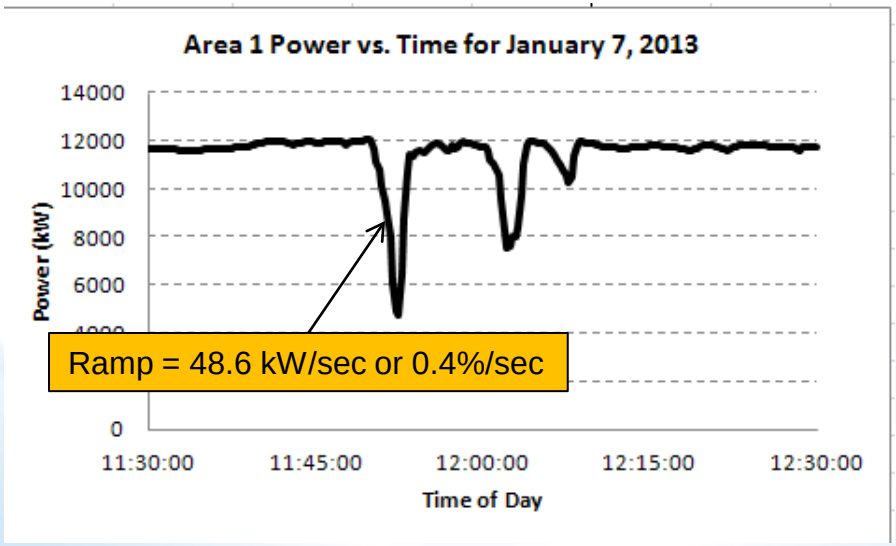
Local irradiance on cloudy day can be higher due to reflection from clouds

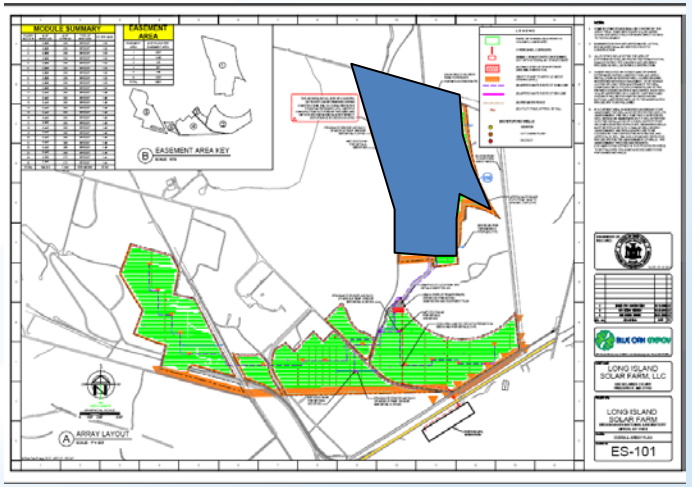
Power Output and Ramps During Cloud Transients

(Power data from 1 power block and total for Area 1)



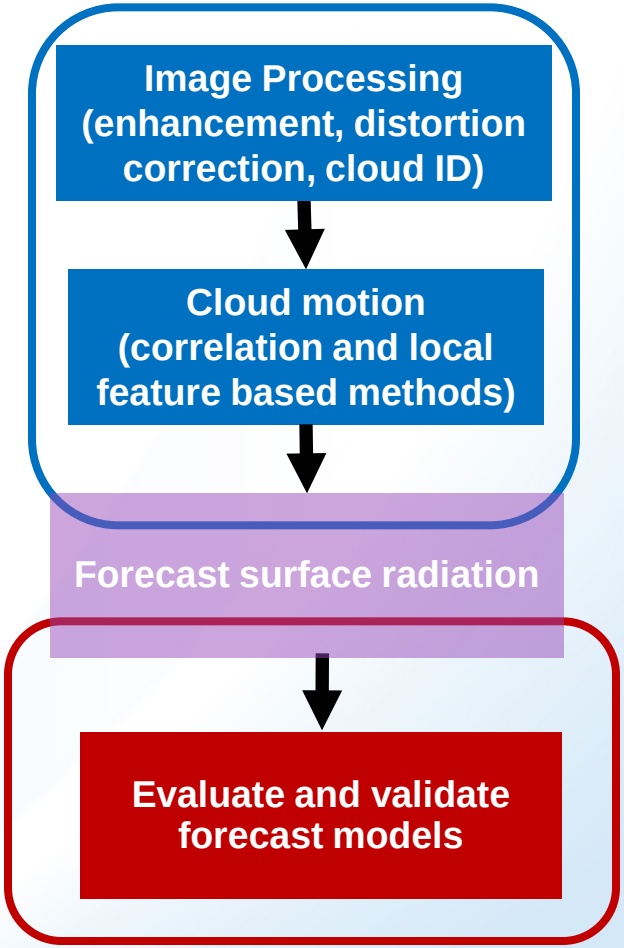






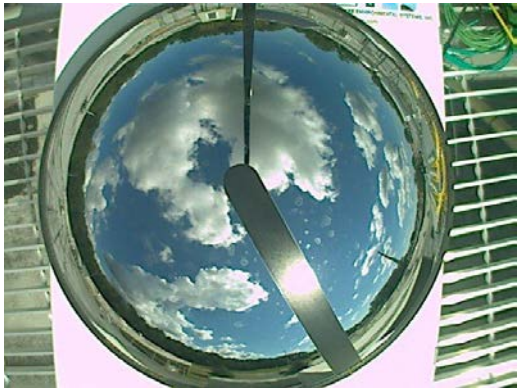
Forecasting Research Agenda

- Develop tools for real-time processing of TSI images;
- Estimate cloud motion vectors based on sequential TSI images;
- Develop empirical/physical/hybrid models for radiation forecast;
- Test and validate the forecast system using LISF data;
- Interface cloud/radiation data for assimilation into VDRAS and WRF-Solar.



TSI image processing provides info about cloud location, size, and brightness.

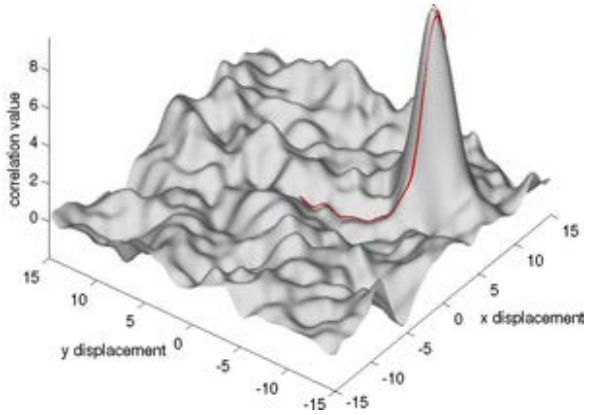
- RGB and contrast enhancement

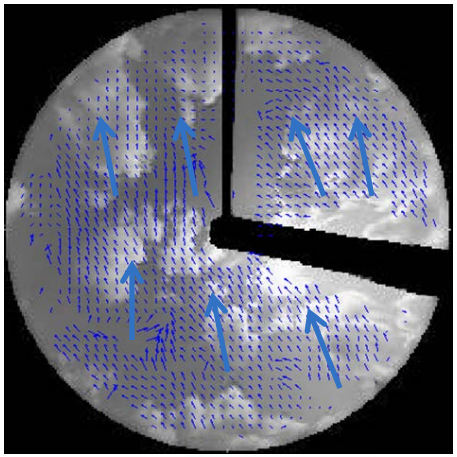


- Distortion correction

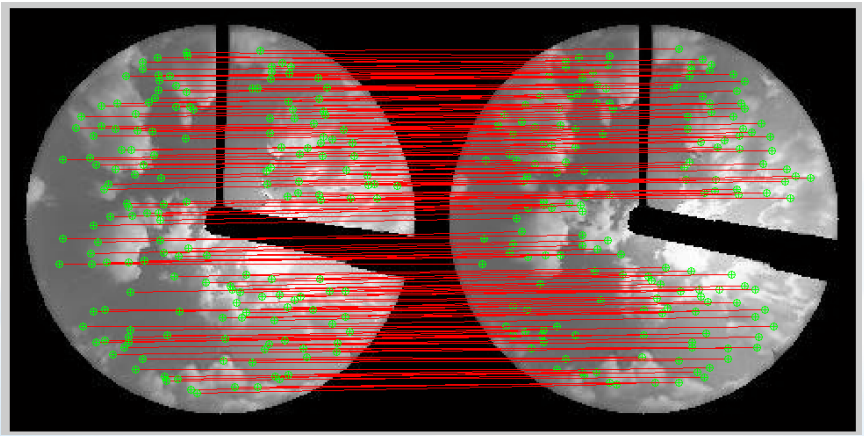
Cloud motion estimation

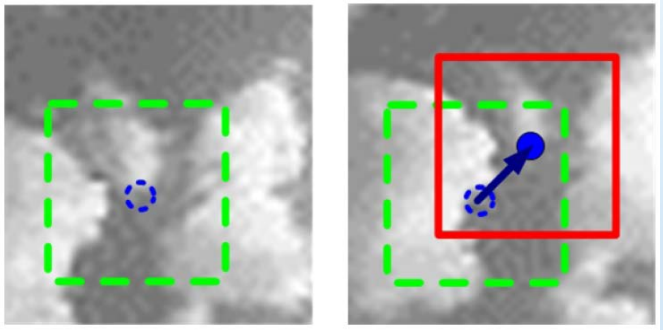
- Cross-correlation based approaches





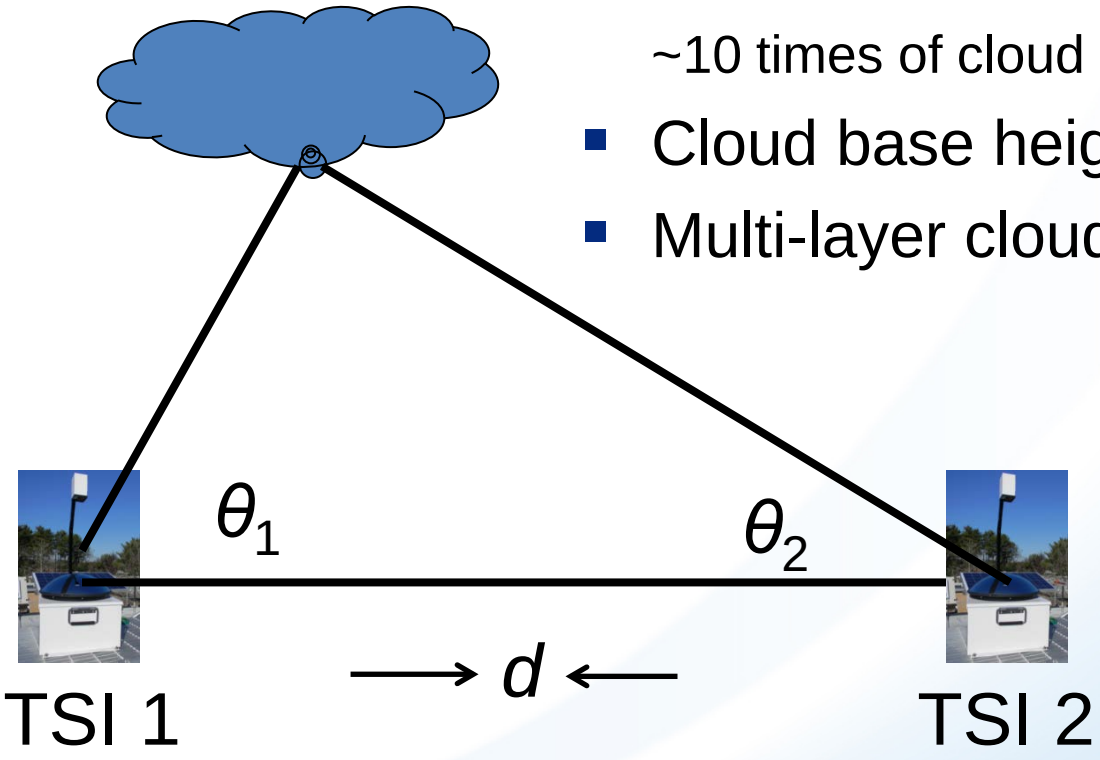
- Local feature based approaches





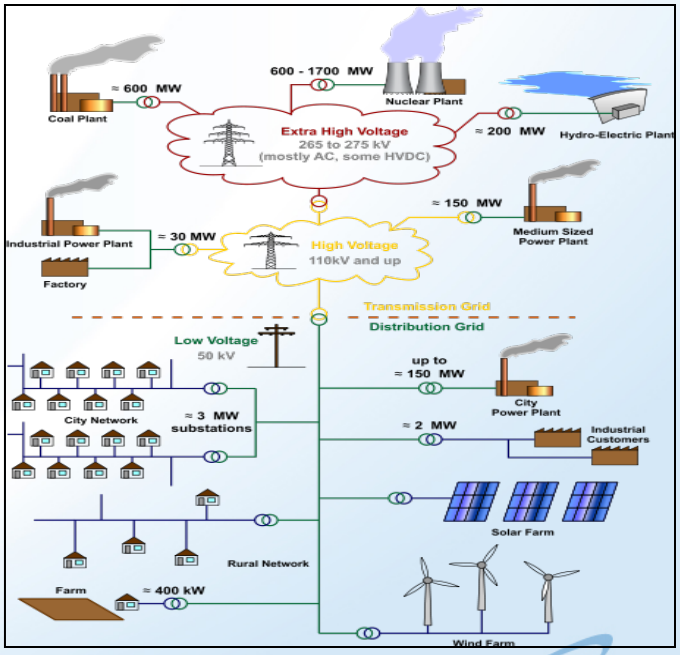
A network of TSIs can provide more information about clouds.

- Larger field of view (max horizontal view of a single TSI is ~10 times of cloud base height)
- Cloud base height
- Multi-layer clouds



LISF data enables research on issues that will foster the deployment of utility-scale solar PV systems

- **Solar Variability and Grid Integration**
  - Characterize solar variability for plants in the northeast
  - Impact of solar variability on grid management for different penetration levels
  - Impact of distributed generation on feeder performance (power quality, reliability)
  - The role of storage to mitigate variability impacts
  - The role of smart grid inverters providing ancillary services (DVAR, voltage regulation)
- **Forecasting**
  - Min/Hour/Day ahead solar resource forecasts
  - Leverage BNL core capability in cloud physics and access to NOAA facility on site
- **Capacity Credit**
  - Develop and validate algorithms
- **Environmental Sustainability**
  - Impact of utility-scale solar PV plants on local environment and ecology
  - Life cycle cost, recycling



BNL is also developing the Northeast Solar Energy Research Center (NSERC)

- Supplements LISF research
  - DOE owned facility on BNL campus
  - Available to support industry needs
- Comprised of two elements
  - Research array for field testing
  - Laboratories for standardized testing
- Resource for the Northeast
  - Field testing under actual northeast conditions
  - Technology development test bed
- Solar array connected to BNL electrical system
  - Help with BNL sustainability goals
  - Enable micro-grid test bed

NSERC Research Facility

- ✓ **Field Testing***
- ✓ **Grid Integration**
- ✓ **Solar PV**
- ✓ **Smart Grid Test Bed**
- ✓ **Energy Storage**
- ✓ **Smart Grid Inverters**
- ✓ **Solar Forecasting**
- ✓ **Reliability & Degradation**
- ✓ **Environmental Sustainability**

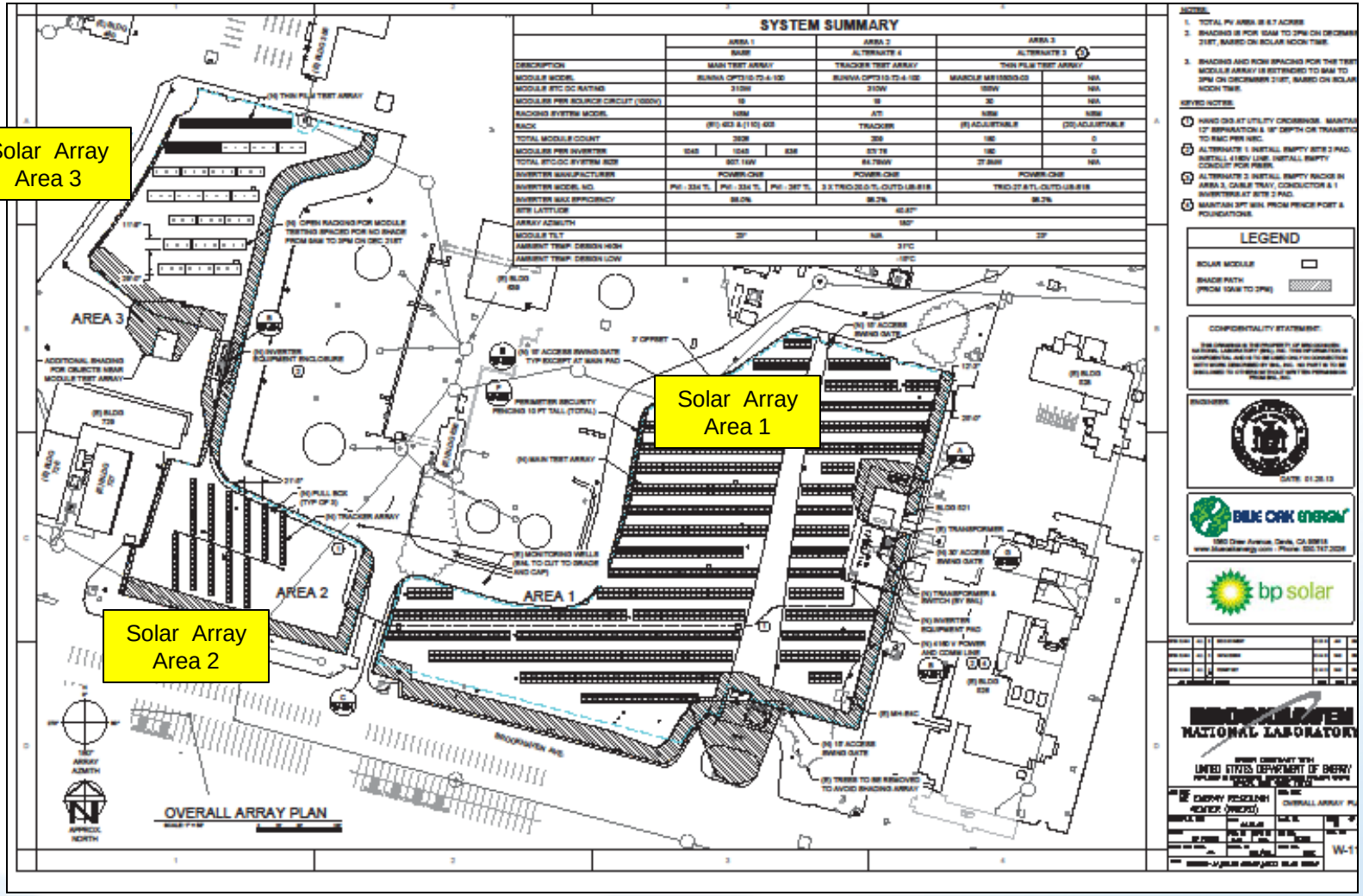
Development of the array is underway…

- Site selected for the research array
  - BNL main campus ~6.9 acres
  - Land prep is completed
- Architect-Engineering firm hired
  - Blue Oak Energy (designed LISF)
- Final design complete
  - Received January 24, 2013
- Long-lead equipment ordered
  - Solar Modules for Area 1
  - Inverters for Area 1
  - Racks for Area 1
  - Transformer for connection to BNL
- Construction contract out for bid
  - Bids expected Feb 22
- SCADA contract out for proposal
  - Proposals expected Feb 4

Final Design of the research array is complete

- Nominal Specifications
  - Power output: ~1MW-ac
  - Reconfigurable architecture
    - 50kw – 350kw blocks
    - Voltage 600V/1000V
  - Solar Modules – Suniva Crystalline silicon
    - ~16% efficiency
    - Buy American Compliant
  - Racking: Northern States Metal
    - Fixed tilt (90%) /Single Axis trackers (10%)
  - Inverters: Aurora Power One Modular
    - Capability for individual MPPT control of blocks
- Test Capabilities
  - Inverter testing from utility-scale to string level and micro inverters
  - Storage systems – separate test pad provided
  - Microgrid – ring bus architecture included
  - Solar module testing – empty racks for module testing

The design includes 3 separate test areas…



Area 1: ~907kw-dc for testing inverters, storage and micro-grids – and provide power to BNL
Area 2: ~ 65kw-dc for testing modules on trackers
Area 3: ~150kw-dc for testing new module designs and inverter topologies

BNL is installing smart sensors in the campus electrical network as part of the smarter grid research agenda

Smart Micro-Grid (SMG) Demonstration Project

- BNL has a 20 MW base load representative of a typical industrial complex; 13.8 kV primary distribution, peak load of ~70MW
- An active collaboration is in place for placing a network of new generation grid sensors in the BNL distribution system
- BNL will evaluate how advanced monitoring and modeling can be used to better manage distribution systems
- NSERC includes renewable generation on the BNL grid and will enable using the site as a microgrid test bed.

Thank you!