U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

SOLAR ENERGY TECHNOLOGIES PROGRAM

High Penetration of Photovoltaic (PV) Systems into the Distribution Grid

WORKSHOP REPORT

February 24-25, 2009

Ontario, CA

Sponsored by:

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Solar Energy Technologies Program

Systems Integration Subprogram

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Executive Summary

The Solar Energy Technologies Program (SETP), in the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), held a technical workshop on high penetration of photovoltaic (PV) systems into the distribution grid on February 24-25, 2009, in Ontario, CA. The purpose of the workshop was to convene experts and practitioners in the PV/grid integration field to reach agreements on several key topics, including:

- Identifying key technical issues and barriers associated with high PV penetration levels
- Determining high-priority research, development, and demonstration (RD&D) activities for the near-term, mid-term, and long-term to address the identified issues and barriers
- Defining performance requirements for high-priority RD&D activities

A workshop planning committee with members representing PV/grid integration stakeholder groups was assembled by the SETP to develop the workshop process and sessions to accomplish the tasks above. Additionally, the committee members provided their nominated lists of experts and practitioners to the DOE for invitation to the workshop. Organizations represented on the committee included the following:

Professional Associations ▪ Solar Electric Power Association ▪ Electric Power Research Institute Electric Utilities/Building Group ▪ Southern California Edison ▪ FirstEnergy ▪ ConSol System Integrators ▪ SunEdison ▪ SunPower	National Labs ▪ National Renewable Energy Lab ▪ Sandia National Labs ▪ Oak Ridge National Lab ▪ Pacific Northwest National Lab DOE ▪ Office of Electricity Delivery and Energy Reliability (OE) ▪ EERE

More than 110 experts from key stakeholder groups attended. These groups included: electric utilities, suppliers and services providers, research institutes (national labs and universities), end-use groups (residential, commercial, and industrial buildings), and Federal and State programs. To achieve the desired levels of interactive dialogs and engagements, all attendees were assigned to four teams (red, blue, green, yellow), with each team composed of 25-30 members and having a balanced representation of key constituency groups. In addition, a facilitator and a co-facilitator were assigned to each team to facilitate team member discussions toward reaching agreements on the discussion topics.

Workshop conclusions on the top issues and barriers surrounding high penetration of PV systems into the distribution grid and their corresponding RD&D activities are summarized in this section. Performance requirements (such as end goals, milestones, performance metrics, and cost and duration) for each of the top 5-6 RD&D activities identified by each team are listed in individual team sections (see Sections 2-5). Furthermore, Section 6 summarizes key policy/regulation and financial issues that were presented and discussed at the workshop.

Major Findings

The **top issues and barriers** across all four teams are summarized below:

- Grid Integration
  - Smart grid characteristics such as two-way controls and communications
  - Inverter development with intelligent bundling for ancillary services (e.g., voltage support)
- Solar Variability/Intermittency
  - Standardized collection and analysis of data from PV sites for forecasting generation and modeling effects on grid
  - Storage as a possible solution
- Modeling Integration of PV generation
  - Steady-state and dynamic models to simulate penetration levels
  - To encourage acceptance of PV by electric utilities and ensure stable power supply
- Revision of Standards and Codes
  - To establish agreement on PV equipment capabilities
  - Update Institute of Electrical and Electronics Engineers (IEEE) Standard 1547 to address high penetration levels

The **top RD&D activities** stemming from these issues and barriers were organized into three categories:

	Duration (years)	Rough Cost Estimates (USD M/yr)
Near Term	0-3	2-8
Mid Term	3-5	5-10
Long Term	>5	10-30

A key near-term RD&D activity that was identified in multiple teams was collection and analysis of sub-hourly data sets on solar variability, which feeds into forecasting PV generation and modeling the effects of such generation on the grid. Modeling of more complex high-penetration scenarios could extend into a mid-term activity.

There was general agreement that standards for inverter operation and performance (e.g., IEEE 1547) need to be revised and developed to enable ancillary services such as local voltage regulation. These changes in standards are expected to be near- to mid-term activities, depending on the availability of technical evidence to support changes.

Demonstrations of low-cost, high-speed, and secure communications via smart metering were identified as another important near-term RD&D activity. Demonstrations of bundling additional smart grid components (e.g., storage) and grid integration (controls and communications) will be a mid-term activity. Finally, demonstrations of energy management systems (EMS) that include standards for communications and controls, interoperable components, and ancillary services at high-penetration levels will be a long-term activity.

Caveats

Before discussion of technical issues and barriers preventing high penetration of PV, multiple teams were uncertain about the meaning of each penetration scenario: <15%, 15-30% and >30%, which were defined by the DOE for workshop discussion purposes as the [peak AC output from PV]/[peak load]. This simple definition, however, does not take into account other key variables such as demand load, line impedance, and load shapes, which should be considered in determining RD&D solutions under each penetration scenario. Eventually, it was determined that the definition has some limitations from an operational standpoint.

Path-Forward Discussions

During the closing plenary, the workshop participants further discussed the next steps concerning implementation of workshop findings and their progress updates. These discussions are summarized as follows:

To facilitate achieving the end goals of the RD&D activities, high-level action items detailing their implementation and pathways or roadmaps should be created. Additionally, the RD&D cannot be done in isolation or in a vertical (stovepipe) management environment. Rather, the RD&D ought to be approached holistically to include broader issues such as wind generation, net load, interoperability and smart grid. This systems engineering approach needs to consider both positive and negative attributes related not only to energy, but also to the environment (air, water, etc.) and to overall national security. More industry, utility and government partnerships should be developed and working groups should be formed to support these RD&D activities in pilot projects and hands-on study participation by utilities, vendors, and others. A starting point could be making the Renewable Systems Interconnection (RSI) reports more user-friendly by consolidating the fourteen documents into one and publicizing its availability.

There was widespread interest in continuing this workshop in the form of progress updates on the recommended RD&D activities. The frequency of these meetings would depend on DOE goals for the workshop: high level or detailed analysis. Recommendations were made to hold workshops on both coasts or in a webinar format, and to invite more participants such as the chair for IEEE 1547 and the Western Electricity Coordinating Council (WECC) modeling group.

As presented, the findings of this workshop will be used by the SETP as recommendations for the development of technical topic areas in funding opportunity announcements to industry for PV systems integration. The SETP will continue to target PV, Concentrating Solar Power (CSP), systems integration, and market transformation as key areas for RD&D investments to achieve grid parity for PV electricity by 2015 and accelerate widespread commercialization of clean solar energy technologies across America.

Table of Contents

1. Introduction

The solar energy market has been growing rapidly during the past five years, especially in the grid-tied photovoltaic (PV) market sector. According to a recent industry report, cumulative grid-tied PV capacity in the U.S. grew to 792 MW by the end of year 2008,[1] with an 81% increase in new grid-tied PV installations in 2008 over 2007 and 53% in 2007 over 2006. These rapid growth rates are expected to continue and be further spurred by the President's energy plan to double renewable capacity in the next three years to help the Nation concurrently meet its economic, energy security, and environmental challenges.

As solar electricity continues to grow its share in the U.S. electricity generation mix, it becomes increasingly important to understand technical challenges facing high penetration of solar electricity, especially considering the effects of its variable nature of generation on the reliability and stability of the electric power system. Overcoming the technical challenges will be critical to placing solar electricity on an even playing field with other dispatchable generation resources in an integrated resources planning process and will allow solar electricity to be fully integrated into power system operations, from serving local loads to serving as grid resources for the interconnected transmission and generation system. This full integration of solar electricity into the power system planning process and operations is needed to further accelerate the growth trajectory of grid-tied PV systems and meet the energy plan goal.

Recognizing that a limited number of high-penetration PV installations currently exist, their effects on the reliability of grid operations are beginning to be monitored by the DOE and its partner organizations. These installations include: 91 Solar Smart homes in the Anatolia III subdivision in Rancho Cordova, California; a 4.6 MW power plant in Springerville, Arizona; an 8 MW PV power plant in Alamosa, Colorado serving normal agriculture loads; and a 14 MW PV plant at Nellis Air Force Base in Nevada with 70,000 PV panels, i.e., the largest PV power plant in North America. Nonetheless, they are far too few in occurrence and few in representative case studies. With many larger PV installations coming online soon or being announced, they are expected to be interconnected with distribution circuits having different characteristics like circuit designs, load and generation mixes, etc.; their penetration effects will likely need to be dealt with differently depending on various penetration levels and circuit characteristics.

1.1 Solar Energy Technologies Program (SETP)

The SETP, within the DOE Office of Energy Efficiency and Renewable Energy (EERE), conducts research, development, demonstration and deployment (RDD&D) activities to accelerate widespread commercialization of clean solar energy technologies (PV and concentrating solar power [CSP]) across America. The clean solar energy technologies, through the SETP partnership efforts with industry, will lower greenhouse gas emissions, provide a clean and secure domestic source of energy, and create thousands of high-paying jobs in a green economy.

The goals of the SETP are to make PV solar energy cost-competitive across the United States by 2015 and to directly contribute to private sector development of more than 70 gigawatts of solar electricity supplied to the grid to reduce carbon emissions by 40 million metric tons by 2030. To accomplish these goals, the SETP structures its RDD&D activities into four subprograms: PV, CSP, Systems Integration, and Market Transformation.

The primary goal of the Systems Integration effort is to reduce both the technical and economic barriers to achieving high penetration levels of distributed renewable systems on the electric power system. Since integration-related issues for the distribution system are likely to emerge first for PV technology, Systems Integration has placed high importance on working with utilities, industry, and other stakeholders to develop the technologies and methods enabling the widespread deployment of distributed PV technologies, including storage systems, advanced power electronics, and controls, into the U.S. electricity grid.

[1] Solar Energy Industries Association, US Solar Industry Year in Review 2008, March 2009, available at http://www.seia.org/galleries/pdf/2008_Year_in_Review-small.pdf

To address critical grid integration issues, Systems Integration launched the Renewable Systems Interconnection (RSI) study effort in 2007 and completed its reports in early 2008.[2] The 14 RSI topical reports and its Executive Summary identified major technical areas for high-penetration PV research, development, and demonstration (RD&D). These reports have guided Systems Integration in launching new development activities with industry, notably the Solar Energy Grid Integration Systems (SEGIS) awards to 12 industry/university teams for developing advanced inverters/controllers for PV/grid integration applications.

The Systems Integration RD&D activities require changes to be effected on both traditional grid and PV system operations and controls. First, PV systems will need to operate interactively with conditions on the grid and other local resources, including load control and generation and storage. Second, the distribution grid will need to be modified and operated in a more intelligent fashion, becoming part of a smart grid, to be more accommodating to the two-way power flow and variable generation introduced by distributed PV systems. Interoperability technology and operational standards are paramount to meeting PV systems integration challenges.

As a continuing effort to broaden and deepen stakeholder engagement in jointly planning and implementing RD&D activities, Systems Integration convened the High-Penetration PV workshop to seek industry input on identifying key technical issues facing PV penetration levels, including their effects on operations of different distribution circuits, and defining their technical solutions.

1.2 Workshop Plan Development

The Systems Integration subprogram began the workshop effort by first assembling a Workshop Planning Committee with members representing PV/grid integration stakeholder groups:

Professional Associations ▪ Solar Electric Power Association ▪ Electric Power Research Institute Electric Utilities/Building Group ▪ Southern California Edison ▪ FirstEnergy ▪ ConSol System Integrators ▪ SunEdison ▪ SunPower	National Labs ▪ National Renewable Energy Lab ▪ Sandia National Labs ▪ Oak Ridge National Lab ▪ Pacific Northwest National Lab DOE ▪ Office of Electricity Delivery and Energy Reliability (OE) ▪ EERE

The Planning Committee held a one-day meeting in Washington, DC, on November 6, 2008, and developed a workplan and a draft agenda (Appendix A). The workplan included the following:

Purposes

- To identify key technical issues and barriers associated with three PV penetration levels (i.e., <15%, 15-30%, and >30%). The % penetration is defined as AC output of PV divided by peak load capacity.
- To define high-priority RD&D activities for the near term (0-3 years), mid term (3-5 years), and long term (>5 years) to address identified issues/barriers
- To define performance requirements for high-priority RD&D activities
- To build stakeholder agreement on the above
- To provide input to the DOE for solicitations in FY09 and beyond on high-penetration PV RD&D
- To facilitate dialogs on financial/policy/regulation issues and potential changes

[2] The 14 RSI topic reports and an Executive Summary are available at http://www1.eere.energy.gov/solar/solar_america/rsi.html.

Non-purposes

- Not to discuss renewable integration issues other than PV with the distribution grid
- Not to address transmission-related issues, including intermittent sources at the transmission level (i.e., only intermittent sources at the distribution level will be addressed when considering high-penetration impacts of PV)

Products

- Tabulated summaries capturing all information on the index cards, boards, and PowerPoint slides at each breakout session (produced by the session facilitators)
- Detailed workshop report, including major discussions at plenary sessions (Appendix B) and breakout sessions (Appendix C). Assigned Technical Leads in each breakout session to take input from the co-facilitators and facilitators to produce respective report sections.

Participants

- About 120 invited experts/practitioners representing key stakeholder organizations will be allocated to the breakout sessions based on their interest/expertise
    - Electric utilities (distribution and generation utilities)
    - Solar system integrators
    - Manufacturers & technology providers
    - Industry associations
    - End-use groups (homebuilders, building groups)
    - National labs
    - Universities
    - Consultants

Each Planning Committee member was further requested to provide a list of ~20 of their nominated experts or practitioners. A Committee conference call was convened on November 18, 2008 to discuss the compiled list of invitees (252 people from 157 organizations) to identify any under-represented stakeholder groups, as well as to develop the following timeline items:

- November 24: Save-the-date-notice sent by the DOE to all invitees
- December 19: Official DOE invitations sent to all invitees, along with the workshop agenda, with RSVP due January 6; workshop Web site open for registration; all speakers confirmed
- January 7: Planning Committee conference call
- January 14: If needed, send the invitation letters to the second round of invitees
- Week of February 9: Breakout session tech leads/facilitator/co-facilitator to go over the session game plan and all the details (to be scheduled by each facilitator)
- February 24-25: Workshop event
- March 9: Summary reports due from session facilitators; detailed session discussion notes due from note-takers
- March 23: Individual breakout session reports due from Technical Leads
- April 6: Draft workshop report ready for comments by all participants

Additional nominees from under-represented groups were further provided by committee members, which resulted in a total of 287 invitations by the DOE to 178 organizations.

Subsequently, Jennifer Stinebaugh of Sandia National Laboratories agreed to serve as the lead facilitator for the workshop. A sub-working group involving Dan Ton, Marie Mapes, Paul Wang, and Jennifer Stinebaugh was convened to develop the facilitation plan. This facilitation plan was further refined with input from individual session facilitators, co-facilitators, and technical leads, as identified below, through conference calls held by each individual team facilitator.

Red Team	Green Team
Facilitator: Jen Stinebaugh Co-Facilitator: Maria Wang Technical Leads: ▪ Ben Kroposki* ▪ Juan Torres ▪ Ethan Sprague	Facilitator: Scott Stephens Co-Facilitator: Toni Leon Kovarik Technical Leads: ▪ Peter McNutt* ▪ Frank Habibi-Ashrafi ▪ Ross Guttromson
Blue Team Facilitator: Marie Mapes Co-Facilitator: Stephen Sexton Technical Leads: ▪ John Kueck* ▪ Adrianne Kimber ▪ Abe Ellis	**Yellow Team** Facilitator: Marie Garcia Co-Facilitator: Kevin Lynn Technical Leads: ▪ Scott Kuszmaul* ▪ Christy Herig ▪ Tom Key

* Team leads who were also responsible for drafting the individual team discussion summary write-ups.

The workshop was conducted on February 24-25, 2009 with 116 pre-registrants representing 64 entities as listed in Appendix D:

- 16 electric utilities (37 registrants)
- 28 suppliers and services providers (37 registrants)
- 7 research institutes (16 registrants)
- 3 Federal/State agencies (10 registrants)
- 3 associations (7 registrants)
- 7 consulting firms (9 registrants)

2. Red Team Breakout Sessions

As penetration levels of PV increase on the distribution grid, the traditional grid and renewable energy systems' operations and controls will need to change. First, distributed generation will need to operate interactively with both the conditions on the grid and with other local resources, including load control and generation and storage. Second, the distribution grid will need to be modified and operated in a more intelligent fashion, becoming part of a smart grid, to be more accommodating to the new requirements of distributed renewable energy systems. Interoperability technology and operational standards are becoming paramount to having a smart grid evolve that will meet the transition for renewable energy system integration. Successful implementation of high levels of PV into the utility grid requires close coordination between the PV systems, electrical utility and local loads. It also requires an accurate understanding of the PV system and electric grid variability and capabilities.

A critical challenge for widespread deployment of PV systems at the distribution level is that the current distribution system was designed, built, and operated for use with centralized generation. With limited capacity for two-way power flow and without control and communication at the point of use, the existing distribution grid is not capable of realizing the full potential of distributed PV systems.

Key issues and barriers preventing high penetration levels of PV include:

- Variability of the solar resource
- Aging grid infrastructure and system flexibility
- Grid operations: protection and coordination between devices
- Grid impact assessment tools and models
- Value enhancements
- Interconnection and interoperability standards

Variability of the Solar Resource

Sunlight is an inherently variable resource due to day/night cycles and changes in cloud cover. In order to understand the impact of high levels of solar energy integrated into the electric power system, solar data sets and the corresponding response of various-sized PV systems to changes need to be characterized. The variability and nondispatchability of today's PV systems affect not only the stability of the utility grid but also the economics of both the PV system and the energy distribution system. There are a number of critical solar resource data and information gaps identified that need to be filled to support expanded high-penetration PV analysis and systems operations in the future. Reliable, sub-hourly data sets (perhaps even sub-minute), representing the time response of solar PV, especially over compact service territories, need to be developed. These data can be used as part of load-control and load-following studies under high-penetration scenarios with no storage available. There is also a need for improved spatial resolution of data sets so that the resource information can be more accurately pinpointed to specific locations where grid-tied PV systems are likely to be installed. A critical need is advanced solar resource forecasting capabilities over a variety of time steps, including very short term (1-3 hour) for load dispatching, day ahead for system operations, and seasonal and interannual for long-term system planning and cash-flow analyses. This information also needs to be available in a user-interactive data archive so that end users can create and access specialized data sets on-line to meet specific analytical requirements.

Aging Grid Infrastructure and System Flexibility

The electrical power system was never designed for two-way power flow at the distribution level. It was designed mostly as a radial system where power flowed from central station power plants through transmission systems, to distribution systems and finally to customer loads. One of the unique aspects of PV is the ability to distribute generation at several levels of the power system and specifically at the distribution level. Integration issues (e.g., voltage regulation, unintentional islanding, and protection coordination) need to be addressed from the distributed PV system side and from the utility side for high-penetration PV scenarios. Grid planning methodologies also do not account for distributed PV and need to be revised. The electric power system currently does not have a way to store large amounts of electricity. Energy storage needs to be developed and optimized to address variability and generation shifting. Other techniques such as load management and demand response also need to be integrated into system operations to increase grid flexibility.

Grid Operations: Protection and Coordination between Devices

When multiple sources of energy are integrated on the distribution system, their operations must be coordinated. Combining PV systems with energy efficiency, demand response, and plug-in hybrid electric vehicles to improve system efficiency and maintain adequate spinning reserves is critical. There is a need to develop monitoring and control technologies and protocols for PV systems to increase interoperability and enable coordinated operation and protection of all equipment on the distribution feeder. Protocols should allow energy and ancillary services market participation by the renewable energy systems. One common infrastructure with interoperability throughout can be used to enable demand-side management, implementation of flexible metering tariffs and energy markets, voltage regulation, and enhanced distribution system management. This would allow aggregation of hundreds of individual systems and tie back to utility grid management.

Grid Impact Assessment Tools and Models

Understanding the impacts of high-penetration PV scenarios is key to giving utilities confidence that they can allow the installations of these systems. Utilities will need dynamic and steady-state models both on the transmission and distribution levels to simulate current and future penetration levels. Currently the commercially-available simulation tools do not incorporate PV system models or solar resource information. There is also a need to be able to evaluate the impacts of PV and loads as an integrated system.

Value Enhancements

As penetration levels rise and advanced grid concepts are implemented, PV systems will be positioned to provide reliability services that conventional generators provide today, such as frequency and reactive power support (voltage control), regulation service (for regulating the rapid swings in power on a minute-by-minute basis and stabilization of intermodal oscillations), and backup power when combined with energy storage. With these high-value capabilities, power generation on the "customer-side of the meter" can enhance the reliability of the power system, while creating an opportunity for residential customers to enhance the economics of electricity consumption. In order to accomplish these enhancements, changes are needed to existing interconnection standards and regulations to accommodate inverters providing ancillary services.

Interconnection and Interoperability Standards

The U.S. electric grid safety and reliability infrastructure is comprised of linked installation codes, product standards, and regulatory functions such as inspection and operation principles. Current interconnection standards were designed around low penetration levels of distributed generation and need to be updated to address high penetration levels. Lifecycle maintenance of standards also needs to be addressed with standards being on a five-year reaffirmation cycle. IEEE 1547 needs to address low-voltage ride-through requirements seen in wind grid codes and active voltage regulation on the distribution system, and look beyond the point-of-common coupling to system impacts.

RD&D to Address PV Integration

In order to allow higher penetrations of PV systems on the electric power system, utilities will need to understand the behavior of the PV system, especially the inverter, under fault conditions or rapid fluctuations due to clouds. The DOE should address this area with specific research in characterizing PV system output and evaluate it in both lab and fielded conditions. In the future, fully implementing a solar forecasting model to determine PV system output over various time scales (seconds, minutes, and hours) for utility operations will be needed. The model would include: array type, array size, inverter response, probability of clouds, historical data, and real-time weather data. It could then develop accurate weather/solar forecast, compare existing system data to predicted weather and system output, and determine the sensitivity of panels to pollution, dirt, and other factors including various cloud types.

As high levels of PV systems are integrated into the utility grid at specific locations, basic planning and operations methodologies should be developed for determining PV integration and penetration limits. In order to accomplish this, models of PV system performance should be integrated with existing utility planning tools and simulation software. Advanced transmission and generation planning and analysis best practices (including techniques and tools) for high penetrations of renewables on distribution systems need to be developed. This would include the development of steady-state and dynamic open source inverter-models, conducting analysis of test data, model validation, and case studies with groups such as IEEE and WECC. Also linking solar resource models and forecasts into the operations needs to be completed. With respect to advanced operations, microgrid capabilities will be needed to improve customer reliability, enhance power quality, and provide backup power functions.

As technology evolves to allow high-penetration levels, existing interconnection standards and regulations will need to be modified. New research testing and modeling of high-penetration scenarios will need to demonstrate why standards should be adjusted to reflect high-penetration PV system operations. This is extremely important in developing support from industry for these changes.

TABLE 2.1. LIST OF PARTICIPANTS

Name	Organization
Mark Baldassari	Enphase Energy
Michael Bradley	Hawaii Electric Light Co.
Richard Bravo	Southern California Edison
Patrick Chapman	SmartSpark Energy Systems
Darell Holmes	Southern California Edison
Mary Huller	Duke Energy
Charles Korman	GE Global Research
Ben Kroposki[1, 2]	National Renewable Energy Laboratory
Bill Mulligan	SunPower Corp.
Dan Pearson	Pacific Gas and Electric Co.
Ann Peterson	Itron, Inc.
Roger Salas	Southern California Edison
Colin Schauder	Satcon
Kevin Schneider	Pacific Northwest National Laboratory
Michael Sheehan	Interstate Renewable Energy Council
Ethan Sprague[1]	ConSol
Jen Stinebaugh, Facilitator	Sandia National Laboratories
Holly Thomas	U.S. DOE
Dan Ton	U.S. DOE
Juan Torres[1]	Sandia National Laboratories
Wechung Maria Wang, Co-Facilitator	Energy & Environmental Resources Group
Bob Yinger	Southern California Edison

1: Denotes Planning Committee member & session Technical Lead
2: Denotes primary author of the session summary description

TABLE 2.2. TECHNICAL ISSUES AND BARRIERS

(DIAMONDS INDICATE THE NUMBER OF VOTES RECEIVED TO IDENTIFY THE TOP FIVE PRIORITIES)

Variability of Solar Resources	Aging Grid Infrastructure	Protection and Coordinated Operations	Grid Impact Assessment Tools and Models	System Flexibility	Value Enhancements	Standards
▪ Need forecasting and better resource data ♦♦♦♦♦♦ ▪ Cloud transients - Ramp rates ♦♦♦♦♦♦♦♦♦	▪ System planning for load growth ▪ Nuisance, low power faults and trips (<15% penetration) ▪ Two-way power flow currently not feasible (15-30% penetration) ♦♦♦♦ ▪ Need to catalog known problems/ best practices	▪ Data aggregation from multiple energy sources ♦♦♦♦♦♦♦♦♦♦♦ ▪ Voltage regulation ♦♦♦♦♦ ▪ Communications/coordinated operations/protection ♦♦♦♦♦♦♦♦♦♦♦♦♦♦♦ ▪ Training and education (e.g., installation) ▪ Power quality -Harmonics (>15% penetration) ♦♦	▪ Lack of integration of solar models into distribution models ♦♦♦♦ ▪ Need PV/dynamic modeling - Of PV inverters during faults ♦♦♦♦♦♦♦♦♦♦♦♦♦ ▪ LTC, line regulation, capacitor regulation during clonal events	▪ High cost and lack of energy storage for PV ♦♦♦♦	▪ Ancillary services (storage, power regulation, VAR compensation, etc.) ♦♦♦♦♦♦♦♦ ▪ PV as backup power ♦♦♦ ▪ Future PV for smart grid ♦♦ ▪ PV inverter voltage regulation (15-30% penetration) ♦	▪ Update standards and codes - Revise IEEE standard 1547 ♦♦♦♦♦♦♦♦♦♦ ▪ Worker and customer safety

TABLE 2.3. RD&D ACTIVITIES

(DIAMONDS INDICATE THE NUMBER OF VOTES RECEIVED TO IDENTIFY THE TOP FIVE PRIORITIES)

	Modeling	Communications/ Coordinated Operations/Protection	System Aggregation/Management	Update Standards and Codes	Resource Variability
Near Term	▪ Integrate NREL models and data with existing software (e.g., synergee) ▪ Develop steady state and dynamic models ♦♦♦♦♦♦♦♦♦♦ ♦♦♦♦♦♦	▪ Develop data aggregation and transport infrastructure ♦ ▪ Develop standard protocols for utilities to remotely control PV equipment operation ♦ ▪ Examine anti-islanding protection enhancement and more stringent ride-through requirements ♦ ▪ Protection and inverter performance ♦♦♦♦♦♦♦♦	▪ Communication and management of technology equipment (what information needs to be gathered at what level of transparency and granularity? What level of analysis needs to be applied to this information? Who are the end users of this information?) ♦	▪ Revise and expand IEEE 1547 ♦♦♦♦♦♦♦♦ ▪ Limit harmonics generation by inverters used in PV generation stations	▪ Comprehensive study on effects of cloud transients, including analysis of empirical data and modeling, and factors such as PV system size, local penetration level, grid interaction, cloud type ♦♦♦♦♦ ▪ Forecast PV generation (sub-hourly) ♦♦♦♦♦♦♦♦♦♦♦♦

	Modeling	Communications/ Coordinated Operations/Protection	System Aggregation/Management	Update Standards and Codes	Resource Variability
Mid Term	▪ Develop steady state and dynamic models	▪ New circuit configurations to accommodate high PV penetration ♦♦♦♦ ▪ Distribution communication with RE inverters for curtailment, VAR support, ride through ♦♦ ▪ Communications and collection technology to automate PV aggregation ▪ Develop best practices for distribution operations with embedded generation ♦ ▪ Technology to smooth the effects of variable generation ♦	▪ Aggregate system impacts - Analyze circuit and grid impacts of high PV penetration ♦♦♦♦♦♦♦♦♦♦ ▪ Utility system architecture that would permit islanding at the residential level ▪ Module-level monitoring and communication and power-point tracking ▪ Design/test system to track amount of PV generation on a circuit to determine real load ♦♦ ▪ Research changes to the demand side from consumer behavior (energy efficiency and demand response) ♦♦	▪ Demonstrate PV system projects that can show possible standards changes (e.g., inverters that regulate voltage) ▪ Uniform interconnection standards for high PV penetration ♦♦	▪ Work with weather services to predict power loss due to shading and power increase due to cloud enhancement, then compare forecasted with actual PV generation ♦♦♦ ▪ Fast dynamic response inverter that can restore maximum power points in seconds ♦♦♦ ▪ Incorporate cloud cover impacts on short-term PV output into an open source program such as PV Solar ♦
Long Term	▪ Develop steady state and dynamic models ▪ Systems modeling that captures variable generation, communication and control, business/ markets ♦♦♦	▪ Develop communications technologies to improve monitoring and control of PV systems (integrates demand response, distributed generation, transmission) ▪ Determine if inverters should provide ancillary services (e.g., voltage support) ♦♦♦♦♦♦♦ ▪ What level of feedback changes consumer behavior? ▪ Develop software and hardware to model, predict and react to the effects of cloud transients	▪ System aggregation through time of use rates, smart grid leading to home automation in conjunction with demand side management programs, energy storage ▪ Aggregate system impacts - Analyze circuit and grid impacts of high PV penetration ♦♦♦♦♦♦♦♦♦♦ ▪ Utility system architecture that would permit islanding at the residential level ▪ Module-level monitoring and communication and power-point tracking	▪ Revise IEEE 1547 (must show technical merit to make changes) ▪ Develop new or better communication standards to improve monitoring and control of PV systems ♦♦♦♦♦♦	

	Modeling	Communications/ Coordinated Operations/Protection	System Aggregation/Management	Update Standards and Codes	Resource Variability
		▪ Develop best practices for zero-energy homes on a road map	▪ Design/test system to track amount of PV generation on a circuit to determine real load ♦♦ ▪ Research changes to the demand side from consumer behavior (energy efficiency and demand response) ♦		

TABLE 2.4. PERFORMANCE REQUIREMENTS

	Protection and Inverter Performance	Modeling	Forecast PV Generation Capabilities	Revise IEEE 1547	Aggregate System Impacts	Design and Test New Circuit Configurations to Accommodate High PV Penetration	Determine If Inverters Should Provide Ancillary Services
End Goals	▪ Understand inverter behavior under fault conditions, both on residential (1-30kW) and commercial/ utility (>50kW) scales) ▪ Communicate test conditions and results to utility engineers/ operations	▪ Ability to model effects of solar generation sites in T&D systems ▪ Planning and operations ▪ Evaluation of economics and security ▪ Develop an integrated model	▪ Fully implement-ed solar forecasting methods to determine PV output over various time scales: sec, min, hrs for utility operations ▪ Utility tool	▪ Address LVRT, local voltage regula-tion, beyond PCC to system impacts	▪ Analyze circuit and grid impacts of high PV penetration ▪ Planning guidelines for deter-mining PV integration and penetration limits on distribution systems (to utility engineers for circuit design)	▪ Green-field design guidelines for high-penetration PV feeders	▪ Change IEEE 1547 and UL 1741 to accommo-date inverters providing ancillary services ▪ Provide reactive power control, voltage regulation, backup power (intentional islanding) ▪ Value proposition

	Protection and Inverter Performance	Modeling	Forecast PV Generation Capabilities	Revise IEEE 1547	Aggregate System Impacts	Design and Test New Circuit Configurations to Accommodate High PV Penetration	Determine If Inverters Should Provide Ancillary Services
Milestones	▪ Test inverters under fault conditions in labs or field ▪ Data collection and analysis ▪ Compare with manufacturer and literature ▪ Generate report	▪ Develop open source inverter model (steady state and dynamic) ▪ Testing inverters ▪ Analysis of testing data ▪ Model coding ▪ Validation ▪ Case studies	▪ Develop models that include array type and size, inverter response, probability of clouds, historical data, real-time weather data ▪ Develop accurate weather/ solar forecast ▪ Compare system data to predicted weather and system output ▪ Analyze existing system data ▪ Determine panel sensitivity to pollution, dirt, other factors including various cloud types	▪ Demo-nstrate proposed changes in real life ▪ Model high penetra-tion scenarios ▪ Make studies more trans-parent ▪ Refer to Germany and Japan for bench-mark studies	▪ Modeling to determine limiting factors ▪ Run scenarios with different penetra-tions ▪ Verify models with field data ▪ Data analysis ▪ Generate report	▪ Identify key characteristics of feeders ▪ Pilot project/demo	▪ Determine value of ancillary services ▪ Demo-nstrate communi-cations from utility to PV systems ▪ Demo-nstrate inverters can provide ancillary services

	Protection and Inverter Performance	Modeling	Forecast PV Generation Capabilities	Revise IEEE 1547	Aggregate System Impacts	Design and Test New Circuit Configurations to Accommodate High PV Penetration	Determine If Inverters Should Provide Ancillary Services
Performance Metrics	▪ Select equipment, sites ▪ Obtain data sheets ▪ Obtain data from lab and field ▪ Draft analysis for review/ comment ▪ Draft final report	▪ Usability, adoption and integration ▪ Validation ▪ Collaborate with IEEE committees and WECC working group	▪ Predict within 20%, 10%, or 5% accuracy of measured data for validation sites ▪ Understand the value of PV system location and how much variability can be accommo-dated at that point ▪ Study how accurate forecast needs to be (minimize spinning reserve costs) ▪ Forecast-ing models need to be operational tools	▪ New projects ▪ DOE support ▪ Draft ▪ Multiple iterations	▪ Construct functioning model ▪ Matrix of scenarios/ configur-ations ▪ Model verification with field data ▪ Draft analysis for review/ comment ▪ Draft final report	▪ Compare performance of design and operation with existing circuits ▪ Cost analysis	▪ Availability of products that provide ancillary services ▪ Grid parity for ancillary services
Cost and Duration	▪ $1-2M over 2 years	▪ $5M over 1-3 years	▪ $5M/yr for 3 years	▪ $1.5M/yr from DOE for 5 years	▪ $0.5-1M over 2 years	▪ $5-10M over 3-5 years	▪ $3M/yr for first 2 years ▪ $10M/yr for first 3 years for inverter develop-ment ▪ $2M/yr for 2 years for demo

3. Blue Team Breakout Sessions

Successful PV integration requires that cost and economics are clearly understood and carefully planned. Cost and economic issues will ultimately be at the basis of what is done. Also, the technical and policy issues are interwoven, and there are a number of questions that must be resolved before integrating high penetration levels of PV into the distribution grid. The following are issues needing immediate resolution:

- Who takes control of and dispatches the power flow: the customer or utility?
- Is this an open market issue or a simple tariff issue?
- Both the commercial and technical authority must be clearly established.
- A uniform technical standard that is fair to all is needed.
- Safety, protection and coordination issues must be resolved.
- Storage and responsive load can address variability, but statistical modeling methods must be developed.

Key issues and barriers and their associated RD&D activities include:

Real-Time Control of Distributed PV

In the near term, it is necessary to demonstrate control of distribution feeders with high levels of penetration, including real time system monitoring and dispatch. This control must include frequency and voltage control. In the mid term, this control will be performed using a robust system model. In the long term, a “black box” will be developed to provide “plug and play” capability over a wide area. Controls will be fully integrated with market operations.

Standard Models for Planning and Operation

In the near term, it is necessary to expand existing power system models to include PV, validate the model performance, and expand the models to large scale, statistically aggregated systems. For this effort, data on existing systems/environments must be gathered. Models to predict PV plant performance in real time, based on observed and historical weather patterns, need to be developed. In the mid term, the models will be extended to include high penetration levels of PV and the appropriate (minimal) communication between the system operator and PV. In the long term, locational models will be developed to predict PV park performance on a statistical basis with high penetration levels.

Smart Grid Components: Bandwidth, Controls, Communication

In the near term, the smart grid needs to be defined more clearly and demonstrations with smart inverters need to be built. These devices should implement low cost, secure, high-speed communications technology for two-way communication of monitored parameters and control commands. In the mid term, a common vocabulary will be defined, a demonstration smart grid will be planned, and components for transitioning from the old grid to the new grid will be designed. In the long term, the demo smart grid will be tested, validated and published.

Managing Variability in Operations

In the near term, power electronics need to be developed for power flow control and managing bi-directional power flow on circuits. It is necessary to evaluate options and methods for forecasting large integrations of PV, and use demand management to balance variability. In the mid term, both voltage regulation with PV inverters and the effect of generation variability on conventional regulation assets will be evaluated. In the long term, ancillary services with a range of distributed energy resources and responsive load will be used to balance variability.

Standards for Protocols, Interconnection, Safety

In the near term, it is necessary to develop standards for interaction between PV systems and the grid by performing a comparative analysis between the standards of IEEE, FERC, NERC, etc., to identify conflicts, overlap, and perform a high level coordination. Historically entrenched groups and interests are in charge of the standards currently, and the Federal government must provide a framework for developing new standards. The Solar America Board is currently engaged in these efforts, but a comprehensive view must be undertaken with authority to set up and monitor this process until a set of comprehensive, fair and workable national standards are developed. This work is classified as near term.

TABLE 3.1. LIST OF PARTICIPANTS

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1: Denotes Planning Committee member & session Technical Lead
2: Denotes primary author of the session summary description

TABLE 3.2. TECHNICAL ISSUES AND BARRIERS

(DIAMONDS INDICATE THE NUMBER OF VOTES RECEIVED TO IDENTIFY THE TOP FIVE PRIORITIES)

Variability of Solar Resources	Aging Grid Infrastructure	Protection and Coordinated Operations	Grid Impact Assessment Tools and Models	System Flexibility	Value Enhancements	Standards
▪ Storage Technologies: integration of load following technologies ♦ ▪ Managing variability - Time shift generation vs. peak load - Real-time production monitoring/prediction ♦♦ ▪ Lack of appropriate low cost storage technologies (PHEV currently not designed to provide power to grid) ♦♦♦♦♦♦ ▪ How does utility meet "duty to serve" and minimize fossil fuel usage? - Meet ramp rates and stability - Meet peak load on cloudy days - Could lower 52% load factor number - How can utility increase asset utilization? ♦♦♦♦♦♦♦♦♦♦♦	▪ Intelligent grid with bandwidth to handle information and data that allows DG to achieve its highest value ♦♦♦♦♦♦♦♦♦♦ ▪ Codes and Standards: Is there an inverter that allows a customer to use the power if the grid goes down? But when the grid comes back up and the "smart inverter" automatically hooks into the grid, who controls the inverter: utility or the customer? ♦♦♦♦♦ ▪ What happens to distribution line overcurrent protection coordination at higher levels of penetration? What controls are available for reverse energy flows on radial circuits? ♦♦♦♦	▪ Standards, national policy, interconnection standards, feed in program, RPS safety standards and system design issue standards, codes, regulation ♦ ▪ New inverter standards, RSI - SEGIS required utility interface to all inverters and other DG devices - PV could exceed 100% of circuit load and flow through substation to higher voltage ♦♦♦♦ ▪ Monitor and control backfeed from PV systems ♦♦♦	▪ Data infrastructure needed to support collection, monitoring, archiving individual inverters, grid components ♦♦ ▪ Dynamic models and analyses - All elements at distribution level, address, equipment, communication, control, grid operation ♦♦ ▪ Lack of decision support tools for planning and operation of high-penetration PV ♦♦♦♦ ▪ Grid impact assessment: What evaluation methods are used for voltage rise on high impedance distribution systems? Should standards be established for level of generation as related to placement of facilities? ♦♦♦	▪ Life cycle operation of inverters; make PV reliable and interchange-able ♦♦♦ ▪ Control active power manage-ment on distribution network - voltage regulation - protection coordination - dynamic network reconfigure-tion - Generation and load control - Modeling simulation for real time operations support ♦♦♦♦♦♦♦ ▪ System stability, frequency support, voltage support ♦♦♦♦♦♦ ▪ Reliability: How reliable are the PV installations perceived?	▪ Current system design not well suited to residential or small commercial sites (<15% penetration). Conventional inverters (centralized for a whole system) do not address derating issues of reduced energy in series DC systems - Need to get on a different curve for LCOE in small solar systems via AC PV ♦ ▪ Develop solar technologies to allow lower costs - Education for credits, etc. - Lack of trained installers ♦	▪ Standards, national policy, intercon-nection standards, feed in program, RPS safety standards and system design issue standards, codes, regulation ♦ ▪ New inverter standards, RSI - SEGIS required utility interface to all inverters and other DG devices - PV could exceed 100% of circuit load and flow through substation to higher voltage ♦♦♦♦ ▪ Monitor and control backfeed from PV systems ♦♦♦

Variability of Solar Resources	Aging Grid Infrastructure	Protection and Coordinated Operations	Grid Impact Assessment Tools and Models	System Flexibility	Value Enhancements	Standards
			▪ Dynamic modeling and analysis, especially at small time intervals - Lack of input data for these models, e.g., 1 minute solar resource data ♦ ▪ Factors affecting grid design: - Distributed vs centralized PV generation mix - Training and education - Codes and standards - Communica-tion and control - Dynamic modeling - How important does consumer generation become or does PV power primarily come downhill from utility? ♦♦♦♦ ▪ Modeling and simulation -Communica-tions - Wide area controls - Statistical methods - With and without smart controls ♦♦			

Table 3.3. RD&D Activities

	Real Time Control of Distributed PV	Standard Models for Planning and Operation	Smart Grid Components	Variability in Operations	Standard Protocols
Near Term	▪ Demonstrate real time utility operation/ control of feeder with high level of PV penetration, e.g., >15% ▪ Install real time system monitoring and start to collect data ▪ Real time control of data, identify technical barriers that keep control technologies from scaling up ▪ Demonstrate voltage and frequency control methods	▪ Modify existing models to include validation models ▪ Standards for exchanging model information between systems ♦♦ ▪ Simulations of large distribution systems with statistical/ aggregation methods ♦ ▪ Perform studies, develop models, define example "smart circuits" (radial and otherwise) with varying amounts of DG located at different parts of the circuit - Provide various sample operating solutions, designs and protocols ▪ Gather data on existing systems/ environments and extrapolate to high penetration scenarios - Performance and contextual data to inform new dynamic models	▪ Need to define a smart grid or component - Establish common terminology - Show how smart grid components work together with DG to provide improved/reliable services ♦♦♦ ▪ Build and demonstrate inverters with smart components ♦♦ ▪ Team with smart grid programs already in place ▪ Identify key components and needs - Define performance standards/metrics, not specific technologies - Develop program bringing together companies, utilities, basic and applied researchers to create near, mid and long term solutions ▪ Auto adaptability to smart grid (i.e., standard communications protocol) ♦ ▪ Integrated PV, energy storage, and demand management practices ♦♦	▪ R&D for management of bi-directional energy flow on distribution circuits ♦ ▪ Evaluate options for time-shifting PV ♦ ▪ Develop hour-ahead or less-PV-output forecasting by real-time monitoring of distributed PV systems - Measure solar resource ♦♦ ▪ Manage variability - Real-time (on-line) state estimation on stress level of grid	▪ Standards governing body comparative analysis; standards governance matrix (public, private, public/private partnership) ▪ Develop standards for PV and dispatchable load communication and control ▪ Communication and control standards development for inverters ♦ ▪ Standard protocol/monitoring and standard point list (what type of data?) ▪ Develop protocols that are interoperable, not necessarily universal ▪ Define operating limits and expected behavior for inverter-based systems that operate in both active and passive modes, e.g., VAR/voltage control, dynamic power output ♦♦♦♦

	Real Time Control of Distributed PV	Standard Models for Planning and Operation	Smart Grid Components	Variability in Operations	Standard Protocols
		- Develop new models and test these versus real world scenarios - Models to predict PV plant performance on a real time basis, based on observed and historical weather patterns ♦♦♦♦♦♦♦♦♦♦♦♦	▪ Develop low cost, secure, high speed communications technology for two-way communication of monitored parameters and control commands - Involves hardware and protocols ♦♦♦♦♦♦♦♦		
Mid Term	▪ Apply model-based, adaptive and robust controls for grid management ♦	▪ Develop locational models for planning (consider wind and other generation) ▪ Extend current model/ simulation platform to incorporate wide area control methods ♦♦ ▪ Develop a model/planning activity for the utilities to play instead of being forced to do something and business is taken away - Set up models to show utilities how to "play"; how this can be controlled/ optimized - Work with utility input to match pre-existing models	▪ Develop smart grid for distribution system ▪ Set up a collaborative between manufacturers of grid components, such as inverters, to work with utilities to design components that would fit the "old" grid but also work in developing a new, updated grid	▪ Voltage and VAR regulation with PV inverters ▪ Manage variability - Model variability on distribution circuit, stability, frequency and voltage control, regulation - Roll up many variable distribution circuits to determine effect on transmission - What role can storage play? What size, what location? - What is effect of this variability on conventional assets? ♦ ▪ Aggregate ancillary services using DER ♦ ▪ Low cost, low maintenance energy storage for time-shifting energy generation ♦♦	▪ Standards or protocols for monitoring equipment ▪ Develop standard process for solar interconnection study - What models, what inputs? ▪ Framework to harmonize from top down, hardware and software ▪ Customer "inside the meter" PV interconnection vs. utility or IPP grid "inside the fence" PV interconnect rules (different standards apply) ▪ Need a coherent and timely implementation of standards to comply with key aspects of PV-Grid interaction - Top-down approach that transcends historical agencies ♦♦♦♦♦♦♦♦♦♦

	Real Time Control of Distributed PV	Standard Models for Planning and Operation	Smart Grid Components	Variability in Operations	Standard Protocols
		- Lack of communication between players or a lack of understanding of utility drivers - Develop more activities to get the groups to table and to understand the drivers ♦♦		▪ Identify needs in storage program to develop small- and mid-scale storage solutions/ technologies from materials all the way to systems, particular emphasis on cheap/scalable versus high performance ♦♦♦♦	
Long Term	▪ Develop standard "Black Box" interface - Hardware and software - Self adapting - Plug and play ▪ Integrate wide area controls with market operation ♦♦	▪ Probabilistic models for power system operations with large penetrations of DER and stability analysis	▪ Develop smart grid EMS - Effectively use variety of assets: PV, storage, utility, load control, etc. - Easily configurable to add/remove components - Needs standards for communication and control (plug and play) - Be self learning to grow as system gets older ♦♦♦♦♦♦♦	▪ Power electronics for power flow control (switching)	

Table 3.4. Performance Requirements

	Small-(Residential) and Mid-Scale (<Substation) Storage Solutions	Extrapolate Existing Systems/ Models	Low Cost, Secure, High Speed Communication	Develop Smart Grid EMS	Timely, Top-Down Standards Approach	Standards – Define Expected Behavior
End Goals	▪ Technical demonstrations (both sides of meter) ▪ Benchmarking duration and capacity of storage (<1MW with 5 hours of storage) ▪ Scalable modules (1 block vs. 10 linked blocks) ▪ Identify architectures ▪ PV supplemental	▪ Utilities will know what will happen to their systems (short circuit, stability, reliability, capacitors) ▪ Models that predict behavior of distributed PV over different time frames (fault events (ms) to seasonal (months)) ▪ Predict system behavior over time in order to forecast system variation	▪ Utilize smart meter deployment to control PV/demand response ▪ Solutions for decoupled vs. coupled ▪ Demonstrate on residential, light commercial, and industrial circuits ▪ Benchmark geographic capability	▪ Adaptable system for optimized performance ▪ Secure, multi user access over web ▪ All components are interoperable ▪ PV Inverters are compatible (effectively communicate with other components)	▪ National standard for key interactions between PV systems and the grid - Communica-tion - Command - Control - EMS ▪ One sanctioned process to propose and approve new standards and interoperability requirements	▪ Convert existing inverter/ power electronic system from passive (e.g., 1547) to active, providing VAR, voltage control, etc. ▪ System can respond to external EMS command or autonomous-ly take action/ respond to sensed conditions ▪ Standard/ functional description for inverters (utilities, mfg. agreements)
Milestones	▪ Identify candidate technologies and roadmap ▪ Define charge/ discharge cycles ▪ Define parameters/ boundaries/ problems ▪ Identify scale of appropriate demonstration	▪ Define data collection requirements (which data, how often) ▪ Consult with stakeholders ▪ "Bible of grid interaction" reference (standards, operating procedures, best practices)	▪ Complete installation of AMI systems ▪ Integration of PV into software platform ▪ Integration of storage, demand response, web platform (data retrieval), home area network	▪ Survey/ lessons learned report from existing similar projects ▪ Roadmap to expected PV/DG deployment/ penetration	▪ Compose lead working group ▪ Assess current technology/ standards and determine what is base for building vs. completely new requirements (i.e., gap analysis)	▪ Industry survey of current activities ▪ Develop prototype inverters ▪ Demonstrate response to EMS and sensed conditions

	Small-(Residential) and Mid-Scale (<Substation) Storage Solutions	Extrapolate Existing Systems/ Models	Low Cost, Secure, High Speed Communication	Develop Smart Grid EMS	Timely, Top-Down Standards Approach	Standards – Define Expected Behavior
	▪ Cost analysis/ comparison (cheap, scalable)	▪ Benchmark existing high penetration systems	▪ Identify protocols: Zigbee vs. others; power line carrier ▪ Establish adequacy of protocols	▪ Demonstrate protocols, hardware, and user interface on specific, real circuits, integrated with utilities operations center ▪ Develop tools for simulation/ system planning	▪ Develop an agenda/set of recommend-ations for feedback from state agencies and utilities	▪ Accurate mathematic-al models (and inputs) of behavior ▪ Modify 1547.4 and 1741 to allow behavior identified by models ▪ Create standard interface protocols
Performance Metrics	▪ Cost/kWhr/kW ▪ Delay time of storage ▪ Reliability/ lifetime/ degradation ▪ Roundtrip efficiency (AC to AC) ▪ Environmental impact of storage device ▪ Safety of storage device (reliability, lifetime)	▪ Define a framework for data collection/ monitoring to support development and validation of models ▪ Represent-ative system scenarios monitored (several systems, large central (MW size), high density distributed PV) - Validation (how close is enough?)	▪ Data utility (cost/demand reduction) ▪ Impact on customer energy use ▪ Timing of feedback (monthly vs. real time) ▪ Data security ▪ Identify bandwidth requirements ▪ Cost per customer, payback time	▪ Data speed/latency ▪ Bandwidth ▪ Availability/ reliability of communication ▪ System stability/ reliability ▪ System security (hacker resistant) ▪ Load factor improvement	▪ Working group effectiveness (Utilities, PV food chain, EMS, utility committees, networking, SCADA, NIST, DOE, FERC) ▪ Establish working group to address gaps by end of year 1 ▪ Draft standard ready for circulation by end of year 2 ▪ Incorporate feedback by end of year 3	▪ Meets tolerances defined in functional specifica-tions ▪ Manufactur-ability/ scalable ▪ Reliability/ durability/ stability/ security of operation ▪ Remotely program-mable ▪ Interoper-ability with other grid components

	Small- (Residential) and Mid-Scale (<Substation) Storage Solutions	Extrapolate Existing Systems/ Models	Low Cost, Secure, High Speed Communication	Develop Smart Grid EMS	Timely, Top-Down Standards Approach	Standards – Define Expected Behavior
Cost and Duration	▪ $10M/yr for multiple projects over 3 to 5 years	▪ $2.5M over years 1-3 for data collection effort ▪ $2.5M over years 1-3 for prototype modeling, analysis ▪ $4M over years 2-3 for verification and coding into utility tools	▪ $3-5M/yr over 2 to 3 years	▪ $5-10M for each demo project (3 to 5 per year) for 5 to 10 years ▪ $2-3M for each R&D project (3 to 5 total)	▪ $0.5M for year 1 ▪ $1.5M for year 2 ▪ $1.0M for year 3 ▪ $0.5M/yr for year 4 and +	▪ $24M over 1 to 3 years (time to change standards), then over 2 to 3 years (implementa-tion)

4. Green Team Breakout Sessions

The Green Team decided that solar intermittency is the fundamental problem with achieving 50 – 65% penetrations of PV into primarily residential distribution grids. The group discussed several solutions to the intermittency issue, including energy storage, interoperability between devices, smart communications and controls, and advanced power electronics. For example, in order to overcome transients due to passing clouds, utilities will need to coordinate with distributed energy storage. Smart communications and control standards, along with specialized power electronics for different sizes and types of grid designs, will need to be developed to achieve this coordination. To help utilities understand the interactions, models need to be developed that predict power quality as a function of penetration level, as well as focus on forecasting, voltage distribution, dynamic simulations, and effective load-carrying capability. Before any of these can be implemented, though, protection and interconnection standards and procedures will need to be revised, improved and developed.

The following RD&D activities are key to overcoming the intermittency of high penetrations of PV into residential distribution grids:

- Form a utility/industry coordination working group
- PV demonstrations with managed voltage and balancing dispatch control
- Develop high-penetration distribution models
- Revise IEEE 1547
- Intentional islanding demonstrations (not necessarily specific to PV)

Form a Utility/Industry Coordination Working Group

A consortium of national laboratories, utilities, non-profits, PV industry and others needs to form a working group to recommend codes, standards and best practices, especially addressing the issue of multiple points of PV generation on distribution systems. The working group would hold meetings and workshops on an ongoing basis.

PV Demonstrations with Managed Voltage and Balancing Dispatch Control

This RD&D activity would demonstrate the feasibility of PV with storage on the utility and customer side in a cost-effective assessment, taking advantage of newly developed standards and protocols for grid integration. Ultimately this will produce a cost-effective methodology utilizing sound engineering design and system-integration requirements and controls.

Develop High-Penetration Distribution Models

The outcome of this activity will be to have a diverse set of stakeholders, including utilities, manufacturers and PV system integrators, produce a PV system model that will also incorporate weather forecasting. The system model will include PV array, inverter and storage components. It will include static and dynamic models and will integrate with utility distribution system models. Initially a survey of any existing products will be conducted, compiling the objectives, inputs, outputs, scenarios, strengths and weaknesses of each.

Revise IEEE 1547

In order for high penetrations of PV to be integrated into distribution systems, IEEE 1547 needs to be revised in a couple ways: it needs to account for how neighboring PV systems affect the utility consensus, and it must also account for ride-through of multiple events. Higher penetrations of PV systems attached to distribution systems will make it critical to account for the interaction of large numbers of systems on harmonics, voltage, frequency, supply voltage and load. The standard must also address supporting distribution systems by means of internal communications to help ride-through utility events.

Intentional Islanding Demonstrations

Intentional islanding demonstrations should test the operation of microgrids for one month of continuous islanding and then increase time steps to one year. Smart controls and communications would be implemented in phases to test demand response with storage. This activity is not necessarily specific to PV.

The above activities will lead to the development of the models, standards, communications, controls and equipment required to integrate high penetrations of PV systems into the distribution grid so that they contribute to its reliability, leading to greater capacity and more stable operation, and ultimately increasing the value of PV to the utilities and customers.

TABLE 4.1. LIST OF PARTICIPANTS

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1: Denotes Planning Committee member & session Technical Lead
2: Denotes primary author of the session summary description

TABLE 4.2. TECHNICAL ISSUES AND BARRIERS

(DIAMONDS INDICATE THE NUMBER OF VOTES RECEIVED TO IDENTIFY THE TOP FIVE PRIORITIES)

Modeling	Inverters	Variability of Solar Resources	Smart Communications	Protection and Coordinated Operations and Standards	Grid Impacts
▪ Better forecasting models and tools - Screening tools for distribution engineers to evaluate impacts on capacity, etc. - Software tool to determine dynamic impact of PV during PV intermittencies - Especially for ISO RTO and other system operators - IEC 61850 extension to encompass PV - Voltage disturbance due to high number of generation (PV) connected on the system ♦♦♦♦♦♦♦♦♦♦ ▪ Value of solar electricity for grid operators - Peak shaving, TOU rates, other? - Transformer performance, O&M, or other components - Second order value drivers (Non-LCOE) ♦♦♦ ▪ Optimizing value of utility vs. customer side investment to better manage solar intermittency and availability - Technical, financial and regulatory barriers	▪ AC/DC inverters ride through ability: 100 MW ♦♦♦♦♦ ▪ Harmonic oscillations due to inverter interaction with power grid and inverter/ inverter interaction ♦♦♦ ▪ System controls and capacity issues of varying PV output (i.e. clouds), particularly if system wide penetration is high ♦♦♦♦♦♦ ▪ Capacity factors: balancing system in light of variations in PV output, particularly if system wide penetration is high ♦ ▪ Integration of energy storage to mitigate transients (high ramp rates) resulting from large array variability (>30% penetration) ▪ Bride disconnect between time of peak PV output and circuit peak demand: need storage for shifting PV output to match peak demand ♦	▪ Grid capacity regulation interface (non-dispatchability problem) ♦ ▪ Rapid changes in power due to wind-driven clouds - solar array output may change up to 70 – 80% within minutes ♦♦♦♦♦♦♦♦ ▪ Implement research program similar to “Active Distribution” networks (ala Oklahoma) ♦ ▪ Variability of PV; communications and control; flexibility; utility use of consumer energy storage; architecture, communications, and marketing ♦♦♦♦♦♦♦♦♦♦♦	▪ Data issues: - Gathering and analysis and IT limitations - Processing and storage Communications and controls: - Communication standards - Smart meter integration and control ♦♦♦♦♦♦♦♦♦♦♦♦♦♦	▪ Streamlining interconnection application and process - Online processing? - Are requirements practical for actual use and implementation? - Onsite inspection, at scale of thousands of systems per year - Islanding protocols - Revisit IEEE 1547 to reflect new penetration levels, gateway to issue technical platform - Anti-islanding -Two-way power flow on circuits designed for rapid power flow ♦♦♦♦♦♦♦♦♦♦♦♦♦ ▪ Safety - Protection relay maintenance - Location of lockable and visible disconnects - Identification of the generator ♦♦ ▪ Test and incorporate (UL): visible open and lockable AC disconnects near Main EB (see IRECs 2008 teleconference on this issue) - Have tank exits to verify mutual feeding been validated on actual implementations with different technologies?	▪ Systems impact (voltage control, power quality issues) - Quantity of generation on a distribution system before impact on the distribution grid - Power quality studies due to great number of inverters on the grid ♦♦♦♦♦♦♦♦ ▪ At what point does the penetration on a distribution circuit cause voltage and frequency problems to customers? (10MW capacity circuit, 8MW PV system) ♦♦♦♦♦ ▪ Installation of PV within a network grid, i.e. under what conditions if at all

Modeling	Inverters	Variability of Solar Resources	Smart Communications	Protection and Coordinated Operations and Standards	Grid Impacts
- Currently the decision making is divorced - Technical optimization for lowest cost ♦	▪ How to bundle, market, sell, operate PV with PHEVs: PHEV provides battery for PV backup, PV provides economically protected fuel prices for PHEV ♦				▪ Aggregated net metering limits at a state level - % peak by DC or AC capacity - % annual sales by kWh - explicit # by DC/AC capacity What is the policy driver: technical concerns or market concerns? - Exploring technical or market issues of each - Will it be a problem in the future?

TABLE 4.3. RD&D ACTIVITIES

(DIAMONDS INDICATE THE NUMBER OF VOTES RECEIVED TO IDENTIFY THE TOP FIVE PRIORITIES)

	Smart Communications	Managing Variability	Power Quality	Modeling	Inverter Technology	Protection, Interconnection Standards and Procedures
Near Term	▪ Smart-grid demo on controlling, managing solar generation with voltage control - Tie in with EPRI smart-grid demo; need transparency and real-world use for utilities ♦♦♦♦♦ ▪ Evaluate the feasibility of current candidates for an ANSI communications standard to be extended to support utility use of PHEV and battery energy storage; identify communication and control required for utility use of PHEV and battery energy storage - Explore how IEC 61850 and ZigBee smart energy profile can be extended to support the required communications and control ♦♦♦	▪ Improve predictability of PV system output using a network of geographically distributed meteorological stations - Install a network of micro meteorological stations around one or more PV systems that detect and forecast wind, cloud and irradiance ▪ Fund demo installation of Solar Energy Grid Integration Systems (SEGIS) intelligent PV inverter with storage to test "variability" applications - Demand response - Ancillary services - Power quality - Inverter integration with grid ♦ ▪ Demonstrate integrating energy storage with PV to enable greater power quality, smart communication, and high quality dispatchable renewables ♦♦	▪ Investigate power harmonics or power systems and allowable limits and methods/ criteria to prevent interaction ♦♦ ▪ VR, VD, VARS ♦ ▪ Power quality study on the allowable number of inverters on a distribution system before they impact the system, regardless of the inverter ♦	▪ Advanced PV system forecasting through modeling and simulation specifically with varying distribution scenarios and climate zones; demo project collecting solar output data at fine interval (<1 minute) for detailed models ▪ Model to represent large PV project (100 – 200 MW) for transmission planning analysis ▪ Develop model for the power output characteristics of a PV system with severe intermittencies (clouds); use this model to plug into an existing dynamic program ▪ For green-field master planned communities (mixed residential communities), what does the ideal grid look like with high PV penetration? (staff from scratch opportunities) ♦	▪ Next generation high reliability inverters (more than ten years lifetime) ♦♦♦ ▪ Improve communications between grid inverters to support improved power quality - Develop an inverter protocol for communications and control between utilities and residential and commercial grid - Inverters to improve grid voltage regulation, frequency regulation, and overall power quality ♦	▪ Islanding: can circuit stand on its own? - Study spectrum of distribution circuits and consider what two-way power flow means - What does it take to island a 12 kV circuit by run back invert to match load? - Feeder level power factor control through "smart" solid state inverters "system feeder" ♦♦♦♦♦♦ ▪ Provide a communication standard between PV and utility - Development of standard for communications with STD utility smart meter vendors that will have "in order of ascending need" capacity availability to dispatch; order for curtailment/ demand, ride through of system fluctuations, VAR/power factor adjustment - Frequency/ harmonic support ♦♦♦♦

	Smart Communications	Managing Variability	Power Quality	Modeling	Inverter Technology	Protection, Interconnection Standards and Procedures
Near Term				▪ Continue work on common distribution system analysis data to enhance ability of third parties to produce new modeling tools for analyzing impacts ▪ Create utility modeling SAM modules as add ons or spin offs ▪ Joint utility/solar industry coordination working group (technical coordination) solar ABC for smart grid ♦♦♦♦♦♦		
Mid Term	▪ How can PV and energy storage be integrated to enable smart, firm, dispatchable renewable energy? - Demonstrate at a customer and utility location - Define communication protocols and grid interface requirements ♦♦♦♦	▪ Fast detection of power quality and effect some remedy (shut PV system down?) ♦♦		▪ Develop modeling tools to determine the value proposition of an integrated, customer sited solar storage project - Factor in multiple value streams, potential incentives, and total installed system costs - From various perspectives, i.e., end use customer, project developer - May be used by industry stakeholders and policy makers ♦	▪ Replicate inertia using inverters for ride through and micro grid support - Inverter technology, design condition, capability to ride through short-term disturbances ♦♦♦♦♦	▪ Determine the life expected on the protection devices of the inverters, and study how often the inverters (protection) should be tested

	Smart Communications	Managing Variability	Power Quality	Modeling	Inverter Technology	Protection, Interconnection Standards and Procedures
				▪ System capacity modeling: stress, upgrades (cost), PSLF (area specific) ▪ Study the effect of multiple generation in the grid without regulation ▪ Solar resource data availability and assess some of these intermittency issues		
Long Term				▪ High penetration distribution system modeling - Model the impact on the distribution system due to integration and generation greater than 20-50% of the actual peak demand of the circuit ♦♦♦♦♦♦♦♦♦		

TABLE 4.4. Performance Requirements

	Intentional Islanding	Utility/Industry Coordination Working Group	PV Demonstration with Managed Voltage and Balancing Dispatch Control	High-Penetration Distribution Modeling	Power Quality	Inverter Frequency and Voltage Ride Through
End goals	▪ Demonstrate a no-green-house-gas (GHG) microgrid for 1 year of continuous islanding	▪ Consortium of national labs, non profits, industry (PV +), utilities ▪ Recommend codes, standards, best practices (address multiple points of PV generation)	▪ Demonstrate by simulation (feasibility) ▪ Verify by demonstration (PV w/ storage) on customer and utility side ▪ New standards and protocols for grid interface ▪ Cost-effectiveness assessment	▪ Solar array model (incorporate weather forecasts) ▪ Solar package model (solar array + inverter + storage) ▪ Static and dynamic models ▪ Integrate with systems model	▪ Criteria for applying PV to distribution circuit in a design-to document or specification	▪ Next-generation inverter
Milestones	▪ Demonstrate shorter period (<1 yr) maybe with GHG fuels ▪ Controls integration (microgrid wide) ▪ Smart meters, demand response, storage (implemented in phases)	▪ Meetings/ workshops ▪ Formal recommendation letters	▪ Cost effectiveness methodology ▪ Engineering design ▪ System integration requirements/ controls	▪ Survey of available products - matrix of strengths and weaknesses, willingness of vendor to collaborate (IP issues) ▪ Model objectives, inputs, outputs, scenarios ▪ Advisory board (diverse set of stakeholders including utilities, mfgs, system integrators, etc.)	▪ IEEE 1547 revision to update for neighboring systems utility consensus	▪ Draft revision of IEEE 1547 to account for ride-through of multiple events ▪ Utility and industry review

	Intentional Islanding	Utility/Industry Coordination Working Group	PV Demonstration with Managed Voltage and Balancing Dispatch Control	High-Penetration Distribution Modeling	Power Quality	Inverter Frequency and Voltage Ride Through
Performance Metrics	▪ Pounds of CO_2 used ▪ Response ▪ Power quality (VARs, amps, voltage)	▪ Industry feedback report cards	▪ Satisfy standards ▪ Dispatchability ▪ PV ability to reduce peak demand ▪ Impact to PV intermittency – reduce negative impact to grid	▪ Verify accuracy using field data and simulations ▪ Holistic cost analysis from customer viewpoint (e.g., reduced distribution costs further leveraged by spending savings on energy efficiency)	▪ Harmonics ▪ Voltage ▪ Frequency ▪ Supply voltage ▪ Load	▪ Bi-directional ▪ Ride through ▪ Higher power ▪ Internal communication to the utility
Cost and Duration	▪ $25M/year for 3 years	▪ $250K/yr (ongoing)	▪ $25M (potentially lower with cost share) for medium term (sooner if customer cited)	▪ $5M for short term + 3 years	▪ $5-$10M for 2-3 years	▪ $25M over 5 years

5. Yellow Team Breakout Sessions

Research and development investment is needed in the areas of system communications, controls, and modeling in order to achieve successful integration of high PV penetration levels in the distribution grid. A key area of investment is detailed investigations, including application and testing, of new renewable energy resources deployed in a traditional power grid. Future RD&D programs must recognize the interdependency and location-specific aspects of grid modeling results in order to select the best control schemes for use and the most appropriate communication protocols and configurations for implementation. Doing this in larger scale field demonstrations is also important.

Each of the top research areas identified had various elements of communications, controls, and modeling. Several activities were identified to address variability and integration issues. These activities include development of beneficial ancillary services between the utility and end customer, modeling to study how the presence of storage and deployment of active control techniques could mitigate the impact of high PV penetration, and high-resolution collection of solar data using a standardized format to support analysis and understanding of PV transients due to clouds.

The top issues and barriers and the suggested RD&D activities are summarized below:

- Demonstrate Intelligent Bundling of Ancillary Services
- Develop Models of Storage and Control System Technologies
- Develop Methods to Standardize Solar Intermittency Data Collection and Analysis
- Provide Grid Protection Design Criteria and Guidelines for High-Penetration PV Integration

Demonstrate Intelligent Bundling of Ancillary Services

In order for end users and utilities to realize the full value of distributed ancillary services, there is a need for intelligent bundling of PV attributes with demand-side management, communication and control schemes, and grid storage. No particular near-term activity was identified; instead other existing smart grid projects with communications and PV already in place need to be leveraged. In the mid term, a centralized or distributed topology type of demonstration that is selected based on available feeder routing and customer feedback needs to be performed to validate ancillary services and grid performance at high PV penetration levels. Voltage regulation, power quality, and PV performance indices need to be monitored. In the long term, a pilot demonstration with very high PV penetration defined as 30% of the maximum peak needs to be conducted. Performance evaluation would be based on market acceptance of price signals at the consumer level and surveys eliciting overall consumer satisfaction levels.

Develop Models of Storage and Control System Technologies

There is a need to focus on the acquisition of data representing the impact of deploying storage on the grid and the development of analysis tools to sufficiently model and simulate storage and control aspects of specific high-penetration PV scenarios and different solar variability situations. In the near term, a report on storage applications and control techniques to mitigate solar variability needs to be created and an advisory stakeholder group needs to be formed. The report would list market opportunities, financial propositions and technology barriers, and would identify the optimal storage amounts relative to various penetration scenarios for each major market segment. Advantages of different communication protocols would also be explored. Note that no mid- or long-term projects were identified.

Develop Methods to Standardize Solar Intermittency Data Collection and Analysis

There needs to be further development of storage application methods and devices to control and mitigate the variability of solar resources. The collection of data from geographically disperse sites needs to be standardized in order to facilitate the forecasting of generation, followed by actual data collection and model development. In the near term, a committee needs to be formed to pursue the development and eventual publishing of a specification on best practices for acquiring solar intermittency data. The specification would detail data formats, acquisition rates, temporal and geographic granularity, and solar electrical characteristics. In the mid term, quality data from pre-selected sites owned by different entities would be gathered based on the specification developed. A goal would be for all the data acquisition systems to be implemented with commercially available equipment and that no custom development would be required. In the long term, the collected data would be subjected to a suite of analytical tools. The models would output highly accurate irradiance characteristics and electrical PV performance and would aid further development of forecasting tools.

Provide Grid Protection Design Criteria and Guidelines for High-Penetration PV Integration

There is a desire to make measurements and deploy controls to determine how to enhance protection and grid safety coordination capability in anticipation of worst-case scenarios. No particular near-term activity was identified; instead other existing smart grid projects already in place need to be leveraged. In the mid term, an effort to encourage the adoption of standardized distribution system design manuals and utility templates would be undertaken, along with the implementation of a commercial-scale demonstration. Legacy grid components that must be changed out for equal or improved reliability and safety would be identified. Note that there was no long-term project identified.

TABLE 5.1. LIST OF PARTICIPANTS

Name	Organization
Bruce Barney	Portland General Electric
Obadiah Bartholomy	Sacramento Municipal Utility District
Marie Garcia, Facilitator	Sandia National Laboratories
Wil Grady	Southern California Edison
Christy Herig[1]	Solar Electric Power Association
Tom Hoff	Clean Power Research
Ray Hudson	BEW Engineering
Thomas Key[1]	Electric Power Research Institute
David Krause	AES Solar Energy, Ltd.
Scott Kuszmaul[1, 2]	Sandia National Laboratories
Carl Lenox	SunPower Corp
Kevin Lynn, Co-Facilitator	Sentech, Inc.
Robert Margolis	National Renewable Energy Laboratory
Stanley Merritt	DuPont
Peter Michalski	Edison Mission Energy
Alison Silverstein	Alison Silverstein Consulting
Devarajan Srinivasan	ViaSol Energy Solutions
James Suell	Salt River Project
Charlie Vartanian	A123 Systems
Tom Veselka	Argonne National Laboratory
Lorin Todd Wall	Southern Company Services
Jeff Yang	United Solar Ovonic, LLC

1: Denotes Planning Committee member & session Technical Lead
2: Denotes primary author of the session summary description

TABLE 5.2. TECHNICAL ISSUES AND BARRIERS

(DIAMONDS INDICATE THE NUMBER OF VOTES RECEIVED TO IDENTIFY THE TOP FIVE PRIORITIES)

Protection and Coordinated Operations	System Flexibility	Value Enhancements	Grid Impact Assessment Tools and Models	Existing Grid Infrastructure	Variability of Solar Resources	Training and Education
▪ Is this a "no problem" level of penetration? - Reliability - Protection ▪ End of feed on voltage control, reactive power, voltage regulation ▪ Voltage control on distribution feeder is limited once PV generation >50% of demand on feed (PV systems are driving voltage) - Will need to have utility control of individual output or sufficient storage or flexibility ♦♦♦♦♦ ▪ Fault detection ability is limited at PV generation >50% of feeder minimum load - Require improved instrumentation and communication throughout distribution feeder ▪ Protection and coordination needed if feeder is at low (min) load and PV is high ♦♦♦♦♦♦♦	▪ Interoperability of distributed resources and communications ♦ ▪ Minimum system loading vs. managing PV output during spring and fall ♦ ▪ System controls and capacity issues of varying PV output (i.e. clouds), particularly if system wide penetration is high ♦♦♦♦♦♦ ▪ Capacity factors: balancing system in light of variations in PV output, particularly for high system-wide penetration ♦ ▪ Integration of energy storage to mitigate transients (high ramp rates) resulting from large array variability (>30% penetration)	▪ Combining PV with load, demand management, and storage ♦♦♦♦♦♦ ▪ Understand how to intelligently bundle PV with other end use devices to minimize cost of "penetration" issues ♦♦♦♦♦♦♦ ▪ Development of appropriate ancillary service markets which value unique services that PV can provide (or PV storage) ♦♦♦ ▪ Storage & DSM/Controls, Communications - Integrate with smart grid technologies - Integrate PV as system into operation of distributed network ♦ ▪ Bride disconnect between time of peak PV output and circuit peak demand - Need storage for shifting PV output to match peak demand ♦	▪ Lack of data at sufficient resolution to model impact ▪ Lack of data on variability or resource impact (clouds, large area) ♦♦♦♦♦♦♦♦ ▪ Self healing network	▪ Utility engineers design to expected reliability difference from current distribution design with PV ▪ Distribution feeder substation interconnect will need redesign to allow power exporting ♦♦	▪ Solar resource availability and variability - PV variability (caused by intermittent clouds) can destabilize the grid (>30% penetration) - Storage resources to mitigate solar variability ♦♦♦♦♦♦♦♦♦♦♦ ▪ Effective means and methods through equipment, devices, technology; integration problems associated with variability, higher penetration; high ranking on thermal system	▪ Technical support terms, public acceptance, qualified workforce bottlenecks ♦♦ ▪ Education on anti-islanding is 1747 sufficient ▪ Additional features/ services to provide homeowner with automation that grows acceptance, baseline (outreach and education) (<15% penetration) ▪ How do we communicate the advantages and benefits of using renewables, such as solar PV, to the general public? ♦ ▪ General understand-ing of distribution and operations (0-3 years)

Protection and Coordinated Operations	System Flexibility	Value Enhancements	Grid Impact Assessment Tools and Models	Existing Grid Infrastructure	Variability of Solar Resources	Training and Education
▪ Self healing network ▪ Self isolation of voltage source ♦ ▪ Ancillary services at > 15% penetration ▪ Communication and control (standard) to aggregate resources for block usage (DR, load shed, etc.)		▪ Know how to bundle, market, sell, operate PV with PHEVs - PHEV provides battery for PV backup, PV provides economically protected fuel prices for PHEV ♦				

TABLE 5.3. RD&D Activities

(DIAMONDS INDICATE THE NUMBER OF VOTES RECEIVED TO IDENTIFY THE TOP FIVE PRIORITIES)

	Data, Analysis, and Tools to Model/Simulate Impacts on Grid	Intelligent Bundling of PV for Development of Ancillary Services	Enhance Protection and Coordination through Instrumentation and Measurement	Methods, Devices, and Technologies to Integrate Solar Intermittency on Grid	Development of Codes and Standards
Near Term	▪ Initiate a program of detailed data gathering at existing large/high penetration sites - Standardize data acquisition techniques to enable sharing - Develop database to characterize intermittency based on geographic regions	▪ Perform a study that evaluates alternative methods of intelligent bundling - Sending price signals to control behavior - Direct utility control ♦♦	▪ Identify worst cases/thresholds for each feeder on a distribution system ♦ ▪ Develop protection/coordination distribution design schemes using the "changes" developed by utility engineers ♦ ▪ Further define (more criteria) penetration scenario and set up measurement (may require use of international data); Research (with actual installations) effects/ problems/issues with high penetration (>50%) PV ♦♦♦♦♦	▪ Develop storage technologies, criteria, and best practices to allow bundling with PV (include thermal batteries, demand control, building envelope) - Mitigation of intermittent nature of PV - Cost reduction of kWh - Stability VAR, Voltage control - Battery systems that are safe, reliable, and cost effective (Lithium ion) ♦♦♦♦♦♦♦♦♦♦♦	▪ Develop communication protocol best practice and write codes for protocols - Establish standards to collect useful data (time, resolution, measurement point, time stamp) - Establish a uniform set of requirements for grid interconnect equipment communications

	Data, Analysis, and Tools to Model/Simulate Impacts on Grid	Intelligent Bundling of PV for Development of Ancillary Services	Enhance Protection and Coordination through Instrumentation and Measurement	Methods, Devices, and Technologies to Integrate Solar Intermittency on Grid	Development of Codes and Standards
	- Team up industries, universities, and national labs to launch a comprehensive modeling program to generate data for impact of solar on the grid - Gather data, develop models/ tools, and standardize forecasting ♦♦♦♦♦ ▪ Identify existing modeling tool shortcomings; for user group, develop new modeling capabilities; classify load profiles at the feeder level and assess PV potential and attributes for affected building sites ♦♦ ▪ Solar resources assessment at high granular spatial and temporal level to determine intermittency levels - Analysis of cloud shadow propagation speeds and resulting PV ramp rates for a given service territory				▪ Team industry, universities, and national labs to address codes and standards applicable to high penetration of PV into distribution grid (e.g., Solar ABC) - Identify proper groups to address current standards relevant to integration - Generate a list of new actions based on gaps in knowledge - Aggressively establish a committee to address protocol and procedures for code compliance ♦♦♦ ▪ Develop standard communications protocol for grid interconnection equipment

	Data, Analysis, and Tools to Model/Simulate Impacts on Grid	Intelligent Bundling of PV for Development of Ancillary Services	Enhance Protection and Coordination through Instrumentation and Measurement	Methods, Devices, and Technologies to Integrate Solar Intermittency on Grid	Development of Codes and Standards
	- Assess the conditions under which rapidly changing weather translates to rapid PV system output changes for existing fleets of installed PV systems (i.e., work with utility or program or PV monitoring company to run test) ♦♦♦♦♦♦				
Mid Term	▪ Research forecasting PV output (1 day or more in advance) and model widespread (geographically) PV performance at a system level ♦♦ ▪ Research (modeling simulations) effects, problems, issues of high penetration (>50%) PV - Develop distribution modeling and analysis tool for dynamic or distributed resources and different scenarios	▪ Piggy-back on existing PV developments to evaluate if control approach works (price sending or direct utility control) to achieve intelligent bundling - Smart grid and building controls - Continue to develop behind the meter end use - PV device storage integration, analysis, communication and controls, system protocols and standards - Pilot demo for suitably equipped (i.e., smart grid) distribution systems - Develop systems that integrate generation and load optimally ♦♦♦♦♦♦♦♦♦	▪ Develop feeder-level analytical tools to model and understand differing impacts of load net PV variability on feeder reliability and performance - Vary/test definition of numerator (load net PV) and denominator (feeder capacity) ♦♦♦ ▪ Develop cut-off switches at the meter and feeder to limit flows from customer-side generation upstream into grid ▪ Plots and field demos for adapting existing distribution system for higher penetration - Evaluate different relaying, switching, and control and the grid ▪ Dispatchability: including command control, data acquisition, protection, demand side management, and storage (PHEV) ♦♦	▪ Control demonstration of methods, devices, technologies at meaningful scale; leverage existing smart grid demonstration efforts, i.e., at the community, utility level and include PV technologies via DOE co-funding ♦♦ ▪ Reliability and Cost: devices and technologies for integration of PV, including storage, controls, ancillary services and data acquisition; voltage control integration; integrating new devices with latency grid ♦♦♦♦♦♦♦	▪ Support IEEE standard development process and allow low voltage ride through, VAR control, etc.; develop test bed for industry to verify/validate equipment designed for upcoming standards revision ♦♦♦♦♦ ▪ Interconnection rules need to evolve; current codes and standards limit grid interconnection equipment capabilities – IEEE 1547, UL 1741. France is already ahead ♦♦♦♦♦♦♦♦

	Data, Analysis, and Tools to Model/Simulate Impacts on Grid	Intelligent Bundling of PV for Development of Ancillary Services	Enhance Protection and Coordination through Instrumentation and Measurement	Methods, Devices, and Technologies to Integrate Solar Intermittency on Grid	Development of Codes and Standards
	- Create software using complex adaptive systems simulation principles that will allow the distribution system to prevent, solve, and appropriately react to potential problems ♦♦ ▪ Publish data from demonstrations to be modeled - Data set needs to be extensive and contain more than 5 yrs of results - Develop a "what if" menu driven database simulator/ program for operations training - High time resolution data collection on geographically dispersed set of commercial PV systems, including system performance, building loads, and weather data ♦				
Long Term		▪ Demonstrate ultra-high penetration (100%) through integrated and interoperable PV, DR, storage, and legacy grid ♦♦♦♦♦♦♦♦♦♦	▪ Develop adaptive relaying concepts to change responses for varying load, solar operations	▪ Develop flow control, intermittency mitigation, added grid support and customer P/Q capability	

TABLE 5.4. PERFORMANCE REQUIREMENTS

	Develop Storage and Control System Technologies	Standards for Data on Solar Intermittency	Collection of Data on Solar Intermittency	Data Modeling and Forecasting	Methods and Devices for Integrating PV into the Legacy Grid	Pilot/ Demo of Intelligent Bundling	Pilot/ Demo of Intelligent Bundling with High Penetra-tion (30% of Max Peak)
End Goals	▪ R&D report on storage applications (market opportunities, financial propositions, technologies, barriers) ▪ Identify optimal storage amount relative to penetration scenarios for each market ▪ Develop protocols and technology components for communica-tion and control of storage	▪ Measurement specifications and formats - Where, what, how fast - Temporal and geographic granularity - Solar electrical character-istics	▪ Irradiance and electrical data ▪ Quality data streams and data viewer/ processor for 1+ yr for 3+ sites ▪ Consistent data across sites	▪ Describe irradiance character-istics/site ▪ Describe resulting electrical perform-ance of PV/site ▪ Produce models for these that help forecasting	▪ Commer-cial demo of utility commun-ication and control of inverters and storage ▪ Creation of ancillary services markets and values for PV integration devices/ methods ▪ Adoption of distribution system design manuals and templates for utilities ▪ Design integration into municipal compre-hensive planning and utility integrated resource planning processes	▪ Demonstrate ability to integrate PV at high levels while maintaining or improving grid performance with reasonable cost	▪ Demo-nstrate ability to integrate PV at high levels while main-taining or improve-ing grid perform-ance with reason-able cost

	Develop Storage and Control System Technologies	Standards for Data on Solar Intermittency	Collection of Data on Solar Intermittency	Data Modeling and Forecasting	Methods and Devices for Integrating PV into the Legacy Grid	Pilot/ Demo of Intelligent Bundling	Pilot/ Demo of Intelligent Bundling with High Penetra-tion (30% of Max Peak)
Milestones	▪ Road map identifying markets, technologies and applications ▪ Broad stakeholder advisory group ▪ Demonstration of component and/or controls at meaningful scale	▪ Draft ▪ Test with measurement and modeling communities ▪ Adopt and publish	▪ Pick sites ▪ Install equipment ▪ Data quality check ▪ Make datasets available	▪ Data analysis and probability distribu-tions ▪ Develop modeling tools (spatial and temporal) ▪ Determine correla-tions between land and PV perform-ance ▪ Verify and validate models ▪ Adopt and publish	▪ Define legacy grid compo-nents that must be changed for equal or improved reliability or power quality with increased PV penetra-tions ▪ Create distribution system design manuals and templates for utilities ▪ Industrial park and or campus demos ▪ Demos of smart grid at a meaningful scale (feeder, city)	▪ Piggy-back on existing smart grid projects (communi-cations in place, add PV) and/or start adding controls to existing high PV density locations ▪ Study control options: central vs. distributed; determine where on this range to pilot or maybe both depend on customers/ feeders	▪ Test on market accept-ance of price signals at consu-mer level

	Develop Storage and Control System Technologies	Standards for Data on Solar Intermittency	Collection of Data on Solar Intermittency	Data Modeling and Forecasting	Methods and Devices for Integrating PV into the Legacy Grid	Pilot/ Demo of Intelligent Bundling	Pilot/ Demo of Intelligent Bundling with High Penetra-tion (30% of Max Peak)
Performance Metrics	▪ Industry participation and education ▪ Commercial-ization of storage and control technologies specific to PV market	▪ Acceptance ▪ Final product	▪ Quality data, complete ▪ Max COTS rather than customer implement-ation	▪ Model accuracy ▪ Model insights ▪ Industry accept-ance and use	▪ Commer-cialization; # of utilities, and their level of develop-ment of smart grids ▪ Manufact-urers of legacy grid compo-nents developing new devices	▪ Reliability indices (SAIFI, SARFI) ▪ Voltage regulation ▪ Power Quality ▪ PV performance index ▪ Regulation, load follow, ramp rates on load profiles	▪ Custom-er happi-ness with pricing and impacts
Cost and Duration	▪ $2-10M over 3 years	▪ $250K over 6+ months	▪ $400K/site for instruments (6 to 9 weather stations per site) ▪ $30K/site/ month for monitoring and communica-tions ▪ 3 years ongoing	▪ $3M over 3 years	▪ $25-50M over 5 years	▪ $10M/yr for 3 years ▪ Hardware (no $ for PV itself) ▪ Software ▪ Analysis/ Report ▪ Overhead ▪ Communica-tion/ automated meter infrastruc-ture	▪ $30M/yr for 3 years

6. Financial and Policy Issues

Since the goal of this workshop was to identify *technical* issues preventing high-penetration of PV, all financial and policy issues that were mentioned during the breakout sessions were compiled for further discussion in the closing plenary session. Many participants believed that technical, financial and policy issues could not be deconvoluted and need to be considered together, perhaps via use cases. The following is a summary of policy/regulation issues and financial issues as presented respectively by Alison Silverstein, Consultant, and Sheldon Kimber, VP, Development, Recurrent Energy.

Compilation of Key Policy/Regulation and Financial Issues

- High cost of PV (time and money) leads to need for regulatory action
    - Lower effective cost to customer
        - Incentives: tax credits, subsidies, tax benefits in revenues, renewable energy credits
        - Easier: installation, financing (loans, pay-as-you-save), pre-packaged PV units, building-integrated PV
    - Lower cost to suppliers/producers
        - Production tax credits/incentives/subsidies
        - Uniform technical interconnection standards/certifications
        - R&D: reduce production cost, improve yield, reduce risk, increase confidence
        - Demand pull strategy
    - Handicap other competing technologies: carbon tax, regulation, transmission construction
    - Force people to do what they don't want to do
        - Energy efficiency standards, legal municipal codes, standard 1547
        - Renewable portfolio standards (RPF)
        - Domestic production requirements, local siting rules
    - Interoperability
- Remove non-cost, non-time obstacles (hassle factor)
    - Regulation: site-specific interconnection analysis requirements
    - Interoperability
    - Education and training: not very effective for regulators (high turnover rate)
    - Workforce building
    - Market transformation
- Learning from others/catching up
    - PV behind other technologies (e.g., wind) on cost, performance, etc.
        - More real-life, granular data and analysis
        - More predictable and manageable intermittency
        - Leverage and partner with others regarding smart grid, IT communications (e.g., IBM) to secure smart grid funding
        - Integrating devices via dynamic response
        - Storage more than batteries: thermal storage may be better for some applications
- Miscellaneous
    - Price signaling/markets
        - Markets are too complicated
        - Price signaling is too subtle; biases are more important
        - Make ancillary services easy and fast; don't create a market
    - Don't monetize everything
        - Extra value may not be there
    - Fallacy that utilities can finance distributed generation more effectively if they own it
    - Carbon legislation: within 3 yrs
    - National vs. state action with respect to interconnection

    - Success with regulators through communication with staff (educate them, explain why PV good for everyone, simple message)
    - Technical standards more impact than regulatory models
    - DOE advocacy: limited
    - Coordination councils: improve already existing institutions, don't need more meetings
- Policy recommendations
    - Technical standards to promote interoperability
        - Peer review
    - National RPS
    - Create pre-packaged PV sold in Walmart/Home Depot, publicized in Oprah → lower cost barrier
    - Help utilities succeed with high PV penetration and protection issues
    - Provide models, forecasting tools and data to prove PV works
    - Reduce hassle, operational burden, protect profits (sharing ownership of PV), decoupling
    - Lower delivery costs

Subsequent Discussion on Key Policy/Regulation and Financial Issues

- Wind has data, validated models and results; history in Europe; history in utility integration. PV is 5-10 yrs behind. Need to bring utilities in for integration.
- Lessons from rest of world
    - Need non-incremental regulatory changes (cf. Hawaii)
- Rate structures
    - No single purpose to change rate, too many reasons/issues
    - Depends on and affects other rates
    - Odds are slim for successful rate case
- IEEE 1547 activities
    - Installing field systems + testing
    - Downfall: oak-table standard
        - Can't run some lab tests described in 1547

Appendix A

AGENDA

Workshop on High Penetration of PV into Distribution Grid

February 24-25, 2009

Hilton Ontario Airport
700 North Haven Avenue
Ontario, CA 91764
Tel : 1-909-980-0400

Pre-Workshop Event

Monday, February 23, 2009

3:30-5:00 PM – Tour of Southern California Edison Facility

Day 1, Tuesday, February 24, 2009

7:30 **Continental Breakfast**

8:00 **Opening Plenary Session**

- **Welcome by Southern California Edison** (10 minutes)
- **Solar Energy Powering the 21st Century Electric Energy System**
  Paul DeMartini, VP–Advanced Technologies,
  Southern California Edison (20 minutes)
- **DOE's perspectives** about hi-PV penetrations, the workshop, its objectives and expected outcomes, and DOE's use of workshop findings
  John Lushetsky, Program Manager,
  DOE Solar Energy Technologies Program (20 minutes)
- **SEPA's perspectives** about hi-PV penetrations, the workshop, its objectives and expected outcomes, and the Association's use of workshop findings
  Julia Hamm, Executive Director, Solar Electric Power Association (20 minutes)
- **EPRI's perspectives** about hi-PV penetrations, the workshop, its objectives and expected outcomes, and the institute's use of workshop findings
  Clark Gellings, Vice President, Technology, EPRI (20 minutes)
- **Setting the stage** for the workshop (including a system view on integration of renewables with the grid, workshop focus on PV/distribution grid integration, definition of high-penetration scenarios, current examples of high-penetration levels of PV and their observed impacts to distribution grid, and this workshop leading to many high-penetration levels across the US)
  Dan Ton, DOE Systems Integration Team Lead (20 minutes)

- **Breakout team instructions** Meeting Facilitator (10 minutes)

  Red Team – Facilitator/Co-Facilitator: Jen Stinebaugh/Maria Wang
  (Technical Leads: Ben Kroposki/Juan Torres/Ethan Sprague)

  Yellow Team – Facilitator/Co-Facilitator: Marie Garcia/Kevin Lynn
  (Technical Leads: Scott Kuszmaul/Christy Herig/Tom Key)

  Green Team – Facilitator/Co-Facilitator: Scott Stephens/Toni Leon Kovarik
  (Technical Leads: Peter McNutt/Frank Habibi-Ashrafi/Ross Guttromson)

  Blue Team – Facilitator/Co-Facilitator: Marie Mapes/Stephen Sexton
  (Technical Leads: John Kueck/Adrianne Kimber/Abe Ellis)

10:00 **Break**

10:20 **Breakout Session #1:**

Issues/barriers identification & prioritization

What do you see as the key technical issues/barriers impeding PV penetration under each of the three penetration scenarios, i.e., <15%, 15-30%, and >30%?

The session facilitator will initiate discussions on the focus question (<1 min/ participant), collect issues/barriers written on index cards by participants, post the cards on a poster, consolidate the issues/barriers, pass out 5 sticky dots to each participant, and ask participants to use their dots to vote on their top 5 issues.

Technical leads will make sure session discussions focus on technical issues and barriers.

Noon **Lunch**

1:00 **Breakout Session #2:**

RD&D activities & prioritization

What are the key RD&D activities required to be undertaken in near-term (0-3 years), mid-term (3-5 years), and long-term (>5 years) to address the identified top-5 issues/barriers?

For each of the top 5 issues/barriers identified across all three penetration scenarios (<15%, 15-30%, and >30%), the facilitator will initiate discussions on the RD&D activities needed, collect the written activities on index cards from participants, post the cards on a poster into near-, mid-, and long-term channels, pass out 5 sticky dots to each participant, and ask participants to use their dots to vote on their top-5 priority activities (across the three penetration scenarios, with 2 dots on activities in near- and mid-term channels each, and one dot for activities in long-term channel).

2:30 **Break**

2:45 **Breakout Session #3:**

Performance requirements for the high-priority RD&D activities

For the top-3, -2, and -1 activities in near-, mid-, and long-term channels, respectively, the facilitator will guide discussions to build consensus on final outcomes (end goals), interim milestones, performance metrics, and cost and duration of activity.

4:45 **Breakout Session #4:**

Major findings and suggestions

The presentation templates for the breakout group reports during the closing plenary session will be provided before the workshop. These templates will consist of the following PowerPoint slides:

- Major findings/caveats (overall)
- Top 3-5 issues/barriers
- Top-3, -2, and -1 RD&D activities for near-, mid-, and long-term, respectively, and associated key performance requirements for each activity
- Suggestions for how to proceed to meet performance requirements

The facilitator will ask for a volunteer to be the team's spokesperson during the closing plenary session. The facilitator will guide the discussion to complete the slide templates.

5:30 **Adjourn for Day 1**

6:00 **Networking Reception,** sponsored by Solar Electric Power Association (SEPA)

Day 2, Wednesday, February 25

7:30 **Continental Breakfast**

8:00 **Closing Plenary Session**

- **Report-out by each breakout team spokesperson** using PowerPoint slides (20 minutes/team)
- **Facilitated discussions** on key issues, RD&D activities, and potential next steps

9:45 **Break**

10:00 **Key Financial Issues or Barriers**
Sheldon A. Kimber, Vice President – Development, Recurrent Energy, Inc.

10:20 **Key Policy/Regulation Issues or Barriers**
Alison Silverstein, Consultant

10:40 **Facilitated Dialogs** on suggested or recommended steps for issue resolution or barrier mitigation

Noon **Workshop Adjourn**

ADVANCED TECHNOLOGY
Transmission & Distribution Business Unit


Solar Energy Powering the 21st Century Electric System

February 24, 2009

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SCE Strategy for a Clean Energy Future

Innovation in Energy Technology will Deliver Environmental Benefits & Customer Value




- SCE is doing its part to reduce greenhouse gas emissions by providing its customers with energy from renewable resources
- Smart power delivery is needed to manage greater diversity of supply and to optimize existing capacity
- Smart metering enables customers to increase energy conservation and reduce peaks while improving customer service and operational efficiency
- Plug-in electric vehicles will achieve transportation sustainability and enable distributed energy storage systems

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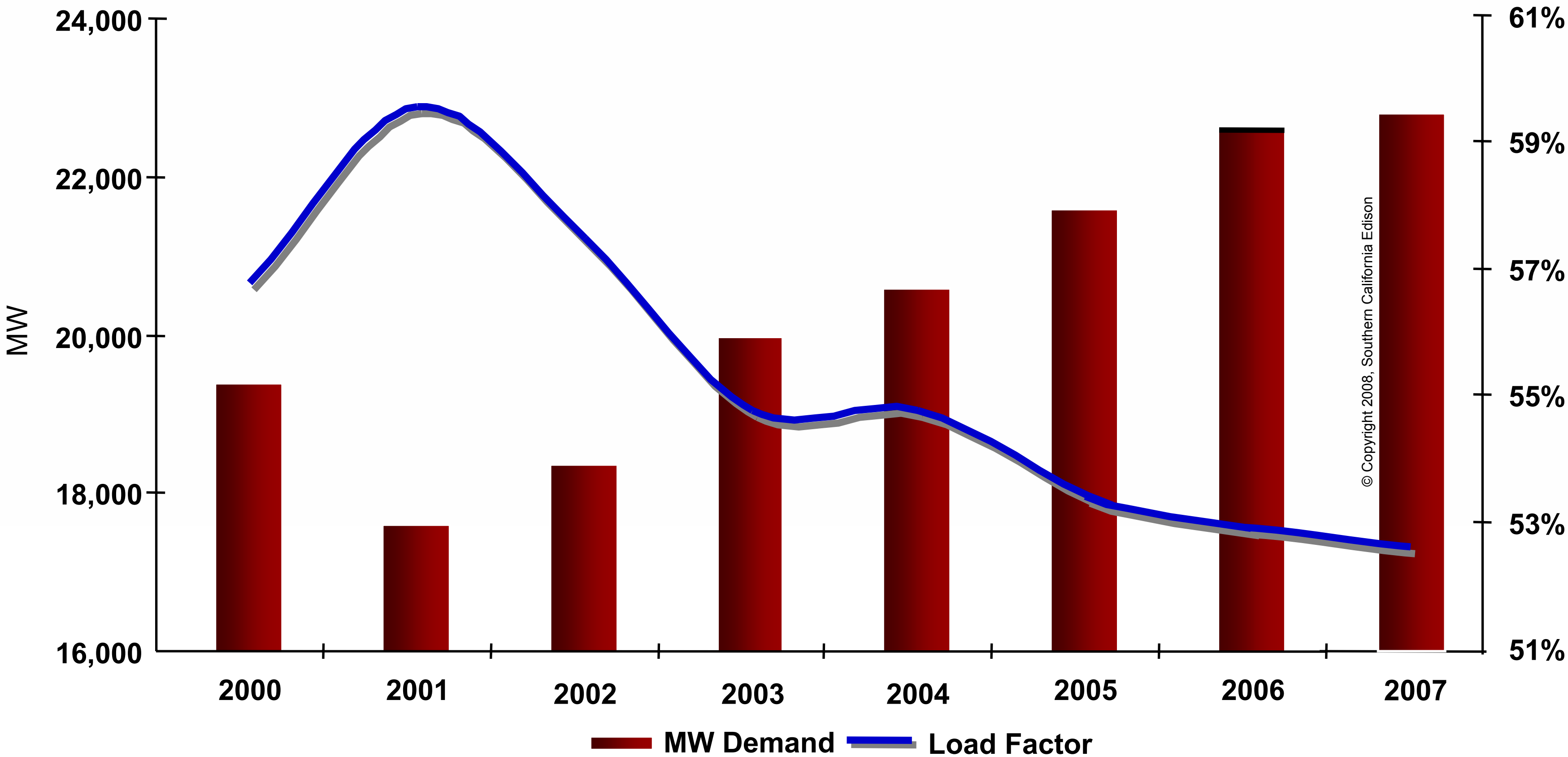
www.sce.com/smartgrid

SCE Peak Load Growth

Over 4% Average Annual Peak Growth



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Renewable & DER Growth

California law and policy is driving growth that requires a smarter grid

CA Renewable Portfolio Standard

- **20% by 2010**
- Possibly **33% by 2020** (statute under consideration)

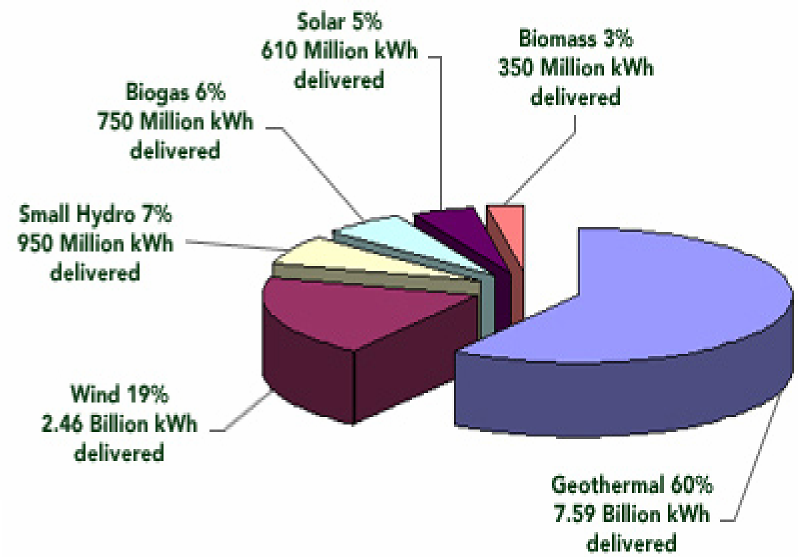
California Solar Initiative (CSI)

- Goal of install 3,000 megawatts (MW) of new, customer-side solar photovoltaic projects by 2017. The CPUC provides incentives for all solar installations in existing structures.

CA Carbon Reduction Law (AB32)

- Reduce GHG by 25% by 2025

Renewable Portfolio 2007



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SCE SmartGrid Vision

SCE's SmartGrid vision will provide environmental benefits associated with improved asset, system, and energy efficiency

Renewable, DER & Storage Integration

Integrate and manage new sources of renewable and distributed energy supply and storage

Grid Control & Asset Optimization

Improve capital efficiency and assets using better intelligence and technology for optimal system planning

Workforce Effectiveness

Maximize workforce productivity, effectiveness, and safety by using enabling tools

Smart Metering

Enable the grid to automatically adjust to changing loads and supply requirements

Energy Smart Customer Solutions & PEVs

Empower customers to become "active" participants in the energy supply chain managing their own energy consumption

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Renewables Integration

SCE leads the nation in renewable power delivery, procuring about 13 billion kilowatt-hours per year

- Provide real-time voltage support to mitigate volatility associated with intermittent renewable energy resources
- Increase transmission capacity to integrate more bulk renewable energy resources
- Integrate large scale energy storage systems as a parallel power source for Voltage/VAR/frequency support with bulk intermittent renewable energy supply

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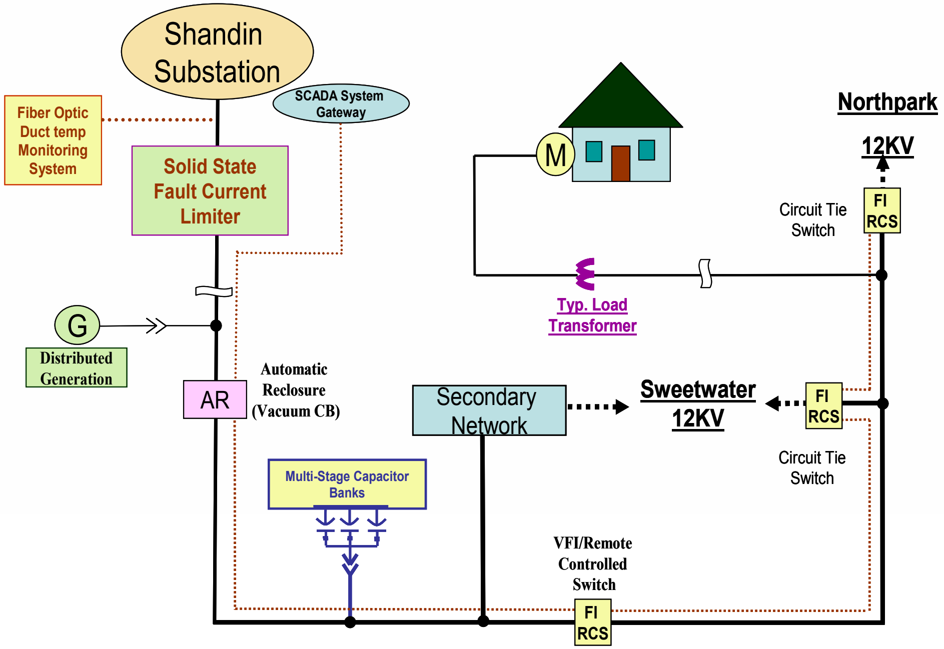
Transmission & Distribution Automation

Expand smart technology deployment in the field and operational systems building on investments over the past decade

- Enable distributed energy resources and storage to support customer choice and improve grid stability
- Prevent catastrophic system failures through innovative real time power system analytics and grid technologies
- Minimize customer power disruptions due to distribution system failures through expansive automation



Avanti - Circuit of the Future

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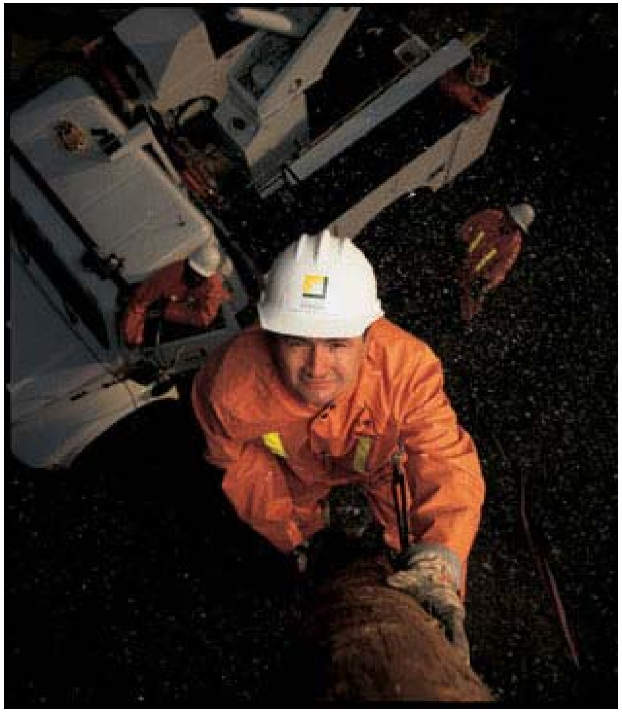
Workforce Safety & Productivity

Integrate mobile computing technology & apply safety technologies to create a more productive and safer field workforce

Lineman of the Future

- Wearable Computer
- Helmet-mounted Camera
- Wireless Data Connection
- Voice-activated Controls
- RFID Tag Reading
- Equipment Recognition
- Personal Voltage Detector



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Edison SmartConnect™

Empowering Customers

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- Choice to Manage Cost & Peak Demand
  - Rates
    - Time of Use and Tiered Rates
    - Critical Peak Pricing (CPP)
    - Peak Time Rebate (PTR)
  - Programs
    - Smart Communicating Thermostats
  - Outcome
    - Reduce Peak Load by 1,000 MWs

- Energy Information Drives Conservation
  - Reduce Residential Energy Consumption by 1% (minimum)
  - Reduce GHG by 365,000 tons/yr

- Automation Self-Service
  - Remote Service Switch
  - Payment and Billing Options

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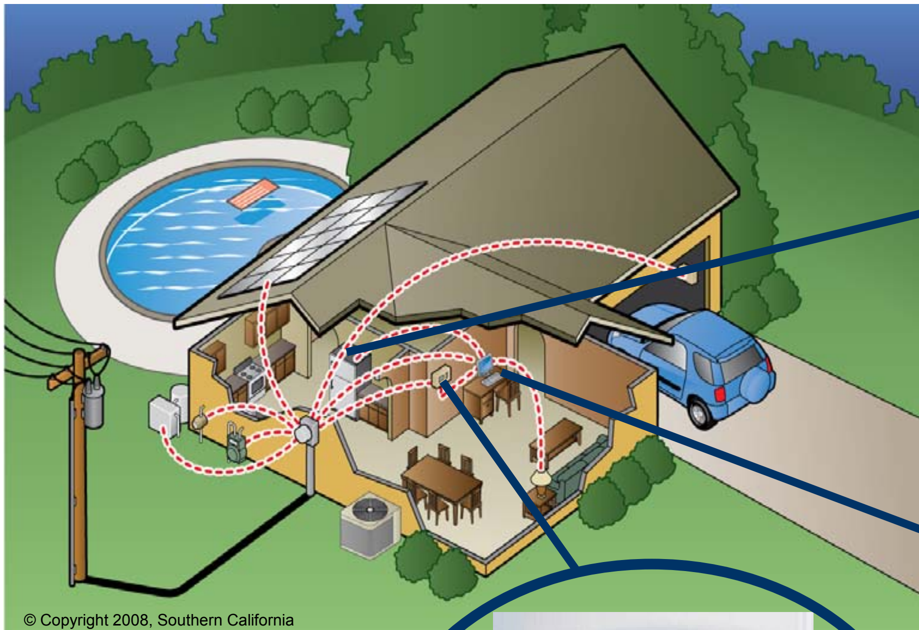
Reduce Energy Consumption & Demand



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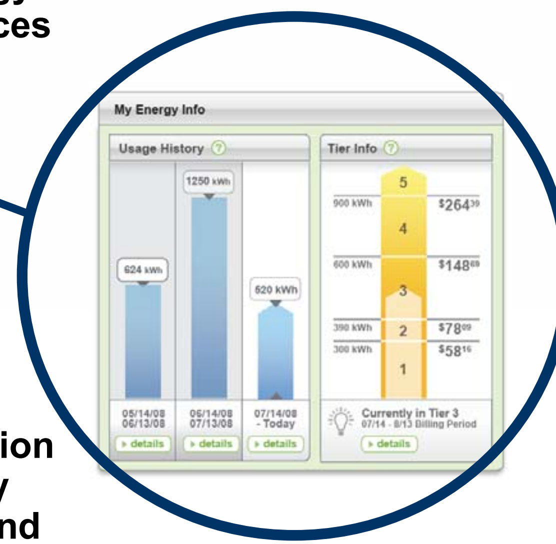
Customer Enabled Automated Response through Energy-Smart Appliances



Energy Information Drives Energy Conservation and GHG Reductions

Improved Load Management through Edison Smart Connect™ Technologies

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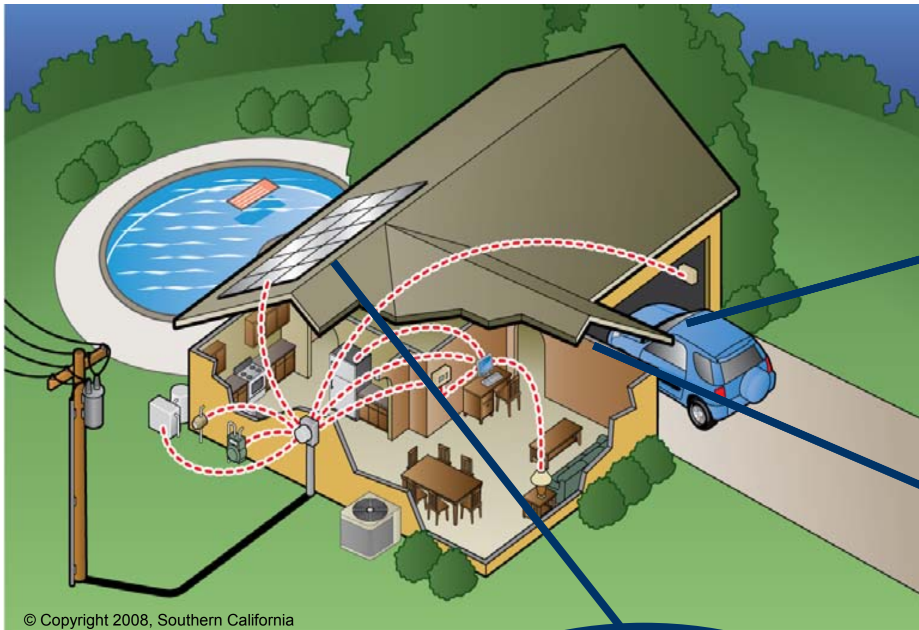
www.sce.com/smartgrid

Distributed Energy Resources



Discrete Metering, Incentive Programs, and Demand Response for PEVs

Home Energy Storage Creates Opportunities for Increased Renewables

Enable Net Metering, Discrete metering and Integrated Energy Management w/Solar Panel

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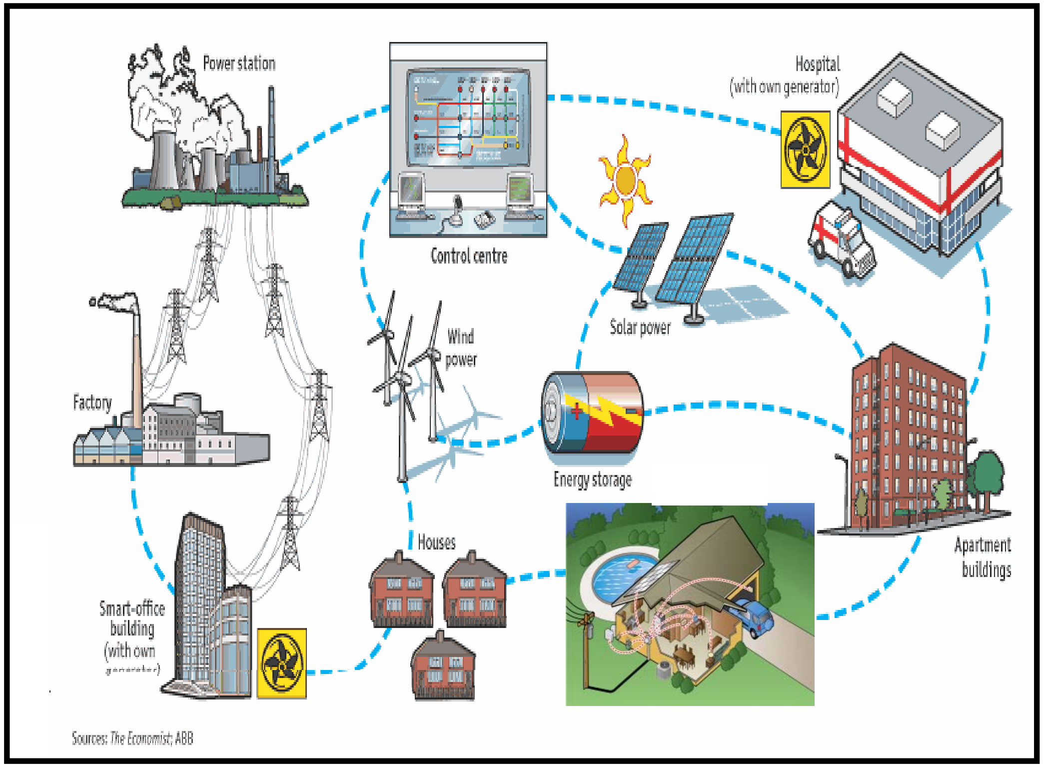
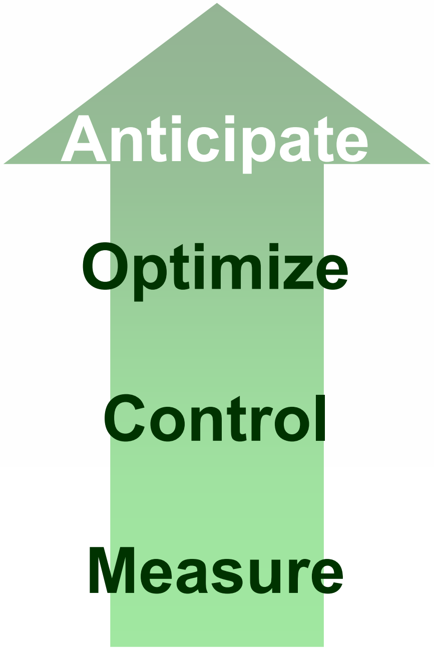
SmartGrid Evolution

Increasing integration of intermittent resources combined with price responsive demand and growth in distributed resources including storage

Development of new "systems of systems" with increased systems' integration





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Distributed Resource Mgmt R&D:
DER/PEV/Storage/Smart Meter

- Enable Distributed Energy Resources
  - Distribution VAR on the Circuit of the Future
  - Communications Architecture
  - Data Beyond SCADA
  - DER Integration
  - Plug-in Electric Vehicle Integration

- Storage <1 MW
  - Rooftop PV – stationary battery optimization
  - Vehicle to home for load management
  - PEV battery for stationary storage applications

- Smart Metering & SmartGrid Integration
  - Next generation Communications Architecture
  - Cyber-security advancement with DoE’s AMI Security Acceleration Project
  - Complex Data & Event Management research with Caltech
  - Use Case development of smart metering integration with SmartGrid

- PEV
  - Ford-EPRI Partnership
  - Integration standards development with SAE & GM
  - Use Case development
  - PEV metrology development

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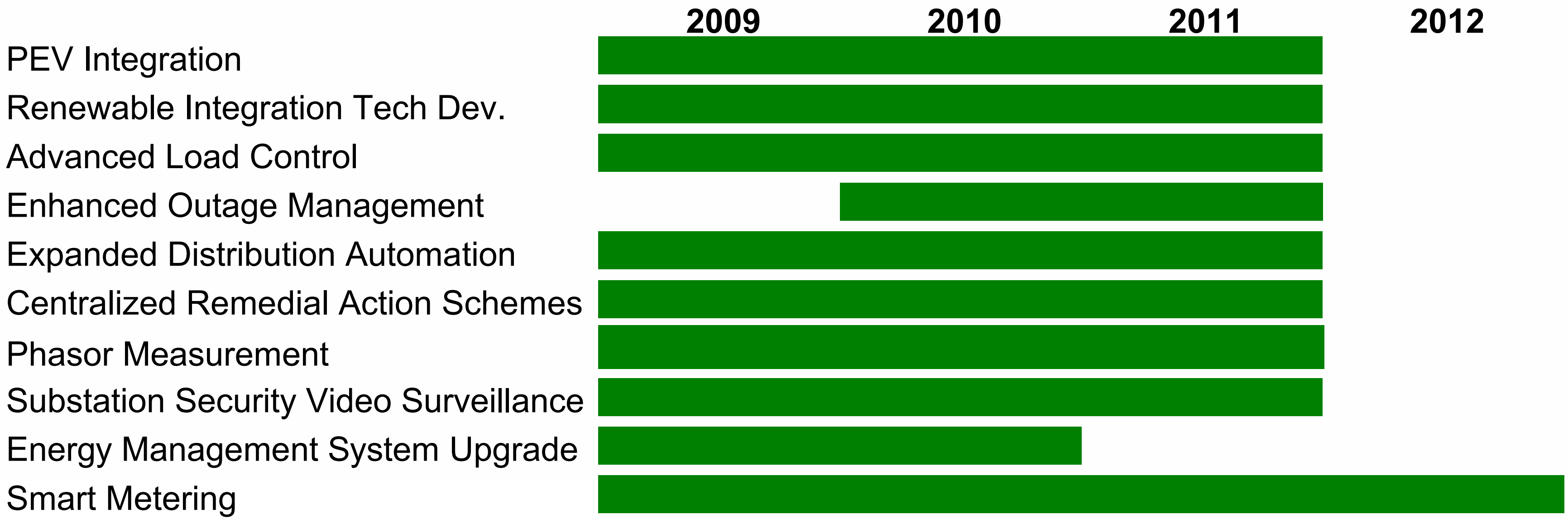
SCE SmartGrid Development

Building on smart foundation built over the past decade

~$2 Billion* SmartGrid Development Projects



*** Includes proposed project funding requests in the 2009 GRC pending CPUC approval**
SCE's $1.63b smart metering program was approved by CPUC in Sept. 2008

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OPPORTUNITY AND CHALLENGE for the U.S. SOLAR INDUSTRY

"High-Penetration PV into Distribution Grid"

John M. Lushetsky
Program Manager
Solar Energy Technologies Program (SETP)
Department of Energy
Office of Energy Efficiency and Renewable Energy

February 24, 2009

Acknowledgement of Organizations Serving on Workshop Planning Committee

U.S. DEPARTMENT OF ENERGY

Solar Electric Power Association

Electric Power Research Institute

Solar Energy Industries Association

Southern California Edison

FirstEnergy

ConSol

SunEdison

SunPower

DOE

- National Renewable Energy Laboratory
- Sandia National Laboratories
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory
- Office of Electricity Delivery and Energy Reliability

Excitement, Leadership and Opportunity

President Barack Obama

President Obama's Swearing-In Ceremony
January 20, 2009

Dr Steven Chu, Secretary of Energy
Nobel Laureate, Ph.D. Physics,
Former Director of LBNL

"We will harness the sun and the winds and the soil to fuel our cars and run our factories…All this we can do. All this we will do."

President Obama, January 20, 2009

B17

Solar Highlights in H.R. 1, the American Recovery and Reinvestment Act of 2009

U.S. DEPARTMENT OF ENERGY

- The stimulus bill, with an estimated $787 billion in spending projects and tax cuts, puts an emphasis on increasing jobs through the deployment of renewable energy and energy efficiency technologies
- Within the spending provisions, the bill includes:
  - $6.0 billion to cover the cost of loan guarantees for renewable energy and transmission projects. This funding is expected to guarantee more than $60 billion of loans.
  - $2.5 billion for applied R&D and deployment of RE and EE projects
  - $6.3 billion for state and local energy efficiency and renewable energy projects
  - $4.5 billion to convert federal buildings to High-Performance Green Buildings
  - $0.4 billion for ARPA-E, an agency within the DOE modeled after DARPA
- Within the tax cut provisions, the bill includes:
  - The option to receive a 30% grant from the Treasury in lieu of the ITC for solar installations placed in service in 2009-2010 or solar projects that begin construction in 2009-2010
  - A 30% manufacturing tax credit for renewable energy technologies, capped at a total of $2.3 billion of tax credits
  - Repeal of the "subsidized energy financing" limitation on the ITC. Solar projects financed with subsidized energy financing are now eligible to take the full ITC.
  - Extension of bonus 50% depreciation for solar property acquired in 2009

President's Energy Plan and Solar Energy's Challenge

U.S. DEPARTMENT OF ENERGY

Double renewable capacity in the next 3 years

10% renewables by 2012, and 25% by 2025

Create 5M new green jobs

Economy-wide GHG cap-and-trade program

- 80% GHG reduction by 2050

For the solar industry that equals *over* 1 GW of PV manufactured and installed over the next 3 years

Studies by Google's Climate Investment Fund and DOE show a potential for 170 to 200 GW of solar by 2030.

= 26% compounded annual growth rate over the next 20 yrs

An undertaking perhaps never seen in any other industry

How do we get there from here?

B19

National Clean Energy Project held February 23

U.S. DEPARTMENT OF ENERGY

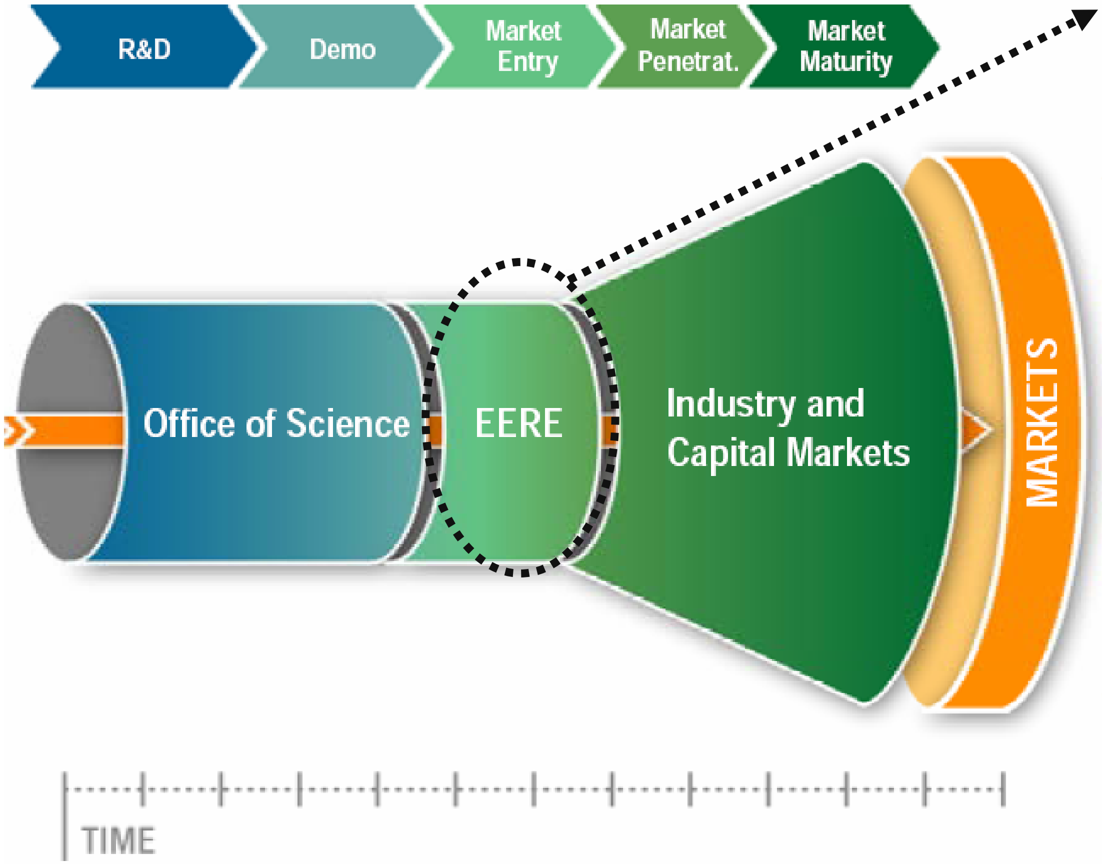
B20

U.S. Department of Energy Budget Breakdown

U.S. DEPARTMENT OF ENERGY

U.S. Department of Energy

Annual Budget: $23.9 Billion (FY08)



Energy Efficiency, Renewable Energy (EERE)

Annual Budget: $1.7 Billion (FY08)

10 Programs

Energy Efficiency

- Building Technologies
- Weatherization & Intergovernmental
- Industrial Technologies
- Federal Energy Management
- Vehicles

Renewable Energy

- Wind & Hydropower
- Biomass
- Geothermal
- Hydrogen, Fuel Cells & Infrastructure
- and ….

Solar Energy Technologies Program (SETP)

Annual Budget: $168 Million (FY08)

B21

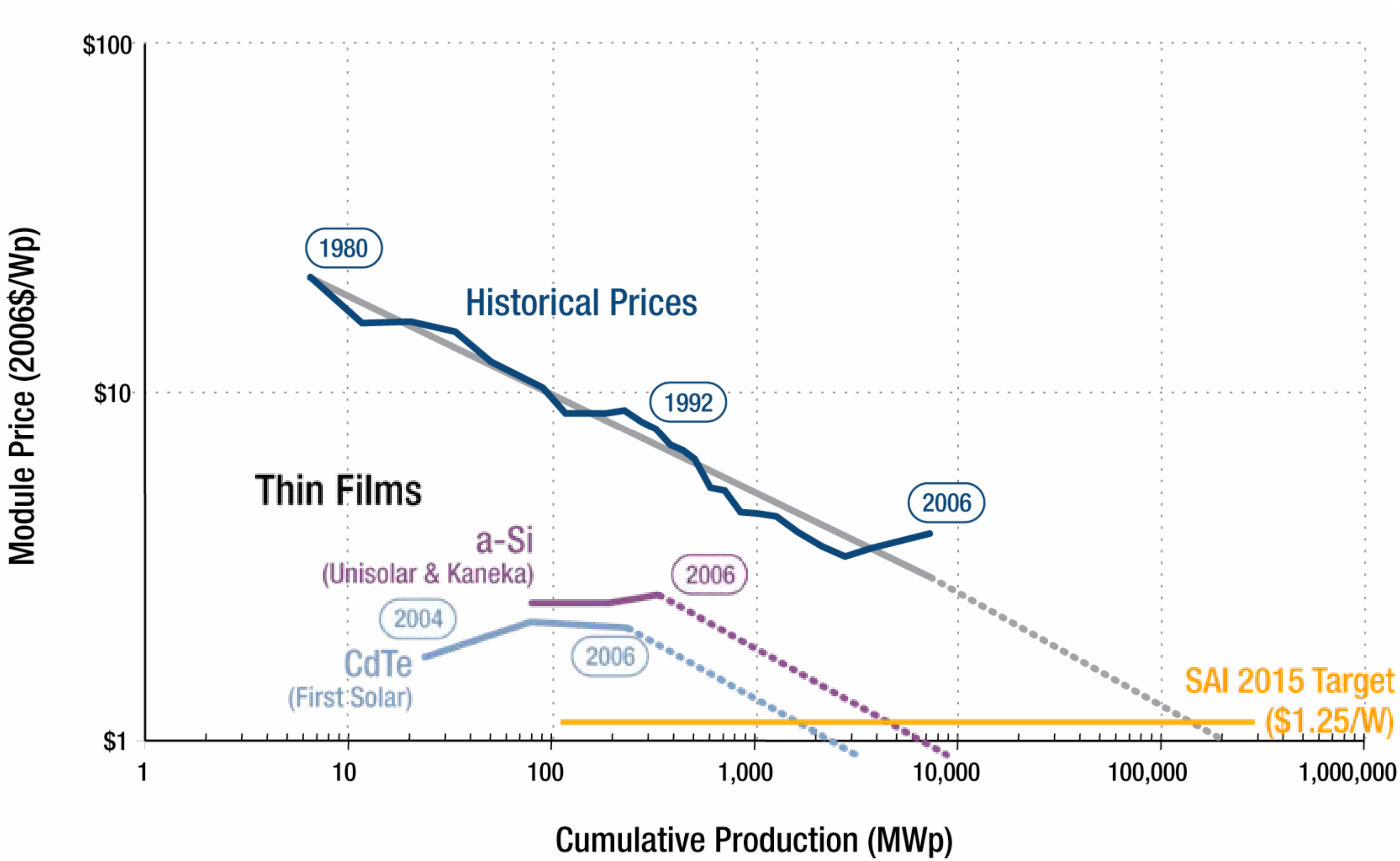
DOE's Solar Energy Technology Program

U.S. DEPARTMENT OF ENERGY

B22

Tremendous progress has been made in reducing module costs

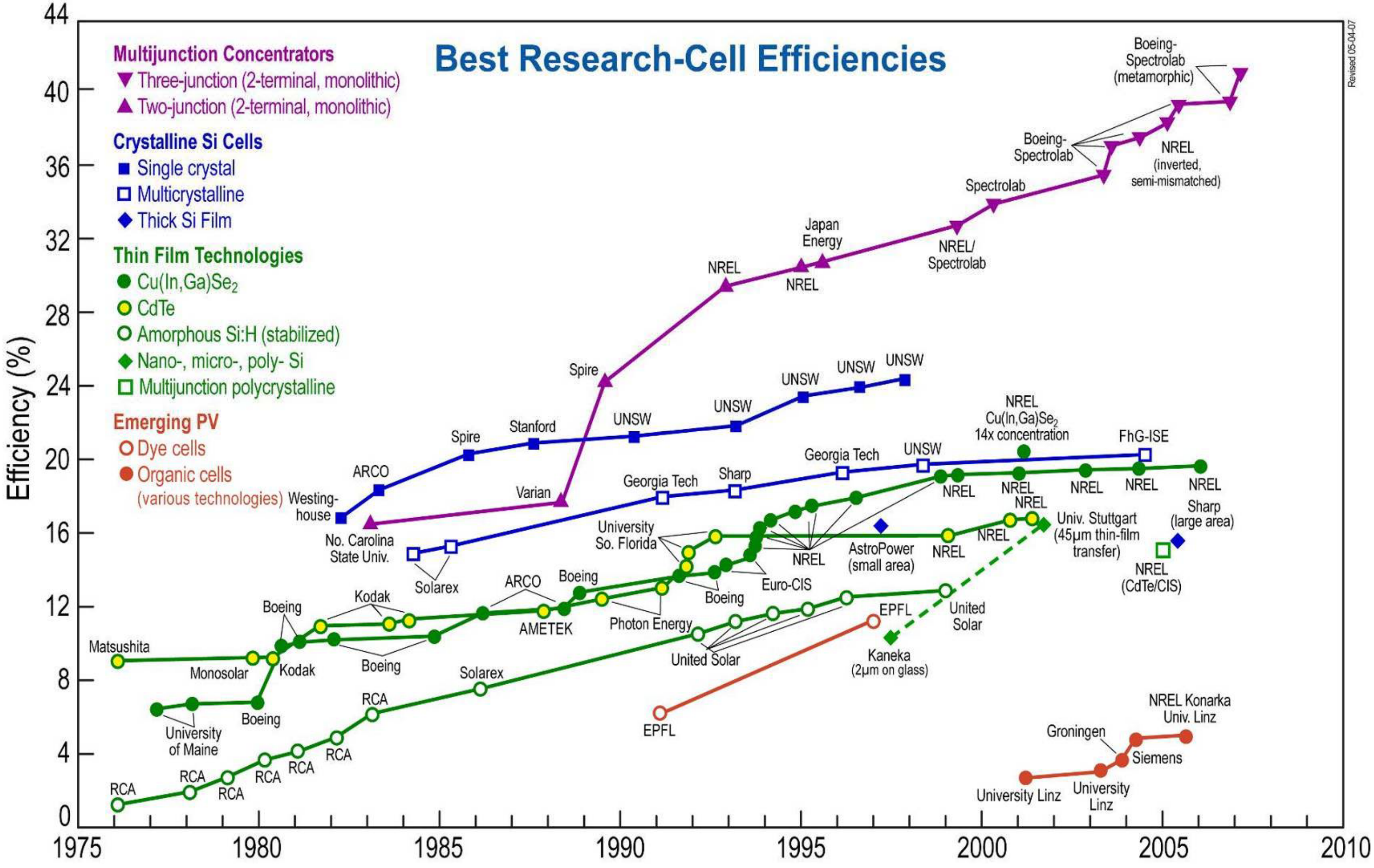
U.S. DEPARTMENT OF ENERGY



Source: Historical Data from Navigant (2007).

B23

Historical Record Efficiencies – 30 years of R&D success



B24

diverse technologies for potentially diverse PV markets

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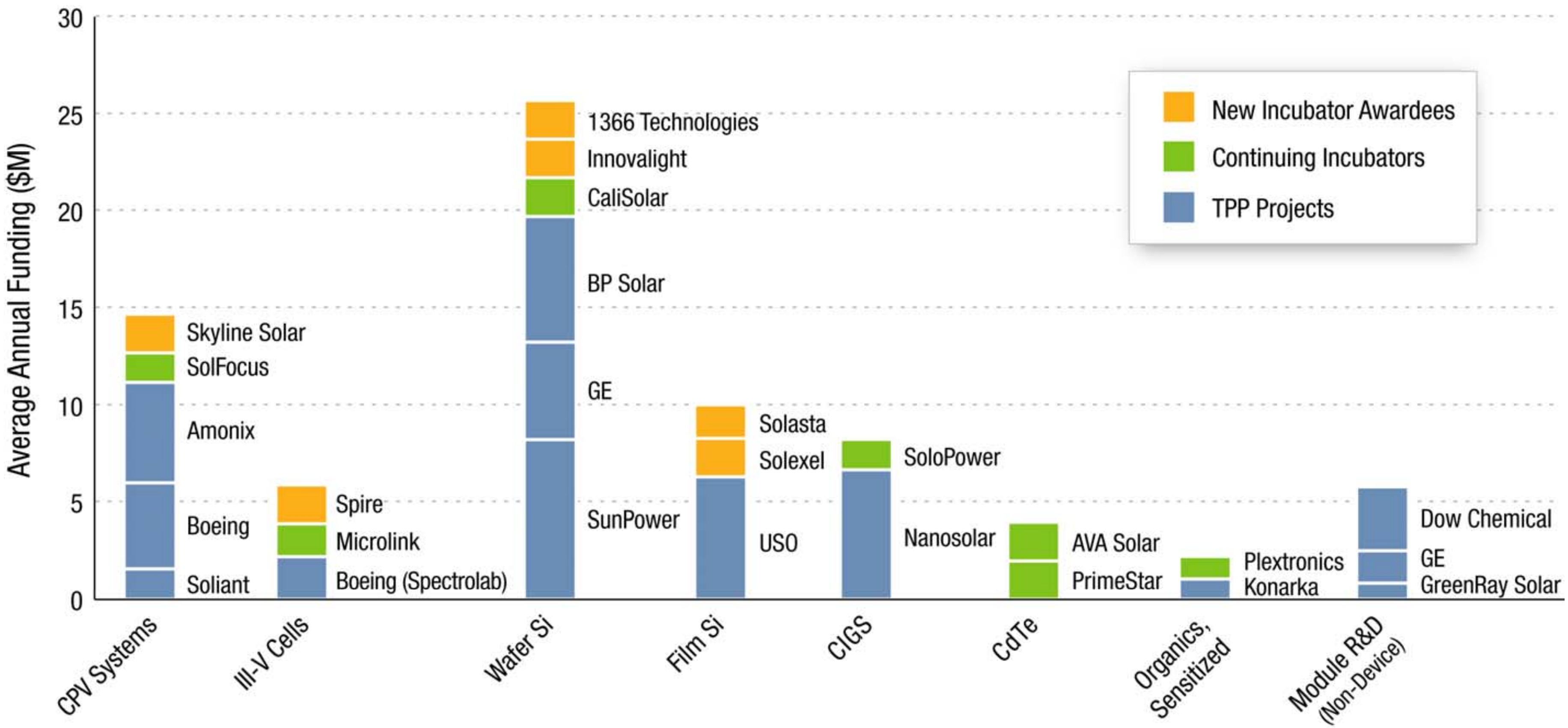

B25

The SETP is focused on enabling high penetration of solar energy technologies and achieving grid parity by 2015

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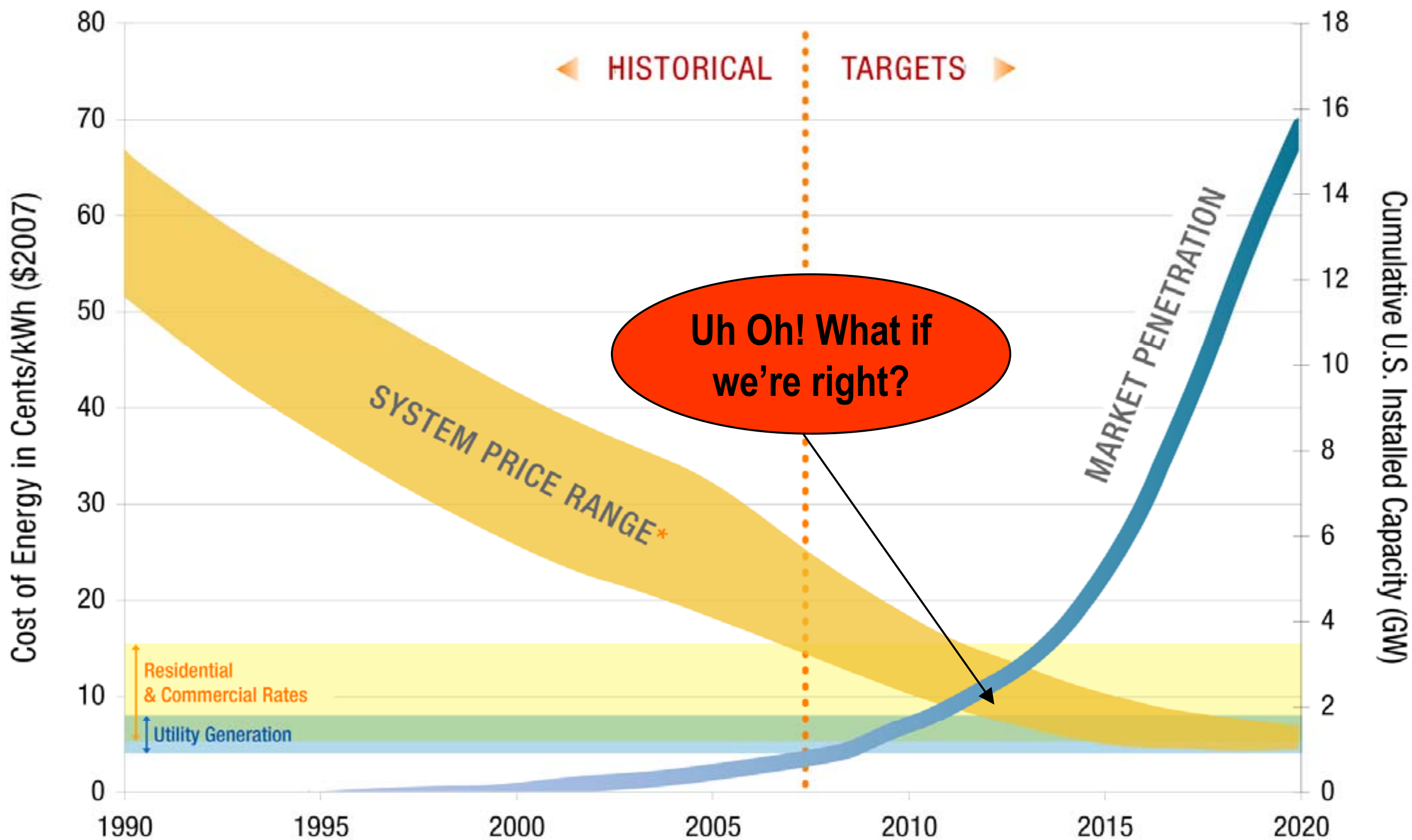

Market Sector	Current U.S. Market Price Range (¢/kWh)	Cost (¢/kWh) Benchmark 2005	Cost (¢/kWh) Target 2010	Cost (¢/kWh) Target 2015
Residential	5.8 - 16.7	23 - 32	13 - 18	8 - 10
Commercial	5.4 - 15.0	16 - 22	9 - 12	6 - 8
Utility	4.0 - 7.6	13 - 22	10 - 15	5 - 7

B26

Growth of Grid-Tied PV at a Fast Clip

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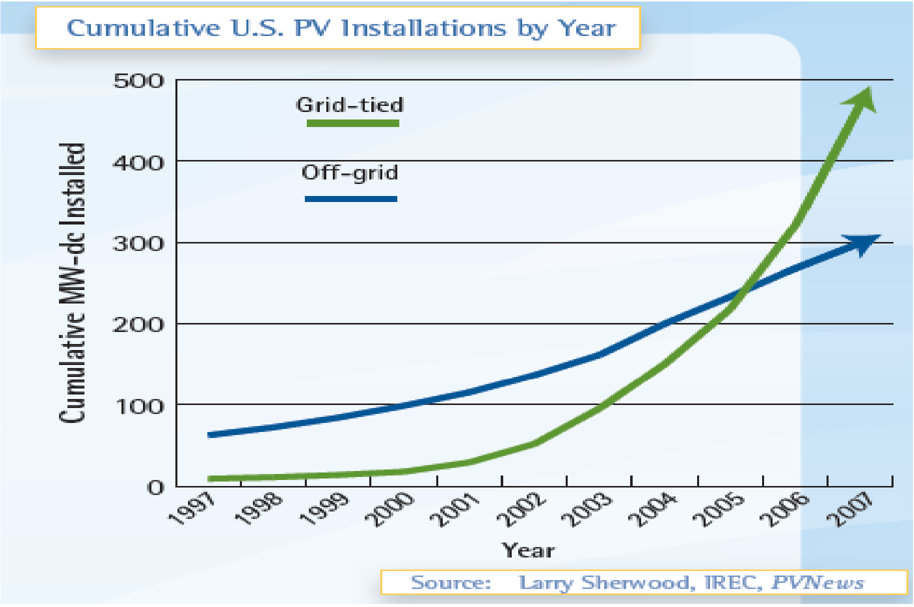
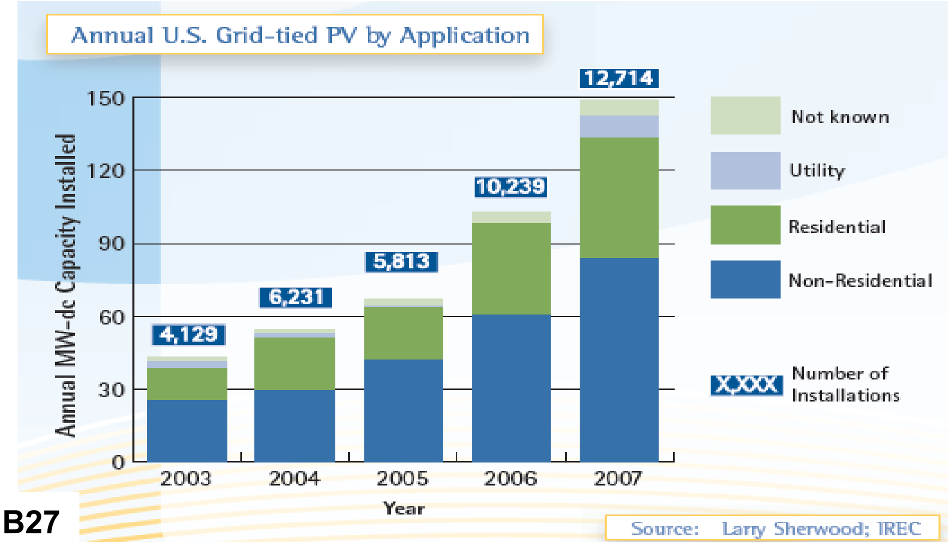
- Based on latest industry information on grid-tied PV:
  - 45% growth rate in U.S. PV installations in 2007 over 2006
  - Annual installed capacity more than doubled since 2005
  - In 2008, CA alone installed 158MW, exceeding the 150MW growth achieved by entire U.S. in 2007
  - Outside CA, annual installations grew 83% in 2007 over 2006

- High-penetration PV will inevitably become more prevalent in foreseeable future, based on growth trajectory

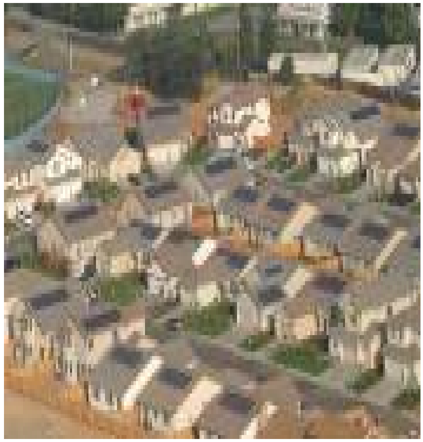




B27

Technical Challenges for High-Penetration PV

- Ensure safe and reliable two-way electricity flow
- Develop smart grid interoperability
- Develop advanced communication and control functionalities of inverters
- Integrate renewable systems models into power system planning and operation tools
- Integrate with energy storage, load management, and demand response to enhance system flexibility
- Understand high-penetration limiting conditions
- Understand how various climates and cloud transients affect system reliability



B28

SETP Implementation of Workshop Findings

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FY09 Systems Integration Funding Opportunity:

Analyze and demonstrate effects of high-penetration PV systems on varying designs and operations of distribution circuits

- Industry call with topic areas derived from workshop findings on high-priority RD&D activities and performance requirements for defined high-penetration PV scenarios
  - Integrated team approaches (industry lead with national lab partner) to be solicited
  - Industry call targeted for release in May 2009, with awards made by September 2009

We have a big job to do

U.S. DEPARTMENT OF ENERGY

Picture of the Giza Pyramids looking West from Cairo B30

Thank You

Contact Information:

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Program Manager
U.S. Department of Energy

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john.lushetsky@ee.doe.gov
Phone**: 202-287-1685**
on the web:
www.solar.energy.gov

Sign up for SETP quarterly newsletter by emailing: solar@ee.doe.gov

B31

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EPRI Perspectives

DOE Workshop on High Penetration of PV into Distributed Grid

Clark W. Gellings, EPRI
Vice President – Technology

Ontario, CA

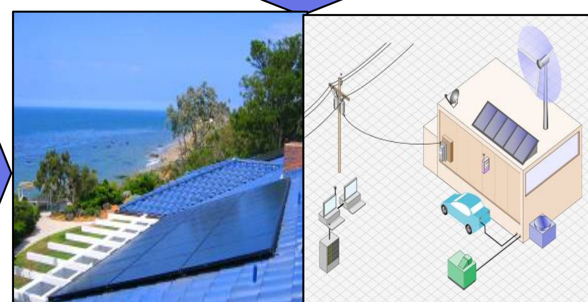
February 24, 2009

B32

Distributed Renewable Integration R&D

Distribution System Interconnection
(Communication, Control, Protection, Monitoring)

Distribution System Integration
(Data management & Integration, market integration)



Interface Technologies
(inverters, control, Advanced Metering, Direct DC Integration)

Balancing Resources
(Energy Storage, Demand Response, etc.)

Increase the Value of Distributed Renewables by Safely and Reliably Integrating Them with a Smart Distribution Infrastructure

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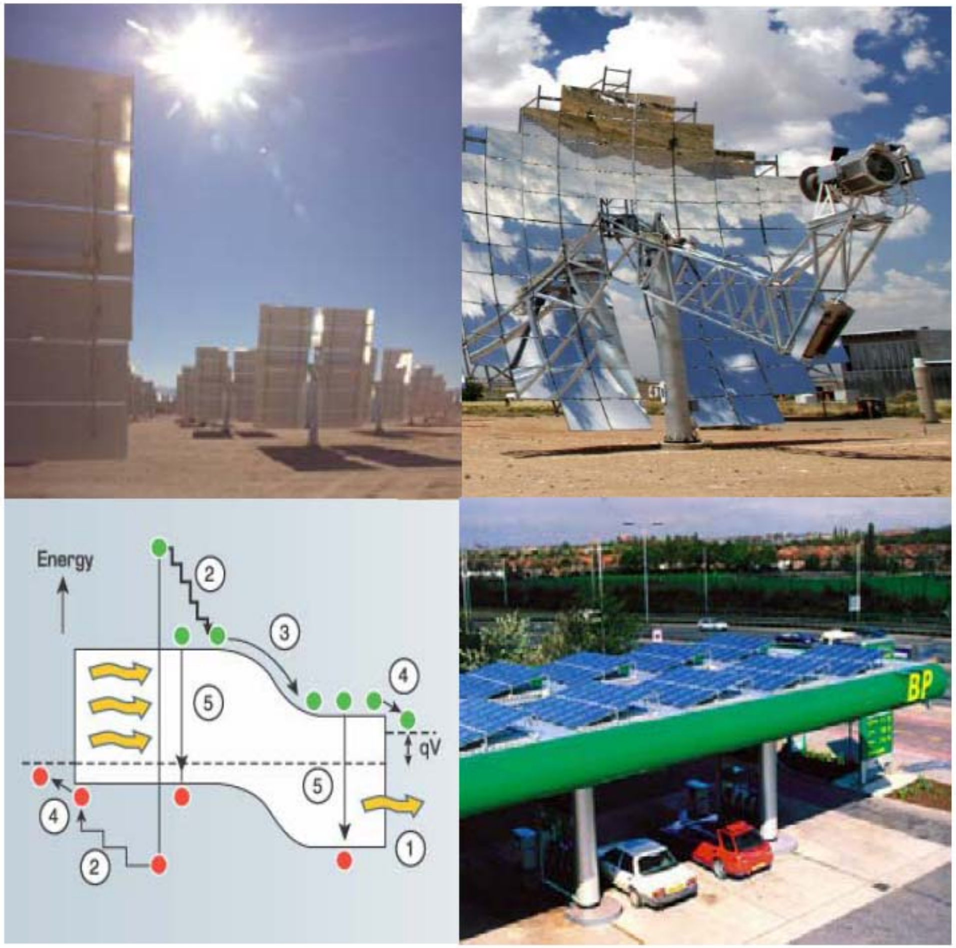
EPRI Solar Electric Interest Group (SEIG)



Solar Power has much to offer the utility industry in a wide variety of unfamiliar forms

- Third year ~ 50 members, 5 events per year, in 2009
  - Feb 25/26 Ontario, CA, SCE and DOE workshop
  - Mar 12, Las Vegas, REWorld conf.
  - June Webcast
  - Oct 20, Denver, NREL
  - Oct 28, Anaheim, Solar Power
- Interest group addresses both Distributed and Central Solar
- Wed site www.epri.com/seig
- Objective to share experiences, on current issues related to deployment of solar energy

Cara Libby
clibby@epri.com

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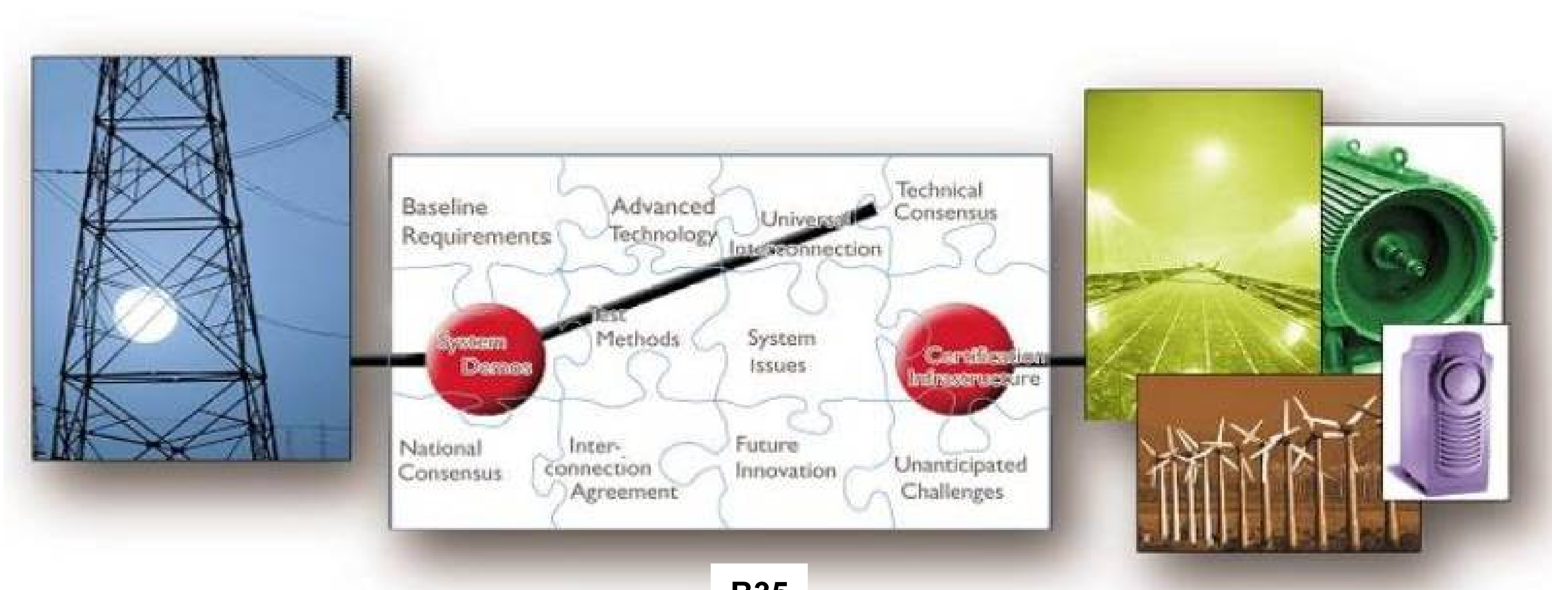
Research Needs

- How to increase penetration and maintain reliability in existing radial distribution?
- What is the distribution system of the future and how do we get there?
- Role, deployment and integration of AMI with distributed resources?
- Utility engagement in emerging distributed business…PV-DC, grid interface models?
- How will it all work together and need for testing, demonstrations, best practices?



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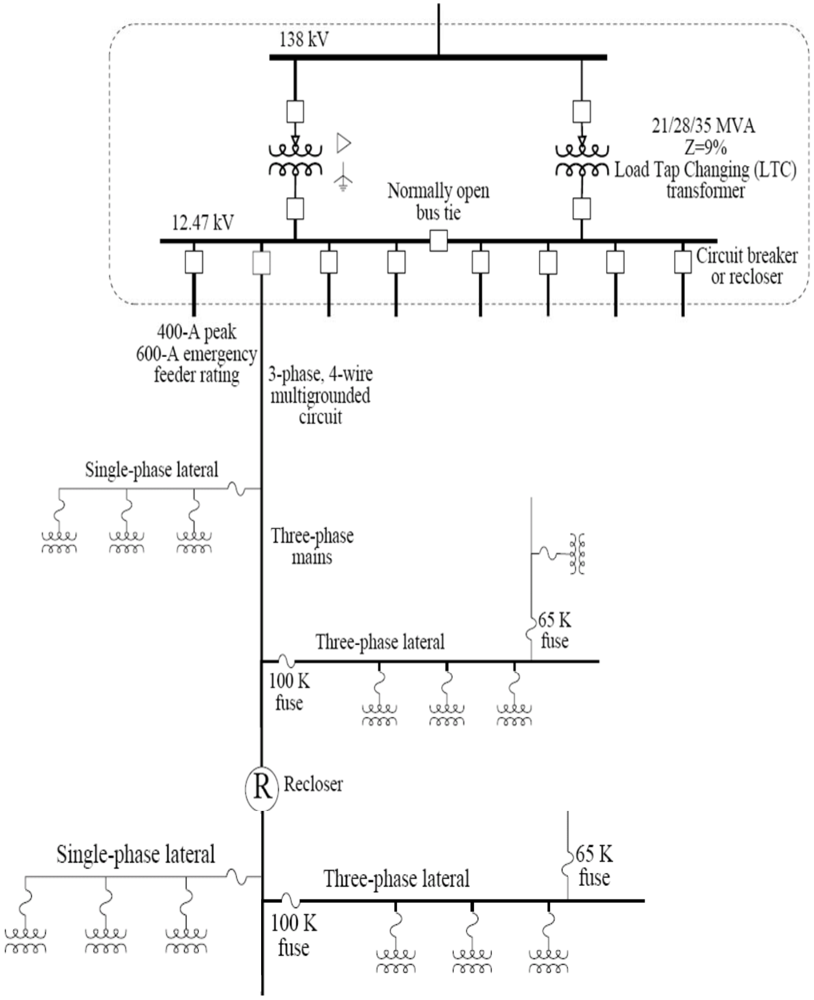
174.001 – Planning & Design for Renewable Integration into Existing Distribution

- **Industry Issues**
  - Existing distribution is not ready for high penetration of renewable distributed generation.
- **Work Scope**
  - Investigates how to make incremental increases of renewable generation into today's radial and network distribution without sacrificing safety, reliability and effectiveness.
- **Proposed Deliverables**
  - Screening software
  - Application guideline and criteria report
  - Workshop on current practices



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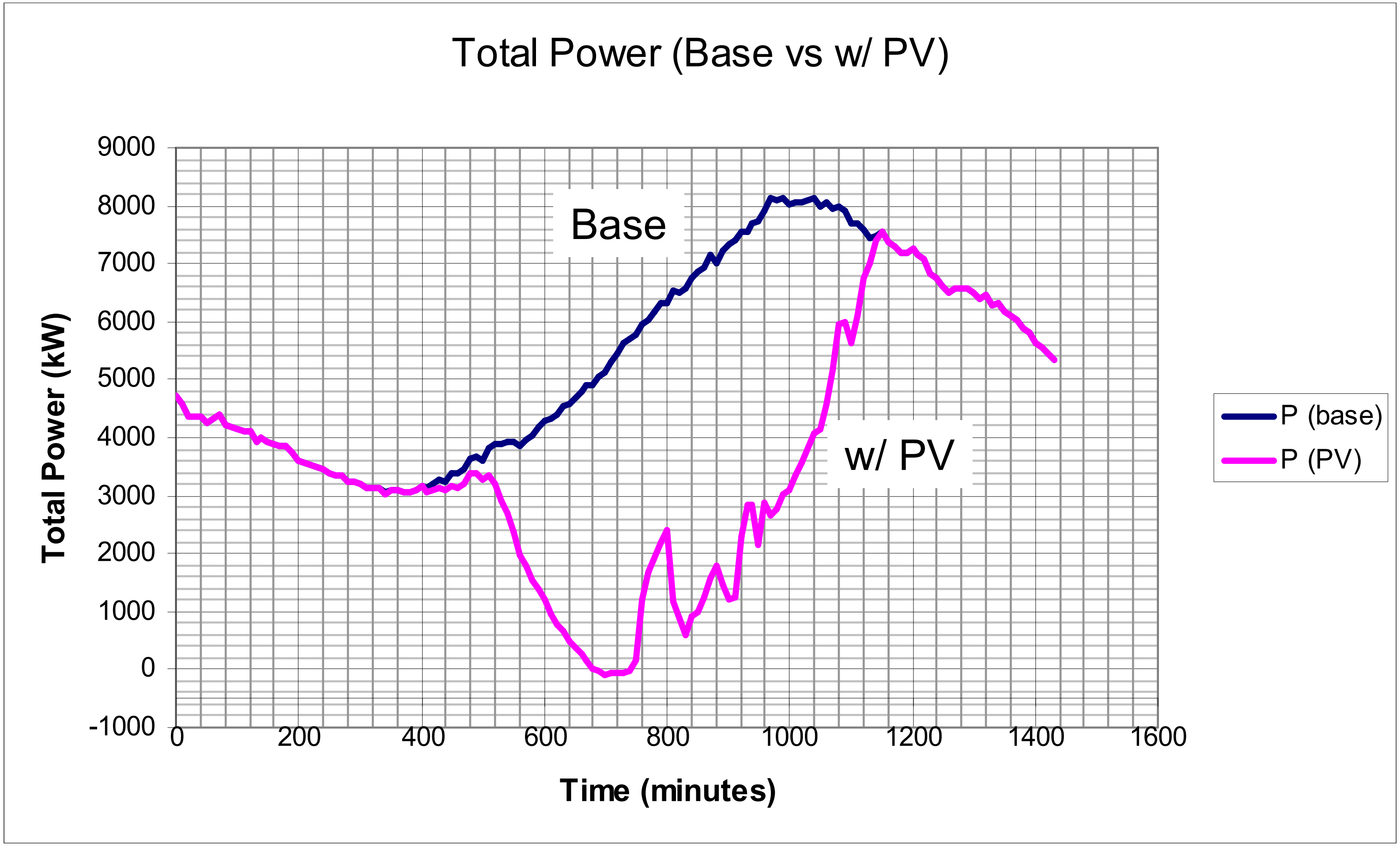
Distribution System Simulator Example – Effect of PV Power on Power Profile



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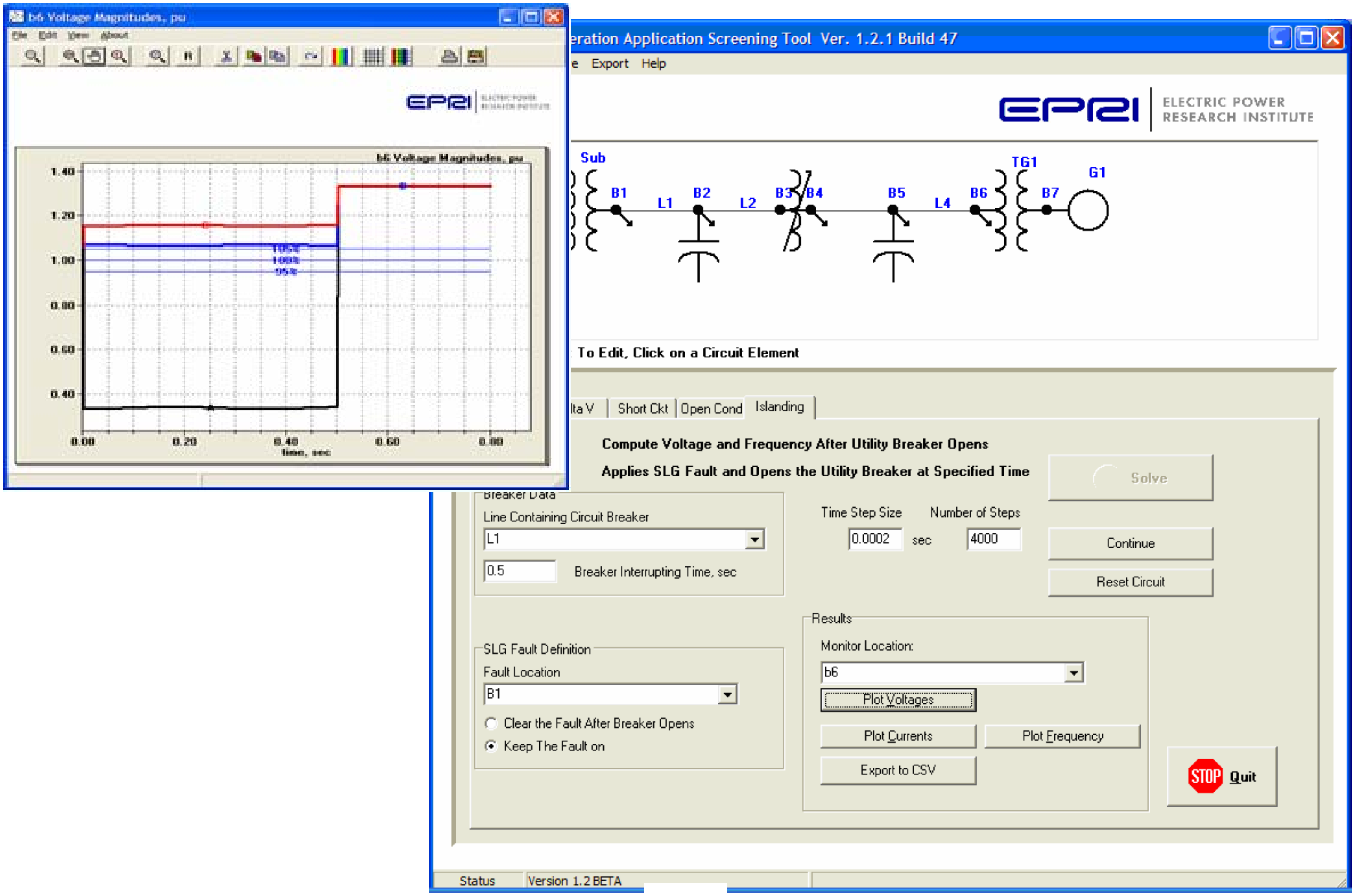
EPRI ELECTRIC POWER RESEARCH INSTITUTE

Sample of a DG Screening Applet

Go to http://electricdss.sourceforge.net/



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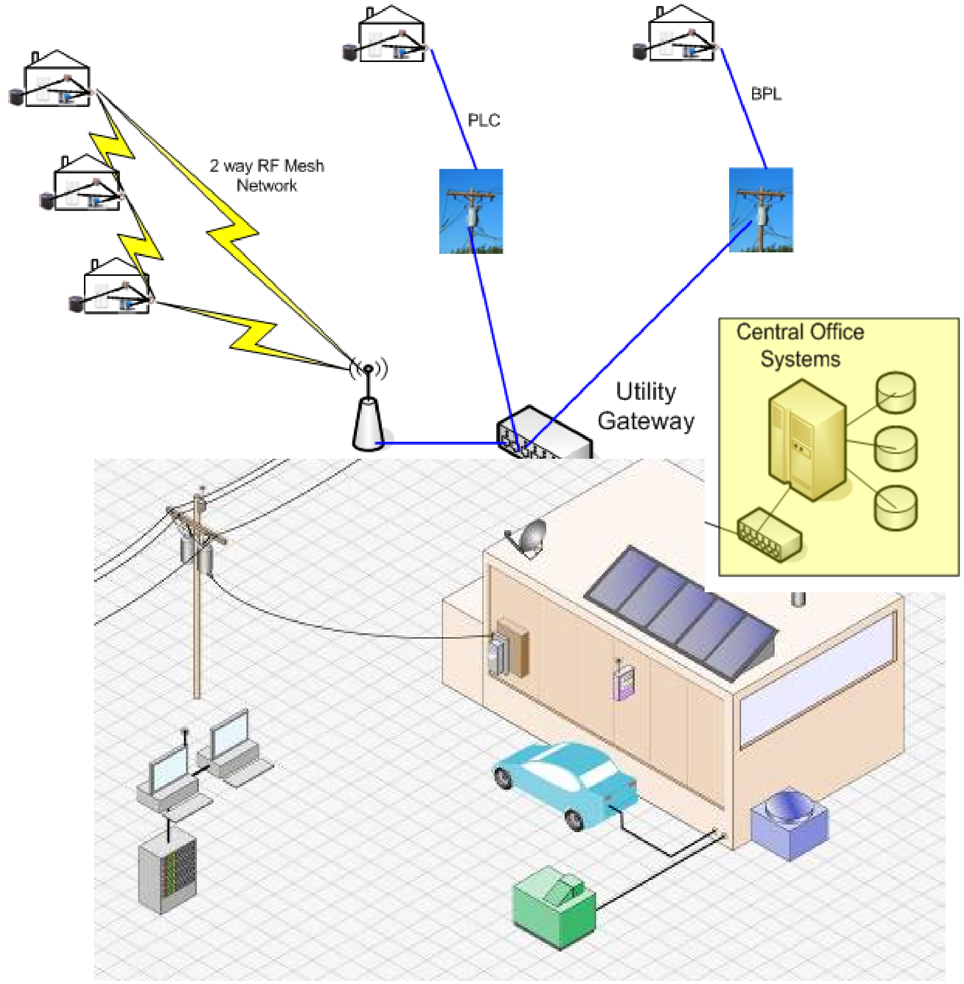
Opportunity: Distributed PV & Smart Grid Integration

- Grid Interface inverters can provide voltage/var support if properly designed and integrated with the distribution system
- Utility communication and metering infrastructure can enhance the value of distributed renewable
- Utility communication infrastructure can provide remote diagnostic and maintenance capability to the weakest link – inverters



B39

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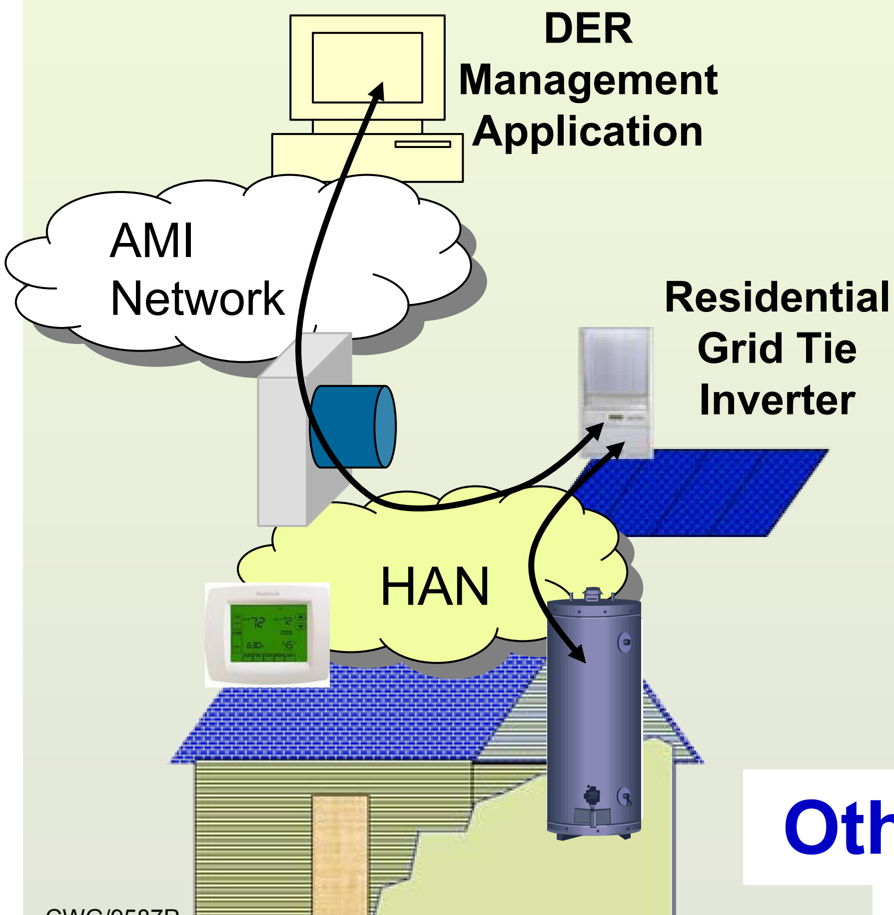
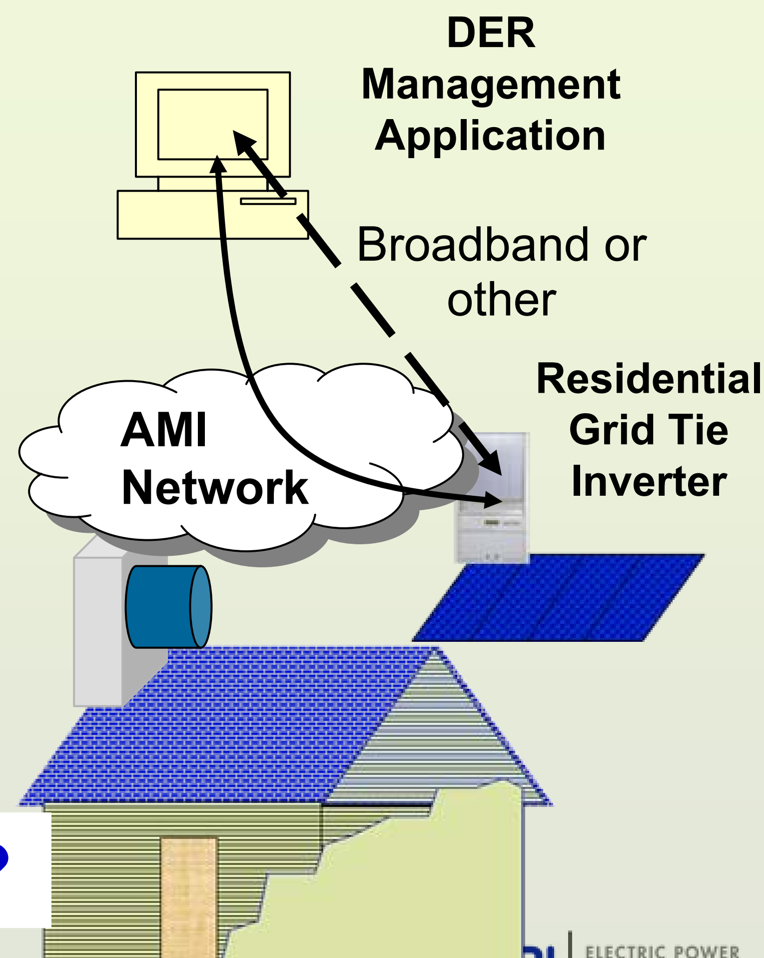
Possibility of Multiple Architecture

Inverter on a Premises Network



Inverter on a Wide Area Network



Others?

B40

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Need for Standard Communication Protocol

- All Offer Communication Options
- Working with Utilities on Integration Projects
- None Involved in a Common Approach to the Utility Interface

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Data Model & Protocol Decisions…

Standards Starting Points:

- **IEC61850-7-420 , ANSI C12.19 Tables**

If inverter is on a premise network:

- Coordination with Smart Energy Profile – common language / messaging on the HAN

If inverter is on an AMI network:

- Coordination with ANSI C12.18&19 and 22
- A tunneling method for 61850?

If inverter is broadband connected:

- Use 61850 messaging / exchange formats

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EPRI ELECTRIC POWER RESEARCH INSTITUTE

Interested in Inverter Architecture?

Contact Brian Seal

Senior Project Manager, EPRI

bseal@epri.com

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Evaluation of Grid Interface Systems

- Industry Issues
  - Utilities need to be proactive in understanding and advancing new grid interface systems
  - Improve system efficiency through better integration of modules

- Work Scope
  - Evaluates grid integration hardware, systems and configurations including inverters, metering, communication and control interface devices

  - Topics include immunity, emissions and energy performance, protection settings, availability, cost.

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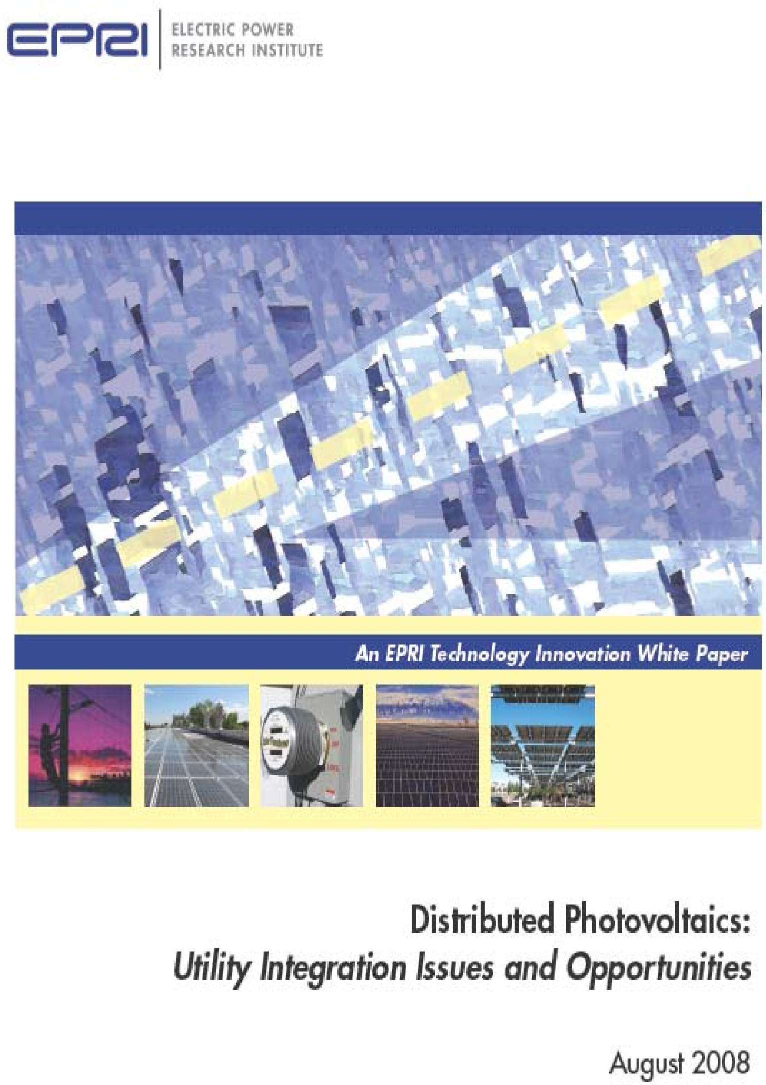
Summary of EPRI PV Integration Deliverables White paper available at EPRI SEIG, #1018096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An EPRI Technology Innovation White Paper

Distributed Photovoltaics:

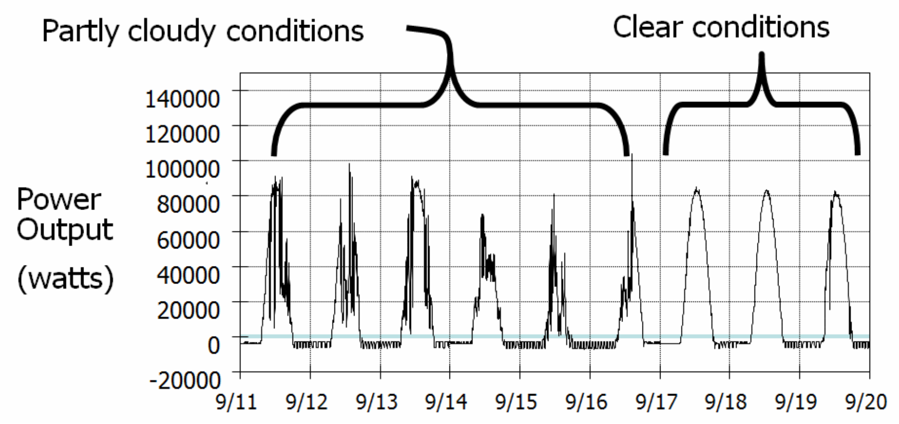
Utility Integration Issues and Opportunities

August 2008

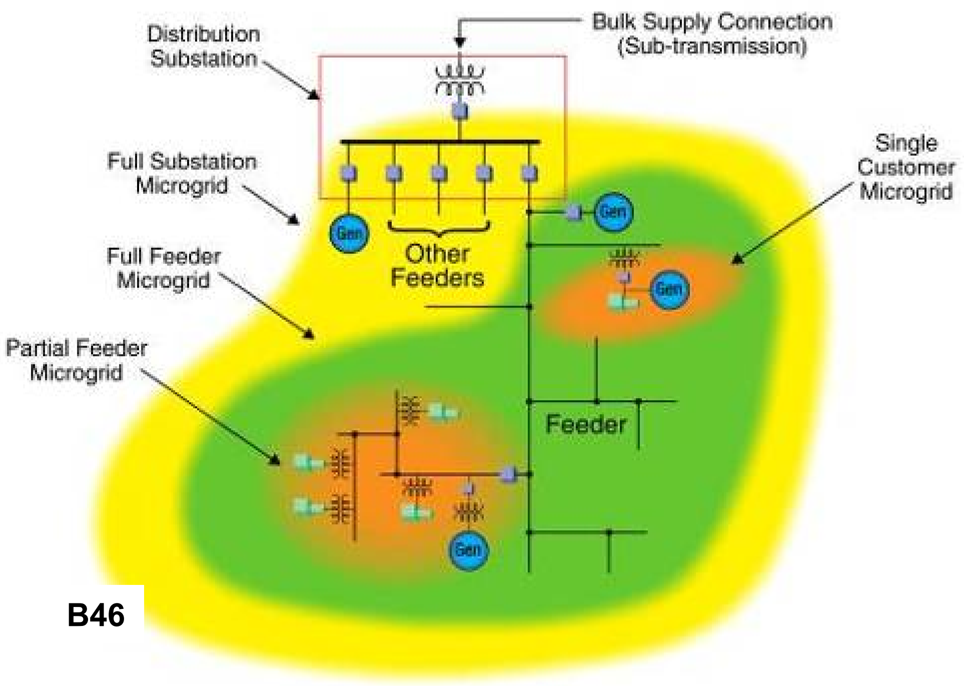
- Integrating Renewable into Distribution
  - Screening tools, guidelines and deployment criteria, technical updates, workshops on utility practices, and reports on future grid functionality requirements.
- PV & Metering Integration into Distribution
  - Surveys on new products and applications, guide for integrating AMI and other PV interface devices, laboratory test protocols, evaluations reports and field monitoring.

Future Distribution System Design

- Industry Issues
  - Decisions to replace or upgrade aging distribution systems need to consider potential of high distributed generation levels



- Work Scope
  - Addresses future options for distribution planning, design and operation with new devices, advanced configurations, related tools and practices



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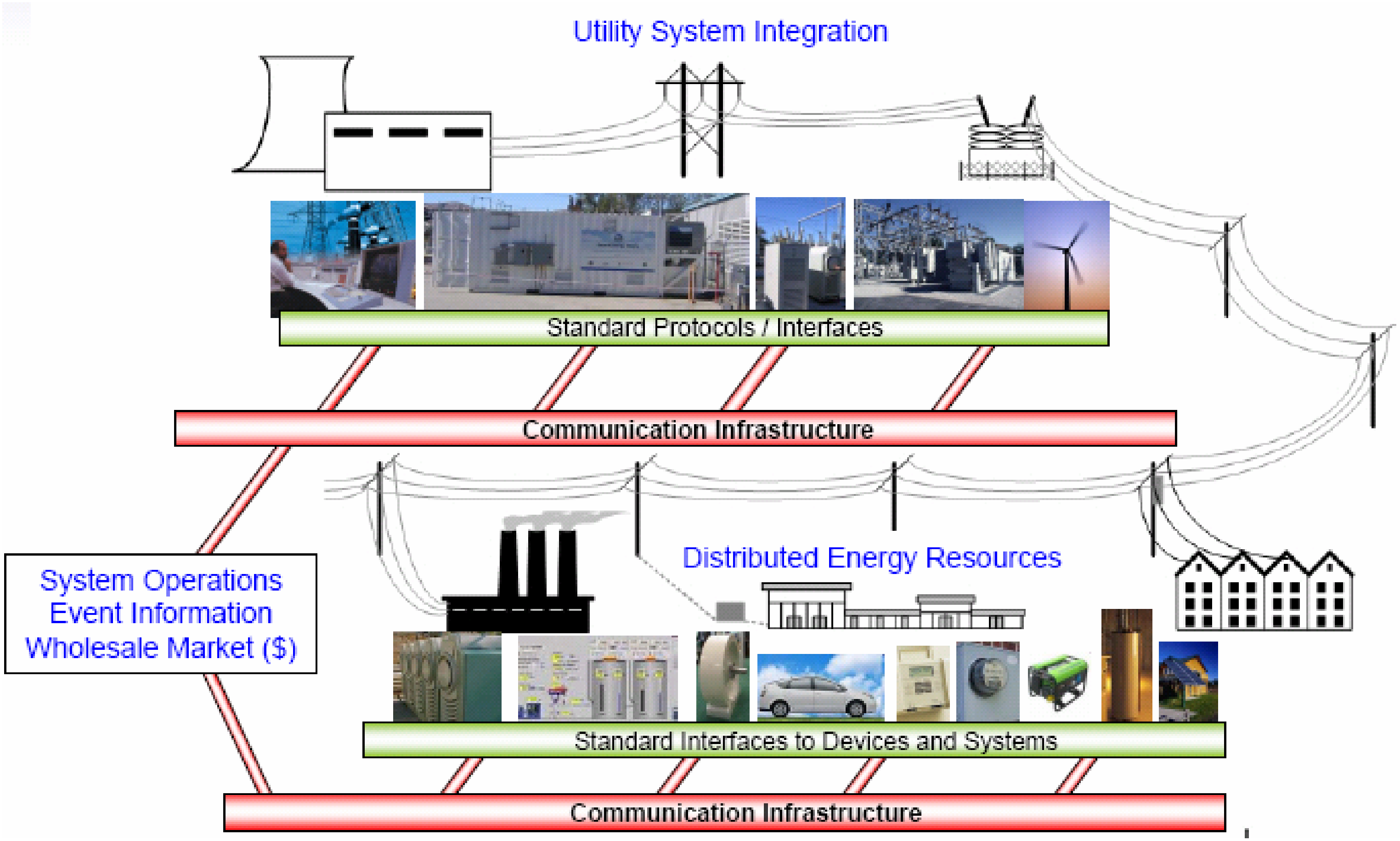
EPRI Smart Grid Demonstrations (~$25M)
Integrating Distributed Resources



8-10 Regional Demonstrations in 5 Years Highlighting Interoperability and Integration of Distributed Resources with the Utility System

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First Three Host-Sites Selected

	Consolidated Edison	FirstEnergy	PNM Resources
Resources	Distributed Generation Demand Response Wind Plant	HVAC (Res., C&I) DR Electric Storage Thermal Storage	Solar PV (residential & System) Storage & DR
Integration	End-to-end (Customer owned DG, DR provider, Con Edison, NYISO)	Real Time T&D Ops & Planning PJM	HAN, SCADA, System Ops & Planning
Diversity	Dense Urban Environment Customer Owned Resources	Smart Grid w/Out use of AMI system Master Controller Concept	Large deployment of Residential PV. Optimization Incl. Volt & Freq control
Business Case	Increase Reliability Reduce Peak Demand	Grid efficiency and reliability at local level	15% peak load reduction at feeder
Furthers Industry	Interoperability of Distributed Energy Resources (DER)	Local delivery system Integration of DER	Technologies & Standards for Renewable Integration

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PNM Resources

- Further the understanding of critical integration technologies and standards to integrate renewables (PV), storage, DR & EE.
- Integration of Multiple Resources
  – Substation-level PV and storage - 100kW-1MW with ~2 hours storage
  – Residential-level PV and storage - Residential Greenfield development
  – Commercial & Residential Demand Response
- Application of Critical Integration Technologies and Standards
  – IntelliGrid Based Use Case Analysis - Define system architectures
  – Leverage & Further Standards - Utility & Customer/HAN

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Action Framework… Four Evolving Infrastructures

Low-Carbon Generation

Where do we want to be?

Local Energy Networks

*Electri*Net[SM]

Smart Grids

How do we get there?

Electric Transportation

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EPRI's ElectriNet Framework Development Effort (2009-2011)

- **A "top down" effort to**
  - Define the organization and interaction of the components
  - Define the data that will be exchanged between the components and the requirements for the communications infrastructure that will connect the components
  - Determine how the massive networks of smart components are secured, managed and maintained
  - Determine how and where data is converted into usable information and how that information is used to optimize the performance of the grid.

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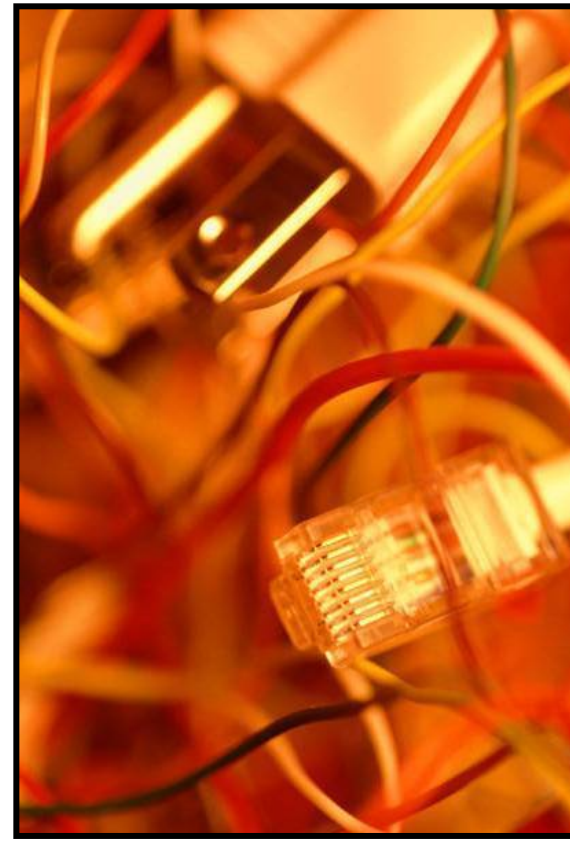
ElectriNet – Local Energy Networks

State of the technology…

- PV and local storage technology is reaching maturity
- PHEV connectivity not completed
- Stand-alone operations only
- Missing energy network controllers for in-network operations
- Missing standard for interactive grid interface
- Multiple proprietary and standard communication networks available



ElectriNet℠

CWG/9587P

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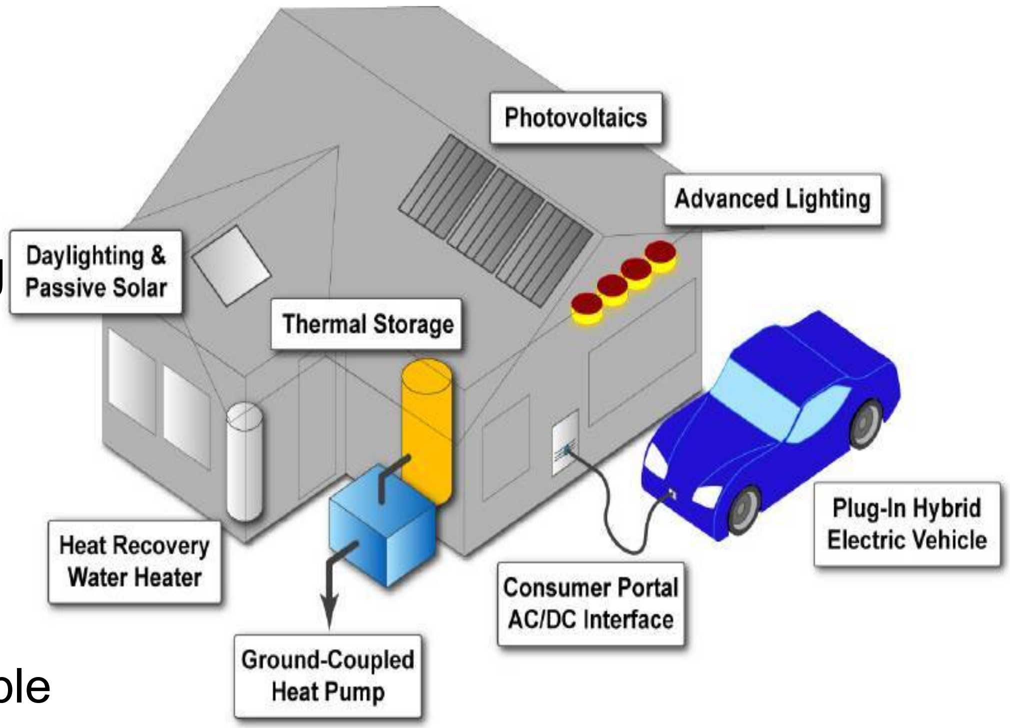
Local Energy Networks

Where we want to be…

- Create a self-organizing group of energy-producing and -consuming devices interacting with the grid to provide electricity to meet evolving lifestyle, infrastructure and environmental demands
- What it means for the networks
  - Meeting energy demand and emitting less carbon
  - Significant savings through available energy sourcing options
  - Achieving optimum economics through local management



ElectriNet℠

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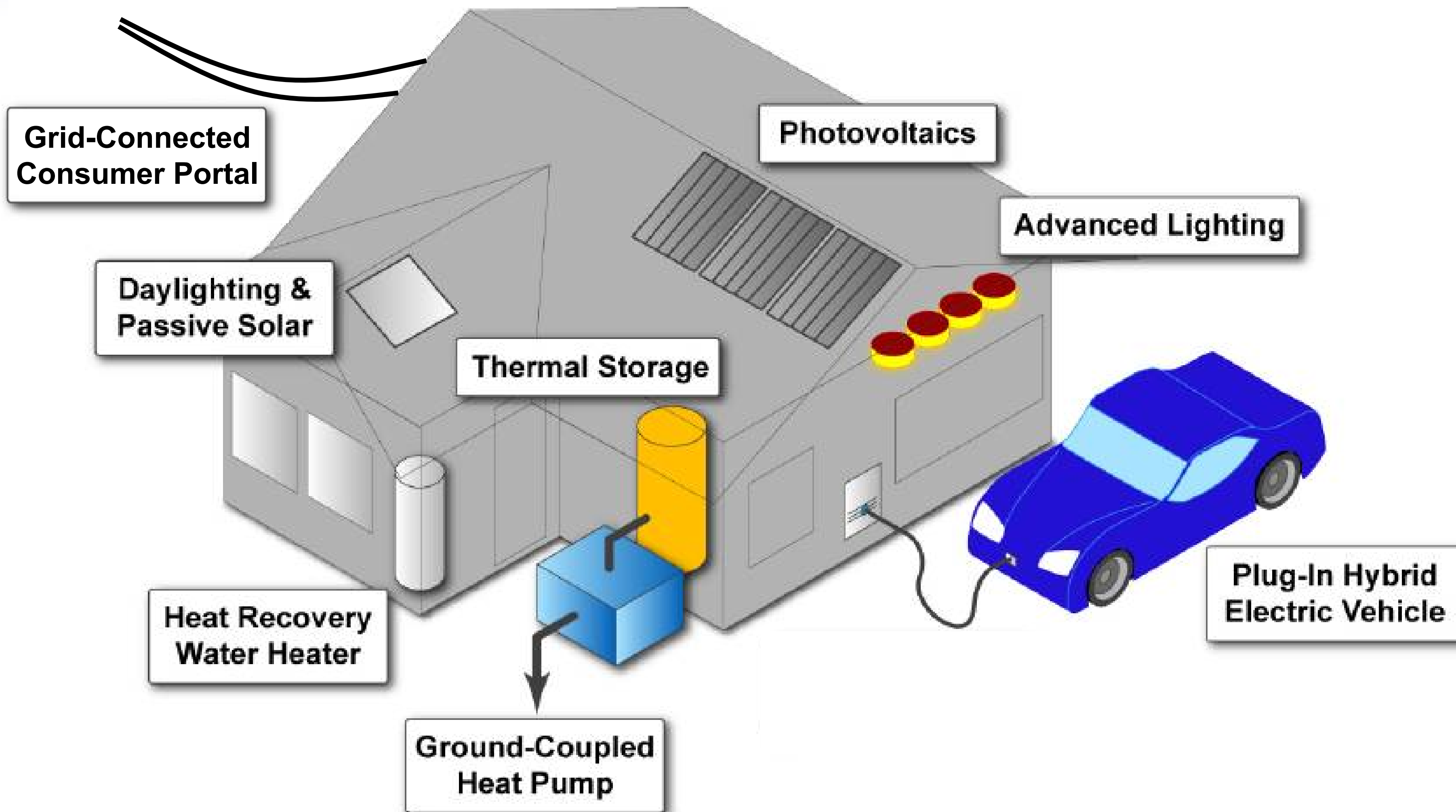
Local Energy Networks… an Example



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Together…Shaping the Future of Electricity

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U.S. Department of Energy
Energy Efficiency
and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Solar Energy Technologies Program

Setting the Stage for

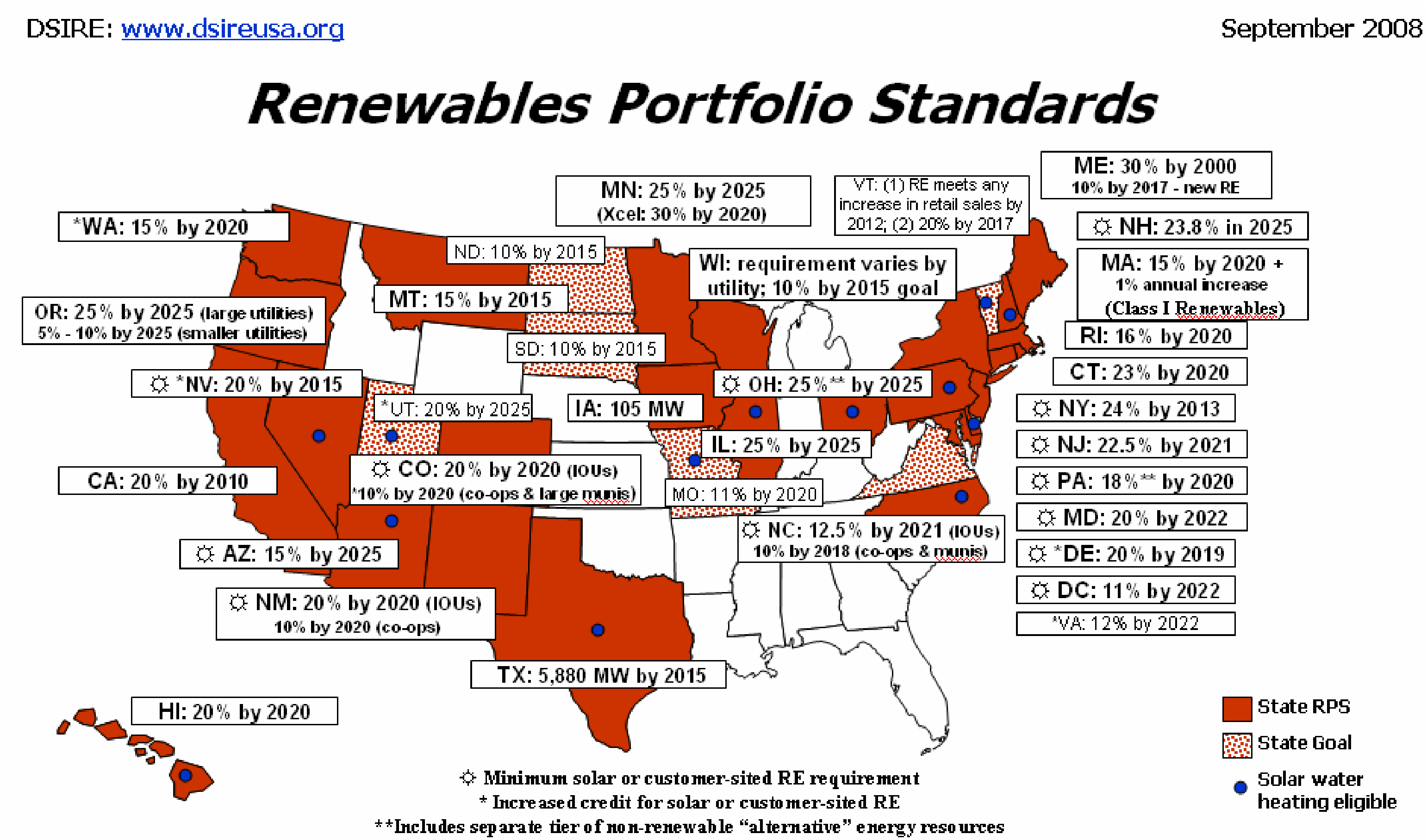
High-Penetration PV into Distribution Grid

Dan T. Ton
Systems Integration Team Lead
Solar Energy Technologies Program (SETP)
Department of Energy
Office of Energy Efficiency and Renewable Energy

February 24, 2009

Drivers for Renewable Systems Integration

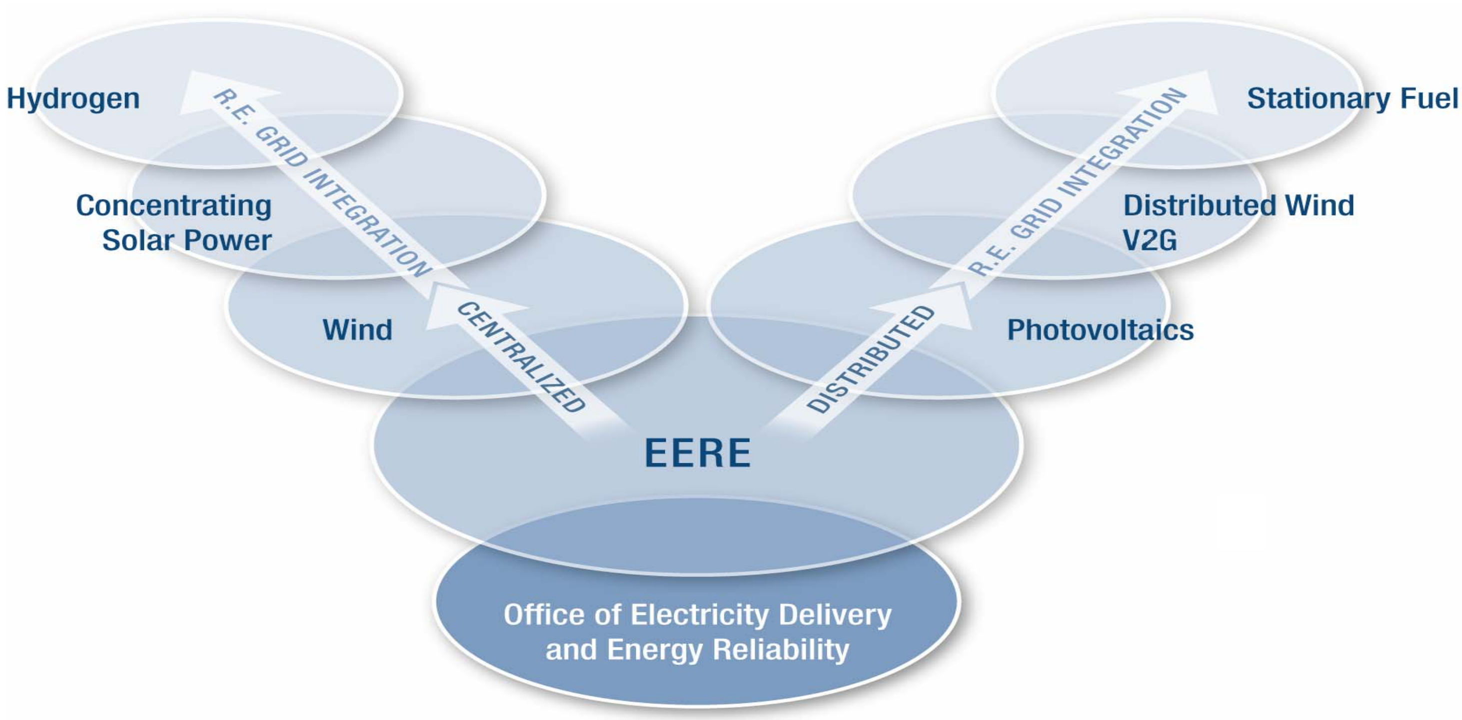
Climate change concerns, renewable portfolio standards, energy security, and green job growth are driving renewable systems integration with grid (e.g., 28 States & DC with RPS mandates)



B57

DOE Approach to Developing RSI Strategy

U.S. DEPARTMENT OF ENERGY



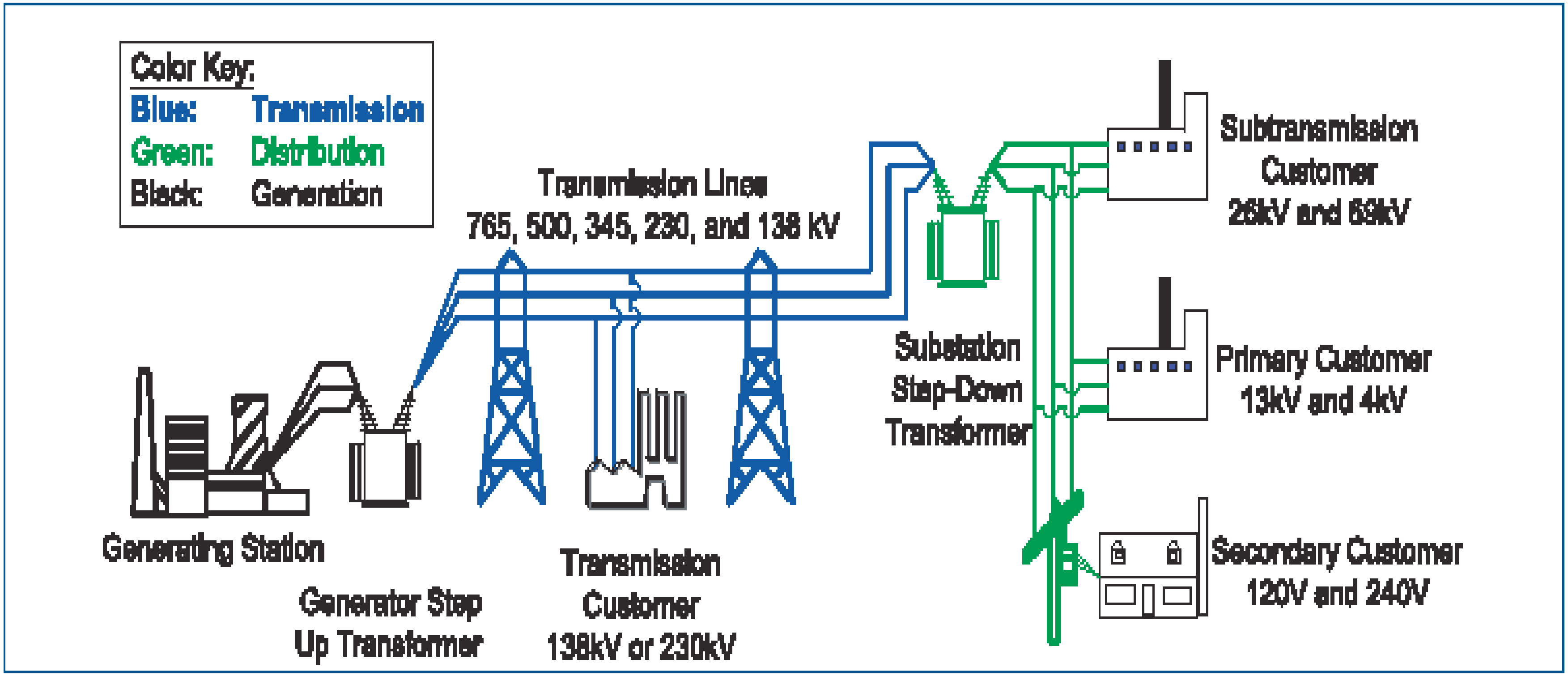
- **Transmission-grid integration for wind and CSP**
- ***Distribution-grid integration for PV****, wind, V2G, and others interconnected at the distribution level (<15kV)**

** Workshop Focus*

B58

Electric Grid

U.S. DEPARTMENT OF ENERGY



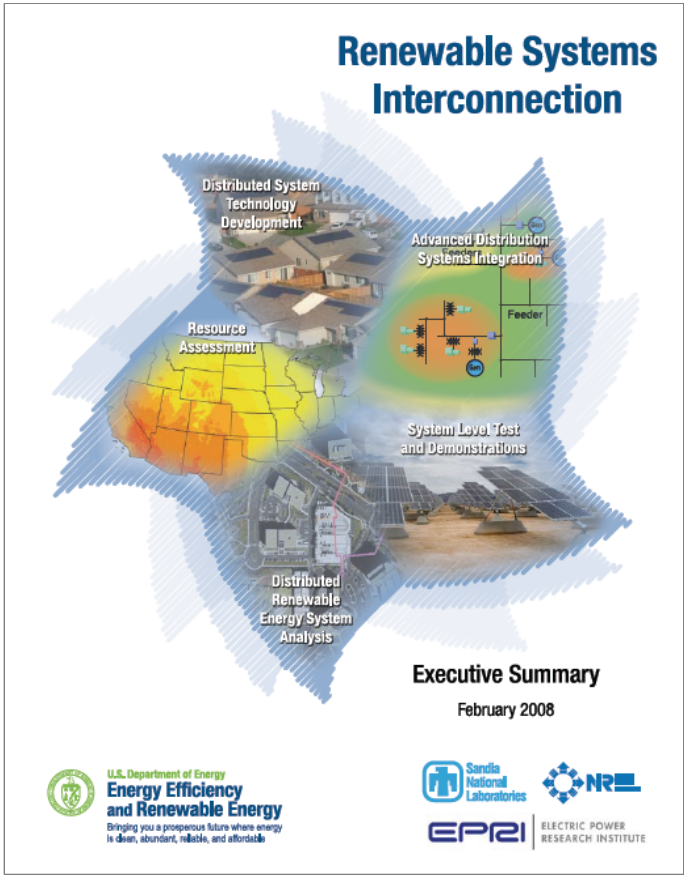
- Distribution grid, shown in green, from substation transformer (69kV and down) to customer premises
- Serving over 140 million customers in the U.S.
  - 122 million residential customers (37% sales)
  - 17 million commercial customers (35% sales)
  - 17 million industrial customers (28% sales)

B59

Workshop Building on the RSI Study Effort in 2007-2008

14 RSI topic reports and an Executive Summary published by the DOE covering:

- Distributed systems technology development
- Advanced distribution systems integration
- System-level tests and demonstrations
- Technical and market analysis
- Resource assessment
- Codes, standards, and regulatory implementation



This Workshop is to build and engage key and broad stakeholder constituencies for a consensus-based process on the agenda items

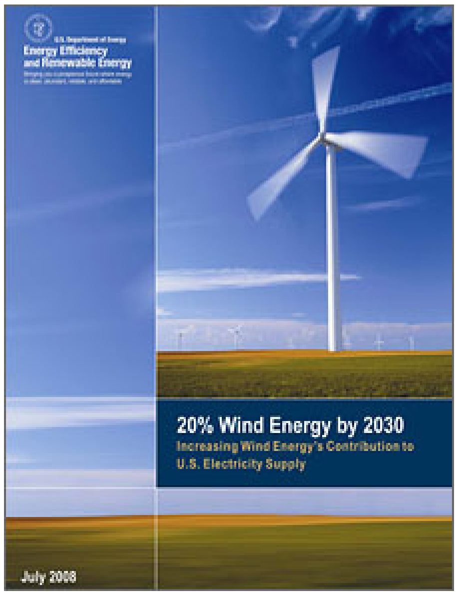
- Also, laying the foundation for public/private partnerships for RD&D plan development and implementation

B60

High-Penetration PV Scenarios

20% Wind Energy by 2030 report published by the DOE in 2008

- i.e., 300 GW of wind generating capacity by 2030



What are high-penetration scenarios for solar energy electricity?
Three penetration scenarios <u>arbitrarily</u> defined for this Workshop:

- *<15% penetration*
  (rule-of-thumb level when DG interconnection to the electric power system is considered not a concern; is that valid for PV?)
- *15%-30% penetration*
  (indicating mid-to-high-penetration scenario)
- *>30% penetration*
  (indicating very high penetration scenario)

Definition:

% penetration = AC output of PV divided by peak load capacity

This Workshop is not set to define PV penetration targets; rather, the penetration scenarios are chosen to guide discussions on respective technical challenges and performance requirements

B61

Examples of PV Penetration Cases

U.S. DEPARTMENT OF ENERGY

Collaborative projects analyzing distribution system data to understand effects of high penetration of PV on electric power system

SMUD

- Anatolia subdivision: 91 Solar Smart homes, each with a 2kW PV system
- PV penetration: 3% (based on a peak load of ~6MW); penetration level going up as 600 homes planned with PV

Premier Gardens Subdivision, Rancho Cordova, CA

Xcel Energy and SunEdison

- 260% penetration (based on a peak load of ~3MW with normal agricultural loads)

8MW PV Plant, Alamosa, CO

MMA Renewable Ventures / NV Energy / SunPower

- 70,000 PV panels supplying over 25% power used at the base (12,000 military and civilians)

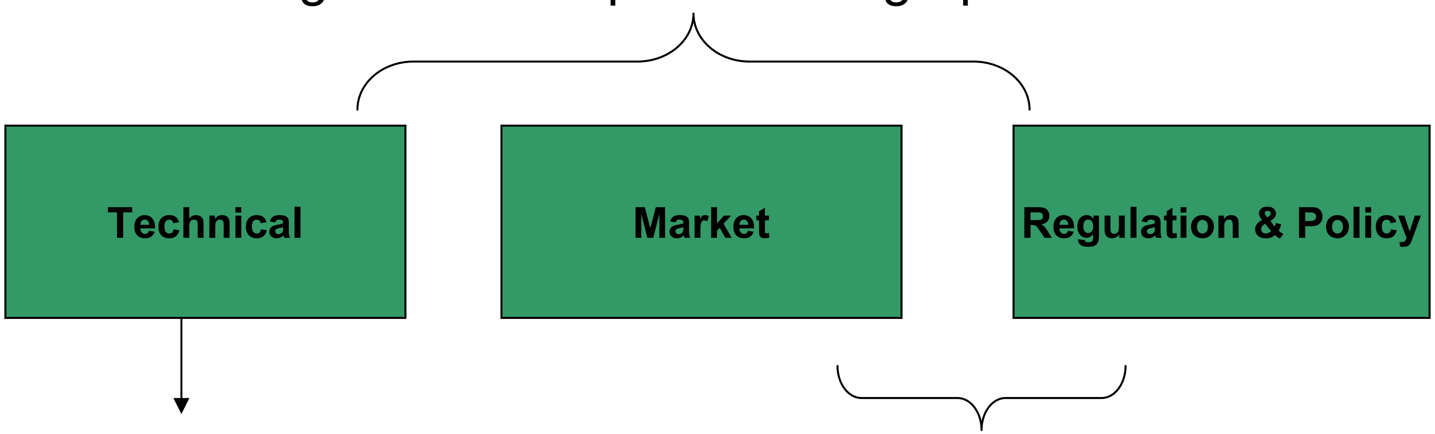
14MW PV Plant at Nellis AFB, NV (largest PV plant in the North America)

B62

Effects of PV Penetration Levels on Grid Operations

Limited penetration cases exist; better understanding of effects of PV penetration levels on grid operations with respect to different distribution circuit characteristics is needed for broad acceptance of many high-penetration PV levels

Addressing broad acceptance of high-penetration PV



Main Focus of the Workshop breakout discussions on Day 1

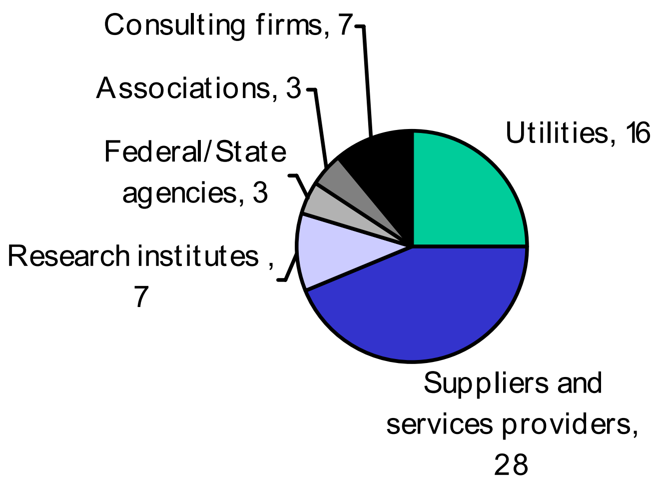
- Not a primary focus of this Workshop
- Issues identified during the breakout sessions to be put on the parking lot for discussions on Day 2

B63

This Workshop

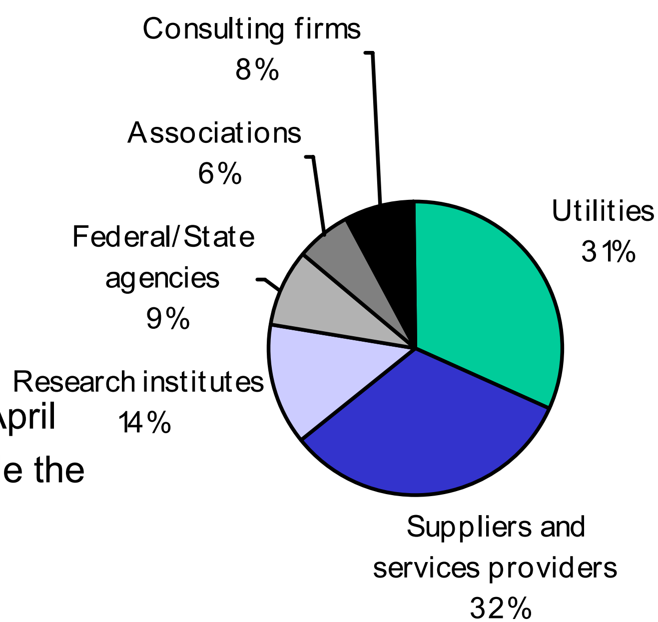
Planning committee assembled to:

- Define purpose with supporting agenda and session topics
- Nominate experts and practitioners for DOE to invite
- Define workshop outcome and product



116 registrants representing 64 entities:

- 16 electric utilities (32% participants)
- 28 suppliers and services providers (32%)
- 7 research institutes (14%)
- 3 Federal/State agencies (9%)
- 3 associations (6%)
- 7 consulting firms (8%)



Workshop outcome and product:

- Forging consensus on high penetration of PV issues / activities / requirements
- Draft workshop report planned for your input in early April
- Final workshop report in late April or early May to guide the industry and the DOE in advancing high penetration

B64

Workshop Breakout Sessions

U.S. DEPARTMENT OF ENERGY

Red Team

- Facilitator: Jen Stinebaugh
- Co-facilitator: Maria Wang
- Tech Leads: Ben Kroposki, Juan Torres, Ethan Sprague

Green Team

- Facilitator: Scott Stephens
- Co-facilitator: Toni Leon Kovarik
- Tech Leads: Peter McNutt, Frank Habibi-Ashrafi, Ross Guttromson

Yellow Team

- Facilitator: Marie Garcia
- Co-facilitator: Kevin Lynn
- Tech Leads: Scott Kuszmaul, Christy Herig, Tom Key

Blue Team

- Facilitator: Marie Mapes
- Co-facilitator: Stephen Sexton
- Tech Leads: John Kueck, Adrianne Kimber, Abe Ellis

Roles and Responsibilities

Facilitator: Leading and managing session discussions

Co-facilitator: Supporting facilitator & taking notes of major discussions

Tech Leads: Providing clarification on discussion topics & writing session summaries

Ground Rules

- All participants to equally share session discussion time
  - No long speech or dominance of speaking time by any individual
- Allow one person to speak at a time
- Stay with your team throughout the four breakout sessions
- Engage in discussions
- Turn cell phones off or on mute
- Start and end on time
- Enjoy the process

B66

Contact Information:

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Systems Integration Team Lead
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U.S. Department of Energy
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Sign up for SETP quarterly newsletter by emailing: **solar@ee.doe.gov**

B67

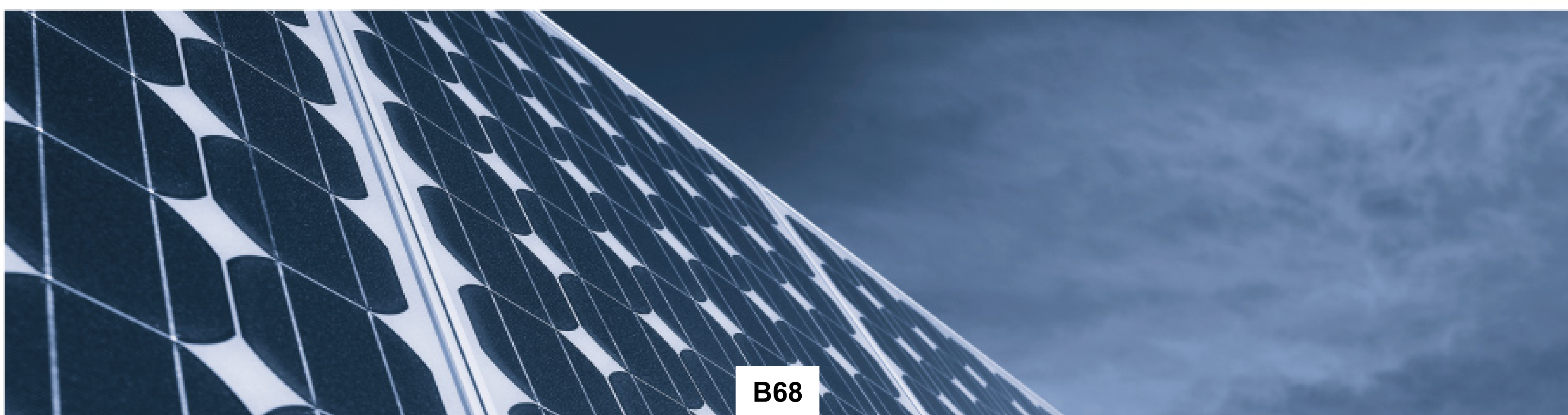
FINANCING DISTRIBUTED SOLAR POWER ASSETS

DOE DG PV WORKSHOP

Sheldon Kimber
VP, Development
Recurrent Energy

FEBRUARY 2009

RECURRENT ENERGY



B68

TODAY'S TALK

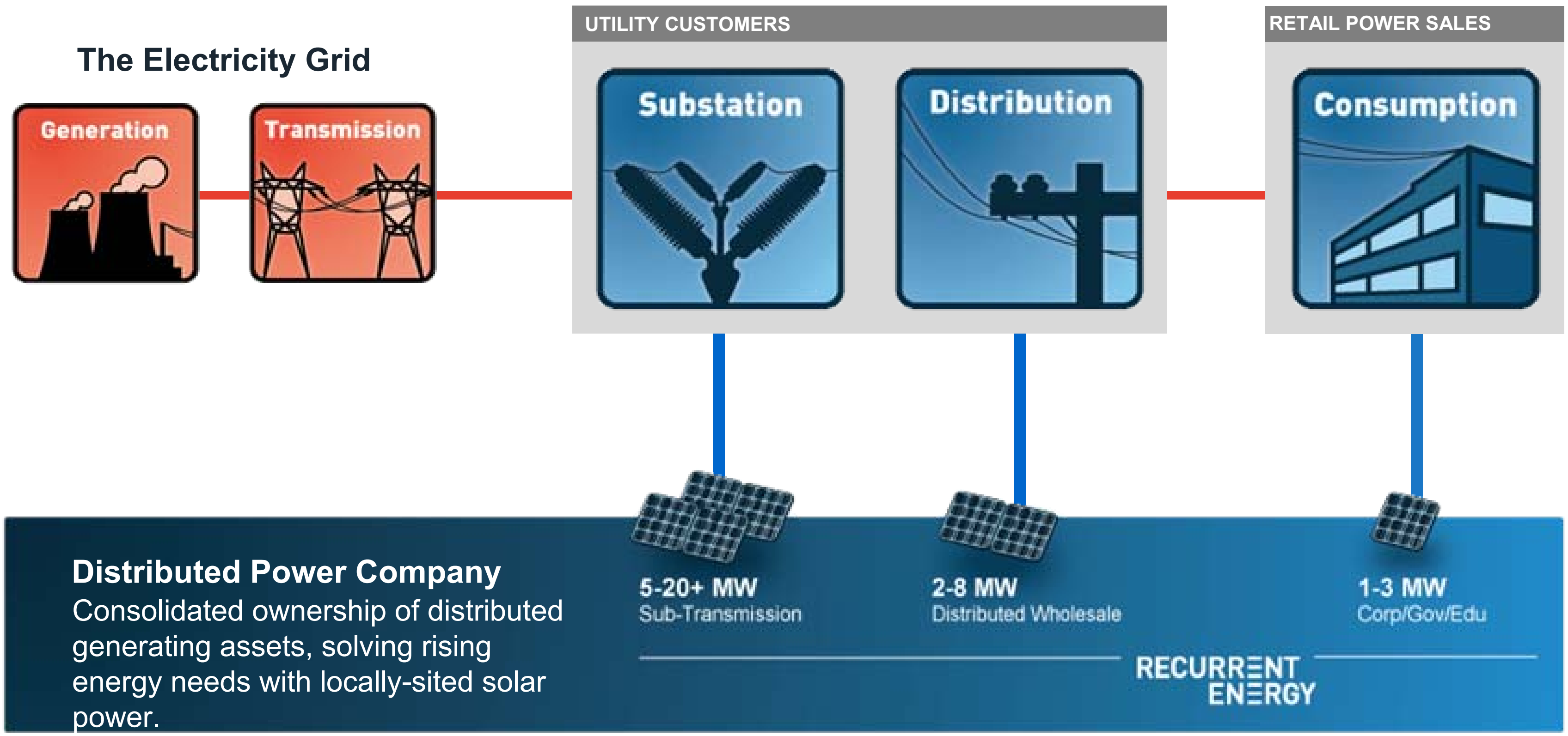
- Introduction
- Financing Power Projects: The Basics
- Applying the Model to DG Solar
- Challenges and Solutions in Practice
- Industry Trends and the Future
- Q&A

ABOUT RECURRENT ENERGY

- A distributed power company and a leading provider of solar energy
- Leadership team with 100+ years experience in solar power, construction, energy finance, and engineering
- $75M corporate equity plus extensive banking relationships enable the company to deliver PV projects of almost any size
- Global focus on scale opportunities in commercial, government, and utility PV markets
- Strong project pipeline across US, Europe, and Asia

WHAT IS A DISTRIBUTED POWER COMPANY?

Recurrent Energy builds and operates distributed solar power systems. We sell clean electricity to utility, commercial, and government customers at competitive prices via Power Purchase Agreements and Feed-in Tariffs.



FINANCING DG BASICS: “FIRST COST” AND THE PPA

- “First cost” is often cited as a barrier to solar adoption
- Power Purchase Agreements (PPA) are standard service contracts that have been in use for decades across all utility-scale generation technologies
- A well structured PPA with a creditworthy counterparty = stable revenues for bank financing

FINANCING DG BASICS: NON-RECOURSE FINANCE

- Long term contractually guaranteed cash flows have been used to finance assorted infrastructure for ages

- Project developers/owners don't need to rely on the strength of their own balance sheet anymore

- Non-recourse finance has not been applied to DG solar until recently and it is still far less mature than in other applications

- The application of non-recourse finance to DG solar enabled a project developer business model to emerge

WHAT DOES A DG SOLAR PROJECT "MAKE"?

- For purposes of this example we'll take a California behind the meter project. CA projects make a return on investment through 6 key streams:
  1. Investment tax credit (ITC)
  2. Tax depreciation (MACRS)
  3. PPA revenue
  4. California Solar Initiative (CSI) payments
  5. Renewable Energy Credit (REC) revenue
  6. O&M, Insurance and other ongoing costs

- Net cash benefits = free cash flow stream from CSI+REC+PPA-O&M
- Net tax benefits = ITC in year one + MACRS over 5 yrs

OBVIOUS CHALLENGES IN APPLYING BASIC MODEL

- **Credit:** golf courses may exist in lots of sunny places, but very few of them are investment-grade
- **Term:** where will you be in 20 years?
- **Scale:** project finance requires some minimum volume to justify the transaction cost

TECHNICAL CHALLENGES IN APPLYING BASIC MODEL

PERFORMANCE RISK	Creditworthy PPA eliminates revenue risk so long as it performs, who guarantees performance?
TECHNOLOGY RISK	Debt holders have no upside only downside – they are not paid to take technology risk
GUARANTEES/ WARRANTIES	Demands for long-term equipment warranties, EPC performance guarantees, etc

A SERIES OF UNFORTUNATE EVENTS

- **ITC Delays**: Late Spring/Summer 2008
- **Credit Crisis**: Fall 2008 to current
- **Module Economics:** Fall 2005 to Fall 2008
- **Boom, Bust & Credibility**: January 2007 to current

NEW TECHNOLOGIES, SAME OLD ARGUMENT

- Utility ownership has been widely suggested as the only means to address some of the challenges of DG solar financing

- The real culprit - Lack of mature downstream players?

- The old argument has been settled before by regulators and industry and similar outcomes are likely to govern DG solar

THE FUTURE IS GETTING BRIGHTER…

- “Refundability”/DOE grants
- Federally guaranteed loans for renewable power projects
- The result = a brand new capital structure for DG solar projects

THANK YOU

SHELDON KIMBER
VP, Development
Recurrent Energy
sheldon@recurrentenergy.com

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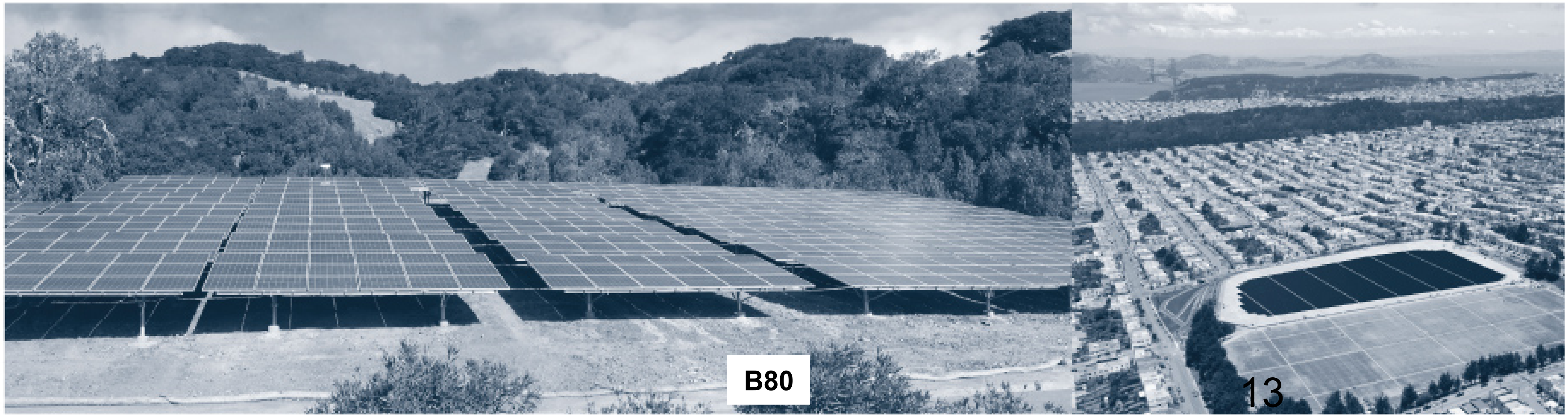
RECURRENT ENERGY



B80

Major Findings and Caveats

- Major Findings
  - Modeling: defining and coming up with a strategy
  - Protection of utility distribution system
  - Forecasting of output

- Caveats
  - Need to better define “penetration level”

C1

Top 5 Issues and Barriers

- #1: Modeling
  - Integration of PV into dynamic and steady-state models
- #2: Communications/Coordinated Operations/Protection
  - Demand response, energy storage, interoperability, etc.
  - Circuit/branch protection
- #3: System Aggregation/Management
  - Processing data from multiple sources
- #4: Update Standards and Codes
  - Such as IEEE 1547
- #5: Resource Variability
  - Cloud transients, forecasting, ramp rates

C2

#1 RD&D Activity for Near Term (0-3 Yrs)

Protection and inverter performance

- End goals: Understand inverter behavior under fault conditions (residential and commercial)
- Milestones: Fault testing in lab, field installations, data collection and analysis, compare with manufacturer and literature, generate report
- Performance metrics: select equipment, sites, obtain data sheets
- Cost and duration: $1-2 MM, 2 yrs

C3

#2 RD&D Activity for Near Term (0-3 Yrs)

Modeling

- End goals: ability to model effects of solar generation sites in T&D systems, evaluation of economics and security
- Milestones: develop inverter model (steady state and dynamics), open source model
- Performance metrics: usability, adoption and integration; validation; collaborate with IEEE committees and WECC working group
- Cost and duration: $5 MM, 1-3 yrs

C4

#3 RD&D Activity for Near Term (0-3 Yrs)

Forecast PV generation capabilities

- End goals: fully implemented solar forecasting methods to determine PV output over various time scales: sec, min, hrs for utility operations; utility tool
- Milestones: develop models that include array type and size, inverter response, probability of clouds, historical data, real-time weather data; analyze existing system data; determine sensitivity to pollution
- Performance metrics: predict within 20%, 10%, or 5% accuracy of measured data for validation sites, value of PV in different areas, forecasting models need to be operational tools
- Cost and duration: $5 MM/yr, 3 yrs

C5

#4 RD&D Activity for Near Term (0-3 Yrs)

Revise IEEE 1547

- End goals: to incorporate local voltage regulation
- Milestones: demonstrating proposed changes in real life, modeling of high penetration scenarios, make studies more transparent, refer to Germany and Japan for benchmark studies
- Performance metrics: new projects, DOE support, draft, multiple iterations
- Cost and duration: $1.5 MM/yr from DOE, 5 yrs

C6

#1 RD&D Activity for Mid Term (3-5 Yrs)

Aggregate system impacts

- End goals: Analyze circuit and grid impacts of high PV penetration, planning guidelines for determining integration and penetration limits (to utility engineers for circuit design)
- Milestones: modeling, run through scenarios, verify models with field data, data analysis, generate report
- Performance metrics: model functioning, matrix of scenarios, model verification with field data, draft analysis for review/comment, draft final report
- Cost and duration: $0.5-1 MM, 2 yrs

#2 RD&D Activity for Mid Term (3-5 Yrs)

Design and test new circuit configurations to accommodate high PV penetration

- End goals: green field design guidelines for high penetration PV feeders
- Milestones: identify key characteristics of feeders, pilot project/demo
- Performance metrics: compare performance of design and operation with existing circuits; cost analysis
- Cost and duration: $5-10 MM, 3-5 yrs

C8

#1 RD&D Activity for Long Term (>5 Yrs)

Determine if inverters should provide ancillary services

- End goals: change 1547 and 1741 to accommodate ancillary services, value proposition, voltage regulation, intentional islanding
- Milestones: determine value of ancillary services, demonstrate communications from utility to PV systems, demonstrate inverters can provide ancillary services
- Performance metrics: availability of products that provide ancillary services, grid parity for ancillary services
- Cost and duration: $3 MM/yr for first 2 yrs, $10 MM/yr for first 3 yrs for inverter development, $2 MM/yr for 2 yrs for demo

Suggestions for Carrying Out RD&D Activities

- Make Renewable Systems Interconnection (RSI) reports user-friendly and publicize
  - Consolidate 14 documents into 1
- Develop more industry, utility and government partnerships
  - Pilot projects
  - Hands-on study participation by utilities, vendors, others
- Workshop continuation
- Solar ABCs
- RFP – let diverse teams "design" projects

Blue Team – Report out

- Presenter: Tom Dossey
  Distributed Energy Resources
  Southern California EDISON

C11

Top 3-5 Issues and Barriers

- Real time control of distributed PV
- Identification of standard models for planning and operation
- Development of Smart Grid components
  - Bandwidth, Controls, Flows
- Managing variability in operations
- Development of standard protocols
  - Interconnection, safety, communication

#1 RD&D Activity for Near Term (0-3 Yrs)

- <u>Low cost, secure, hi-speed communication in support of PV</u>

- End goals/final outcomes:
  - Utilize smart meter deployment to control PV demand/response
  - Develop different solutions for coupled vs. de-coupled
  - Complete demonstrations on residential, light-commercial and industrial circuits
  - Benchmark geographic capability

- Interim milestones:
  - Complete installation of AMI systems
  - Integration of PV into software platform
  - Integration of storage, demand response, web platform (data retrieval)
  - Identify protocols: Zigbee vs. others; power line carrier

C13

#1 RD&D Activity for Near Term (0-3 Yrs) – cont.

- Performance metrics:
  - Data utility – cost/demand reduction
  - Measurable impact on customer energy use
  - Timing of feedback (monthly vs. real time – adjust use in real time)
  - Data security
  - Identify bandwidth requirements
  - Cost per customer, payback time

- Cost: $3-5M/year

- Duration: 2-3 years

#2 RD&D Activity for Near Term (0-3 Yrs)

- <u>Extrapolate existing systems/models from current data to identify effect on PV</u>

- End goals/final outcome:
  - Utilities will know what will happen to their systems (short circuit, stability, reliability, operations)
  - Written guidelines with reference standards, operating procures and best practices
  - Develop models that predict behavior of distributed PV over time (milliseconds to seasons)
  - Predict system behavior over time in order to forecast system variation

- Interim milestones
  - Define data collection requirements
  - Consult with stakeholders
  - Benchmark existing high penetration systems (highest available) and how they are impacting the power system

C15

#2 RD&D Activity for Near Term (0-3 Yrs) – cont.

- Performance metrics
  - Define a framework for data collection/monitoring to support development and validation of models
  - Are representative system scenarios monitored
    - Large central (Mw)
    - High density distributed PV
    - Validation – how close is close enough (need to define benchmark)

- Cost/duration
  - Years 1-3: Data collection – $2.5M
  - Years 1-3: Prototype modeling and data analysis -- $2.5M
  - Years 2-3: Verify models and code them into utility tools – $4M

#3 RD&D Activity for Near Term (0-3 Yrs)

- Define standard operating limits and expected behavior for inverter based systems.

- End goals/final outcomes:
  - Convert existing inverter/power electric systems from passive to active
  - Create standard/functional description for inverters
  - System can respond to external EMS command or autonomously take action/respond to sensed conditions

- Interim milestones:
  - Conduct industry survey of current activities
  - Develop prototype inverters
  - Demonstrate response to EMS & sensed conditions
  - Develop accurate mathematical models (and inputs) of behavior
  - Modify 1547.4 & 1741 to allow behavior identified by models
  - Create standard interface protocols

#3 RD&D Activity for Near Term (0-3 Yrs) – cont.

- Performance Metrics:
  - Meets tolerances defined in functional specifications
  - Manufacturability/Scalable
  - Reliability/durability/stability/security of operation
  - Remotely programmable
  - Interoperability with other Grid components
- Cost: $24.1M
- Duration: 1-3 years (standards changed in third year)

C18

#1 RD&D Activity for Mid Term (3-5 Yrs)

- Small (residential) and Mid-scale (<substation) storage solutions to supplement/amplify the use of PV systems.

- End goals/final outcomes:
  - Tech demos (both sides of the meter) -- house vs. substation
  - Benchmarking duration and capacity of storage (< 1MW with 5 hours of storage)
  - Scalable modules (1 block vs. 10 linked blocks)
  - Identify architectures

- Interim milestones:
  - Identify candidate technologies and roadmap for each (problem definition)
  - Define charge/discharge cycles
  - Define parameters/boundaries/problems
  - Identify appropriate demonstration
  - Cost analysis/comparison (inexpensive, scalable)

#1 RD&D Activity for Mid Term (3-5 Yrs) – cont.

- Performance metrics:
  - Cost
  - Delay time of storage
  - Reliability/lifetime/degradation
  - Roundtrip efficiency (AC to AC)
  - Environmental impact of designed storage device
  - Safety of designed storage device – reliability/lifetime
  - Interoperability with other power systems?

- Cost: $10M/year – multiple projects

- Duration: 3-5 years

#2 RD&D Activity for Mid Term (3-5 Yrs)

- Timely, top-down standards approach to address all aspects of PV integration

- End goals/final outcomes:
  - National standard for key interactions between imbedded PV systems and the Grid
    - Communication, command, control, EMS
  - One sanctioned process to propose and approve new standards and interoperability process requirements

- Interim milestones:
  - Compose lead working group
  - Access current tech/standards and determine what is base to build vs. completely new requirement (i.e gap analysis)
  - Develop an agenda/set of recommendations to take on the road for feedback (PUCs, Utilities, etc.)

#2 RD&D Activity for Mid Term (3-5 Yrs) – cont.

- Performance metrics:
  - Working group effectiveness (full representation across the field – public and private)
  - Establish working group to address gaps by end of year 1
  - Draft standard ready for circulation by end of year 2
  - Incorporate roadshow feedback by end of year 3

- Cost/duration:
  - Year 1 - $.5M
  - Year 2 - $1.5M
  - Year 3 - $1M
  - Year 4 (and after) +$.5M/year

#1 RD&D Activity for Long Term (>5 Yrs)

- Develop Smart Grid Energy Management Systems that will optimize interaction between Grid components

- End goals/final outcomes:
  - Adaptable system for optimized performance
  - Secure, multi-user access over internet
  - All components are interoperable
  - PV inverters are compatible and effectively communicate with other components
  - Systems has predictive capability (“artificial intelligence”)

- Interim milestones:
  - Survey/lessons learned report from existing/similar projects
  - Roadmap to expected PV/DG deployment/penetration
  - Demonstration protocols, hardware, UI on specific, real circuit(s), integrated with utility operations center
  - Develop tools for simulation/system planning

#1 RD&D Activity for Long Term (>5 Yrs) – cont.

- Performance metrics:
  - Data speed/latency
  - Bandwidth
  - Availability/reliability of communication
  - System stability/reliability
  - System security (hacker-resistant)
  - Load factor improvement

- Cost/Duration:
  - 5-10 years.
  - 3-5 demonstration projects per year @ $5-10M each
  - 3-5 R&D projects @ 2-5M each

C24

Major Findings and Caveats

- Intermittency is the fundamental problem and storage is the solution

C25

Top Issues and Barriers

1. Utility coordination distributive energy storage to overcome transients and cloud cover.
2. Smart communication and control standards.
3. Protection, interconnection standards and procedures.
4. Power quality as a function of penetration level.
5. Technical models focused of forecasting, voltage distribution, ELCC.
6. Power electronics development for different system sizes and grid designs.

RD&D Activity

- **Topic Title:** Intentional Islanding:
- **Final Outcomes:** Demo of no GHG Microgrid for 1 yr of continuous islanding
- **Interim Milestones: -** Demo shorter period (<1yr) maybe with GHG fuels
- Controls intergration (microgrid wide),
- smart meters, demand response, storage (phases)
- **Performance Metrics:** lbs of CO_2 used, Response, Power quality (Vars, Amps, Voltage)
- **Costs and duration:** $25M per year for 3 years

C27

RD&D Activity

- **Topic Title:** Utility/Industry Coordination working group
- **Final Outcomes:** Consortium: national labs, non profits, industry (PV +), utilities
- - recommend codes, standards, best practices (address multiple points of PV generation)
- **Interim Milestones:** meetings/workshops
- Formal recommendation letters
- **Performance Metrics:** Industry feedback report cards
- **Costs and duration:** $250k/yr (ongoing)

C28

RD&D Activity

- **Topic Title:** PV Demo with managed Voltage and balancing dispatch control
- **Final Outcomes:** Demonstrate by simulation (Feasiblity)
- verify by Demo (PV w/ storage) on customer side and utility side
- new required standards and protocols for grid interface
- cost effectiveness assessment
- **Interim Milestones:**
- cost effectiveness methodology
- engineering design
- system integration requirements / controls
- **Performance Metrics:** satisfy standards
- dispatchability
- PV ability to reduce peak demand
- Impact to PV intermittency – reduce neg impact to grid
- **Costs and duration:**
- medium term (sooner if customer cited) $25 (potentially lower with cost share)

C29

RD&D Activity

- **Topic Title:** High penetration distribution modeling
- **Final Outcomes:** solar panel model (incorporation weather focasts)
- modular solar package (solar panel + inverter + storage)
- static and dynamic testing
- Intergrate with ssytems model
- **Interim Milestones:** survey of available products- matrix of strengths weakness, willingness of vendor to collaborate (ip issues)
- model objectives, inputs, outputs, sinearieos
- advisory board (diverse set of stakeholders including utilities, mfgers, system intergrators etc)
- **Performance Metrics:** verify accuracy using field data and simulations holistic cost analysis of from customer lens (e.g. reduced distribution costs further leveraged by spending savings on energy efficiency).
- **Costs and duration:** Short term + 3 years ($5M)

C30

RD&D Activity

- **Topic Title:** Power Quality
- **Final Outcomes:** Criteria for applying PV to distributive circuit in a design to document or specification
- **Interim Milestones:** 1547 revision to update for neighboring systems utility concensus
- **Performance Metrics:** harmonics, voltage, frequency, supply V. load
- **Costs and duration:** 2-3 years, $5-$10M

RD&D Activity

- **Topic Title:** Inverter Frequency and Voltage Ride Thru
- **Final Outcomes:** Next Generation Inverter
- **Interim Milestones:** Draft revision of 1547 to account for ride thru of multiple events
- utility and industry review
- **Performance Metrics:** bi-directional, ride thru, higher power, internal communication to the utility
- **Costs and duration:** $25M over 5 years.

C32

Suggestions for Carrying Out RD&D Activities

- Suggested high-level action items on how to carry out these activities to meet their end goals

C33

Yellow Team R&D Priorities

Prologue: Penetration Scenarios Definition

- Load: worst case, average, peak??
  - AC output/peak load (DOE definition)
  - Annual peak easy to define
  - Acknowledgement that the definition has some limitations from an operational standpoint
- What variables (criteria) affect this definition?
  - AC output capacity (PV)
  - Peak load
  - Demand load
  - Line impedance
  - Load shapes
- Consider how we can mitigate these issues using storage, demand response, etc.
- Policies and actions made today

Top 3-5 Issues and Barriers

- Descriptions of key issues/barriers
  - Lack of data, analysis, and tools to sufficiently model and simulate specific impacts of solar on the grid (Grid impact assessment tools and models)
  - Need for intelligent bundling of PV with demand side management, communications and controls, and storage for the development of ancillary services for end users and utilities (value enhancements)
  - Enhance protection and coordination capability in anticipation of worst case scenarios through the use of instrumentation, measurement, and controls (Protection and coordinated operations)
  - Methods/devices/technologies to effectively integrate the intermittency of solar energy on the grid (variability of solar resources)
  - Development and investigation of codes and standards to determine limitations on grid integration equipment capabilities and to establish consensus (codes and standards)

#1 RD&D Activity for Near Term (0-3 Yrs)

- Activity Description
  - ***Develop storage and control system control technologies that enable PV*** *(Todd Wall, Stanley Merritt, Obadiah Bartholomy, Charlie Vartanian, Devarajan Srinivagan)*
- Final Outcomes
  - R&D report on storage applications (market opportunities, financial propositions, technologies, barriers), Identifying optimal storage amount relative to penetration scenarios for each market, Development of protocols and technology components for communication and control of storage
- Interim Milestones
  - Road map identifying: markets, technologies and applications
  - Broad stakeholder advisory group
  - Demonstration of component and/or controls at meaningful scale
- Performance Metrics
  - Industry participation and education
  - Commercialization of storage and control technologies specific to PV market
- Cost and Duration
  - $2-10M, 3 yrs

#2a RD&D Activity for Near Term (0-3 Yrs)

- Activity Description
  - **Standardize and acquire solar intermittency via geographic locations: *Standards for Data*** *(Peter Michalski, Ray Hudson, Jeff Yang, David Drause, James Sciell, Tom Veselka, Alison Silverstein)*
- Final Outcomes
  - Measurement specifications, formats
  - where, what, how fast
  - Temporal and geographic granularity
  - Solar electrical characteristics
- Interim Milestones
  - Draft
  - Test w/ measurement and modeling communities
  - Adopt and publish
- Performance Metrics
  - Acceptance
  - Final product
- Cost and Duration
  - 6 months, $250K

C38

#2b RD&D Activity for Near Term (0-3 Yrs)

- Activity Description
  - **Standardize and acquire solar intermittency via geographic locations: *<u>Data Collection</u>*** *(Peter Michalski, Ray Hudson, Jeff Yang, David Drause, James Sciell, Tom Veselka, Alison Silverstein)*
- Final Outcomes
  - Quality data streams for 1+ yr for 3+ sites +data viewer/processor, consistent data across sites
- Interim Milestones
  - Pick sites
  - Install equipment
  - Data quality check
  - Make datasets available
- Performance Metrics
  - Quality data, complete
  - Max COTS rather than customer implementation
- Cost and Duration
  - 3 yrs ongoing
  - $400K/site for instruments (note 6 to 9 weather stations per site)
  - $30K/site/month for monitoring and communications

#3 RD&D Activity for Near Term (0-3 Yrs)

- Activity Description
  - ***Analyze solar intermittency via geographic locations*** *(Peter Michalski, Ray Hudson, Jeff Yang, David Drause, James Sciell, Tom Veselka, Alison Silverstein)* Characterize Data Modeling and Forecasting
- Final Outcomes
  - Describe irradiance characteristics/site
  - Describe resulting electrical performance of PV/site
  - Produce models for these that help forecasting
- Interim Milestones
  - Data analysis and probability distributions
  - Develop modeling tools (spatial and temporal)
  - Determine correlations between land and PV performance
  - Verify and validate models
  - Adopt and publish
- Performance Metrics
  - Model accuracy
  - Model insights
  - Industry acceptance and use
- Cost and Duration
  - 3 yrs, $3M

#1 RD&D Activity for Mid Term (3-5 Yrs)

- Activity Description
  - ***Methods and devices for integrating PV systems into the legacy grid*** *(Todd Wall, Stanley Merritt, Obadiah Bartholomy, Charlie Vartanian, Devarajan Srinivagan)*
- Final Outcomes
  - Commercial demonstration of utility communication and control of inverters and storage
  - Creation of ancillary services markets and values for PV integration devices/methods
  - Adoption of distribution system design manuals and templates for utilities
  - Design integration into municipal comprehensive planning and utility integrated resource planning processes
- Interim Milestones
  - Define legacy grid components that must be changed for equal or improved reliability or power quality with increased PV penetrations
  - Create distribution system design manuals and templates for utilities
  - Industrial park and or campus demos
  - Demonstration of smart grid at a meaningful scale (feeder, city)
- Performance Metrics
  - Commercialization; # of utilities, and their level of development of smart grids
  - Manufacturers of legacy grid components developing new devices
- Cost and Duration
  - $25-50M, 5 yrs

#2 RD&D Activity for Mid Term (3-5 Yrs)

- Activity Description
  - ***Pilot/demonstration of intelligent bundling*** *(Tom Key, Robert Margolis, Bruce Barney, Tom Hoff, Carl Lenox)*
- Final Outcomes
  - Demonstrate ability to integrate PV at high levels while maintaining or improving grid performance w/ reasonable cost
- Interim Milestones
  - Piggy-back on existing smart grid projects (communications in place, add PV) and/or start adding controls to existing high PV density locations.
  - Study control options: central vs. distributed; determine where on this range to pilot or maybe both depend on customers/feeders.
- Performance Metrics
  - Reliability indices (SAIFI, SARFI)
  - Voltage regulation
  - Power Quality
  - PV performance index
  - Regulation, load follow, ramp rates on load profiles
- Cost and Duration
  - $10M/yr for 3 yrs
  - Hardware (no $ for PV itself)
  - Software
  - Analysis/Report
  - Overhead
  - Communication infrastructure (automated meter infrastructure)

#1 RD&D Activity for Long Term (>5 Yrs)

- Activity Description
  - ***Pilot/demonstration of intelligent bundling w/ very high penetration (30% of max peak)*** *(Tom Key, Robert Margolis, Bruce Barney, Tom Hoff, Carl Lenox)*
- Final Outcomes
  - Demonstrate ability to integrate PV at high levels while maintaining or improving grid performance w/ reasonable cost
- Interim Milestones
  - Test on market acceptance of price signals at consumer level
- Performance Metrics
  - Customer happiness w/ pricing and impacts
- Cost and Duration
  - $30M/yr for 3 yrs

Suggestions for Carrying Out RD&D Activities

- Suggested high-level action items on how to carry out these activities to meet their end goals…
- The R&D cannot be done in isolation
- Needs to be looked at as a puzzle that needs to be pieced together (holistic type of analysis; systems type approach).
- Look at large metrics of both positive and negative attributes (energy, environment, water, nat'l security)
- Identifying pathways for each of these R&D areas from outset (create roadmaps)
- Codes and standards identified one of top 5 issues, but did not receive support in R&D priority phase

Appendix D

REGISTRANT LIST

Workshop on High Penetration of PV into Distribution Grid

February 24-25, 2009
Ontario, CA

Victor Aguilar	Southern California Edison
William Ahlgren	California Polytechnic State University
Gregory Ashley	Canadian Solar CSI
Mark Baldassari	Enphase Energy
Bruce Barney	Portland General Electric
Obadiah Bartholomy	SMUD--Sacramento Municipal Utility District
Tobin Booth	Blue Oak Energy
Kurt Borg	Solar Integrated Technologies
Michael Bradley	Hawaii Electric Light Co.
Richard Bravo	Southern California Edison
Daniel Breig	Southern California Edison
Christopher Cameron	Sandia National Laboratories
Rick Carson	Tennessee Valley Authority
Vladimir Chadliev	NV Energy
Patrick Chapman	SmartSpark Energy Systems
Nicolas Chaset	California Public Utilities Commission
Sunil Cherian	Spirae, Inc.
Marv Dargatz	Enphase Energy
Paul DeMartini	Southern California Edison
Tom Dossey	Southern California Edison
Roger Dugan	EPRI
Carolyn Elam	U.S. Department of Energy
Abraham Ellis	Sandia National Laboratories
Brandon England	Los Angeles Department of Water & Power
Francisco Fernandez	Los Angeles Department of Water & Power
Marie L. Garcia	Sandia National Laboratories
Rick Gardner	San Diego Gas & Electric Co.
Clark Gellings	EPRI
Jay Goth	Suntrek Solar, Inc.

Daniel Gregory	MegaWatt Solar
Ross Guttromson	Pacific Northwest National Laboratory
Frank Habibi-Ashrafi	Southern California Edison
Julia Hamm	Solar Electric Power Association
Bill Henry	Tucson Electric Power
Christy Herig	Solar Electric Power Association
Tom Hobson	GE Energy
Tom Hoff	Clean Power Research
Darell Holmes	Southern California Edison
Thomas Honles	Los Angeles Department of Water & Power
Mark Hoppe	Southern California Edison
Ray Hudson	BEW Engineering
Mary Huller	Duke Energy
Anthony Johnson	Southern California Edison
Robert Johnson	SunPower Corp
Juris Kalejs	American Capital Energy
Ardalan Kamiab	Southern California Edison
Calvin Kawamura	NAVFAC SW
Thomas Key	EPRI
Adrianne Kimber	SunPower Corp
Sheldon Kimber	Recurrent Energy, Inc.
Charles Korman	GE Global Research
David Krause	AES Solar Energy, Ltd.
Ben Kroposki	National Renewable Energy Laboratory
John Kueck	Oak Ridge National Laboratory
Shihab Kuran	Petra Solar
Scott Kuszmaul	Sandia National Laboratories
Carl Lenox	SunPower Corp
Toni Leon Kovarik	Sandia National Laboratories
Janice Lin	StrateGen Consulting
Michael Lopez	Southern California Edison
John Lushetsky	U.S. Department of Energy

Kevin Lynn	Sentech, Inc.
Larry Mansueti	U.S. Department of Energy
Marie Mapes	U.S. Department of Energy
Robert Margolis	National Renewable Energy Laboratory
Mike Martin	EMTEC
Joseph McCabe	Ascent Solar Technologies
Peter McNutt	National Renewable Energy Laboratory
Adje Mensah	Petra Solar
Stanley Merritt	DuPont
Peter Michalski	Edison Mission Energy
Bill Mulligan	SunPower Corp
David Narang	Arizona Public Service Co.
Deanne Nelsen	Southern California Edison
Sean O'Connor	Apollo Solar
Bryan Pai	SunEdison
Gilbert Palomino	Salt River Project
Chris Pardington	Xcel Energy
Dan Pearson	Pacific Gas and Electric Co.
Ann Peterson	Itron, Inc.
Liz Philpot	Southern Company
Jack Pouchet	Emerson Network Power
Devi Prasad	Alameda Power
Mark Ritkouski	Xcel Energy
Roger Salas	Southern California Edison
Kevin Schneider	Pacific Northwest National Laboratory
Judi Schweitzer	Schweitzer + Associates, Inc.
Stephen M. Sexton	U.S. Department of Energy
Michael Sheehan	Interstate Renewable Energy Council
Alison Silverstein	Alison Silverstein Consulting
Martin Smith	Xcel Energy
Phil Smithers	Arizona Public Service Co.
Arun Soni	Sentech, Inc.

Ethan Sprague	ConSol
Devarajan Srinivasan	ViaSol Energy Solutions
Scott Stephens	U.S. Department of Energy
Bic Stevens	Premium Power Corporation
Jen Stinebaugh	Sandia National Laboratories
James Suell	Salt River Project
Dan Tate	Majestic Land
Mike Taylor	Solar Electric Power Association
Holly Thomas	U.S. Department of Energy
Dan Ton	U.S. Department of Energy
Juan Torres	Sandia National Laboratories
Ron Van Dell	SmartSpark Energy Systems
Sam Vanderhoof	Petra Solar
Jon VanDonkelaar	EMTEC
Charlie Vartanian	A123Systems
Thomas Veselka	Argonne National Laboratory
Lorin Wall	Southern Company Services
Paul Wang	Energy & Environmental Resources Group
Wechung Maria Wang	Energy & Environmental Resources Group
Ryan Williams	The MIT Fraunhofer Center for Sustainable Energy Systems
Jeffrey Yang	United Solar Ovonic LLC
Bob Yinger	Southern California Edison
Saul Zambrano	Pacific Gas and Electric Co.

Onsite Registrants

Workshop on High Penetration of PV into Distribution Grid

John Boyes	Sandia National Laboratories
Ilia Gueorguieva	Southern California Edison
Wil Grady	Southern California Edison
Tom Kimbis	U.S. Department of Energy
George Rodriguez	Southern California Edison
Colin Schauder	Satcon