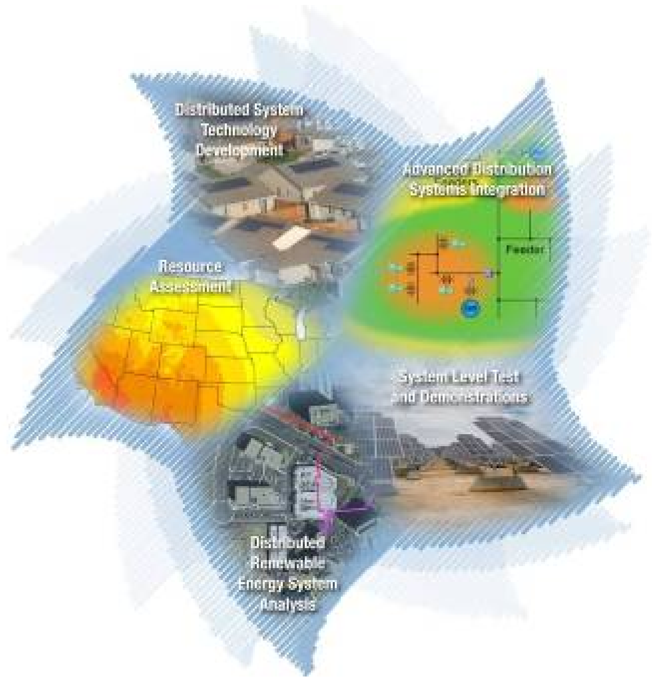
Renewable Systems Interconnection Study Summary

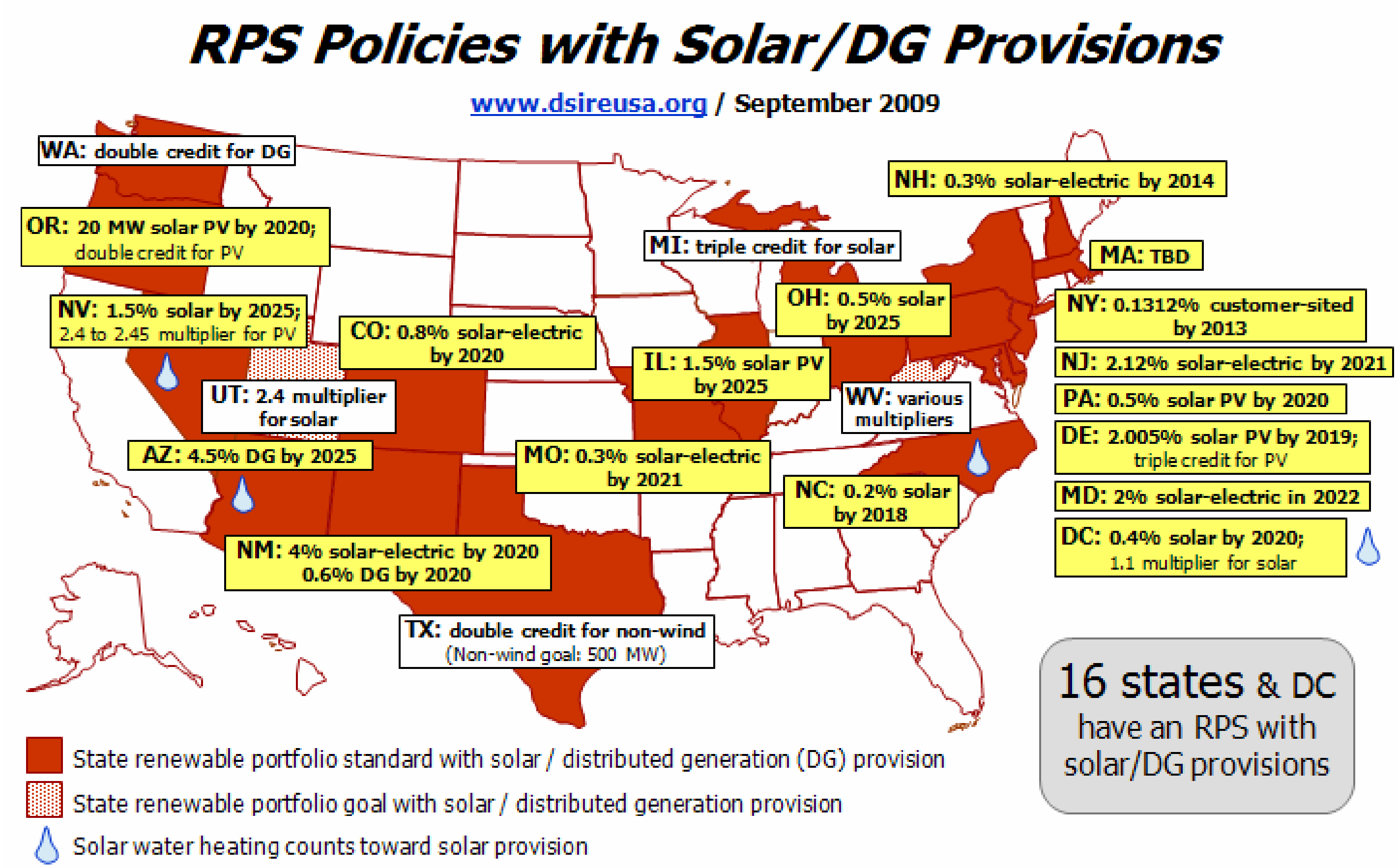
Ben Kroposki, PhD, PE
National Renewable Energy Laboratory



NREL
Sandia National Laboratories
EPRI ELECTRIC POWER RESEARCH INSTITUTE

An Emerging Market:
Preparing for Large-Scale Renewable Energy Interconnection

New Market Scenario: Climate change concerns, renewable portfolio standards, incentives, and accelerated cost reduction driving steep growth in U.S. renewable energy system installations.



NREL Sandia National Laboratories

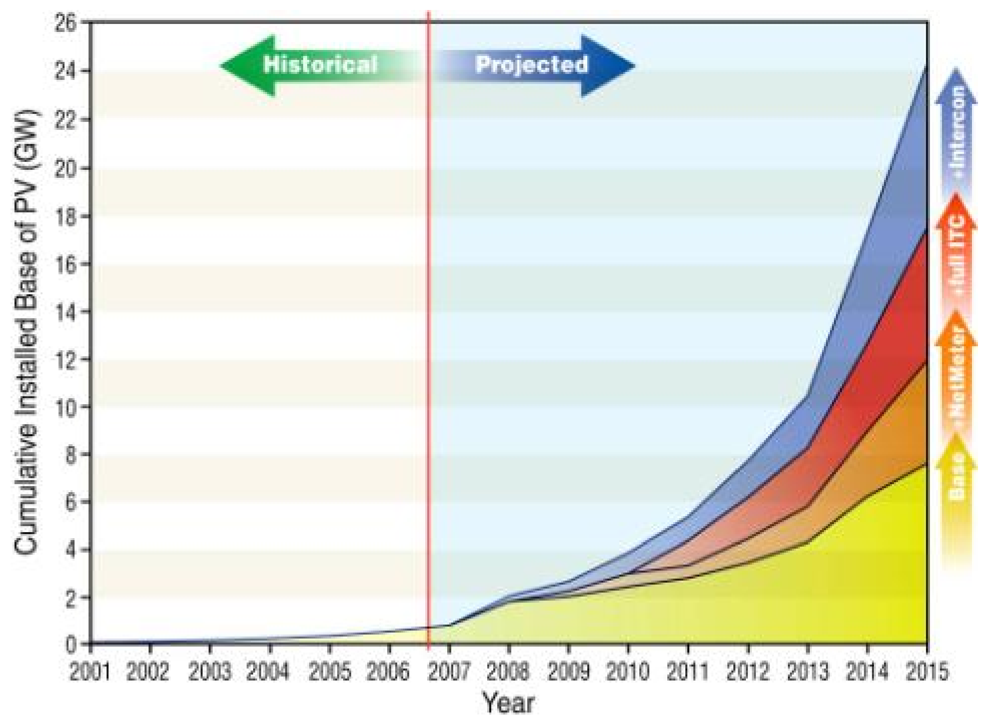
Significant Growth Projected for Distributed Renewable Energy Systems

Driving the market:

- Climate change
- State/Federal incentives
- Cost reductions
- Regulatory/policy drivers

Modeled 4 Scenarios:

1. Base case, existing policies with continued cost reductions ➔ 7.5 GW by 2015.
2. Base (1) plus lifting net metering caps / establishing net metering policies ➔ 12 GW by 2015.
3. (2) plus full extension of federal investment tax credit (ITC) ➔ 17 GW by 2015.
4. (3) plus improved interconnection standards ➔ 24 GW by 2015.

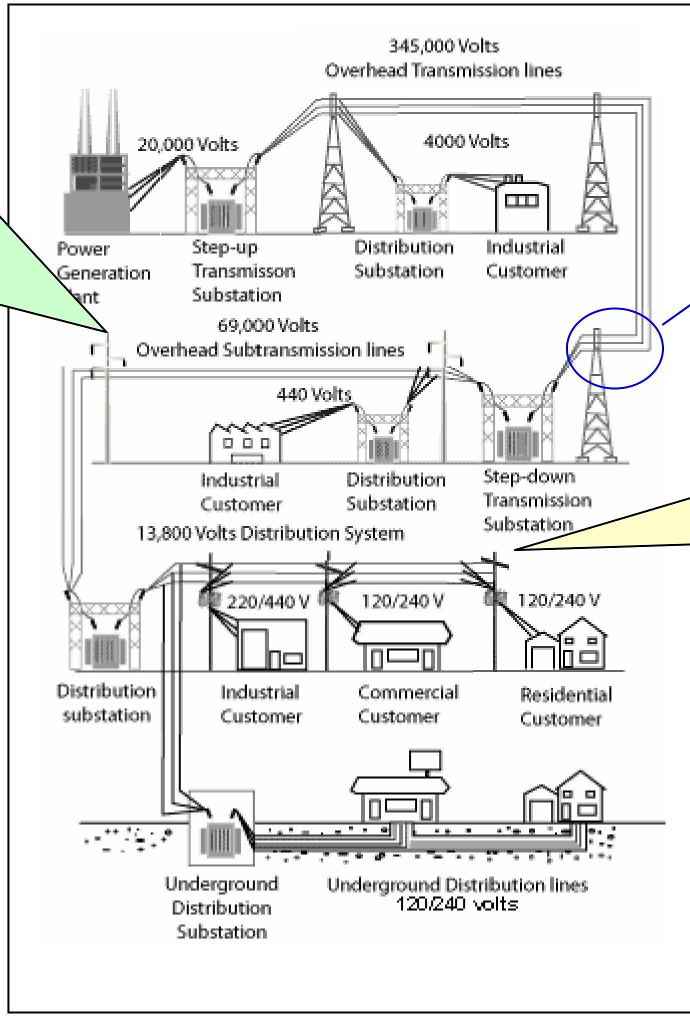


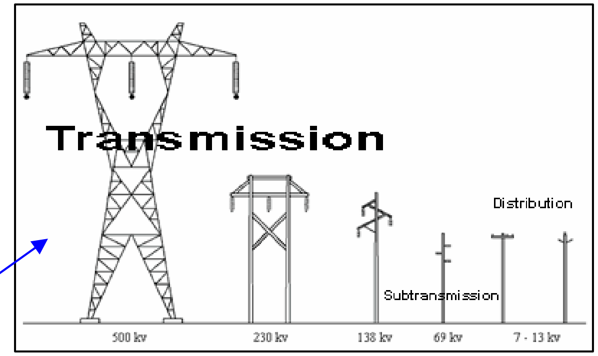
Grid-Connected Distributed PV Growth
2001–2006, Projected to 2015

Where Renewable Energy Interconnects

Central Station

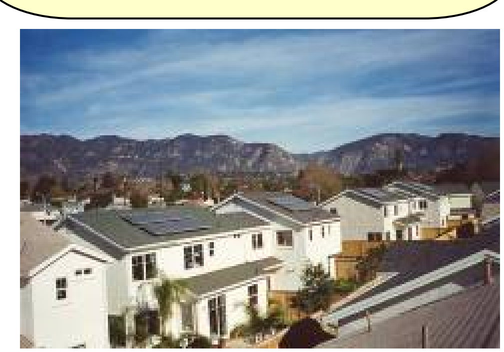
Large
wind farms, CSP
PV, biopower,
hydro, geothermal,
hydrokinetic,
interconnect at
transmission and
sub-transmission
levels





Distributed

PV, small
wind, and fuel cells
interconnect at the
distribution level



NREL
Sandia
National
Laboratories

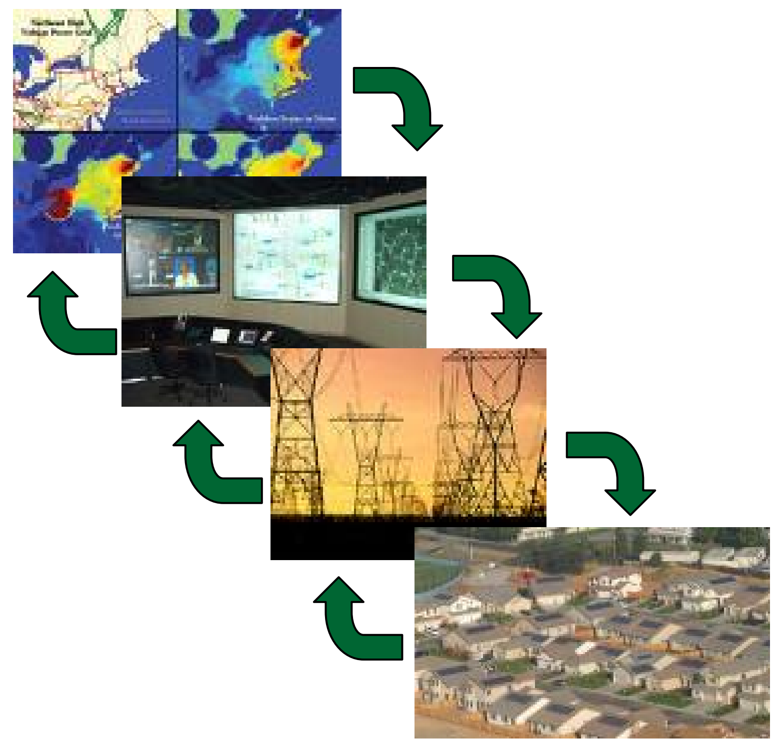
Concerns with Integrating Renewables

- **Penetration**
  - Affected by utilities' existing generation mix regulating capabilities, load characteristics, resource availability, and correlations between system load and resources
  - Additional systems costs imposed by variability and uncertainty may go up with increasing penetration
  - Integration costs are moderate for up to 20-30% penetration levels – depend on balancing authority and market structure

- **Variable and Uncertain Generation**

  Can be solved by
  - spatial diversity of the resource
  - flexible conventional generation
  - grid operations and control areas
  - limited curtailment for extreme events
  - load management
  - energy storage

- **Technical Concerns**
  - Real but solvable – Discussed in RSI Reports



Renewable System Interconnection (RSI) Study
(focus on distributed PV technology)

- DOE has completed 14 reports available at:
  - http://www1.eere.energy.gov/solar/rsi.html

- RSI Reports
  - Advanced Grid Planning and Operations
  - Utility Models, Analysis and Simulation Tools
  - Advanced PV System Designs and Technology Requirements
  - Development of Analysis Methodology for Evaluating the Impact of High Penetration PV
  - Distribution System Performance Analysis for High Penetration PV
  - Enhanced Reliability of PV Systems with Energy Storage and Controls
  - Transmission System Performance Analysis for High Penetration PV
  - Renewable System Interconnection Security Analysis
  - Solar Resource Assessment: Characterization and Forecasting to Support High PV Penetration
  - Test and Demonstration Program Definition to Support High PV Penetration
  - Value Analysis
  - PV Business Models
  - Production Cost Modeling for High Levels of PV Penetration
  - PV Market Penetration Scenarios

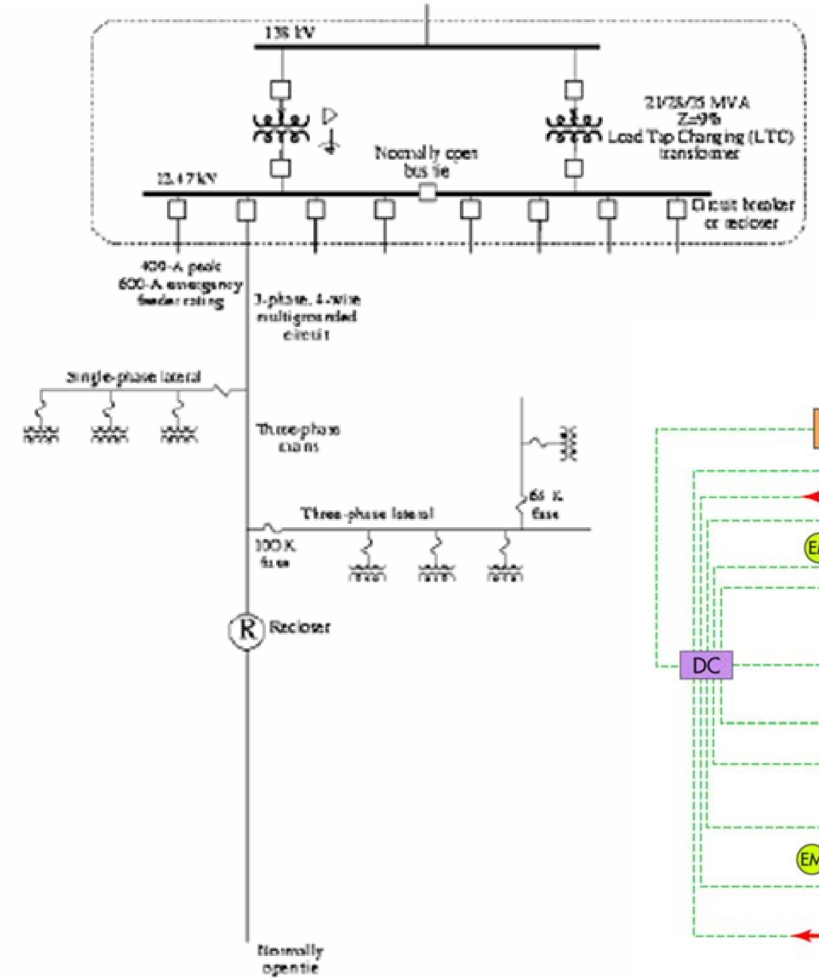
RSI Reports – Summary Slides

Grid Operations and Simulation Tools

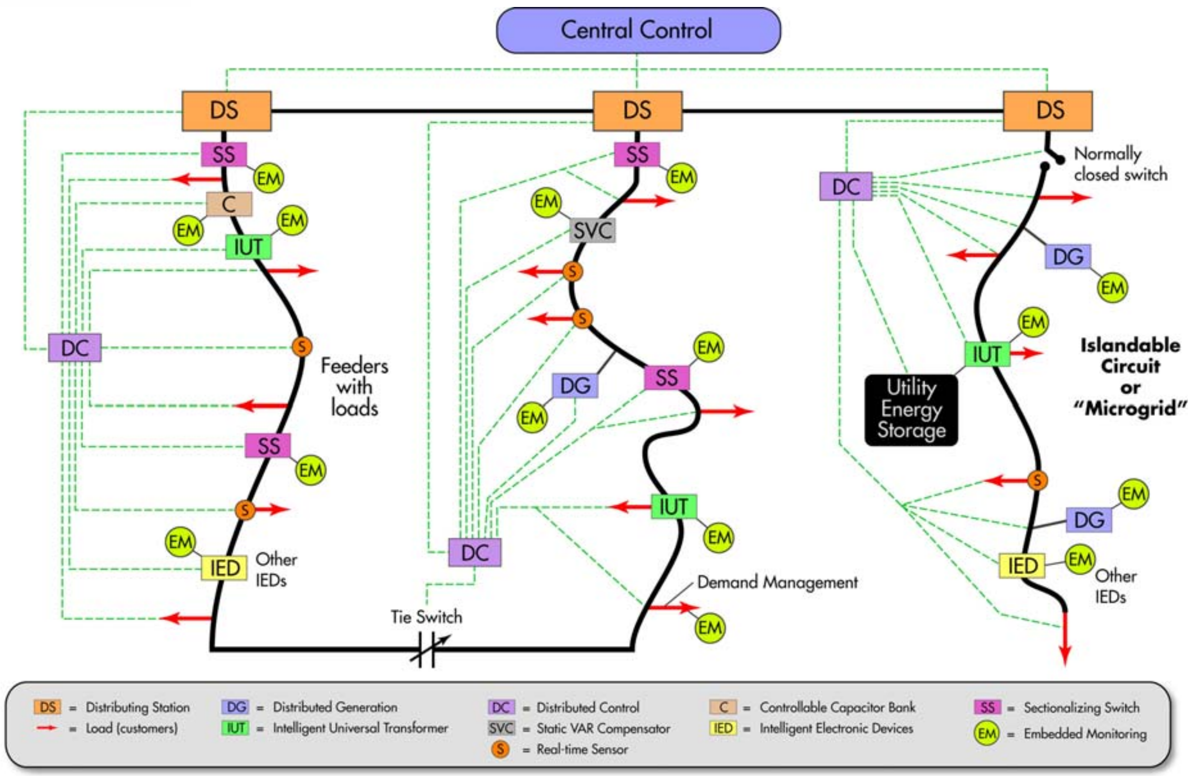
- **EPRI Reports**
  - Advanced Grid Planning and Operations
  - Utility Models, Analysis and Simulation Tools

- Approach
  - Recognize need for distribution system evolution from distributed resources operating at an “appliance” level to their full utilization as grid resources
  - Consider interaction and importance of all distributed resources….EE, PHEV, storage, load as a resource…
  - Identify requirements and related research in the context of creating opportunities on both sides of the meter that lead to “Market-Driven Response”
  - Identify requirements and timing in the necessary grid evolution as operating rules change from insignificant level to microgrids.
  - Retain safety, reliability, quality…..

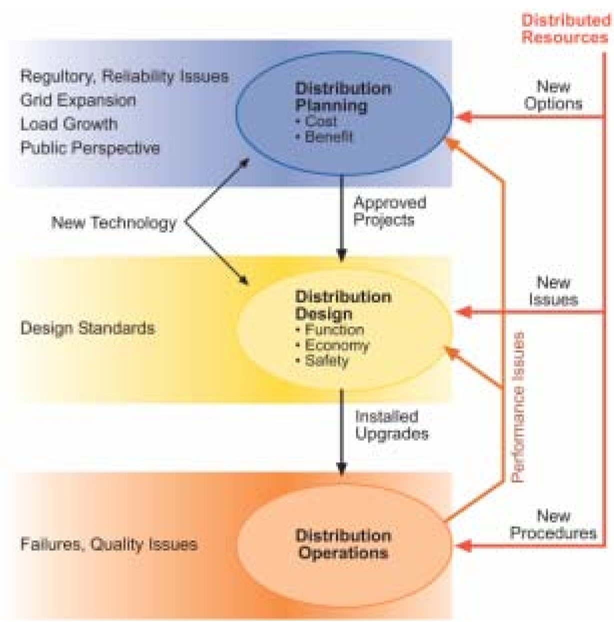
Moving from Current Radial Distribution System….



To Advanced Distribution System Infrastructure



Need for new simulation tools



- Both planning and real-time simulation applications
- New paradigm needed
  - Advanced load models that incorporate energy efficiency technologies, demand response, storage, and generation
  - Load/local generation models updated via information from advanced metering/customer gateway
  - Ability to integrate communications and controls with system electrical models
  - Model new configurations (automation and microgrids)
  - Stochastic methods that include customer preferences and control response
- Planning to include benefits of distributed resources
- Optimize steady state performance
- Contingency analysis

NREL Sandia National Laboratories

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Understanding the Impact of High Penetration of PV

- GE Reports
  - Development of Analysis Methodology for Evaluating the Impact of High Penetration PV
  - Distribution System Performance Analysis for High Penetration PV
  - Enhanced Reliability of PV Systems with Energy Storage and Controls
  - Transmission System Performance Analysis for High Penetration PV

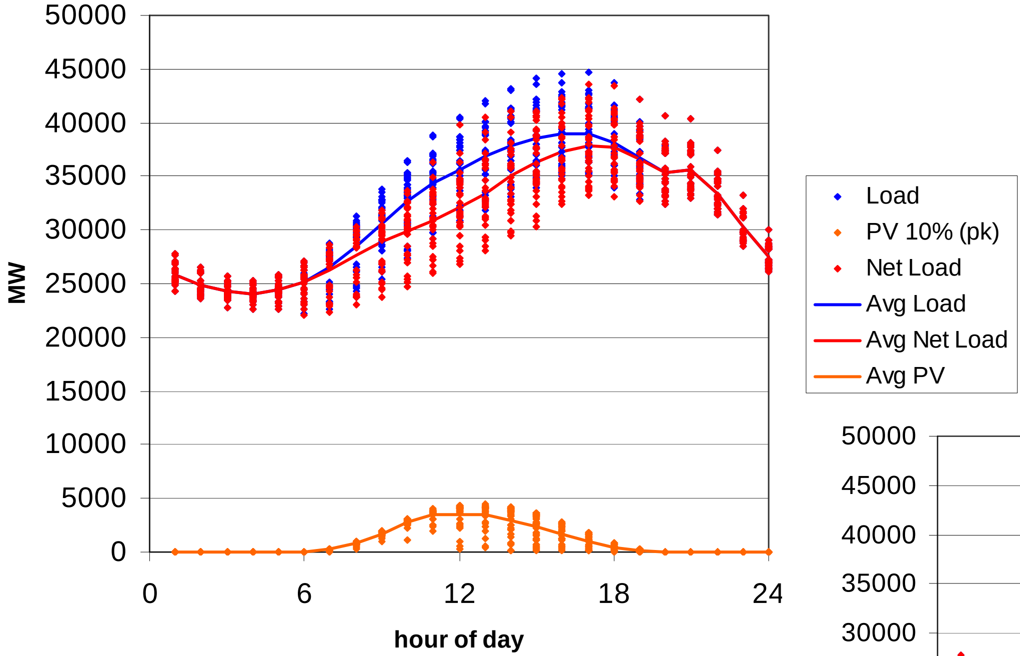
  - These reports by General Electric discuss how utilities analyze systems for implementation with distributed photovoltaic systems at the distribution and transmission level and understand improvements in reliability by adding energy storage

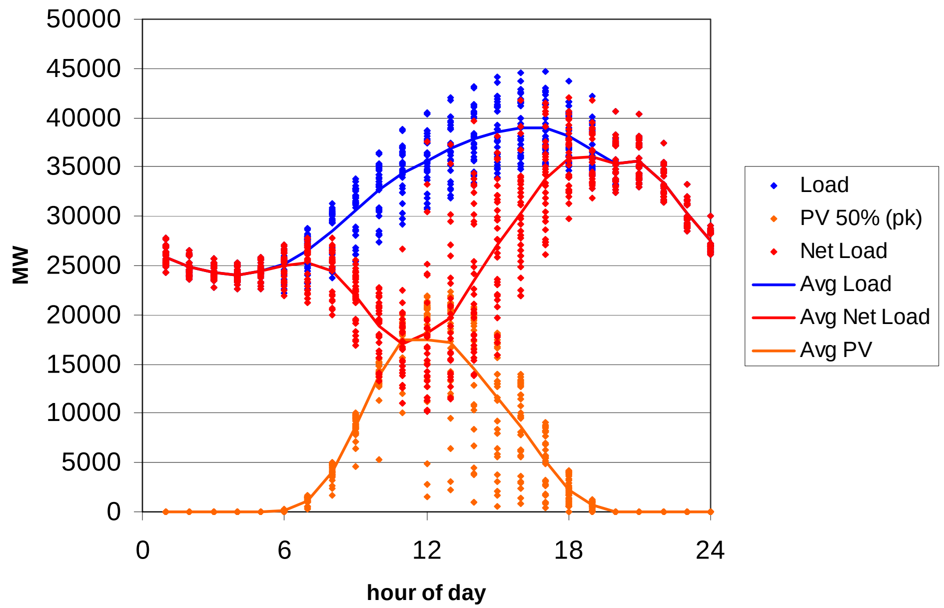
  - Started with PV and Electric System Planning ->
  - PV and Large Area System Stability Analysis ->
  - PV and Distribution System Integration (Focus on Voltage Regulation) - >
  - Enhanced Reliability with PV+Energy Storage +Controls

NREL Sandia National Laboratories

imagination at work

CAISO July 2007, 10% and 50% PV





NREL Sandia National Laboratories

imagination at work

Streamline PV Installations

- Dedicated sections in NEC - to accelerate propagation?
- Update software, and provide test cases to harmonize

Technical

- Need resource and load data to predict reverse power flow (only max load tracked, not min, not peak sun)
- Need to consider voltage drop in sec circuits (revise design guidelines based on ANSI C84.1.
- Evolve 1547: Let inverters help regulate voltage, allow for LVRT, frequency droop, inertial behavior.

Other

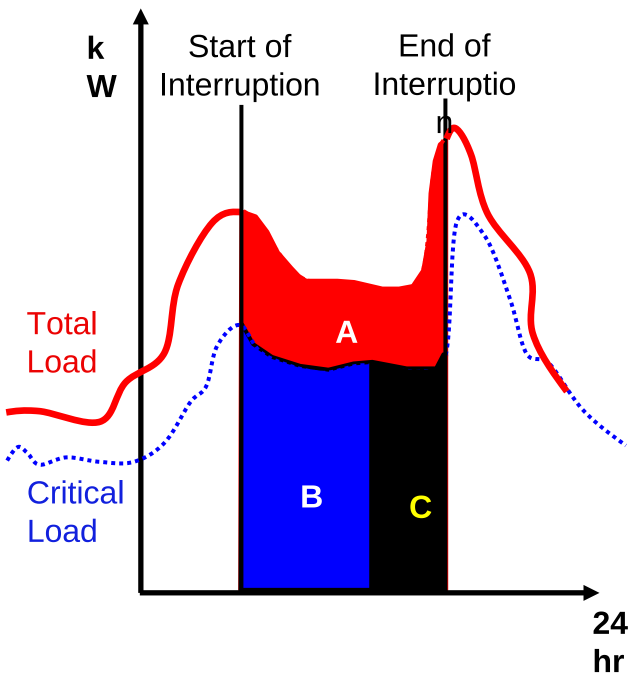
- Communication infrastructure seems imminent!
- Cleverly designed tariffs will drive behavior.
- Try to test out benefits via internet infrastructure.

Enhanced Reliability of PV systems with energy storage and controllable loads

- ***Examine the enhancement in customer reliability by managing PV, energy storage and controllable loads***

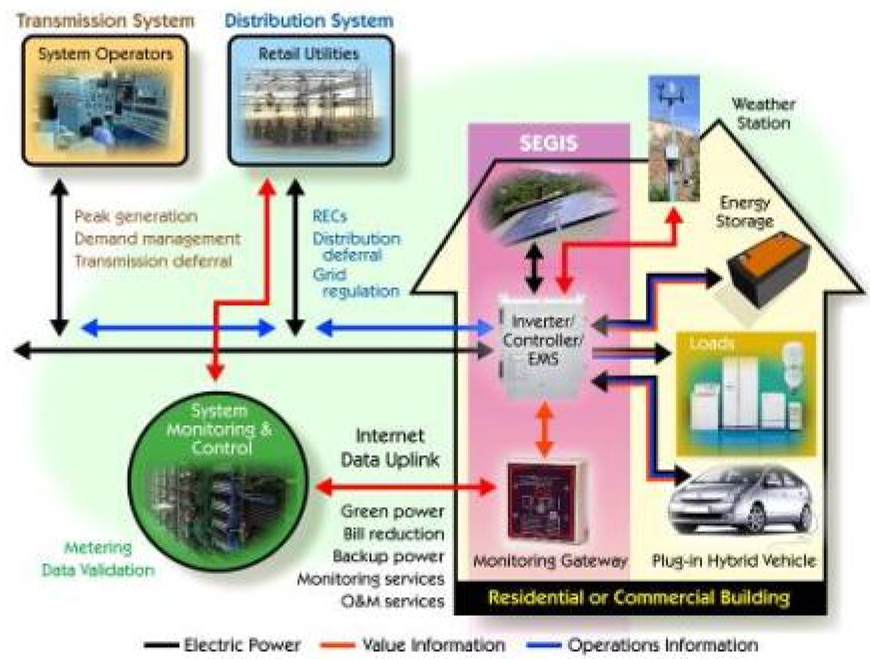
- Quantify improvements in critical SAIDI, critical SAIFI, critical kWh unserved (IEEE 1366) if each home in the community can island and meet only its critical loads. The loads will be broken into critical and deferrable loads in 15min intervals.

- Design of experiments:
  - **PV penetration level** (5, 10, 30 & 50% of peak annual critical load)
  - **Energy storage capacity** (minutes to days)
  - **Community size** - Three community sizes.
  - **Geographic location** - Three geographic regions.



PV System Technology Report

- BEW Engineering Report
  - Advanced PV System Designs and Technology Requirements
  - Investigate characteristics, equipment, and functions of PV Systems intended for high penetration Utility Distribution Systems (Radial and Network) to
  - Generate conceptual system designs that integrate PV, storage, and control technologies
  - Identify technology gaps and R&D needs



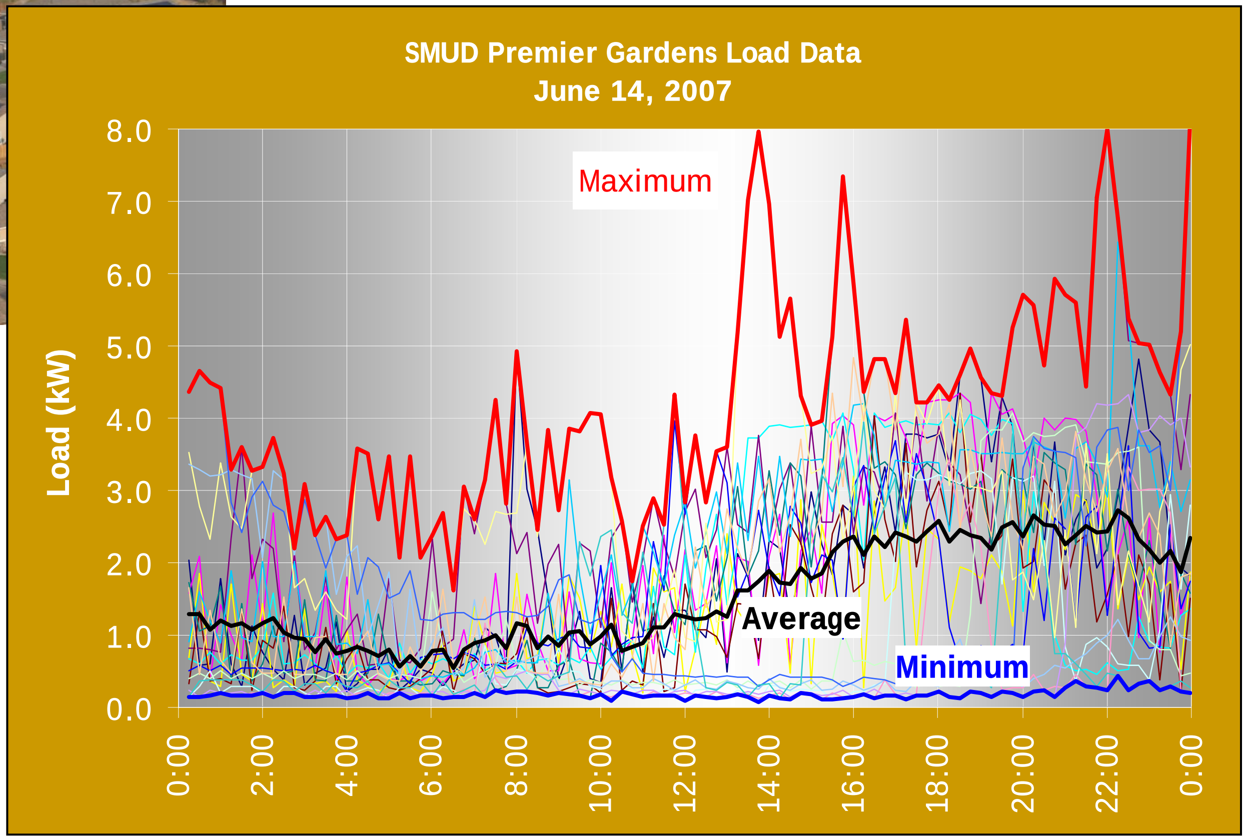
NREL Sandia National Laboratories

BEW ENGINEERING

Developing Testing and Demonstration Programs

- BEW Engineering Report
  - Test and Demonstration Program Definition to Support High PV Penetration
- Define test and demonstration activities required to evaluate the system-wide and local-distribution system impacts of high penetration PV with and without storage.
- Coordinate with the other report areas to determine testing needs necessary to:
  - Evaluate concerns raised through modeling and industry discussions to verify that they represent legitimate issues and to characterize their impact
  - Determine effectiveness of proposed DG and Distribution System solutions
  - Identify fielded applications representing high penetration

Examples of High Penetration PV

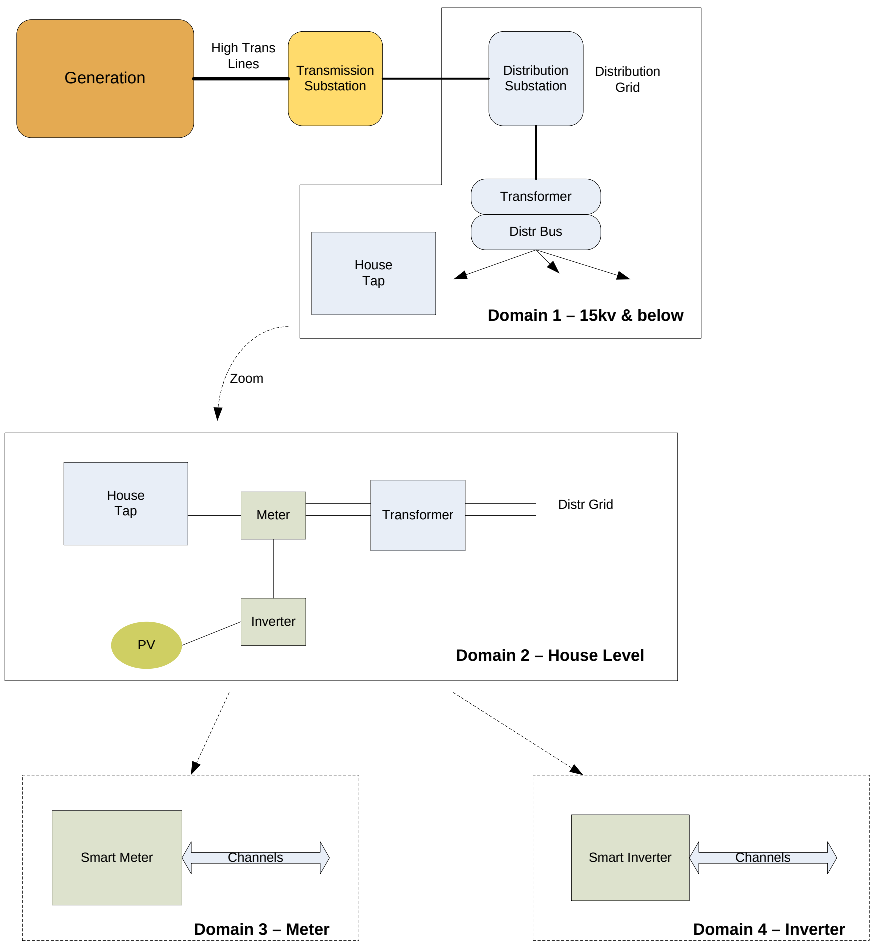


NREL Sandia National Laboratories

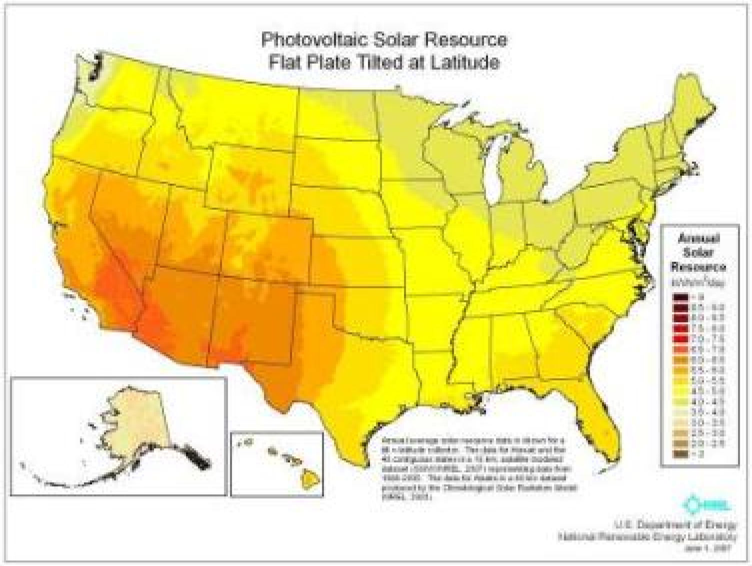
BEW ENGINEERING

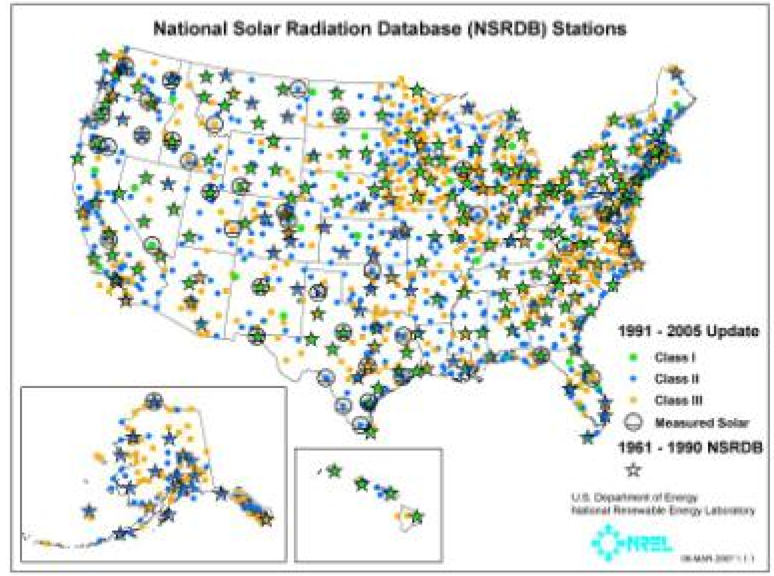
Interconnection Security

- **Sandia Report**
- Renewable System Interconnection Security Analysis
  - The Security Analysis Report discusses the elementary approach of defining the problem space, investigation and analysis, and technical summary.
- Therefore the following steps are included in the basic approach:
  - Define the architecture and future PV trends
  - Identify critical areas for further analysis and research
  - Enumerate potential security hazards based upon the design
  - Suggest mitigations or recommend further study



Solar Resource Assessment: Characterization and Forecasting to Support High PV Penetration





- **NSRDB Gridded SUNY Data**
- Includes hourly satellite modeled solar data for years 1998-2005 on 10km grid
- Hourly solar for any location can be combined with hourly met data for PV and CSP simulation.

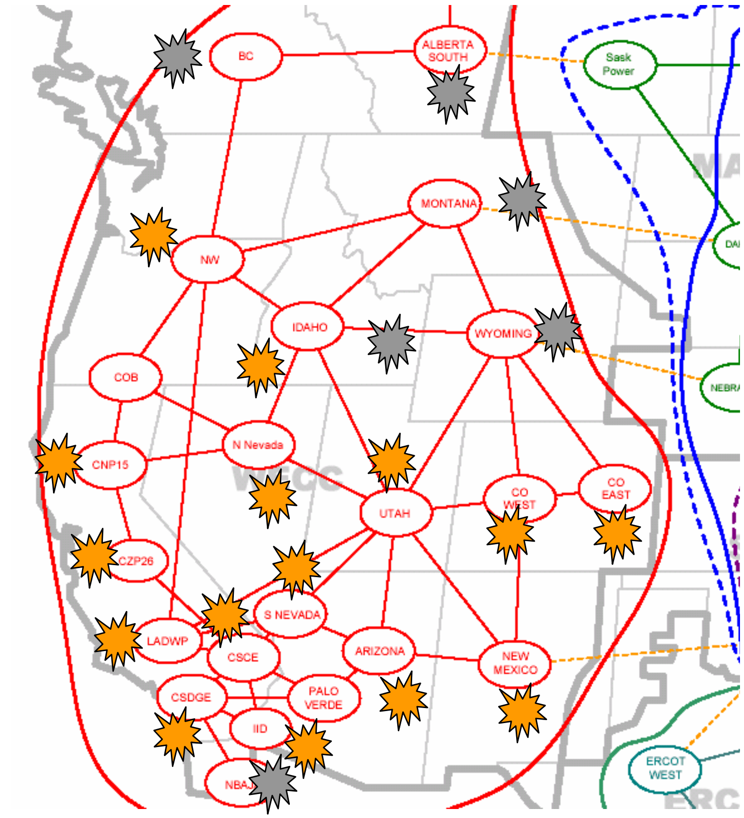
- **NSRDB Station Data**
- Contains hourly solar and meteorological data for 1454 ground locations, 1991-2005
- Distributed by National Climatic Data Center and NREL via web

NREL Sandia National Laboratories

Production Costs Modeling

- **NREL Report**
  - Production Cost Modeling for High Levels of PV Penetration

- Identify grid-level tools capable of analyzing the impact of PV at the grid level
- Perform simulations of PV impact on existing and “future” power systems
  - Avoided generation and fuel use
  - Avoided emissions
- Analyze certain aspects of high-penetration scenarios
  - Generator ramping and minimum loading limits



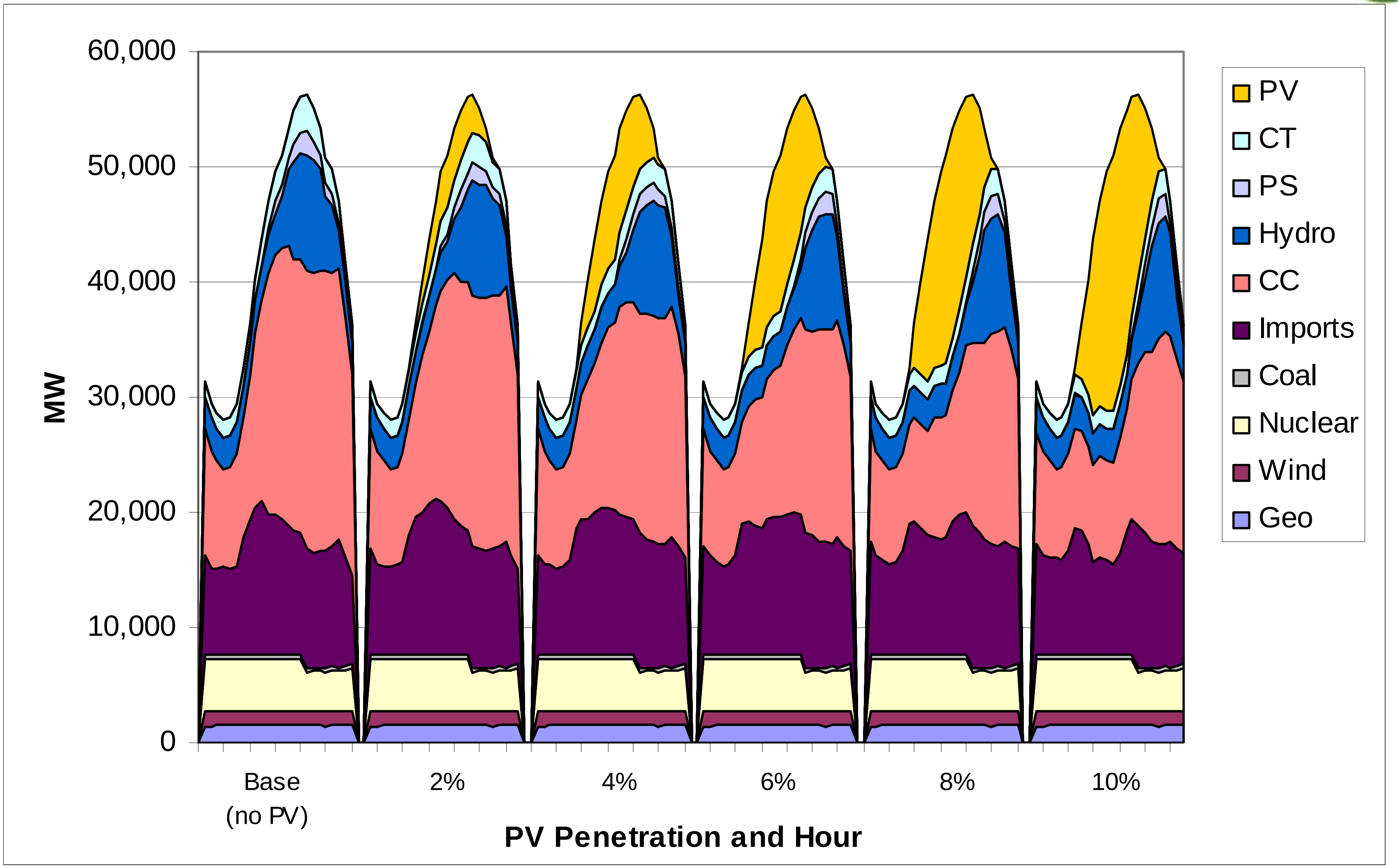
Areas with NO PV

Areas with PV

2003 PV Profile in each area built up several NSRDB sites, weighted by population – 75 total WECC sites

NREL Sandia National Laboratories

Production Costs Modeling



Simulated Dispatch in California for a Summer Day in 2007

PV Value Analysis, Business Models and Market Penetration

- **Navigant Consulting Reports**
- **PV Value Analysis**
  - Identified the various potential values of distributed PV and the best methodologies used for estimating key PV values
  - Quantifies a base case and range for each key PV value
  - Developed a simple tool (Excel based) to conduct sensitivity analyses around each of the key values
- **PV Business Models**
  - Examines three basic types of business models that are contemplated for the future
- **PV Market Penetration Scenarios**
  - develop a model for calculating the penetration of PV from 2007 to 2015 in of all 50 states (plus DC).
  - Examined residential retrofit, residential new construction, commercial retrofit, and commercial new construction markets.

NREL Sandia National Laboratories

NAVIGANT CONSULTING

Identified PV Values and Ranges

	PV Values	Customer/ Participant (₡/kWh)	Utility / Ratepayers (₡/kWh)	Society (₡/kWh)	Net (₡/kWh)	Value Drivers
Benefits	Central Power Generation Cost		5.6 – 8.0		**5.6 – 8.0**	Gas price, heat rate
	Central Power Capacity Cost		1.1 – 10.8		**1.1 – 10.8**	Effective load carrying capacity factor, gas turbine capital cost, life adjustment
	T&D Costs		0.1 – 10.0		**0.1 – 10.0**	Location, growth, climate
	System Loses		0.6 – 0.7		**0.6 – 0.7**	Location, time period, other benefits
	Ancillary Services		0 – 1.5		**0 – 1.5**	Ancillary service prices, voltage support
	System Resiliency		Low		**Low**	Quantification methodology unclear
	Fuel Diversity		Low		**Low**	Quantification methodology unclear
	Market Price Impacts/Elasticity		Low		**Low**	Quantification methodology unclear
	Customer Price Protection	0.5 – 1.0			**0.5 – 1.0**	Calculation method
	Customer Reliability	Low			**Low**	Quantification methodology unclear
	Criteria Pollutant Emissions			0.7 – 2.0	**0.7 – 2.0**	Market value of emissions
	Greenhouse Gas Emissions			0.3 – 3.6	**0.3 – 3.6**	Reduction costs, market value, discount rate
	Implicit Value of PV			0 – 2.0	**0 – 2.0**	Customer willingness to pay premium
Costs	Equipment and Installation	(47) – (19)			**(47) – (19)**	Size, location
	PV O&M Expenses	(0.15) – (0.05)			**(0.15) – (0.05)**	Type of system
	Benefits Overhead		(0.2) – (0.1)		**(0.2) – (0.1)**	Infrastructure and administrative costs
Transfer	PV Owner Electricity Bill	5.0 – 24.0	(24.0) – (5.0)		**-**	Customer type, rate structure, load profile
	Federal Incentives	1.58 – 7.95		(7.95) – (1.58)	**-**	Customer type, size, cap
	State Incentives	0 – 38.2		(38.2) - 0	**-**	State, customer type, size, production, cap
	Stakeholder Total	(40.07) – 52.1	(16.8) – 25.9	(45.15) – 6.02	**(38.45) – 20.45**	

NREL Sandia National Laboratories

NAVIGANT CONSULTING

PV Business Models

Evolution of PV Business Models

0 Generation: PV System Supply

- Business models focused on manufacturing, supply and installation of PV systems
- End-user is the owner
- Utility is largely passive, providing net metering and standard/simplified interconnection, but otherwise, unaffected.

1st Generation: Third-Party Ownership & Operation

- Third parties develop projects and own PV systems
- Reduces hassle & complexity for end-user
- Provides better access to financing
- Leverages current incentives structure (especially for commercial building applications)
- Utility gradually takes on a facilitation role as PV market share grows

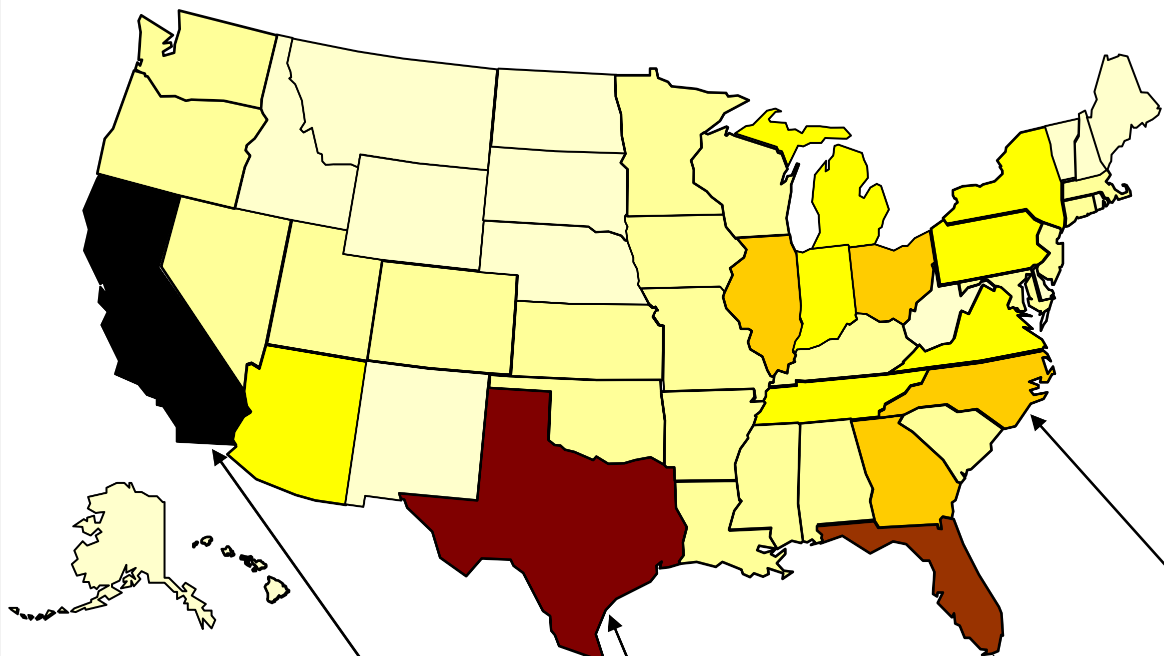
2nd Generation: Full Integration

- PV becomes an integral part of the electricity supply and distribution infrastructure
- Various business models emerge that may address one or more of the following:
  - Ownership
  - Operation
  - Control
- Utility becomes more deeply involved, as PV becomes major consideration
- PV product supply chain becomes "commoditized"

. . . the future will most likely include models that deeply involve utilities and more fully integrate PV into the electricity grid.

Technical Potential is highest in California and Texas

Technical Rooftop Potential in 2015 (MW_{Pdc}) - independent of economics



Range			Unit	Color
Greater than		75000	MW	
75000	to	65000	MW	
65000	to	55000	MW	
55000	to	45000	MW	
45000	to	35000	MW	
35000	to	25000	MW	
25000	to	15000	MW	
15000	to	5000	MW	
5000	to	1000	MW	
1000	to	0	MW	

CA: 81 GW | TX: 71 GW | FL: 61 GW | NC: 28 GW

Technical potential in 2015, independent of economics

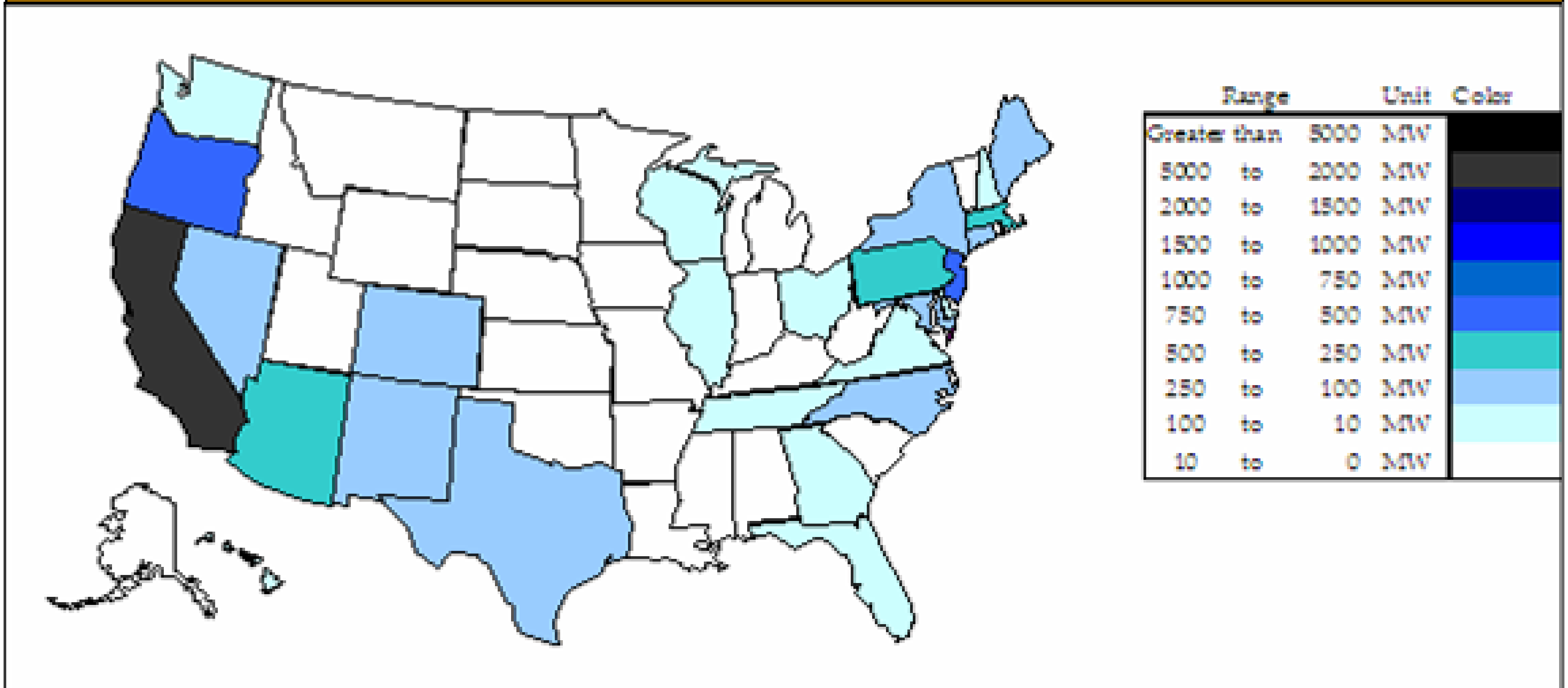
$$Technical\_Potential = \left(\frac{Floor\_Space}{Number\_of\_floors}\right) * System\_Power\_Density * PV\_Access\_Factor$$

NREL | Sandia National Laboratories

NAVIGANT CONSULTING

Best Case Penetration for 2015 based on Model

Best-Case, Cumulative Installations in 2015 (MW) – 7,492 MW



Renewable System Interconnection (RSI) Study
(focus on distributed PV technology)

- DOE has completed 14 reports available at:
  - http://www1.eere.energy.gov/solar/rsi.html

- RSI Reports
  - Advanced Grid Planning and Operations
  - Utility Models, Analysis and Simulation Tools
  - Advanced PV System Designs and Technology Requirements
  - Development of Analysis Methodology for Evaluating the Impact of High Penetration PV
  - Distribution System Performance Analysis for High Penetration PV
  - Enhanced Reliability of PV Systems with Energy Storage and Controls
  - Transmission System Performance Analysis for High Penetration PV
  - Renewable System Interconnection Security Analysis
  - Solar Resource Assessment: Characterization and Forecasting to Support High PV Penetration
  - Test and Demonstration Program Definition to Support High PV Penetration
  - Value Analysis
  - PV Business Models
  - Production Cost Modeling for High Levels of PV Penetration
  - PV Market Penetration Scenarios