2008 Solar Annual Review Meeting

Session: Test and Evaluation
Project: Grid Integration
Title: Demonstrations and Analysis

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Sandia National Laboratories

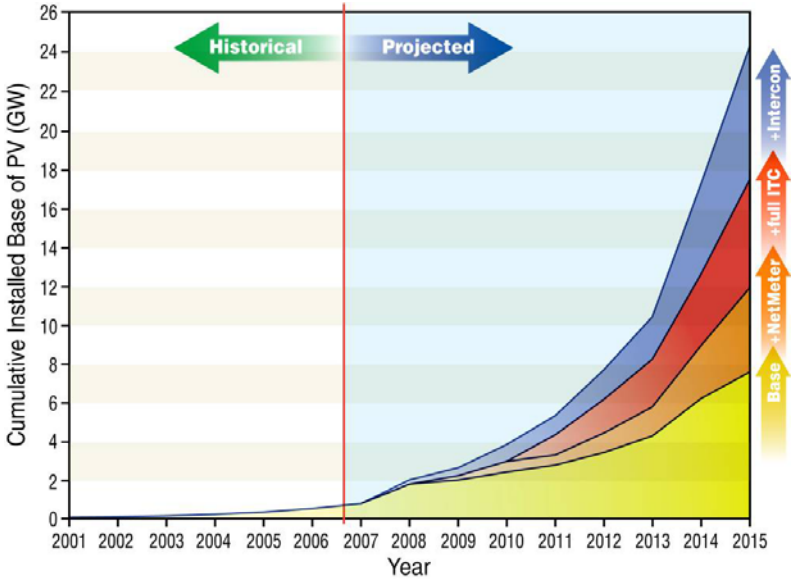
NREL

Austin Airport Marriott South

Austin, TX April 22-24, 2008

Relevance to the SAI

- SAI should produce high growth in the number of installed PV systems.
- The **Grid Integration Project** supports the goals of SAI by conducting R&D to reduce barriers for high penetration of solar technologies into the electric power system.
- This project addresses both technical and economic issues and develops solutions for grid integration.



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

Organization	FY07 Budget	FY08 Budget	Total Budget
Sandia	$700K	$400K	TBD
NREL	$1,950K	$400K	TBD

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Grid Integration Milestones

FY	Milestone/Deliverable	Date	Organization
2007	Complete DRAFT RSI Reports	10/07 ✓	NREL/SNL
2007	Complete SEGIS Whitepaper and release SEGIS Solicitation	10/07 ✓	SNL
2007	Complete DRAFT RSI Multi-year Research Plan	10/07 ✓	NREL/SNL
2008	Complete Final RSI Reports	3/08 ✓	NREL/SNL
2008	Initiate grid integration test and field demonstration program (SMUD, Xcel, Nellis, Hawaii, etc.)	9/08	NREL/SNL
2008	Establish plan for high quality data gathering and analysis of data on fielded systems that represent high penetration of PV on distribution feeders.	9/08	NREL
2008	Establish and implement plan to address key stakeholders including developing briefing package and stakeholder meetings.	9/08	NREL/SNL
2008	Develop white paper on current and future energy storage technology needs for PV systems in support of future DOE related solicitations.	9/08	SNL
2008	Revise RSI Multi-year Research Plan	9/08	NREL/SNL

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Major Accomplishments

- **Completed 14 reports available at:**

  http://www1.eere.energy.gov/solar/solar_america/rsi.html

- **RSI Reports**
  - Advanced Grid Planning and Operations (EPRI)
  - Utility Models, Analysis and Simulation Tools (EPRI)
  - Advanced PV System Designs and Technology Requirements (BEW)
  - Power System Planning: Emerging Practices Suitable for Evaluating the Impact of High-Penetration Photovoltaics (GE)
  - Distribution System Performance Analysis for High Penetration PV (GE)
  - Enhanced Reliability of PV Systems with Energy Storage and Controls (GE)
  - Transmission System Performance Analysis for High Penetration PV (GE)
  - Cyber Security Analysis (Sandia)
  - Solar Resource Assessment: Characterization and Forecasting to Support High PV Penetration (NREL)
  - Test and Demonstration Program Definition to Support High PV Penetration (BEW)
  - Value Analysis (Navigant)
  - PV Business Models (Navigant)
  - Production Cost Modeling for High Levels of PV Penetration (NREL)
  - PV Market Penetration Scenarios (Navigant)

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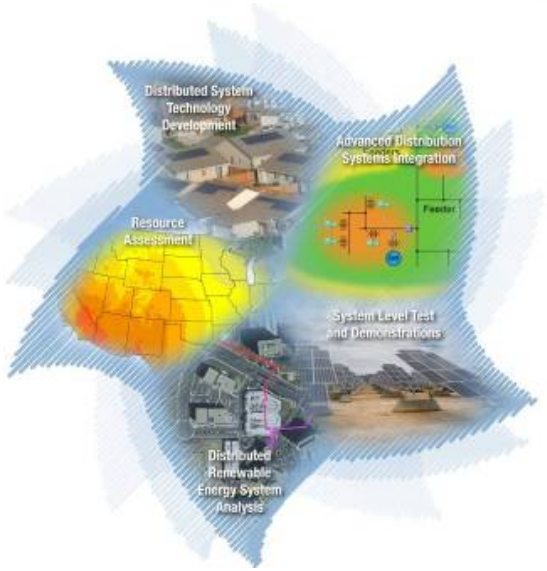
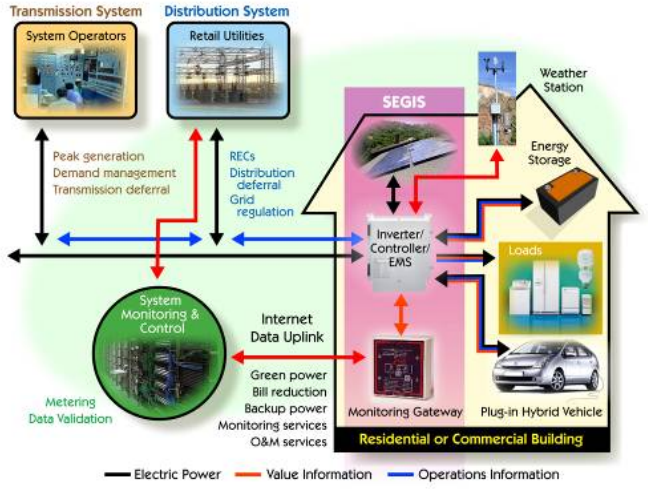
Major Accomplishments

- Completed Multi-Year Research Plan for Renewable Systems Interconnections (FY08-FY12)
  - Distributed PV System Technology Development
  - Advanced Distribution Systems
  - System Level Test and Demonstration
  - Distributed Renewable Energy System Analysis
  - Solar Resource Assessment
  - Codes, Standards, and Regulatory Implementation

- Completed SEGIS Whitepaper
  (discussed in next talk)





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Demonstrations

- Working with utilities, systems integrators, and others to identify locations of high PV penetration (>15%)
- Working with States to implement large scale renewables including: Hawaii
- Working with developer of large-scale PV project including: Mesa del Sol in Albuquerque

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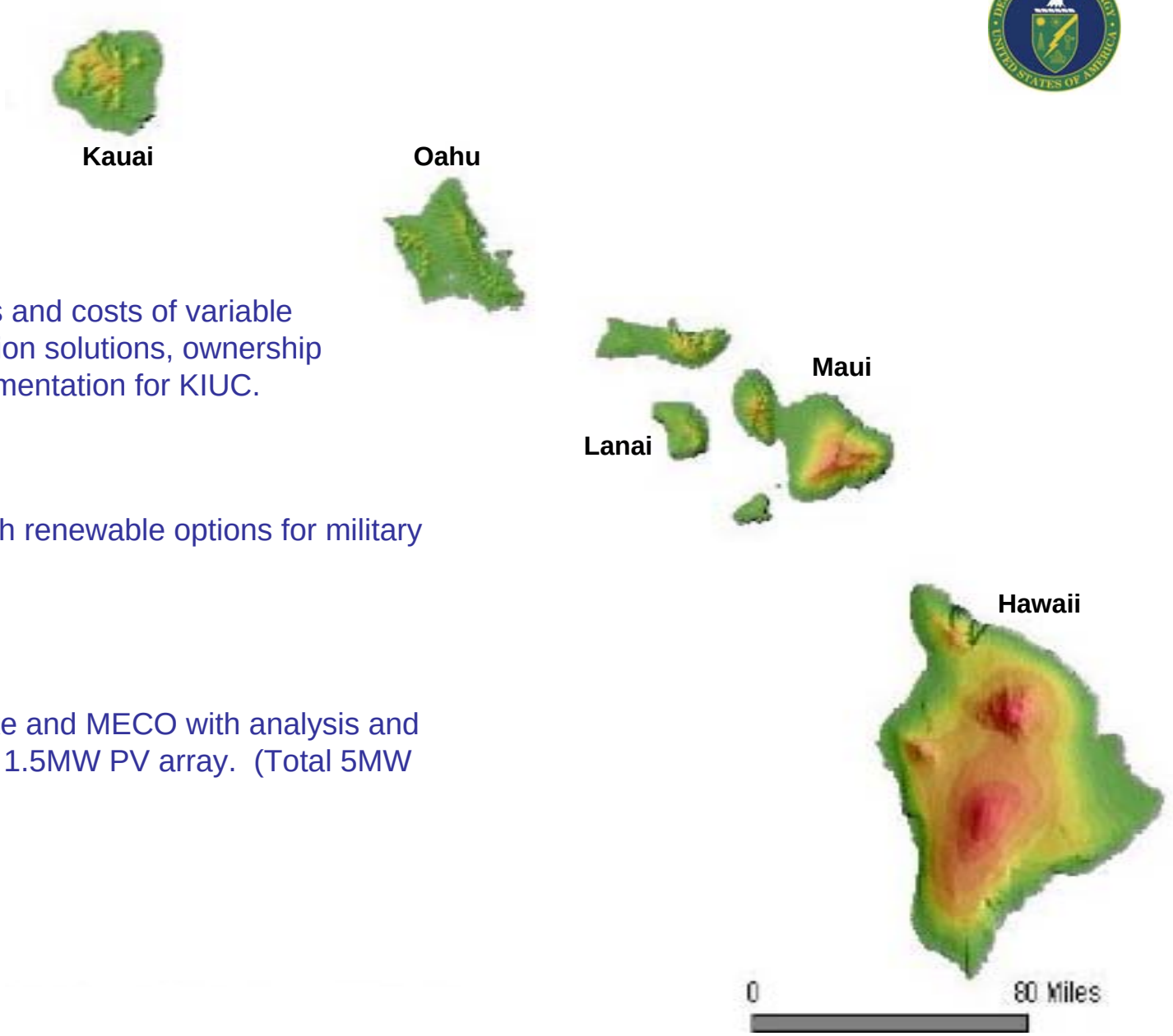
Hawaii



Kauai

Characterize benefits and costs of variable renewable integration solutions, ownership options, and implementation for KIUC.

Oahu

Assist Forest City with renewable options for military housing

Lanai

Assist Castle & Cooke and MECO with analysis and implementation for 1.5MW PV array. (Total 5MW load)

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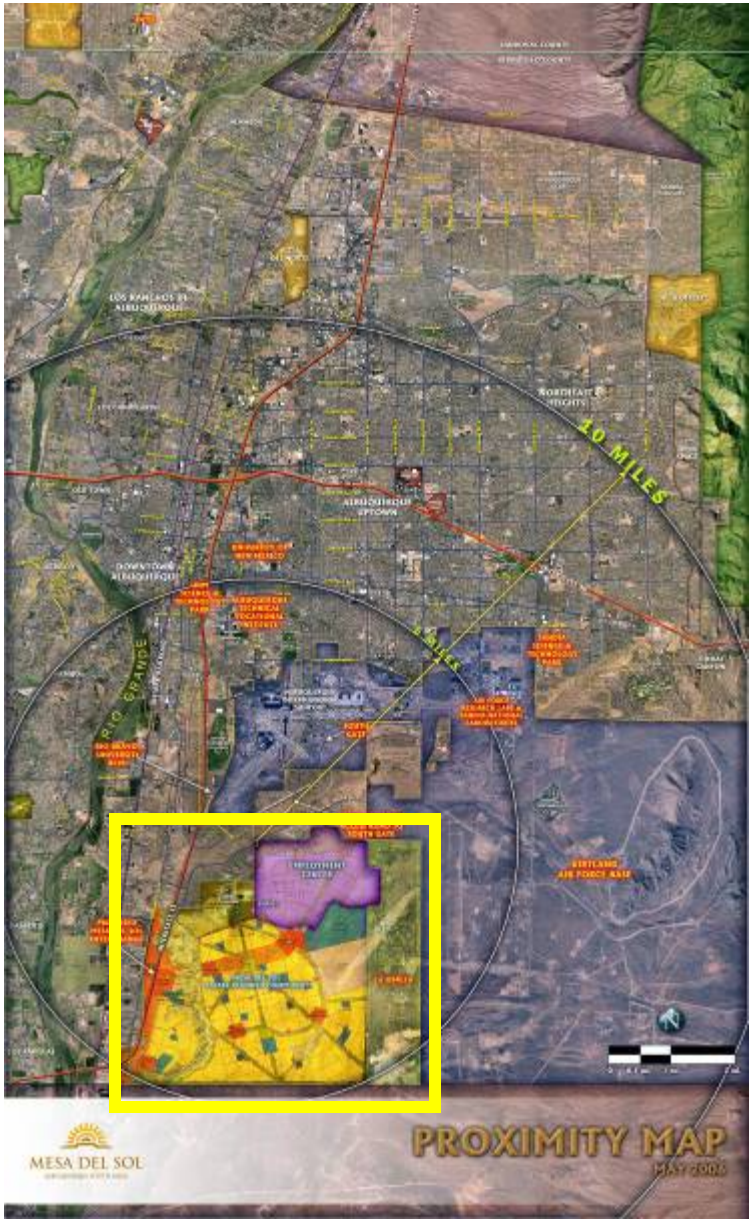
Mesa del Sol

- New sustainable community in Albuquerque, NM
- 38,000 homes planned
- LEED certified buildings and homes
- Microgrid technologies
- Energy storage
- A variety of renewable resources



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Sacramento Municipal Utility District (SMUD)

Currently installing data acquisition and monitoring on distribution feeder at the Anatolia Subdevelopment in Rancho Cordova, CA

Over 600 homes will have 2kW of PV

Monitoring on Distribution Transformer

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Alamosa, CO

Currently monitoring effects of 8MW PV system on distribution feeder in Alamosa, CO.

Working with Xcel Energy (utility) and SunEdison (system integrator).

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Analysis

- RSI Study details analysis of a variety of high penetration PV scenarios

- Technical Analysis
  - Advanced Grid Planning and Operations (EPRI)
  - Utility Models, Analysis and Simulation Tools (EPRI)
  - Analysis Methodology for Evaluating the Impact of High Penetration PV (GE)
  - Distribution System Performance Analysis for High Penetration PV (GE)
  - Enhanced Reliability of PV Systems with Energy Storage and Controls (GE)
  - Transmission System Performance Analysis for High Penetration PV (GE)
- Economic Analysis
  - Value Analysis (Navigant)
  - PV Business Models (Navigant)
  - Production Cost Modeling for High Levels of PV Penetration (NREL)
  - PV Market Penetration Scenarios (Navigant)

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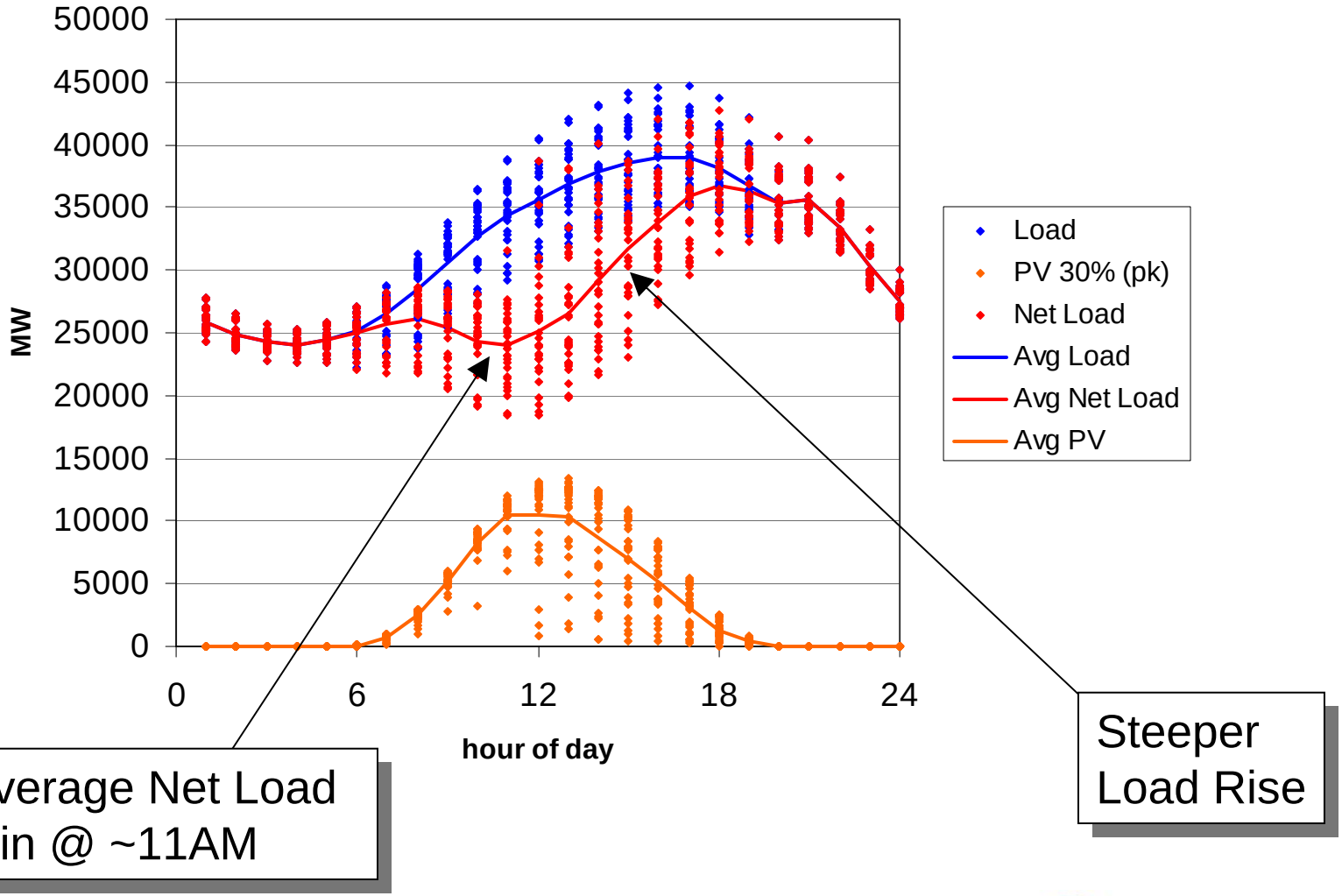
Analysis – Evaluating High Penetration Scenarios



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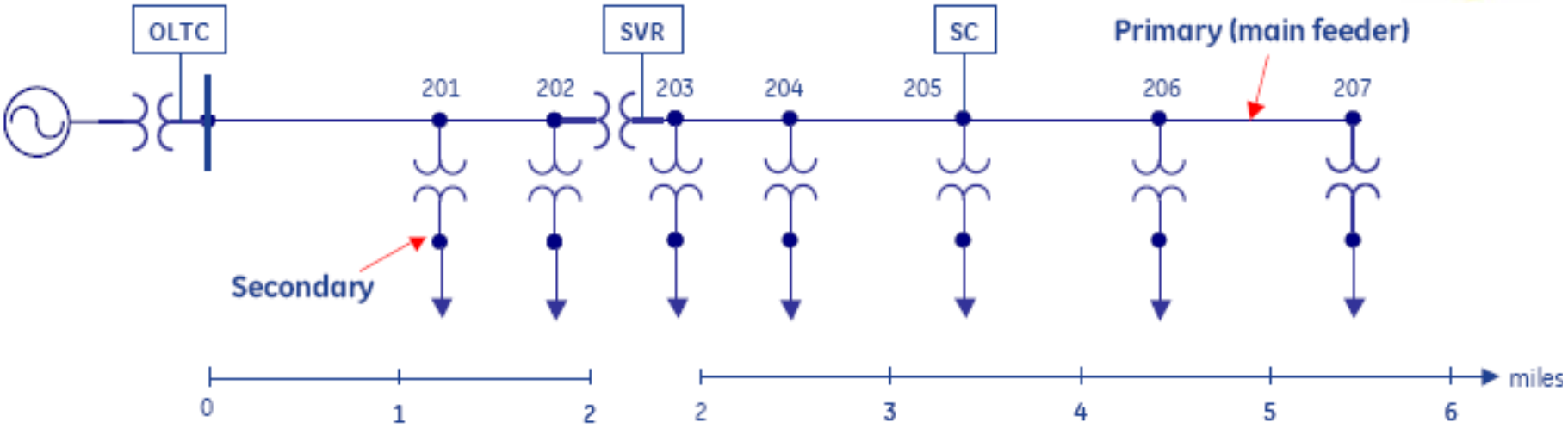
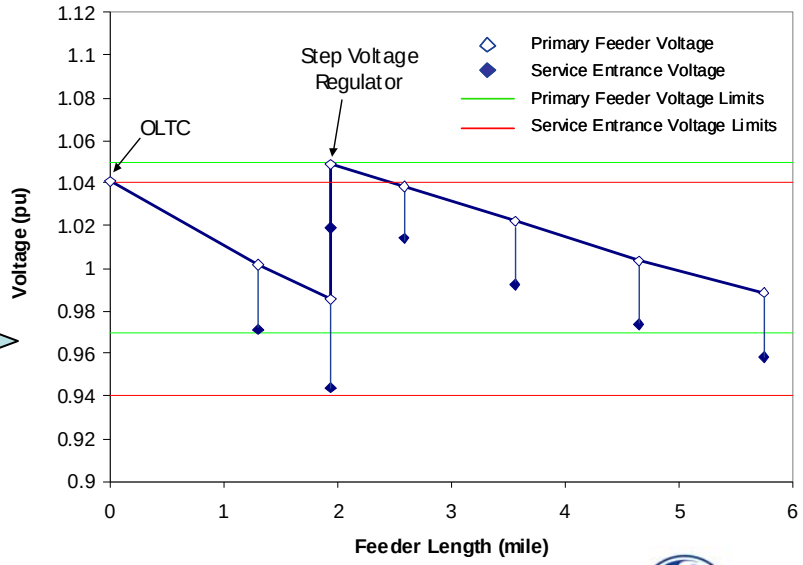
imagination at work

Analysis – Evaluating Distribution Level Impacts



OLTC: On-Load Tap Changer
SVR: Step Voltage Regulator
SC: Switched Capacitor

30% PV penetration voltage profile: peak load with SVR



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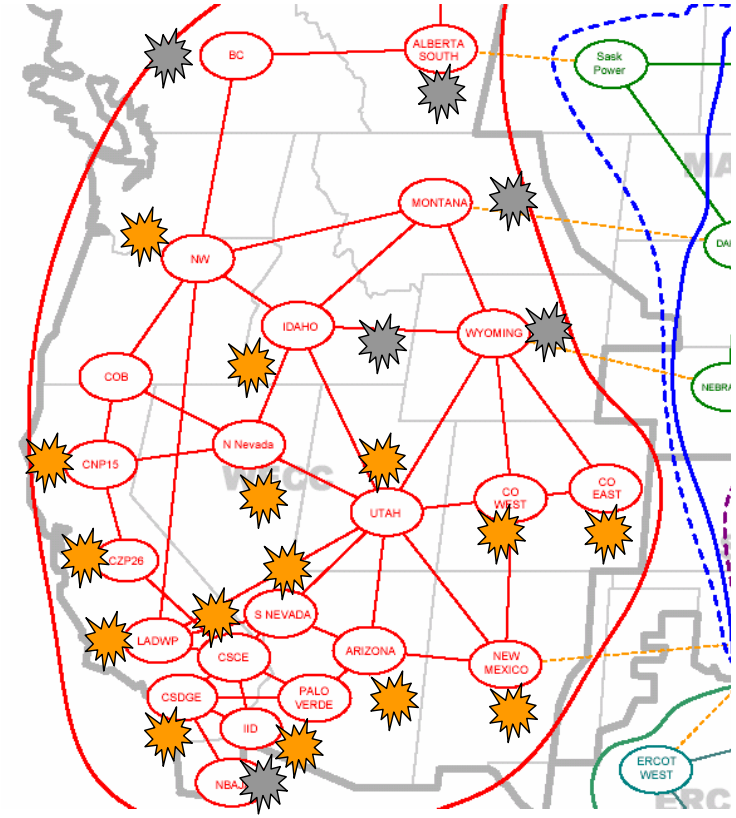
Analysis – Production Cost Modeling

- Geography
  - Western U.S. with focus on impacts in California and Colorado
- PV System Types
  - Single Mix of Tracking, and Flat
- Penetration Levels
  - Up to 10% energy from PV over the entire WECC region
- Years
  - 2007, 2015, 2020



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

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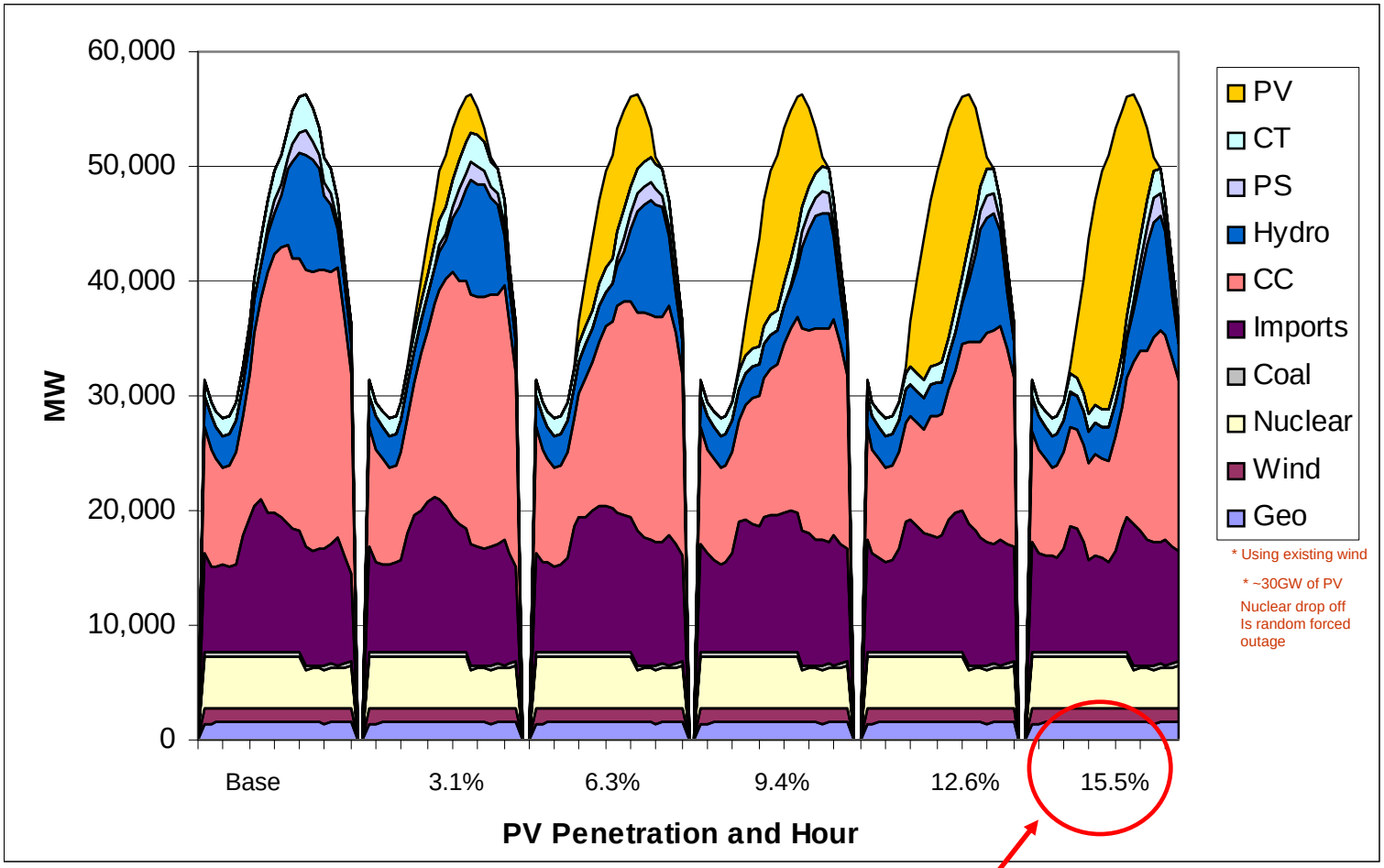
Example of ProSym Dispatch Model
California Summer Day



Energy Penetration Level of PV in CA

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Distributed PV Value Analysis

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**	

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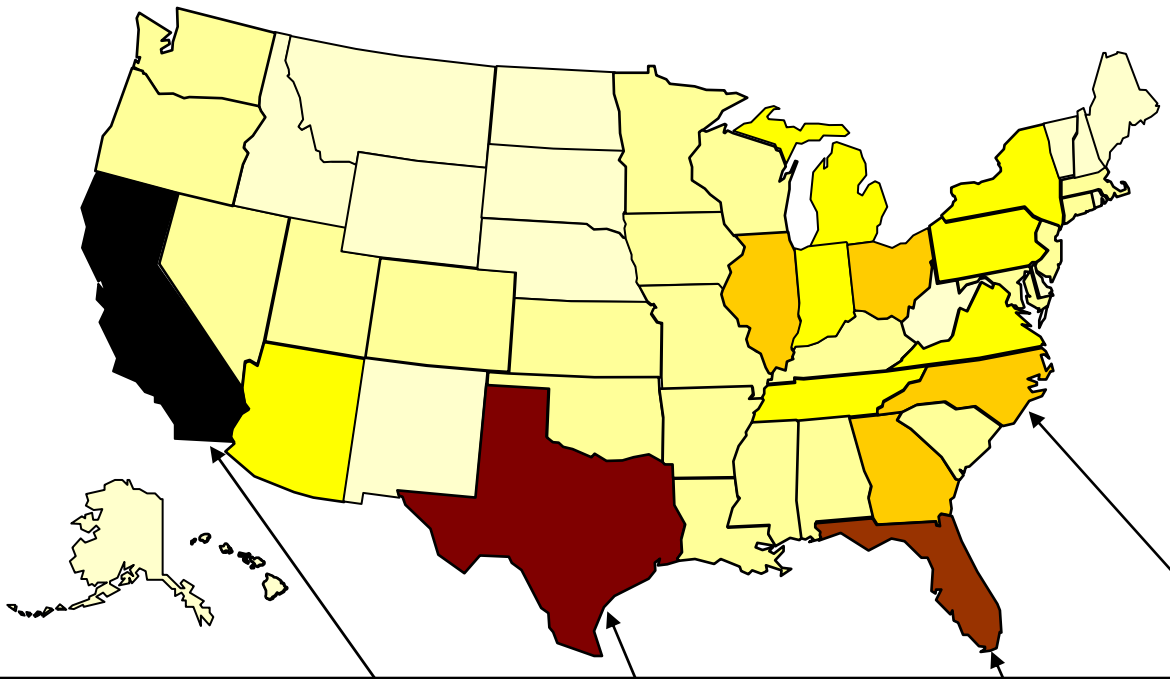
PV Rooftop Potential - 2015

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	

Technical potential in 2015, independent of economics

CA: 81 GW

TX: 71 GW

FL: 61 GW

NC: 28 GW

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

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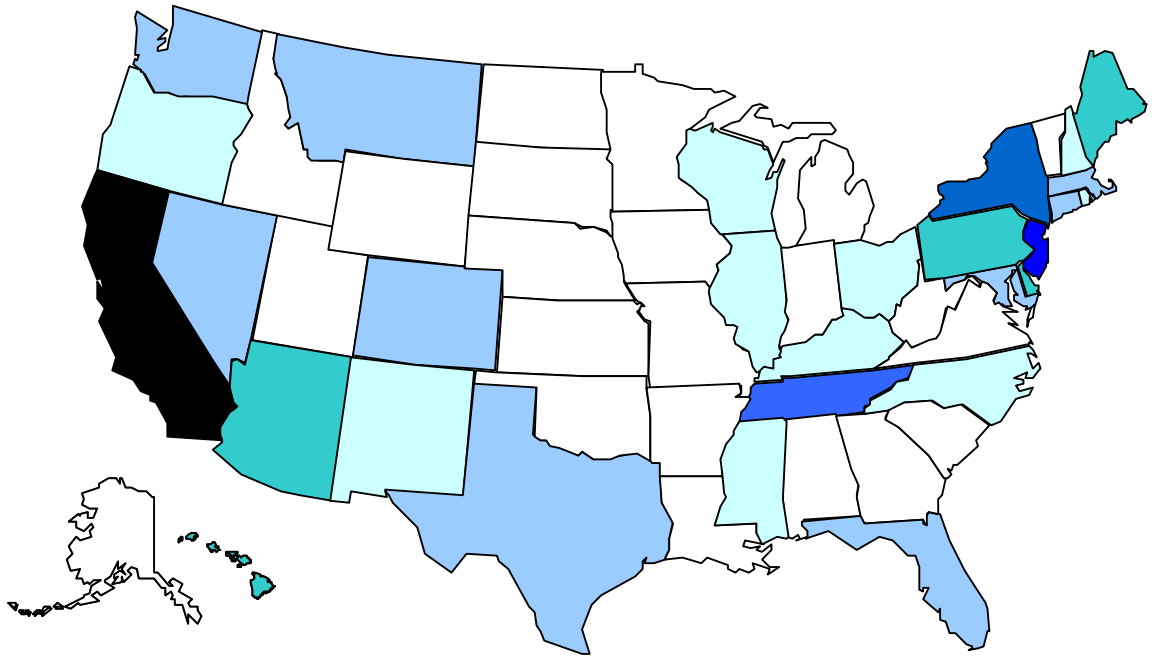
Best Case 2015 Market Penetration

Rooftop PV

Best-Case, Cumulative Installations in 2015 (MW) – 15,170 MW



Range			Unit	Color
Greater than		5000	MW	
5000	to	2000	MW	
2000	to	1500	MW	
1500	to	1000	MW	
1000	to	750	MW	
750	to	500	MW	
500	to	250	MW	
250	to	100	MW	
100	to	10	MW	
10	to	0	MW	

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PV Grid Integration
Looking Forward

- FY08 research activities will focus on:
  - Establish and implement plan to address key stakeholders including developing briefing package and stakeholder meetings.
  - Analyzing distribution system data to understand the effects of high penetration of PV on the electric power system
  - Installing DAS at new locations include Nellis AFB
  - White paper on energy storage for high penetration PV

- Future Year Plans include:
  - Distributed PV System Technology Development
  - Advanced Distribution Systems
  - System Level Test and Demonstration
  - Distributed Renewable Energy System Analysis
  - Solar Resource Assessment for high penetration PV
  - Codes, Standards, and Regulatory Implementation high penetration PV

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Publications

1. *Renewable Systems Interconnection Distributed Photovoltaic Study*, D. Ton, B. Kroposki, R. Margolis, G. Kuswa, J. Torres, and T. Key, 17th PVSEC, Fukuoka, Japan, December 2007.
2. *Renewable Systems Interconnection Distributed PV Activities; Multi-Year Research Plan (MYRP) FY2008-FY2013*; D. Ton, B. Kroposki, R. Margolis, G. Kuswa, J. Torres, W. Bower, C. Hanley, J. Boyes.
3. *Solar Energy Grid Integration Systems (SEGIS); Concept Paper,* D. Ton, W. Bower, C. Cameron.
4. *Renewable Systems Interconnection: Executive Summary.* B. Kroposki, R. Margolis, G. Kuswa , J. Torres, W. Bower, T. Key and D. Ton NREL Technical Report (NREL/TP-581-42292).
5. *Distributed Photovoltaic Systems Design and Technology Requirements* C. Whitaker and J. Newmiller, BEW Engineering; M. Ropp, Northern Plains Power Technologies; B. Norris, Norris Energy Consulting
6. *Advanced Grid Planning and Operation* M. McGranaghan, T. Ortmeyer, D. Crudele, T. Key, and J. Smith, EPRI; P. Barker, NOVA Energy Specialists LLC
7. *Utility Models, Analysis, and Simulation Tools,* T. Ortmeyer, R. Dugan, and D. Crudele, EPRI; P. Barker, NOVA Energy Specialists LLC
8. *Cyber Security Analysis,* A. McIntyre, Sandia National Laboratories
9. *Power System Planning: Emerging Practices Suitable for Evaluating the Impact of High-Penetration Photovoltaics,* J. Bebic, GE Global Research
10. *Distribution System Voltage Performance Analysis for High-Penetration Photovoltaics,* E. Liu and J. Bebic, GE Global Research
11. *Enhanced Reliability of Photovoltaic Systems with Energy Storage and Controls,* D. Manz, O. Schelenz, R. Chandra, S. Bose, M. de Rooij, and J. Bebic, GE Global Research
12. *Transmission System Performance Analysis for High-Penetration Photovoltaics,* S. Achilles, S. Schramm, and J. Bebic, GE Global Research
13. *Solar Resource Assessment,* D. Renné, R. George, S. Wilcox, T. Stoffel, D. Myers, and D. Heimiller, National Renewable Energy Laboratory
14. *Test and Demonstration Program Definition,* C. Whitaker and J. Newmiller, BEW Engineering; M. Ropp, Northern Plains Power Technologies; B. Norris, Norris Energy Consulting
15. *Photovoltaics Value Analysis,* J.L. Contreras, L. Frantzis, S. Blazewicz, D. Pinault, and H. Sawyer, Navigant Consulting Inc.
16. *Photovoltaics Business Models,* L. Frantzis, S. Graham, R. Katofsky, and H. Sawyer, Navigant Consulting Inc.
17. *Production Cost Modeling for High Levels of Photovoltaics Penetration,* P. Denholm, R. Margolis, and J. Milford, National Renewable Energy Laboratory
18. *Rooftop Photovoltaics Market Penetration Scenarios,* J. Paidipati, L. Frantzis, H. Sawyer, and A. Kurrasch, Navigant Consulting, Inc.

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