SMUD STORAGE STRATEGY AND R&D PROGRAM

January 12, 2012

Mark Rawson
Distributed Energy Resources R&D Program Manager

Powering forward. Together.

SMUD™

Topics of Discussion

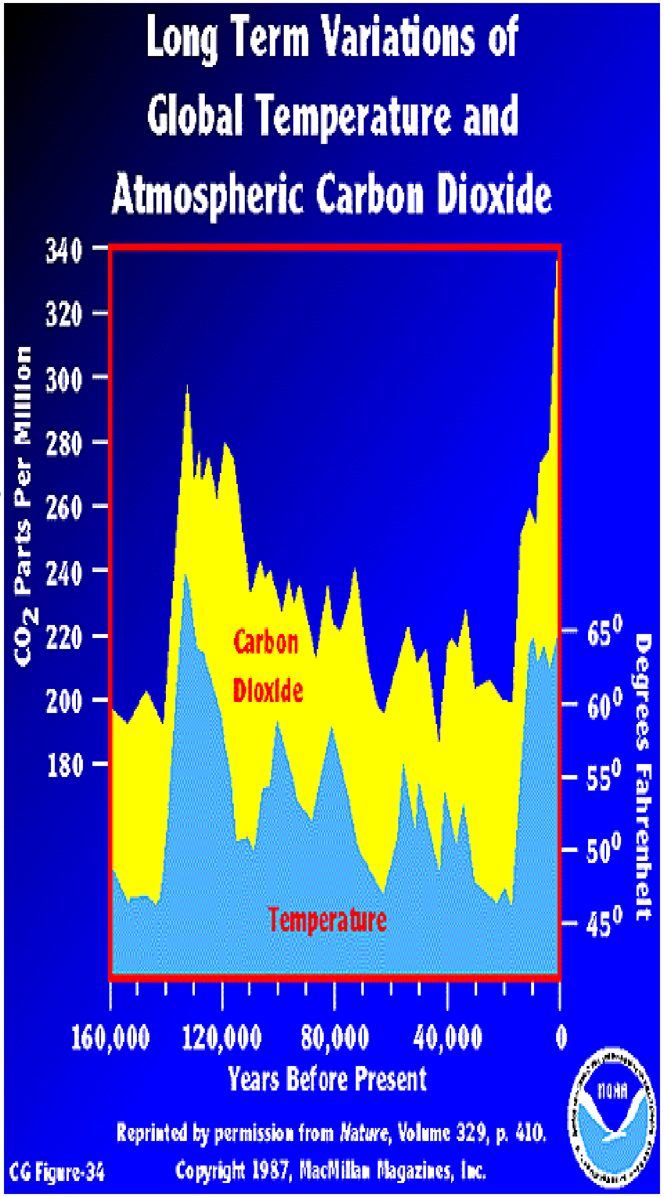
- Drivers for renewables and storage
- Opportunity for renewables and storage
- Challenges of integrating renewables
- SMUD storage strategy
- SMUD storage deployment experiences and lessons learned
- Closing remarks

What Is Driving SMUD's Renewables and Storage Interest?

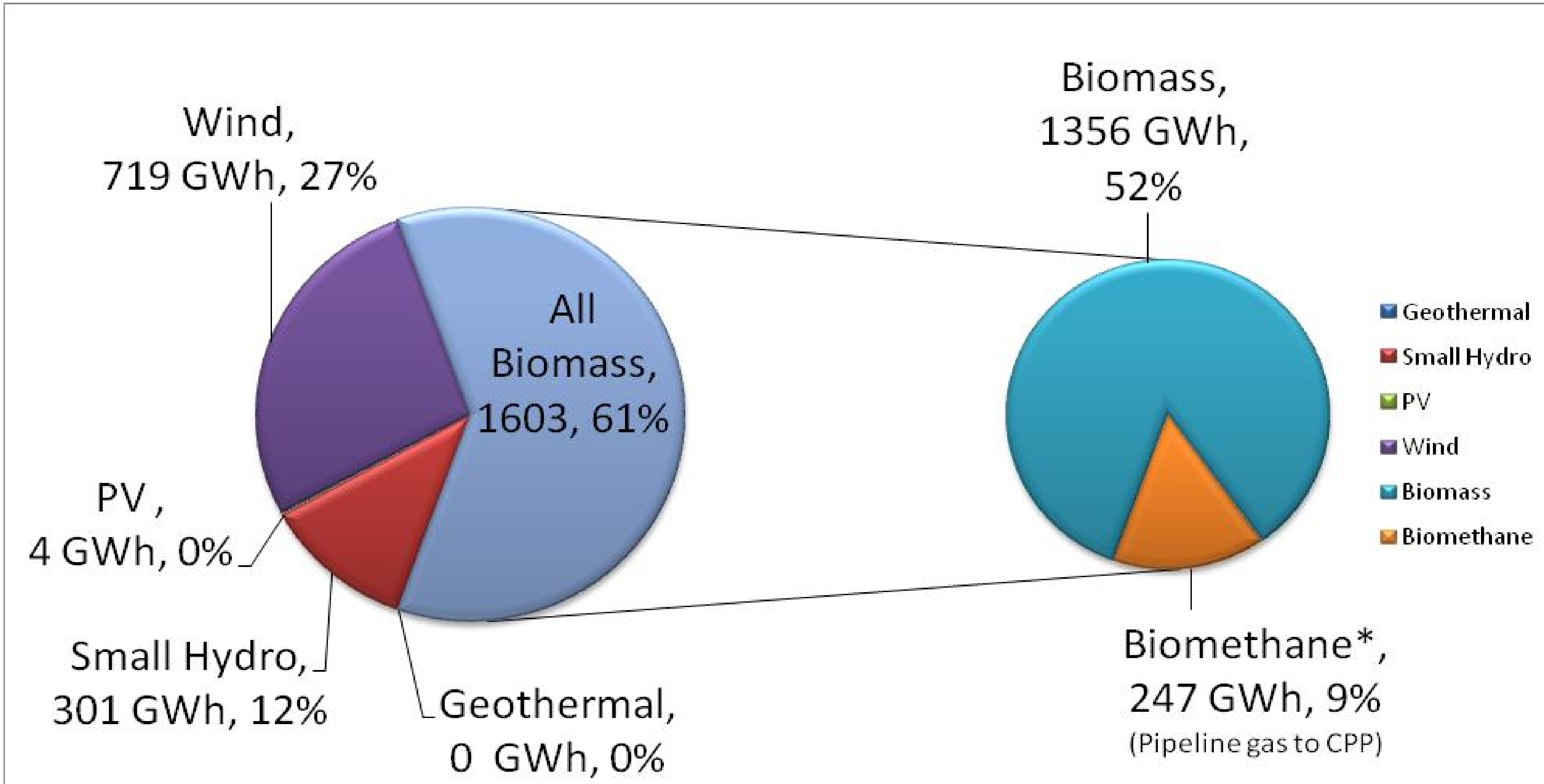
- GHG regulations
  - Reshaping energy supply
- RPS-driven solar energy additions
  - Solar peaks 4-5 hours before utility peak
  - Solar forecasting weak
  - Ramp rates can be significant
  - How much can distribution system take
  - Wind produces in off-peak periods

SMUD Board Policy

Sustainable Power Supply reduces SMUD's long-term **greenhouse gas emissions from generation of electricity to 10% of its 1990 carbon dioxide emission levels by 2050** (<350,000 metric tonnes/year), while **assuring reliability of the system; minimizing environmental impacts** on land, habitat, water quality, and air quality; and **maintaining a competitive position** relative to other California electricity providers.



SMUD Reached 24% in 2010!
(2,600 GWh)



2010 Total GWh ~ 11,000 for all sources

Renewable Energy Programs

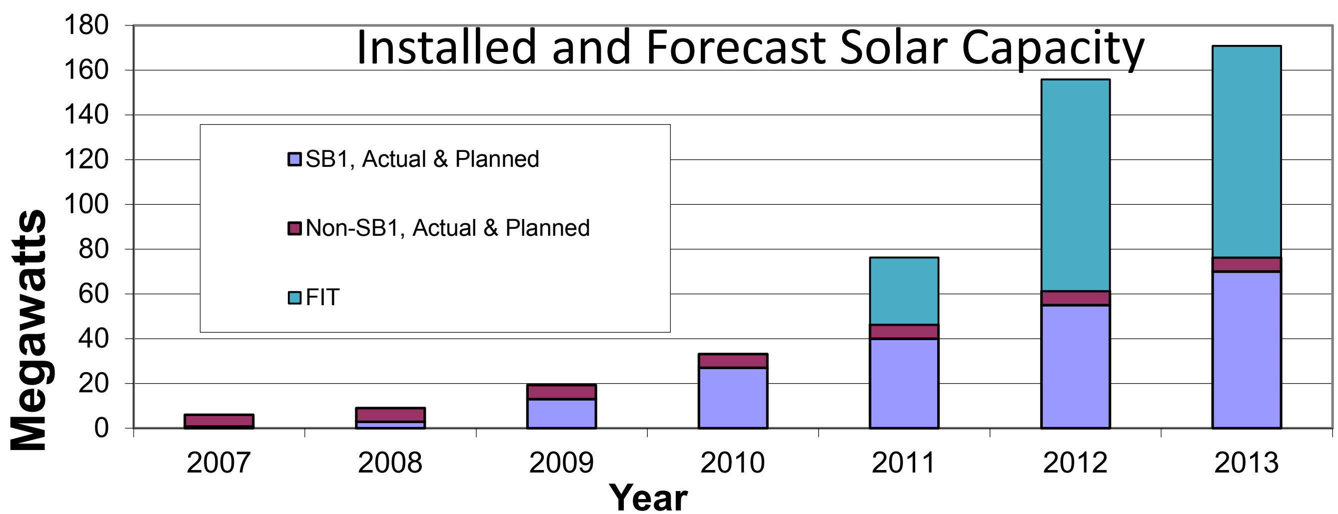
- Utility Solar since 1981
  - 1 MW installation at Rancho Seco began operation in 1984
  - Still operating!
- Solano Wind Project – late 80's
- Solar Pioneer Program – mid-90's
- Green Pricing (Greenergy) – 1997
- SMUD RPS Adopted in 2001 (10% in 2006; 20% in 2011)
- Local Biomass Program – 2004
- CSI - 2007; Solar Shares – 2008
- 100 MW FIT in 2009

SMUD Local Renewables

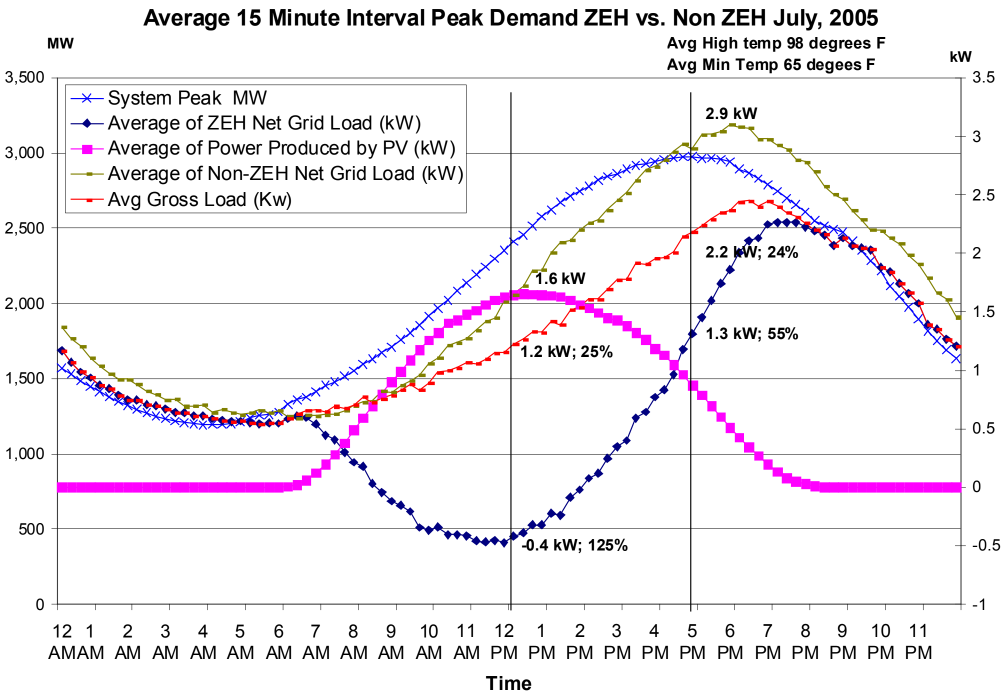
- Limited to Biomass and Solar
  - Solano Wind (233 MW) outside territory
  - Biomass = 81 MW; Solar = 3600 MW (only portion of unshaded rooftops + 13 disturbed land sites)
  - All other Renewables need Transmission!

	2010	2010	2020	2020
Conversion Pathway	Gross Potential (MW)	Technical Potential (MW)	Gross Potential (MW)	Technical Potential (MW)
Thermochemical	200	61	259	69
Biochemical	26	11	28	12
Total MW	226	72	287	81

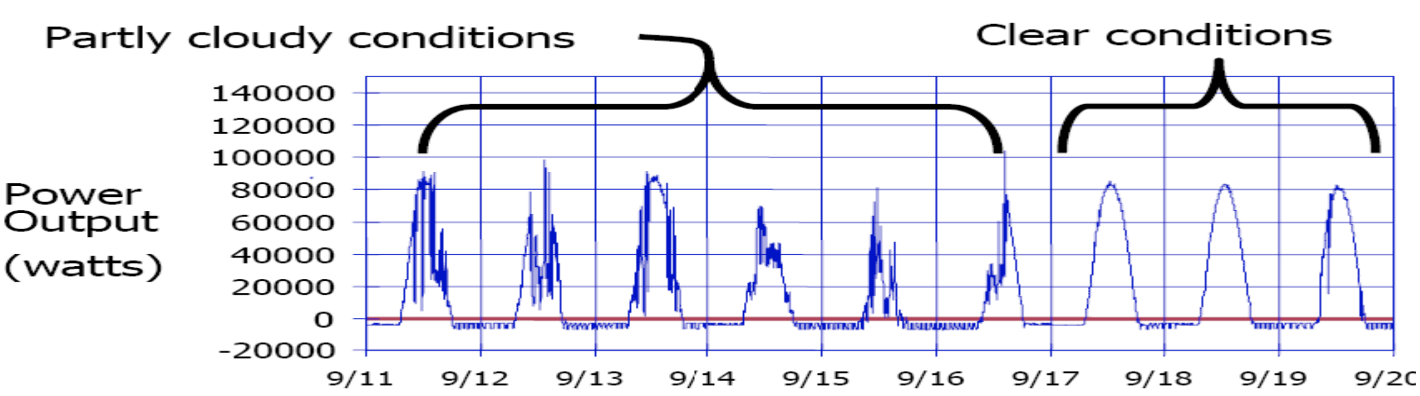
Solar Energy Growth at SMUD



PV Issues For SMUD



- PV coupled with high efficiency measures can reduce home peak load by 55%
- Significant shift still between solar peak and system peak
- Intermittent production resulting from party cloudy conditions

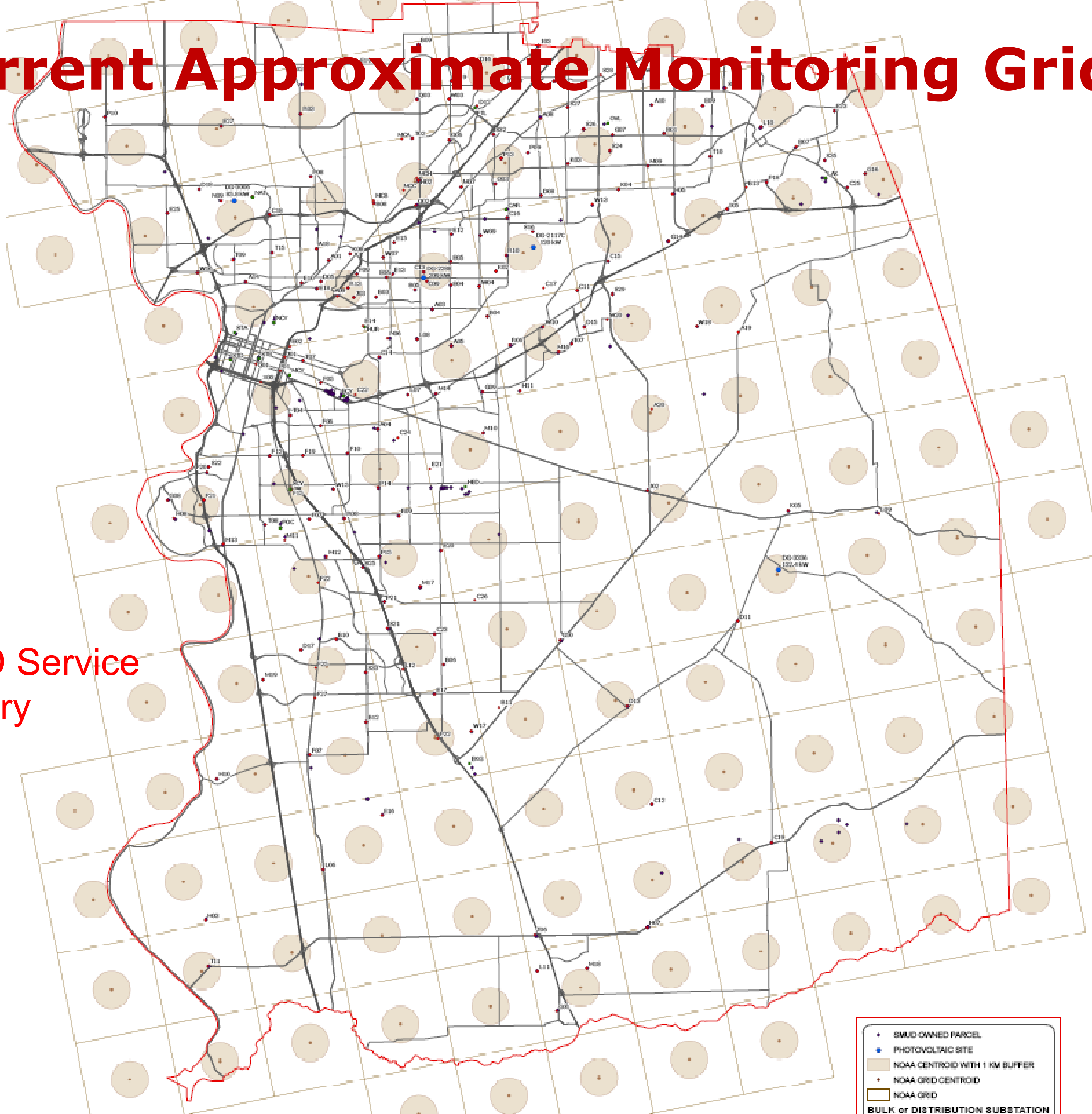


Importance of Variability

- Resource analysis shows that up to 50% of a large PV system output can be lost in 1 minute
- With 250 MW of PV, loss of 125 MW in 1 minute would exceed SMUD's contingency requirements
- Minute to minute load fluctuations at SMUD are much smaller ~10-20 MW
- Correlation of dispersed large systems currently not well known

Current Approximate Monitoring Grid

SMUD Service Territory

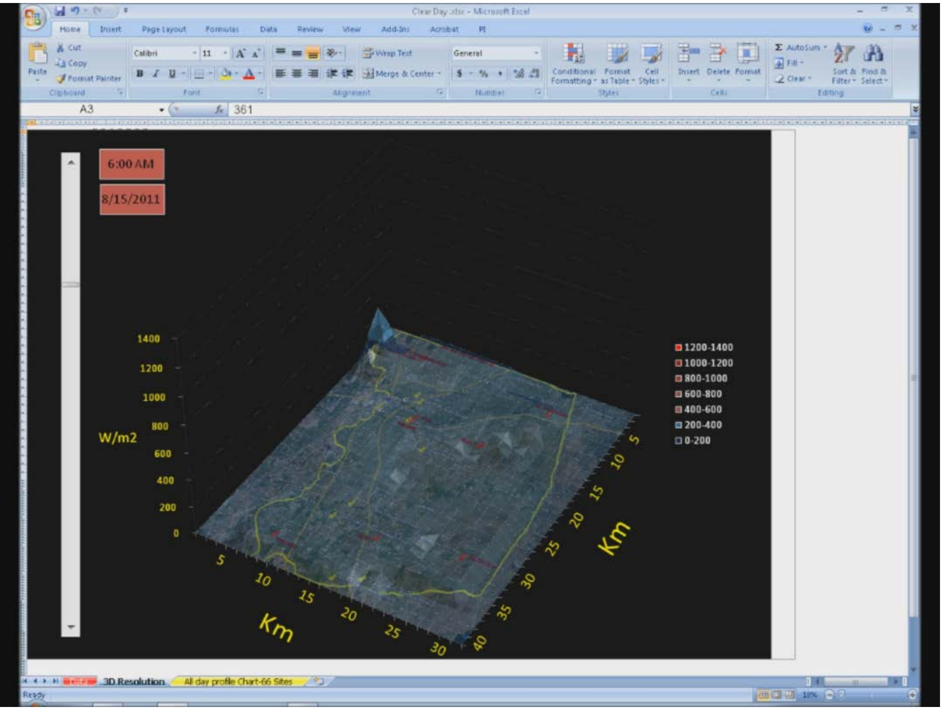


Use for Solar Resource Dataset

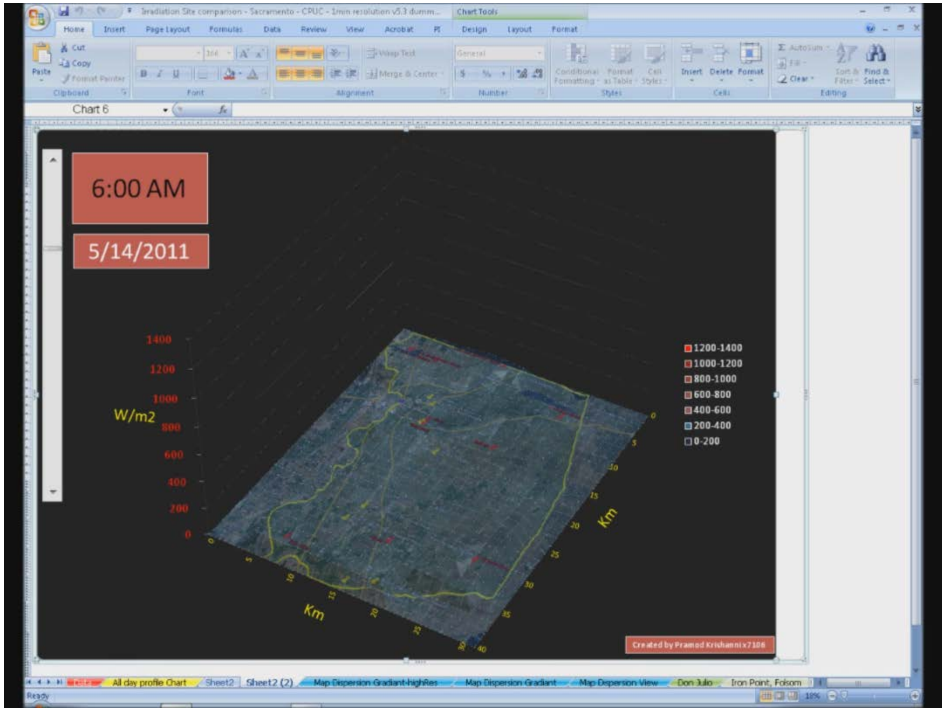
- Goal to validate and improve several different forecasting approaches for Sacramento and solar industry
- Provide feedback to NOAA on performance of NDFD for solar forecast purposes
- Understand need for any additional load following, regulation, storage resources
- Identify optimal PV plant sizing and distribution to minimize need for backup resources

Resource Variability Impact

Clear Day – 8/15/11



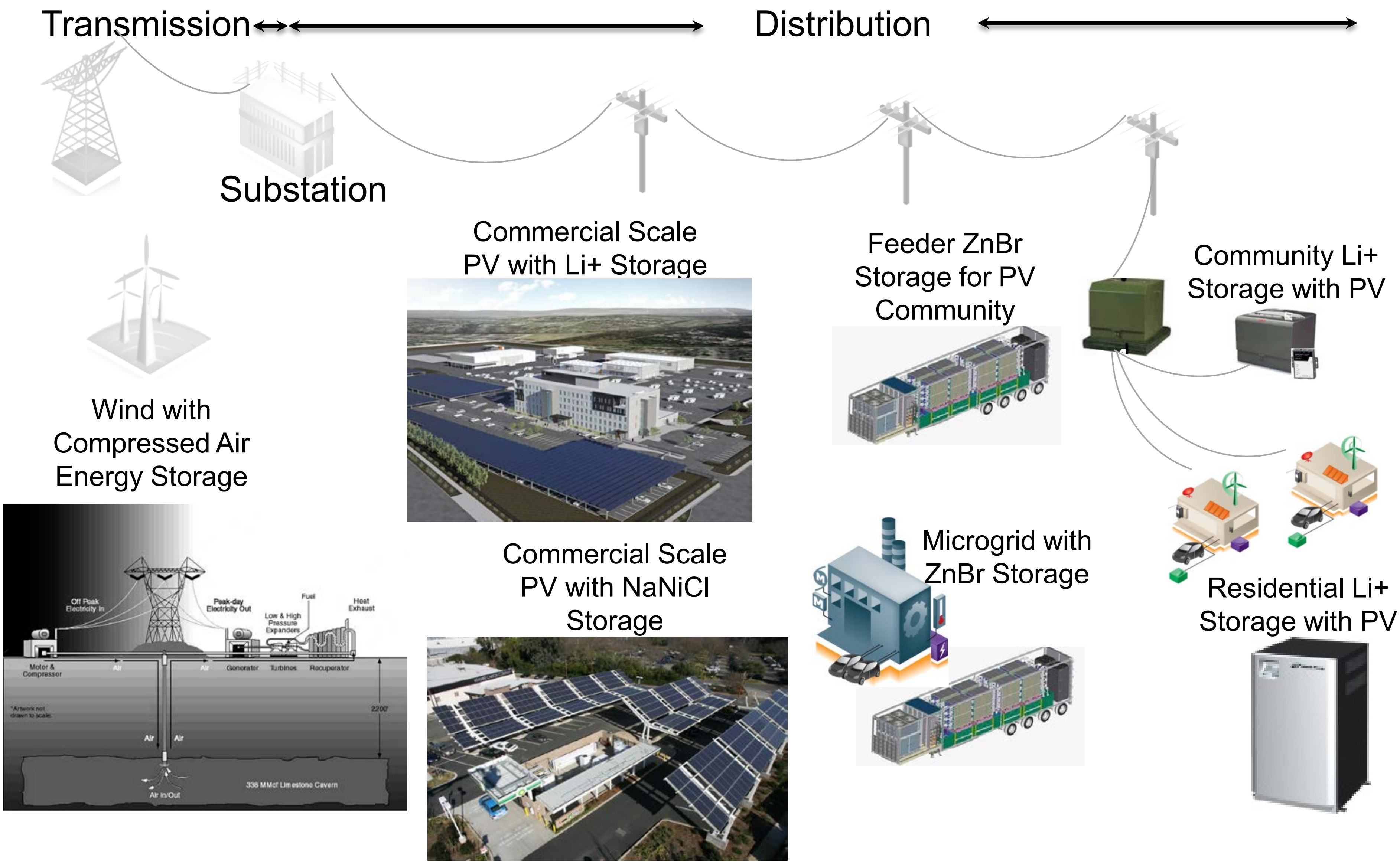
Variable Day – 5/14/11



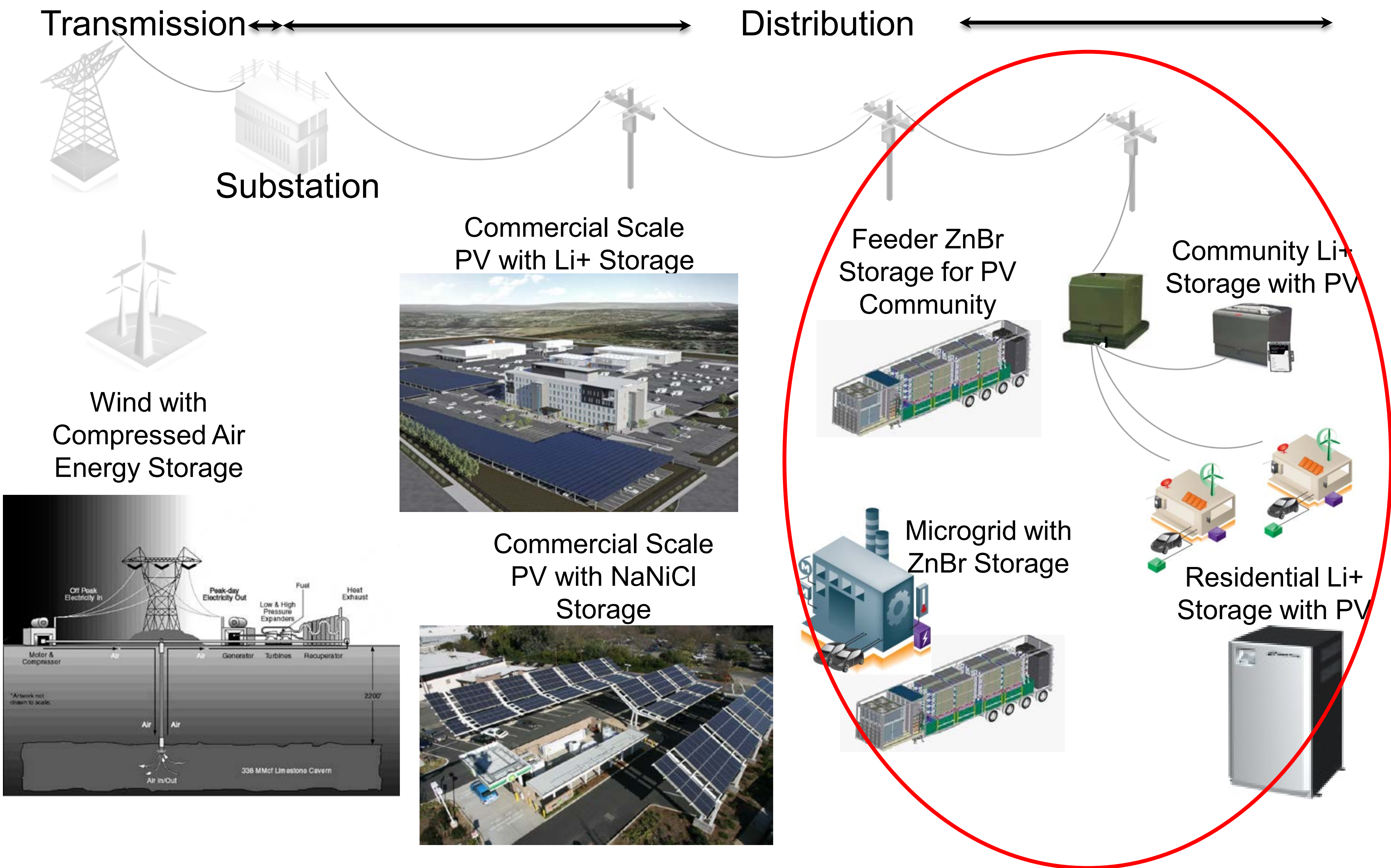
Storage Could Be Mitigation Strategy For High Penetrations Of PV and Wind

- Believe SMUD will need bulk **and** distributed storage in long run
- Questions of what kind, how much of it and when, and how much will it cost
- Pursuing a multi-pronged approach:
  - — Developing improved understanding of storage technologies
  - — Determining the benefits of distributed storage to SMUD
    - Modeling and analytical work – assess the value of different storage technologies deployed at high value sites on the T&D system
  - — Conducting some distributed storage system demonstrations, monitoring performance and cost effectiveness
  - — Preparing SMUD for energy storage utilization and AB2514 Procurement Plan

SMUD Storage Portfolio



SMUD Storage Portfolio



SMUD PV & Smart Grid Pilot at Anatolia

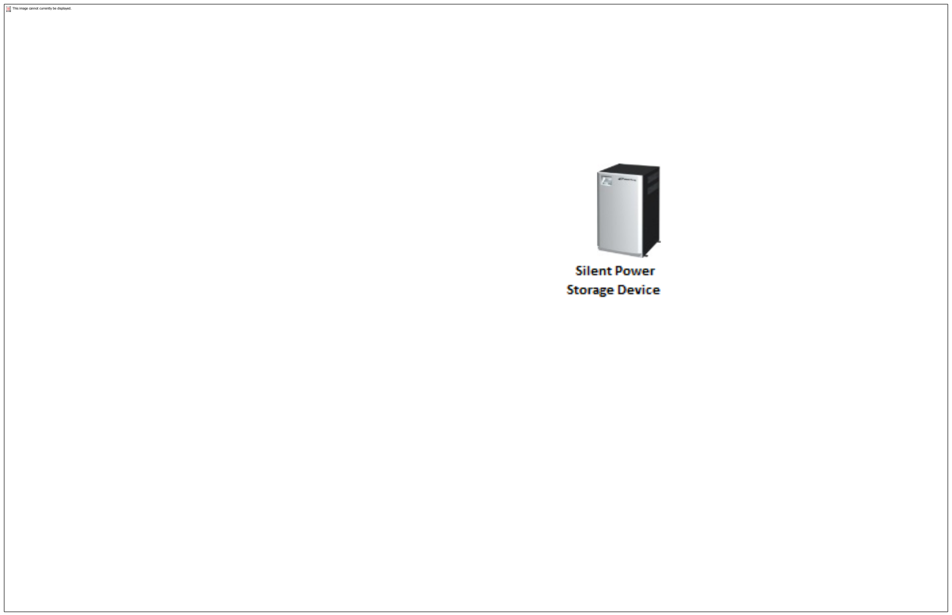
DOE ARRA FOA 85 Topic 4: High Penetration Solar Development

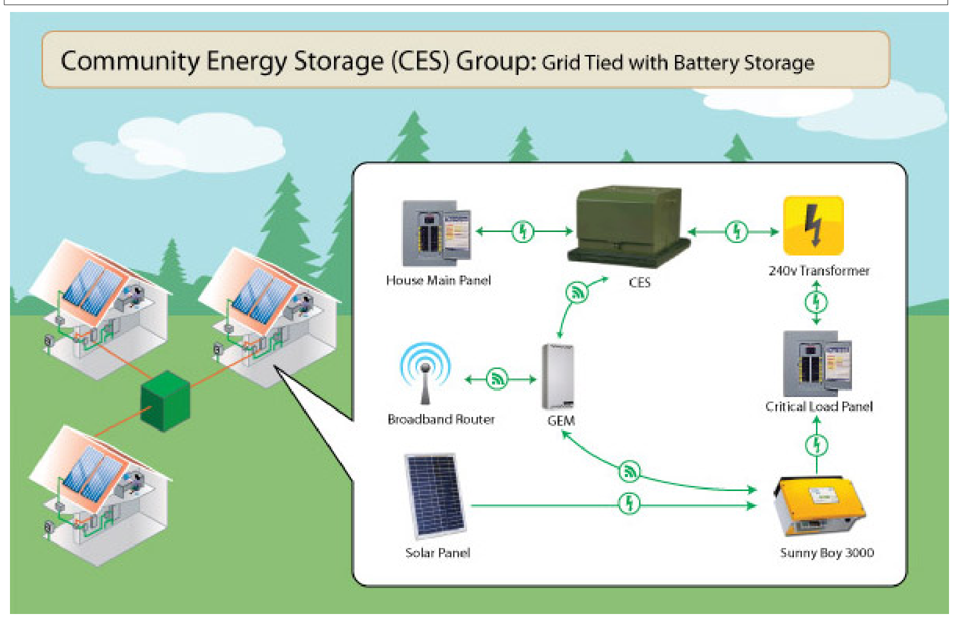
SMUD Solar Smart[SM] Homes

Acknowledgement: This material is based upon work supported by the Department of Energy under Award Number DE-EE0002066.

SMUD PV & Smart Grid Pilot at Anatolia

ARRA FOA 85 Topic 4: High Penetration Solar Development





- $5.9M Project ($4.3M DOE)
- Anatolia SolarSmart^{SM} Homes Community
  - High building efficiency measures
  - 2kW PV systems
- Installing 15 RES (7.8kW/8.8kWh) and 3 CES (30kW/30kWh)
- Will firm renewables, reduce peak load, regulate voltage and improve reliability
- Partners include GridPoint, SunPower, Navigant, NREL, SAFT (lithium ion)
- Installing utility and customer portals to monitor PV, storage, customer load
- Sending price signals to affect changes in customer usage
- Quantifying costs and benefits of this storage deployment to gain insights to broader application for SMUD

Strategic Objectives and Research Questions

Strategic Objective 1	**Understand how the integration of energy storage could enhance the value of distributed PV resources within the community**
Key Research Questions	• Does the location of energy storage significantly change the utility's ability to "firm" customer load and distributed PV capacity? • How much storage is necessary to accomplish the desired PV and load firming effects? • Can an integrated PV/energy storage system provide service reliability benefits for customers?
Strategic Objective 2	**Determine if the addition of energy storage could add value for the utility**
Key Research Questions	• Can energy storage in a high penetration solar deployment help support SMUD's "super-peak" from 4 PM to 7 PM, particularly when PV output drops off after 5PM? • Does the location of energy storage significantly affect the ability of the utility to manage the resource? • How variable is PV output within a community or distribution feeder, and what is the potential operating impact for the utility?

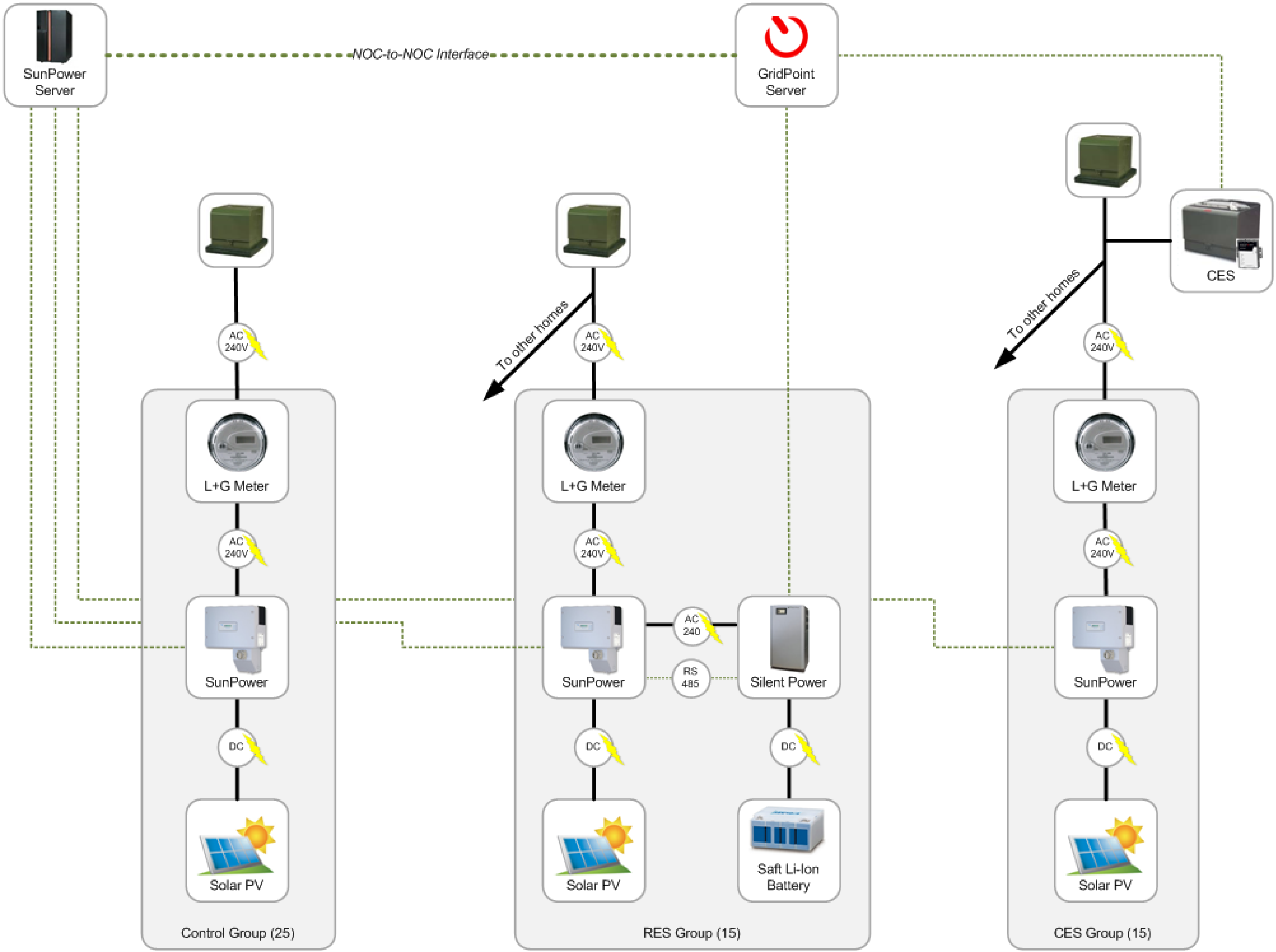
Strategic Objectives and Research Questions

Strategic Objective 3	**Determine how to leverage SMUD's AMI investment to manage a distributed PV/energy storage resource**
Key Research Questions	• Can a smart meter be used to monitor and control a PV system, and to what extent? • What are the practical challenges associated with using AMI for managing PV? • What are the technical requirements for integrating inverters and smart meters, and what codes, standards and reference designs must be developed?
Strategic Objective 4	**Determine if capacity firming and advanced pricing signals will influence the energy usage behaviors of customers**
Key Research Questions	• Do the customers who have capacity firming capability (energy storage) behave differently than those who do not? • Do the customers with the RES behave differently than those with CES? • How does energy storage impact the customer's ability/desire to respond to pricing signals?

Overview of Hardware Solution

- 55 to 65 homes total
- Control group (25 homes)
  - 2kW residential PV with inverter (existing SunPower PV)
  - NOC-to-NOC integration with SunPower provides PV and whole-house data for energy management portal
- Residential Energy Storage (RES) group (15 homes)
  - Same as control group, plus:
  - Silent Power OnDemand storage appliance (5 kW/8.8 kWh)
- Community Energy Storage (CES) group (3 units; 15-25 homes)
  - Same as control group, plus:
  - PowerHub CES system (30 kW/30 kWh)

Overview of Hardware Solution



Use Cases and Benefits

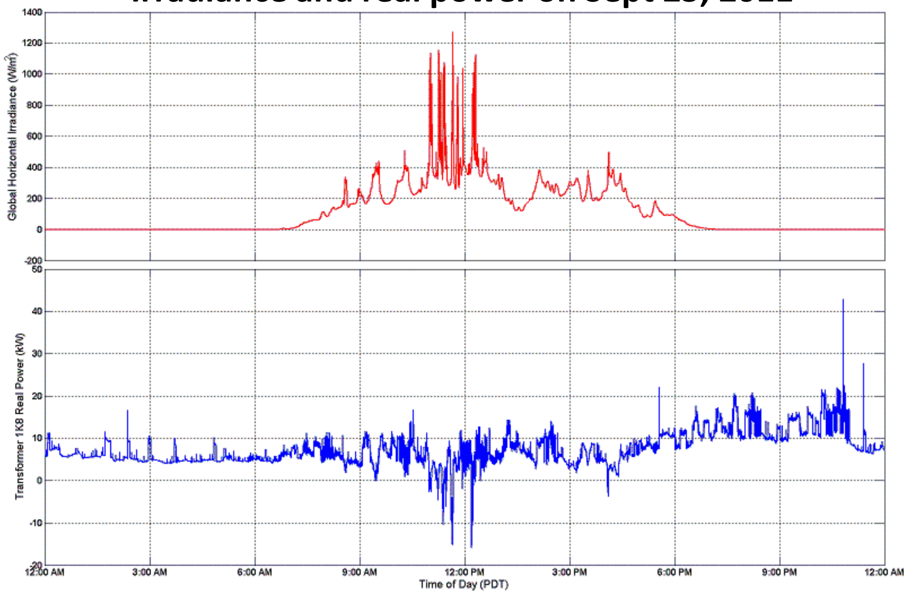
Application	Benefit	Approach
Time-Of-Use Energy Cost Management	Reduced electricity losses (utility/rate payer)	Reduce grid load during high cost time-of-use daily
	Reduced electricity cost (consumer)	
Peak Load Reduction	Reduced electricity losses (utility/rate payer)	Forecast day-ahead load shifting requirements based upon historical load, weather, PV output, etc. and optimize storage dispatch to shave peak load
	Reduced electricity cost (utility)	
Voltage Support	Reduced electricity losses (utility/rate payer)	Using feeder and transformer monitoring voltages, dispatch storage to maintain voltage within set limits
Phase Balancing	Reduced electricity losses (utility/rate payer)	Using feeder and transformer monitoring voltages, demonstrate ability to change loading on a particular phase
Renewables Capacity Firming	Reduced CO_2 Emissions (society)	Using SCADA to monitor feeder output during net excess PV output, and local solar irradiance to estimate diminished PV output, vary energy storage discharge to firm PV generated power
	Reduced SO_x, NO_x, PM-2.5 Emissions (society)	
Renewables Energy Time Shift	Reduced CO_2 Emissions (society)	Charge energy storage with PV power during times of excess output, then discharge energy storage later for peak shaving on the distribution system
	Reduced SO_x, NO_x, PM-2.5 Emissions (society)	

NREL Transformer Monitoring

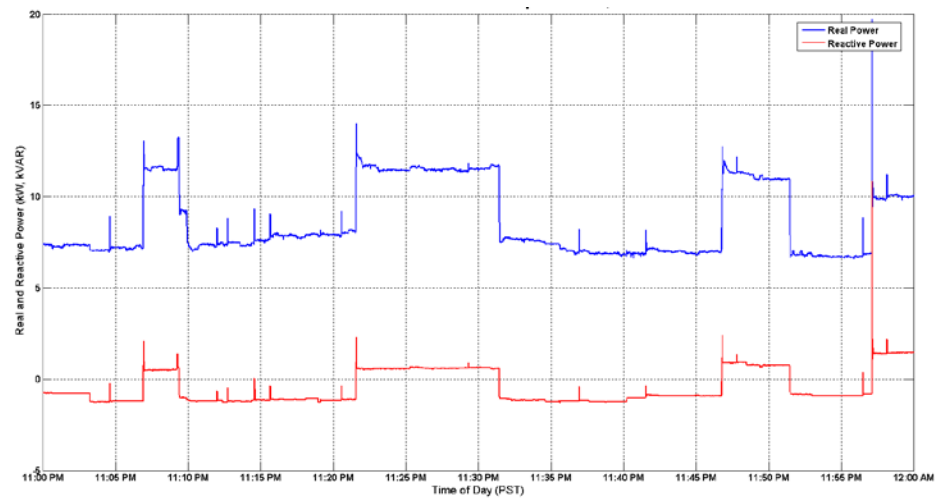
- Twelve Distribution Monitoring Units (DMU) installed at 50 and 75kVA transformers are collecting 1 second data
  - Custom built with off-shelf hardware
  - Timing and location accuracy via GPS receiver
  - Real-time measurements transmitted via cellular modem
  - Uses phasor calculations similar to PMUs
  - Communicates using IEEE Std. C37.118 for synchrophasors
  - Voltage channels sample two 120V legs and neutral of transformer
  - Current measured on each 120V leg and neutral
  - Output includes RMS and phasor info for all sampled wave forms
  - Includes frequency of secondary voltage
  - Apparent, real and reactive power flows are calculated
  - Power factor and displacement power factor derived from power and phasor values
  - Includes PQ calculations
  - Internal DMU and external transformer temperature monitored

NREL Transformer Monitoring

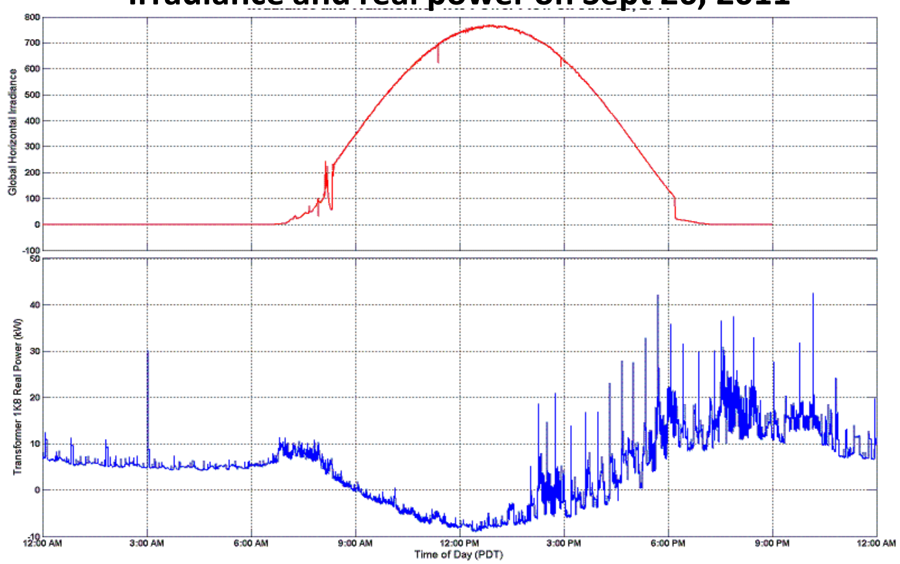
Irradiance and real power on Sept 25, 2011



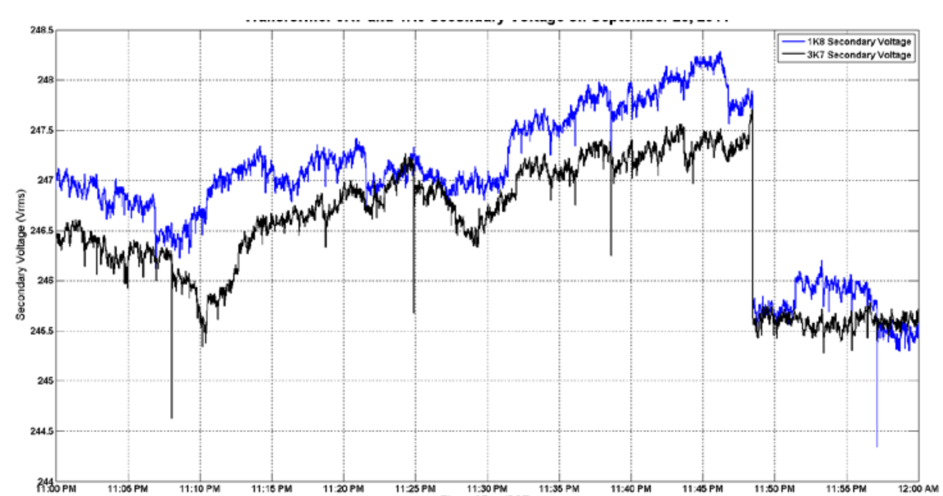
Transformer load, 11:00 PM to 12:00 AM on Sept 26, 2011



Irradiance and real power on Sept 26, 2011



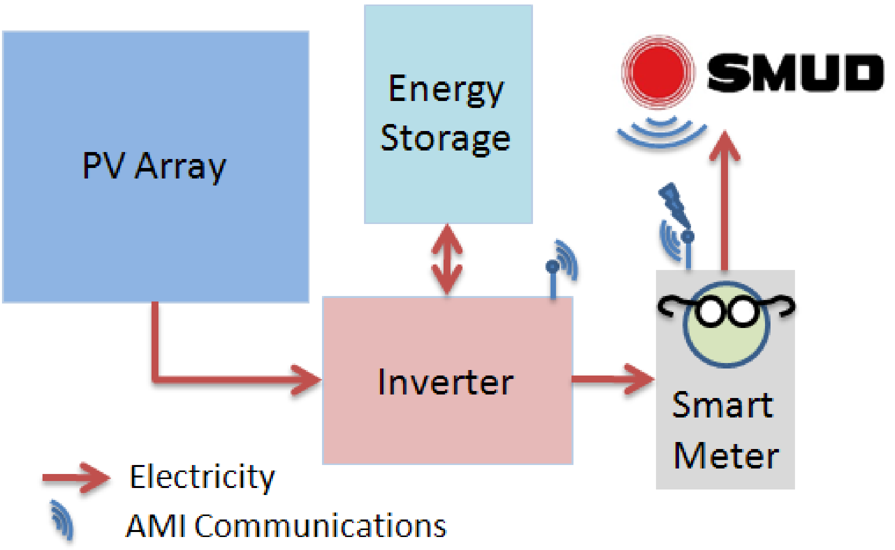
Two different transformer voltages on Sept 26, 2011



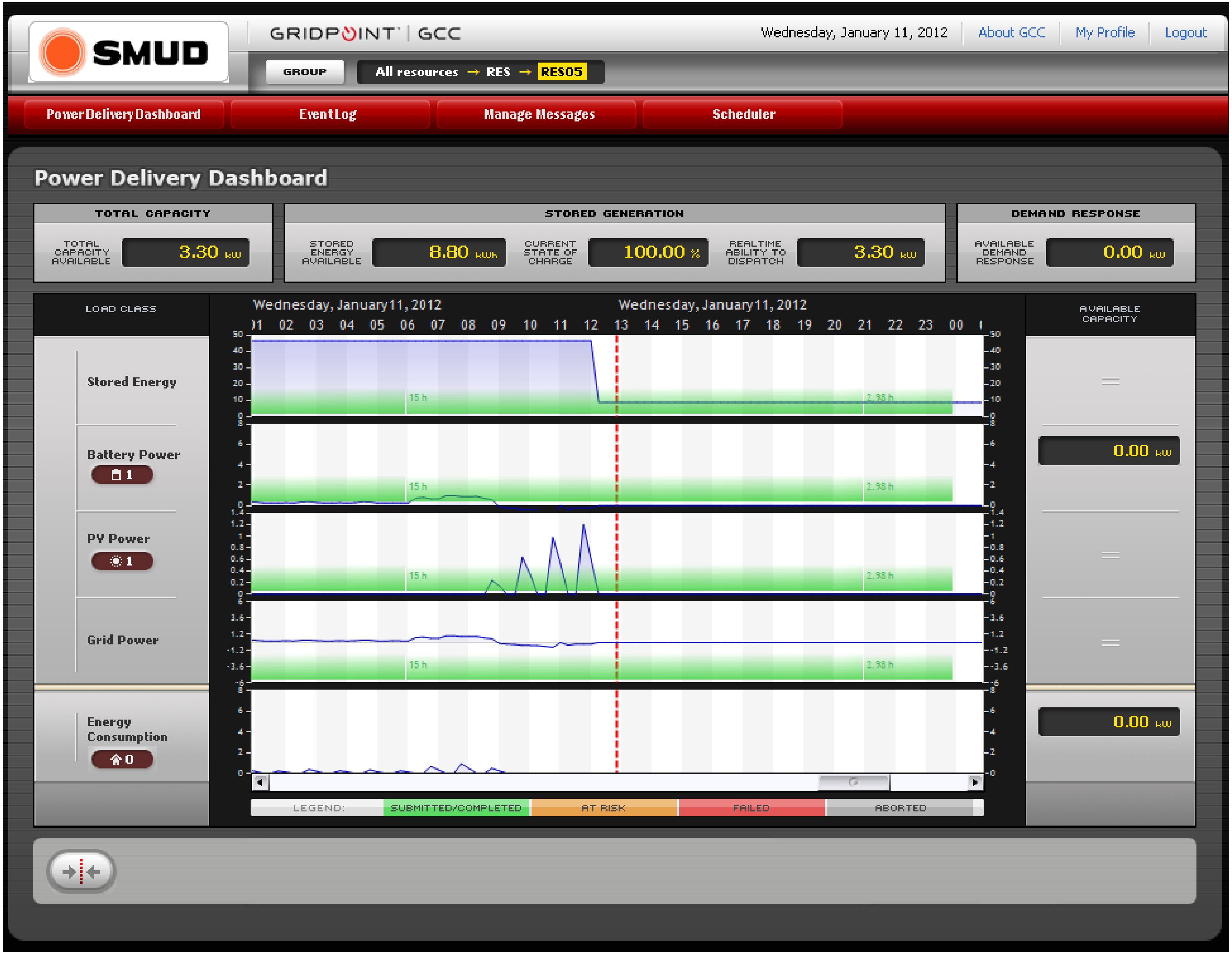
AMI Inverter Communication and Control

Inverter Communications

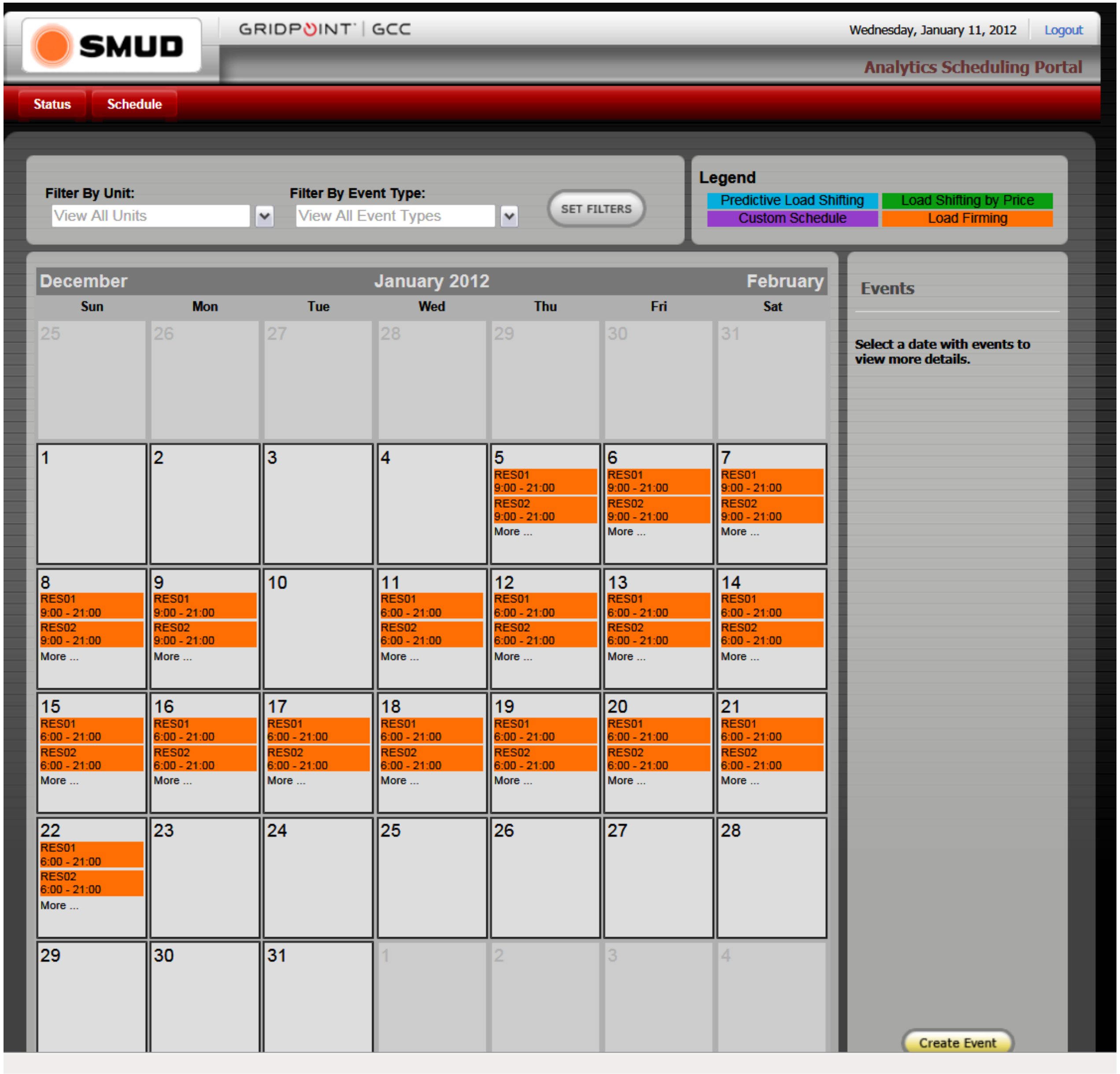
- Demonstrate inverter monitoring via AMI communication from smart meter to inverter
- Demonstrate receiving data, querying for faults, sending control signals
- Vision – use as actively controlled contributors versus passive devices on the grid



Utility Operator Portal – Power Delivery Dashboard



Utility Operator Portal – Scheduler



Progress To Date

- RES sites recruited and participant contracts signed
- RES units received UL Listing
- Fire Service trained on RES technology and emergency response guidelines
- CES sites recruited and contracts signed
- 15 of 15 RES installed and commissioned
- 3 of 3 CES sites prepared for installation
- Testing of CES units underway at NREL
- Home Energy Management Portal launched
- Utility Portal operational
- NREL transformer monitoring installed
- Active Monitoring underway
- Beginning testing of use cases

Lessons Learned

- Allow more time for UL listing and integration testing
- Important to educate building permitting officials and fire service on these technologies
- Close frequent customer contact is essential to success and incentives need to be robust to attract participation
- High resolution data acquisition will be the best of its kind - PV generation, storage, transformers, distribution feeder and solar meteorology
- Ample business case assessment opportunities
  - Rates, types of storage, applications, etc.

Challenges

- Technical efforts more complex than expected
- More time required to coordinate and resolve issues
- More time required to negotiate contracts
- Marketing for CES customers was difficult
- Data acquisition was more complex than expected with disparate systems integrated
- Troubleshooting as a result can be more complex than expected
- Application of Time of Use rates has been a challenge when coupling energy storage and PV

Storage for Grid Support

DOE ARRA FOA 36 Topic 3.6: Grid Support Storage Demonstrations Grant

Premium Power Corporation's TransFlow 2000
500-kW/6-hour zinc bromide flow-battery energy storage system

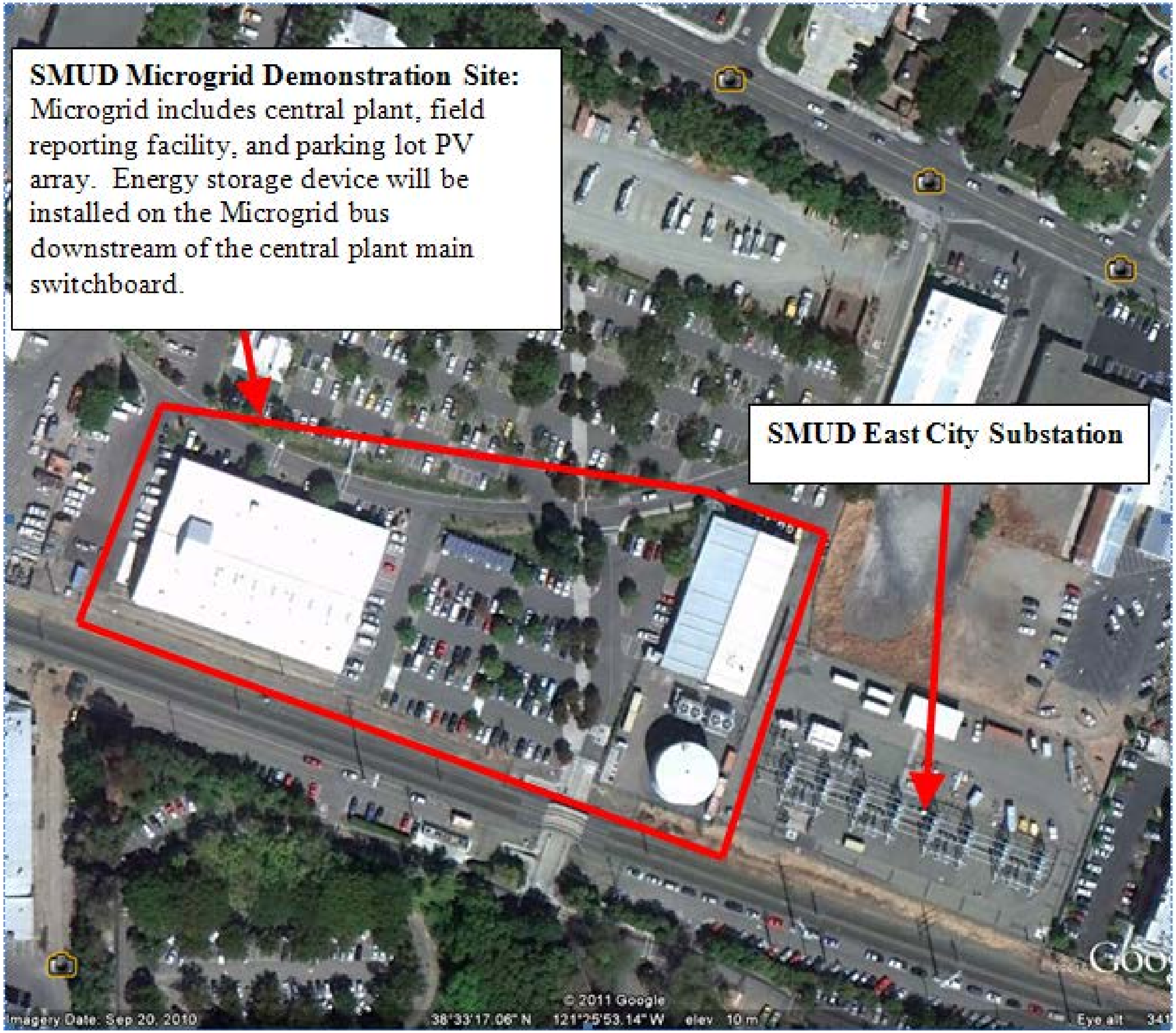
Acknowledgement: This material is based upon work supported by the Department of Energy under Award Number DE-OE0000224.

Storage for Grid Support

DOE ARRA FOA 36 Topic 3.6: Grid Support Storage Demonstrations Grant

- $12M project ($6M DOE)
- Partners are Premium Power, National Grid, SAIC, NREL, Syracuse University
- SMUD installing two Premium Power 500kW/6 hours flow battery systems
- Will firm renewables, reduce peak load and cost to serve peak, and improve reliability
- Operating as a fleet of distribution assets
- Quantifying costs and benefits of this storage deployment to gain insights to broader application for SMUD

SMUD Microgrid Site

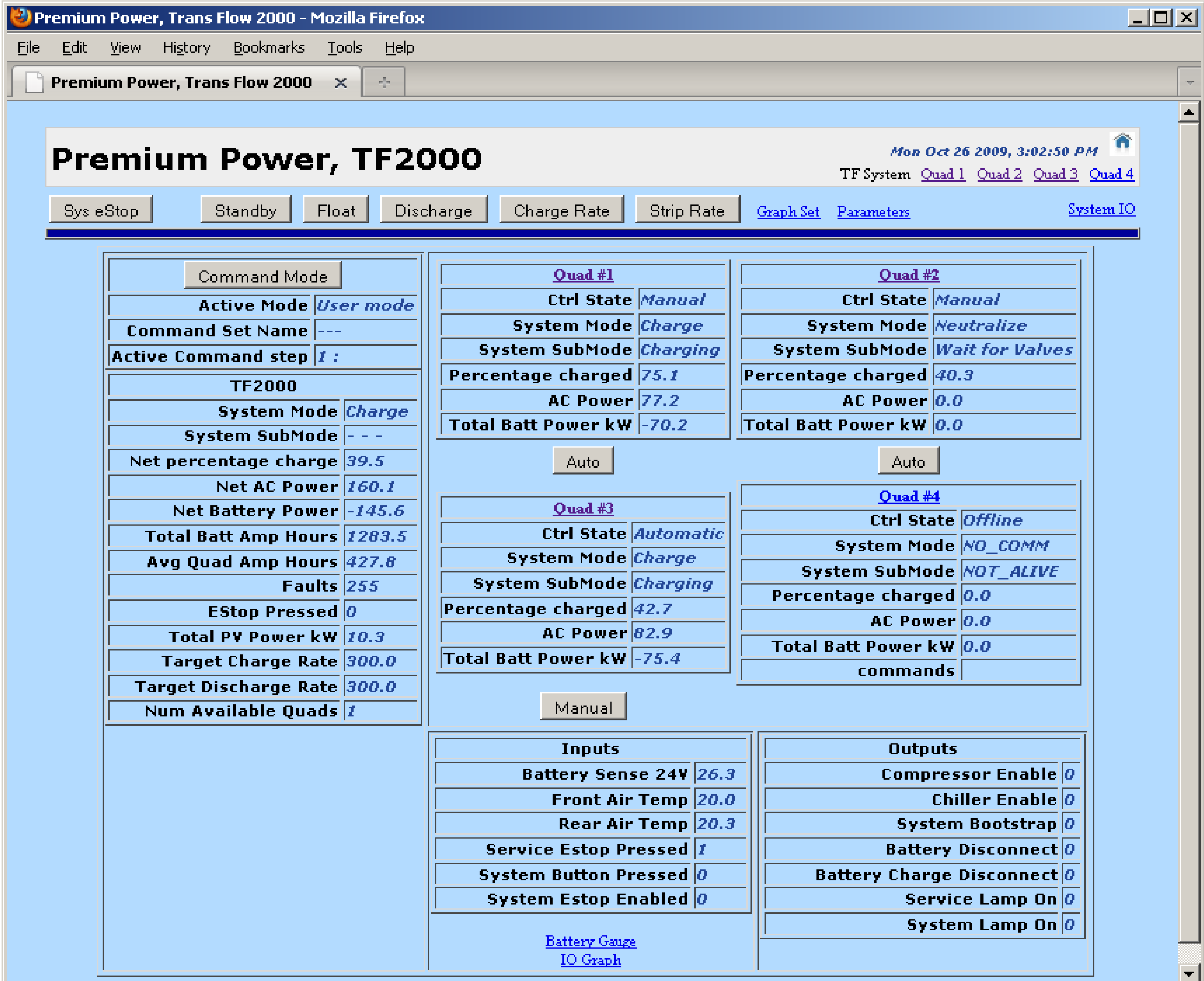


SMUD Anatolia Site

Use Cases and Benefits

Site	Application	Benefit	Approach
SMUD HQ	Demand Charge Management	Reduced electricity losses (utility/rate payer)	When grid connected, peak shaving to reduce monthly demand peak customer charges
		Reduced electricity cost (consumer)	
	Time-Of-Use Energy Cost Management	Reduced electricity losses (utility/rate payer)	When grid connected, reduce grid load during high cost time-of-use daily
		Reduced electricity cost (consumer)	
	Voltage Support	Reduced electricity losses (utility/rate payer)	For microgrid islanding, use existing Building Management System to monitor system voltages, and to dispatch energy storage to maintain voltage within set limits
	Electric Service Reliability	Reduced sustained outages (consumer)	For system outage events, provide uninterrupted service by switching to microgrid islanding with power from energy storage
		Reduced momentary outages (consumer)	
SMUD Anatolia	Renewables Capacity Firming	Reduced CO_2 Emissions (society)	Using SCADA to monitor feeder output during net excess PV output, and local solar irradiance to estimate diminished PV output, vary energy storage discharge to firm PV generated power
		Reduced SO_x, NO_x, PM-2.5 Emissions (society)	
	Renewables Energy Time Shift	Reduced CO_2 Emissions (society)	Charge energy storage with PV power during times of excess output, then discharge energy storage later for peak shaving on the distribution system
		Reduced SO_x, NO_x, PM-2.5 Emissions (society)	
	Voltage Support	Reduced electricity losses (utility/rate payer)	When connected to the grid, voltage to be monitored by SCADA, and energy storage dispatched to ensure system voltages remain within established limits

Operator Portal – PPC Dashboard



Progress To Date

- Completed site design and infrastructure improvements necessary to site the Transflow 2000
- Gained DOE approval of our cyber security plan
- Defined use cases and data collection plan for monitoring performance
- Will begin operator training using a simulator in late Q1 2012
- Will install units in Q2 2012
- Will collect performance data through 2014

Summary

- GHG and renewables driving SMUD to consider storage, microgrids, advanced inverters, etc.
- R&D helping SMUD and customers to understand:
  - Value proposition
  - Grid integration issues
  - Realistic applications
  - Technology performance – reliability, life, durability and cost

Near Term Integration Issues – Distribution System

- Evaluating impact of variable solar resource on distribution feeder voltage levels
- Validation of caps on capacity on feeders at 100% of minimum daytime load
- Identification and testing of appropriate mitigation strategies to accommodate higher penetrations on feeders (e.g., curtailment via SmartGrid, advanced inverters, storage)
- Identification of priority areas and limits for PV on our distribution system

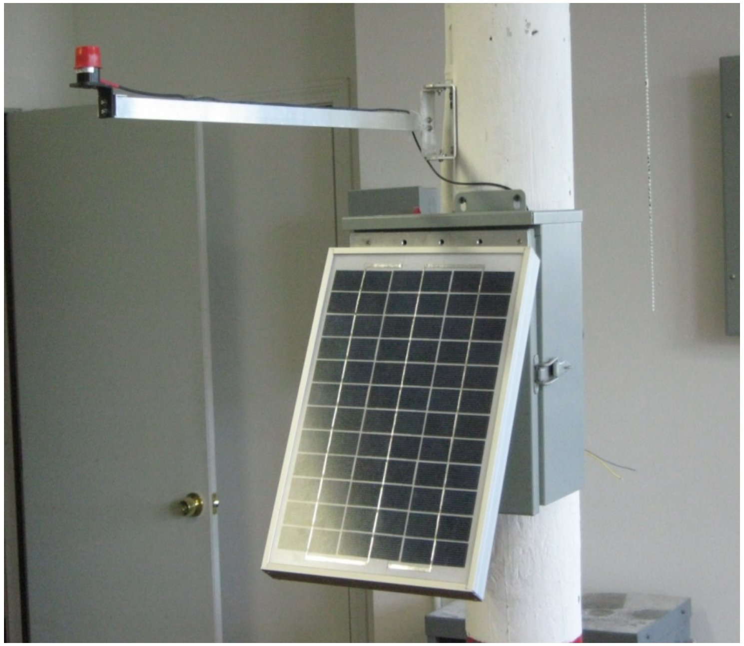
Medium-Term Integration Issues – Bulk Power System

- Evaluation of variability impacts on regulation requirements
- Evaluation of forecasting error impacts on ancillary services requirements and associated costs
- Redesign of distribution system as a supply source to bulk power system

Issues & Need for R&D

- R&D provides advancements such as:
  - New Knowledge (variability, feeder penetration limits, hi-penetration impacts, etc.)
  - New Modeling & Simulation Tools
  - New Forecasting Methods
  - New Inverter Technology
  - Integration with Smart Grid (communications & control) and other New Techs (PEVs, DSM, etc.)
  - New, Cost-Competitive Storage Options
  - 21st Century Electricity Distribution System!

High Penetration PV R&D



- $2.2M grant from CPUC CSI R&D (HECO partner) to better understand & develop mitigation strategies for high penetration PV on distribution grid
- Multi-pronged approach
  - High density service territory-wide solar monitoring and forecasting validation
  - Monitoring of high penetration circuits
  - Distribution/Sub-transmission modeling of loads and PV on high penetration circuits, identification of stress points
  - Mapping of high value locations for PV
  - Real-time display of stressed circuits and renewable resource outputs

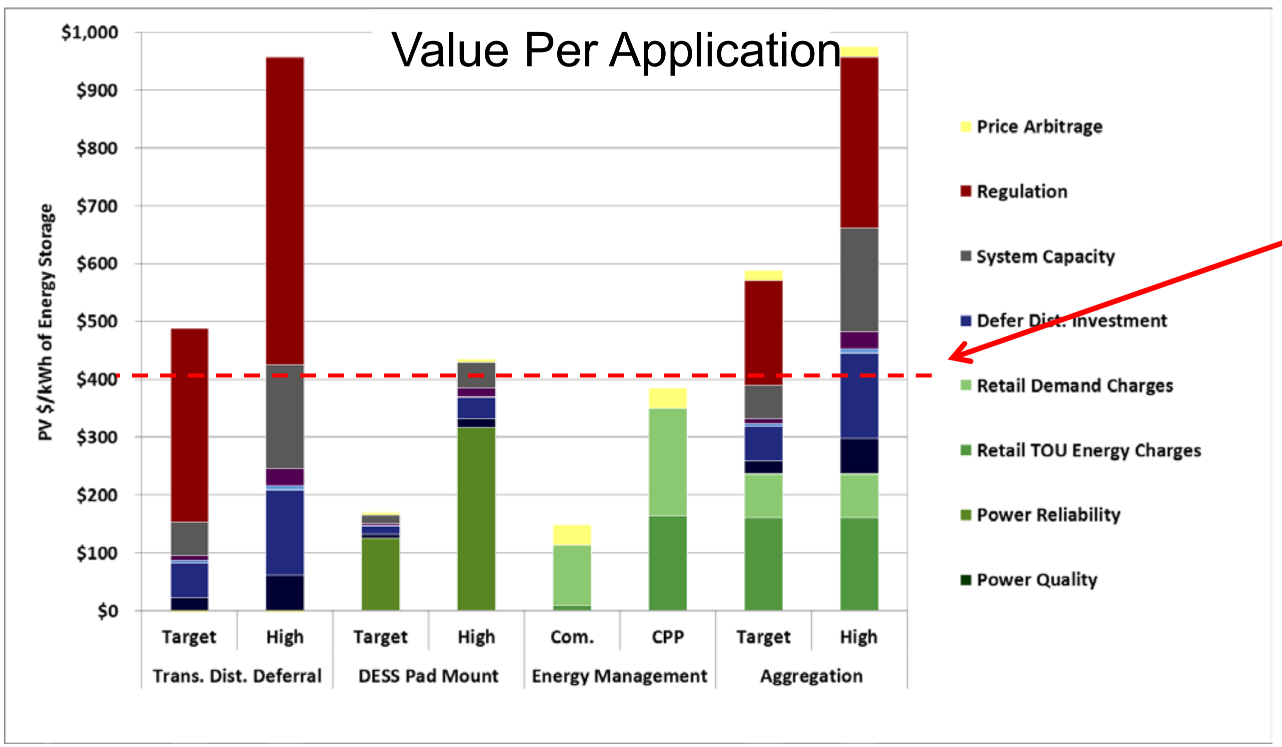
High Density Solar Monitoring and Forecasting

- Working with contractor NEOVirtus Engineering
  - Deploy network of 71 solar monitoring stations across Sacramento on distribution poles and in substations
  - Collect high frequency 1-minute solar resource data (global for 66 stations, global, direct, diffuse for 4 stations)
  - Develop solar forecasting approach using National Weather Service 3 hour forecasts on 5 km grid
  - Validate forecasting approach using solar data for 3 hour ahead and day ahead forecasts

Value of Storage for SMUD

Graphic summarizes present value of different storage applications

- Transportable storage used to defer distribution investments
- Distributed energy storage (DESS) installed adjacent to distribution transformers
- Commercial customer sited storage used to reduce energy costs and demand charges
- Residential and commercial customer sited storage aggregated by a 3rd Party and value sold to utility



- Results — some storage systems could be cost effective for SMUD and SMUD customers at $400/kW-h price point
- Current zinc-bromide flow battery system is within this cost today
- Today though, storage systems remain unproven for life, durability, reliability and cost
  - Current R&D projects are addressing these uncertainties

Source: Energy Storage Benefits for SMUD, EPRI/E3, October 2010 10

Anatolia Project Goals

The Opportunity

Integrating large amounts of distributed renewable energy is critical to California achieving its current Renewable Portfolio Standard target of 33% renewable energy. Moreover, it is increasingly clear that distributed solar PV, both in rooftop and ground- mounted applications, represents the greatest opportunity for implementing distributed renewable energy in California over the next 10 years.

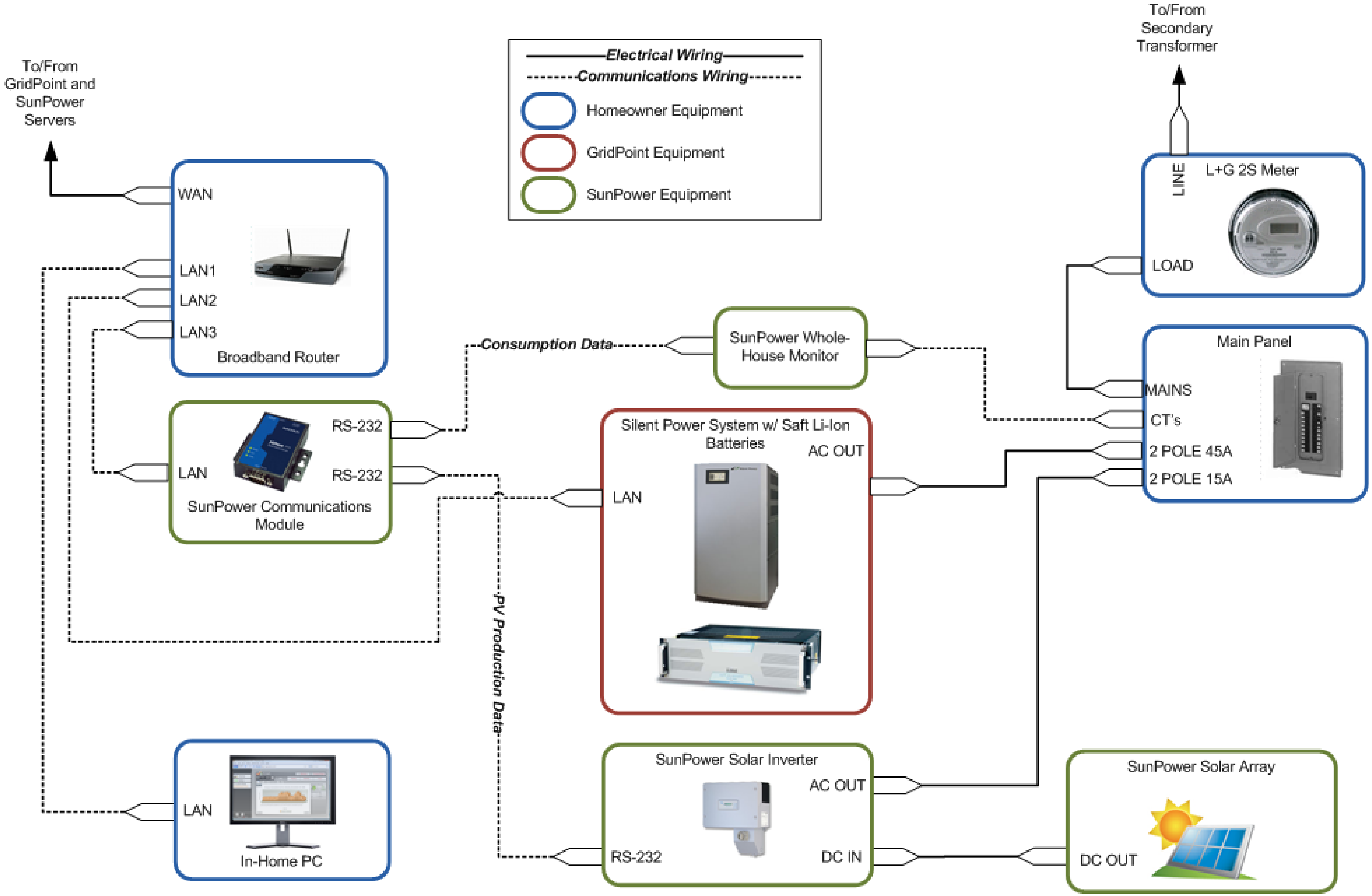
The Challenge

Technical Issue 1: High penetration of grid-connected PV systems cannot be fully integrated into the Smart Grid until there is sufficient two-way communication and control capability between the utility and PV inverters.

Technical Issue 2: The production characteristics of distributed PV in a high penetration scenario have not been sufficiently tested, and utilities have not been able to develop adequate models and forecasting techniques with which to consider distributed PV as a grid resource.

Technical Issue 3: While energy storage is seen as a potential solution for "firming" the variable output of PV, there is a lack of experimental data to show how effective storage might be for overcoming these problems.

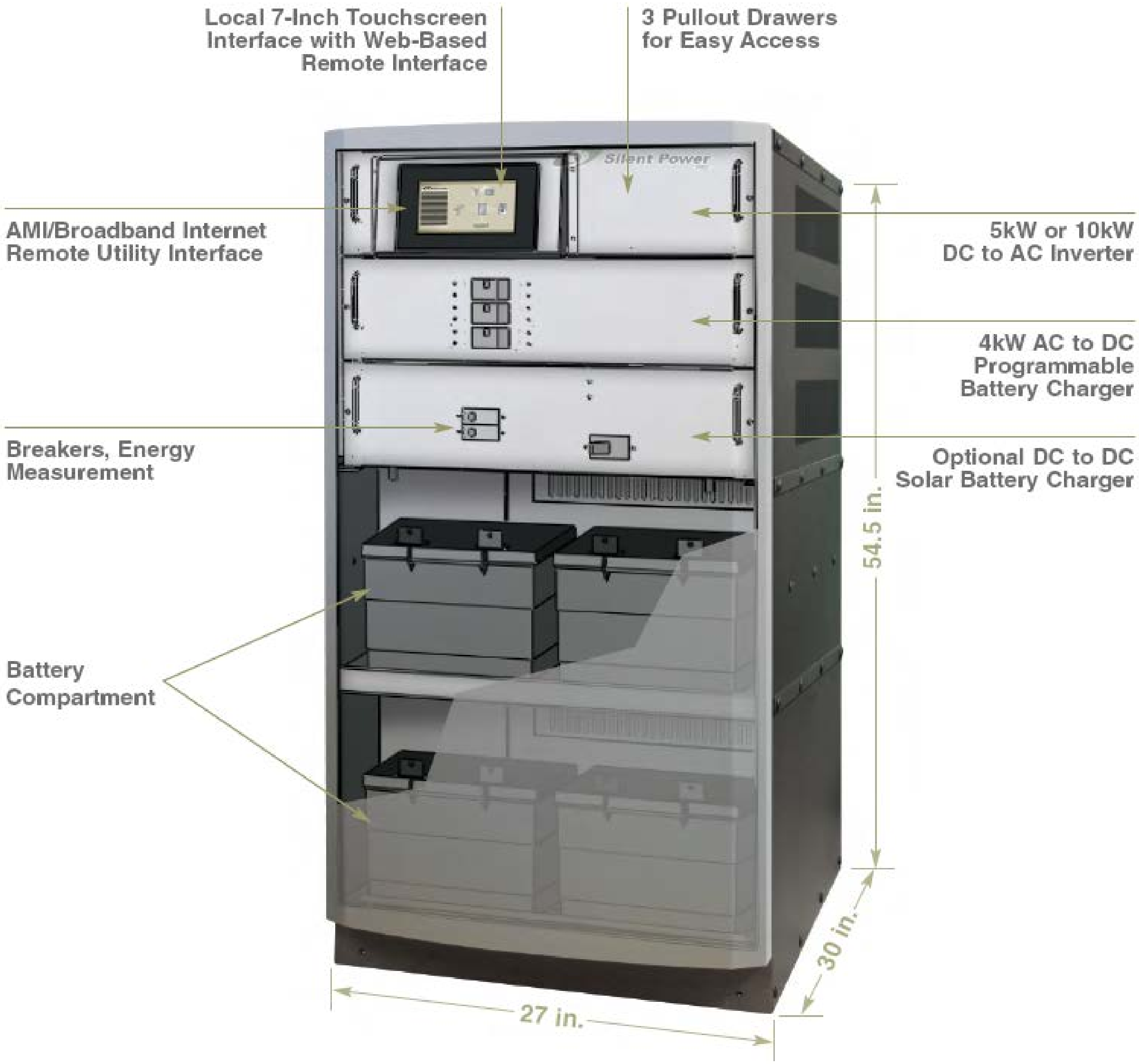
Residential Energy Storage Group



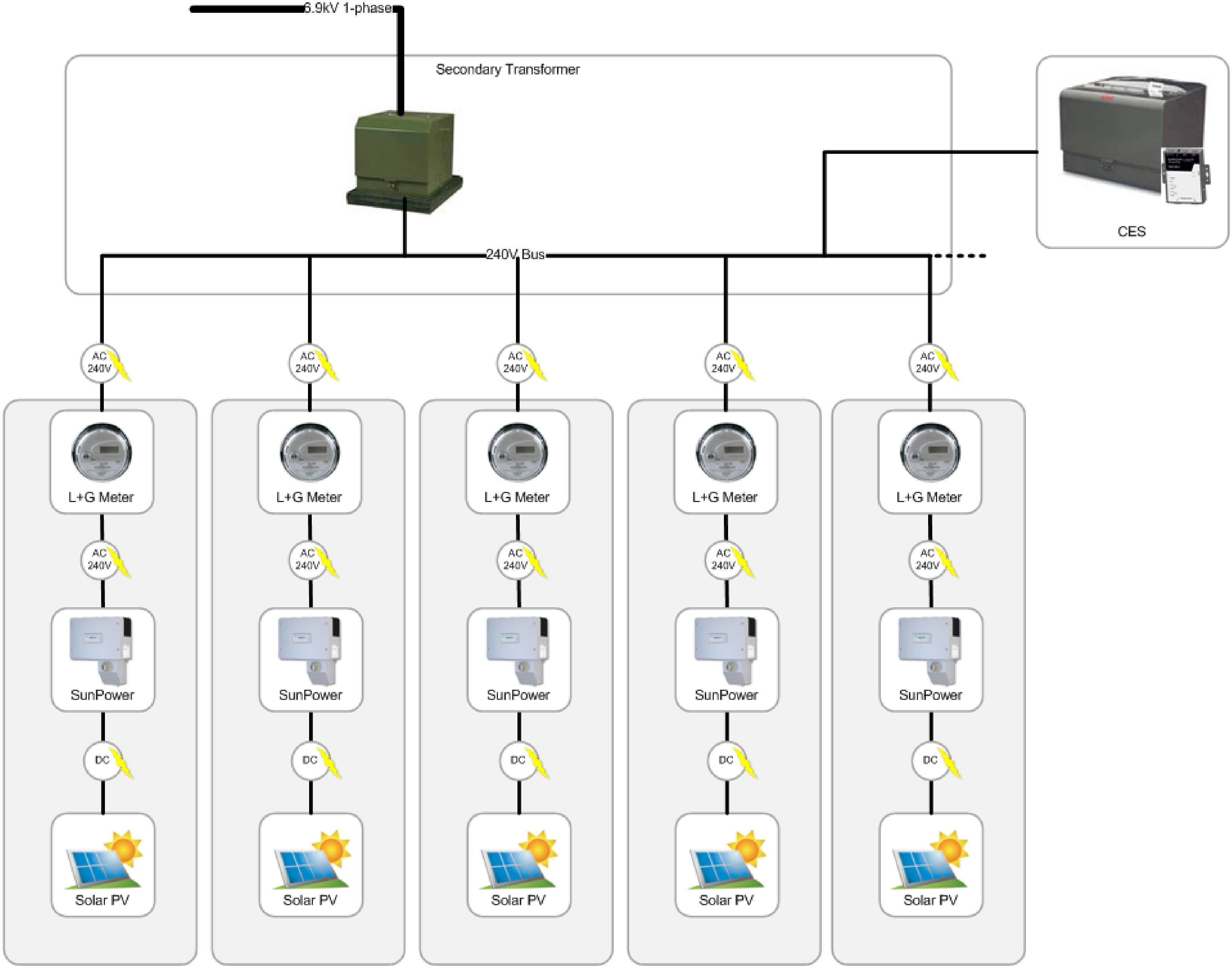
Residential Energy Storage Group

- Functional specifications & Assumptions
  - Same specifications for PV system as for Control/Baseline Group
  - Silent Power OnDemand appliance provides in-home energy storage
    - 5 kW peak output
    - Saft Solion Lithium-Ion batteries (~8.8 kWh usable)
    - On-board software is integrated with GridPoint server
  - Communications through broadband connection
  - SMUD will handle interconnect agreements or other regulatory considerations for battery dispatch
  - GridPoint will provide documentation and support for installation
  - SunPower has primary responsibilities for in-home installation given existing customer relationships

Residential Energy Storage Group



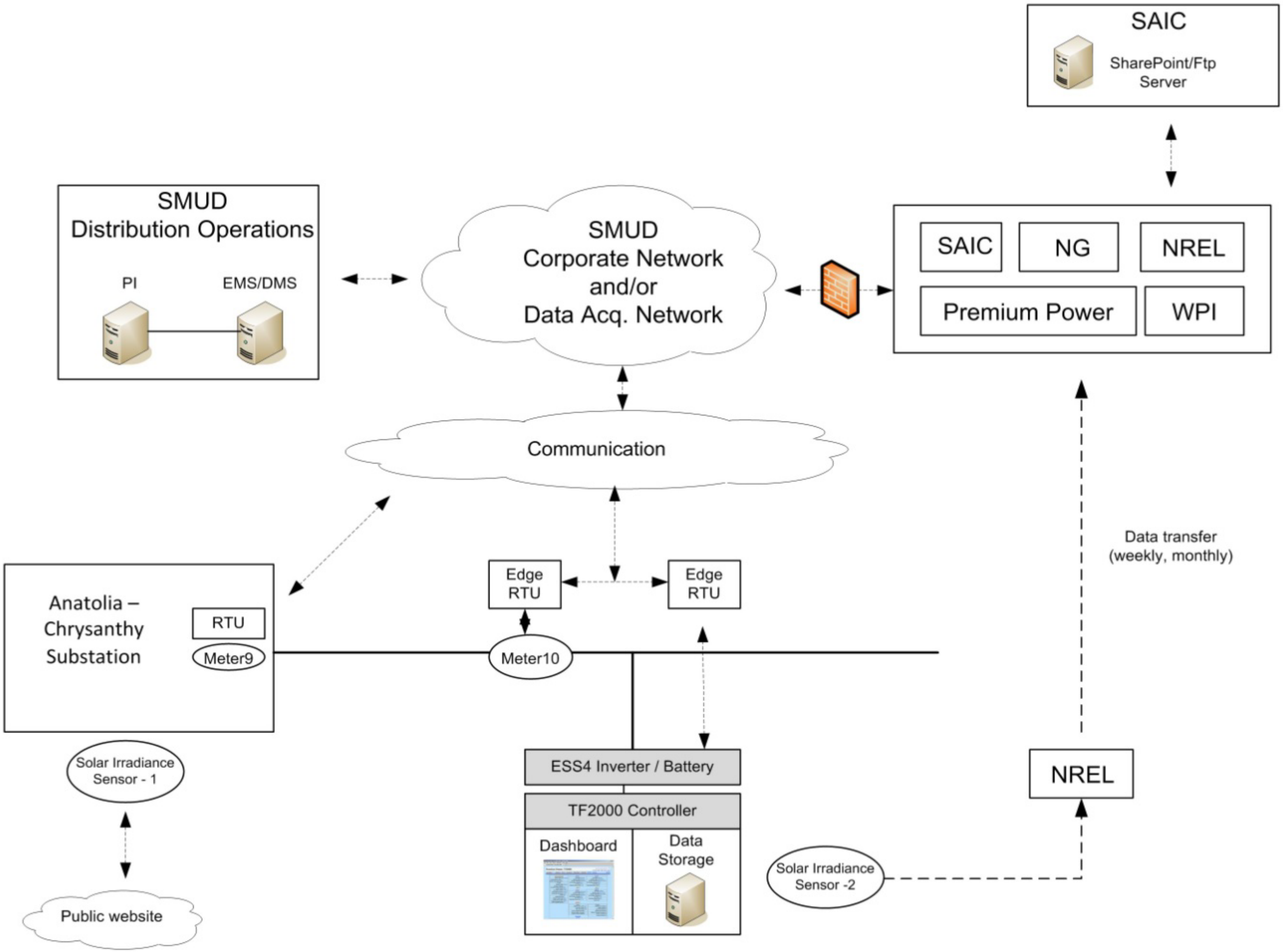
Community Energy Storage Group



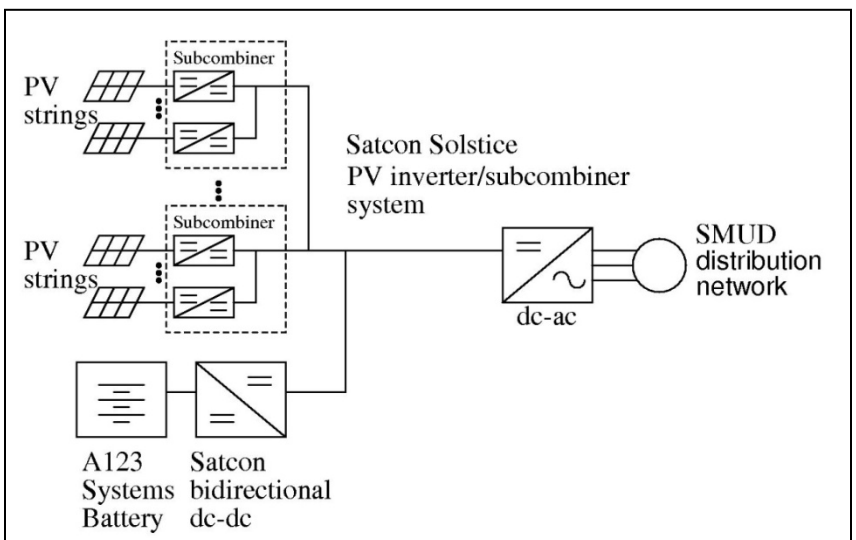
Community Energy Storage Group

- Functional specifications & Assumptions
  - Same specifications for PV system as for Control/Baseline Group
  - Lithium-Ion batteries (~30 kWh usable)
  - CES system peak output of 30 kW (undersized relative to 50 kVA secondary transformers)
  - GEM and Raven cell modem (within CES enclosure) will provide communications between GridPoint and CES
    - External antenna for the Raven modem
  - SMUD will provide equipment isolation on primary (6.9 kV) side of transformer
  - GridPoint will provide documentation and support for installation
  - Installation will be conducted by SMUD line crews under the direct supervision of GridPoint personnel

Anatolia Site Data Flow



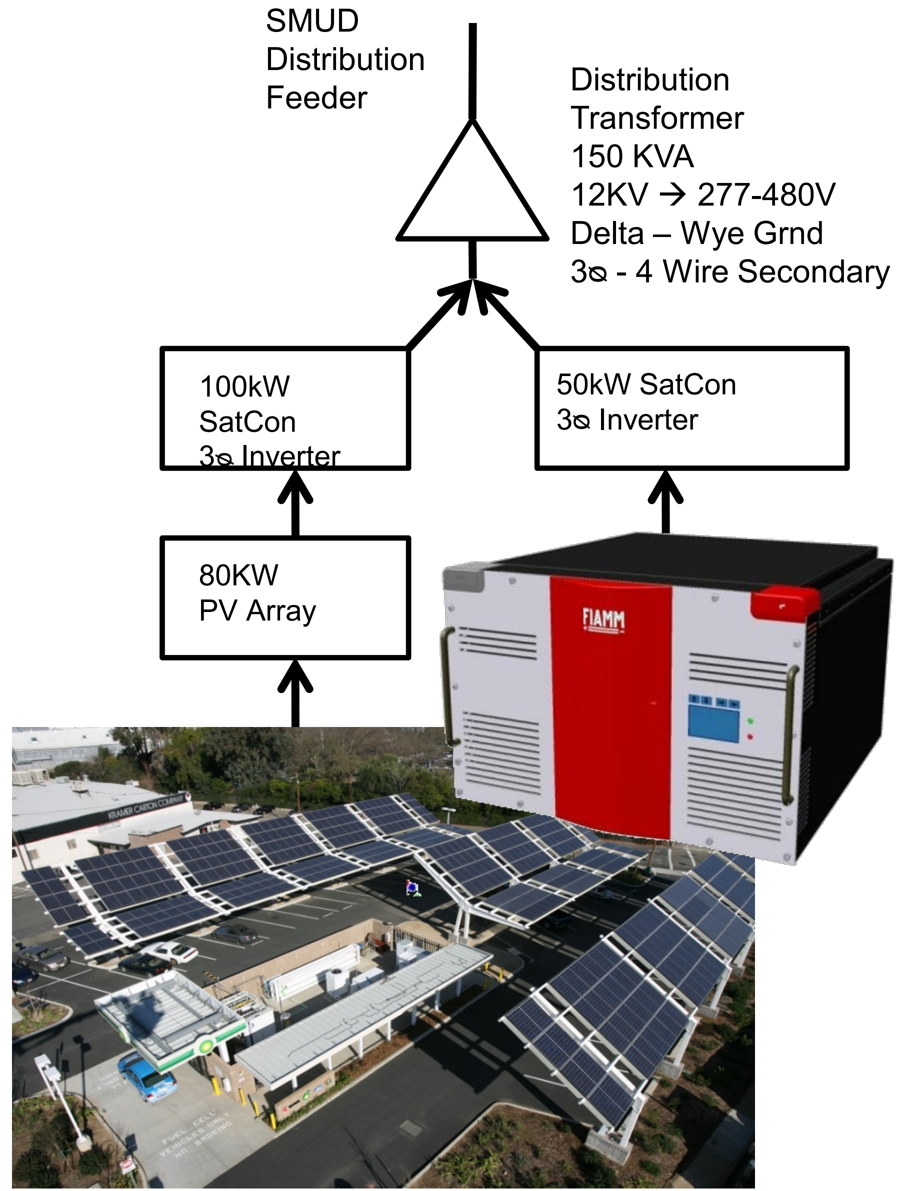
SMUD Operations Center PV/Storage Demo



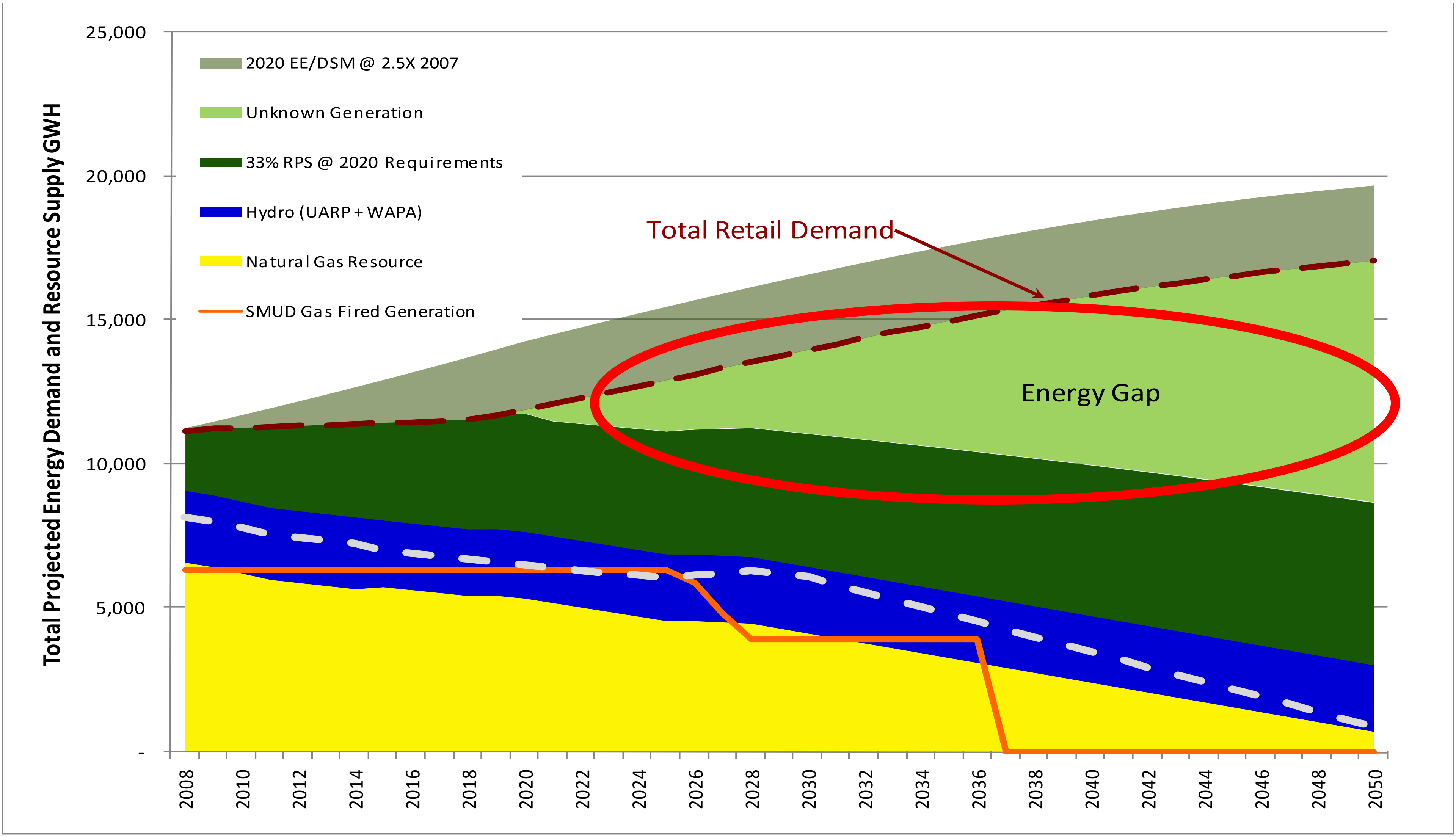
- New storage deployment – to augment planned 1.2MW PV Plant
- $4.2M grant from CEC PIER
- Partners Satcon (prime), A123 and SMUD
- Advanced technologies:
  - Satcon 500kW Solstice advanced inverter technology
  - A123 500kW/500kWh lithium ion battery system
- Objectives
  - Minimize impact of variability
  - Control ramp rates
  - Voltage regulation and voltage sag mitigation
  - Peak load shifting

Solar EV Charge Port

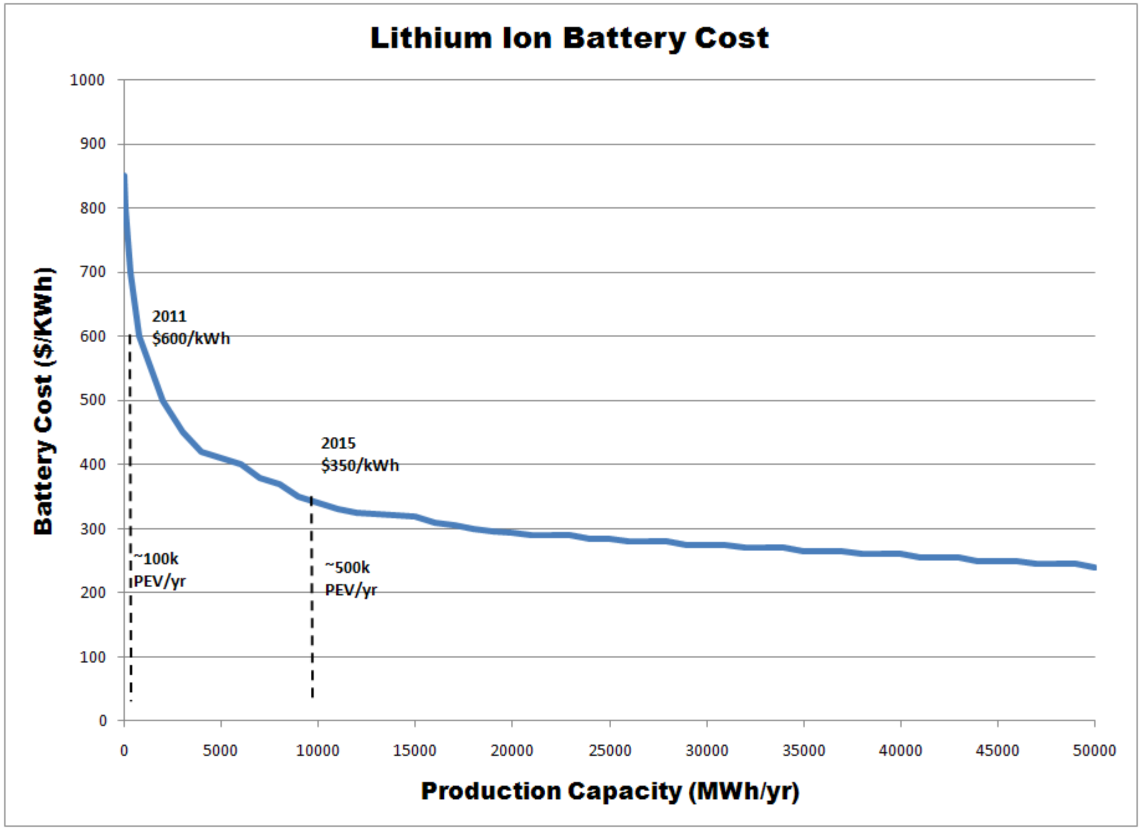
- EPRI FIAMM SatCon project to augment 80kW PV array
- SatCon 50kW PowerPlus inverter
- FIAMM NaNiCl 50kW/100kWh
  - High specific energy (120 Wh/kg)
  - High temperature battery – 260-360°C
  - Long life and high reliability
  - Not susceptible to high ambient temp
  - Planned location for plug-in hybrid charging
- Objectives
  - Minimize impact of PV variability
  - Control PV and PHEV charger ramp rates
  - Voltage regulation and voltage sag mitigation
  - Peak load shifting



SMUD Projected Resource Mix Through 2050



Expected Cost Reductions For Li+



Note: Best fit curve for a family of Li-ion cost projections, including ANL (2009), EPRI (2007), Miller (2006), CARB (2007), and TIAX (2009)

- Source: **Lithium-ion Energy Storage Market Opportunities,** *Application Value Analysis and Technology Gap Assessment,* **EPRI Publication Number 1020074**
- Production of 1,000 MWh of PEV batteries per year would result in $600/kW-h (100,000 vehicles assuming 20kW-h per battery; $12,000 PEV battery pack)
- Production of 10,000 MWh of PEV batteries per year would result in $350/kW-h (500,000 vehicles; $7,000 PEV battery pack)

- Cost estimates in-line with projections provided to EPRI by leading Li-ion battery vendors for 2011 and 2015.
- Future stationary applications for lithium-ion can be on order of $400/kW-h (includes balance of plant costs for power electronics and utility interconnection)

Microgrid Site Data Flow