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*Exceptional service in the national interest*

# PV Integration and Energy Storage

*UWIG Solar Users Group*

*October 11, 2011*

*Maui, Hawaii*


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**Energy Storage and Transmission Analysis**

**Sandia National Laboratories**

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration


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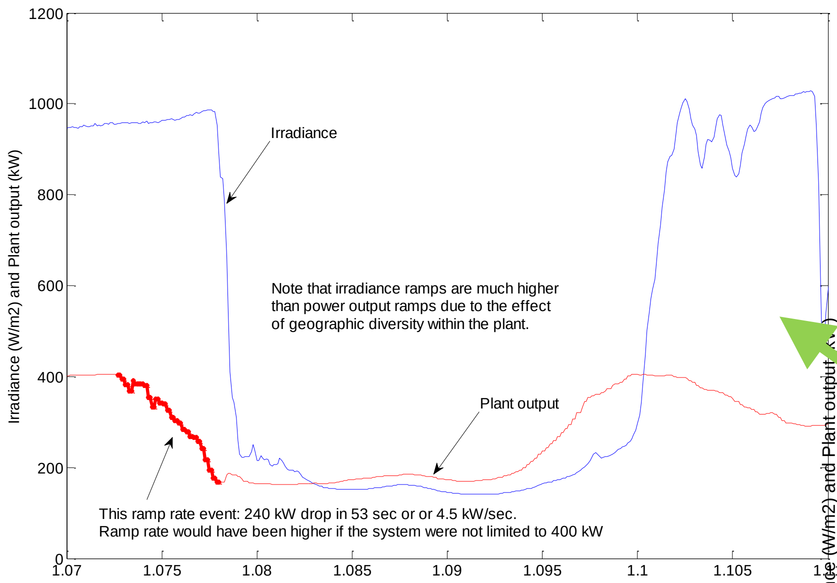
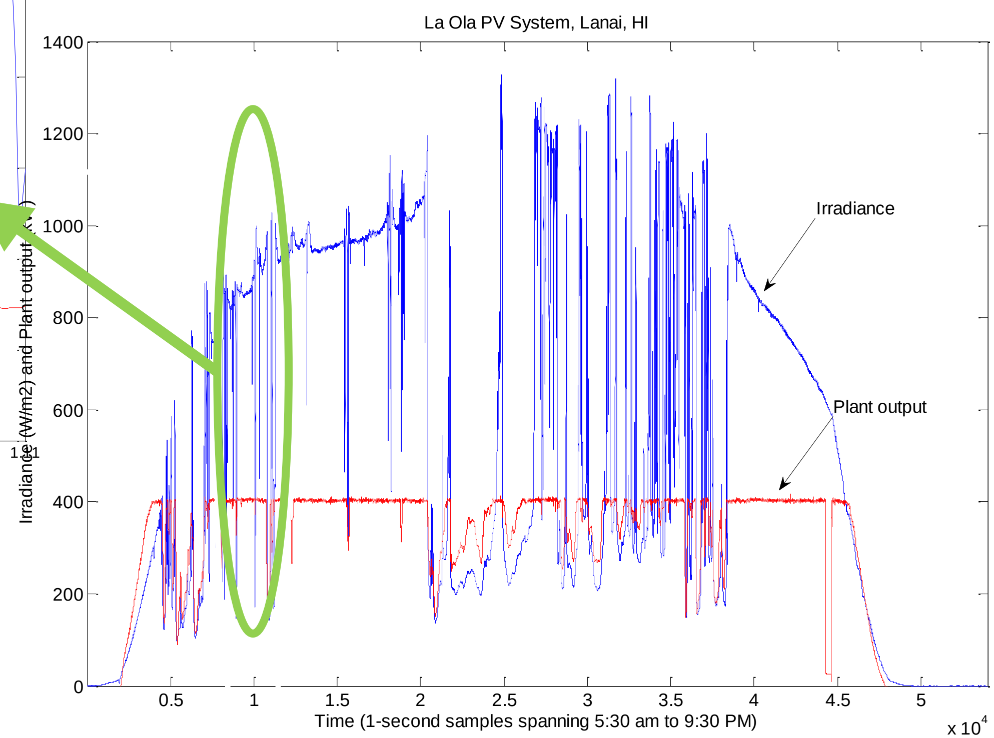
# Solar Penetration

- Introduces a degree of variability.




- Irradiance and PV system AC output A typical partly cloudy day in July
- PV system rating: 1,300 kW ac, presently limited to 400 kW ac (intentionally)

# High Solar Penetration

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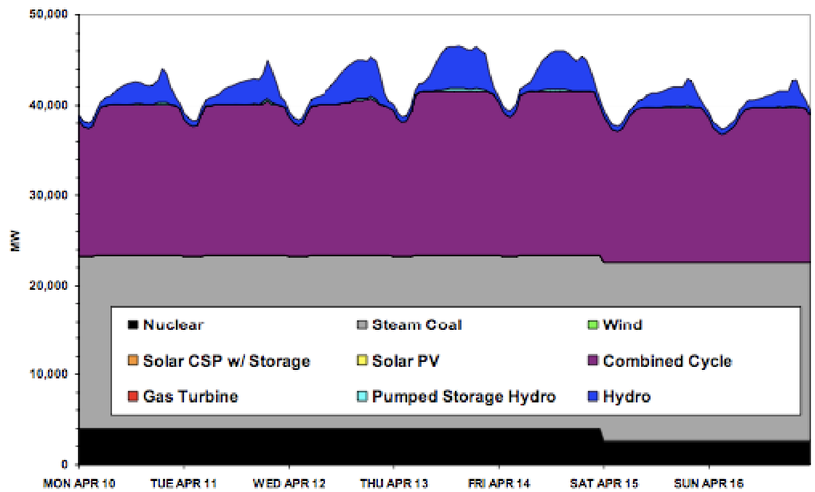
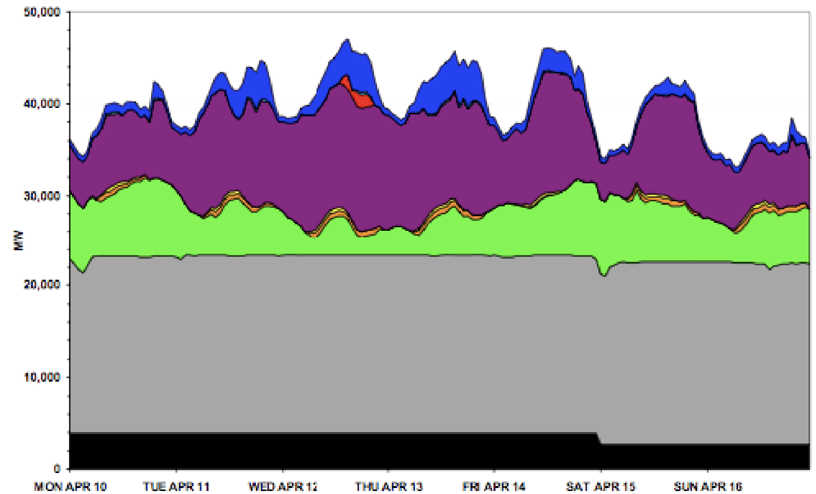
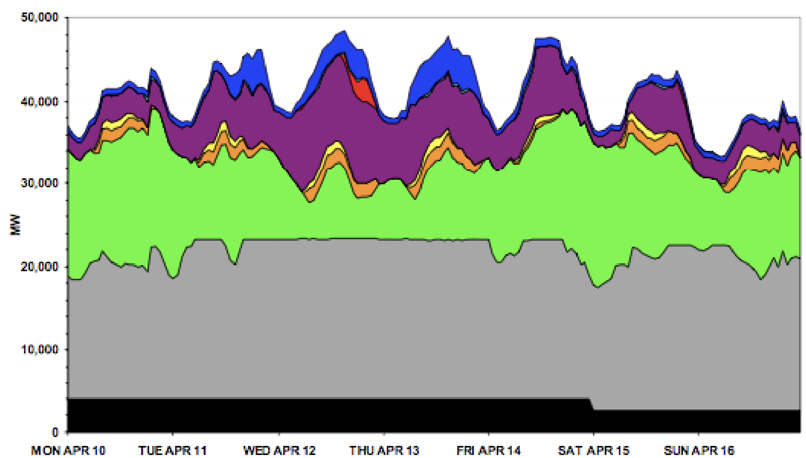
## No renewables



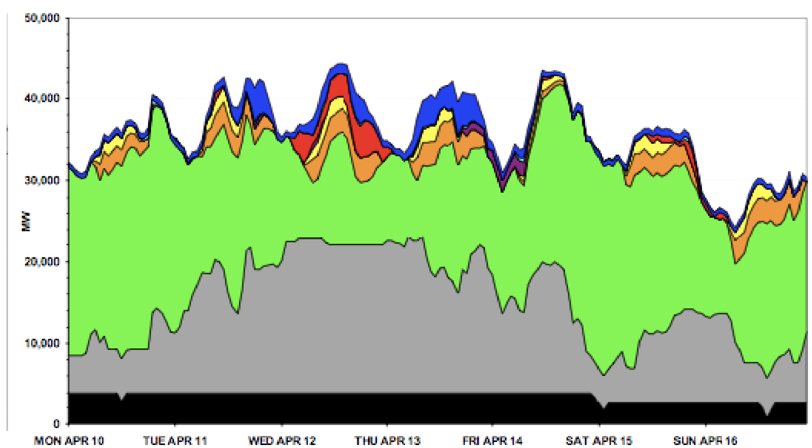

## 11% renewables




## 23% renewables




## 35% renewables




Lew et. al. "How do Wind and Solar Power Affect Grid Operations: The Western Wind and Solar Integration Study". National Renewable Energy Laboratory. (September 2009). p. 6

# Planning for High Solar Penetration

- Common means of managing system imbalance:

| Resources | Operations | Flexibility |
|---|---|---|
| • Generation<br>  • Peaker Plants<br>  • Cycling of generation<br>• Transmission<br>• Demand response<br>  • Smart Charging EVs<br>  • Residential<br>  • Industrial<br>  • Commercial<br>• **Storage** | • Balancing Area Consolidation (ISO formation)<br>• Generator Schedule Compression<br>• Dynamic scheduling of loads and resources<br>• Improved forecasts for wind, solar, and load<br>• Improved (stochastic) commitment process | • The variable resource itself (regulation down and up if spilling)<br>• Expansion of system flexibility (expanded ramp rates, start up times, etc)<br>• Optimization of hydro resources (in coordination with environmental constraints) |

# What Energy Storage Provides

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**End-Use**

- Power Quality/Reliability
- Peak Load Reduction
- Distributed Generation & Smart Grid Support

**Renewable Penetration**

- Reduced Variability
- Ramp rate control
- Load time shifting
- Reserves
- Dispatchability

**Transmission and Distribution**

- Line and Transformer Deferral
- Stability
- Voltage/Frequency Regulation

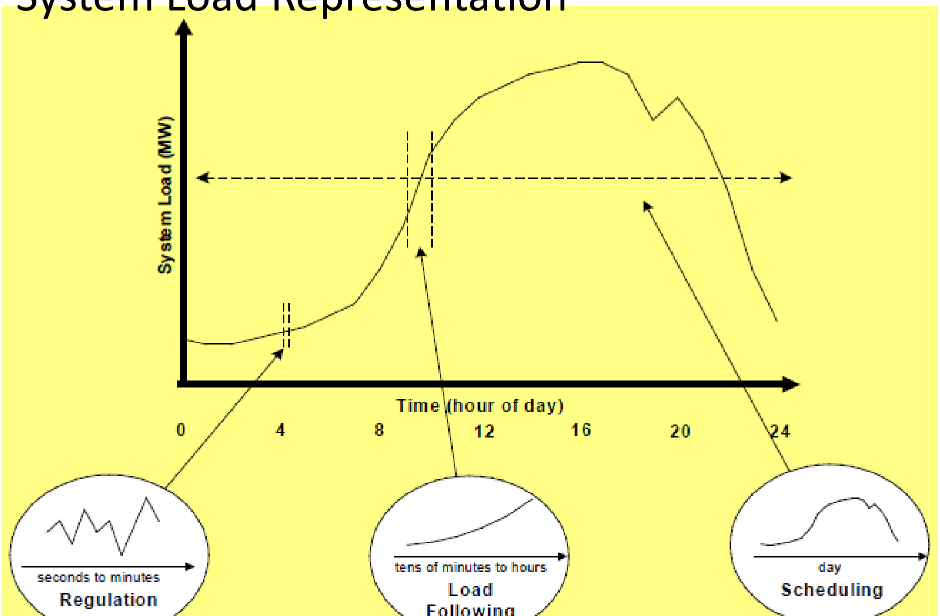
**Generation**

- Spinning Reserve
- Capacity Deferral
- Voltage/Frequency Regulation
- Load Leveling

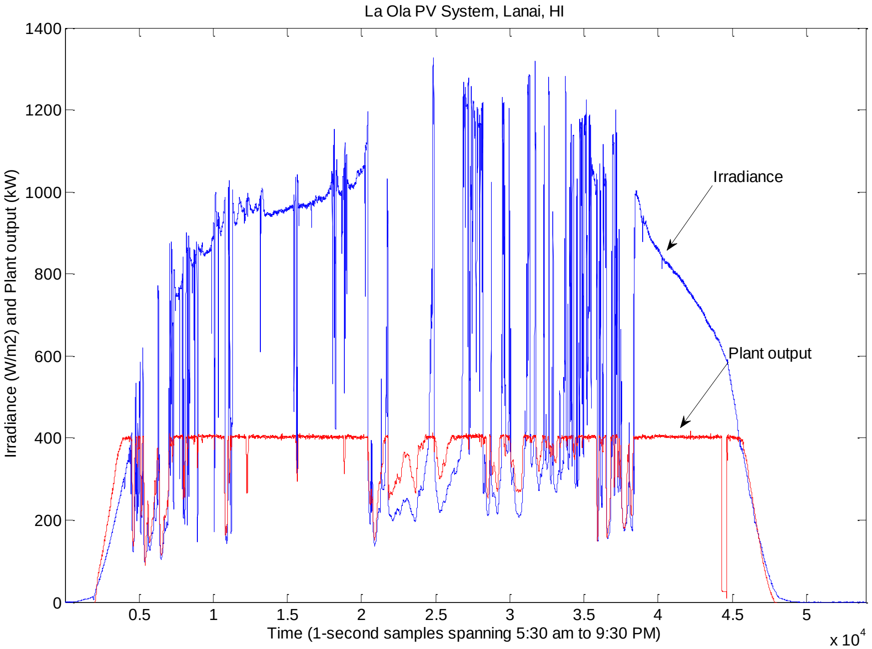
# Energy Storage for PV Variability

- Storage to smooth PV generation creates inefficiency

System Load Representation

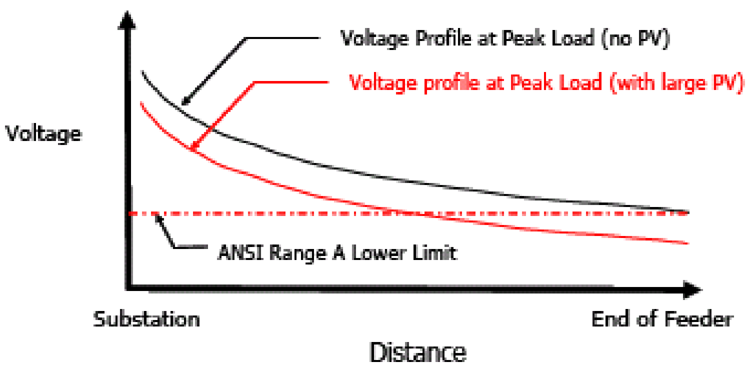



Source: Michael Milligan, NREL

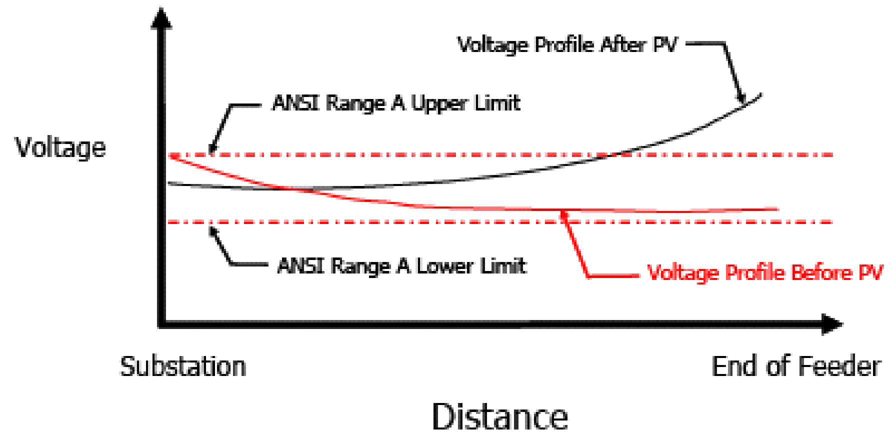



- **Solution: Storage at the system level to address system variability**

# Storage in the Microgrid




**Possible Feeder Profile with Large amount of DG at feeding end**

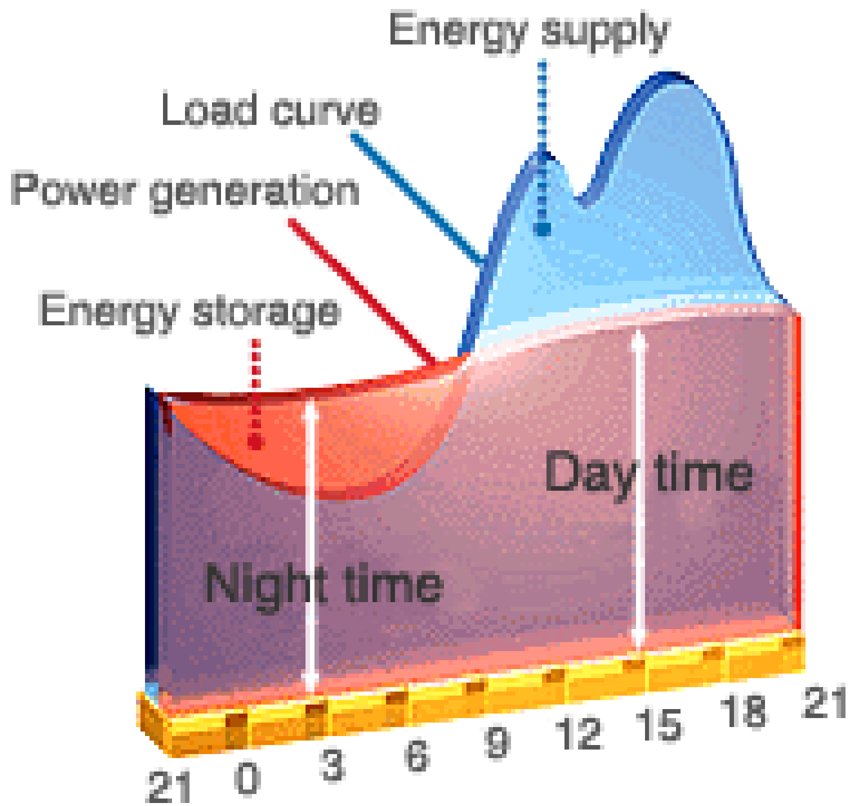



**Possible Feeder Profile with Large amount of DG at the end of the feeder**

A utility's mission is to keep the voltage levels within an acceptable range for all customers on a given feeder – those close to a substation and the customer at the very end of the feeder. Introduction of DG at the beginning of a feeder (close to a substation) presents a different challenge as compared to introduction of DG at the end of a feeder. Further, introduction of an intermittent DG resource can add further voltage stabilization challenges. Storage applied to the output of intermittent DG (solar PV) can mitigate these voltage issues by absorbing or releasing energy as the PV output varies

Courtesy: PNM

# Energy Storage for PV Load Leveling



# Energy Storage Technologies

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Energy

- Pumped Hydro
- Compressed Air Energy Storage (CAES)
- Batteries
  - Sodium Sulfur (NaS)
  - Flow Batteries
  - Lead Acid
  - Advanced Lead Carbon
  - Lithium Ion
- Flywheels
- Electrochemical Capacitors

Power

**Pumped Hydro (Taum Sauk) 400 MW**


**Sodium Sulfur Battery 2 MW**

**Flywheels 1 – 20 MW**

# Flywheels

- To address solar frequency variability
- Fast response: high ramp rates, high power
- Relatively low capital cost

Beacon Power: 20 MW
Flywheel Storage for Frequency
Regulation in PJM

# Advanced Lithium-ion Batteries

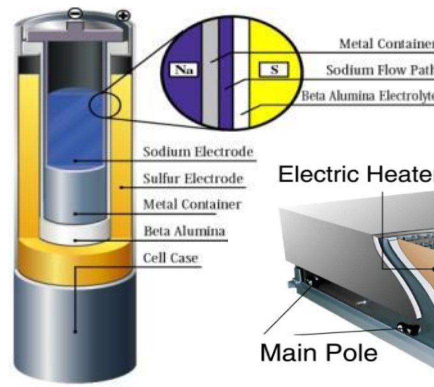
- Solar frequency variability
- Fast response, higher ramp rates than other battery types
  - Fast charging/discharging without electrolyte and electrode degradation

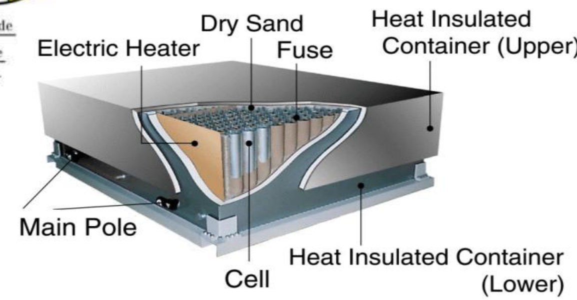
- A123 Systems
- Altairnano

- A123 Systems 20 MW Spinning Reserve Installation in Chile (2011)
- A123 20 MW Frequency Regulation System in Johnson City, NY (2011)

# NaS Batteries

- Electricity time-shift/leveling
- Slower response, high energy density
- Relatively low capital costs
- High efficiency
- Proven system with many installations





AEP APPALACHIAN POWER
A unit of American Electric Power

Started Operation on June 26th, 2006

NGK Insulators Ltd
S&C Electric Co.
DOE / SANDIA

Substation Support & Reliability in Charleston, WV: First 1MW/6hr in 2007, 3 in 2009

# Flow Batteries

- Electricity time-shift/leveling
- Slower response, high energy density
- Relatively low capital costs

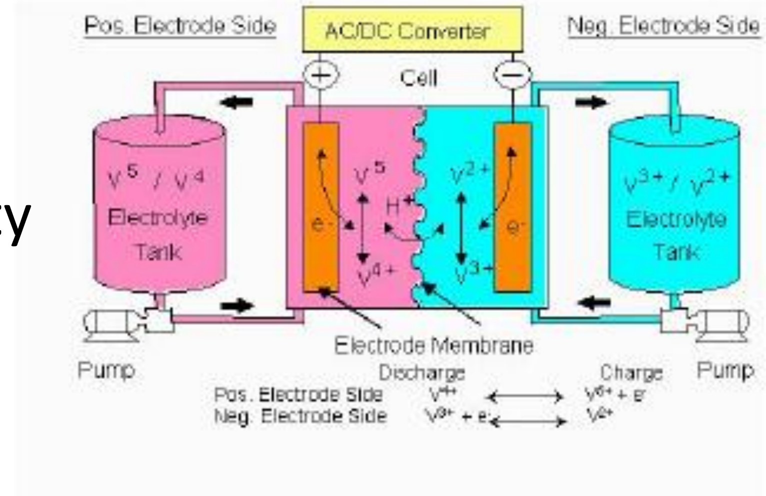
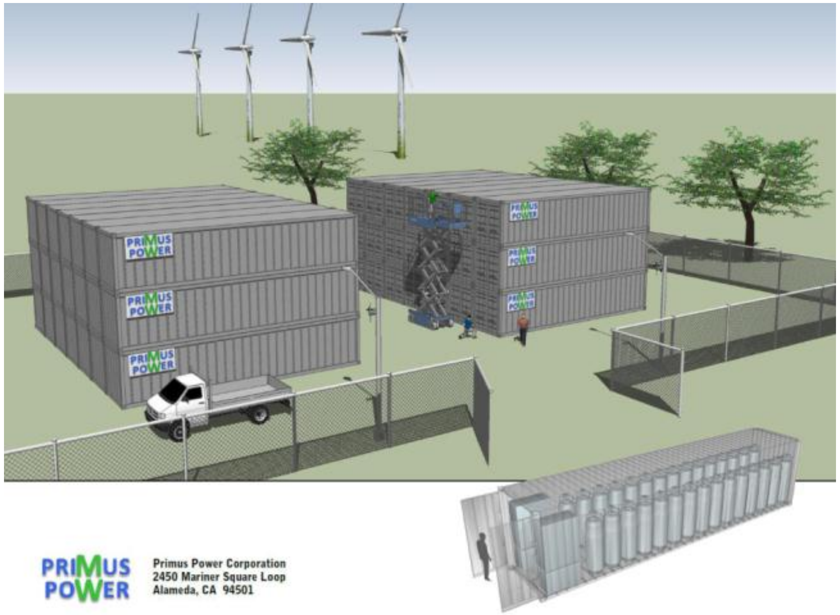


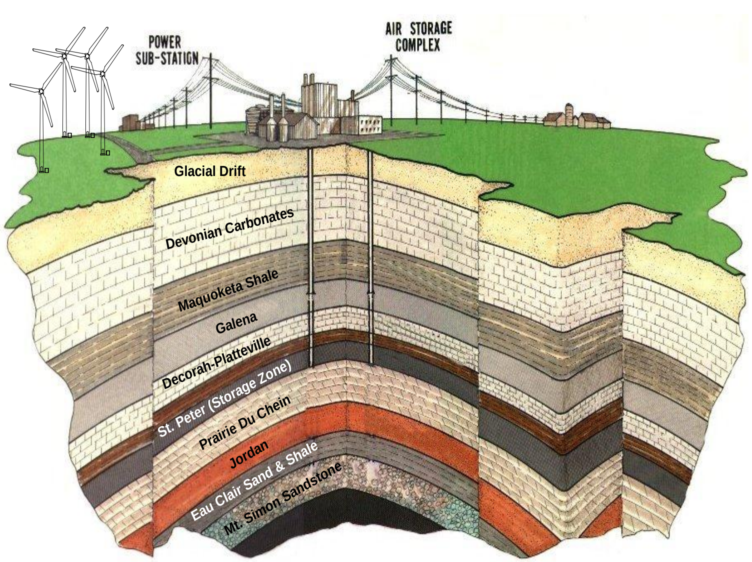
Photo Courtesy of Sumitomo Electric Industries, Ltd. (SEI) – Copyright 2001




**ARRA-Primus Power:**
25MW / 3hr battery plant for the Modesto, CA Irrigation District,
firming 50MW of Wind, replacing $75M of Gas fired Generation.

# Compressed Air Energy Storage (CAES)

- Electricity time-shift/leveling
- Slower response, high power & energy capacity
  - 200 MW
- Relatively low capital costs
  - 20 Perspective CAES Projects

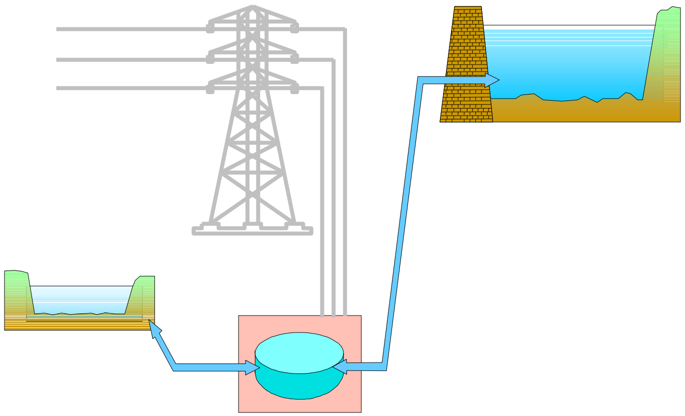



110 MW McIntosh, AL

# Pumped Storage

- Electricity time-shift/leveling
- Slower response, high power and energy capacity (bulk)
  - 400 MW, 2 GWh

**Conventional Systems:** Many Installations, many in consideration

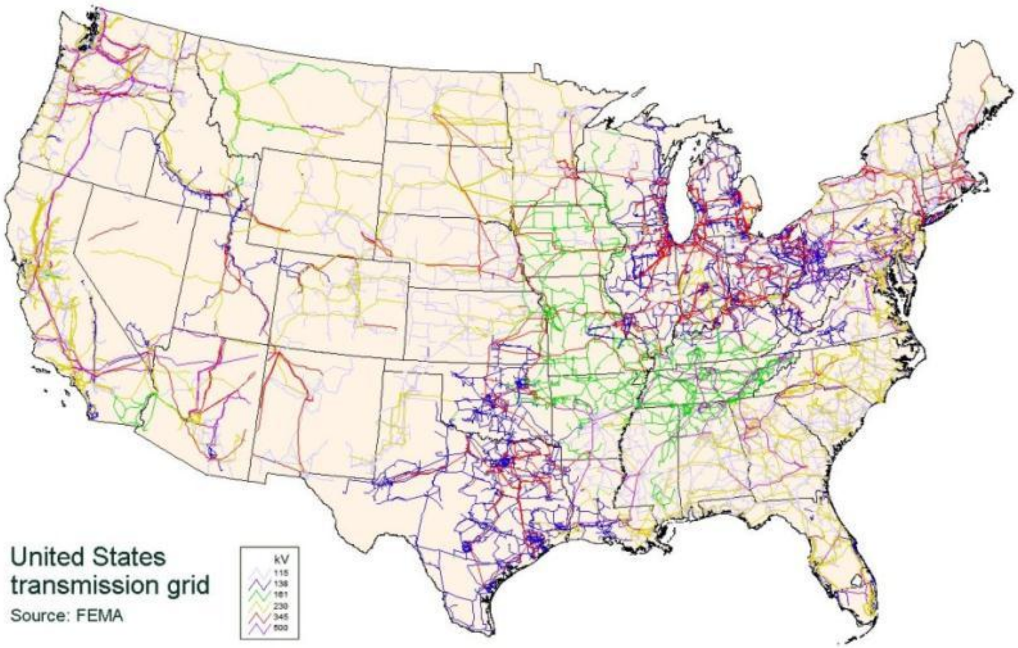


Energy Island

**Novel Systems:**
Aquifer
Archimedes' Screw
Below Ground Reservoir
Energy Island
In ground storage pipe with piston
In-reservoir tube with bubbles
Ocean Pumped
Variable-Speed

# Barriers to Energy Storage

- Uncertainty about Costs & Storage Valuation →
  - Market Challenges
  - Regulatory Challenges



# Barriers: Market Structures

- The way markets are defined and separated presents several issues:
  - Requirements to maintain constant output and minimum run time disqualify some storage resources.

  - Value is not always recoverable
    - Some grid needs are not paid for (inertia, primary frequency regulation, some voltage support)
    - Recovery for providing simultaneous benefits is difficult
      - Storage can receive a regulated return on investment as a transmission asset, BUT then cannot compete in market operations
    - Most market structures do not put value on ramping, although the system needs it, and storage provides it.

# Barriers: Regulatory Issues

- Regulators require full information on how ESS provides value.
  - Regulatory acceptance has not been demonstrated
  - Insufficient number of deployed systems raises perceived technological risk
- Cost-based compensation for regulated utilities versus value based compensation resulting from access to markets
- Regulated utility technological and financial biases against untested or unfamiliar technologies leads to a lag in the adoption of new technologies

# Valuing Storage

Example: Transmission… what services does it provide?

- Delivers power to the loads
- Sufficient transmission keeps nodal price spreads low
- Maintains reliability

*Q. What's more important; transmission, or the services it provides?*

*A: Obviously, the services it provides are more important*

*The Point:* A cost comparison of resource types is largely irrelevant. A more relevant question is how to cost compare methods which reliably meet the needs of the grid.

# Challenge: Select Least Cost Resource Portfolio

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***Grid Services (that need to be fulfilled)***

***Resources that can be used to provide services***

| | Within hour balancing | Frequency Regulation and Inertia | Voltage Support | Stability Support | Scheduled short-term Capacity | Scheduled long-term capacity | Lowering nodal prices |
|---|---|---|---|---|---|---|---|
| ***Combustion Turbine*** | | | | | | | |
| ***Flywheel Storage*** | | | | | | | |
| ***Flow Battery*** | | | | | | | |
| ***FACTS Power Electronics*** | | | | | | | |
| ***Transmission Lines*** | | | | | | | |
| ***Demand Response*** | | | | | | | |

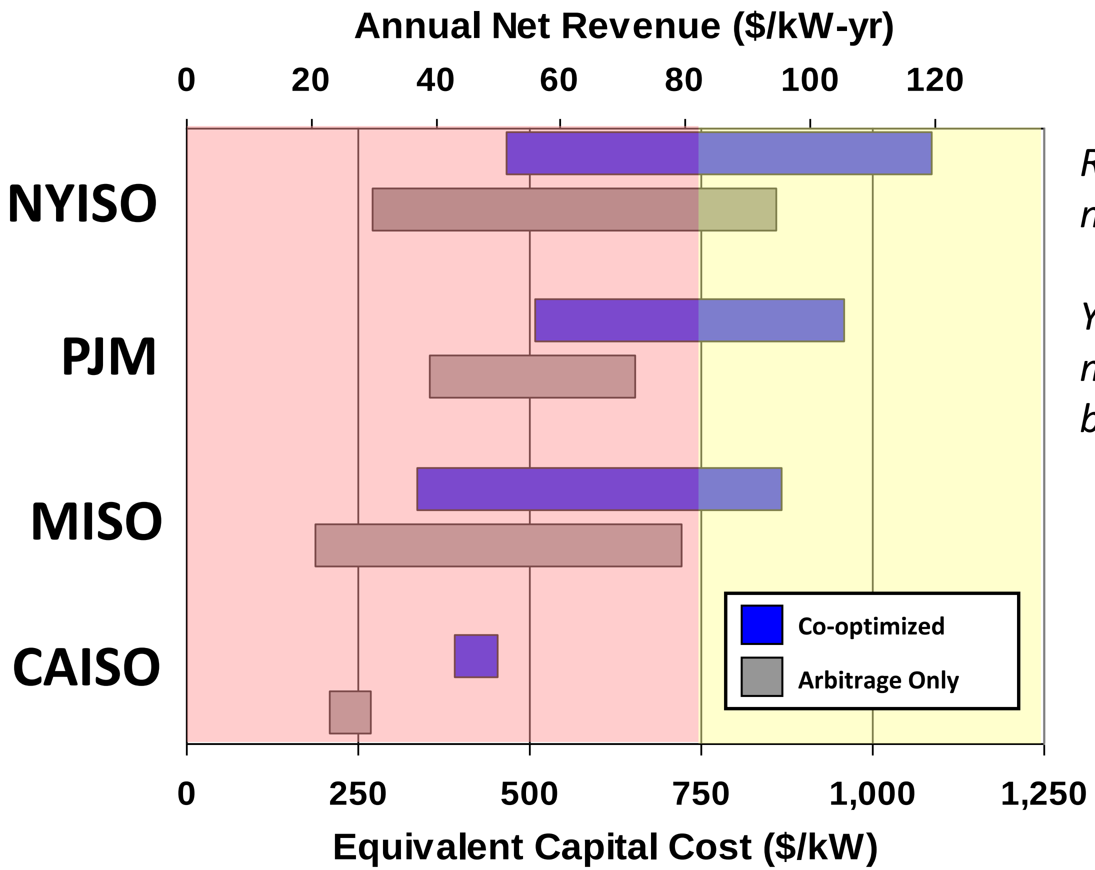
***Orange cells indicate that the resource can meet the need. Cost information is absent***

***This table is not complete, and intended only to demonstrate the principle stated in the title***

# What Does the Value of Storage Depend Upon?

- The number of simultaneous services it can provide and the need for those services.
  - For Arbitrage:  diurnal price spread
  - For infrastructure deferment: The cost of system upgrade
  - For balancing:
    - The system need (and price) for balance
    - The cost of the storage
- The future needs of the items listed above (largely unknown)
- The ability of alternative resources to:
  - Become more cost effective
  - Be exhausted

# Using storage assets for multiple services can increase value



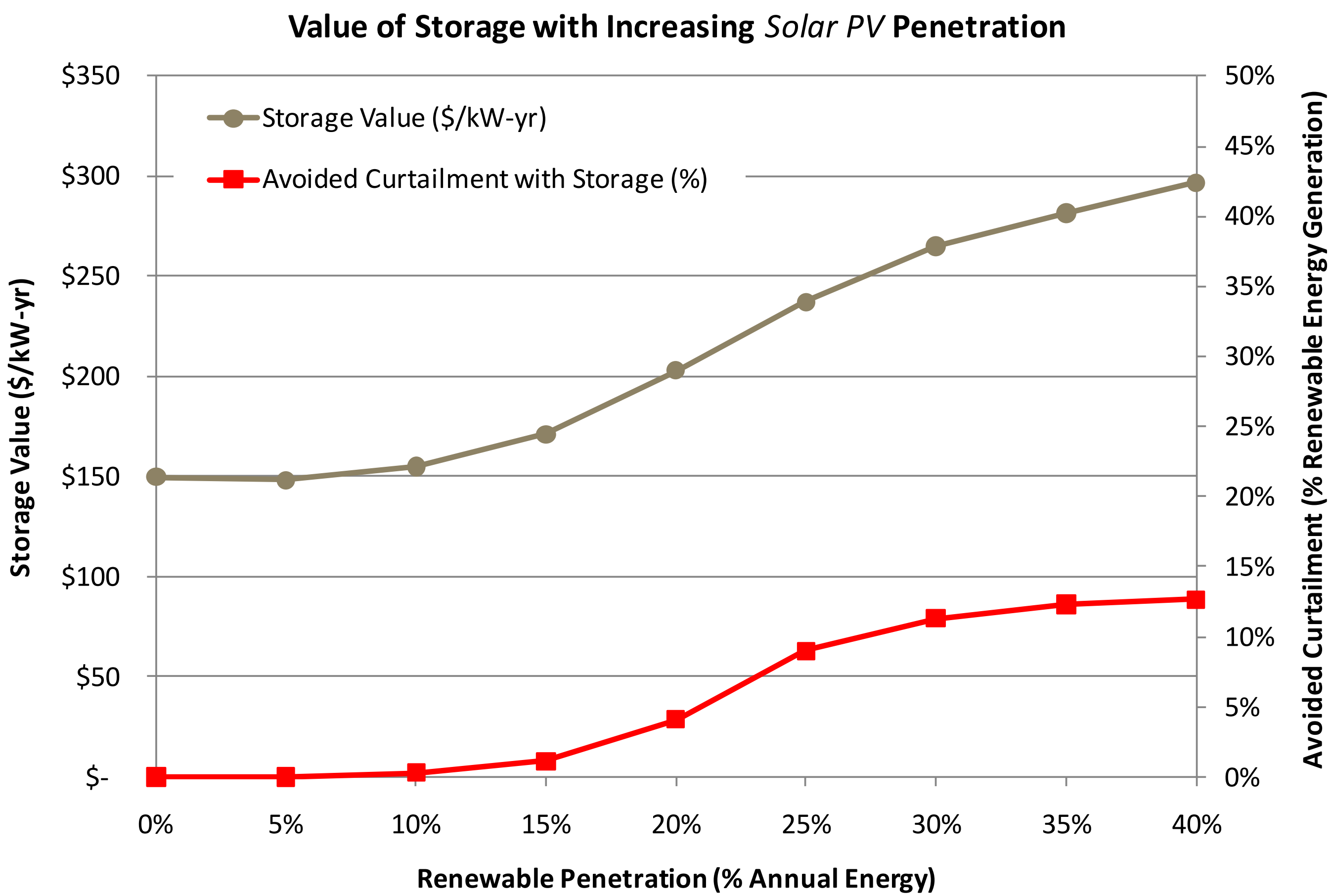

*Red band indicates non-financial viability*

*Yellow band indicates moderate financial viability based on CAES Capital Costs*

- **Co-optimized systems could be profitable in three ISOs**
- **Arbitrage only systems could be profitable in one ISO**

***Several individual Projects were analyzed and their mean returns are reported on this graph***

# The Value of Storage Changes with Solar PV Penetration




- Assumes 20% of peak load is met with new capacity; 10% of the new capacity is storage
- Value of storage does not include ancillary services

# Work at Sandia

- Technology Development
  - Developing New Technologies: *Nitrogen-Oxygen Battery*
  - Improving Current Technologies: Flow Battery Efficiency Improvements and Cost Reduction
- Valuation Assessments
  - System Analyses: Storage Integration with Renewable Penetration
- Demonstration
  - Validation of technical and economic capabilities
- Market Design Development
  - Ancillary Service Markets to value services
- Informing Regulations and Policy
  - PUC Regulatory Guidebook for Energy Storage

# Summary

- Storage and renewables go together, with high PV penetration, storage becomes more valuable, and with storage, PV becomes more valuable.
- Storage must be amongst a portfolio of technologies providing necessary grid services: not a silver bullet.
- Many market and regulatory challenges persist, however addressing these issues can lead to a more efficient electricity system with a high penetration of solar (and other renewables) reducing emissions, while lowering costs for consumers.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PV Integration and Energy Storage

# QUESTIONS?