Comparing Current and Future Storage Technologies and Their Applications

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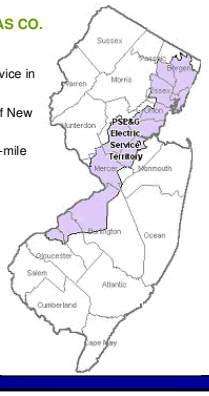
Public Service Enterprise Group

- PSEG Power LLC – 2009 Operating Revenues: $7.1 Billion
- PSE&G – 2009 Operating Revenues: $8.2 Billion

- Nuclear – 53%
- Coal – 24%
- Oil/Natural Gas – 23%

PUBLIC SERVICE ELECTRIC & GAS CO.

- Largest provider of gas and electric service in New Jersey
- Currently serves nearly three quarters of New Jersey population
- Service area consisting of 2,600 square-mile diagonal corridor across the state
- 2.1 million electric customers
- 1.7 million gas customers



Discussion Points

- Assessing Infrastructure Integration
- Overcoming Economic and Policy Challenges
- Drivers for Energy Storage
- Storage Options
- Technology Comparisons
- PSEG Storage Projects

Assessing Infrastructure Integration

- **Converts variable renewable resources** (wind and solar) into firm, dispatchable resources available when customers need power
- **Enhances grid reliability,** which will become increasingly important as variable renewable resources become a larger part of the supply equation
- **Optimizes the utilization of transmission**, minimizing new required construction
- **Increases the value of renewable resources** by shifting production from low-demand, low-price periods (wind generation is greatest at night) to high-demand, high-price periods (reducing the overall price of power to customers)

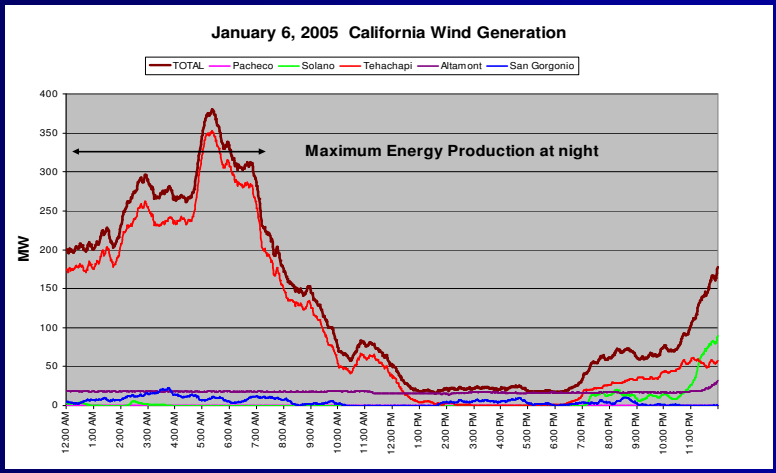
Overcoming Economic and Policy Challenges

- Capital Cost of Storage
- Lack of incentives for development and commercialization
- Uncertain federal and state regulatory terrain
- Depressed energy markets and tight credit markets

Interest in MWH Scale Electric Energy Storage

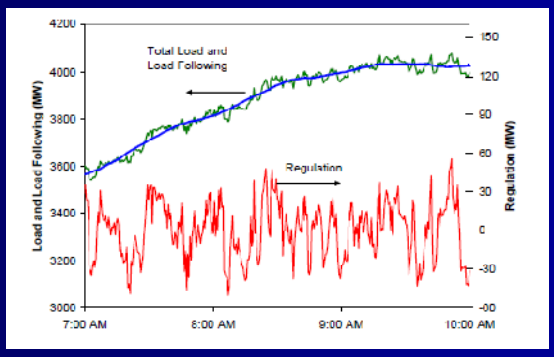
- Managing Increased Wind Penetration
- Ancillary Services – Avoiding the cycling of thermal power plants
- Managing Grid Peaks and Outage Mitigation

Need to Shift Some Wind Energy Production from Off-Peak to On-Peak



Source: California ISO

Grid Frequency Regulation
Opportunities for Fast Storage Systems



Current method to balance constantly shifting load fluctuation is to periodically adjust generation in response to an ISO signal.

PJM: Issues Arising with Intermittency of Wind Power Integration

- Difficult to schedule or predict spawning the need for wind forecasting
- May require holding extra reserves or committing CTs to ensure drop in wind can be covered
- May require backing down baseload units when wind picks up even during shoulder or peak hours
- Has already experienced negative prices with 4 GW of wind generation (40 GW is planned).

Interest in kWh Scale Electric Energy Storage

- Electric Transportation
- Managing Grid Peaks and Outage Mitigation
- Provide Customer Load Control
- Improved Integration of Small Scale PV (Facilitate Zero Energy Home)

Storage Options

- Pumped Storage
- CAES
- Batteries
- Flywheels

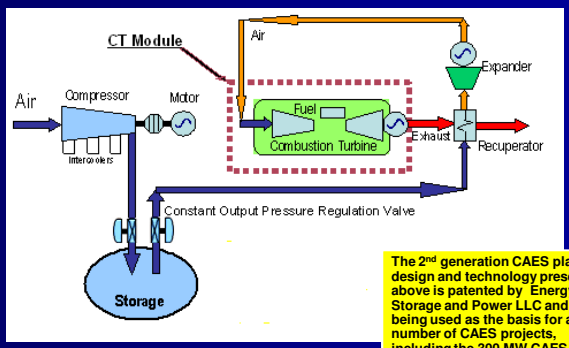
Pumped Storage

The Yards Creek Generating Station is a 400 MW pumped-storage hydro plant located five miles northeast of the Delaware Water Gap in Warren County, NJ. PSEG has a 50% ownership with First Energy, who operates the facility.

Compressed Air Energy Storage (CAES)

- First US CAES Plant: Alabama Electric Cooperative McIntosh Plant (110MW – 26 Hr)
- Started commercial operation: midnight May 31, 1991

Advanced CAES Plant



The 2nd generation CAES plant design and technology presented above is patented by Energy Storage and Power LLC and is being used as the basis for a number of CAES projects, including the 300 MW CAES project announced by PG&E.

Sodium Sulfur Batteries - NaS

1 MW /7.2 MWh NYPA – End-User Peak Shaving

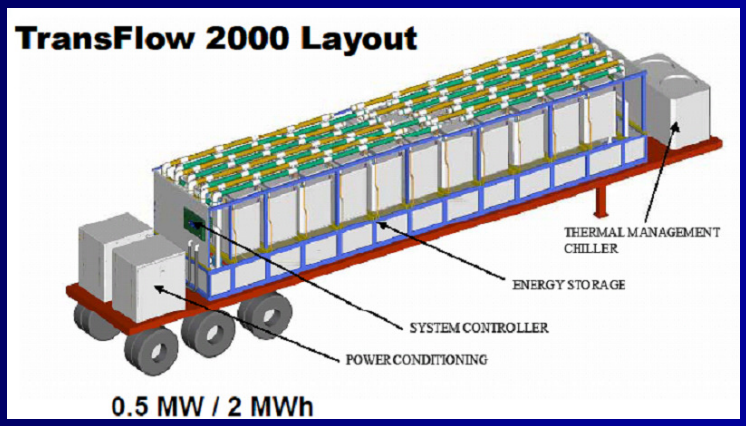
Advanced (Dry Cell) Lead Acid Type Batteries

1.5 MW / 1 MWh unit tested for Wind Farm Application

- Technology assessment & evaluation
- Evaluate field units in wind application
- Plan future utility-scale demonstration
- Assess potential as bulk storage applications

Flow Batteries – Zn / Br

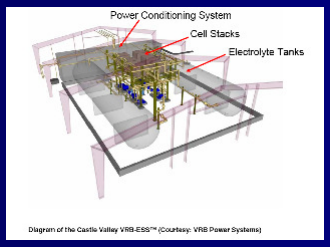
Gaining Utility Consideration for Grid Support Applications



Design by Premium Power

Vanadium Redox Flow Battery Applications

New Products and Systems being Developed by Prudent Energy



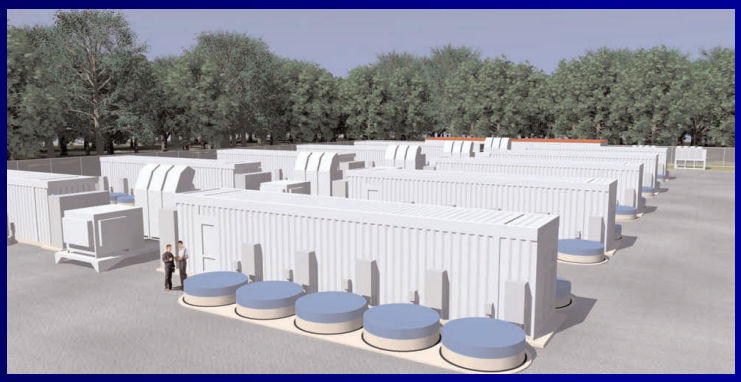
–250 kW, 2 MWh unit at Castle Valley, Utah (PacifiCorp)

2 MW Lithium Ion System for Frequency Regulation

Early Field Trials by:

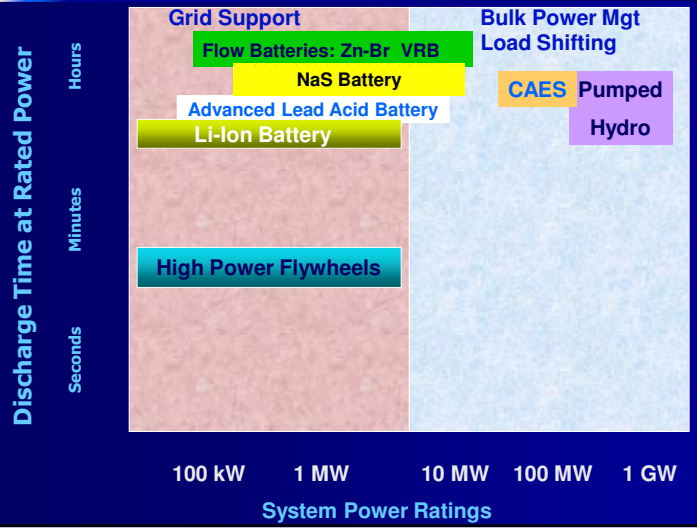
- **Altarnano**
- **A123**

Flywheel Energy Storage

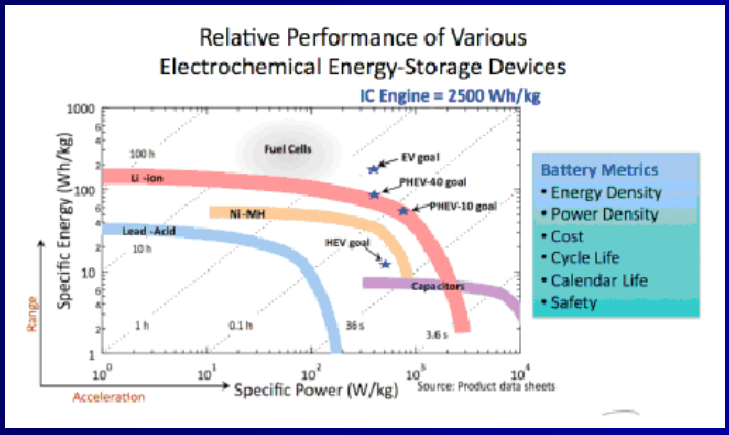


Artist rending of a 20 MW flywheel facility. 200 high-energy (25 kWh/100 kW) flywheels and associated electronics, will be able to provide 20 megawatts of "up and down" regulation-equal to a 40-megawatt swing. Photo Courtesy Beacon Power.

Energy Storage Options

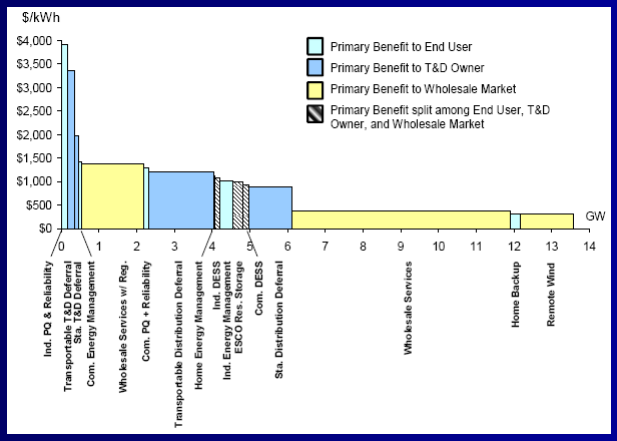


Performance Comparison of Storage Devices



Source LBNL

Market Application for Energy Storage

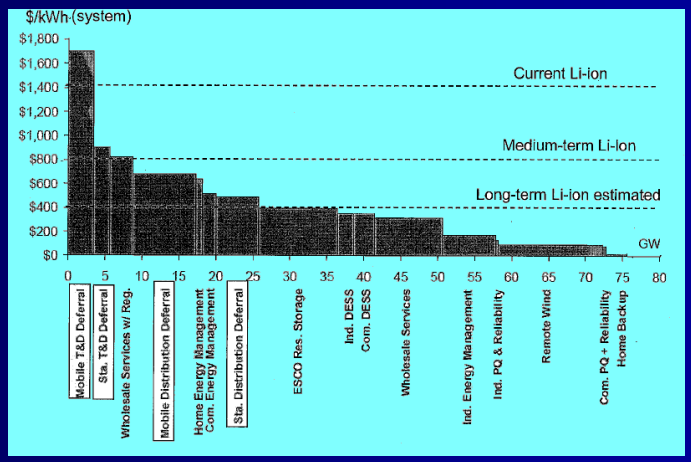


Source- EPRI

Electricity Energy Storage Technology Options - A White Paper Primer on Applications, Costs and Benefits

Final Report, December 2010 Report Number: 1020676

Market Application for Energy Storage (Without Niche Applications)



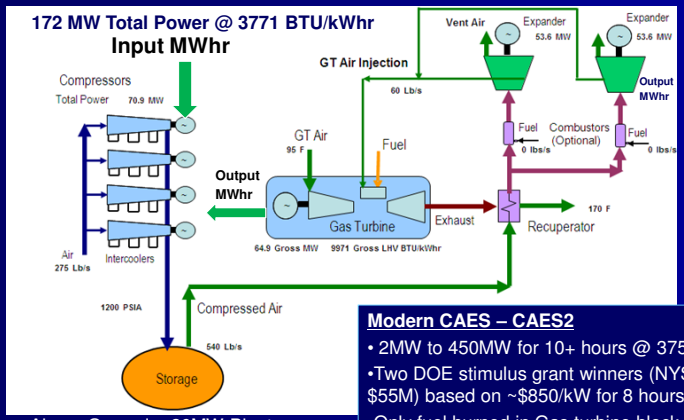
Source-EPRI

Current PSEG Program Focus

- Leverage EPRI research
- Two technologies have most promise based on cost and performance characteristics*
- CAES for >10 hrs energy storage
- Li –ion for < 4 hrs of storage

* Energy Storage: Enabling Grid Ready Solutions (EPRI Journal-Summer 2010)

CAES2 Process Cycle



•Above Ground < 20MW Plants
•Below Ground – 20-450MW Plants (>50 MWhr)

Modern CAES – CAES2

- 2MW to 450MW for 10+ hours @ 3750 BTU/kWh
- Two DOE stimulus grant winners (NYSEG + PG&E = $55M) based on ~$850/kW for 8 hours => $100/kWh
- Only fuel burned in Gas turbine block using OEM Dry Low NOx combustors
- Energy ratio = .71 (energy in/energy out)

Lithium-Ion Battery

- Utility applications: frequency regulation, VAR support, distribution grid infrastructure support (especially for large PV arrays)
- Customer applications: peak shaving, residential storage coupled with dynamic rates
- Expected low cost – currently $1,400 kWh - but projections as low as $250-350/kWh

50 kW BYD System under Factory Acceptance Testing by EPRI

Renewable Integration Issues & Role of Energy Storage

- Need to reduce electric sector GHG emissions
- Increased wind penetration is a potential solution
  - But variable wind generation and electric system integration is a big issue
  - Impacts of wind penetration in backing off base load coal generation
  - Most experts believe energy storage can be part of the solution for wind integration; but
- How much storage is needed for to improve wind penetration
- Best location for storage
- Cost effectiveness of storage vs. other options
- Trade-offs and assessments on transmission planning
- Impacts of policy changes