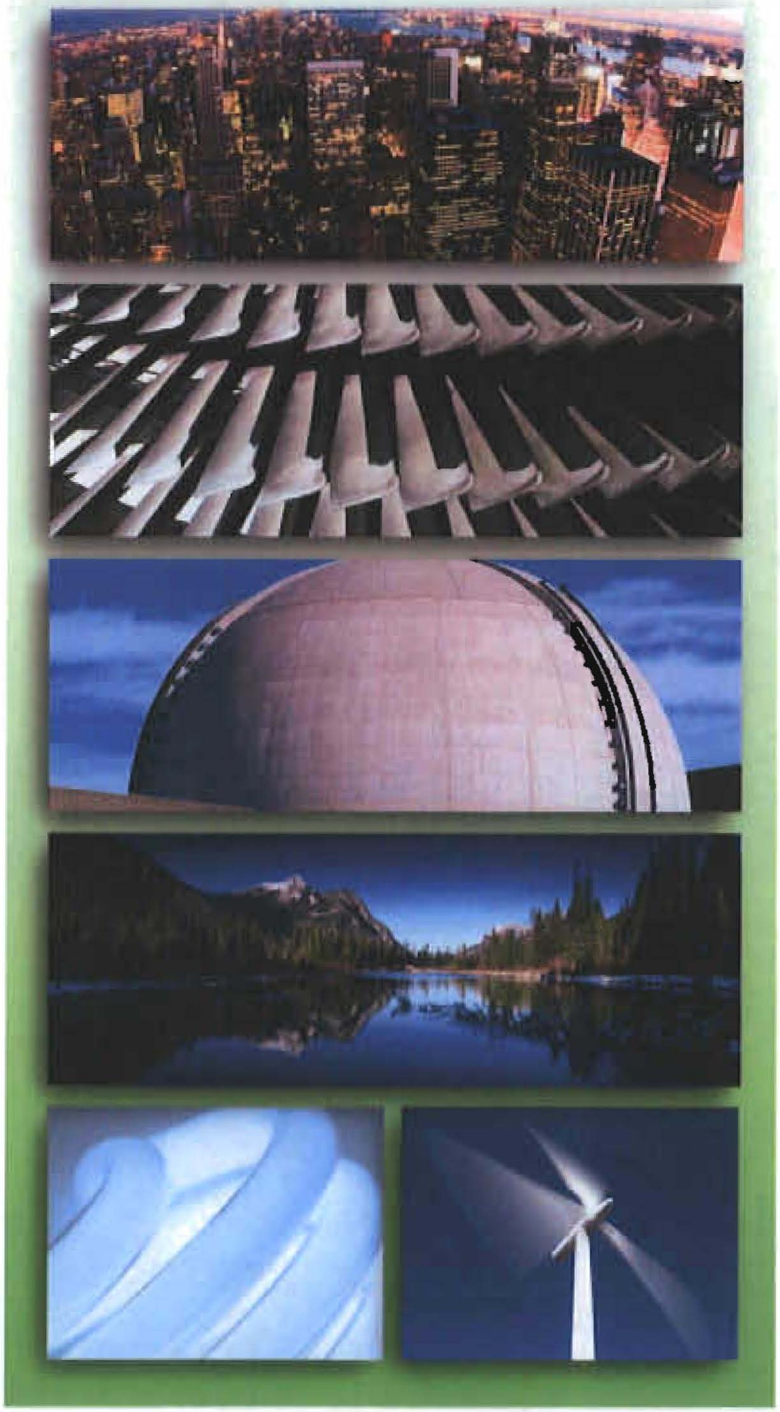

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Overview of Electric Energy Storage Options for the Electric Enterprise

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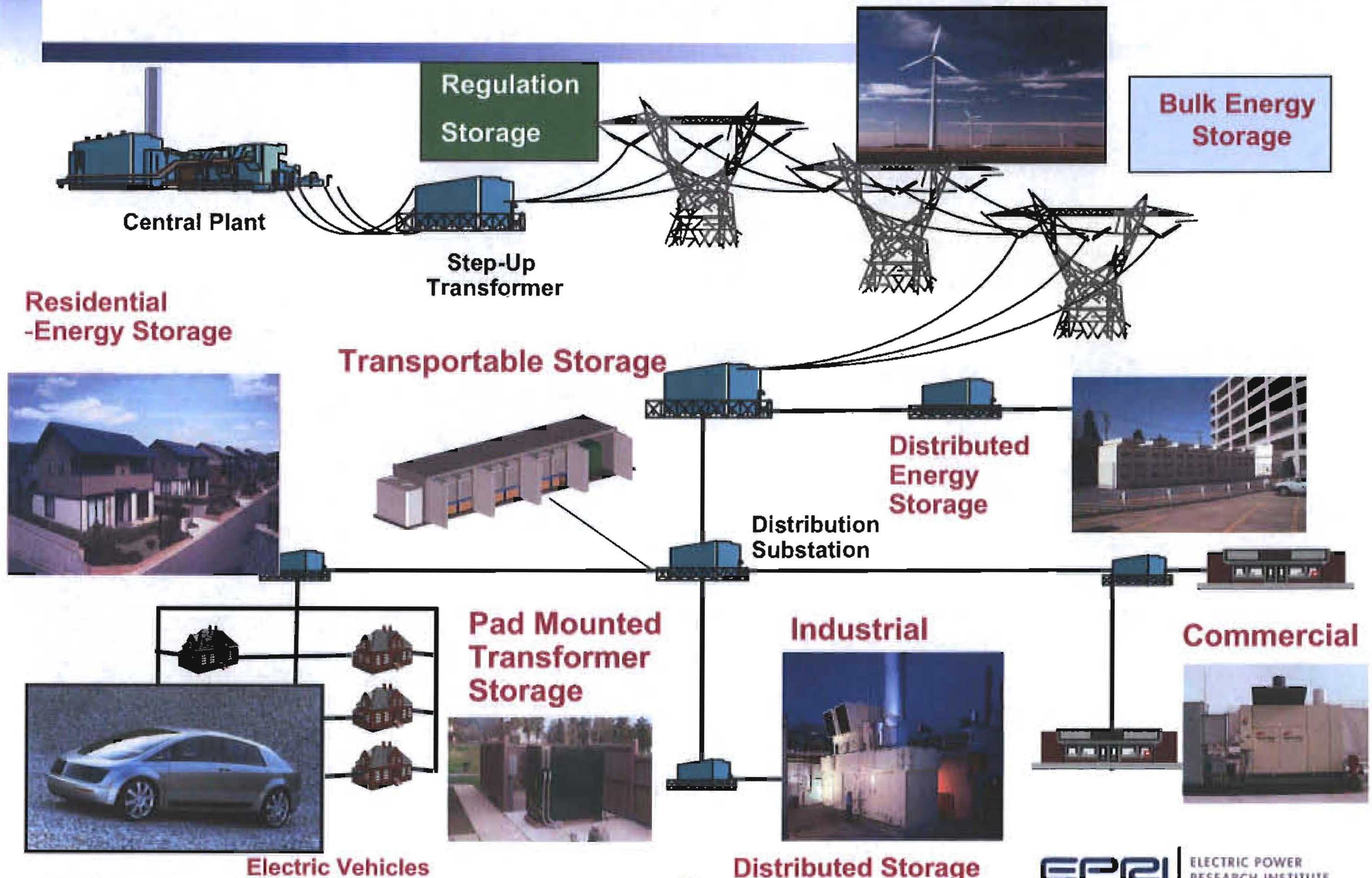
Utility Interest in Electric Energy Storage




- Managing Increased Wind Penetration
- Ancillary Services – Avoiding the cycling of thermal power plants
- Managing Grid Peaks and Outage Mitigation
- Increasing the value of Distributed Photovoltaic systems
- Enhancing the value of a Smart Grid

Utility Interest in Electric Energy Storage

Locational Opportunities for Energy Storage in the Electric Enterprise



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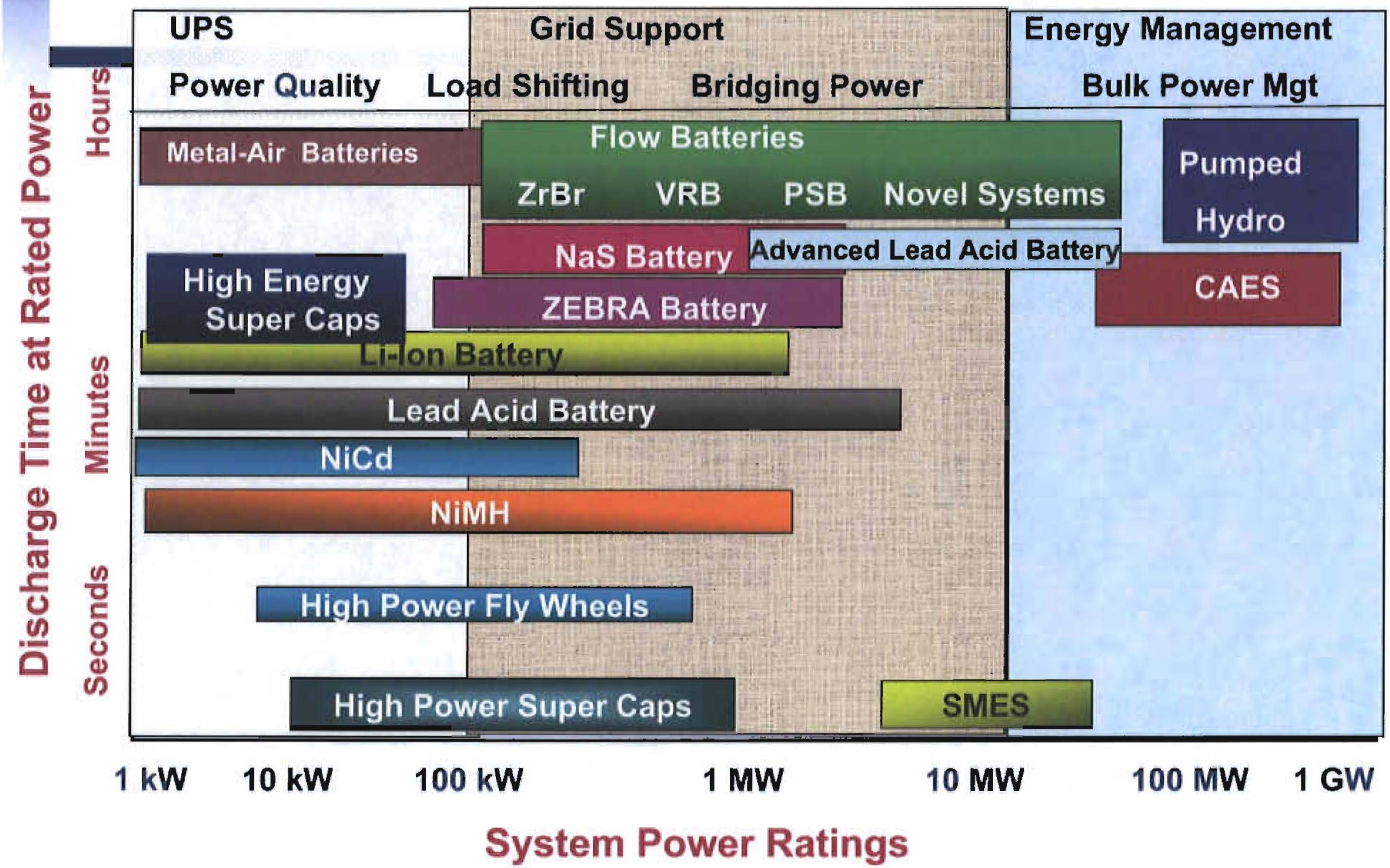
Positioning of Energy Storage Options



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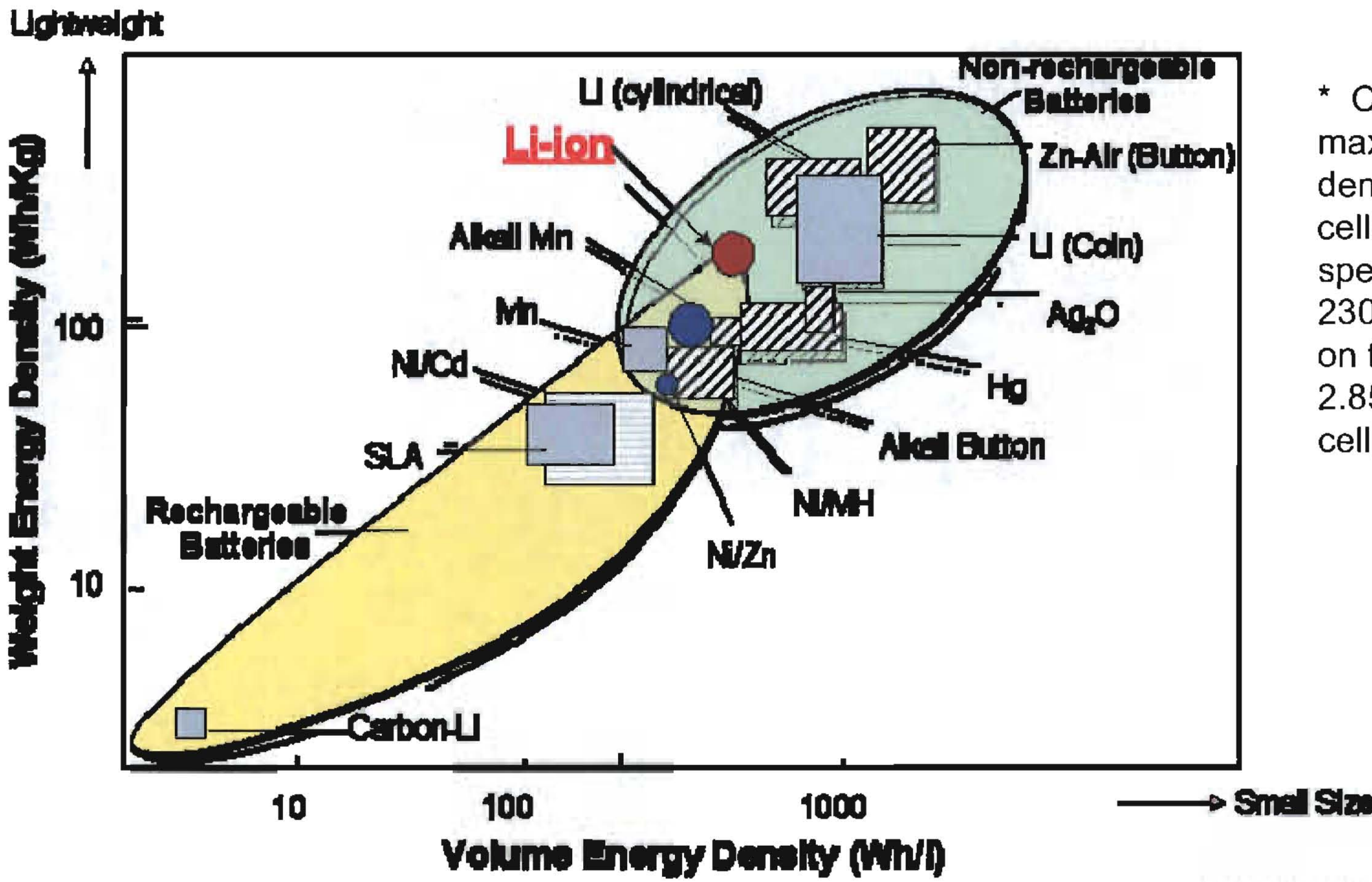
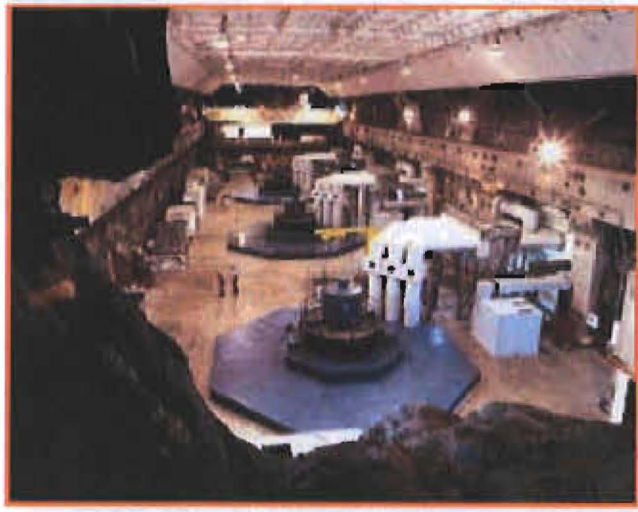
Lithium-ion batteries - Most Energy in the Smallest space.



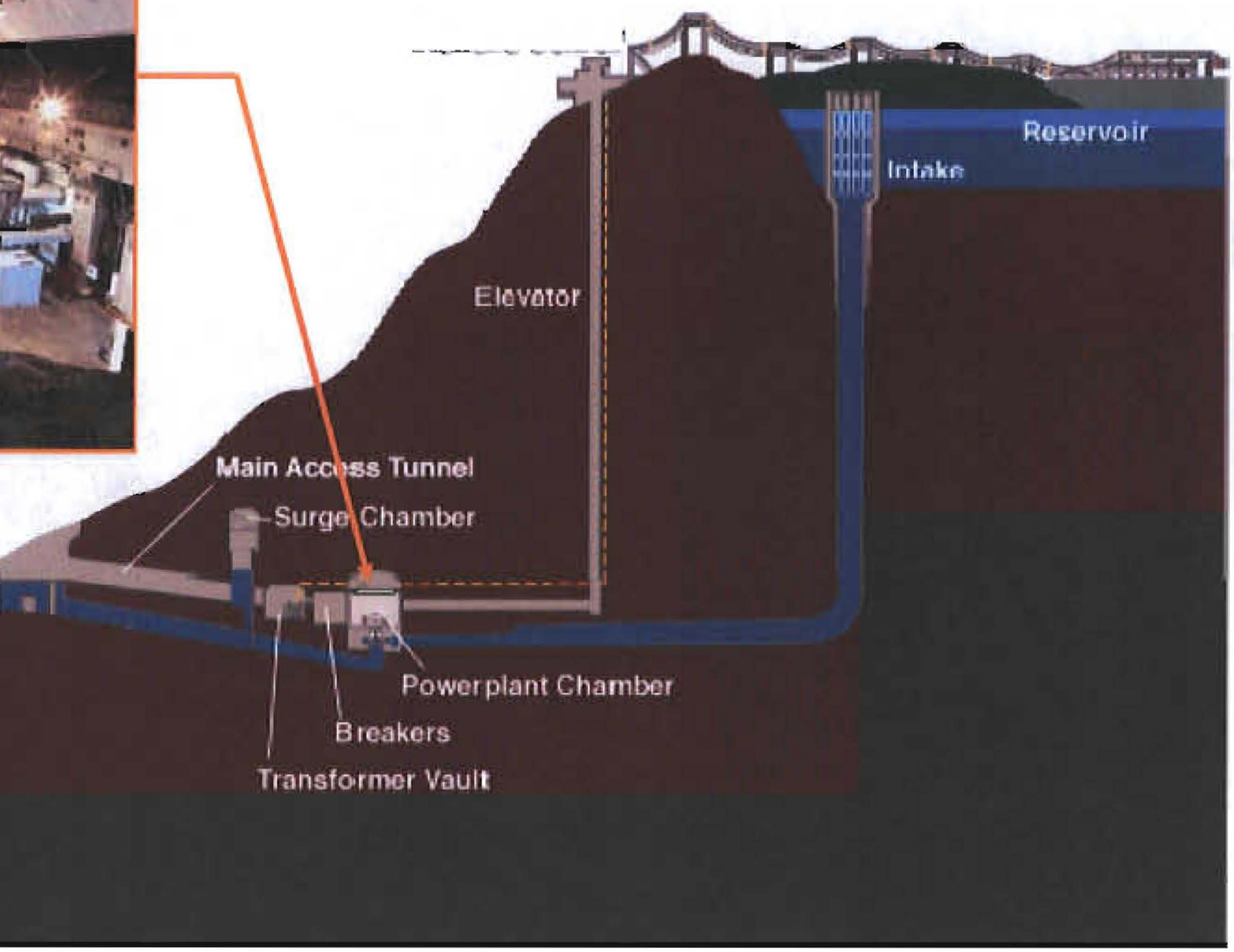
Created by TIAX based on Osaka, Y. Nishi, T. Kawase, *Key Technology Battery*, P21, Maruzen (1996)

* Currently, the maximum energy density for Li-ion cells 630 Wh/l and specific energy is 230 Wh/kg (based on the Panasonic 2.85 Ah 18650 cell).

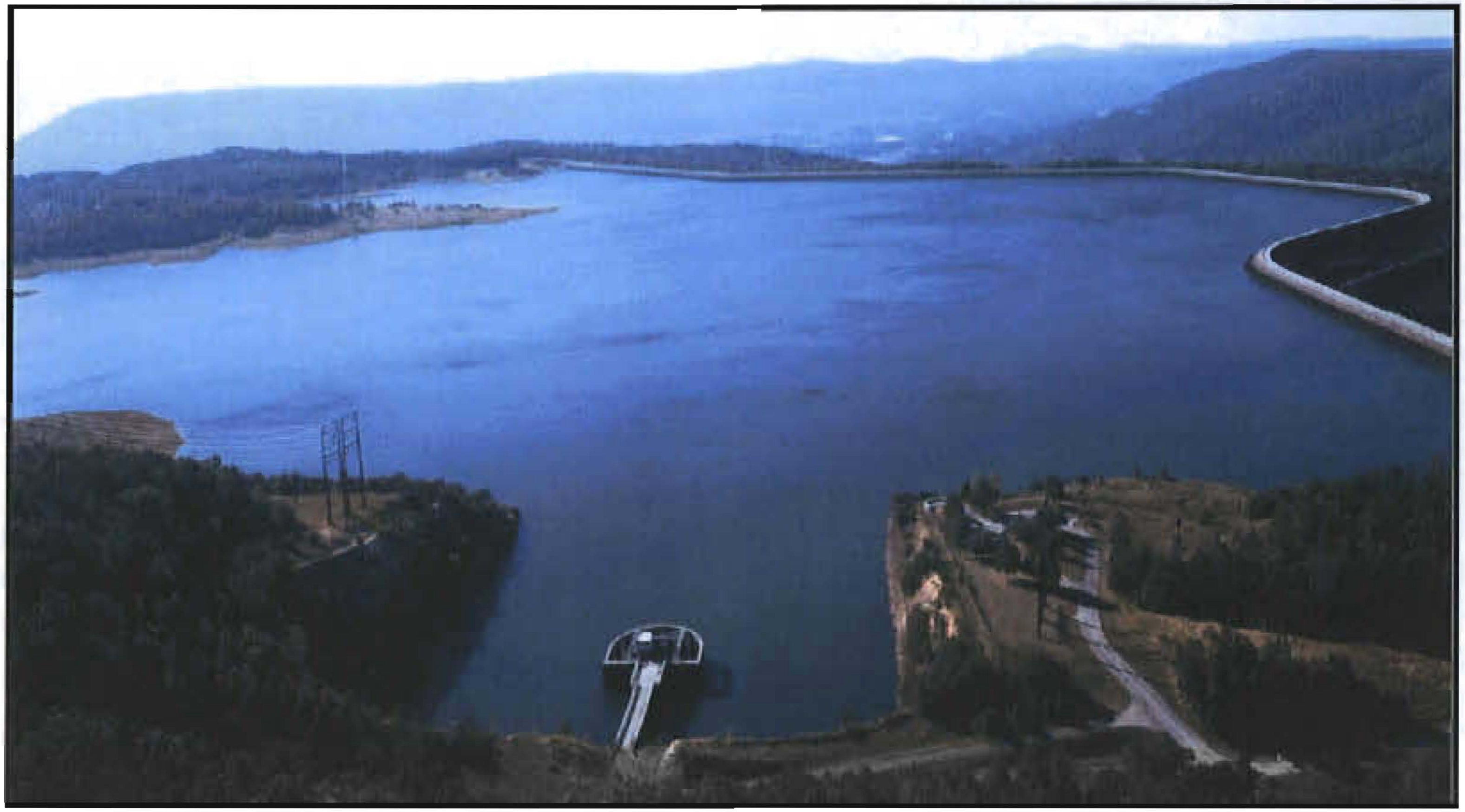
Pumped Hydro



PG&E's 1.2 GW Helms
Pumped Hydro Facility

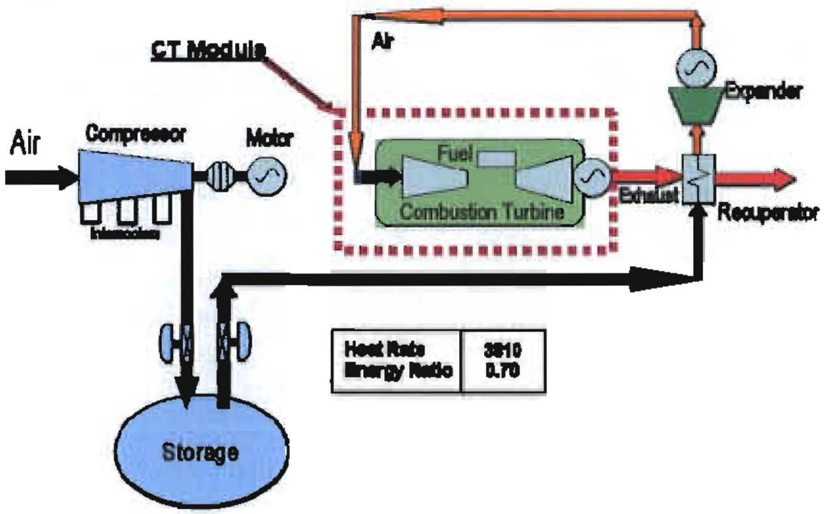


Pumped Hydro Energy Storage Plant



Man-Made Upper Reservoir of TVA's Raccoon Mountain PH Plant
Operational Date: 1979; Capacity: 1620 MW; Max. Discharge Duration: 22 hrs

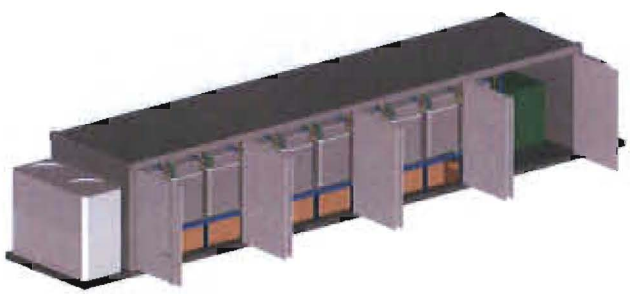
EPRI's Current Energy Storage Research Portfolio



400 MW / 10 hr CAES

1 MW / 7 hr NaS

1 MW / 15 min Li-ion



0.5 MW / 4 hr ZnBr

20 kWh Li-ion System

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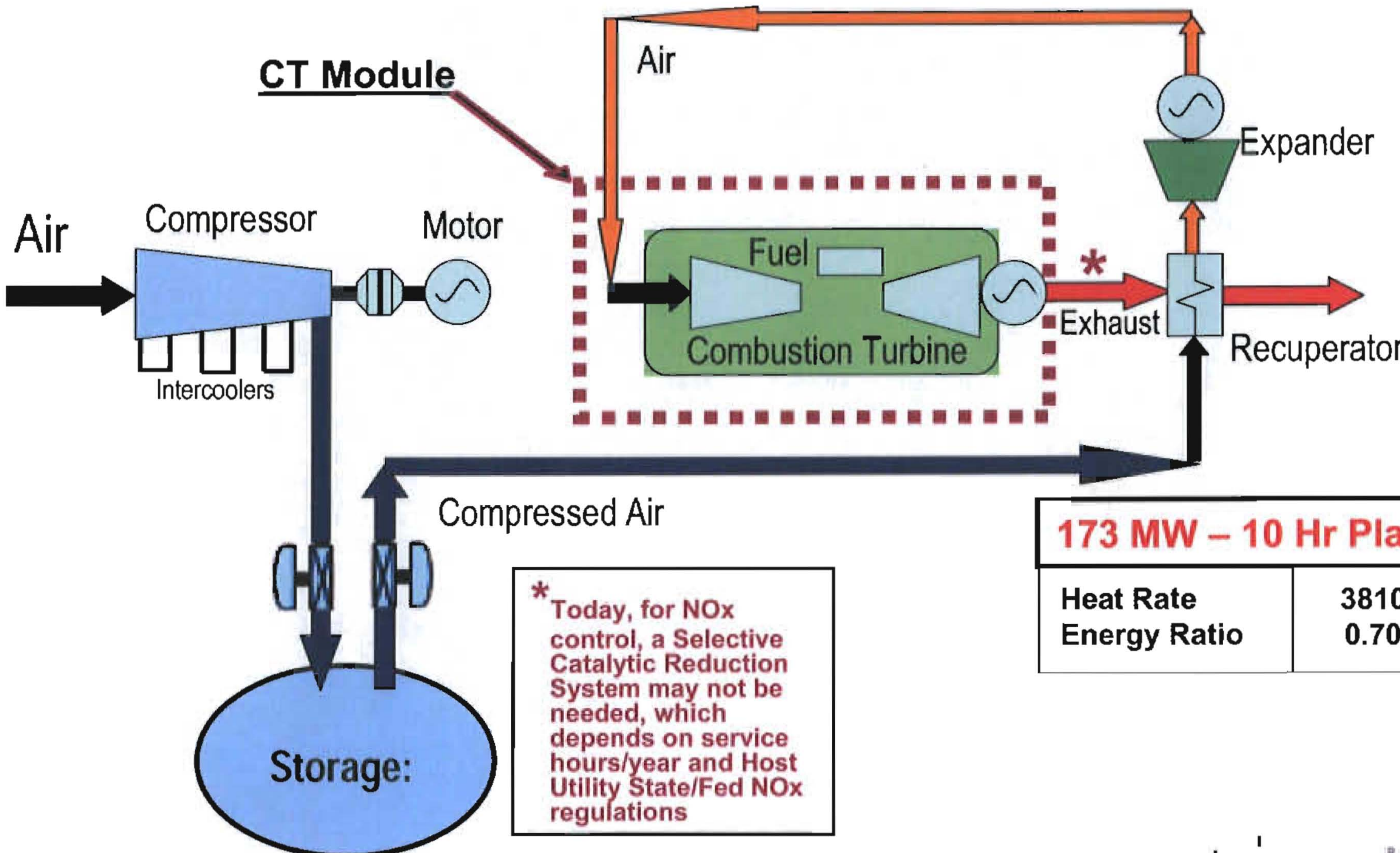
2nd Generation Compressed Air Energy Storage Plant Ready for Field Demonstration and Deployment



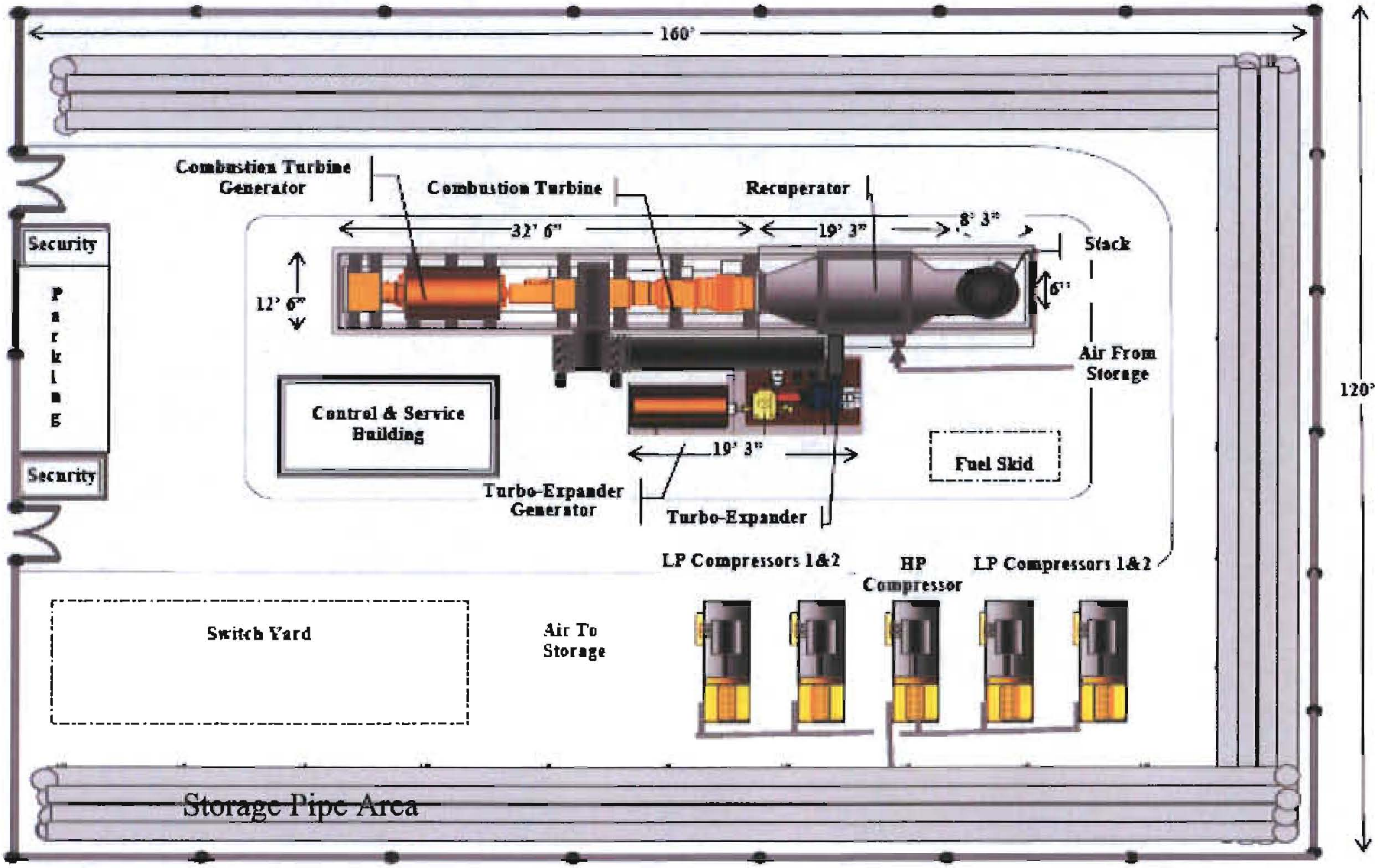
*Today, for NOx control, a Selective Catalytic Reduction System may not be needed, which depends on service hours/year and Host Utility State/Fed NOx regulations

173 MW – 10 Hr Plant

Heat Rate	**3810**
Energy Ratio	**0.70**

Above Ground CAES

15 MW – 2 Hour CAES Plant Using Above Ground Air Store based on Gas Pipeline Technology



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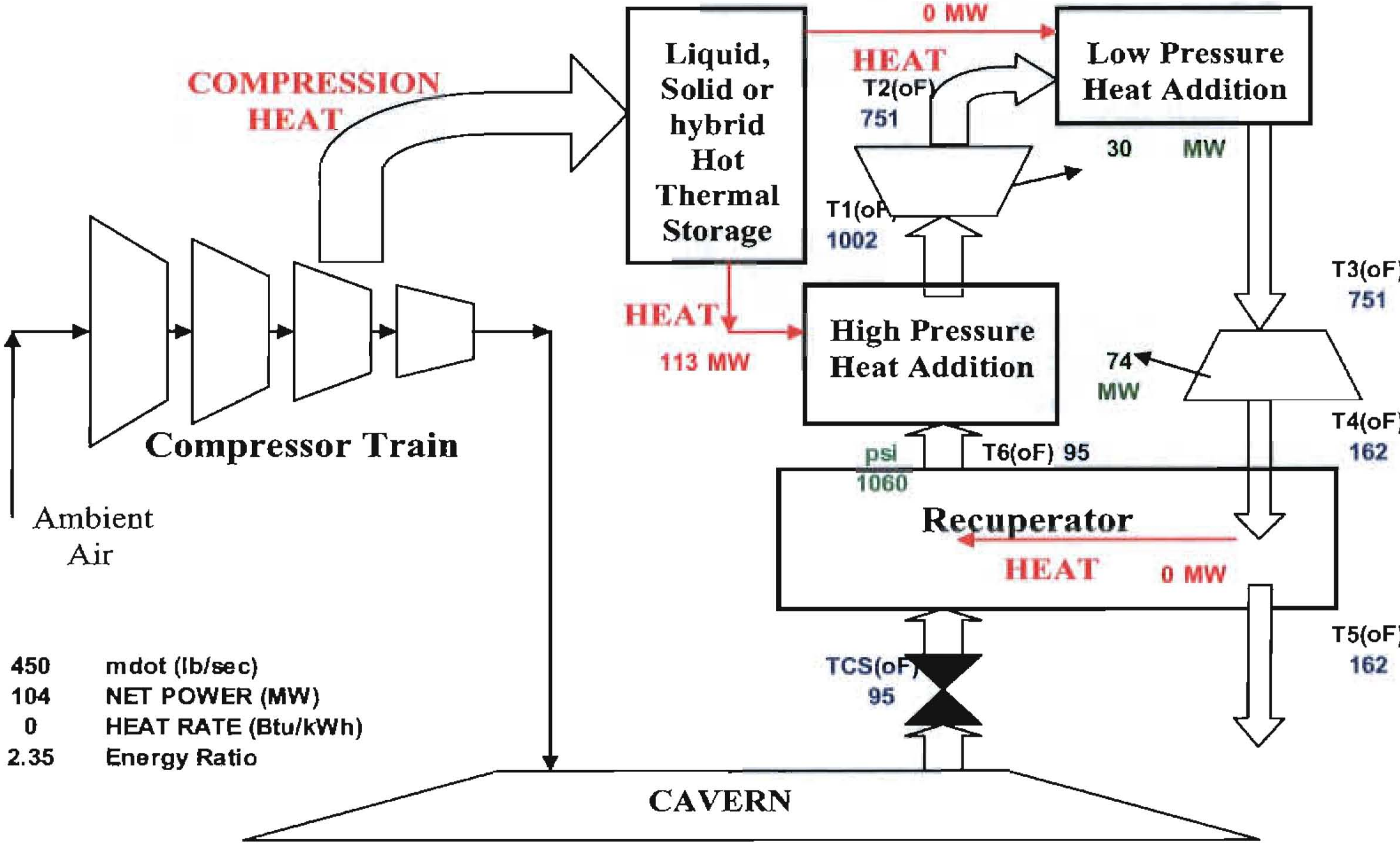
Advanced CAES Cycles - Still in Early R&D Phase

Adiabatic Systems will not require fuel



450	mdot (lb/sec)
104	NET POWER (MW)
0	HEAT RATE (Btu/kWh)
2.35	Energy Ratio

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Utility-Scale PV Generation

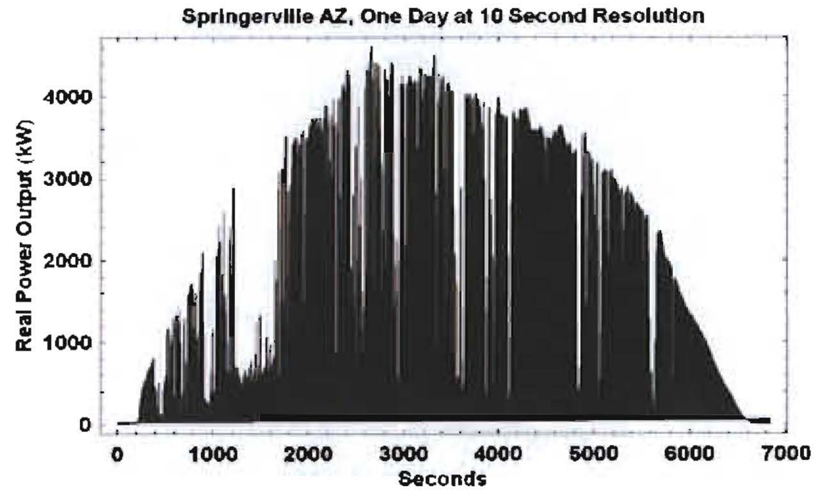
Power Tower and Dish Stirling Engine

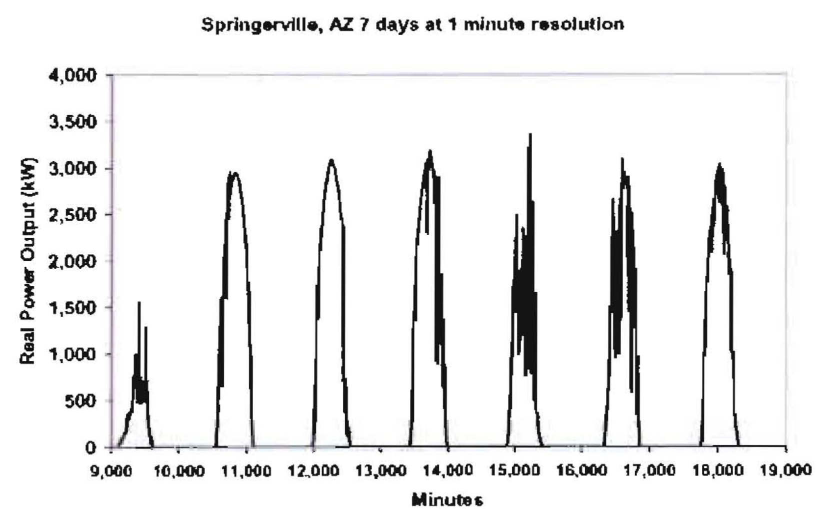
210-kV grid support at substation

Hybrid Gas-Solar Thermal Troughs

Short-term Support for Large-Scale Solar PV

- Solar photovoltaics exhibit short-term variable power output from cloud cover and other sources
- Forms an integration issue
- Short-duration storage (seconds to minutes) can help mitigate these fluctuations by reducing ramp rates
- Requires storage with high-cycle life and power density, without requiring large durations





Jay Apt and Aimee Curtright "The Spectrum of Power from Utility-Scale Wind Farms and Solar Photovoltaic Arrays", Carnegie Mellon Electricity Industry Center Working Paper, CEIC-08-04

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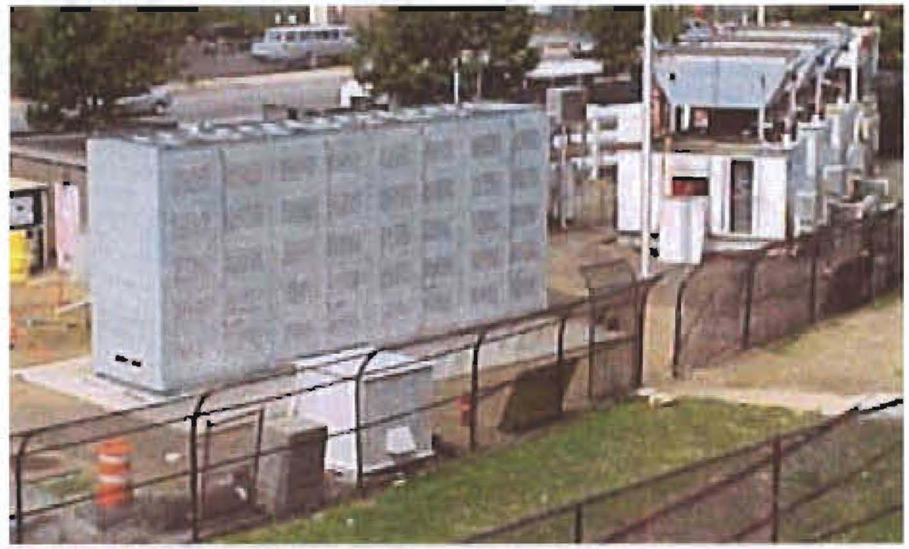
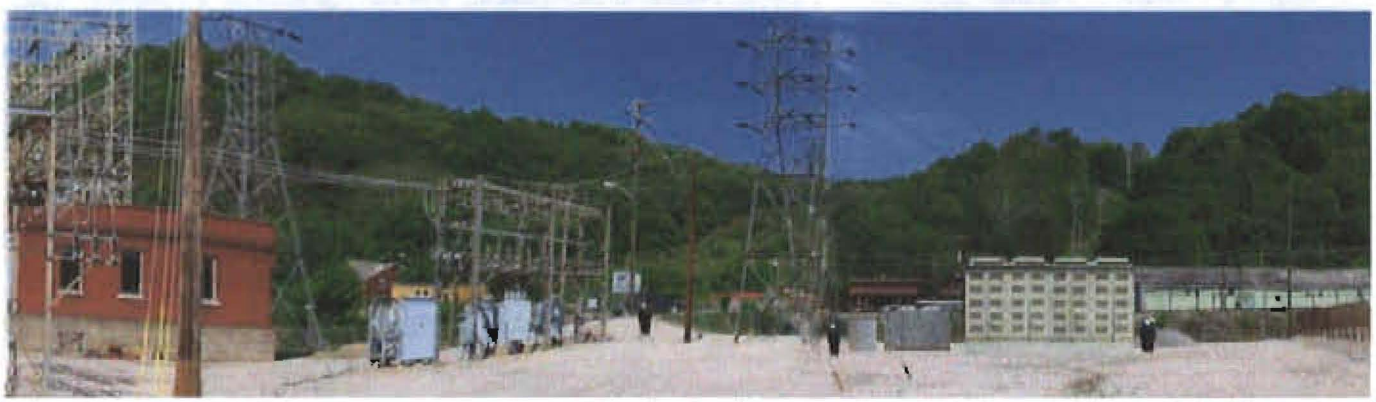
Sodium Sulfur Batteries - NaS

Grid Support and End-user Peak Shaving Applications

6MW / 48MWh at TEPCO's Ohito Substation

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





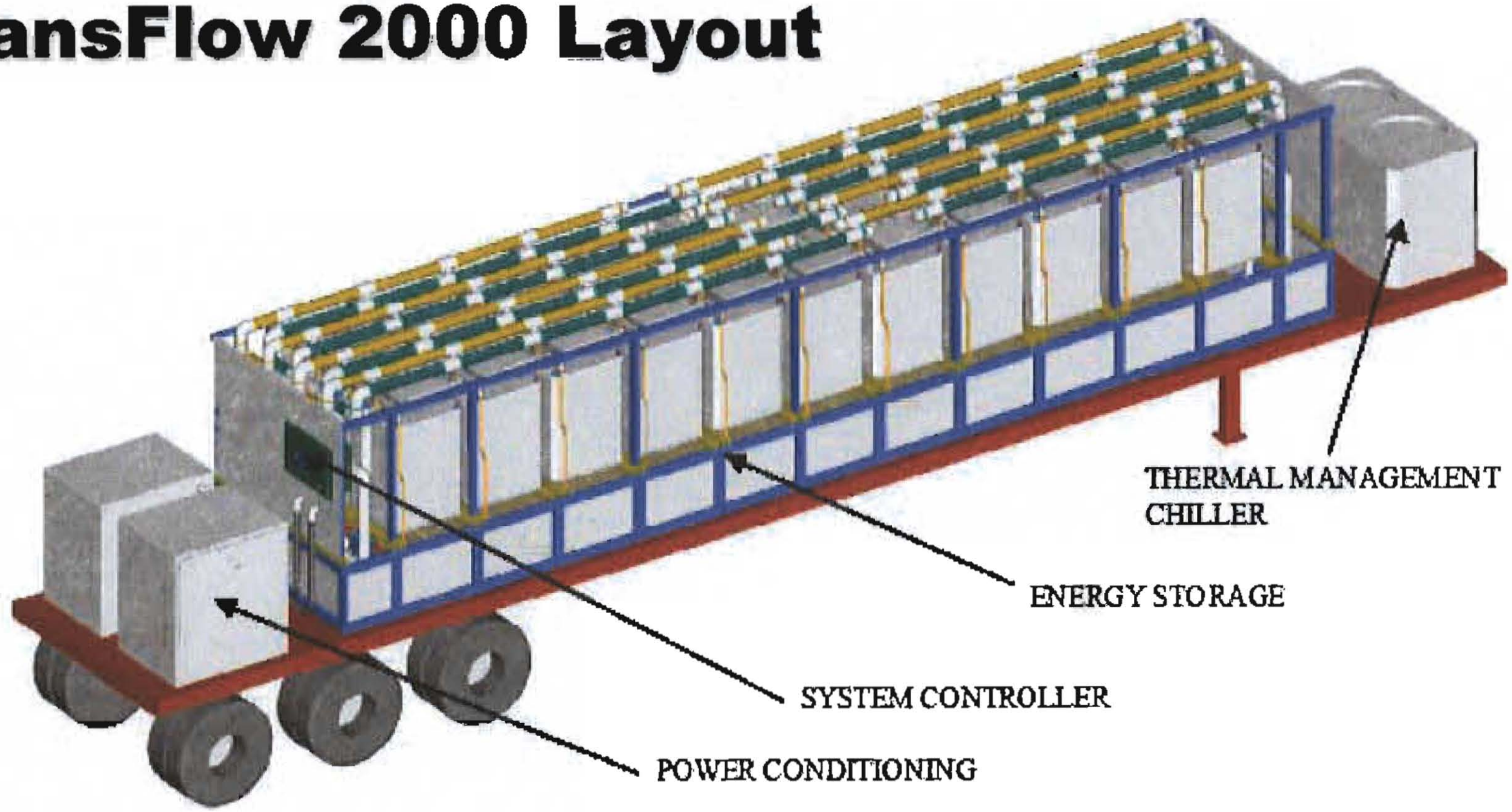
1 MW / 7.2 MWh NAS

AEP Substation

Flow Batteries – Zn / Br

Gaining Utility Consideration for Grid Support Applications

TransFlow 2000 Layout



0.5 MW / 2 MWh

Design by Premium Power Corporation

Zn / Br Flow Batteries (ZBB Energy Corporation)

- Manufactures and sells grid-scalable flow battery systems (calls their product regenerative fuel cells)
- Based in US and Australia
- Two major products: 50 kWh and 500 kWh systems
- Systems positioned for early field demonstration and deployment.

Vanadium Redox Flow Battery Applications

Product Availability Uncertain at this time- One Vendor Restructuring B-Plan

- Several VRB batteries have already been installed
  - 250 kW, 2 MWh unit at Castle Valley, Utah (PacifiCorp)
  - 200 kW, 800 kWh unit at King Island, Tasmania (HydroTasmania)
  - 4MW, 6MWh unit at Tomamae, Hokkaido (JPower)
  - A number of smaller units based on VRB Power's 5kW modules

Other Battery ReDox Couples are Emerging and are still in the R&D Phase

- Zn / Air
- Al / Air
- Fe / Cr
- Zn / Cl
- H_2 / Br
- H_2 / Air

Advanced Lead Acid Batteries - Source: Xtreme Power

1 MW / 4 hr Systems -Ready for Field Trials and Demonstrations

- 1 kWhr @ 3 Hour Rate
- 25 kW Instant. Power
- 5" x 5" x 30"
- 57 Lbs (25.9 kg)
- 12V Cell
- Improved ability to deep cycle

- Solid State "Dry Cell
- Improved Cycle life
- Improved efficiency

Technology entering market Applications in Wind Hawaii); Peak Shaving; and Ancillary Services

1 MW / 4 hr system ~ $ 2 M

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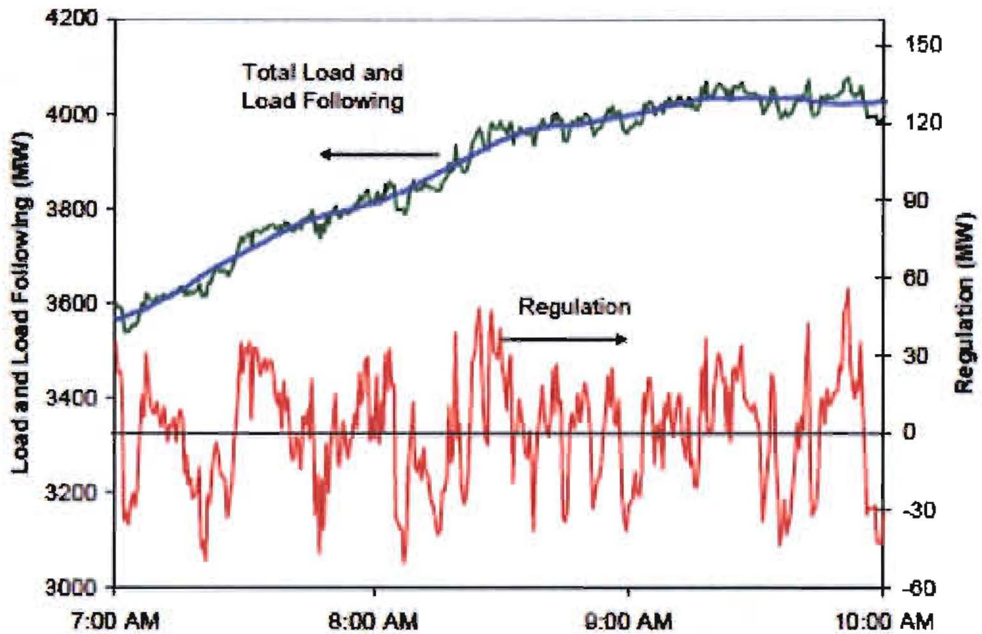
Grid Frequency Regulation Opportunities for Fast Storage Systems



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

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2 MW Lithium Ion System for Frequency Regulation at AES Power Plant

Early Field Trials by

- **Altari Nano**
- **A123**

Flywheel Energy Storage

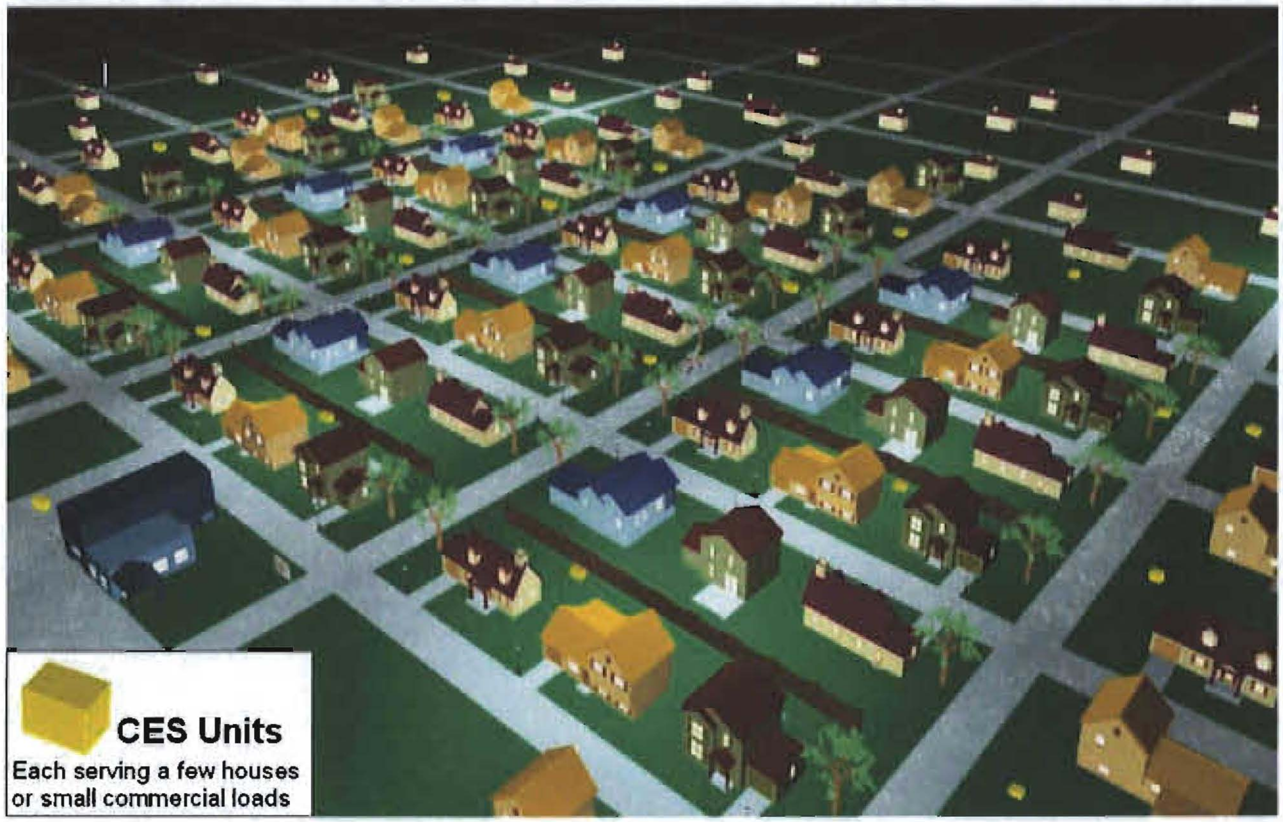
High-Speed Beacon Flywheels Used For Frequency Regulation (Rating of Each FW: 100KW for 15 Min. Discharge)

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 tc a 40-megawatt swing. Photo Courtesy Beacon Power.

Emerging Li-ion Energy Storage Systems

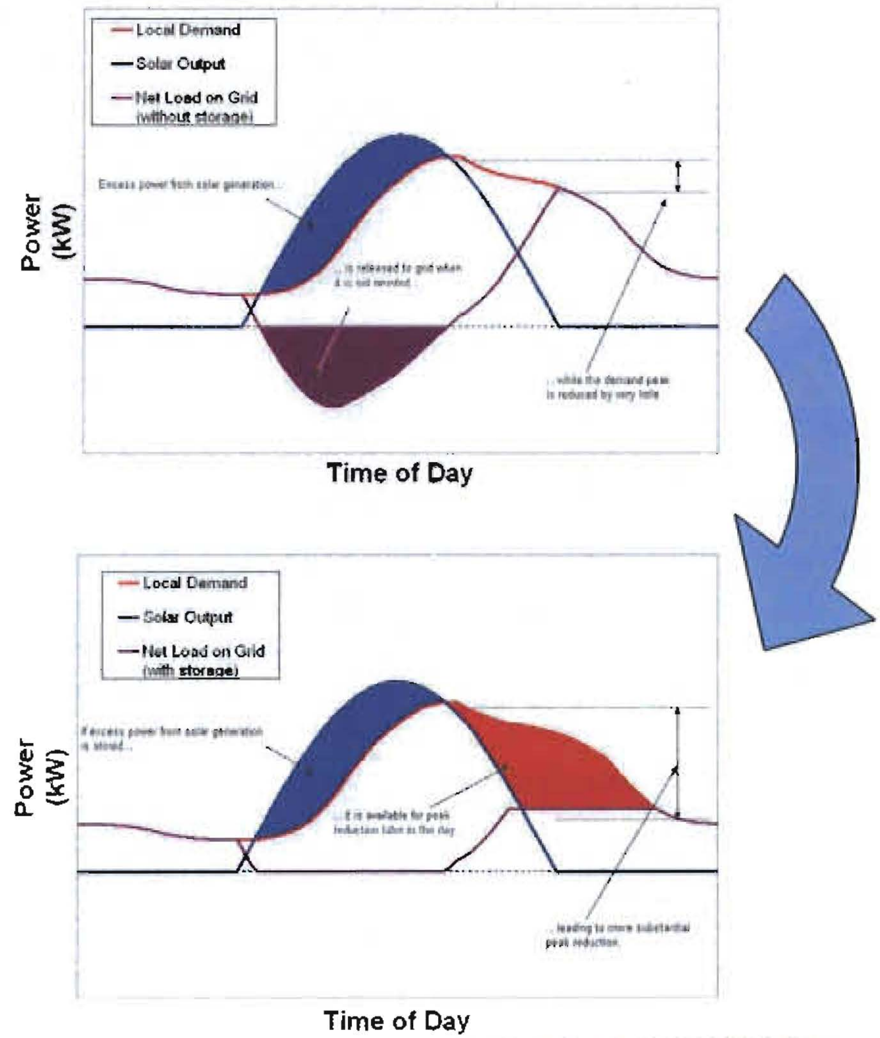
- Fully Integrated Systems
- Numerous Applications:
  - Neighborhood Storage
  - Home / PV
  - Backup / UPS / Dispatachable
- EPRI planning to test several systems in 2009
- Future positioning for Smart Grid Demonstrations.

Potential Applications
Community Energy Storage (CES)



Source: American Electric Power (AEP)

Energy Storage to Improve PV Support for Grid Integration



- PV generation does not align fully with residential demand – leaving excess PV early in the day and unmet demand late in the day.
- Charging storage at night can reduce purchase during peak-rate periods.

Plug-In Hybrid and Electric Vehicles Are Coming

Opportunities to Leverage and Use Storage System in Stationary Markets

PHEV or EREV

Production

Saturn VUE
2-Mode Blended
Intro: 2011 CY

Chevrolet Volt
Extended Range EV
40-mile EV range
16kWh Li-Ion
Intro: 2010 CY

Demo

Ford Escape PHEV
2008 CY, 21 car fleet
with SCE/EPRI/Utilities

Ford/Eaton Trouble Truck
10 truck fleet w/ utilities

Toyota Prius PHEV
500-car fleet
2009 CY

VW Golf TwinDrive
30 mile EV range
20-car fleet, 2009

EV

Production

Nissan
2010 CY

Daimler Smart ForTwo
2010 CY

Mitsubishi iMIEV
2010 CY, 100 mile range,
PG&E, SCE demo

Demo

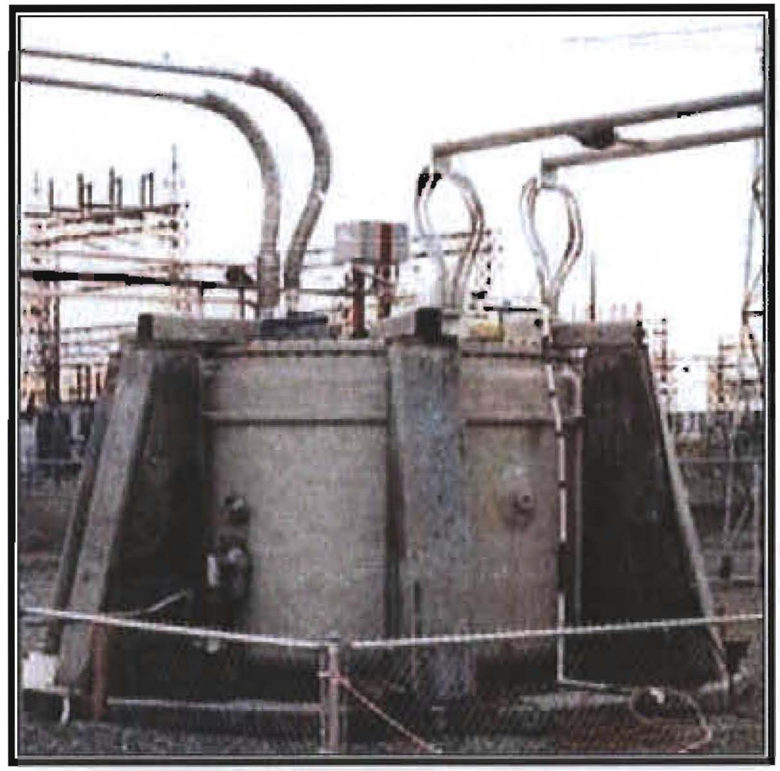
Dodge ZEO
150-200 mile range

BMW Mini E
150 mile range
500 car fleet
2009 CY

Subaru R1e
50 Mile AER
10-car fleet 2008 CY

Superconducting Magnetic Energy Storage (SMES)

- SMES can be used for Power Quality (PQ) and Increased Transmission Asset Utilization Applications
- About 6 Small Plants Are in T/D Operation For PQ Application (1 to 3 MW, with 1 to 3 Seconds of Storage)
- High Temperature Superconductors Will Lower SMES Costs



10 MW – 3 Sec. Coil Tested For Transmission Stability

A Snapshot of current Energy Storage System Costs

Energy Storage Technologies Capital Cost Estimates (EPRI Estimate, February 2009)

Storage Type (See footnotes)	$/kW	$/kWh	Hours[4]	Total Capital, $/kW
Compressed Air Energy Storage Large (100-300 MW Underground storage))	590-730	1-2	10	600-750
Small (10 - 20 MW Above ground storage)	700-800	200-250	3	1300-1550
Pumped Hydro Conventional (1000 MW)	1300	80	10	2100
Battery (10 MW)				
Lead Acid, commercial	420-660	330-480	4	1740-2580
Sodium Sulfur (projected)	450-550	350-400	4	1850-2150
Flow Battery (projected)	425-1300	280-450	4	1545-3100
Lithium ion (small cell)	700 - 1250	450 - 650	4	2300 - 3650
Lithium ion (large cell, projected)	350 - 500	400 - 600	4	1950 - 2900
Flywheel (10 MW)	3360-3920	1340-1570	0.25	3695-4313
Superconducting Magnetic Storage commercial	200-250	650,000-860,000	1 sec	380-489
Supercapacitors (Projected)	250 - 350	20,000 - 30,000	10 sec	300 - 450

1. In this table, Total Capital Cost = $/kW + (Number of Hours x $/kWh)
2. All figures are rough order -of -magnitude estimates and are subject to changes as better information becomes available
3. Total capital costs include power conditioning system and all equipment necessary to supply power to the grid. Not included are battery replacement costs, site permitting, interest during construction and substation costs.
4. These costs are for the hours shown ±25%
5. Cost may vary depending on the price of comodity materials and location of project

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Markets and Applications for Energy Storage Systems

Utility Side of the Meter

- Wind Integration: Smoothing / Bulk Storage
- Substation Grid Support
- Ancillary Services: Frequency Regulation
- Large-scale PV ramping support
- Neighborhood Storage Systems – (at pad-mounted transformers)
- Truck Transportable Power – urban load pockets

Customer (End-User Side of the Meter)

- PV – Distributed and Residential home
- Dispatchable Back-up Generators
- Dispatchable telecom backup
- Dispatachable UPS : Commercial / residential
- Peak shaving / Demand Response
- PHEV

Thanks for your Attention!

Together…Shaping the Future of Electricity

Dan Rastler

Program Manager, Energy Storage Program

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