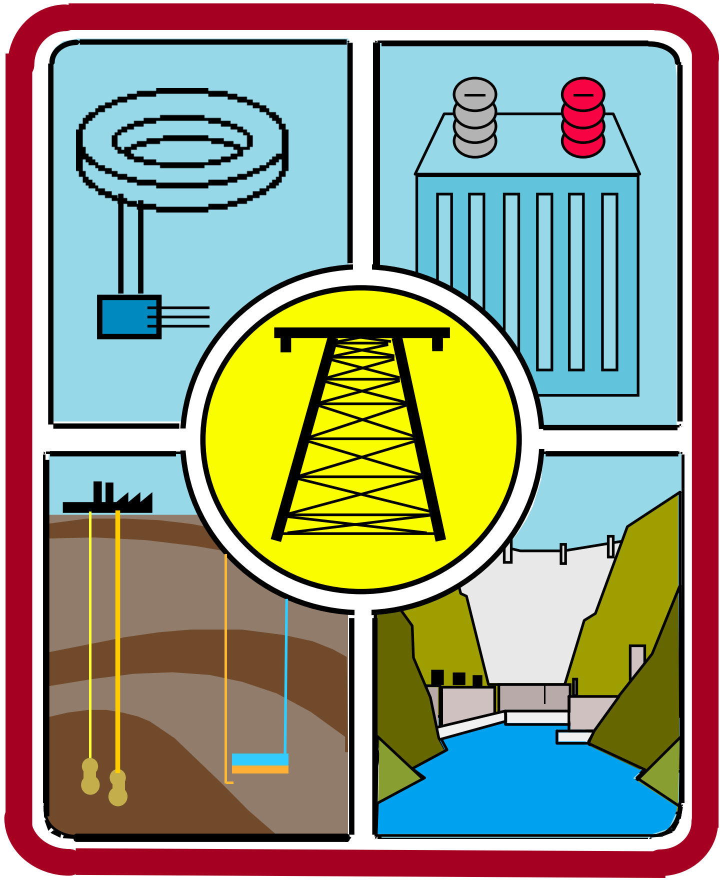
ELECTRIC POWER RESEARCH INSTITUTE



Executive Overview: Electricity Energy Storage

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Electricity Energy Storage:
Providing Energy When and Where its Needed!

Storage Moves Energy In Time…

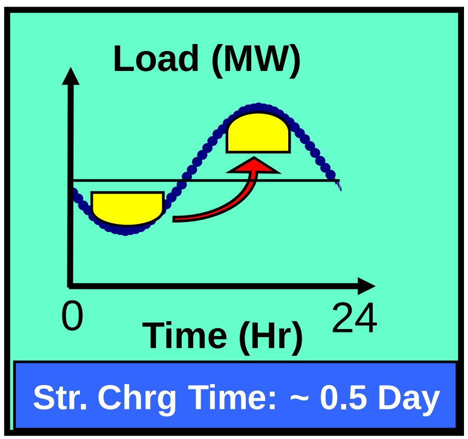
Just as Grid Operators Move Energy Through Space/Distance to the public

Energy Storage Resolves Wind/Solar Power Fluctuations, Ramping and Load Management Issues

Wind/Solar Plants Cause Ramping & Frequency Instabilities

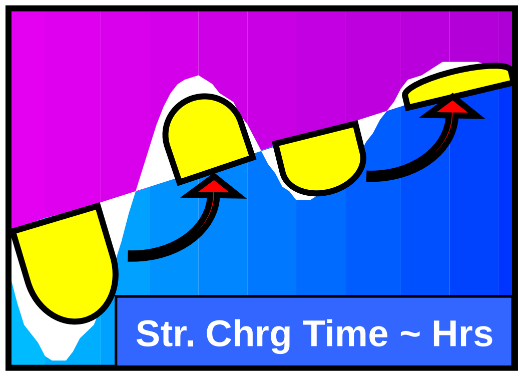
Wind Plants Inject Power In Off-Peak Time Periods

Load Leveling



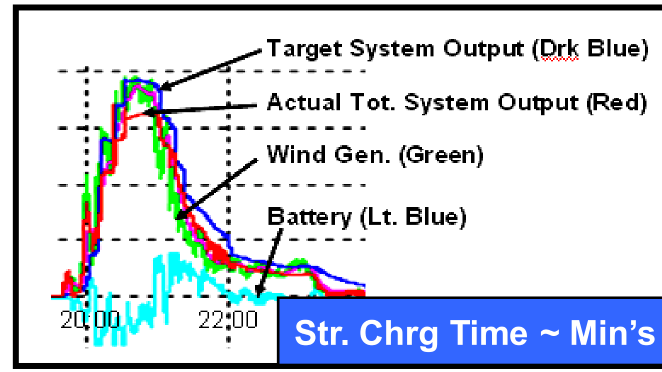
- CAES
- Pumped Hydro

Ramping: On the Ramp and Within the Ramp



- CAES
- Pumped Hydro
- Battery, Flow Type
- Note: For many utilities, ramping and reducing part load problems are high priority, especially due to power fluctuations from wind/solar plants

Frequency Regulation:

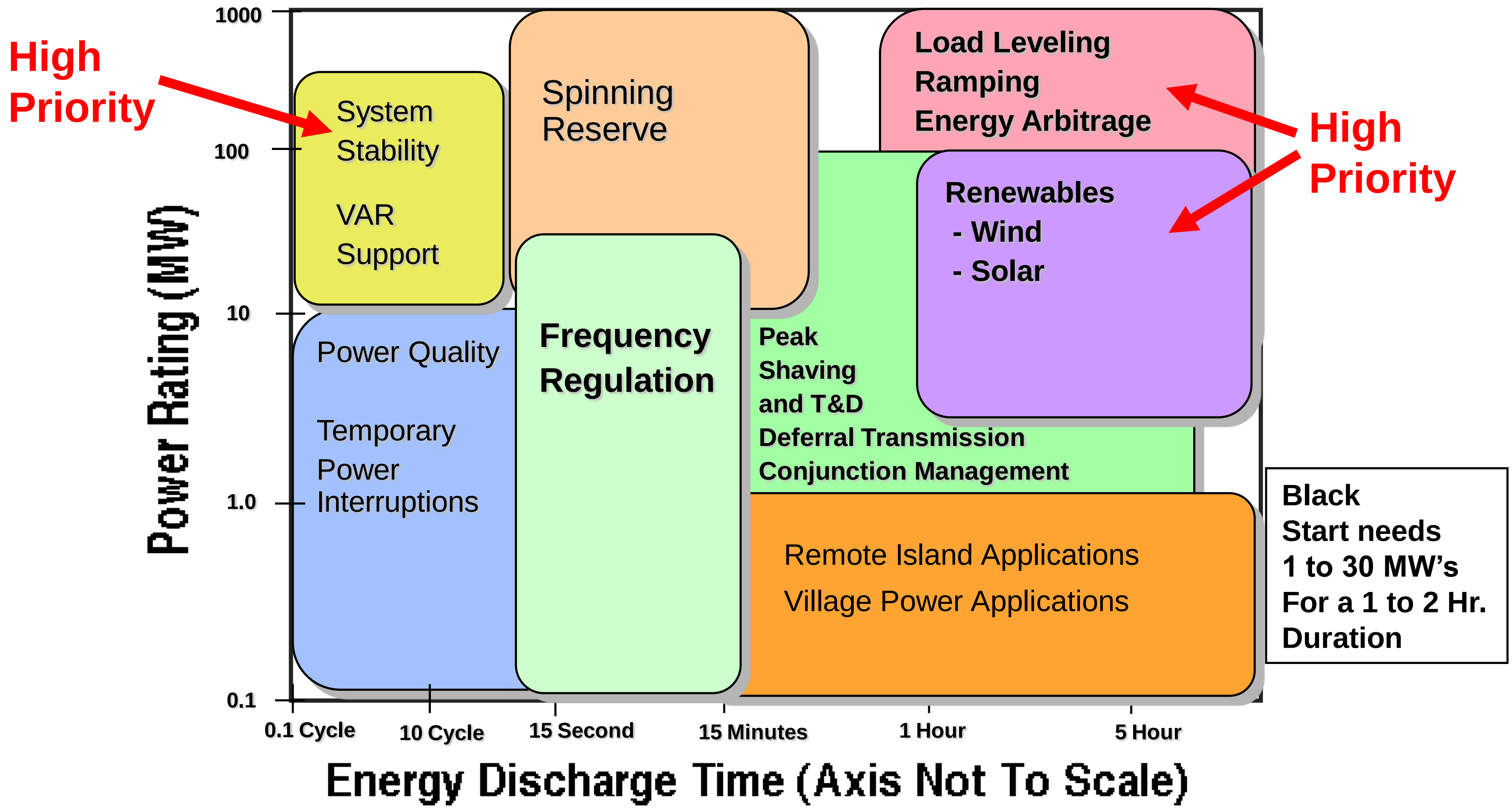


- Battery, Regular or Flow Type
- Super-Capacitor
- Flywheel
- Superconducting Magnetic Storage

Robert Schainker

Electric Energy Storage Applications

(All Boundary Regions Displayed Are Approximate)



Energy Storage Plants: Capital Cost Comparisons

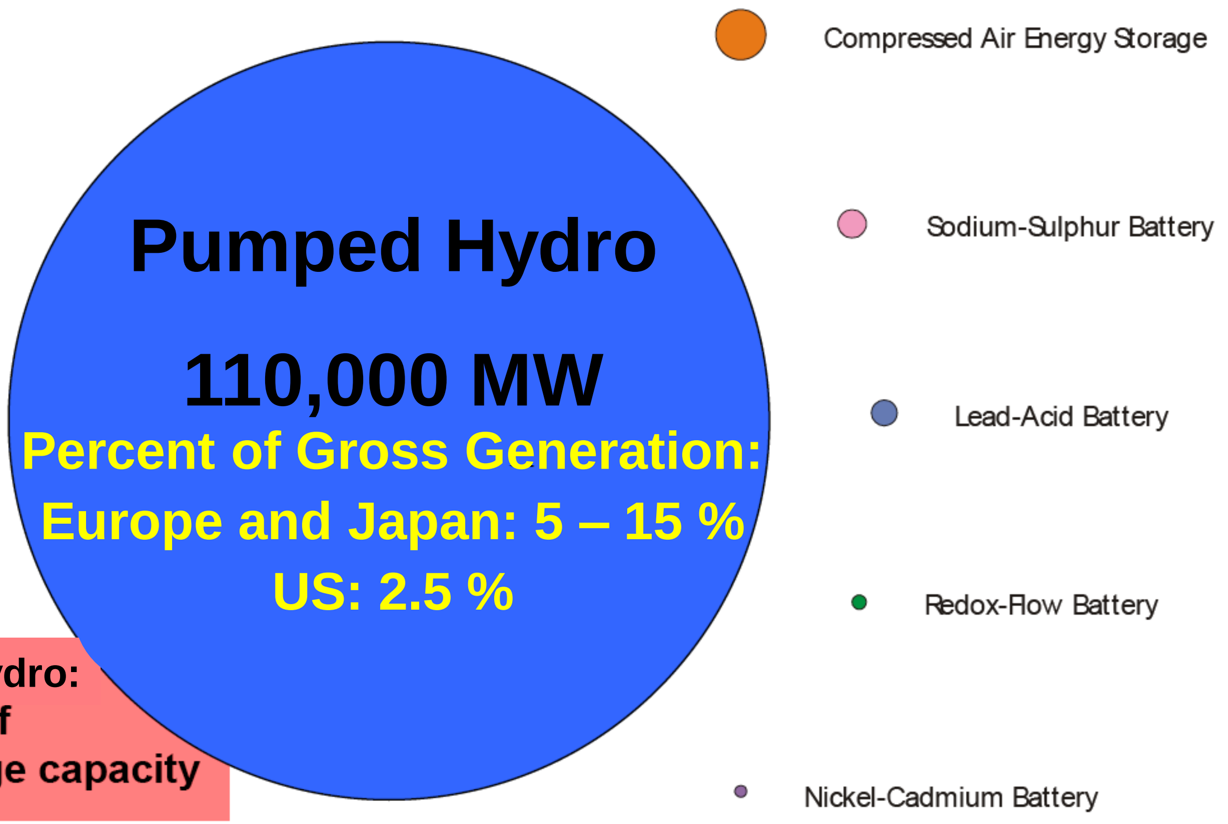
Technology	$/kW	+	$/kW-H*	x	H	=	Total Capital, $/kW
Compressed Air							
- Large, salt (100-300 MW)	640-730		1-2		10		650 to 750
- Small (10-20MW) AbvGr Str	800-900		200-240		2		1200 to 1380
- Small (10-20MW) AbvGr Str	800-900		200-240		4		1600 to 1860
Pumped Hydro							
- Conventional (1000MW)	1500-2000		100-200		10		2500 to 4000
Battery (10 MW)							
- Lead Acid, commercial	420-660		330-480		4		1740 to 2580
- Advanced (target)	450-550		350-400		4		1850 to 2150
- Flow (target)	425-1300		280-450		4		1545 to 3100
Flywheel (target) (100MW)	3360-3920		1340-1570		0.25		3695 to 4315
Superconducting (1 MW) Magnetic Storage	200-250		650,000 - 860,000		1/3600		380 to 490
Super-Capacitors (target)	250-350		20,000 - 30,000		1/360		310 to 435

* This capital cost is for the storage "reservoir", expressed in $/kW for each hour of storage. For battery plants, costs do not include expected cell replacements. The cost data are in 2009 $'s and are updated by EPRI periodically. Costs do not include permits, all contingencies, interest during construction and the substation.

This column determines how many discharge hours one can afford to build.

Pumped Hydro: World Wide, Most Widely Used Energy Storage Technology

Worldwide installed storage capacity for electrical energy (2008)



Pumped Hydro: over 99% of total storage capacity

Source: Fraunhofer Institute and EPRI

Barriers to Implementation of Energy Storage Technologies (1 of 2)

Institutional

- Asset Type: Generation, Transmission or Separate Category ?
- Multiple benefits across distribution, transmission and generation systems

Economic

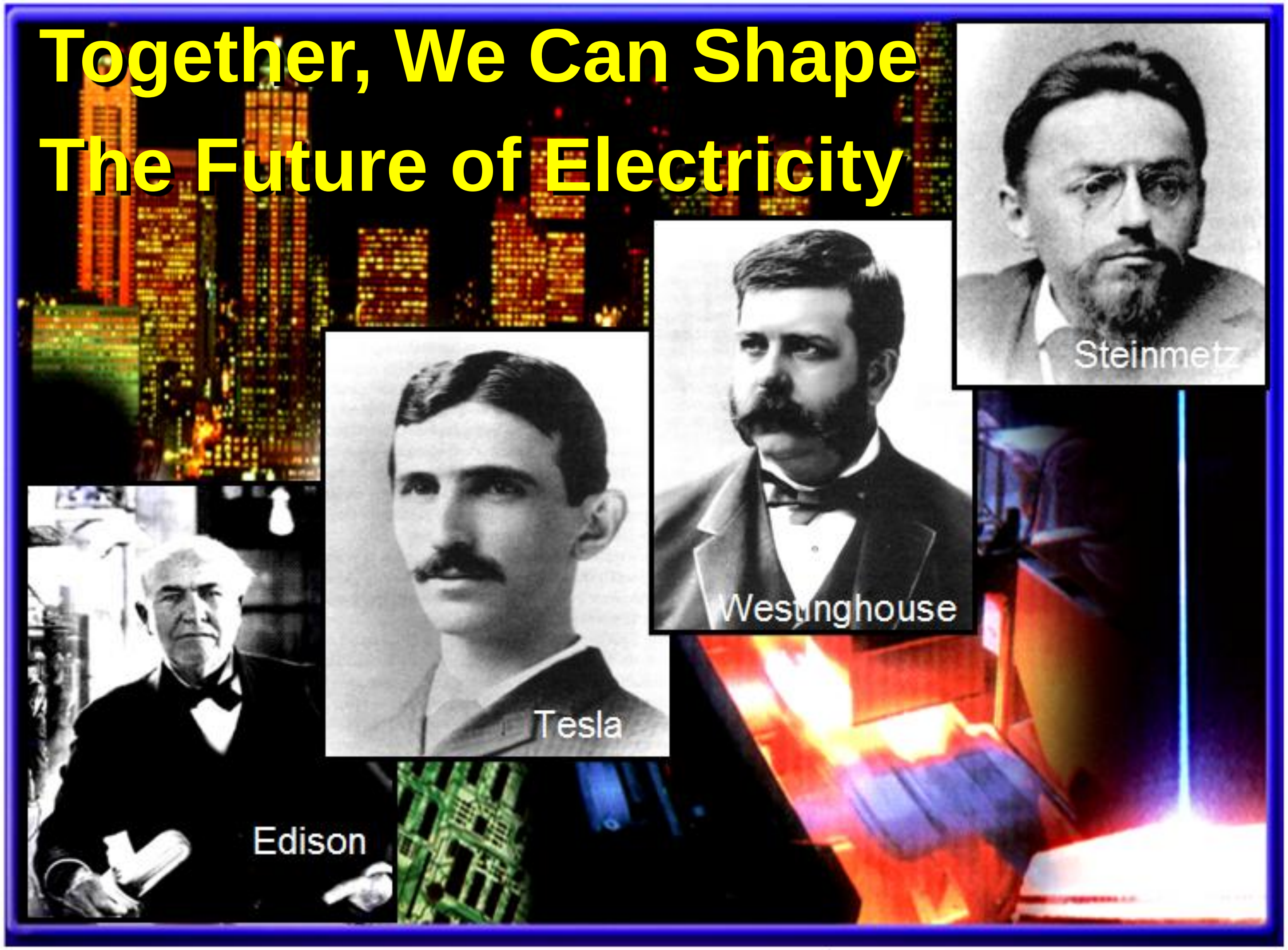
- Some storage plants have short or uncertain life
- Some storage plants have high cost
  - Need volume & competition
  - Need Incentives

Barriers to Implementation of Energy Storage Technologies (2 of 2)

Technical

- Verifiable data on real life performance, reliability and cost
- Standard language for “smart grid” communications to enable storage at the grid operation, transmission and distributed levels
- Industry standards for planning, designing, operating and life cycle management of energy storage technologies

Thank You For Your Attention !

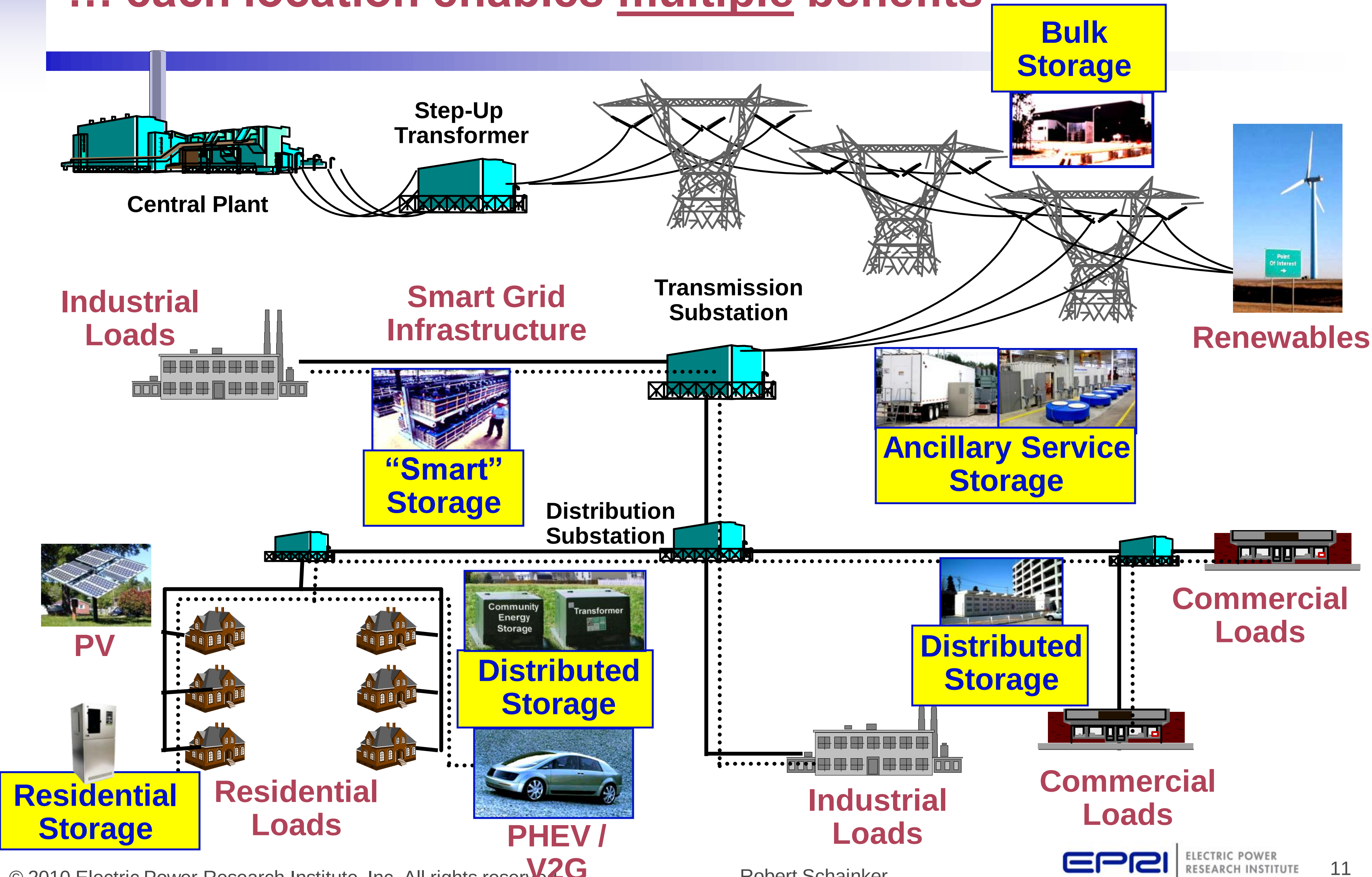


Historical Perspective

- Historical foundations for utility electric energy storage:
  - Pumped hydro (US: ~2.5%; Europe and Japan: 5 - 15%)
  - EPRI Prototypes: Chino Battery (~1988); McIntosh CAES (~1990); PEAC SuperCap (~ 2002); NYPA FW (~2003); AEP NaS (~2006)
  - EPRI benefit analysis tools: Dynastore & Dynamics (1980s and 2004)
- Recent developments:
  - New CAES design using CT as central component of plant
  - Li-Ion Battery, Flywheels, SuperCaps for PQ/VAR control
- Joint EPRI-DOE Energy Storage Handbook
  - First Published December 2003
- CEC/PIER Demonstration/Field Trail Projects (~started in 2004)
  - ZnBr Battery, Flywheel
- Field Trials Of Emerging Technologies Began In 2002:
  - AEP & NYPA NaS Battery; Alaska NiCad Battery, NYPA & CEC Flywheel; TVA SuperCap FACTS, HECO SuperCap-Wind System, FE & PG&E ZnBr Batteries, PJM Li-Ion Battery, and others

The Role of Electricity Storage on the Grid

… each location enables multiple benefits

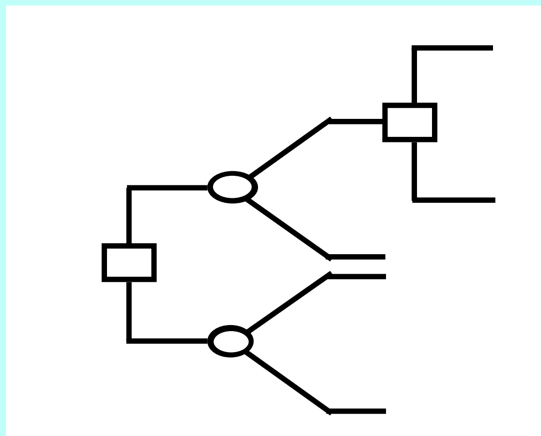


Appendix

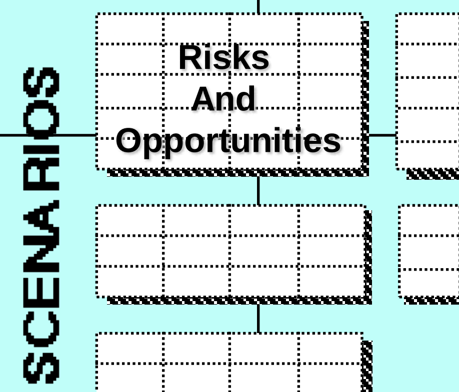
Electric Energy Storage: Value Proposition

Types of Benefits	Physical System: Generation	Physical System: T&D	Corporate Perspective	Customer Perspective

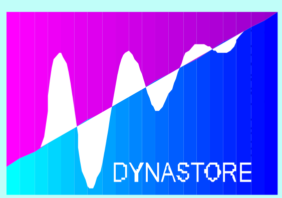
Strategic
- Enhance Renewables
- Mitigate Uncertainty
- CO_2 Reduction

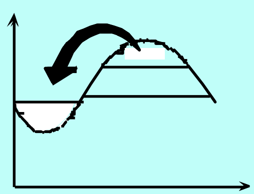


STRATEGIES



Operational
- Dynamic
- Load Leveling





Major DOE Bulk Energy Storage Projects

- **PG&E 300 MW – 10 Hour Adv. CAES Demo Plant**
  - DOE Award to PG&E: $25 M
  - Total Project Cost: $356 M*
  - Underground Air Store: Depleted Gas/Porous Rock Reservoir
- **NYSEG 150 MW – 10 Hour Adv. CAES Plant**
  - DOE Award: $30 M
  - Total Project Cost: $125 M*
  - Underground Air Store: Solution Mined Salt Cavern
- **Duke Energy ~ 20 MW – 6 Hour Lead Acid Battery System**
  - DOE Award: $ 21.8 M
  - Total Project Costs: $ 43.6 M
  - Battery System (TBD) in a Wind Integration Demonstration

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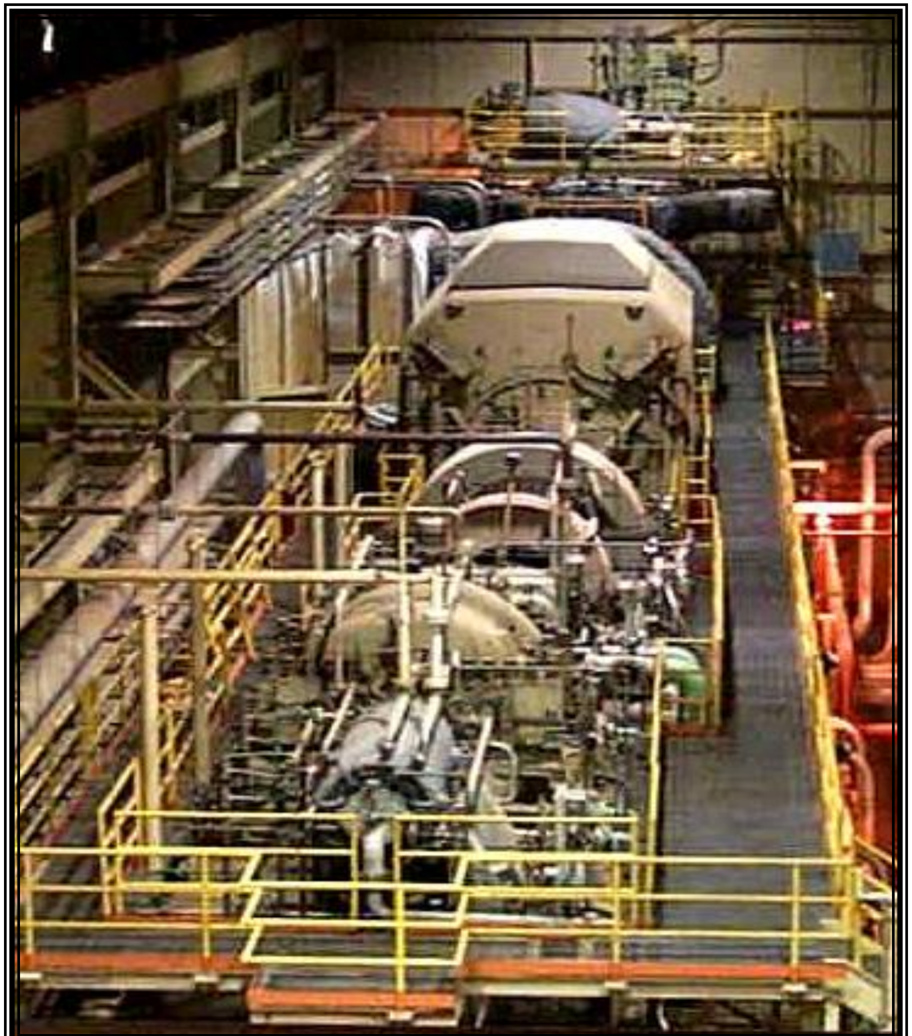
* Note: Some of the above project costs go towards expenses not directly related to the CAES plant (e.g., transmission line & substation upgrade costs)

Compressed Air Energy Storae (CAES): Plants Built, Use and Reliability

- **110 MW – 26 hour Plant: McIntosh Alabama**
  Operational: June 1991
  - Load Mngmt/Regulation
  - Buy Low, Sell High
  - Reliability ~ 95% to 98%

- **290 MW – 4 hour Plant: Huntorf, Germany**
  Operational: December 1978
  - Peak Shaving/Regulation
  - Spinning Reserve
  - Reliability ~ 95% to 98%

Alabama CAES Plant:
110 MW Turbomachinery Hall



Expansion Turbines

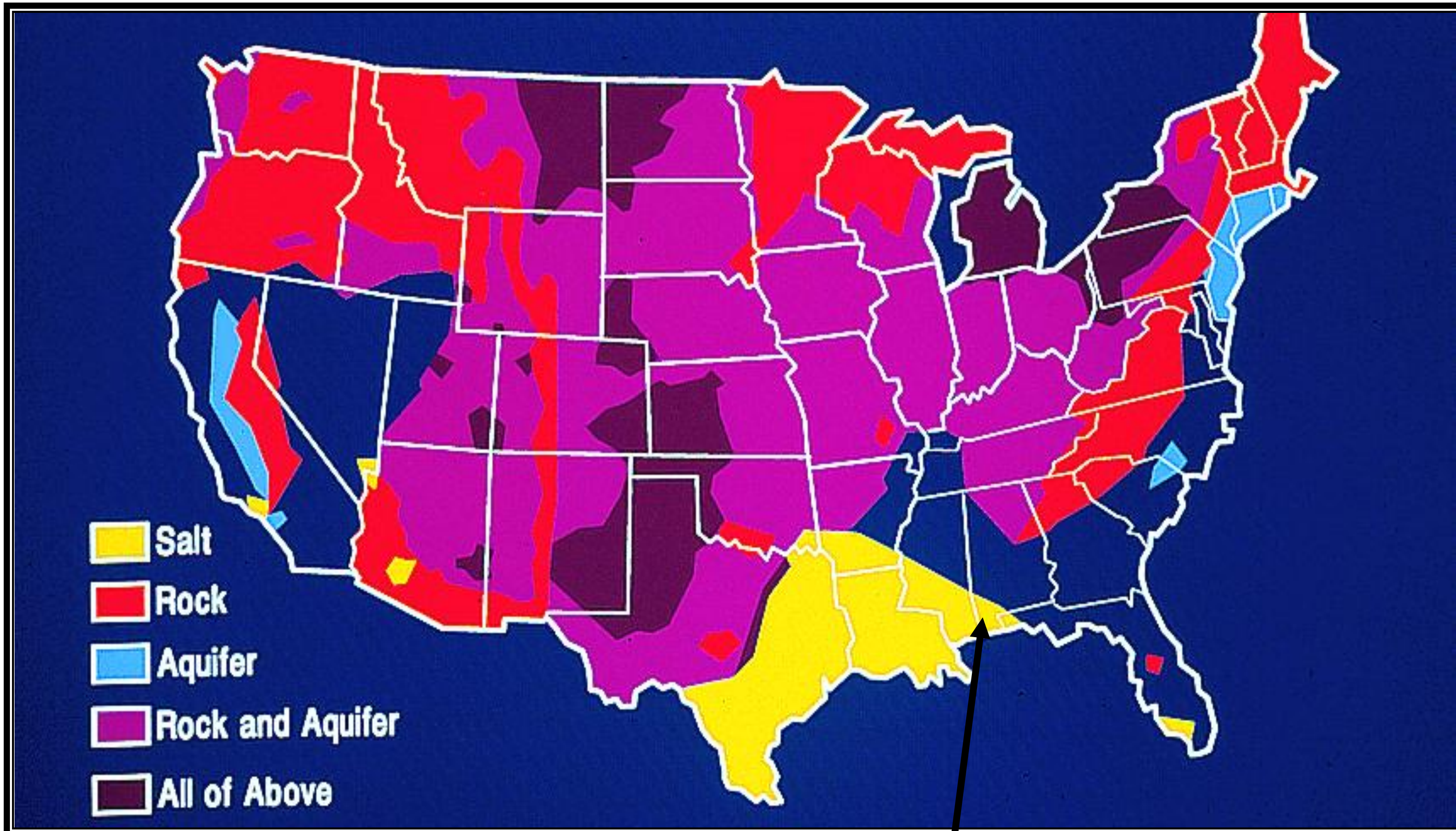
Clutch

Motor-Generator

Clutch

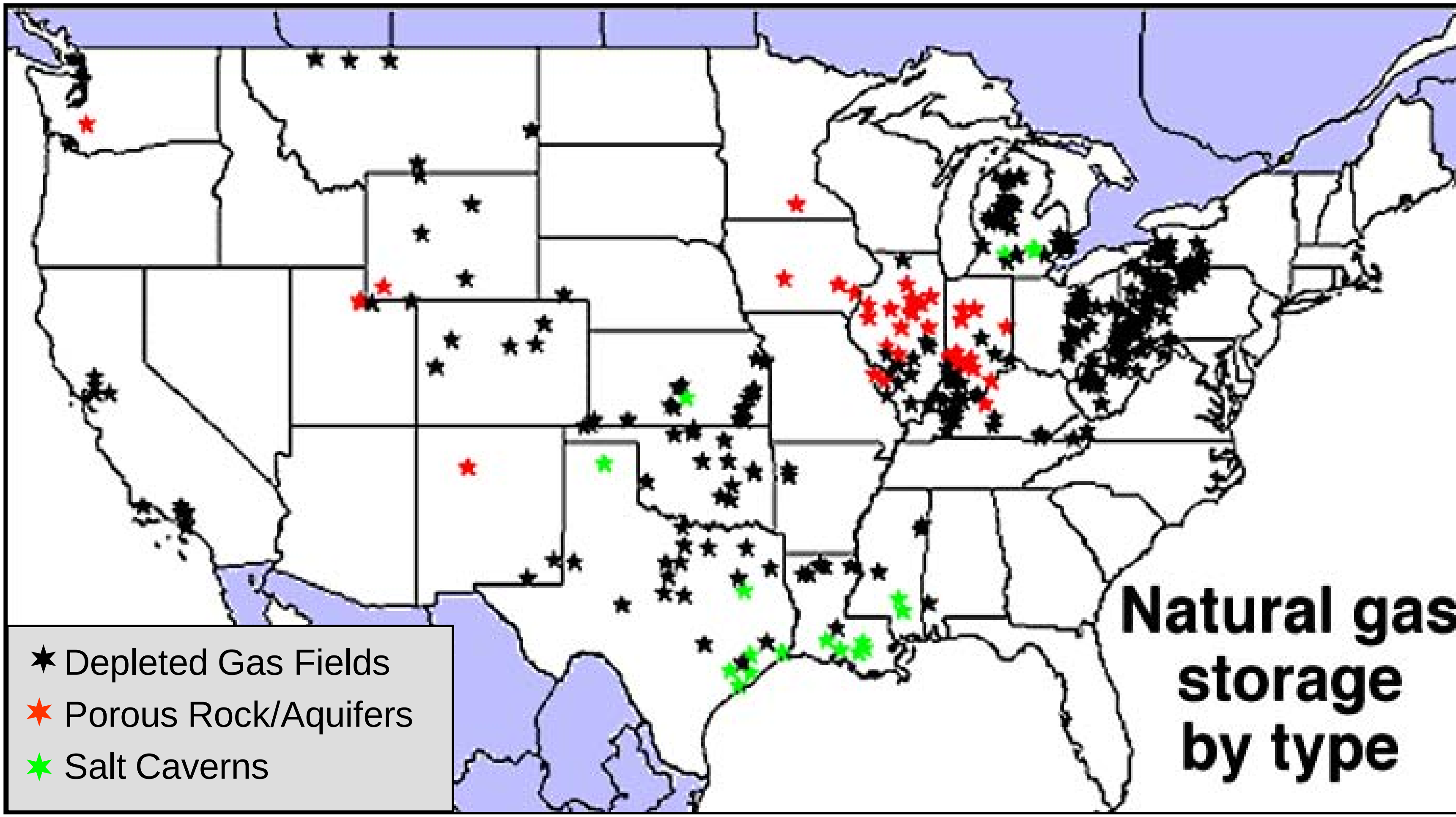
Compressors

Geologic Formations Potentially Suitable for CAES Plants That Use Underground Storage

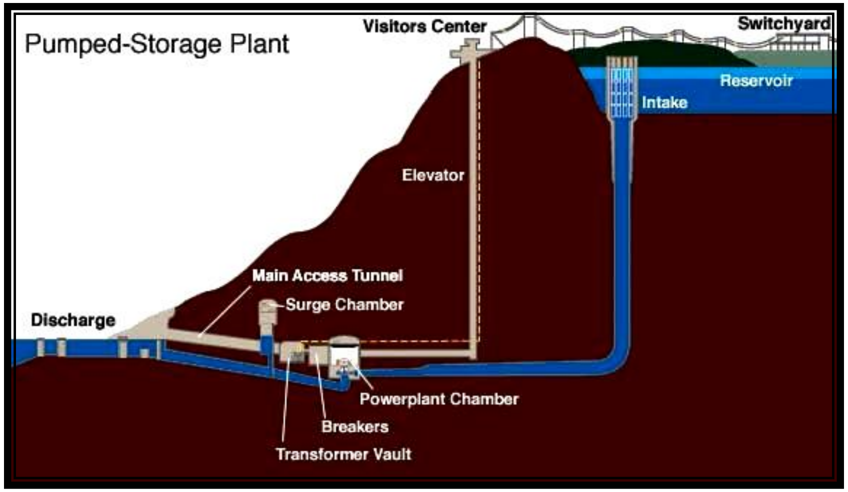


Alabama CAES Plant

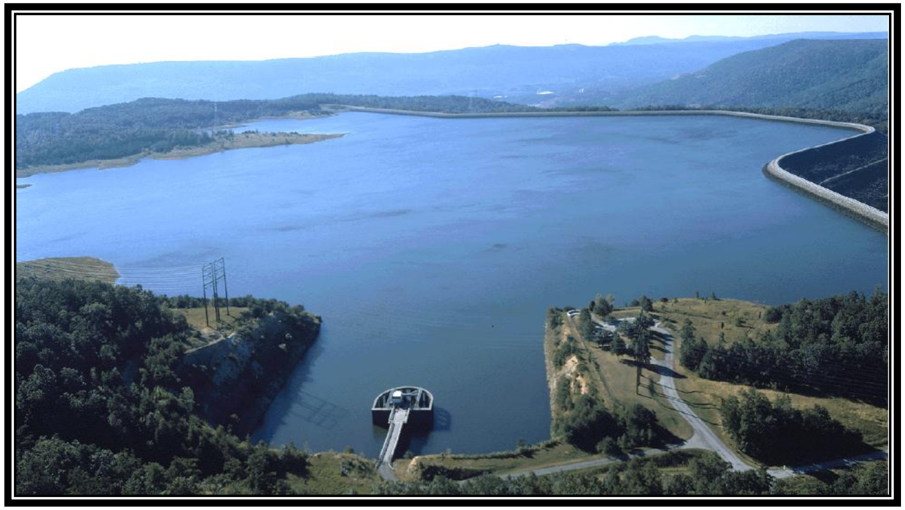
Underground Natural Gas Storage Facilities in the Lower 48 United States



Pumped Hydro Energy Storage Plant



Schematic of Generic Pumped Hydro Plant



Upper Reservoir of TVA's Raccoon Mountain PH Plant

Operational Date: 1979

Capacity: 1620 MW

Max. Discharge Duration: 22 hrs

Battery Energy Storage

Lead-Acid Battery Energy Storage Is One Of The Proven, Commercial Battery Technologies. Of Particular Interest Are NaS and Li-Ion Batteries That Are Less Expensive And Should Live Longer Than Lead-Acid Options For Each KW-H Of Stored Energy

10 MW – 4 Hr Lead Acid Battery Plant At Southern California Edison (1988)

1 MW – 15 Minute Beacon Flywheel System

Superconducting Magnetic Energy Storage (SMES)

- **SMES Is A Viable New Technology For 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 Bonneville Power Administration

SuperCap/UltraCap Demo Plant

Hawaiian Electric Company, Inc. (HECO) and S&C Electric Company held on Jan. 17 a dedication at Lalamilo Wind Farm near Waikoloa on the Big Island of Hawaii to mark the installation of the first PureWave® Electronic Shock Absorber (ESA), an innovative grid stabilizing device for wind farms.

HECO SuperCap Demo (April 2006)
Lalamilo Wind Farm
Uses Maxwell SuperCaps and an S&C Electric AC-DC-AC Inverter

Nominal voltage	800 V DC
No. of Ultracapacitors	640
Max. power / Duration ~	260 kW / 10 sec.

Note: This demo plant was unfortunately destroyed by a 6.7 magnitude earthquake on 10/15/06