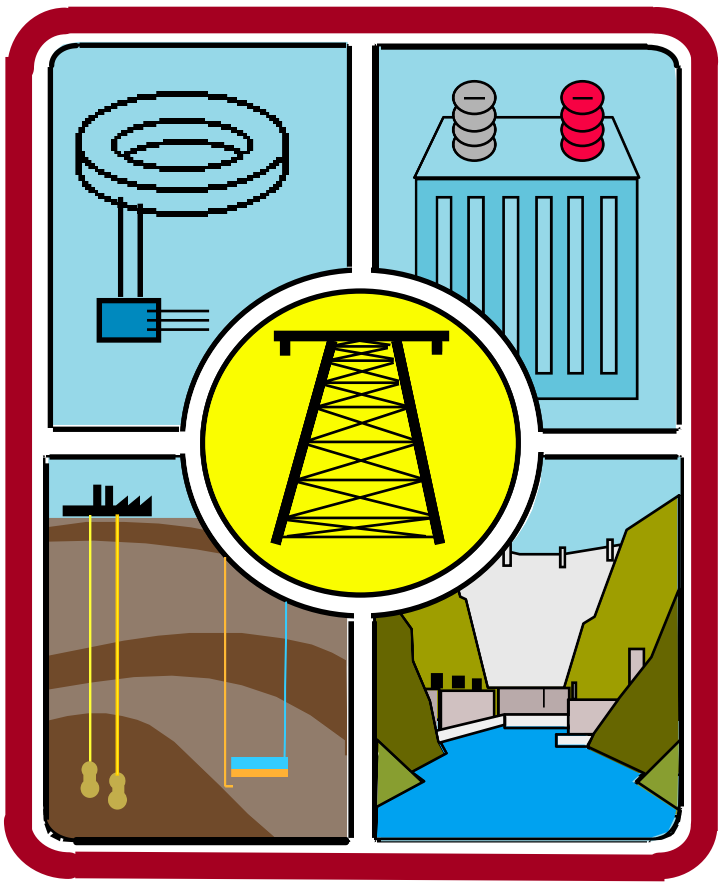
ELECTRIC POWER RESEARCH INSTITUTE



Emerging Technologies to Increase the Penetration and Availability of Renewables:

Energy Storage – Executive Summary

Presented to:
CEC Integrated Energy Policy Workshop

Presented by:
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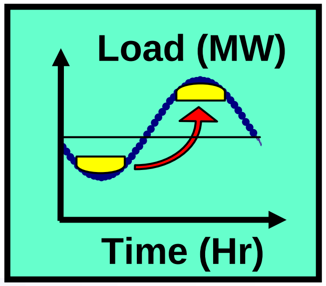
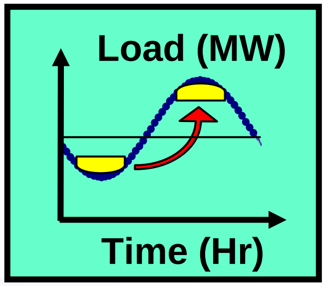
July 31, 2008

Historical Perspective



- Historical foundations for utility electric energy storage:
  - Pumped hydro (US: ~2.5%; Rest of World: 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)
- Joint EPRI-DOE Energy Storage Handbook
  - First Published December 2003
- CEC/PIER Demonstration/Field Trail Projects (~started in 2004)
- Field Trials Of Emerging Technologies Began In 2002:
  - AEP NaS Battery; Alaska NiCad Battery, NYPA Flywheel; TVA SuperCap FACTS, HECO SuperCap-Wind System, PG&E ZnBr, and others
- Recent developments:
  - New CAES design using CT as central component of plant. Can use below ground or above ground air storage system.
  - Li-Ion Battery, Flywheels, SuperCaps for PQ/VAR control

Energy Storage Options: Insights



1. Storage Plants Fall Into Three Economic Categories

- Peak: Battery, Flywheel, Super-Capacitor, SMES
- Intermediate: CAES, Battery (Flow Type)
- Base Load: CAES, Pumped Hydro, Battery (Flow, NaS)

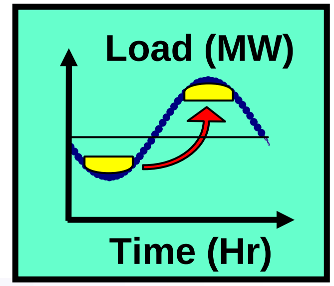
2. Dynamic Benefits From Storage Plants Are 5 To 10 Times Greater Than Their Load Leveling Benefits

- Millisecond Response: Battery, SMES, Flywheel, Capacitor
- Minute Response: CAES, Pumped Hydro

3. To Quantify Benefits, Tools Must:

- Account for Strategic As Well As Operational Benefits
- Be Multi-Disciplinary - Generation, T&D, Corporate, Customer
- Account for Unit Commitment and Chronological Dispatch
- Load duration curve approaches produce erroneous results

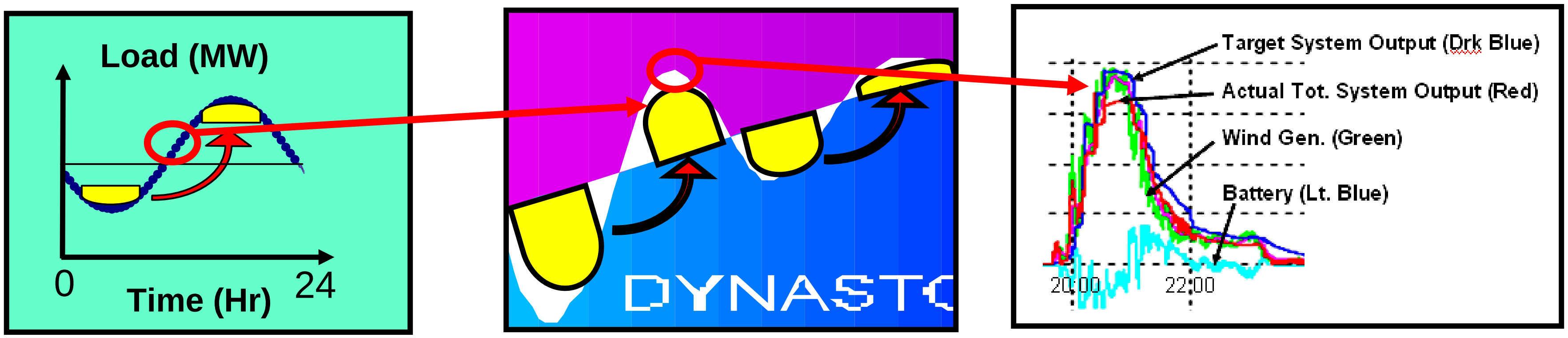
What is Electricity Energy Storage and what are best applications?



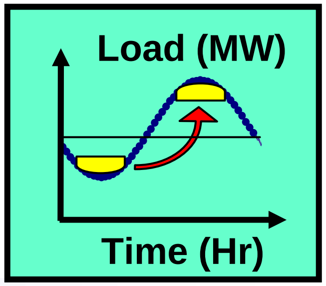
Definition: Electricity energy storage is any means of taking power directly from power plants or the electric grid and storing it for later use.

Examples:

Load Leveling **Ramping:** **Frequency Regulation:**

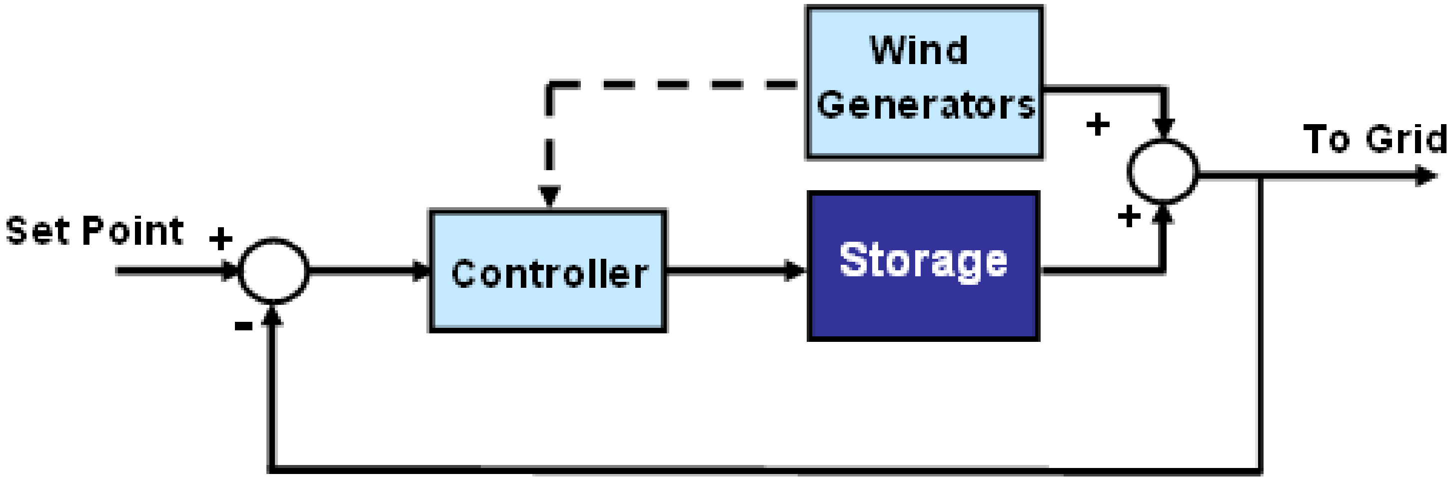


Problem: Renewable Plants Produce Power Output Oscillations or Provide Power When Not Needed, Which Limits Renewable Resource Value

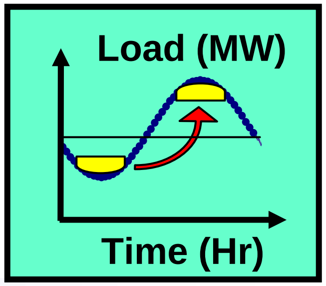


Solution:

Deploy Electric Energy Storage Shock Absorber Plant, Which Is Sized and Controlled To Reduce Load Leveling, Ramping, Frequency Oscillation and/or VAR Problems



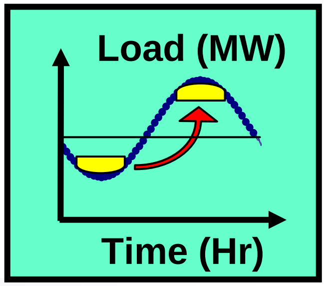
Types of Electric Energy Storage Technologies

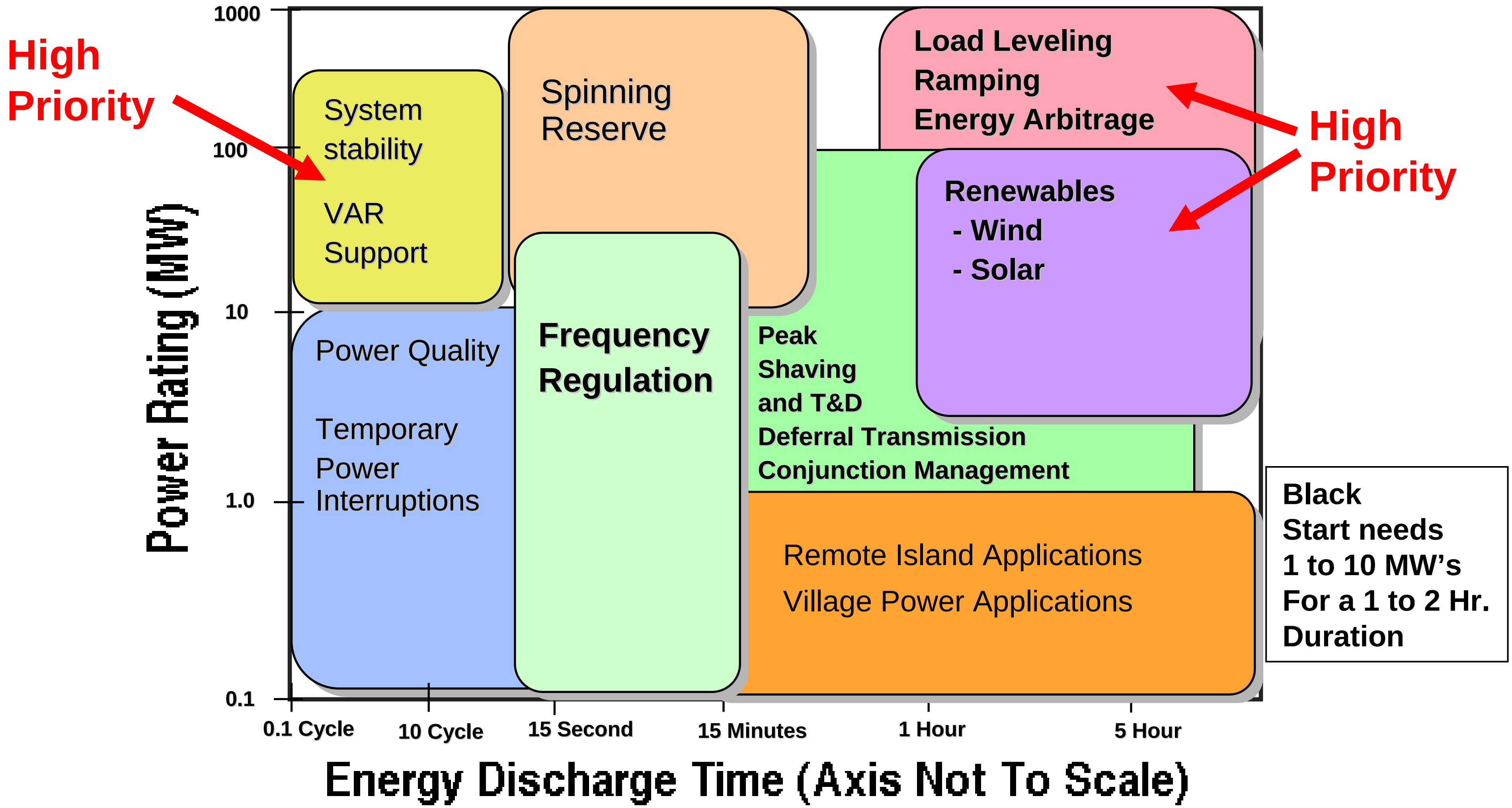


- Pumped Hydro
- Compressed Air Energy Storage (CAES)
- Flywheels
- Batteries
- Super-Capacitors (SuperCaps)
- Superconducting Magnetics
- Thermal Storage
- Fuel Cells (reversible)
- Hydrogen Storage

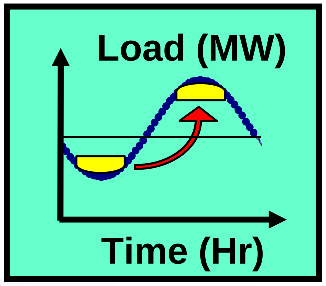
Electric Energy Storage Applications

(All Boundaries Of Regions Displayed Are Approximate)





Capital Cost Comparison of Energy Storage Plants

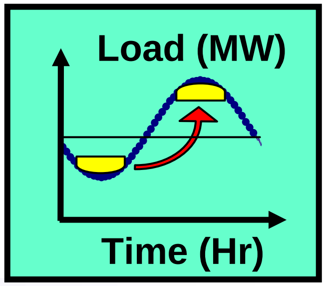


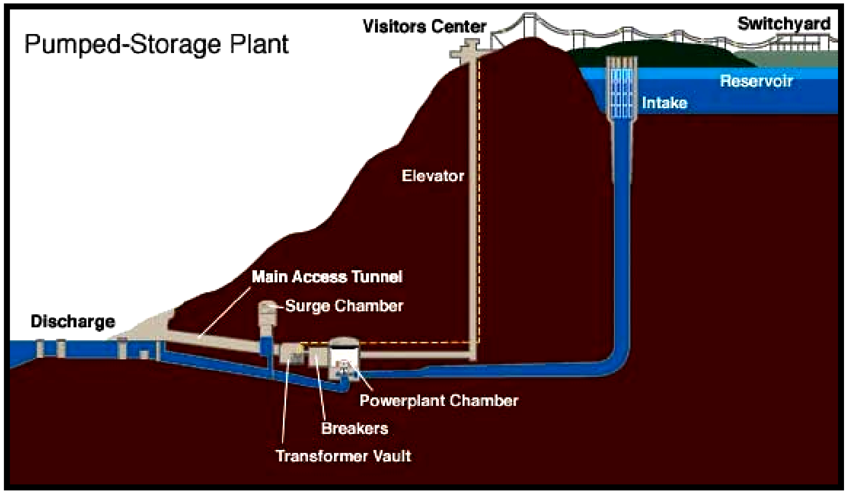
This column determines how many discharge hours one can afford to build

Technology	$/kW	+	$/kWH*	x	H	=	Total Capital, $/kW
Compressed Air							
- Large, salt (100-300 MW)	590-730		1-2		10		600 to 750
- Small (10-20MW) AbvGr Str	700-800		200-250		3		1300 to 1550
Pumped Hydro							
- Conventional (1000MW)	1300-1500		80-120		10		2100 to 2700
Battery (target) (10MW)							
- Lead Acid, commercial	300-400		400-500		3		1500 to 1900
- Advanced / Flow	300-400		500-800		3		1800 to 2800
Flywheel (target) (100MW)	300-400		600-800		3		2100 to 2800
Superconducting (1000MW) Magnetic Storage (target)	300-400		800-1200		3		2700 to 4000
Super-Capacitors (best today)	300-400		12000-18000		1/60		500 to 700
(target)	300-400		1200-1800		1/60		320 to 430

* 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 2008 $'s and are updated by EPRI periodically. Costs do not include permits, contingencies, interest during construction and the substation.

Pumped Hydro Energy Storage Plant





Schematic of Generic Pumped Hydro Plant

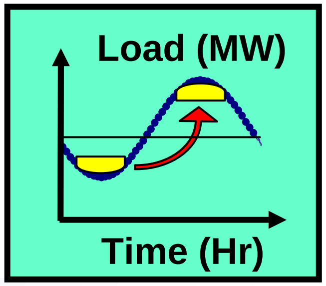
Upper Reservoir of TVA's Raccoon Mountain PH Plant

Operational Date: 1979

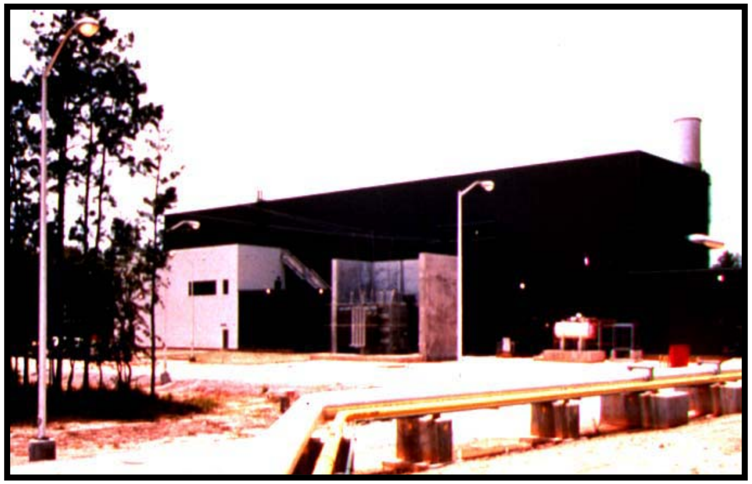
Capacity: 1620 MW

Max. Discharge Duration: 22 hrs

CAES Technology Experience

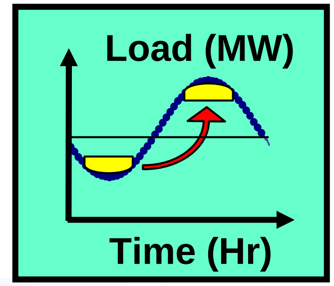


- **110 MW – 26 hour Plant:**
  McIntosh Alabama
  Operational: June 1991
  - **Load Mngmt/Regulation**
  - **Buy Low, Sell High**
  - **Reliability ~ 95% to 98%**

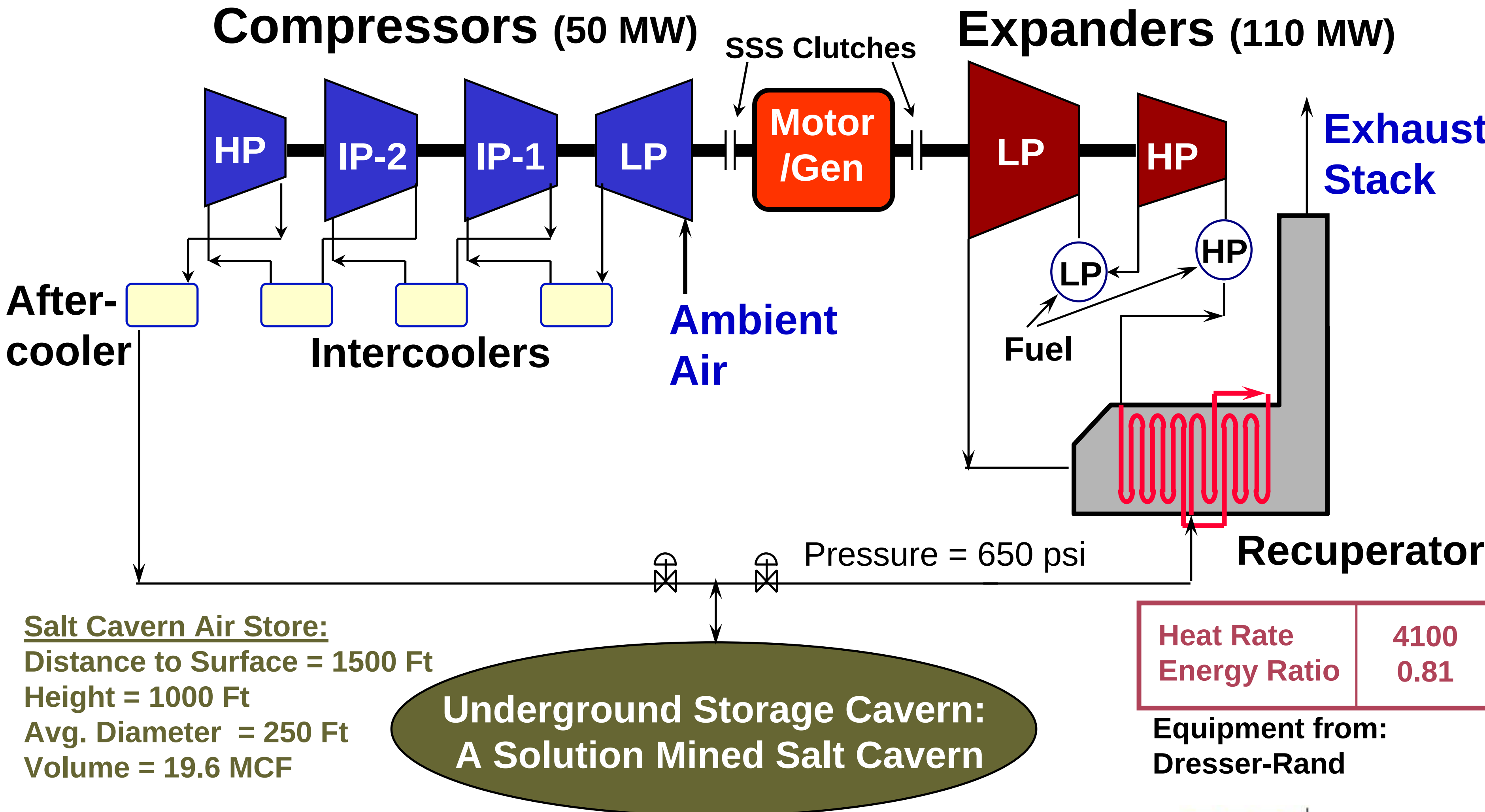


- **290 MW – 4 hour Plant:**
  Huntorf, Germany
  Operational: December 1978
  - **Peak Shaving/Regulation**
  - **Spinning Reserve**
  - **Reliability ~ 95% to 98%**

Alabama CAES Plant: Design Schematic
- - - First Generation Design - - -



Cap. Cost (2008 Dollars) ~ $730/kW to $830/kW + Substation, Permits & Contingencies

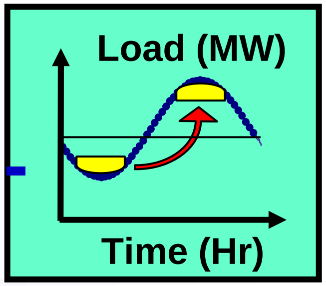


Salt Cavern Air Store:
Distance to Surface = 1500 Ft
Height = 1000 Ft
Avg. Diameter = 250 Ft
Volume = 19.6 MCF

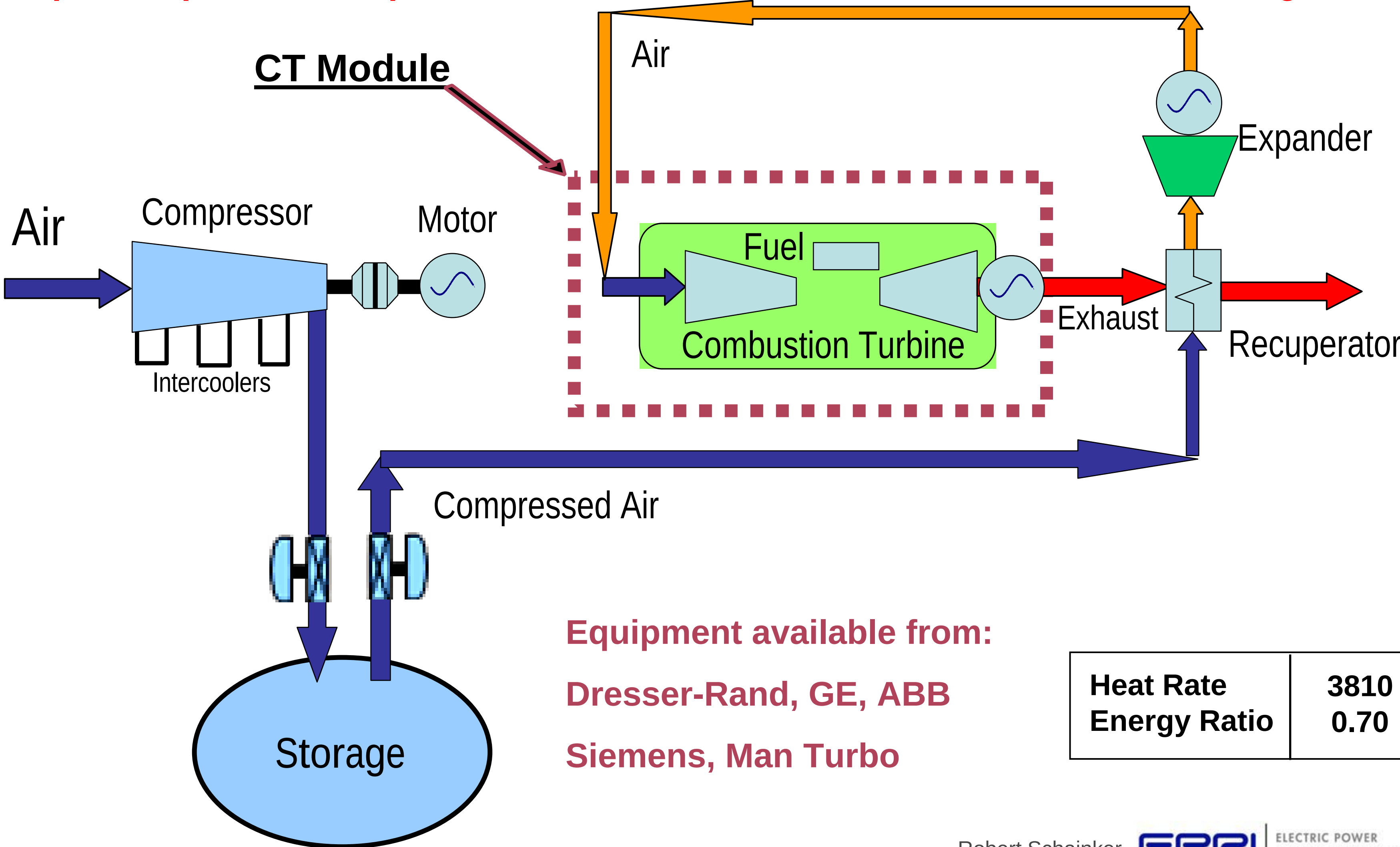
Heat Rate	4100
Energy Ratio	0.81

Equipment from: Dresser-Rand

Advanced CAES Plant: Schematic
- - - Second Generation "Chiller" Design- - -



Cap. Cost (2008 Dollars) ~ $600/kW to $750/kW + Substation, Permits & Contingencies

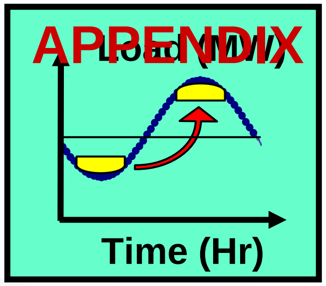


Equipment available from:

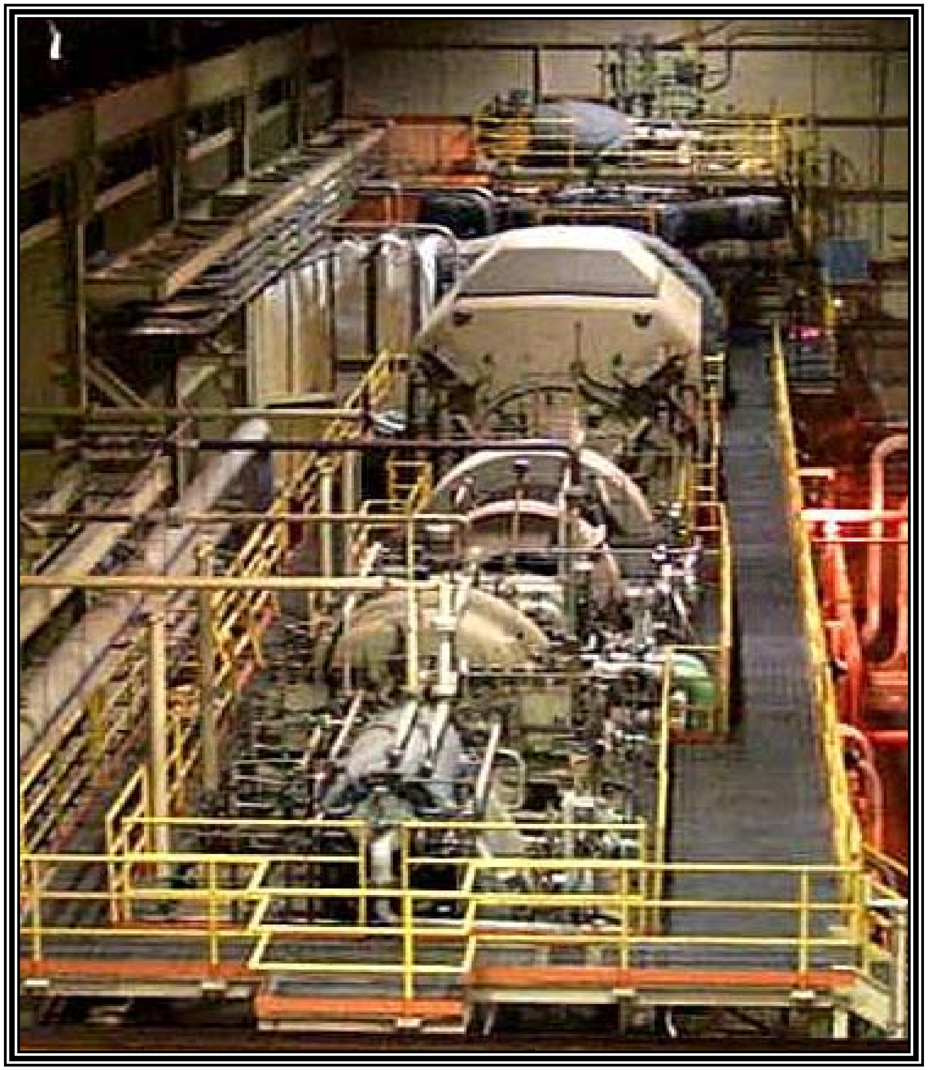
Dresser-Rand, GE, ABB

Siemens, Man Turbo

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



Alabama CAES Plant:
110 MW Turbomachinery Hall



Expansion Turbines

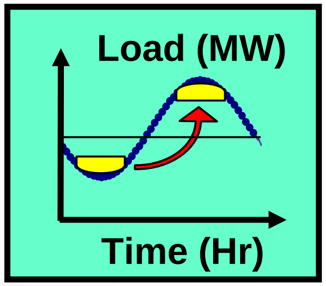
← *Clutch*

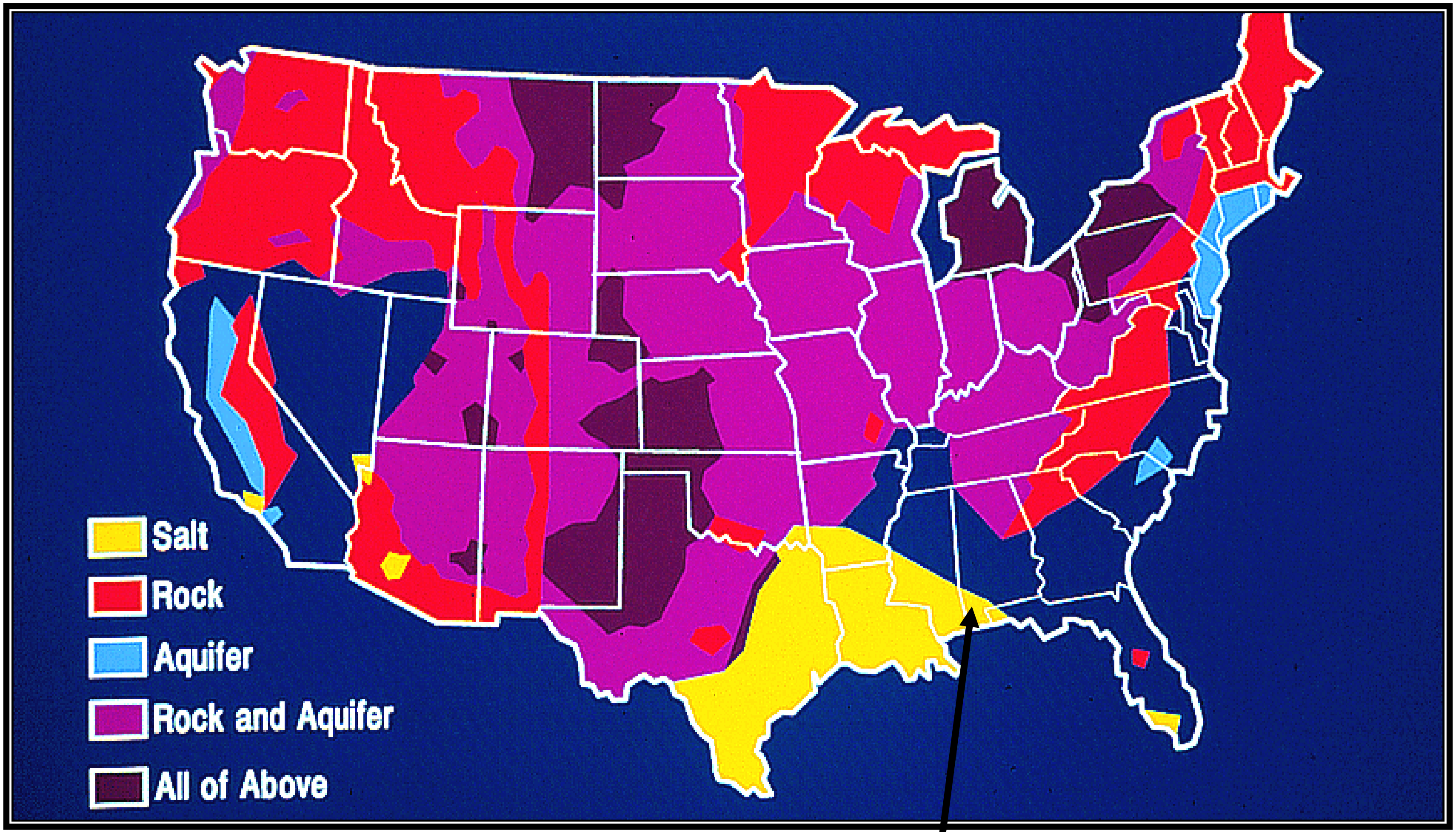
← *Motor-Generator*

← *Clutch*

Compressors

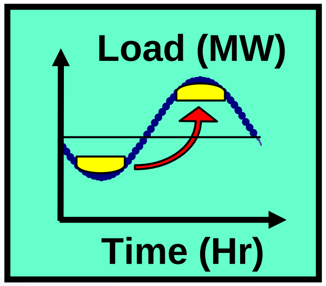
Geologic Formations Potentially Suitable for CAES Plants That Use Underground Storage





Alabama CAES Plant

Battery Energy Storage



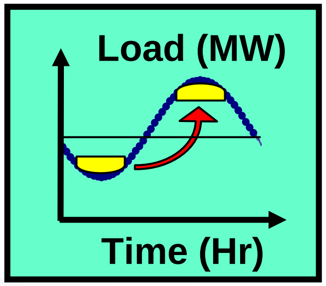
Lead-Acid Battery Energy Storage Is A Proven, Commercial Technology. Many Other Types of Battery Technologies Are Now Commercially Available. Of Particular Interest Are Electrolyte Flow-Base Batteries That Are About 10 Times Less Expensive Than Lead Acid Options For Each KWH Of Stored Energy.

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

Issue:

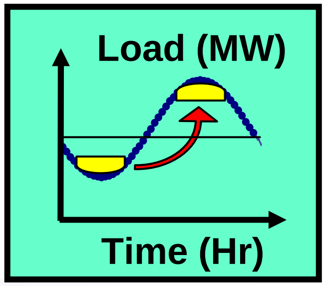
Deep Discharge Battery Cells Need To Be Replaced At About Every 10 Years. This Increases Life Cycle Capital And Maintenance Costs.

Flywheel Energy Storage



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

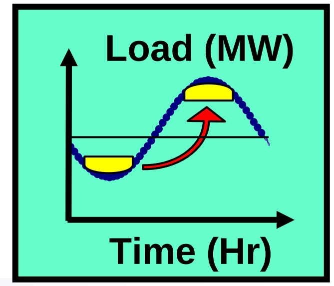
Superconducting Magnetic Energy Storage (SMES)



- 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

SuperCap/UltraCap Demo Plant



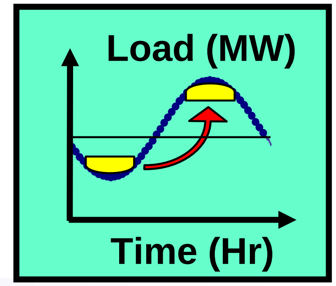
Hawaiian Electric Company, Inc. (HECO) and S&C Electric Company held on Jan. 17 a dedication at Lalamilo Wind Farm near Waikoloa on the Big Island of Hawaii to mark the installation of the first PureWave® Electronic Shock Absorber (ESA), an innovative grid stabilizing device for wind farms.

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
# 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

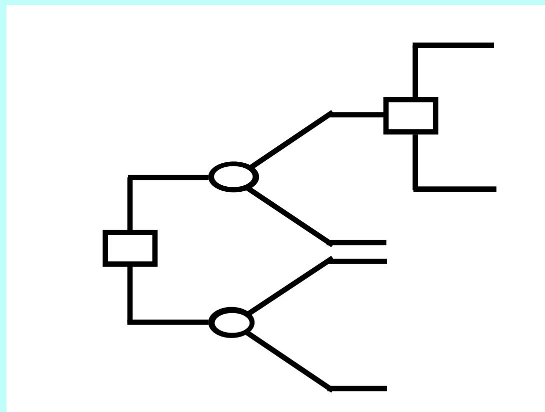
Electric Energy Storage: Value Proposition

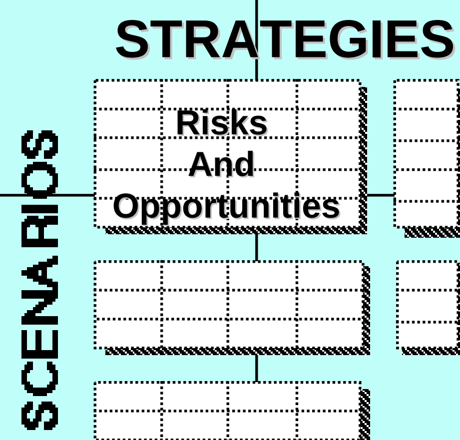


Types of Benefits	Physical System: Generation	Physical System: T&D	Corporate Perspective	Customer Perspective

Strategic

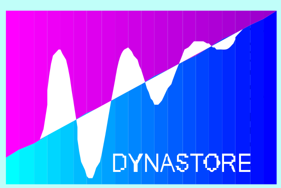
- Enhance Renewables
- Mitigate Uncertainty
- CO_2 Reduction

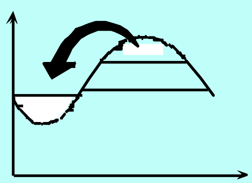




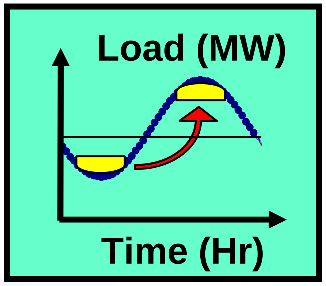
Operational

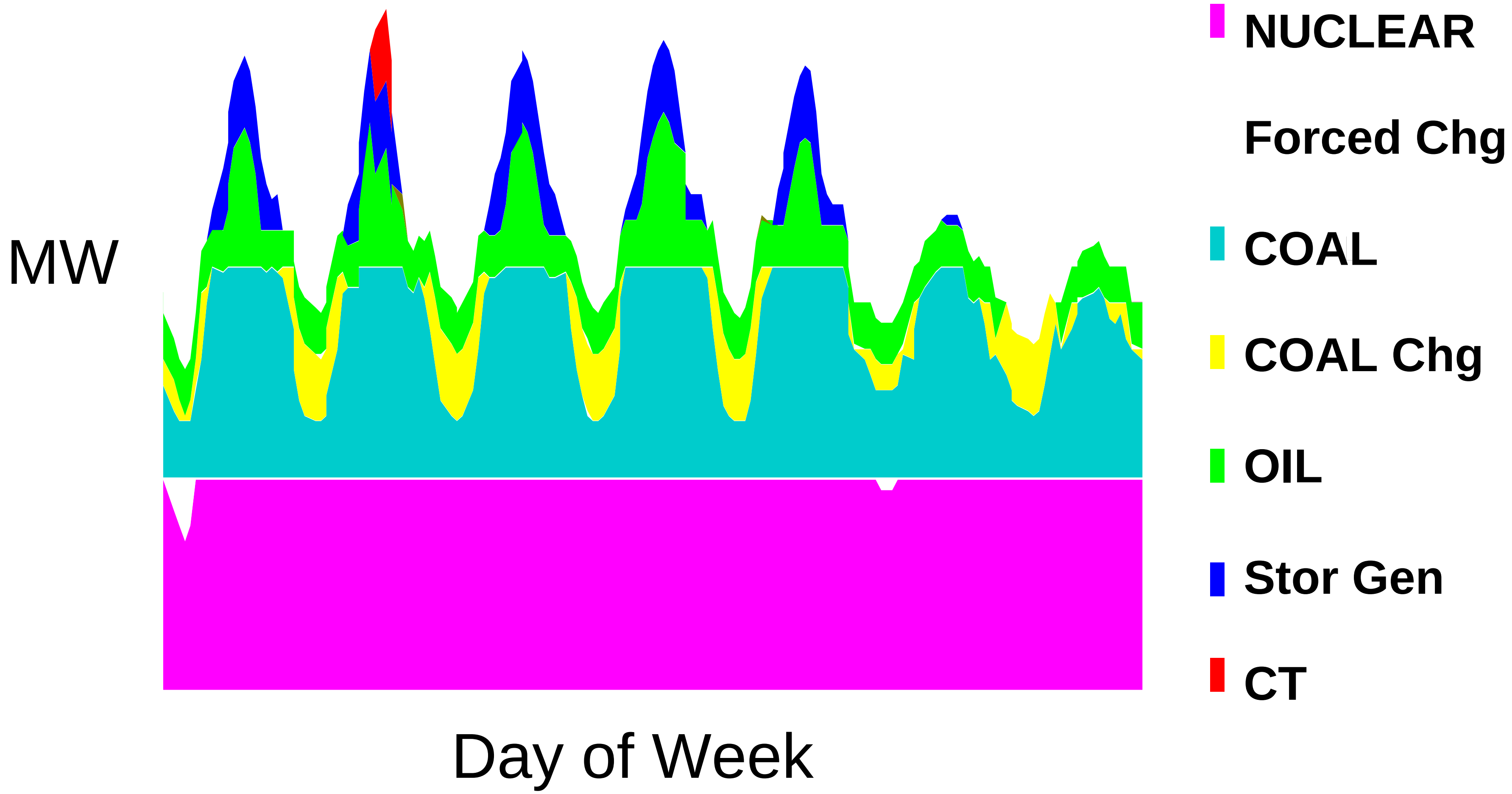
- Dynamic
- Load Leveling



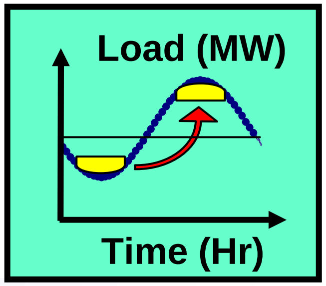


Utility Dispatch With Storage

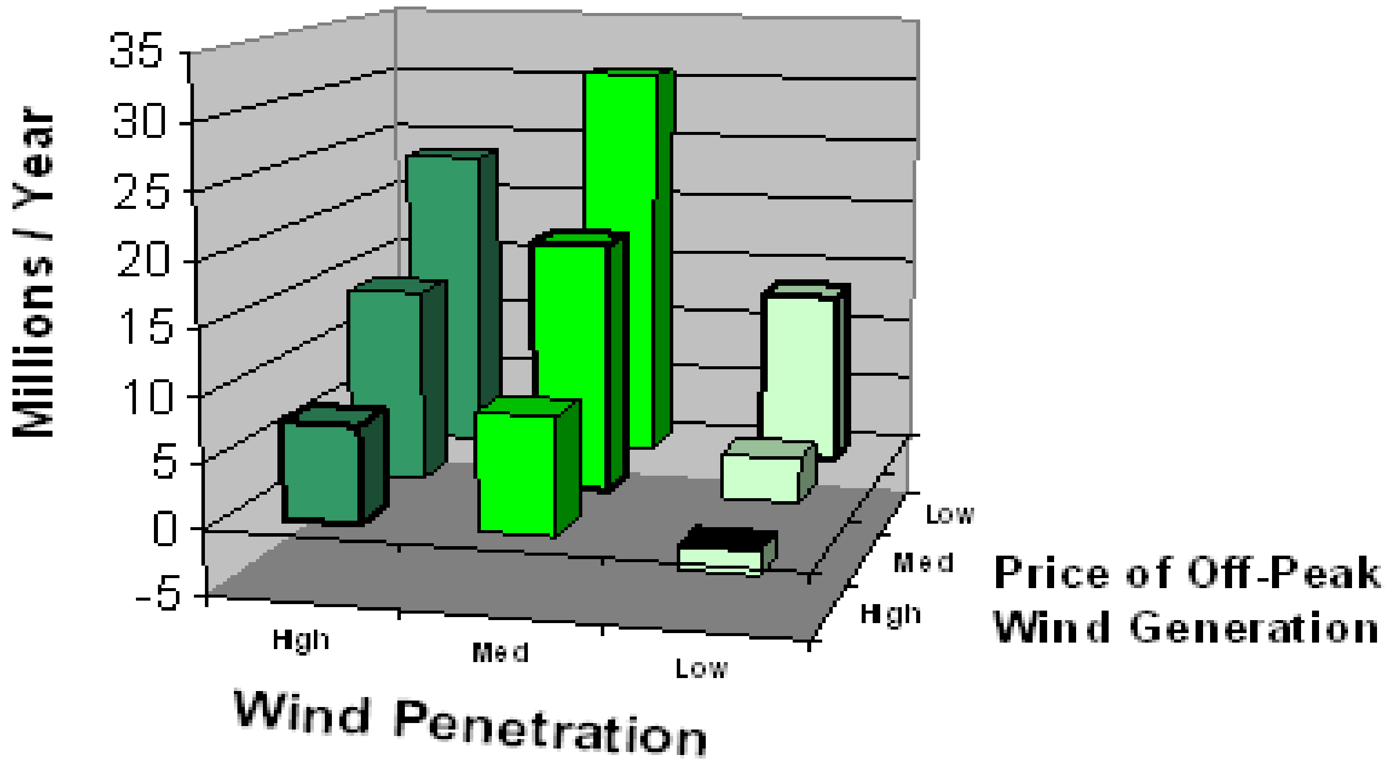




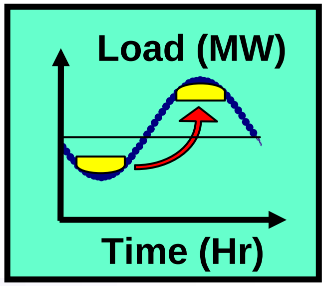
Savings with Energy Storage Integrated with Wind Generation Resources



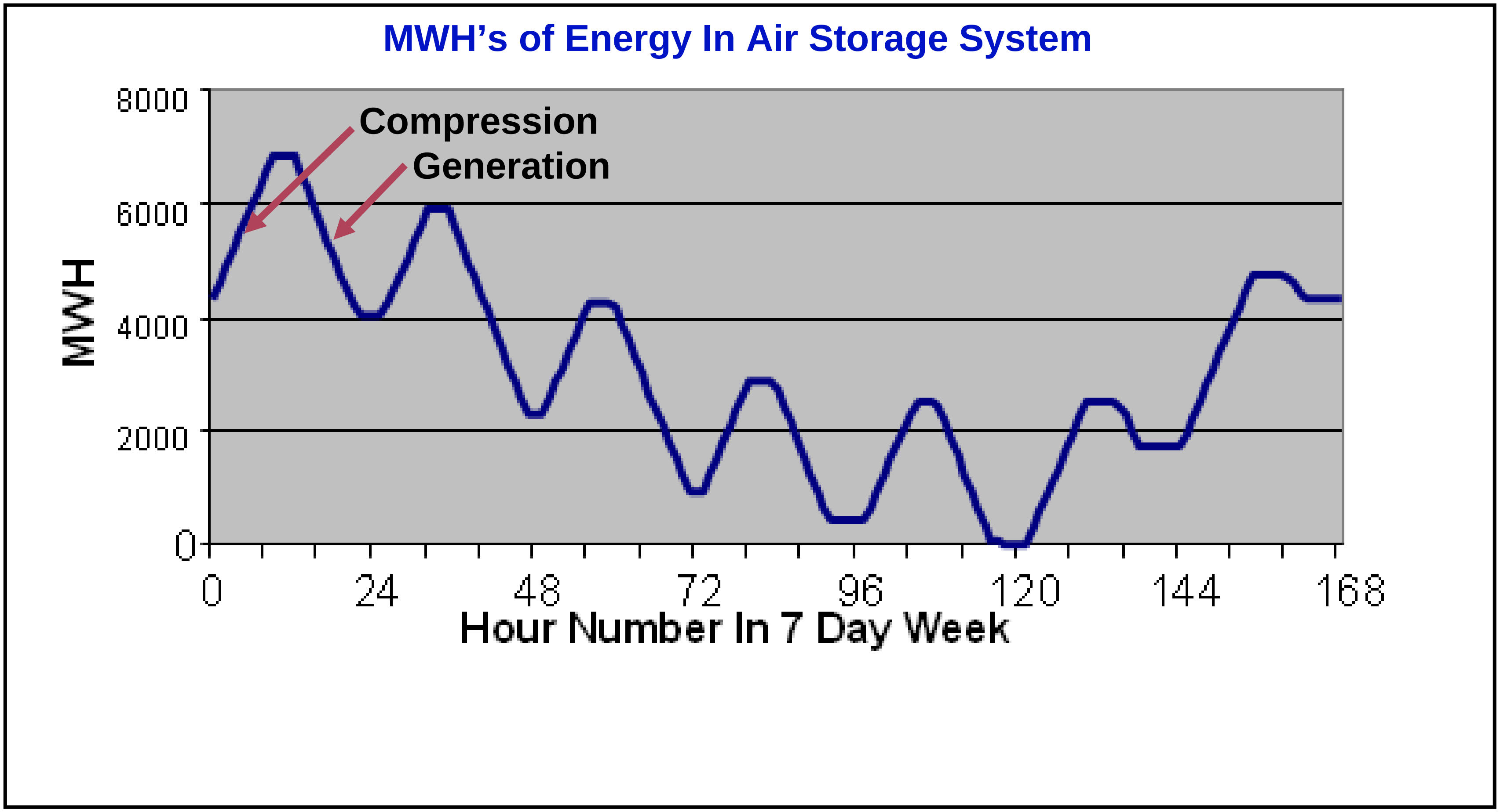
Example Results From EPRI CAES Demonstration Project



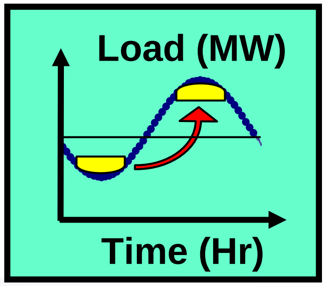
CAES Generation & Compression Cycles (for a Typical Week)



Example Results From EPRI CAES Demonstration Project



Don’t Let The Texas Grid Emergency Caused By Wind Generators Happen In California



Reuters New Flash

Loss of Wind Causes Texas Power Grid Emergency

Wed Feb 27, 2008 8:11pm EST

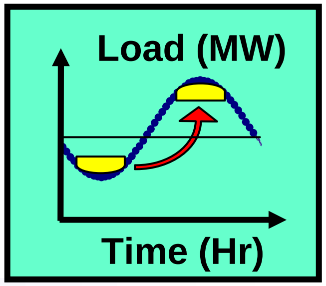
HOUSTON (Reuters) - A drop in wind generation late on Tuesday, coupled with colder weather, triggered an electric emergency that caused the Texas grid operator to cut service to some large customers, the grid agency said on Wednesday.

Electric Reliability Council of Texas (ERCOT) said a decline in wind energy production in west Texas occurred at the same time evening electric demand was building as colder temperatures moved into the state.

The grid operator went directly to the second stage of an emergency plan at 6:41 PM CST (0041 GMT), ERCOT said in a statement.

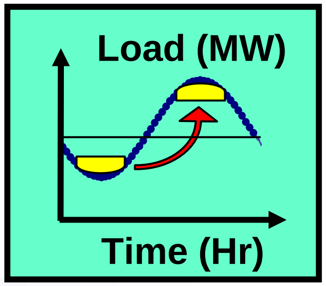
System operators curtailed power . . . .

One of Edison's Most Famous Quotes:
"In Periods of Profound Change, The Most Dangerous Thing Is to Incrementalize Yourself Into The Future."



Appendix

Storage Plant Operating Costs



<u>Operation Costs For All Storage Plants, Except CAES:</u>

$/KWh = $/KWh-In for Charging x KWh In/KWh-Out
+ Variable O&M
= Incremental Cost for Charging Energy / Efficiency
+ Variable O&M

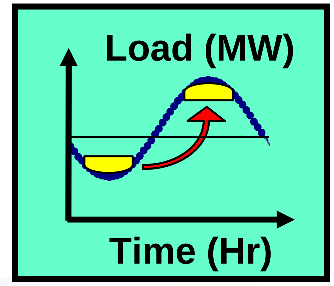
<u>Operational Costs For CAES Plants:</u>

$/KWh = $/KWh-In for Charging x Compression Energy Ratio (KWh-In/KWh-Out)
+ Variable O&M
+ Generation Heat Rate (Btu-In/KWh-Out) x
Fuel Cost ($/Million Btu-In)

Energy Storage Plants Fall Into Three Economically Attractive Regions

Appendix

(Capital and Operational Costs Included In Below Chart)



Economic Attractive Regions For Storage Plants, If Have One Discharge/Day:

Battery (Bat), FlyWh (FW):	< 2 hrs discharge
Compressed Air (CAES):	> 2 hrs and < 12 hrs discharge
Pumped Hydro (PH):	> 12 hours discharge