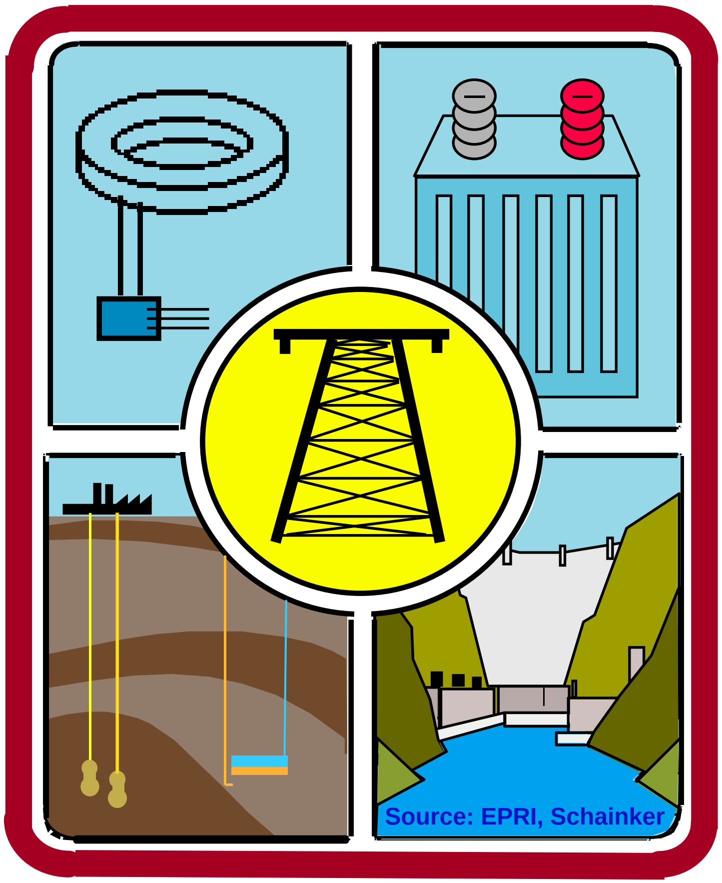

Energy Storage Technologies & Their Role in Renewable Integration

Prepared for:

IEEE SF Power & Energy Society Workshop, November 15, 2010

Prepared by:
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Agenda

- Background Information
  - How the Grid Works
  - Key Challenges (Now and Into the Future)
  - Energy Storage Technologies
    - Value Propositions
    - Applications
    - Capital Cost Estimates
- Key Issues Associated With Renewables
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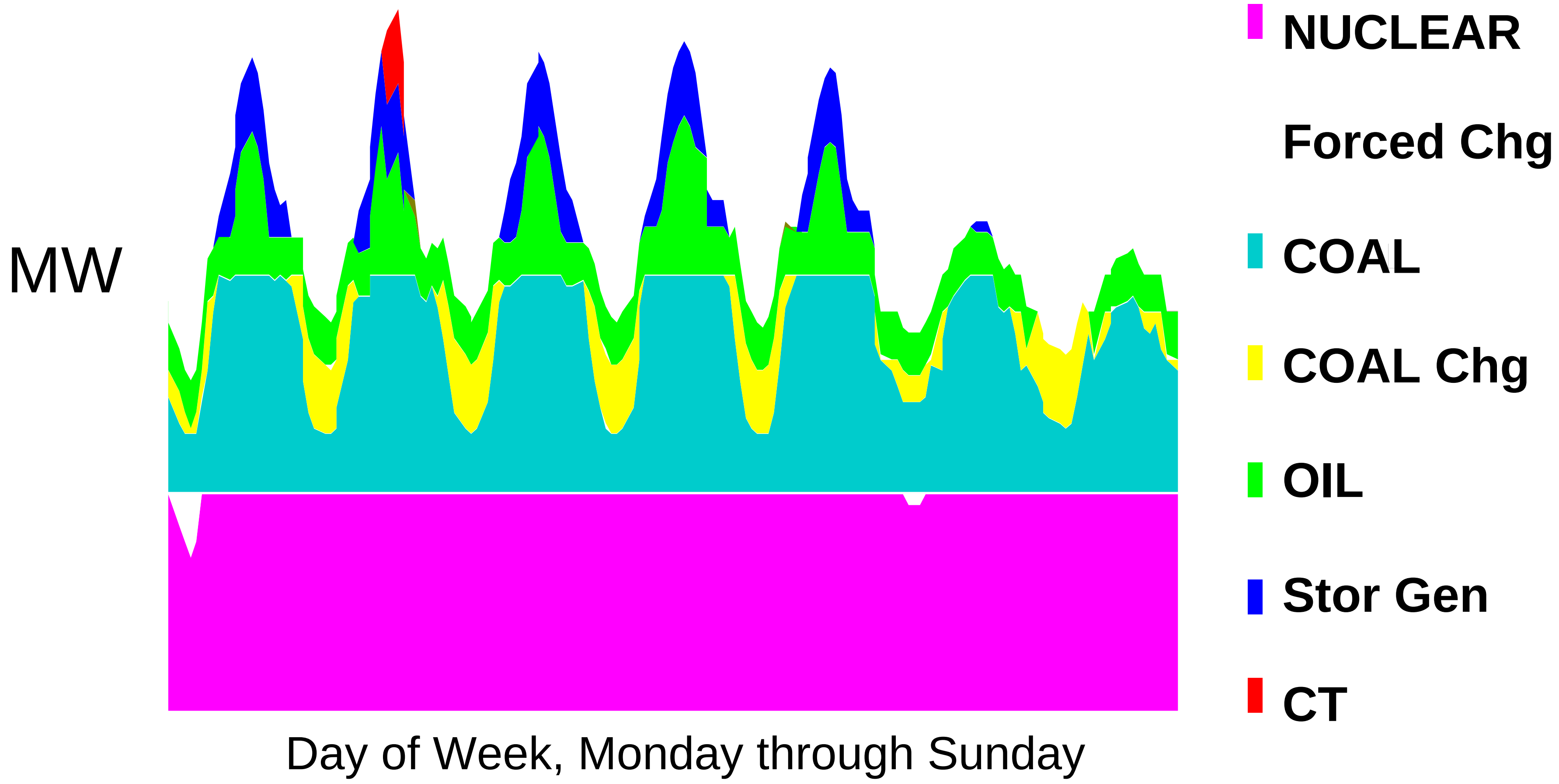
Challenges To The US Electric Infrastructure

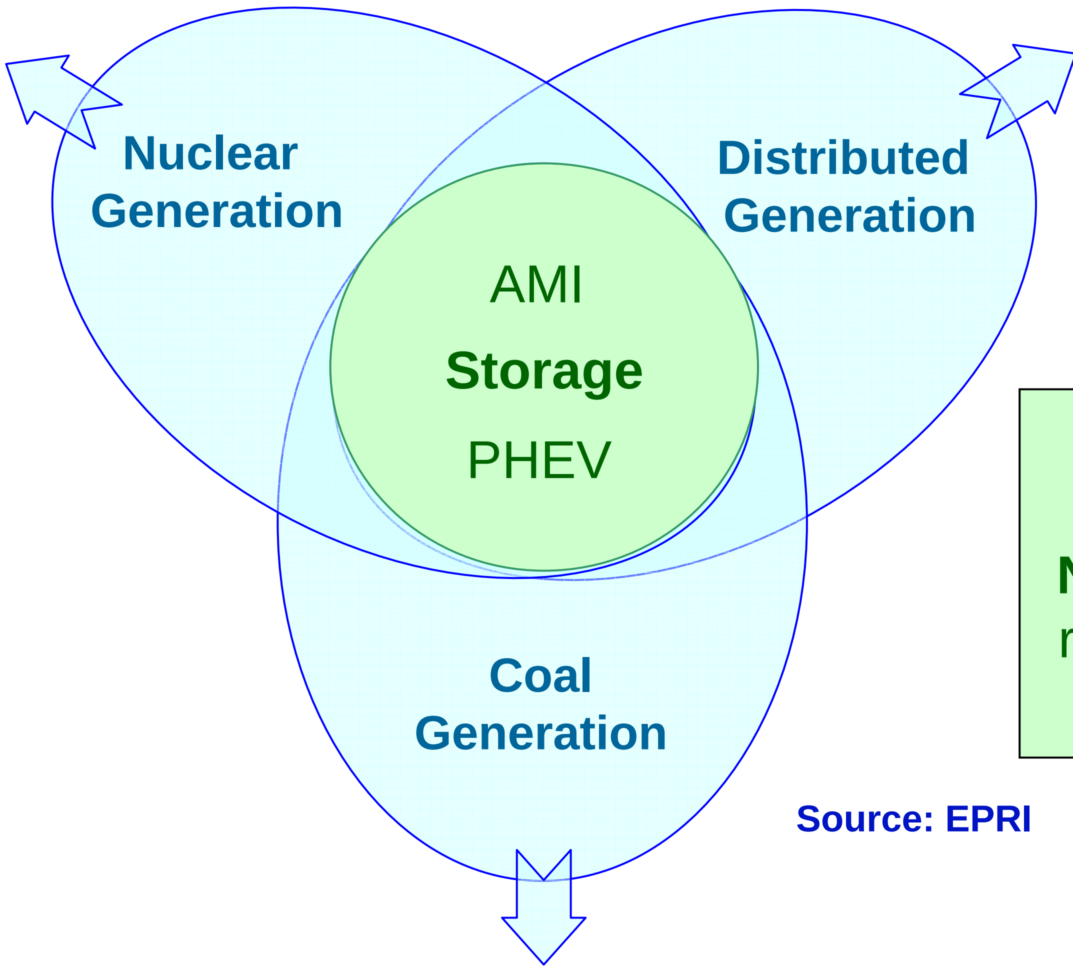
- Intermittent nature and increasing amounts of renewables (e.g., wind & solar) connected to the grid
- An alarming growth rate in customer-owned DG connections to the grid
- Increasing demand for improved service quality and reliability
- Future PHEV load
- Cost control
- Improving use of assets
- Improving efficiency (internal & customers)
- Aging Infrastructure and lack of investments in transmission, distribution and generation equipment

Utility Generation Dispatch With Storage
(Without Any Renewable Generation)



Source: EPRI, Schainker

Energy Storage Is A No-Regret Investment



Energy Storage
is one of the few
No-Regrets Investments
regardless of which future scenario prevails

Source: EPRI

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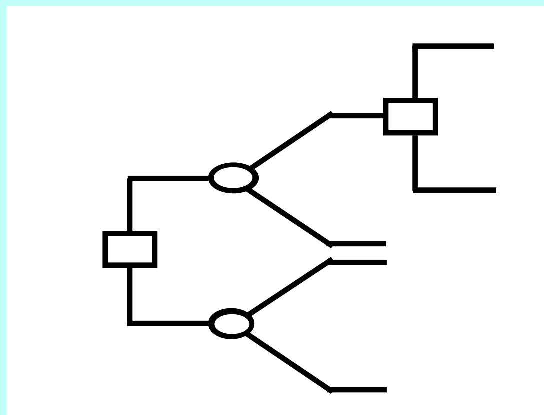
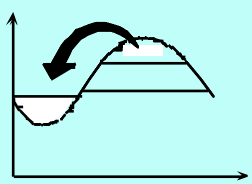
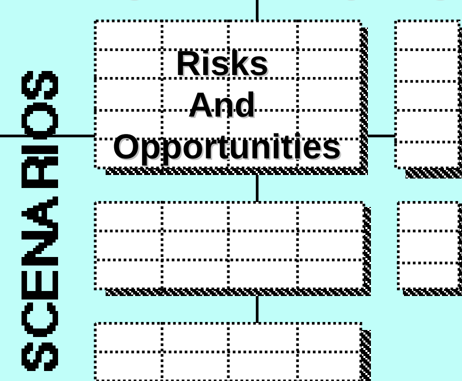
Electric Energy Storage: Value Proposition: Multiple Benefits

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				

Source: EPRI, Schainker

Barriers to Implementation of Energy Storage Technologies

Economic

- Cost of storage
  - Need manufacturing volume & competition
  - Incentives to industry
- Being able to capture multiple values in a given application

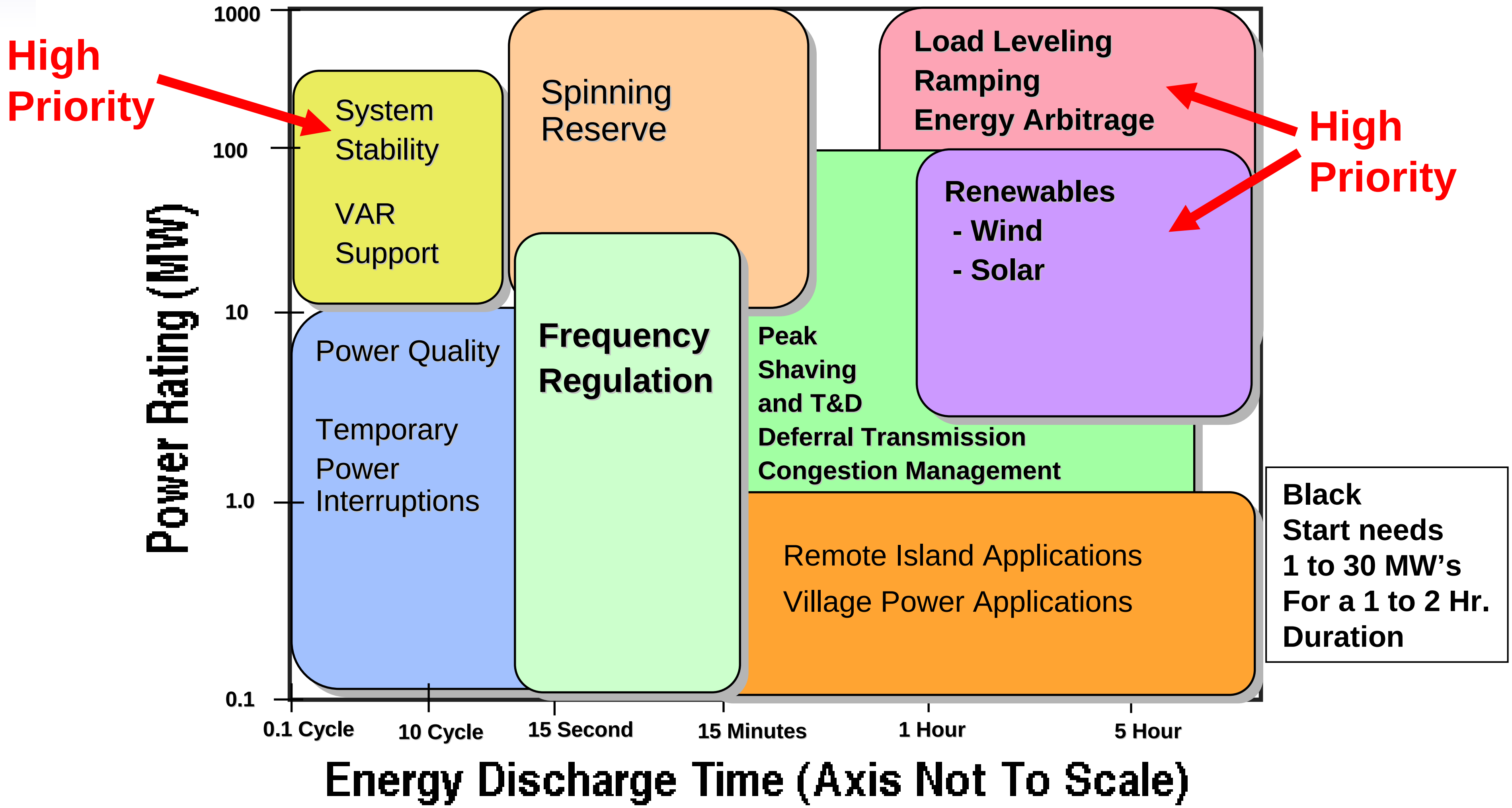
Regulatory

- How to handle multiple benefits across distribution, transmission and generation?
- How to handle energy in and out in a deregulated environment?

Source: EPRI, Schainker

Electric Energy Storage Applications

(All Boundaries Of Regions Displayed Are Approximate)



Source: EPRI, Schainker

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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.

Source: EPRI

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

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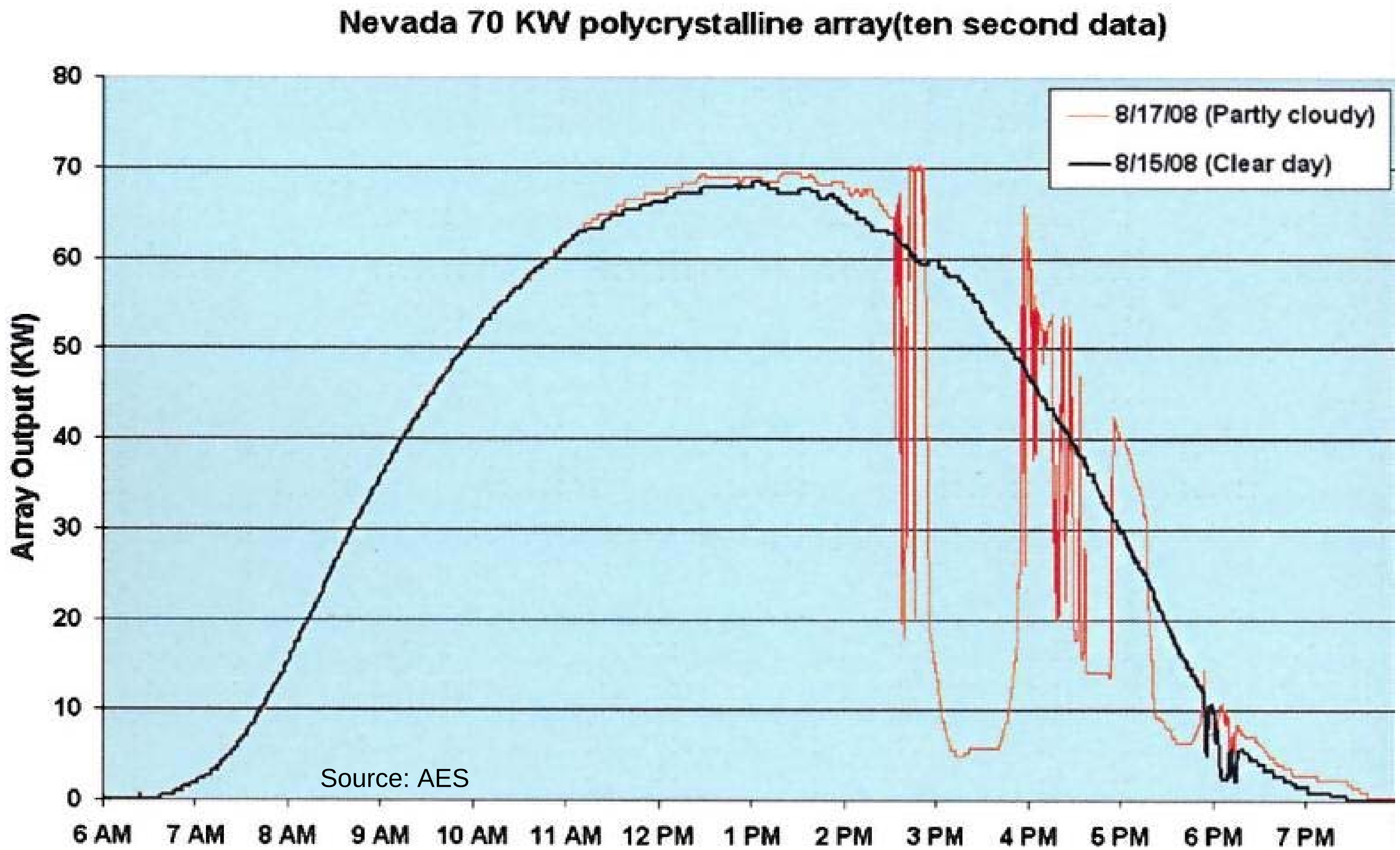
Variation of Solar PV System Output



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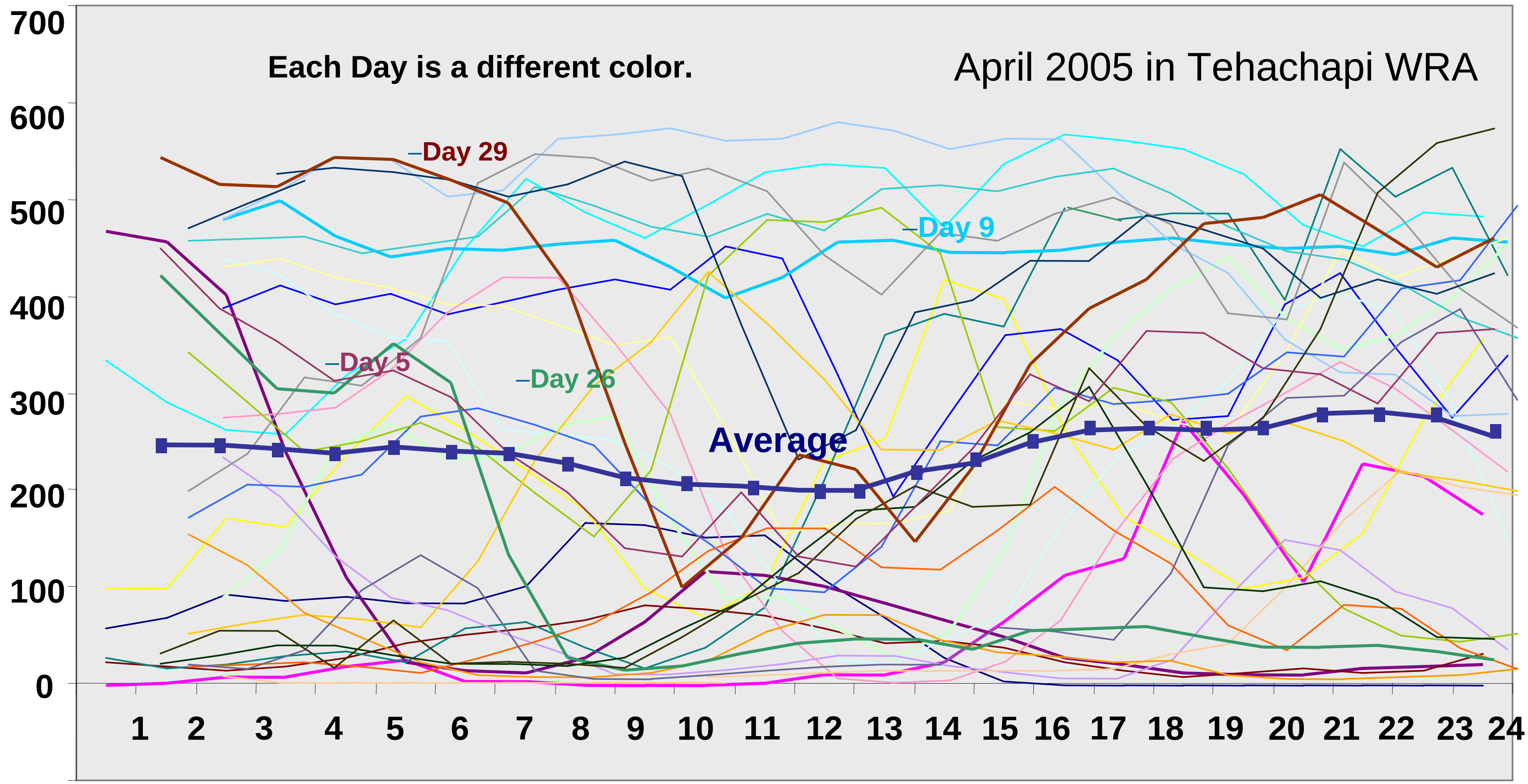
Wind Generation Varies Widely

MW

The average is smooth, but day-to-day variability is great



Hour

Source: CAISO

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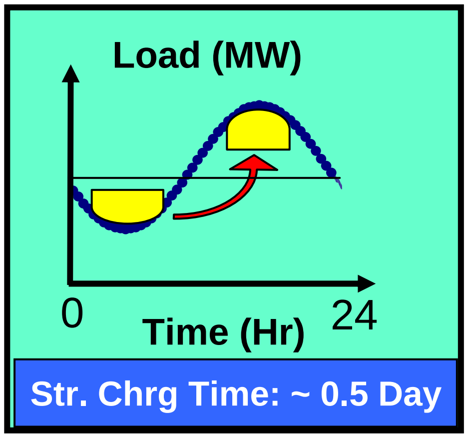
Energy Storage Efficiently Resolves Wind/Solar Power Fluctuations, Ramping and Load Management Issues

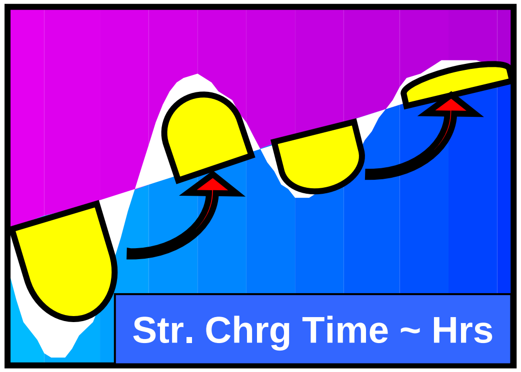
Load Leveling



• CAES

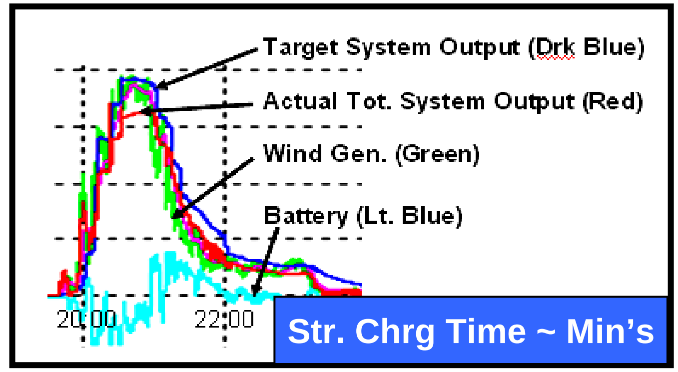
• Pumped Hydro

Ramping:



- 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

Source: EPRI, Schainker

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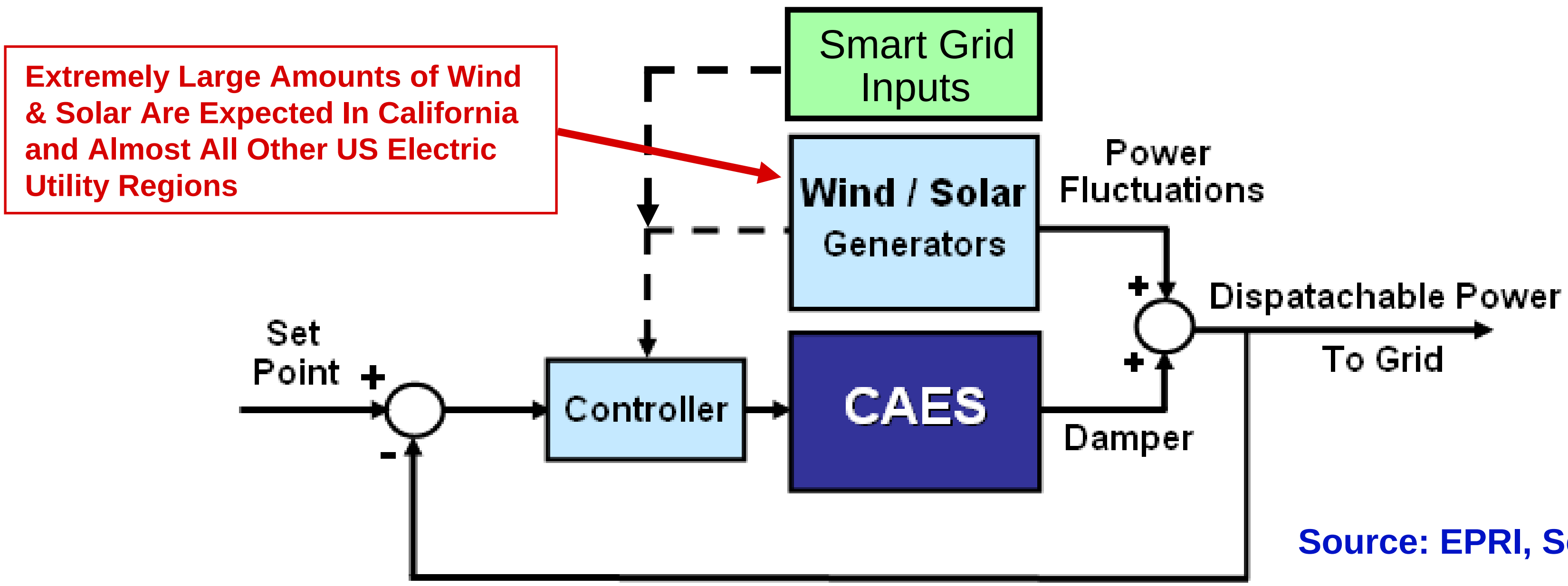
Problem: Wind/Renewable Plants Produce Power Output Oscillations Or Provide Power When Not Needed, Which Limits Their Value

Solution:

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



Source: EPRI, Schainker

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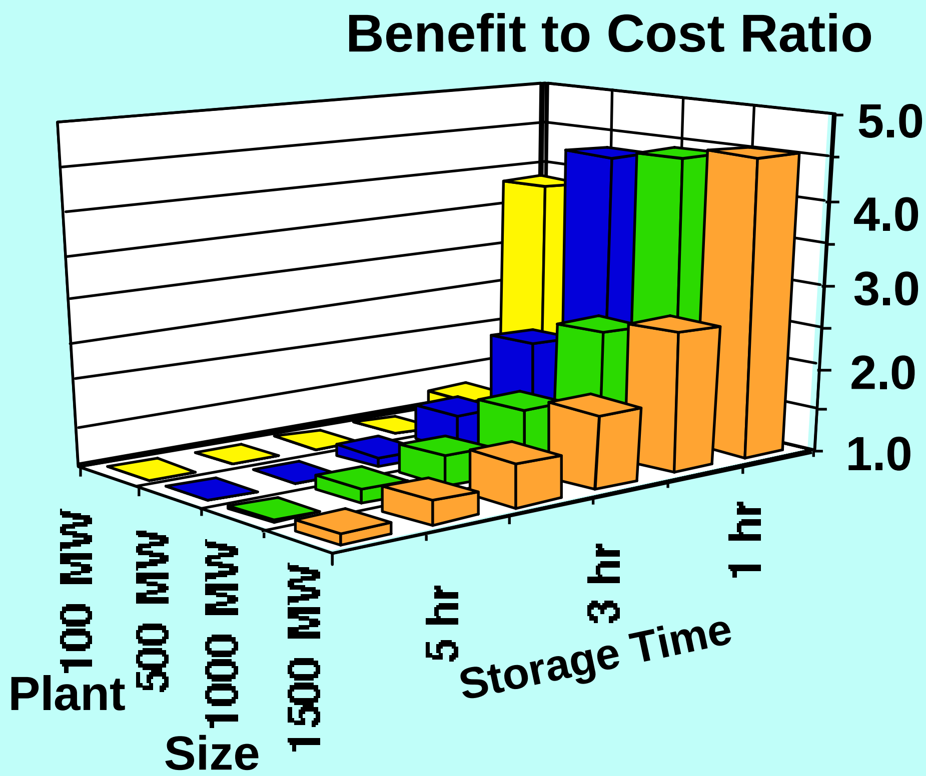
Typical Benefit to Cost Ratio for Battery Plants Versus Hours of Storage and MW Size

Example results from EPRI benefit-cost analyses, which compares different types of energy storage plants



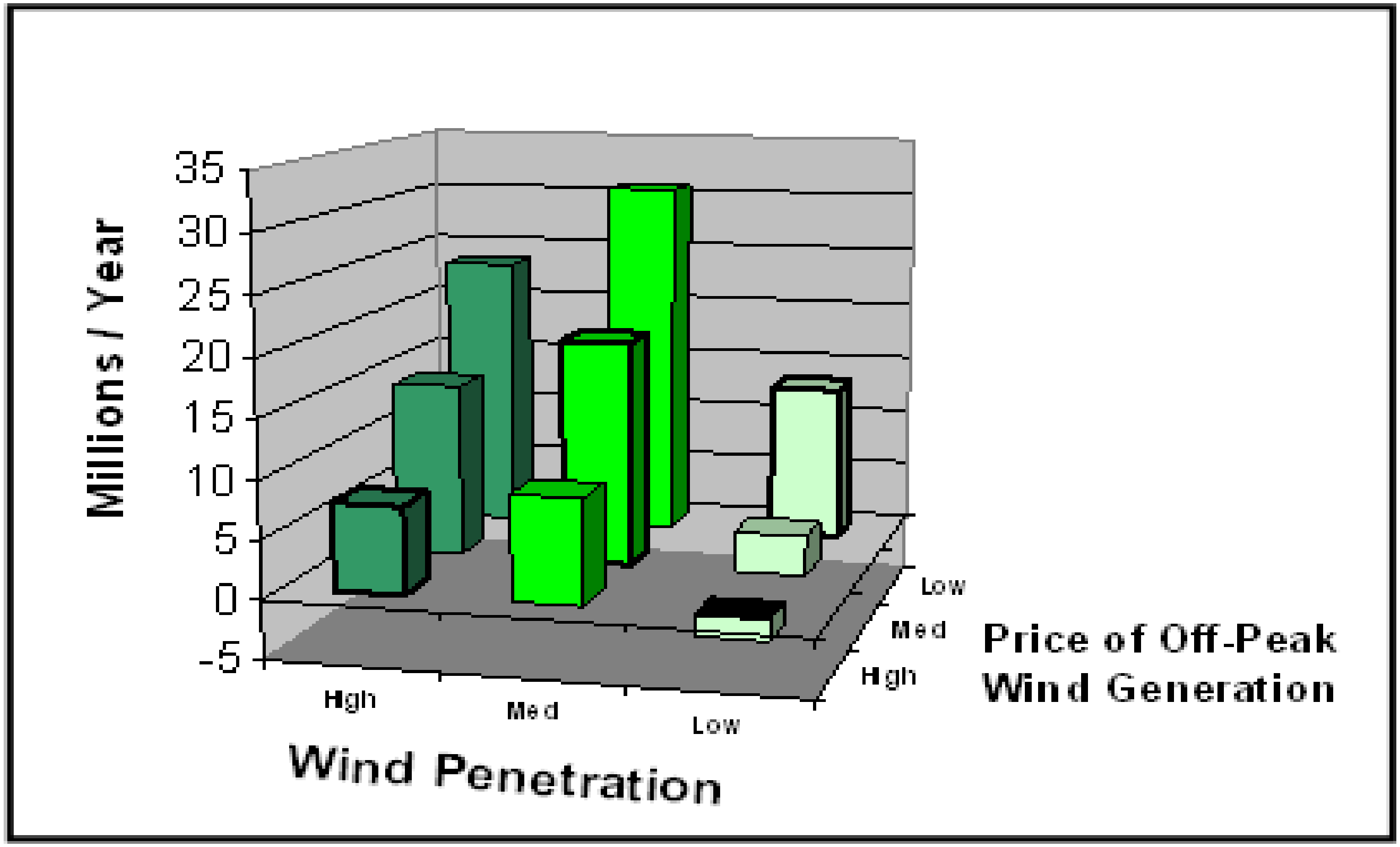
Note: The capital cost for an extra hour of battery storage is about $500/kW, which drives down the B/C ratio so quickly; whereas, the capital cost for an extra hour of CAES storage is about $1/kW, which enables CAES to be cost effective for storage hours much greater than 5.

*** Based on 20GW utility that has USA mix.**

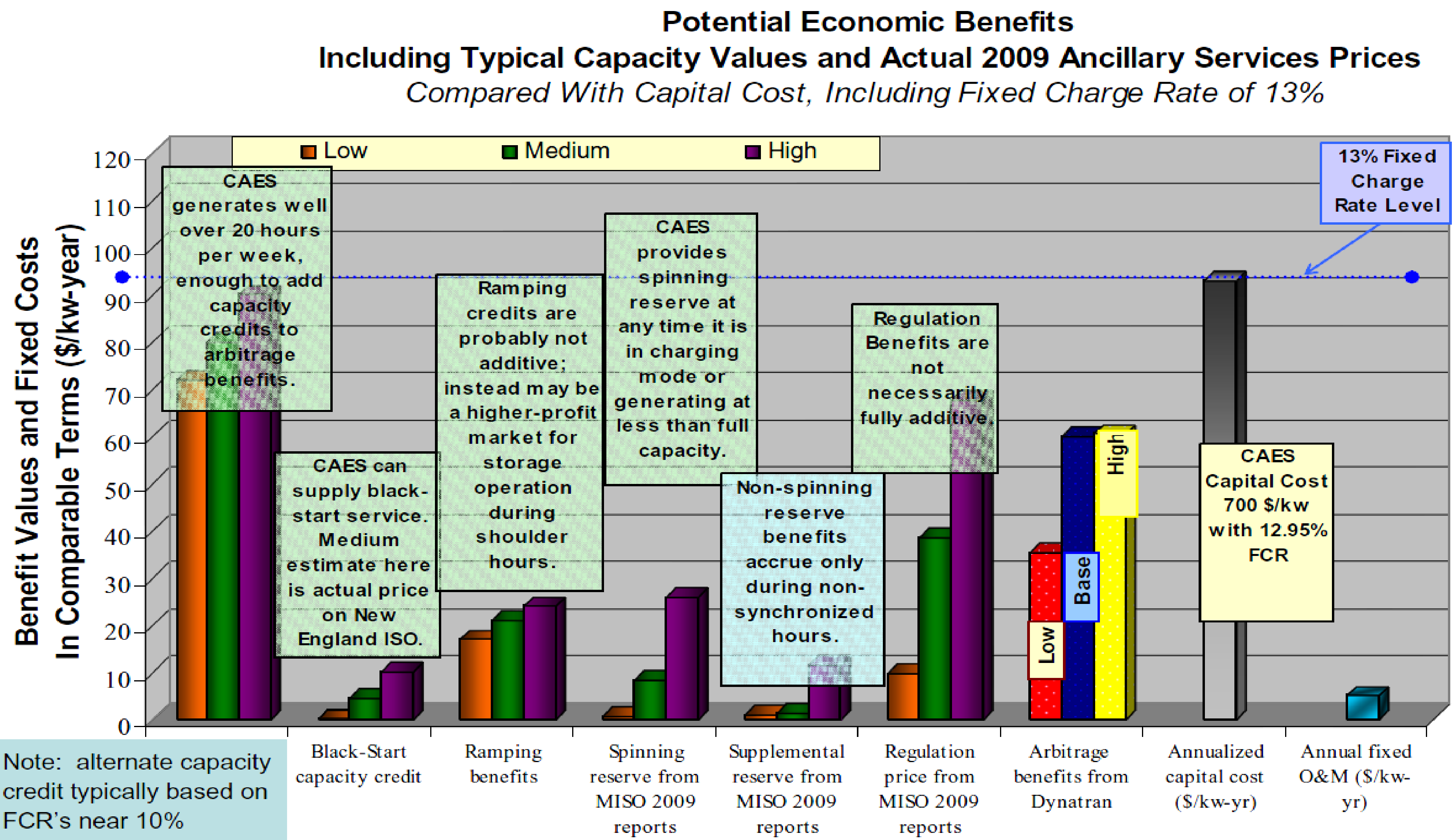
Source: EPRI, Schainker

Anticipated Savings with CAES Plant Integrated with Wind Generation Resources

Example Results from EPRI Economic Analysis

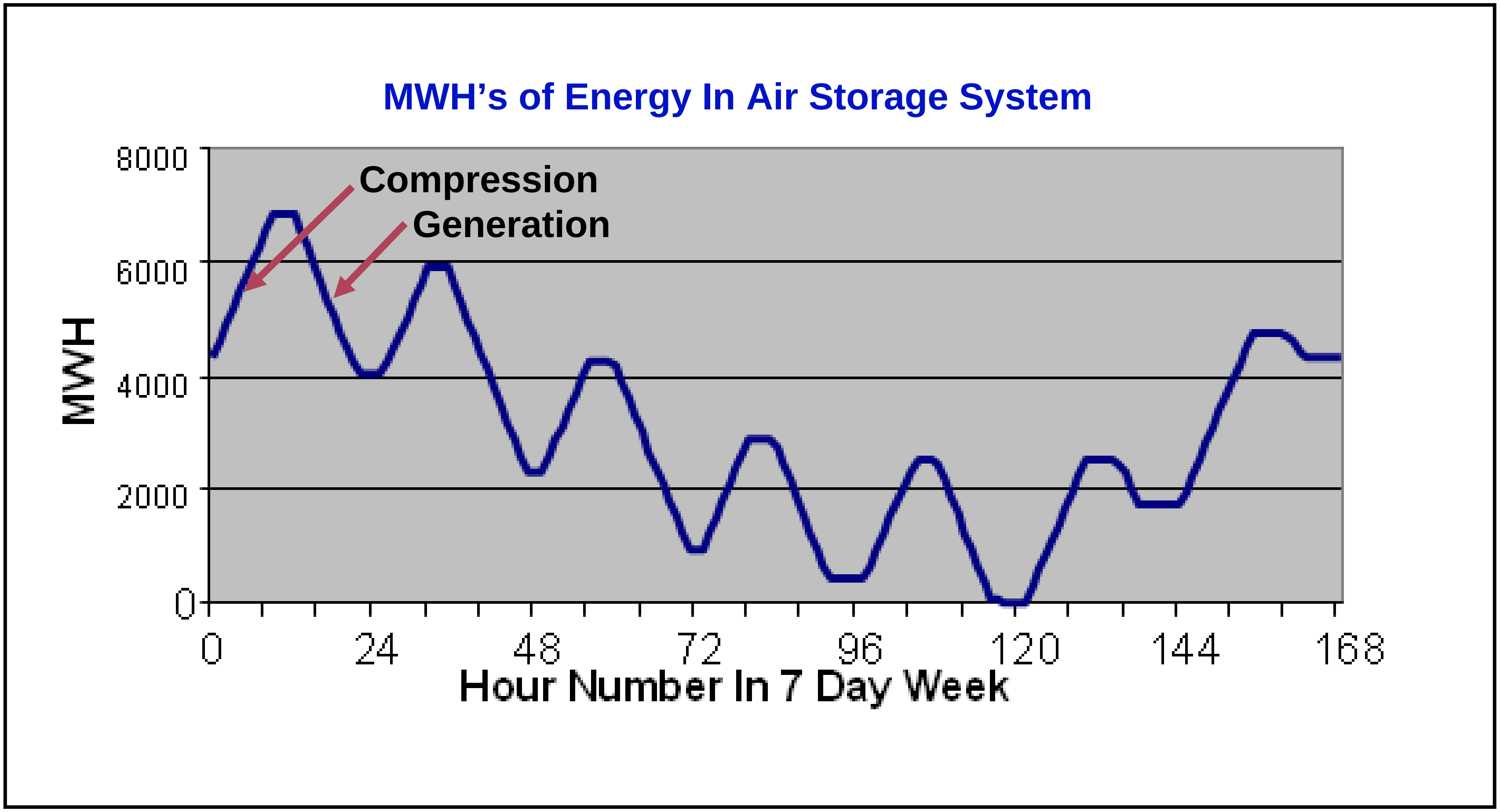


Example Utility Results Showing CAES Economic Benefits Highlighting Ancillary Service Benefits



Note: alternate capacity credit typically based on FCR's near 10%

CAES Generation & Compression Cycles (for a Typical Week)



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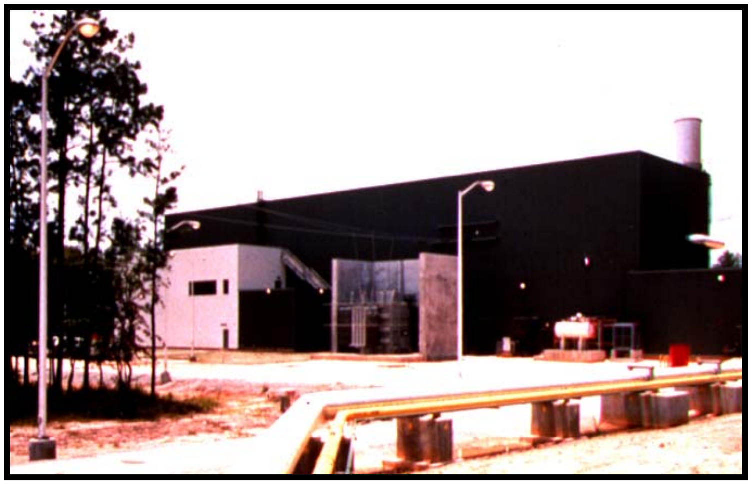
CAES Plants Built, Use and Reliability

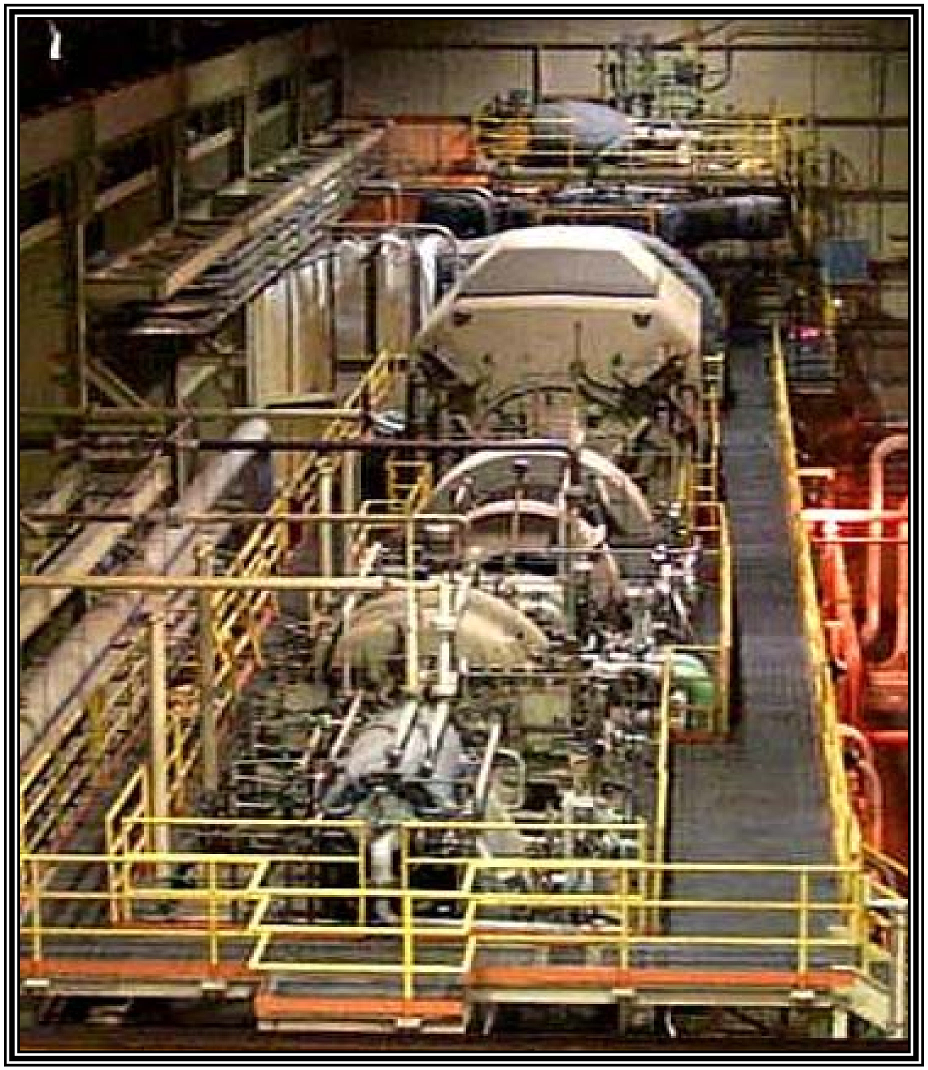
- **110 MW – 26 hour Plant:**
  McIntosh Alabama
  Operational: June 1991
  - **Load Mngmt/Regulation**
  - **Buy Low, Sell High**
  - **Reliability ~ 95% to 98%**

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



Source: EPRI, Schainker

Alabama CAES Plant:
110 MW Turbomachinery Hall



Expansion Turbines

← *Clutch*

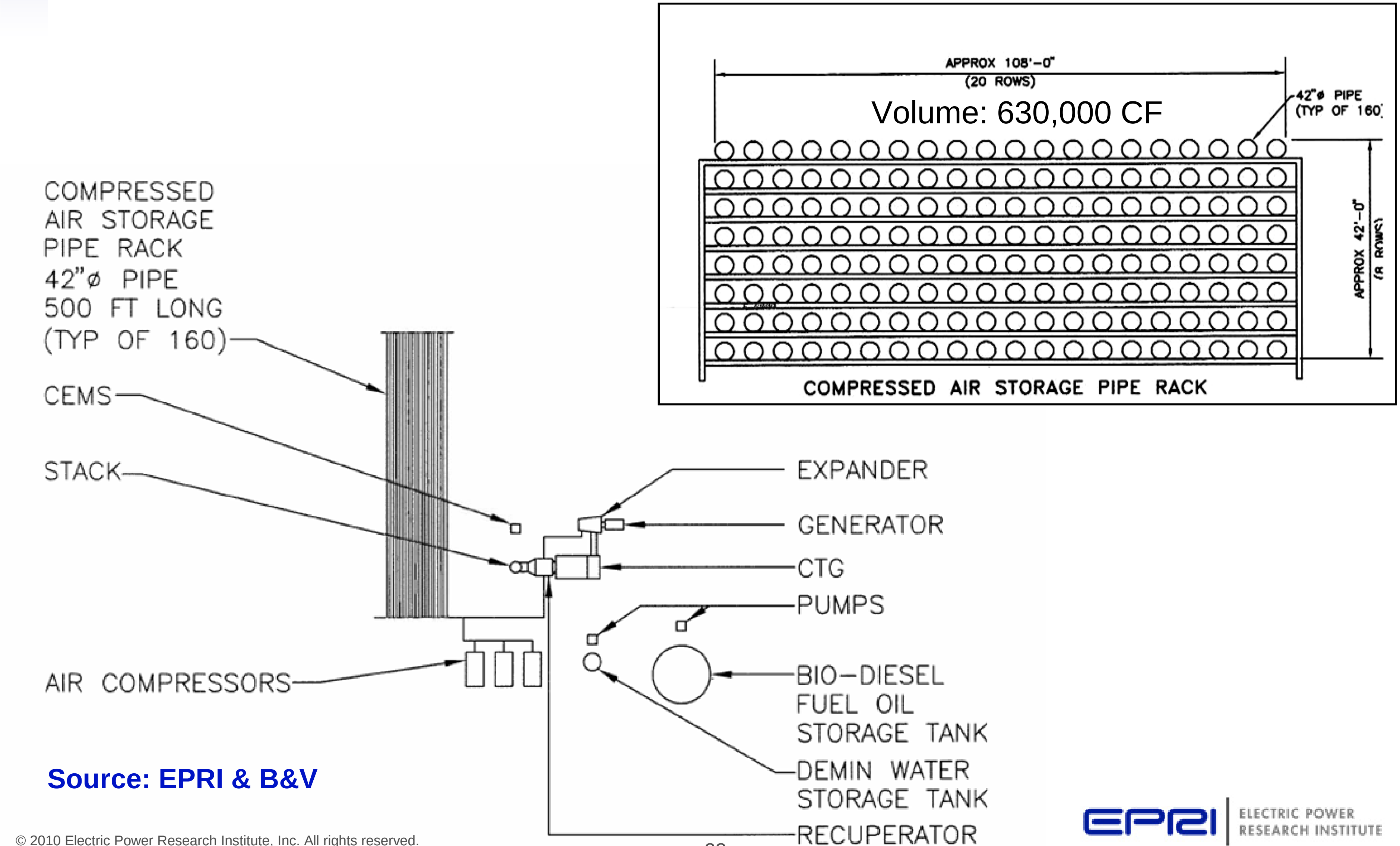
← *Motor-Generator*

← *Clutch*

Compressors

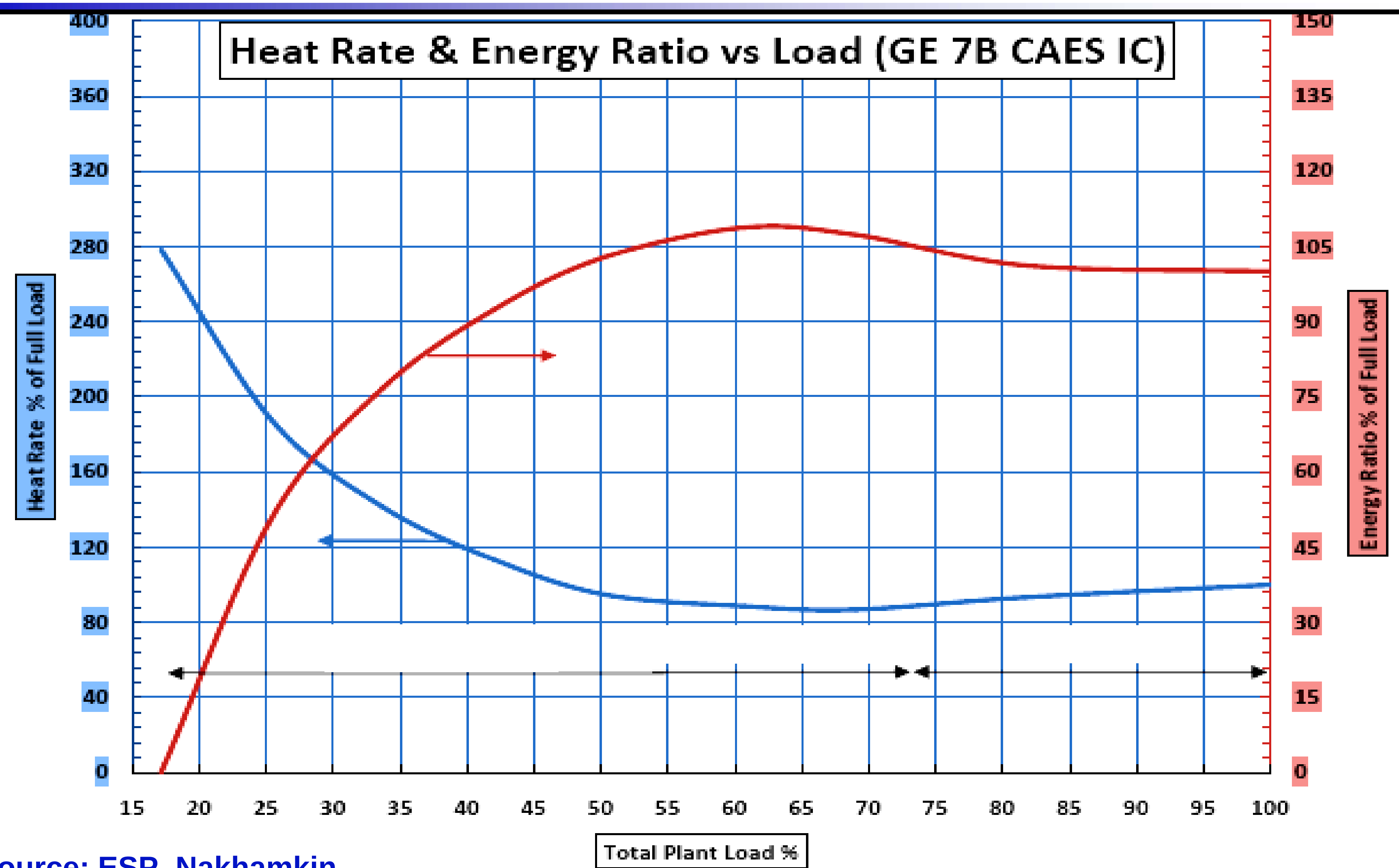
Source: EPRI, Schainker

Above Ground CAES Plant Using Above Ground Air Storage System (58 MW – 4 Hour): Preliminary Plant Layout - - Top View



Source: EPRI & B&V

Advanced CAES Plant: Part Load Heat Rate and Energy Ratio (For Overall Plant, Using Chiller Cycle)



Source: ESP, Nakhamkin

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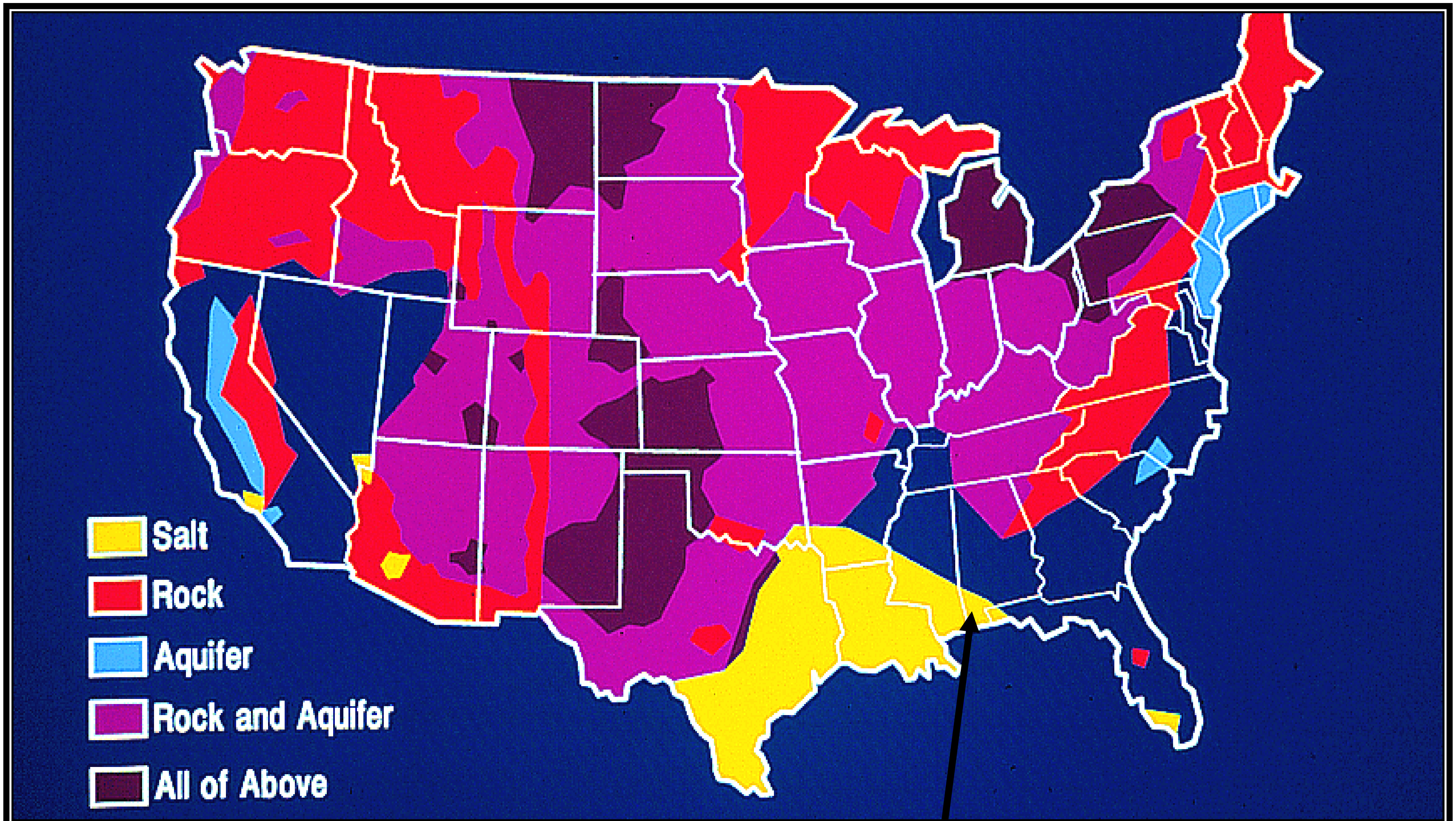
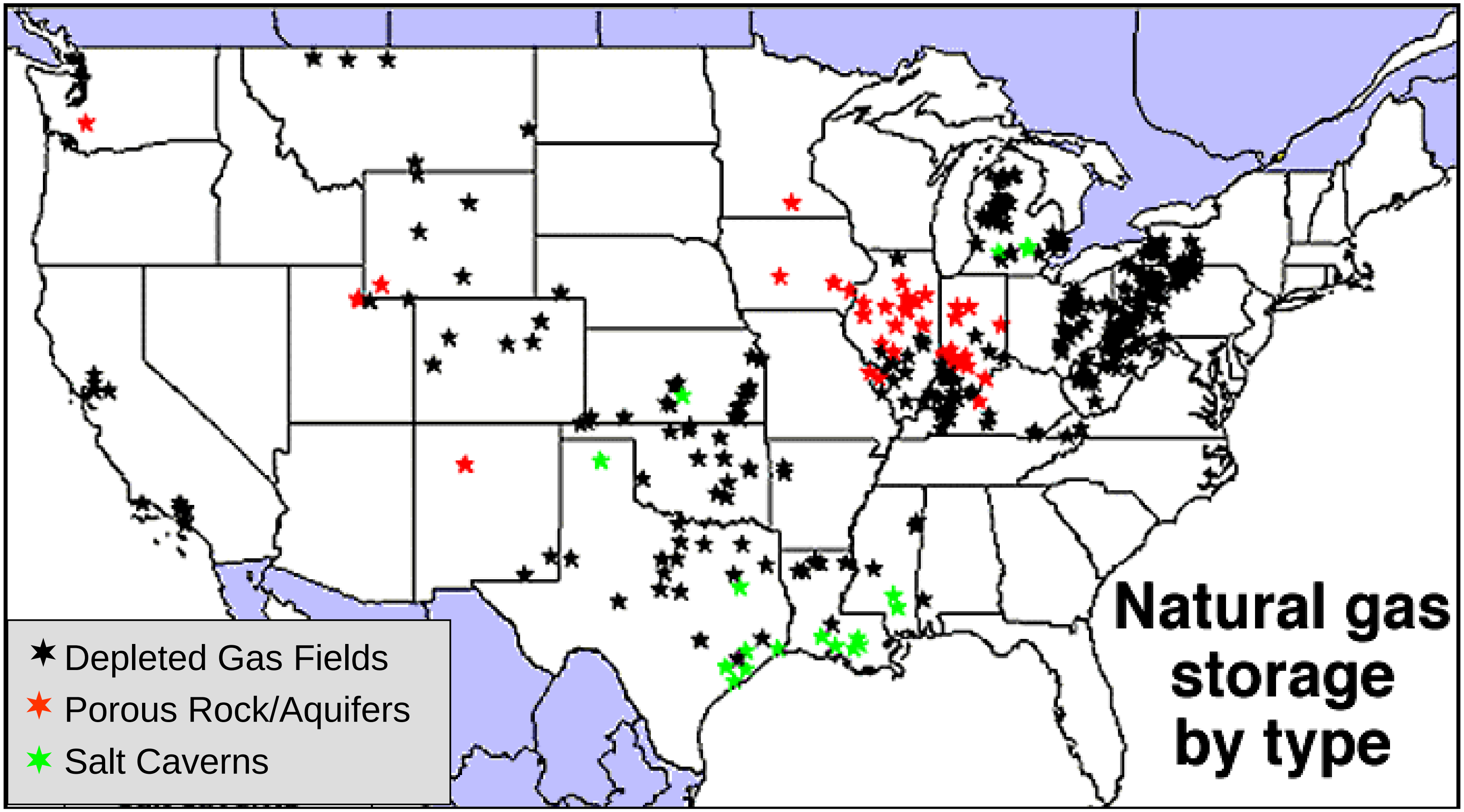
Geologic Formations Potentially Suitable for CAES Plants That Use Underground Storage



Source: EPRI, Schainker

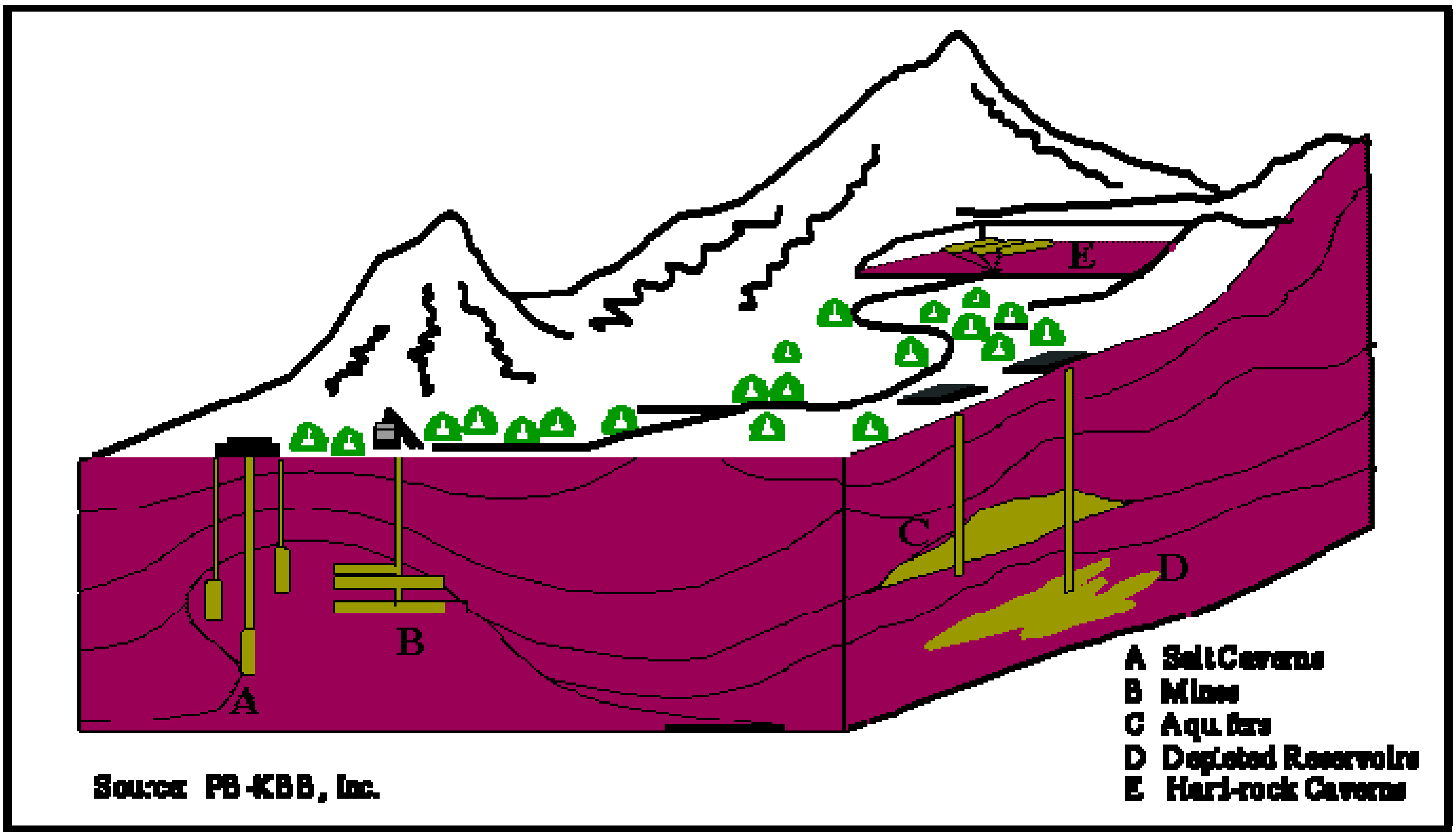
Alabama CAES Plant

Underground Natural Gas Storage Facilities in the Lower 48 United States



Source: PB-ESS

Types of Underground Air Storage Facilities
(same as those used for natural gas storage)



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Major Bulk Energy Storage Projects In USA

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

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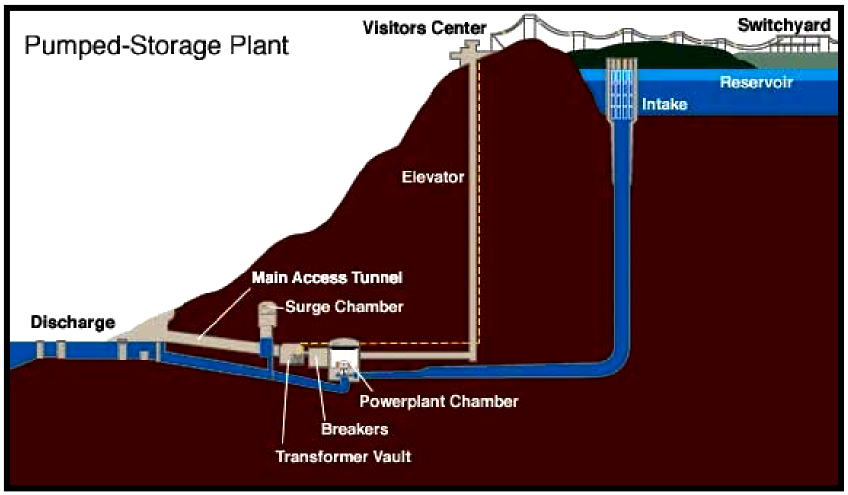
* Note: Some of the above project costs go towards expenses not directly related to the CAES plant (e.g., transmission line & substation upgrade costs)

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

Source: EPRI, Schainker

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)

Source: EPRI, Schainker

1 MW – 15 Minute Beacon Flywheel System

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

Source: EPRI, Schainker

SuperCap 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

Source: HECO

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

Source: EPRI, Schainker

Conclusions

- The US electric grid today is under great stress
- Renewables, due their intermittency and rapid power fluctuations add de-stabilizing challenges to the reliable operation of the US electric grid
- Energy Storage plants can provide extensive "shock absorbing" stability inputs to the US electric grid
- Depending on the grid application needed, different types of energy storage plants need to be deployed
- For bulk energy storage (applicable to the large amounts of new, off-peak wind generation being installed), the compressed air energy storage (CAES) technology seems to be the most cost effective energy storage technology to deploy in the US.
- For short term storage (applicable to the large amounts of solar generation being installed), the lithium-ion battery technology seems to be the most cost effective technology to deploy in the US
- New regulatory initiatives need to be implemented in the US to take advantage of the performance capabilities of energy storage technologies to stabilize the ageing electric infrastructure in the US

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Operating Costs Storage Plants

<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 = $/KWH In for Charging x KWH In/KWH Out
+ Variable O&M
+ Generation Heat Rate (Btu In/KWH out) x
Fuel Cost ($/Million Btu In)

Expected Operating Costs for CAES Plant

Expected Operational Costs For CAES Plants:

$/Kwh = Incremental, Off-Peak Cost for Charging Electricity
x Energy Ratio + Generation Heat Rate (Btu/Kwh)
x Fuel Cost ($/Million Btu)
+ Variable Operational & Maintenance Costs

For Example, If :

CAES Heat Rate = 3810 Btu/kWh

Energy Ratio = 0.7

Off-peak electricity cost = $10/MWh

Fuel Cost = $8/MMBtu

Variable O&M = $5/MWh

Then:

CAES Operational Cost = $42.5/MWh

Appendix

Example Operating Costs For Storage Plants and Combustion Turbines

Source:

	Parameter	Battery	CAES	CT
	KWh Out/KWh In	0.750	1.429	NA
	Heat Rate (Btu/KWh Out)	NA	3810	11000
	Incr Chrg'g Cost ($/MWh)	20.0	20.0	NA
	Fuel Cost ($/Mill.Btu)	NA	6.00	6.00
	Var. O&M (Mills/KWh)	40.0	5.0	10.0
	Total Oper. Costs ($/MHh)	66.7	41.9	76.0
IF:	Incr Chrg'g Cost ($/MWh)	20.0	20.0	NA
IF:	*Fuel Cost ($/Mill.Btu)*	*NA*	*7.00*	*7.00*
Then	Total Oper. Costs ($/MWh)	66.7	45.7	87.0
IF:	*Incr Chrg'g Cost ($/MWh)*	*40.0*	*40.0*	*NA*
IF:	Fuel Cost ($/Mill.Btu)	NA	6.00	6.00
Then	Total Oper. Costs ($/MWh)	93.3	55.9	76.0

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