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Alabama Electric Cooperative's CAES Plant
(110 MW-26 Hr)
Plant Commissioned: June 1, 1991

Compressed Air Energy Storage (CAES): Executive Summary

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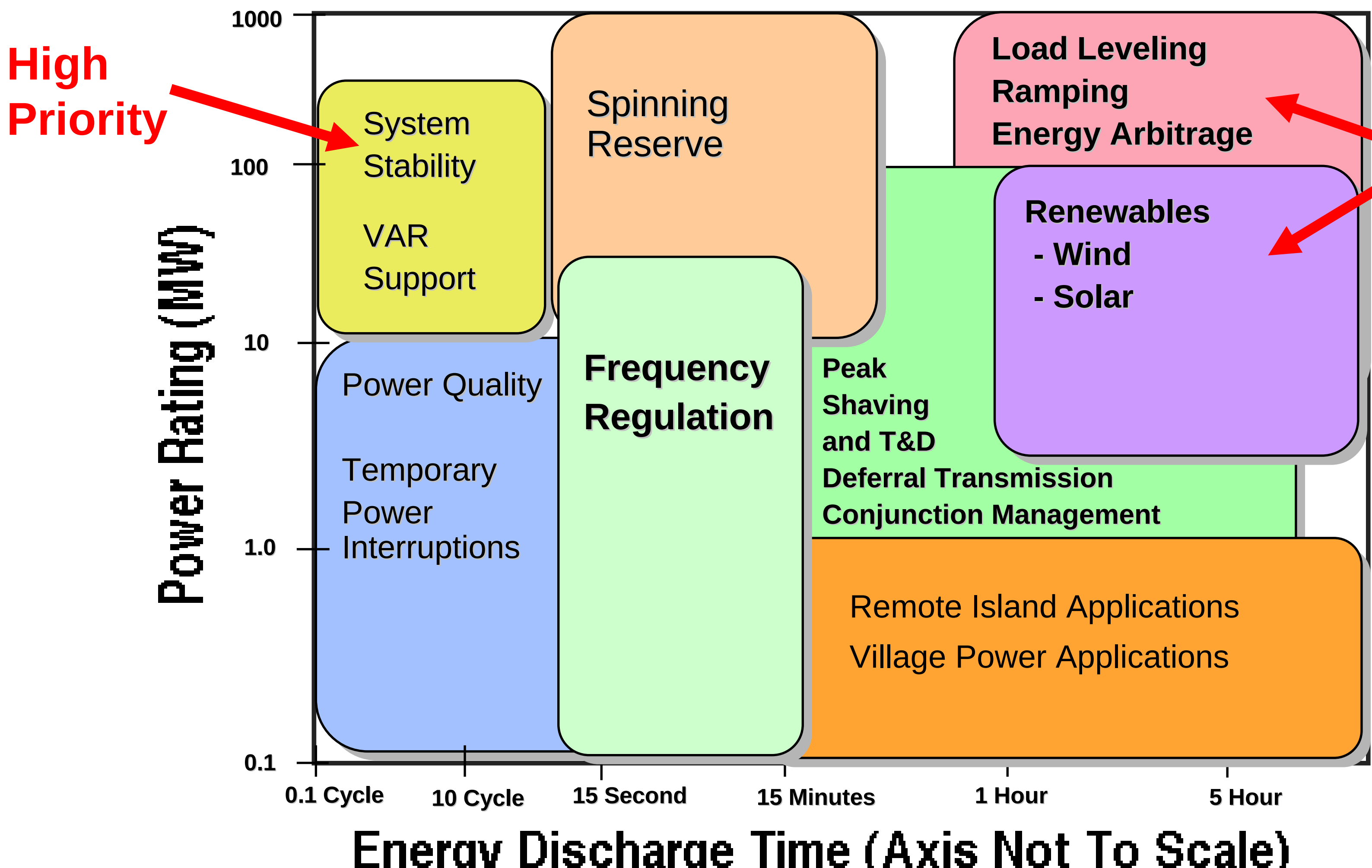
Electric Energy Storage Applications

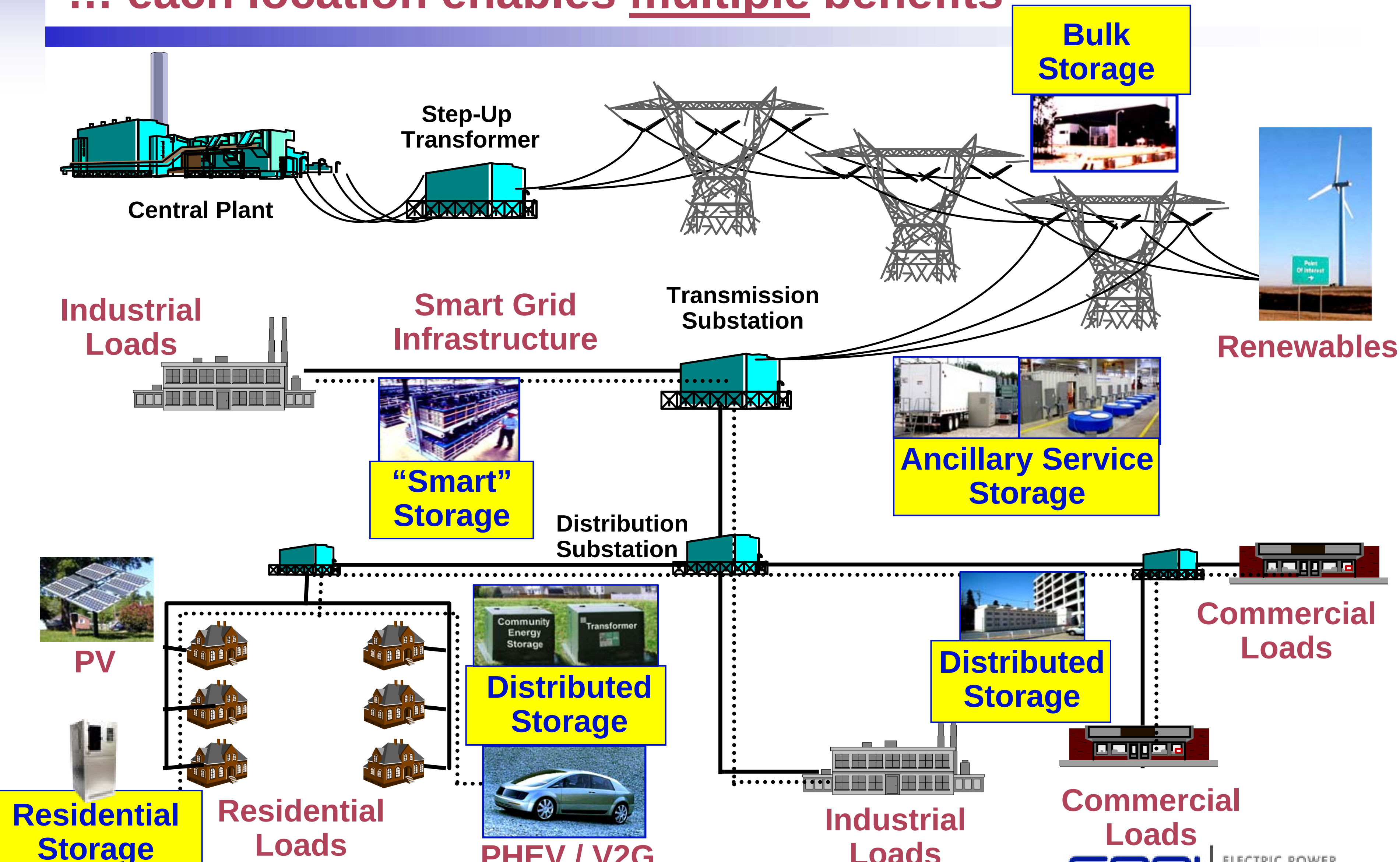
(All Boundary Regions Displayed Are Approximate)



Black Start needs 1 to 30 MW's For a 1 to 2 Hr. Duration

The Role of Electricity Storage on the Grid

… each location enables multiple benefits



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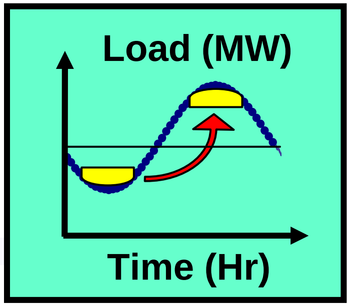
Overview of EPRI Advanced CAES Demonstration Project



- The EPRI Adv. CAES project includes the phased planning, engineering design, construction, demonstration and performance monitoring of two CAES plants.
- This is a critical demonstration project of technology designed to enable higher penetration of intermittent renewable, nuclear or other non emitting base load generation that may substantially reduce carbon emissions.

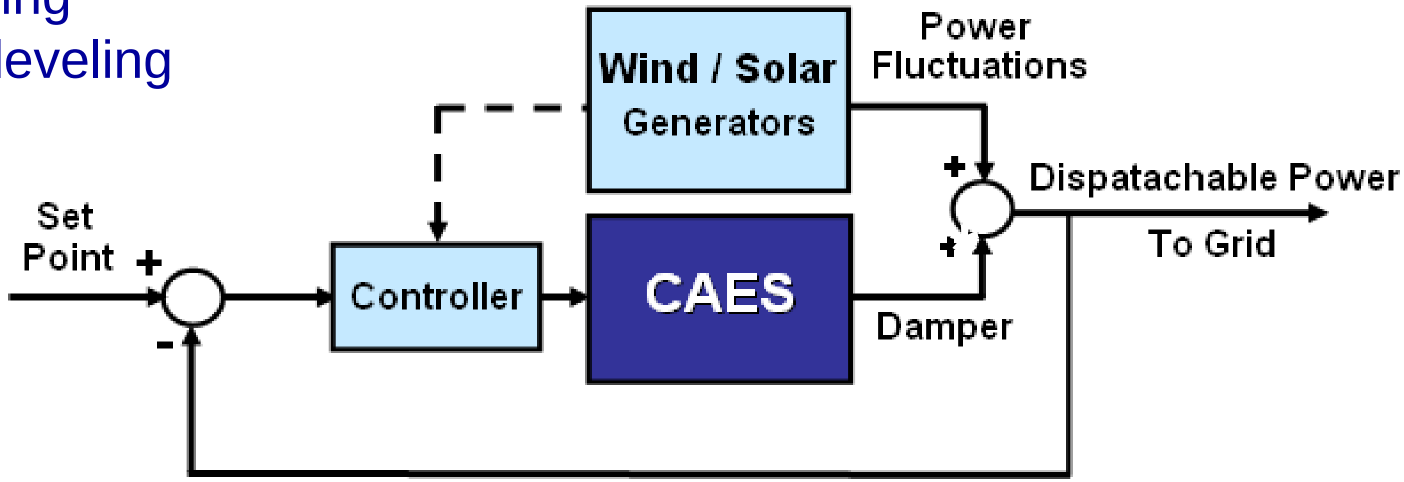
CAES Functionality

- CAES plants use electricity to compress air into an air storage system.
- When electricity is needed, air is withdrawn, heated, and run through an expansion turbine to drive an electric generator.
- Compared to a combustion turbine, such plants burn about one-third the premium fuel and produce about one-third the pollutants per kWh of plant output.

The Wind Challenge and Industry Response

<u>Challenge:</u> Wind/Renewable Fluctuating Power Output
- Produce power oscillations with high, unpredictable ramping problems
- Provide power when not needed (off-peak rather than on-peak time)

<u>Response:</u> Deploy Electric Energy Storage, sized for:
- Frequency regulation
- Ramping
- Load leveling

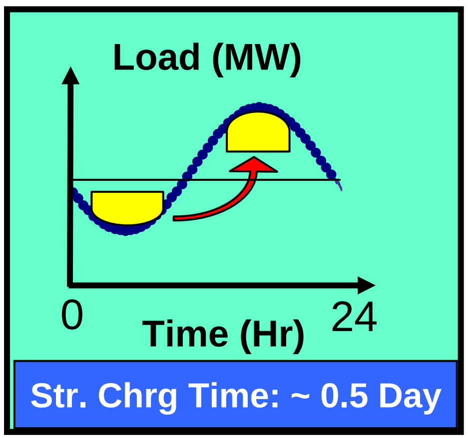


Energy Storage Resolves Wind/Solar Power Fluctuations, Ramping and Load Management Issues

Wind/Solar Plants Cause Ramping & Frequency Instabilities

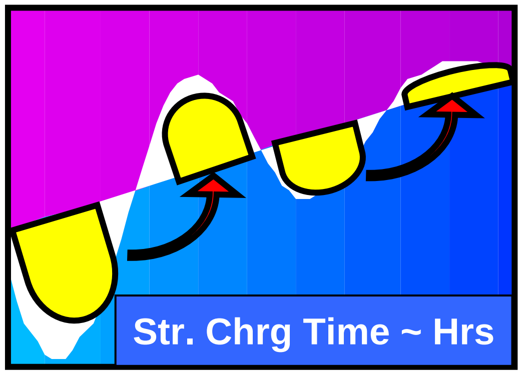
Wind Plants Inject Power In Off-Peak Time Periods

Load Leveling



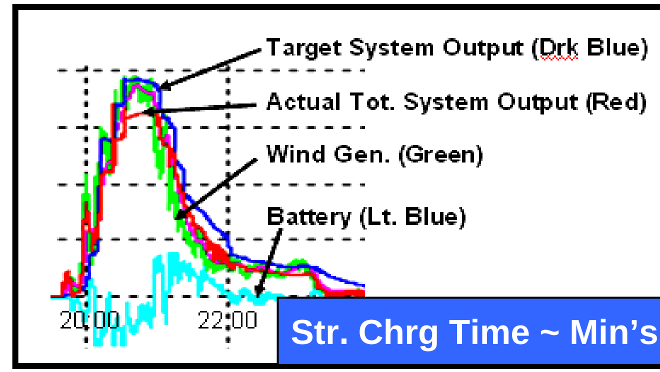
- CAES
- Pumped Hydro

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

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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.

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

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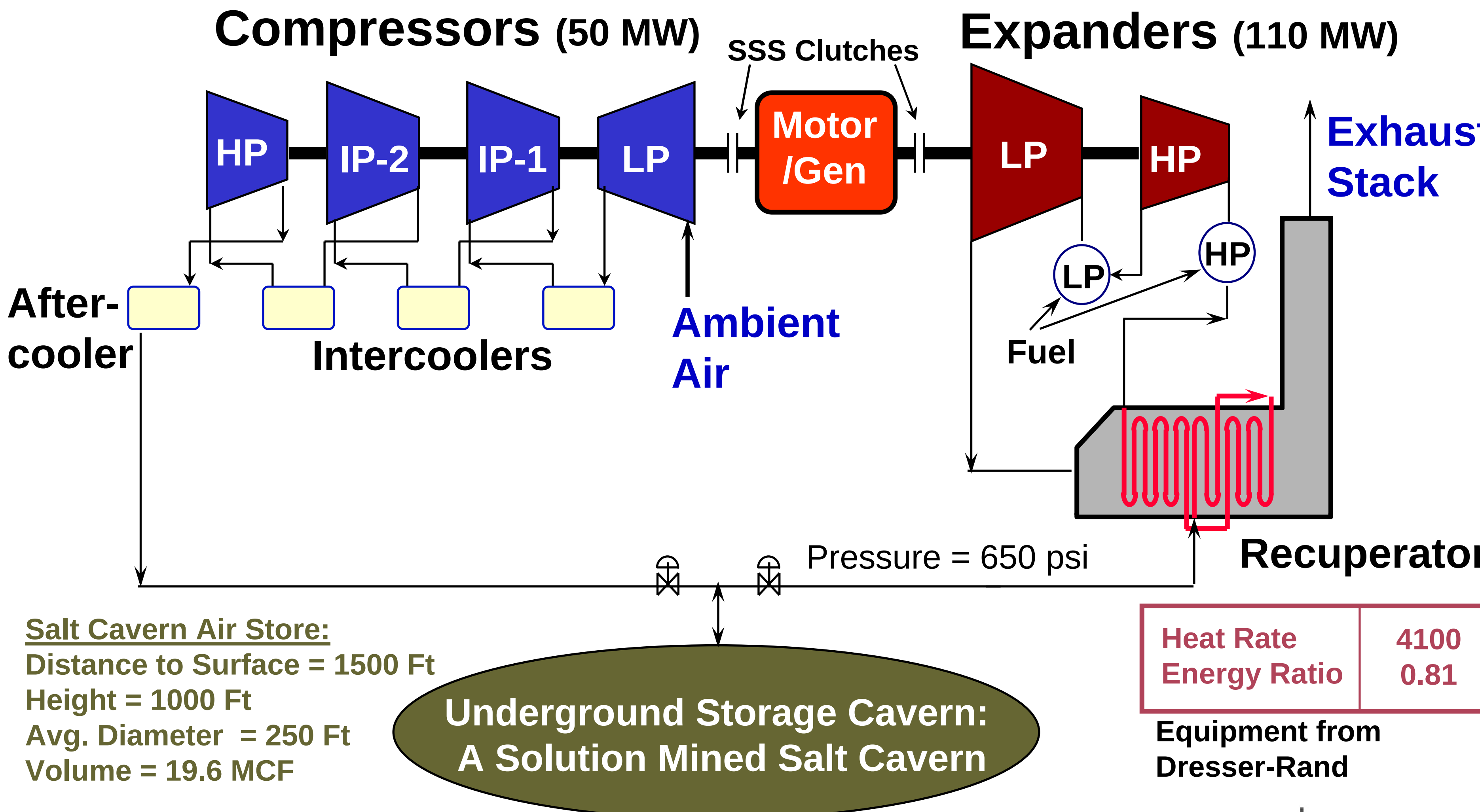
Alabama CAES Plant: Design Schematic
- - - First Generation Design - - -

Cap. Cost (2009 Dollars) ~ $730/kW to $830/kW + Substation, Permits & Contingencies

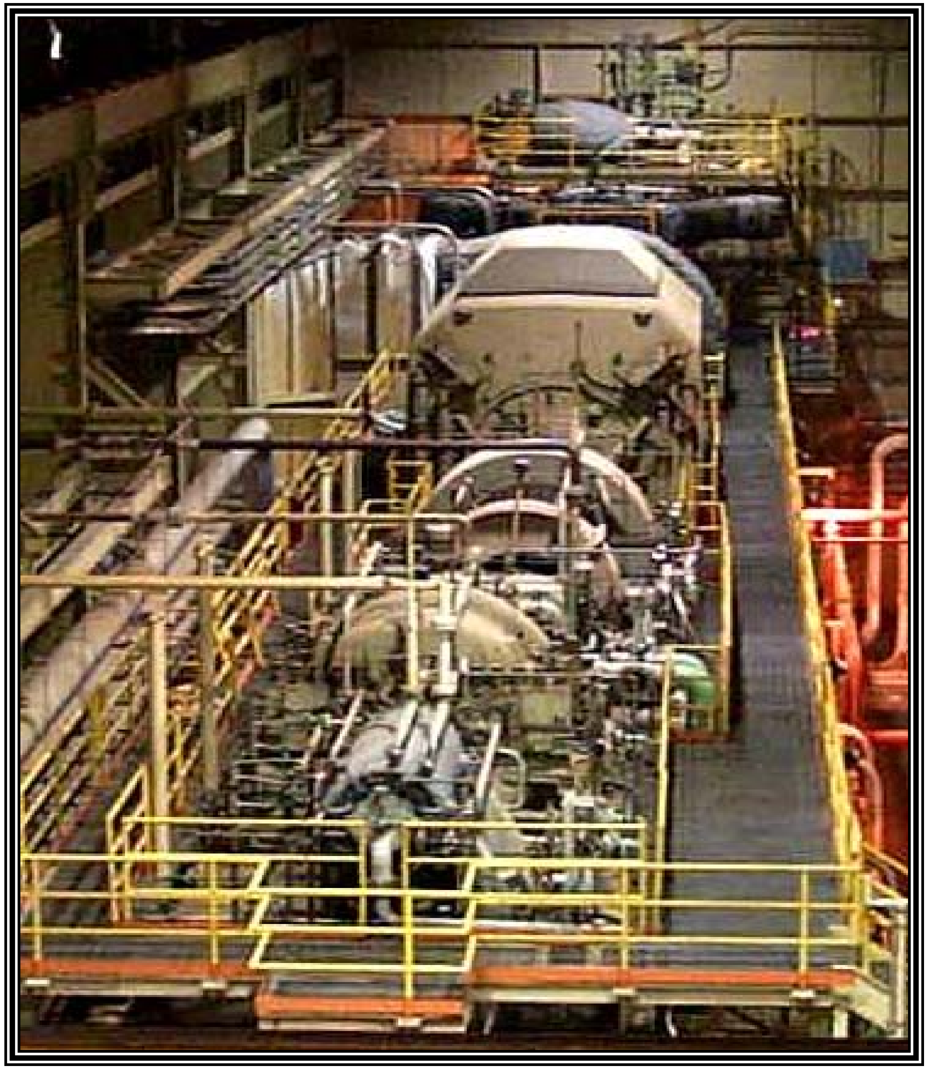


Salt Cavern Air Store:
Distance to Surface = 1500 Ft
Height = 1000 Ft
Avg. Diameter = 250 Ft
Volume = 19.6 MCF

Heat Rate	4100
Energy Ratio	0.81

Equipment from Dresser-Rand

Alabama CAES Plant
110 MW Turbomachinery Hall



Expansion Turbines

Clutch

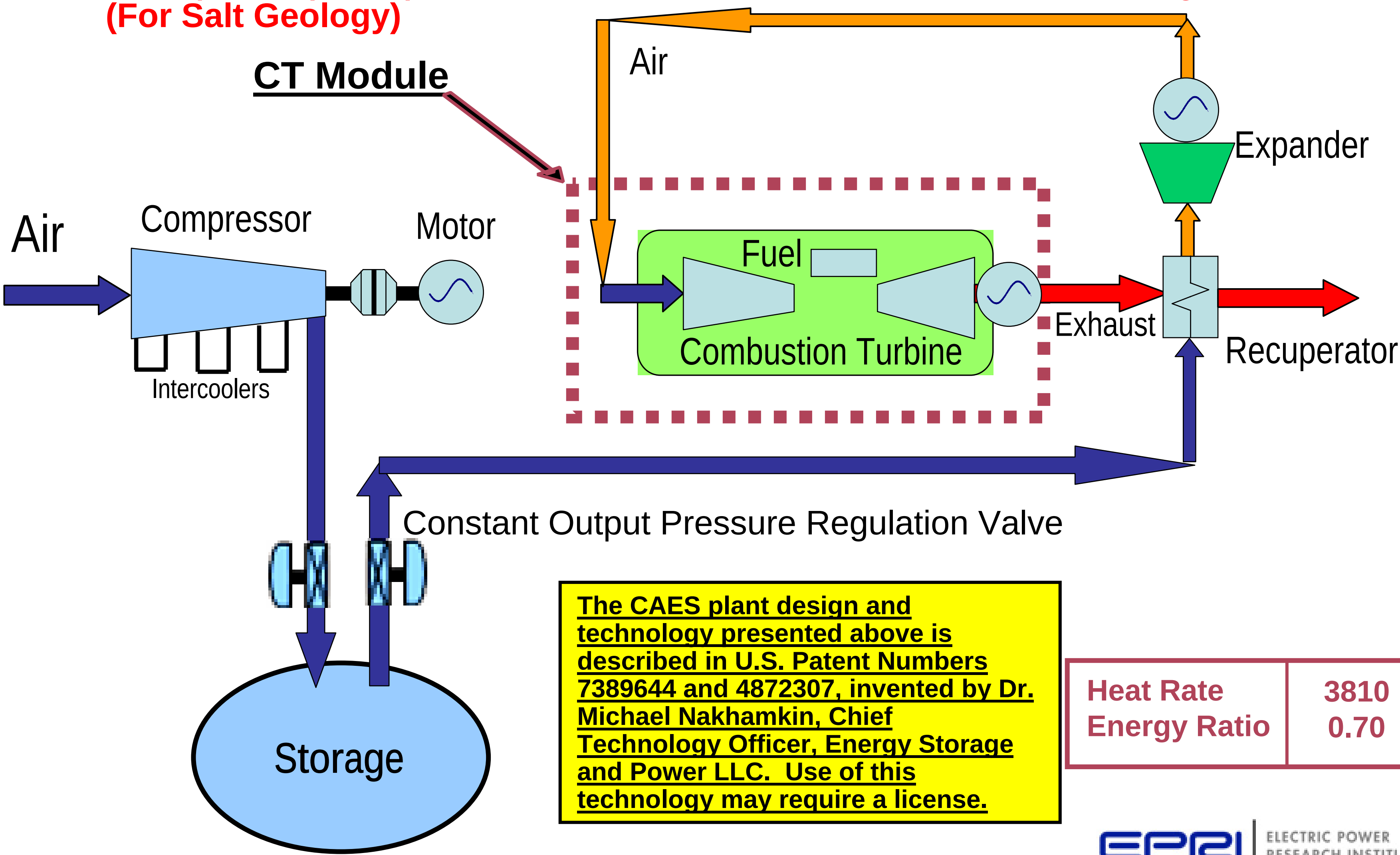
Motor-Generator

Clutch

Compressors

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

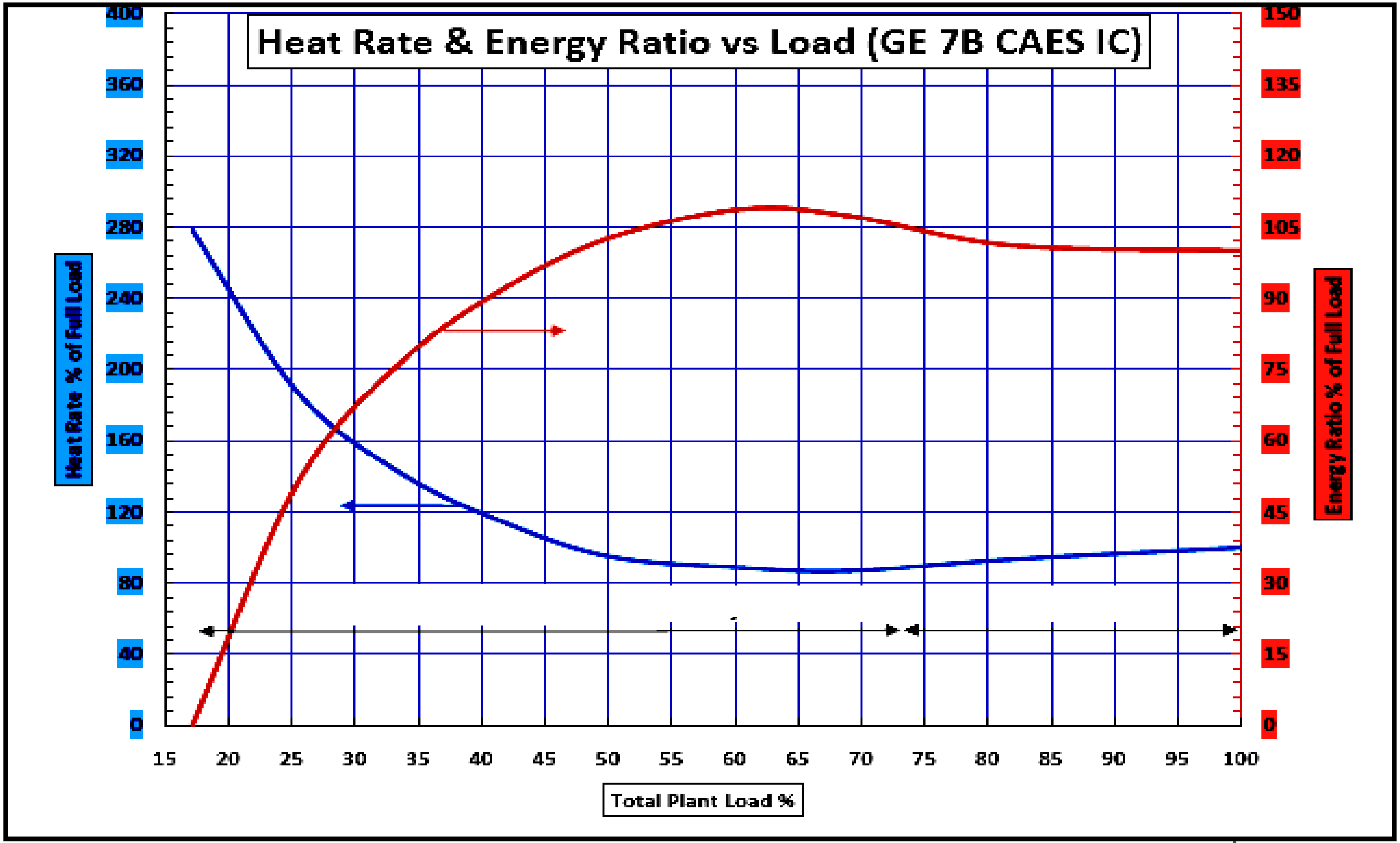
Estimated Cap. Cost (2009 $) ~ $600/kW to $750/kW + Substation, Permits & Contingencies (For Salt Geology)



The CAES plant design and technology presented above is described in U.S. Patent Numbers 7389644 and 4872307, invented by Dr. Michael Nakhamkin, Chief Technology Officer, Energy Storage and Power LLC. Use of this technology may require a license.

Heat Rate	3810
Energy Ratio	0.70

Advanced CAES Plant
Part Load Heat Rate and Energy Ratio (For Overall Plant)



Comparison of First Generation and Advanced CAES Plant Designs

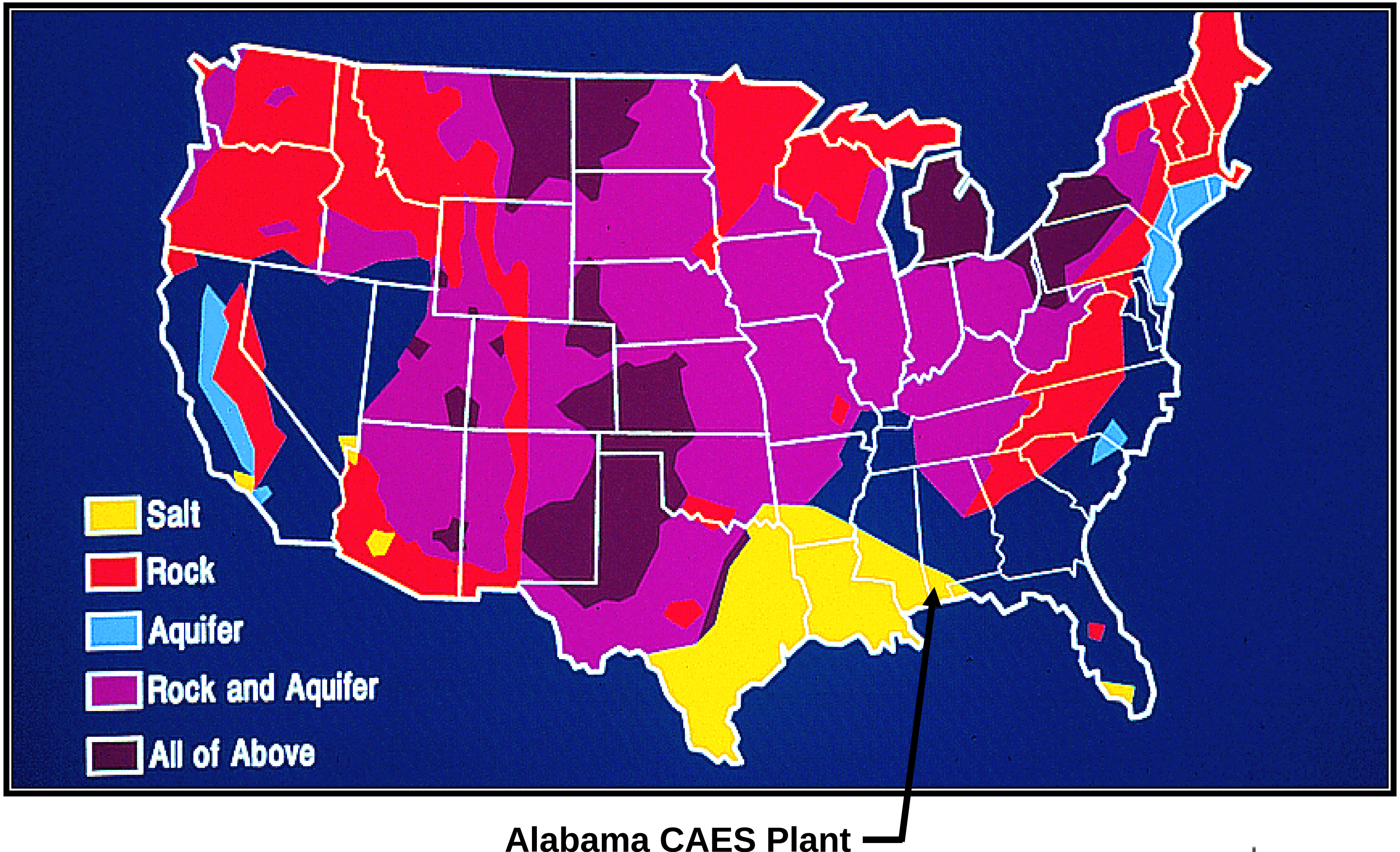
First generation plant design (CAES Alabama

- Complex set of turbomachinery
- Customized high pressure combustor
- Meets NOx air quality emission standards with additional auxiliary equipment
- Cannot process stored air that has any oxygen depletion
- Construction time is two to three years

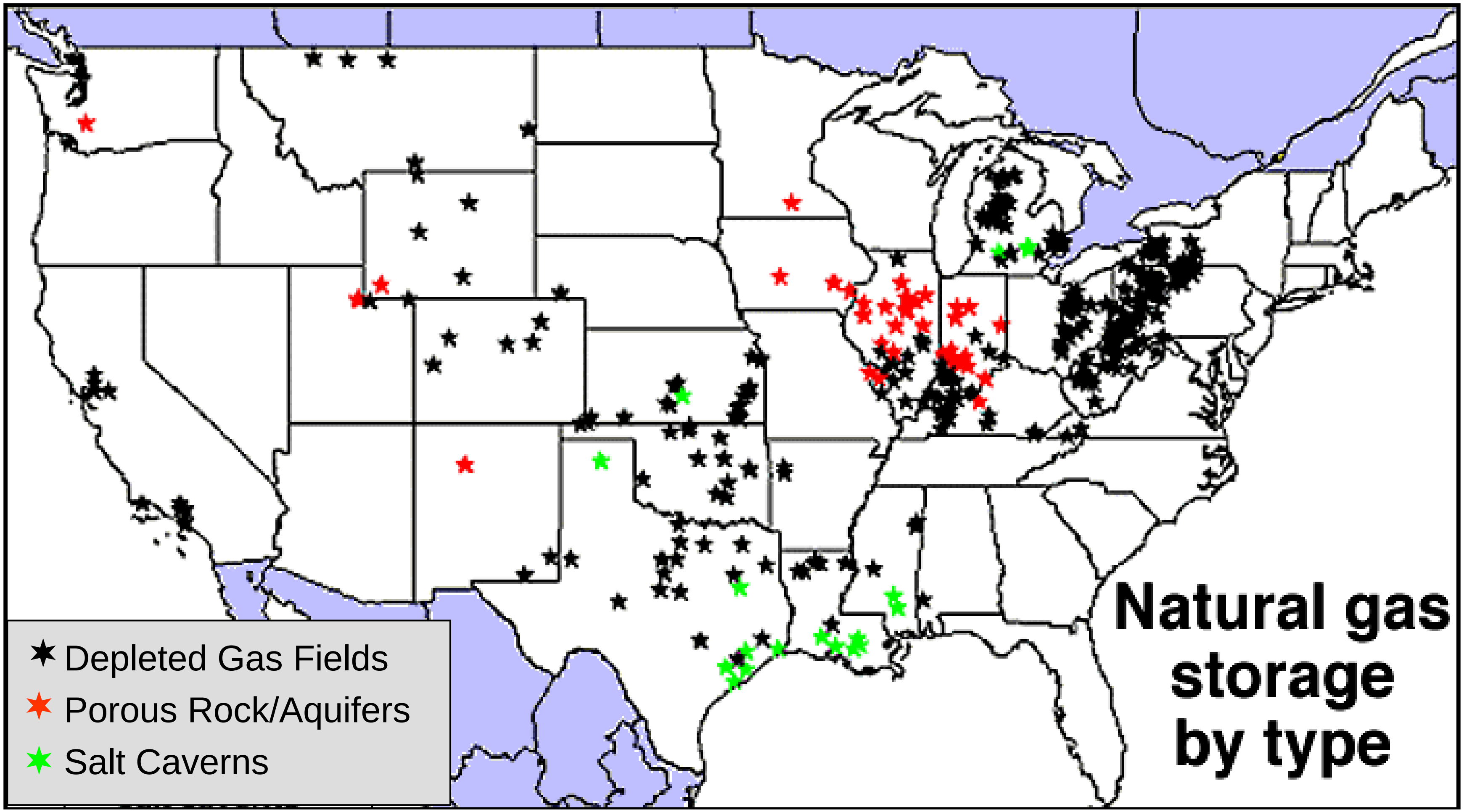
Advanced CAES plant design

- Expected to have lower capital cost and lower operating cost than the first generation plant design
- Plant expected to meet existing air emission standards (including NOx) without additional auxiliary equipment added to the plant
- Construction is anticipated to take two to three years

Geologic Formations Potentially Suitable for CAES Plants That Use Underground Storage



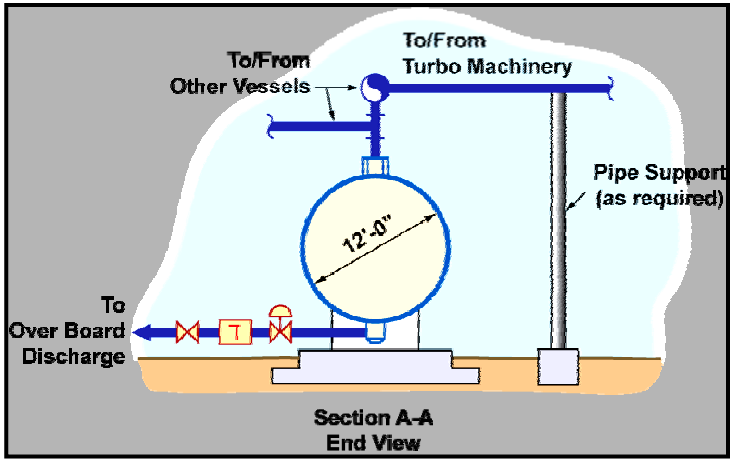
Underground Natural Gas Storage Facilities in the Lower 48 United States



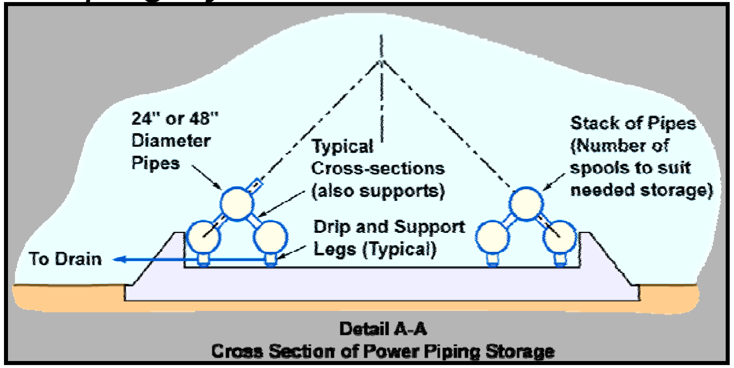
CAES with Above-Ground Air Storage System

- **Plant Size: ~ 15 MW with 2 Hours of Storage**
- **Assess technical and economic feasibility of pipe and/or vessel-based above-ground air storage systems for CAES application**
- **Assess stress-corrosion impact of CAES cyclic pressure and temperature duty**
- **Intend to demonstrate advanced CAES plant design and assess its cost, performance and reliability**
- **Expect to demonstrate power ramping capability to mitigate power fluctuations from wind generators**

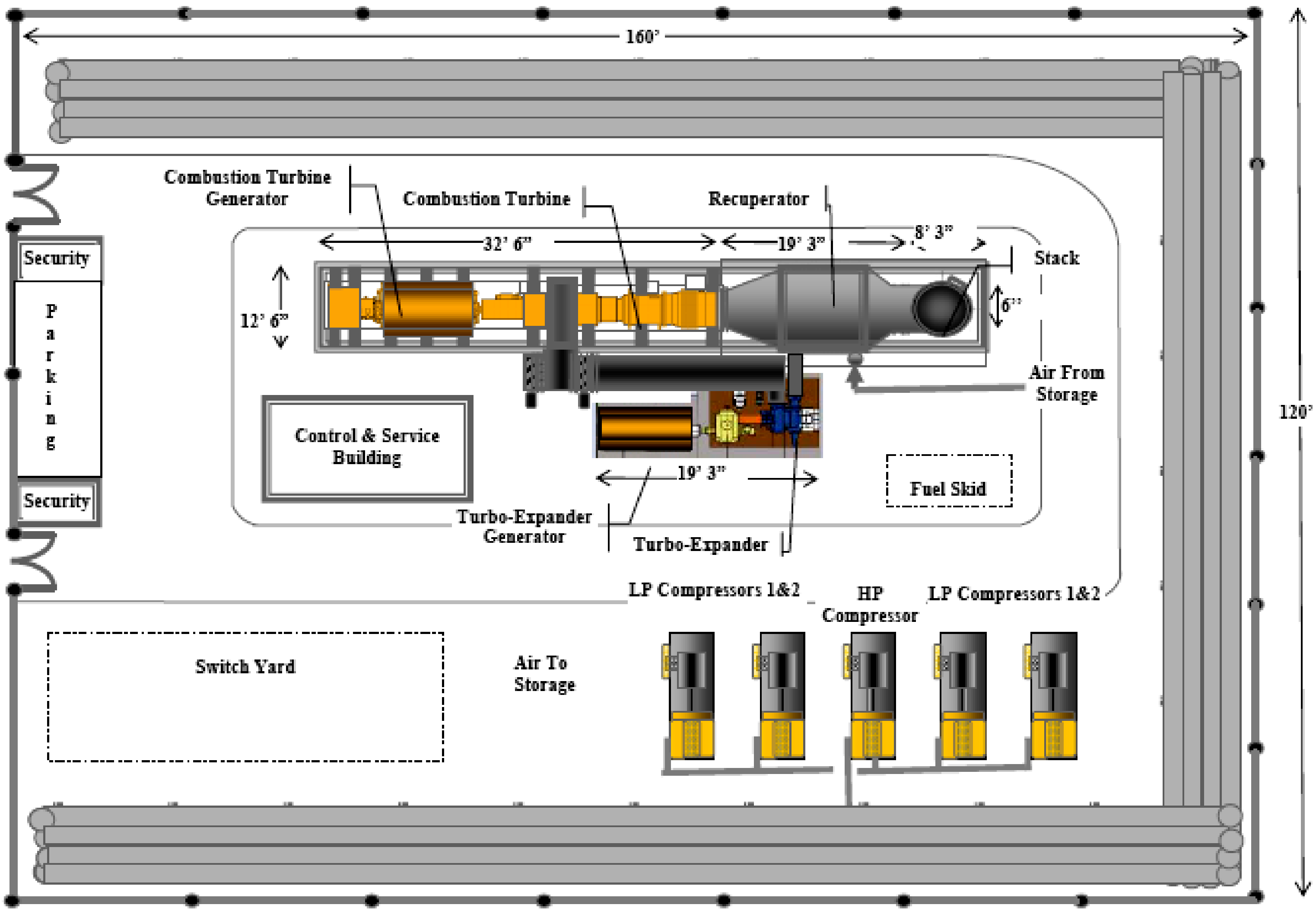
Tanks/Vessels Used For Air Store



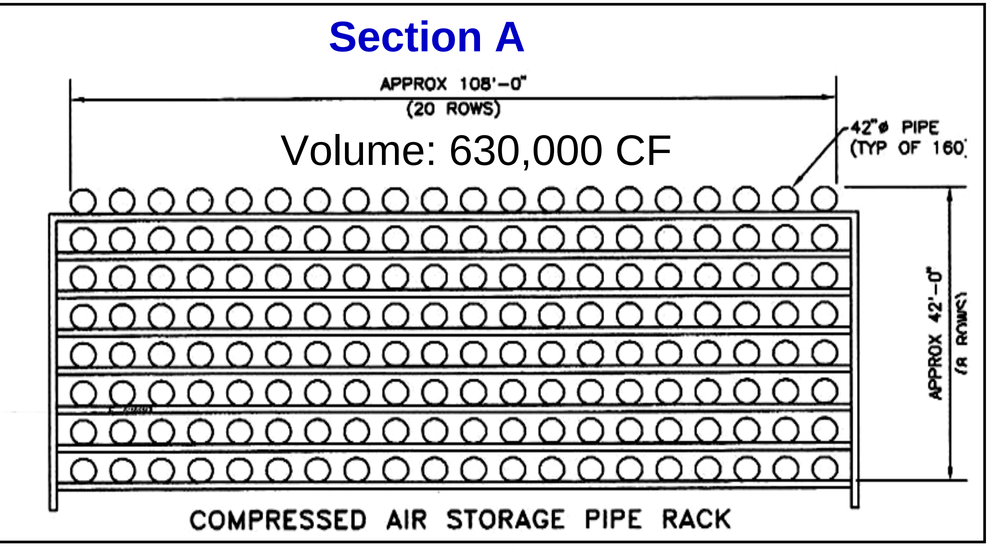
Piping System Used For Air Store

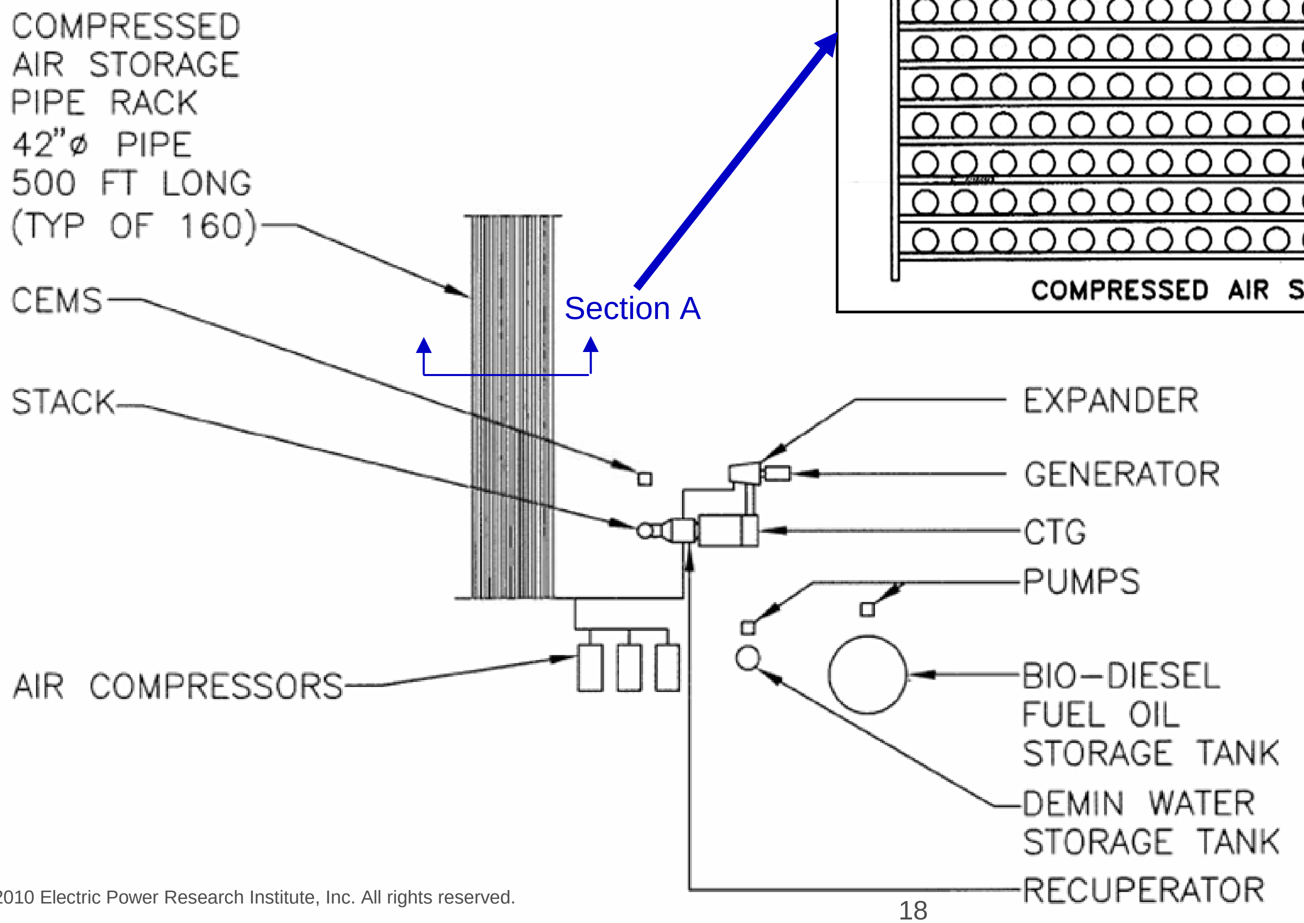


15 MW – 2 Hr. Adv. CAES Plant Using Pipeline Type of Above-Ground Air Storage System

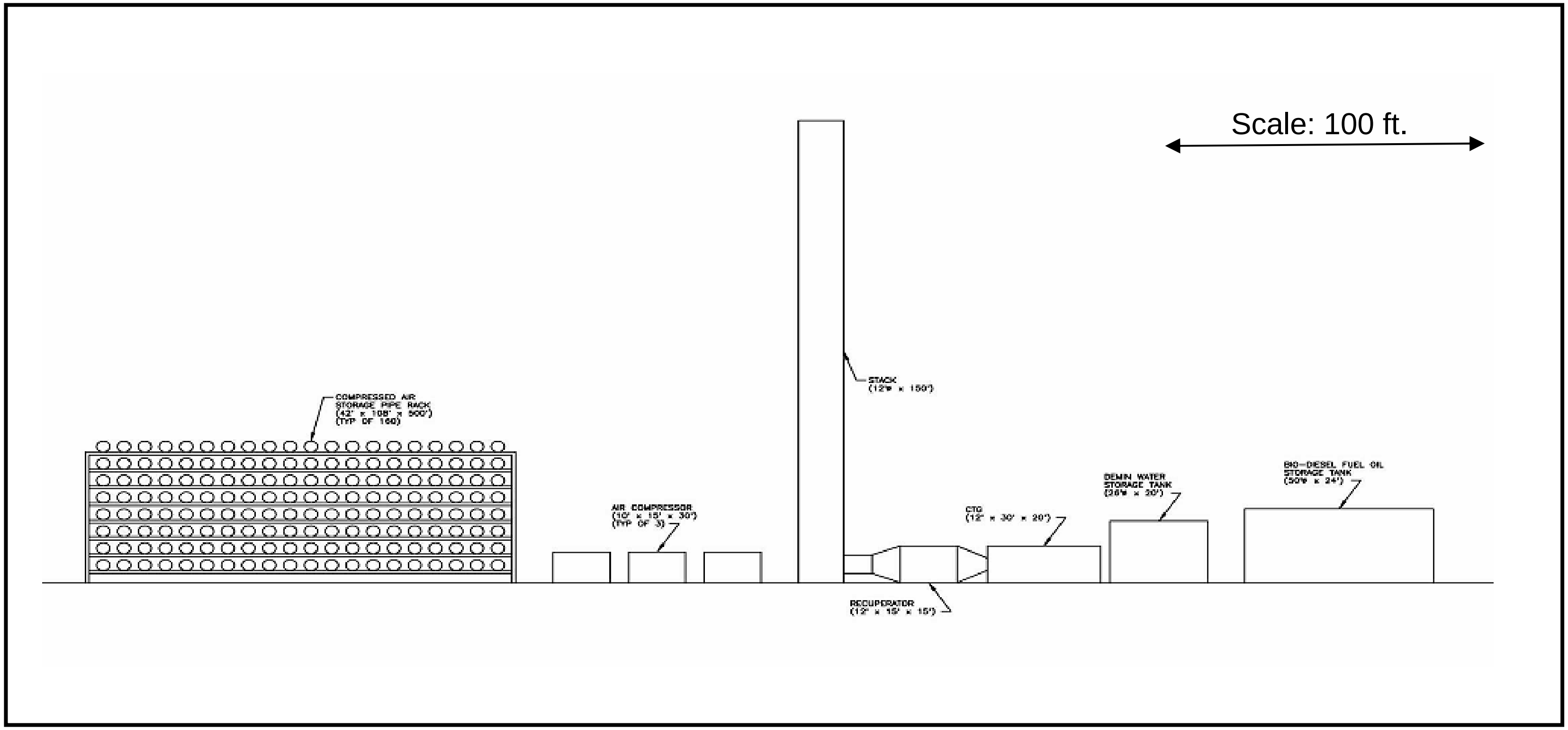


Above Ground CAES Plant Using Above Ground Air Storage System (58 MW – 4 Hour): Preliminary Plant Layout - - Top View

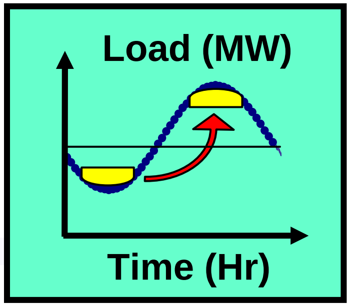




Above Ground CAES Plant Using Above Ground Air Storage System (58 MW – 4 Hour): Preliminary Plant Layout - - Side View



Comparison of Above Vs. Below Ground Based CAES Plants



- CAES may utilize an underground reservoir or an above ground air storage system.
- CAES using a below ground air store is expected to be a bulk energy storage plant that performs load management, peak shaving, regulation and ramping duty.
- CAES using an above ground air store is expected to be a short term energy storage plant that performs peak shaving, regulation and ramping duty. This type of plant is expected to be less expensive and have much longer life than a battery or flywheel energy storage plant.

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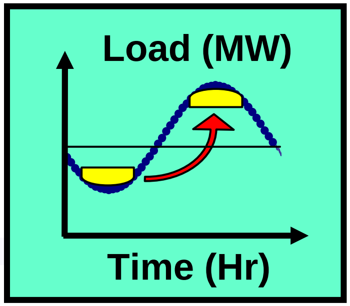
EPRI Adv. CAES Demo Project: Phased Approach



Project Phases:

1. Engineering Design, Costing, Vendor Quotes and Engineering Trade-Off Analyses
2. Construct Plant
3. Monitor Plant Performance and Reliability

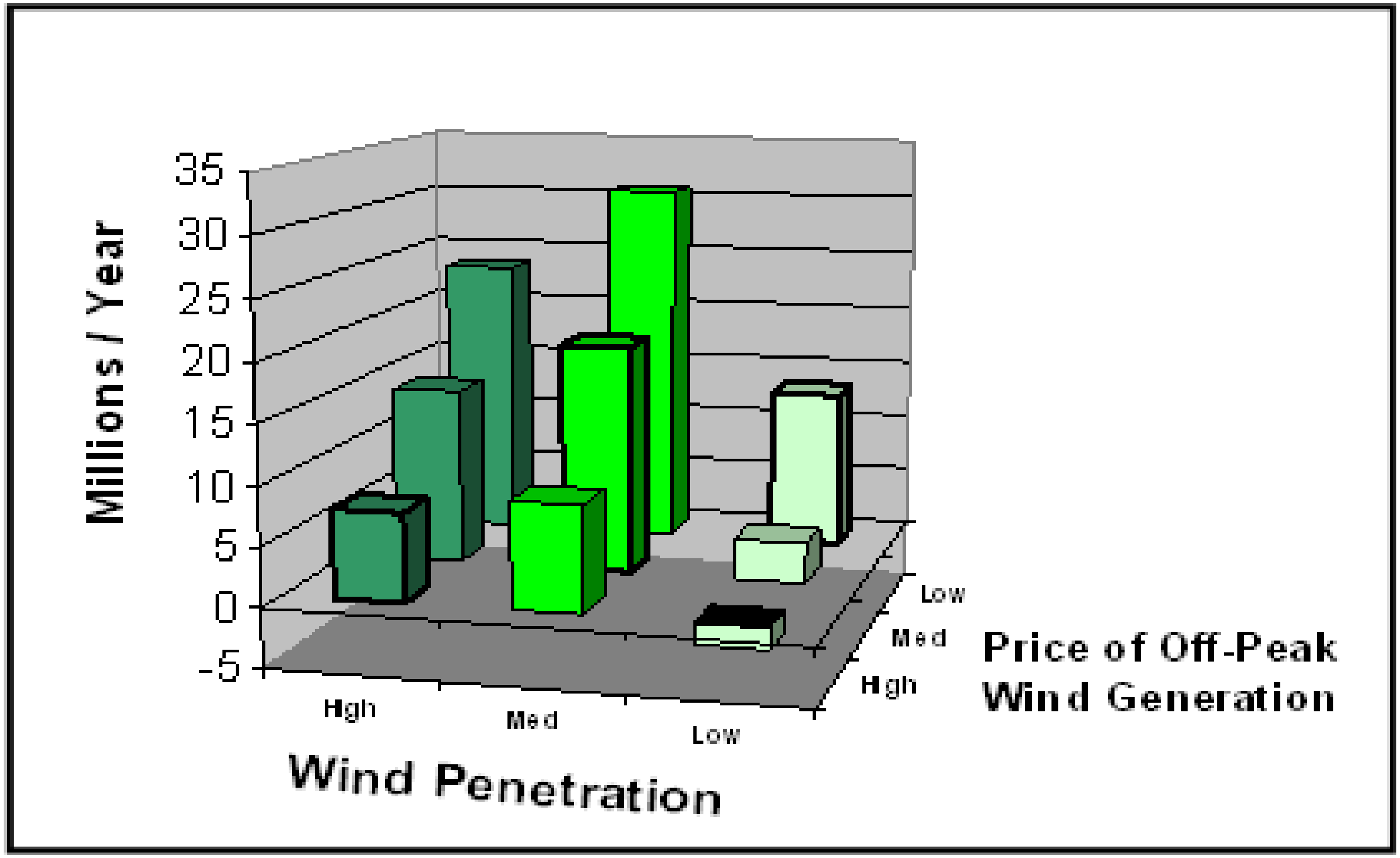
Estimated Phased Schedule:	2008	2009	2010	2011	2012	2013	2014
300 MW - 10 Hr. Plant Using Below Ground Air Store			*				
15 MW - 2 Hr. Plant Using Above Ground Air Store			*				

Notes:

1. *Participants have "off-ramp" if no participants decide to build any type of CAES plant. This off-ramp will occur by 12/31/2010.
2. Final size of plant will be determined by phase 2 host utilities.
3. All participants will obtain project results from both plants and from all phases of the project.

Anticipated Savings with CAES Plant Integrated with Wind Generation Resources

Example Results From Phase 1

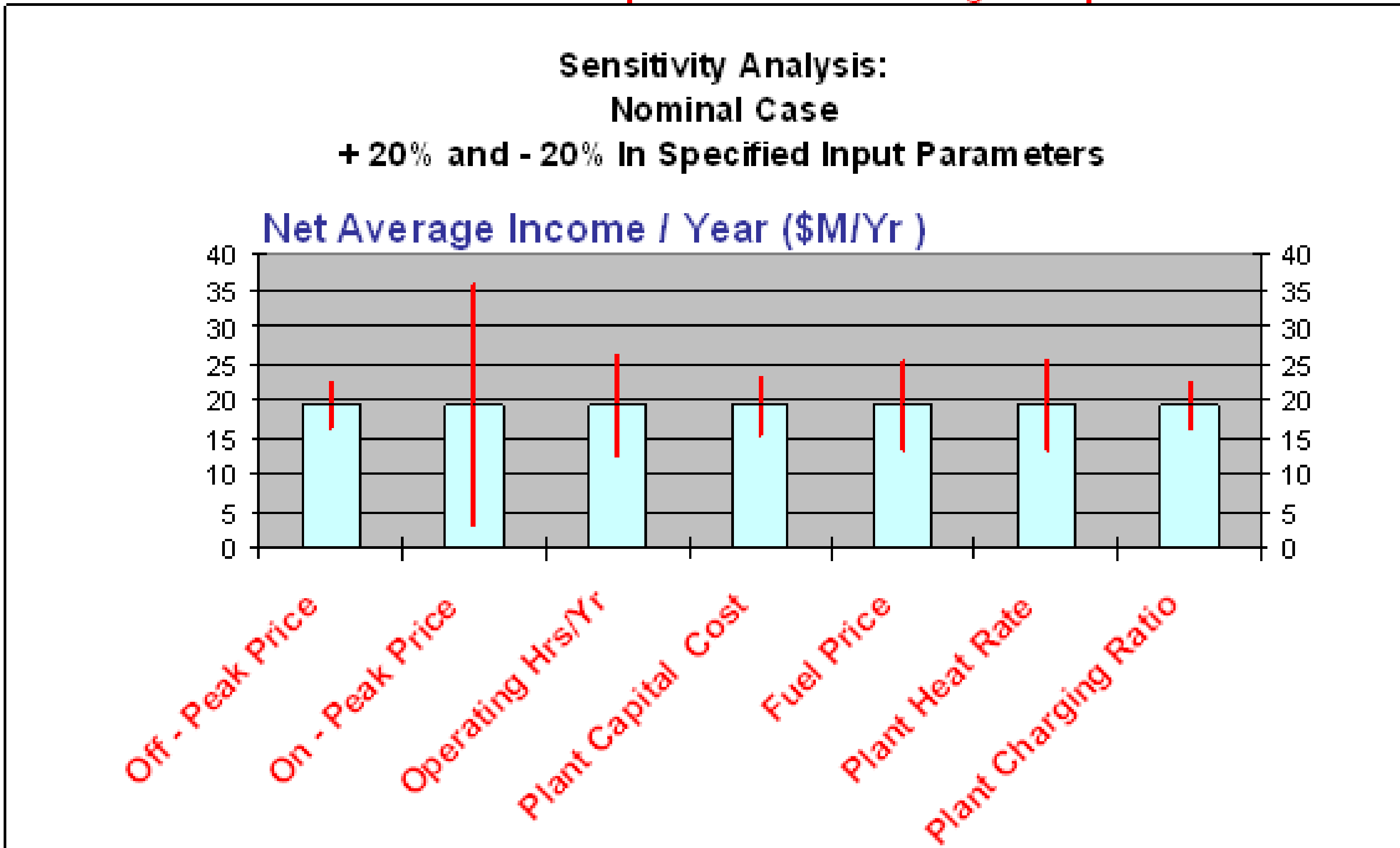


Estimated Economic Benefits

Nominal Case Sensitivity Analysis Results

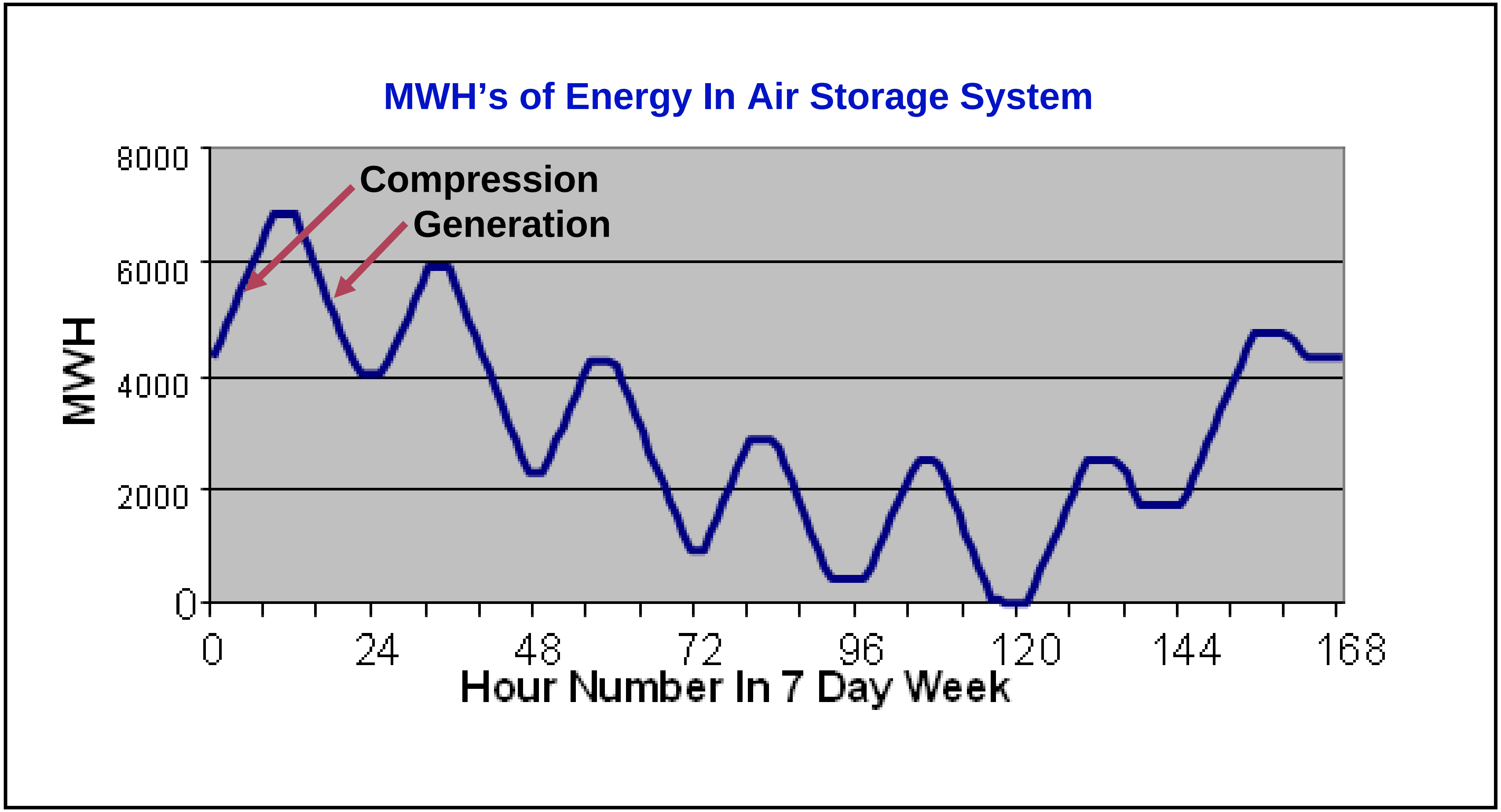
Example Results From Phase 1

Red Vertical Bar's Below Show Impact of + / - 20% Changes In Specified Variables



CAES Generation & Compression Cycles (for a Typical Week)

Example Results Expected From Phase 1



Example Results Showing CAES Economic Benefits Beyond Arbitrage Benefits

Capacity Credit: If online for a minimum number of hours per day, CAES can provide capacity benefits, which can be valued at either the market price for firm capacity, in an ISO environment, or the cost of alternate capacity, in a unit commitment-unit dispatch or system planning situation.

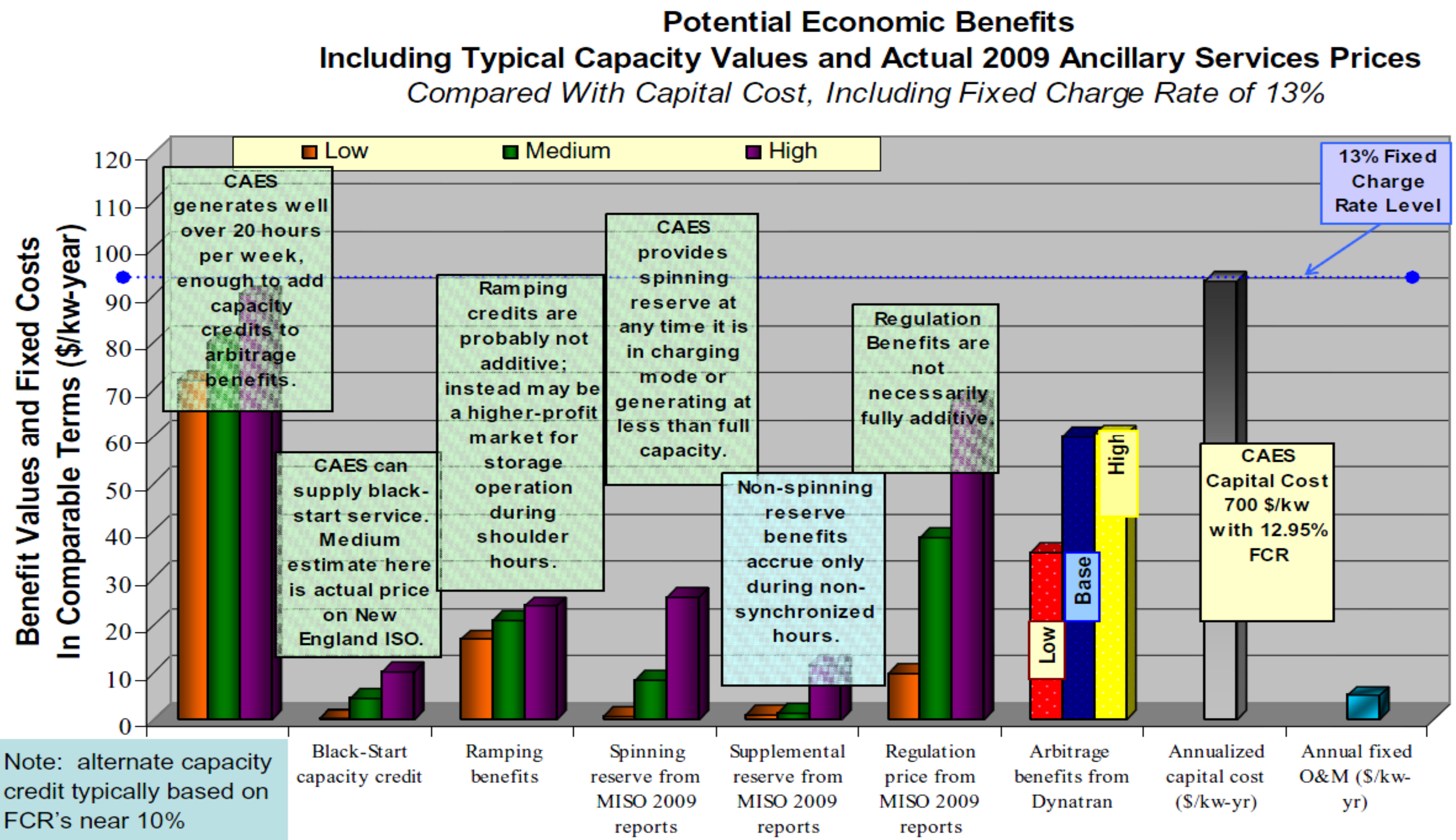
Ramping Benefit: Storage units usually have capacity available in shoulder hours, and can support a utility's needs, as large units ramp up and down.

Spinning Reserve Credit: CAES provides spinning reserve whenever either charging or discharging. In charging mode, spinning reserve credits are available when the unit is in full discharge capacity plus during the charging time intervals. In discharging mode, spinning reserve credits are available when the unit is at part load; namely, the MW difference between full discharge capability and the actual part load discharging level in that hour.

Black Start Capability: CAES can reach full output from an off-line state in about seven minutes, qualifying for black-start credits, where applicable.

Frequency Regulation: When on-line, CAES unit operation is flexible enough to assist with maintaining frequency on the system.

Example Results Showing CAES Economic Benefits Highlighting Ancillary Services



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

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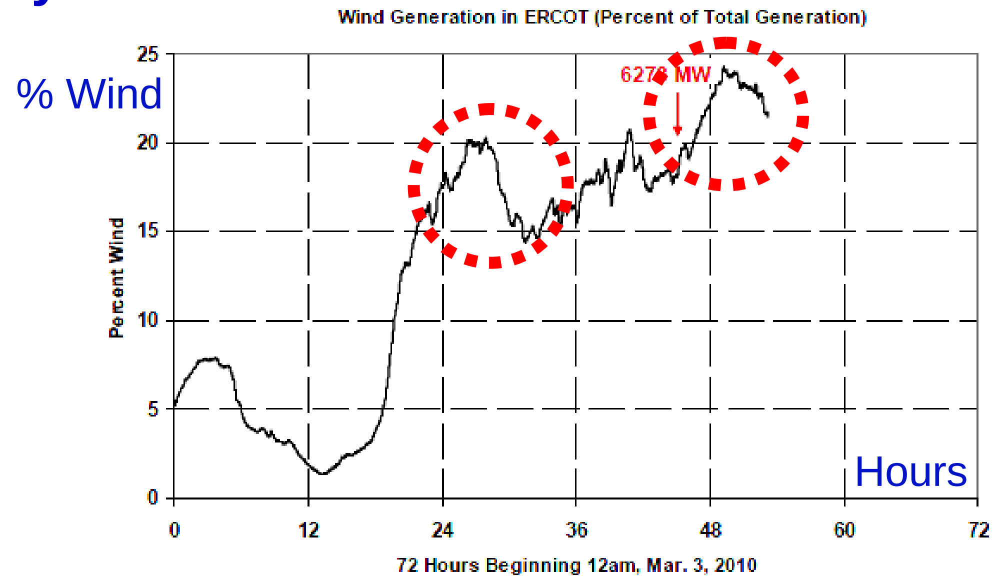
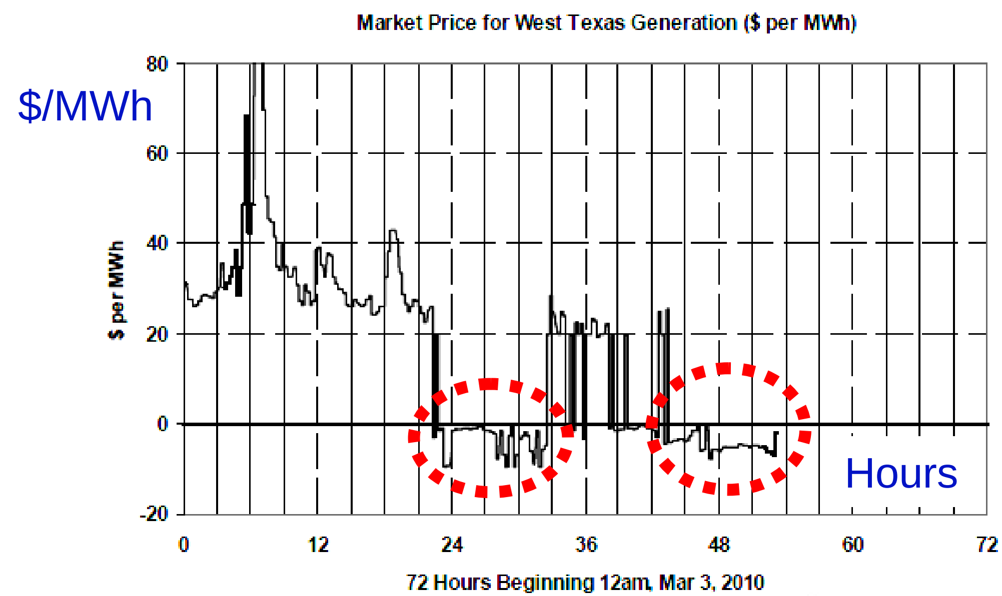
Impact of Wind Penetration: Lower Off Peak Hourly Marginal Electricity Prices

- As wind power output increased on March 3, 2010, ERCOT's electricity market prices went negative. This situation will occur more frequently as wind generation grows.
- This negative price situation is also occurring in other US regions
- Recommendation: Give special attention to forecasting off-peak marginal electricity prices





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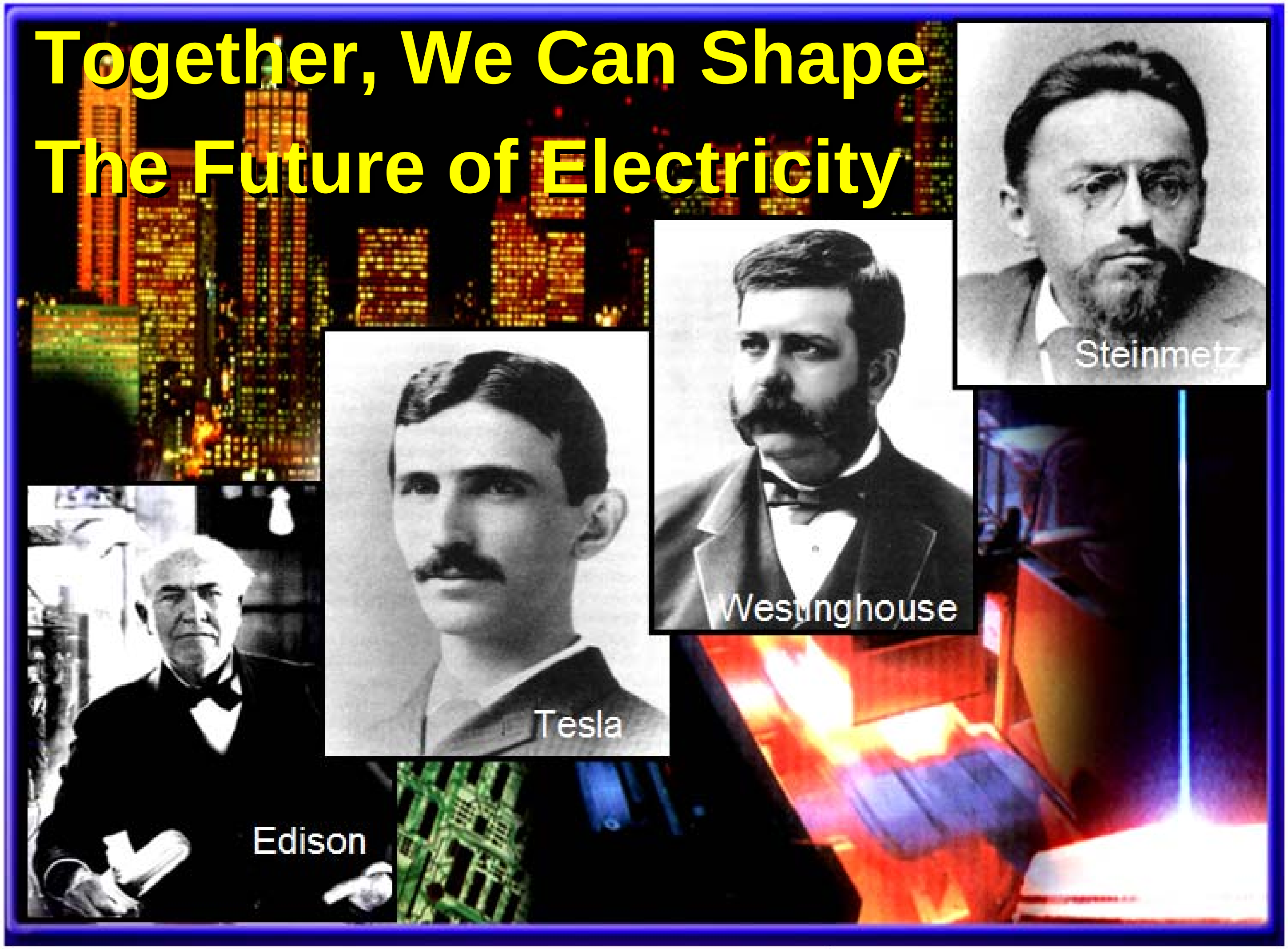
Summary

- **Advanced CAES plants using <u>below ground stores</u> are expected to be less expensive than pumped hydro plants and economically attractive for bulk energy storage, where the major economic benefits are derived from arbitrage, load leveling, peak shaving, regulation and ramping duty**
- **Advanced CAES plants using <u>above ground air stores</u> are expected to be less expensive than battery plants and attractive for short term storage, where the major economic benefits are derived from peak shaving, regulation and ramping duty**
- **CAES plants have ramping capabilities that should mitigate power fluctuations and variability of wind/solar plants**
- **If gas/oil fuel prices increase, the spread between off-peak and on-peak electricity prices increase, CAES could become more economically attractive, especially compared to Combustion Turbine and Combined Cycle plants**

Thank You For Your Attention Questions/Comments ?



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

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Appendix

Example Operating Costs For Storage Plants and Combustion Turbines

Source: Schainker

	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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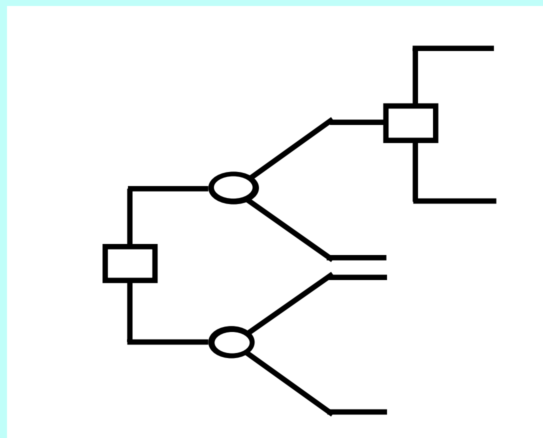
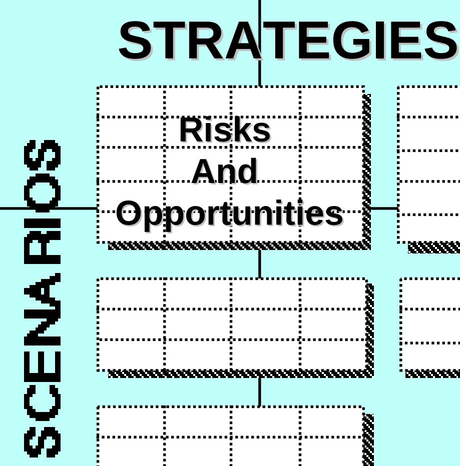
Electric Energy Storage: Value Proposition

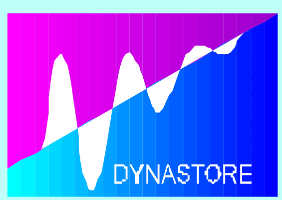
Types of Benefits	Physical System: Generation	Physical System: T&D	Corporate Perspective	Customer Perspective

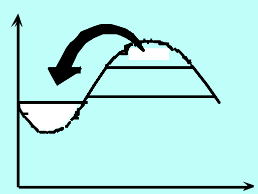
Strategic
- Enhance Renewables
- Mitigate Uncertainty
- CO_2 Reduction





Operational
- Dynamic
- Load Leveling





Time

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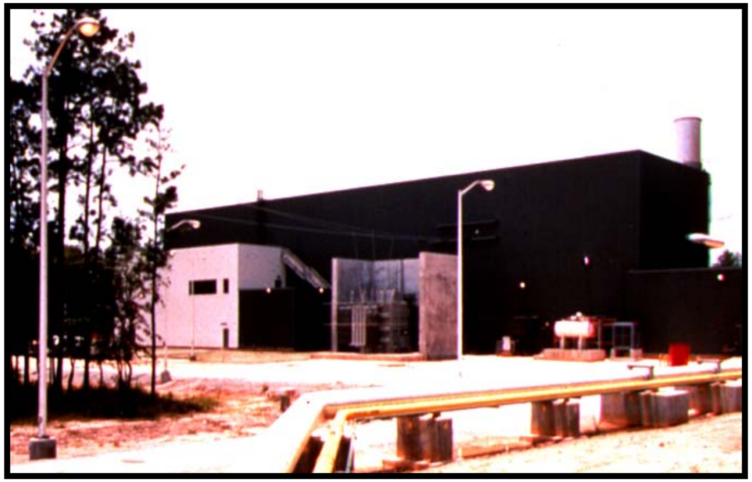
* Note: Some of the above project costs go towards expenses not directly related to the CAES plant (e.g., transmission line & substation upgrade costs)

Compressed Air Energy Storage (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%**

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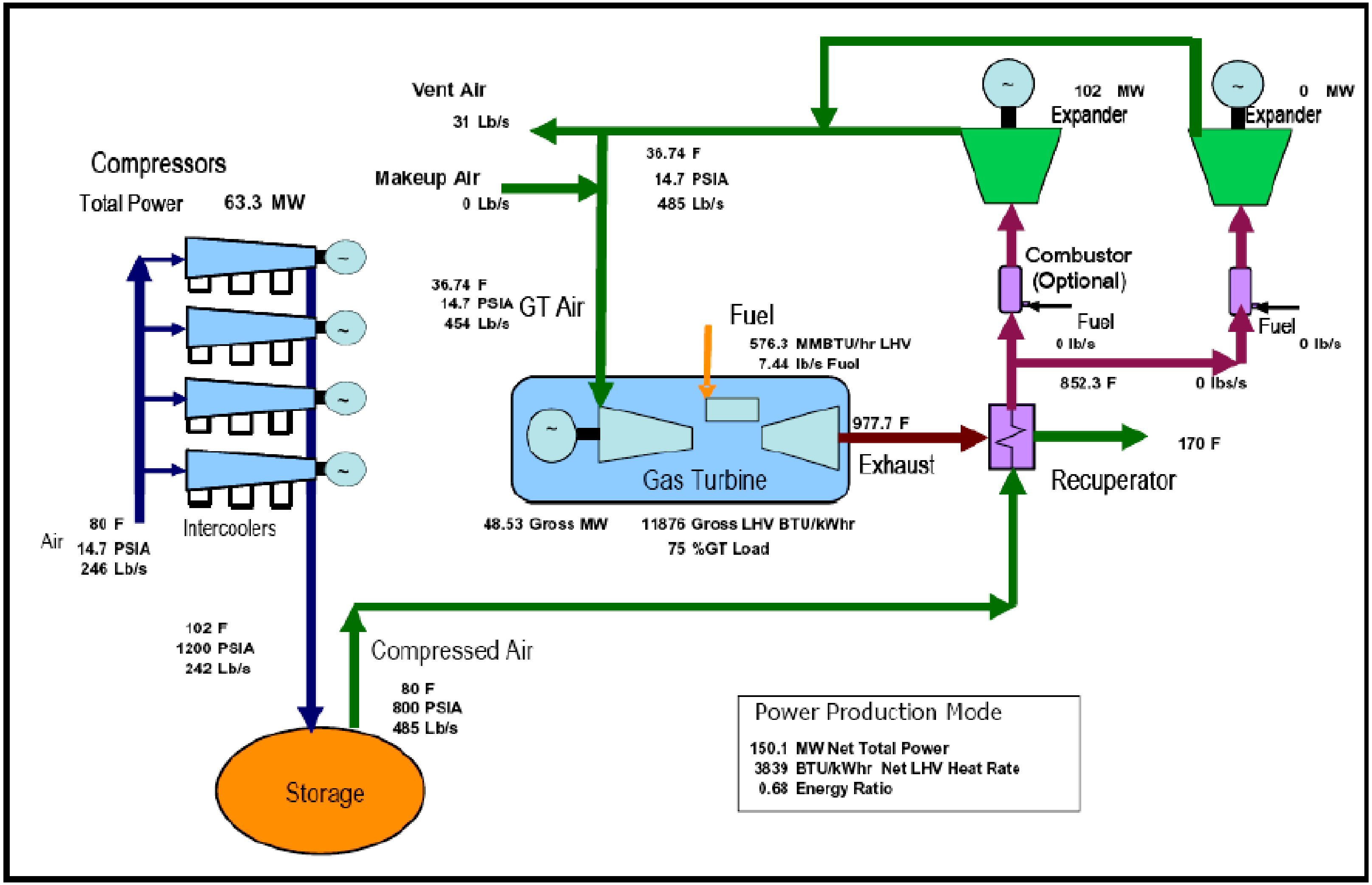
Advanced CAES Plant: Schematic
- - - Second Generation "Chiller" Design- - -



Types of Underground Natural Gas Storage Facilities