Natural Gas Storage Applied to Compressed Air Energy Storage Power Plants

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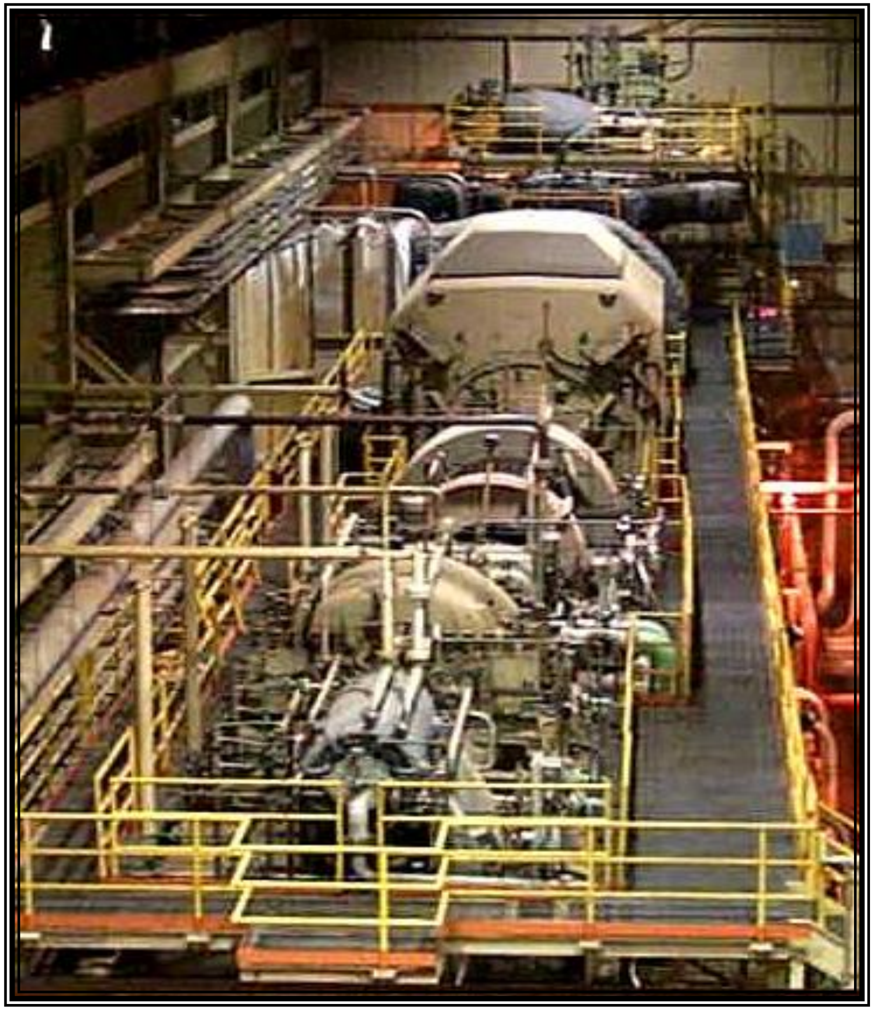
Alabama Electric Cooperative's CAES Plant (110 MW-26 Hr)
Plant Commissioned: June 1, 1991
Air Store: Solution Mined Salt Cavern

Alabama CAES Plant
110 MW Turbomachinery Hall



Expansion Turbines

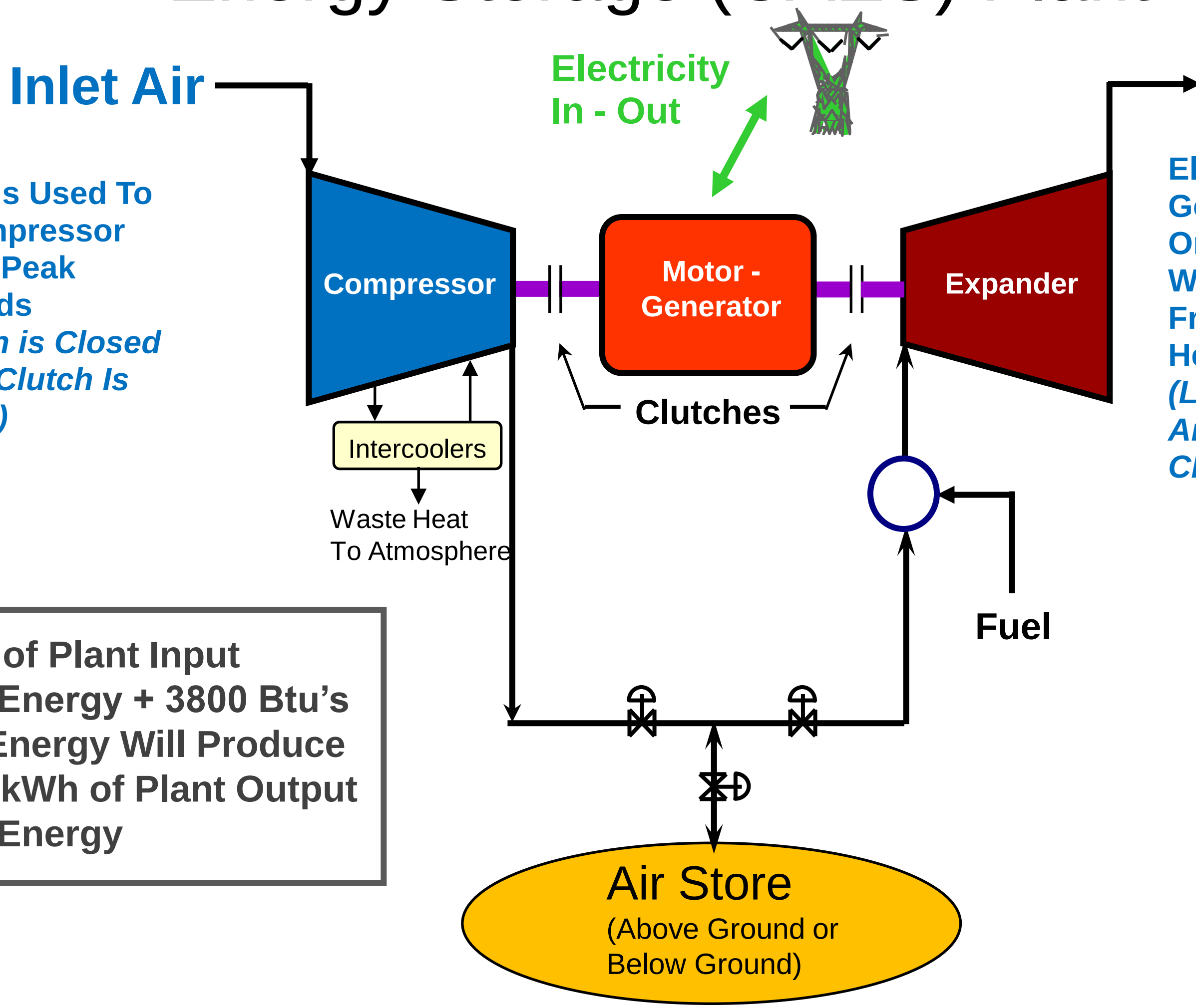
Clutch

Motor-Generator

Clutch

Compressors

Simplified Schematic of Conventional Compressed Air Energy Storage (CAES) Plant

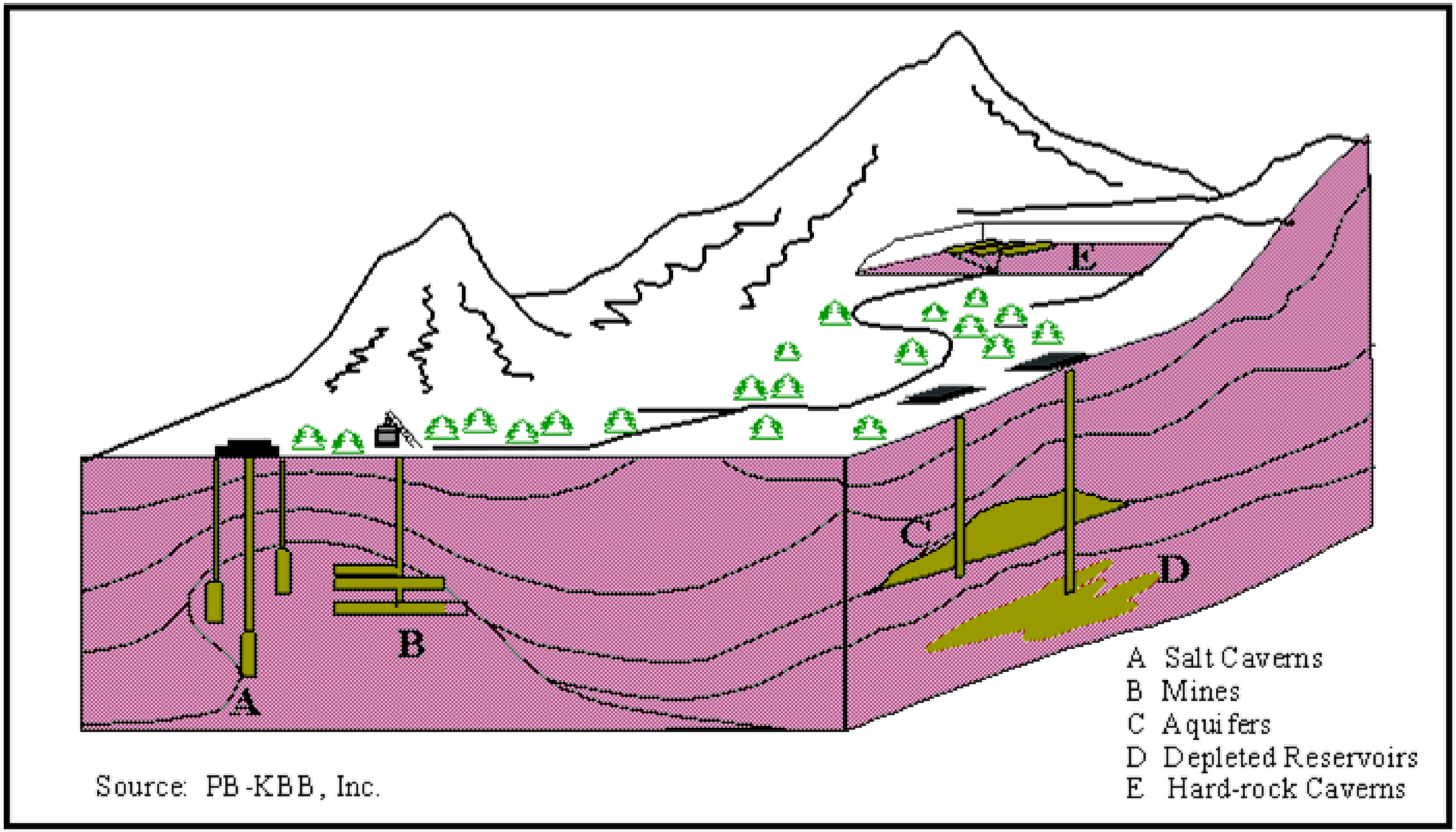


Electricity Is Used To Power Compressor During Off-Peak Time Periods *(Left Clutch is Closed And Right Clutch Is Opened)*

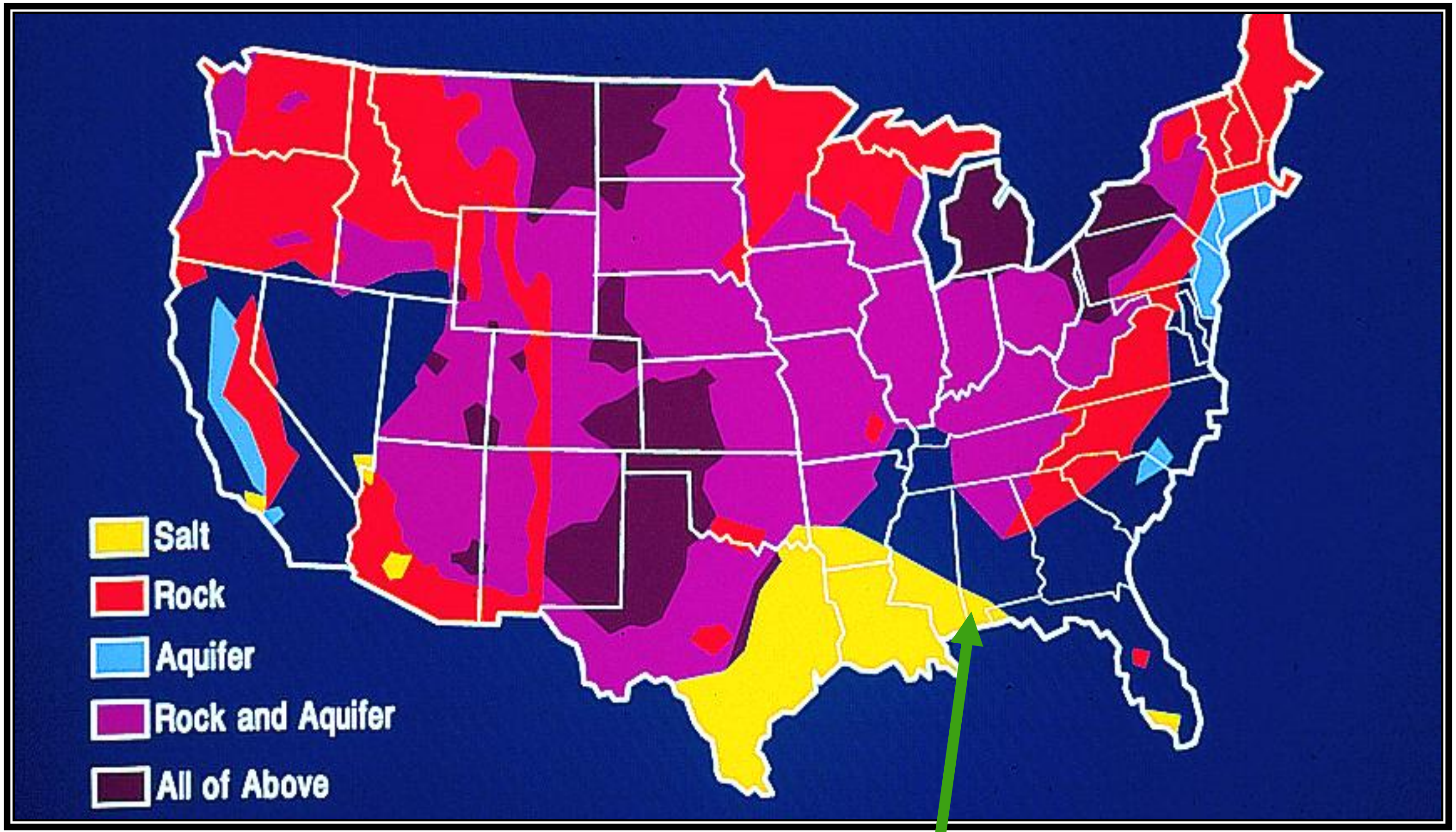
Electric Power is Generated During On-Peak Time Periods When Air Is Released From Store and Heated By Fuel *(Left Clutch is Opened And Right Clutch Is Closed)*

0.7 kWh of Plant Input Electric Energy + 3800 Btu's of Fuel Energy Will Produce About 1 kWh of Plant Output Electric Energy

Types of Underground Natural Gas/ Air Storage Facilities

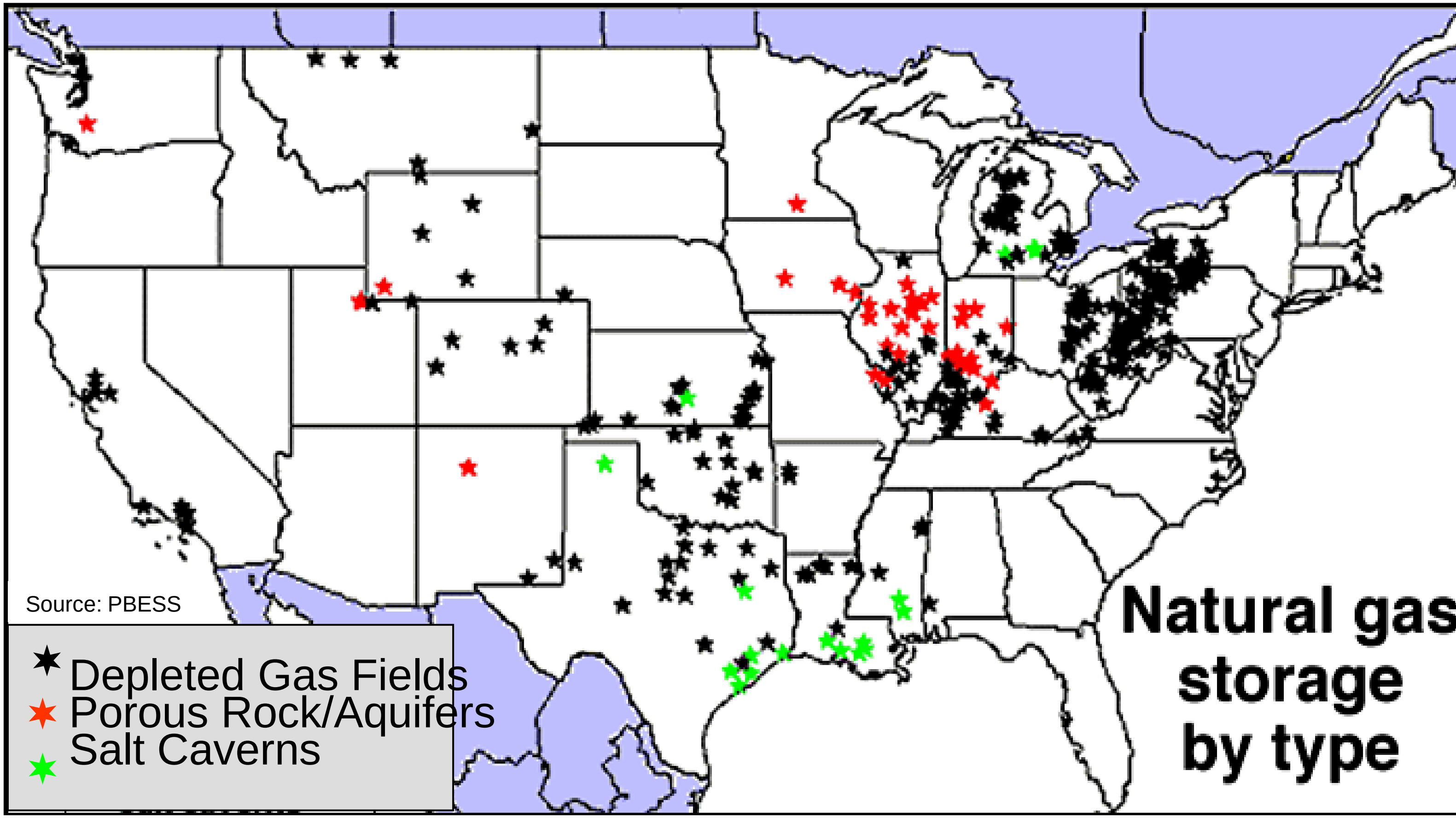


Geologic Formations Potentially Suitable for CAES Plants that Use Underground Storage

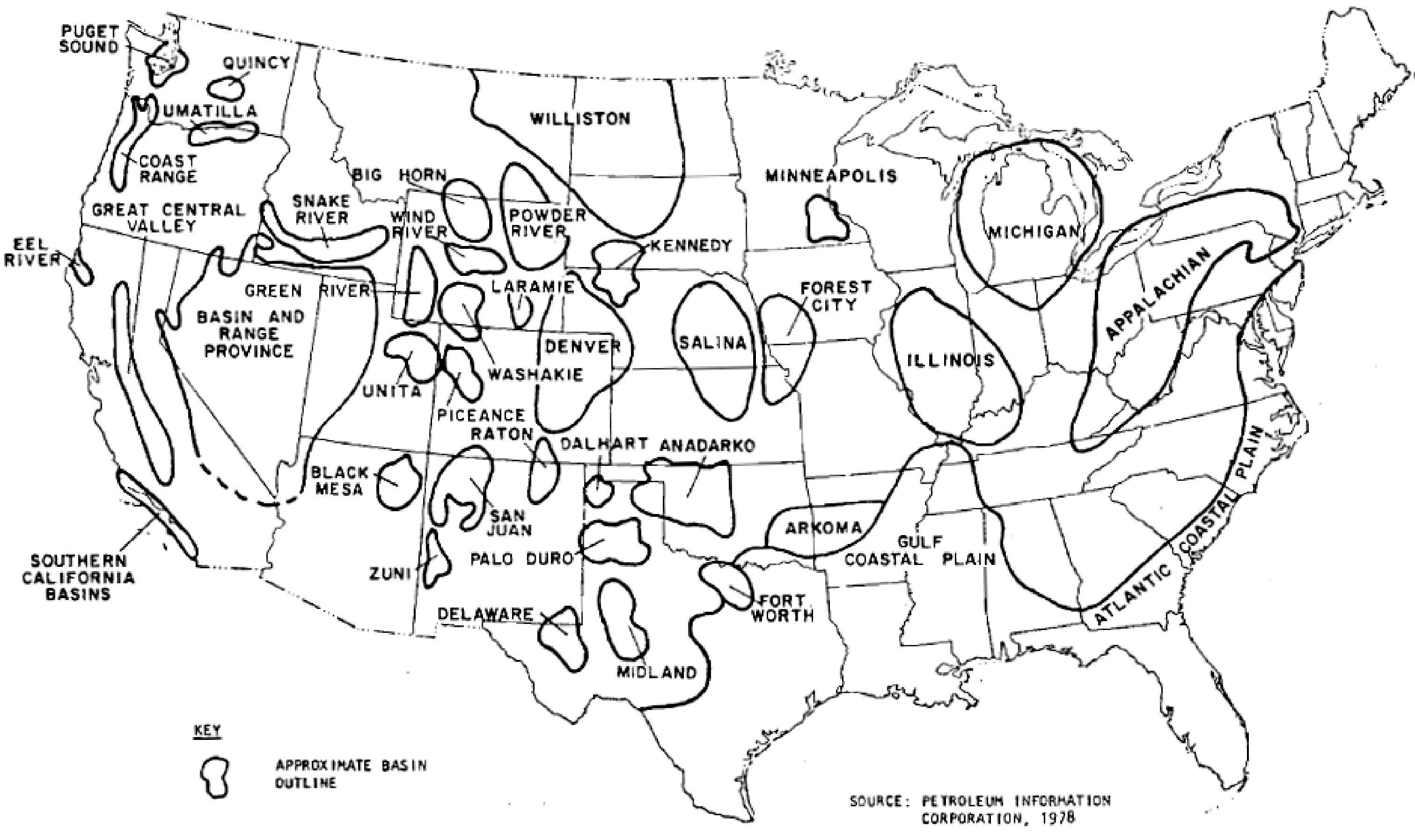


Alabama CAES Plant (110 MW – 26 Hr)

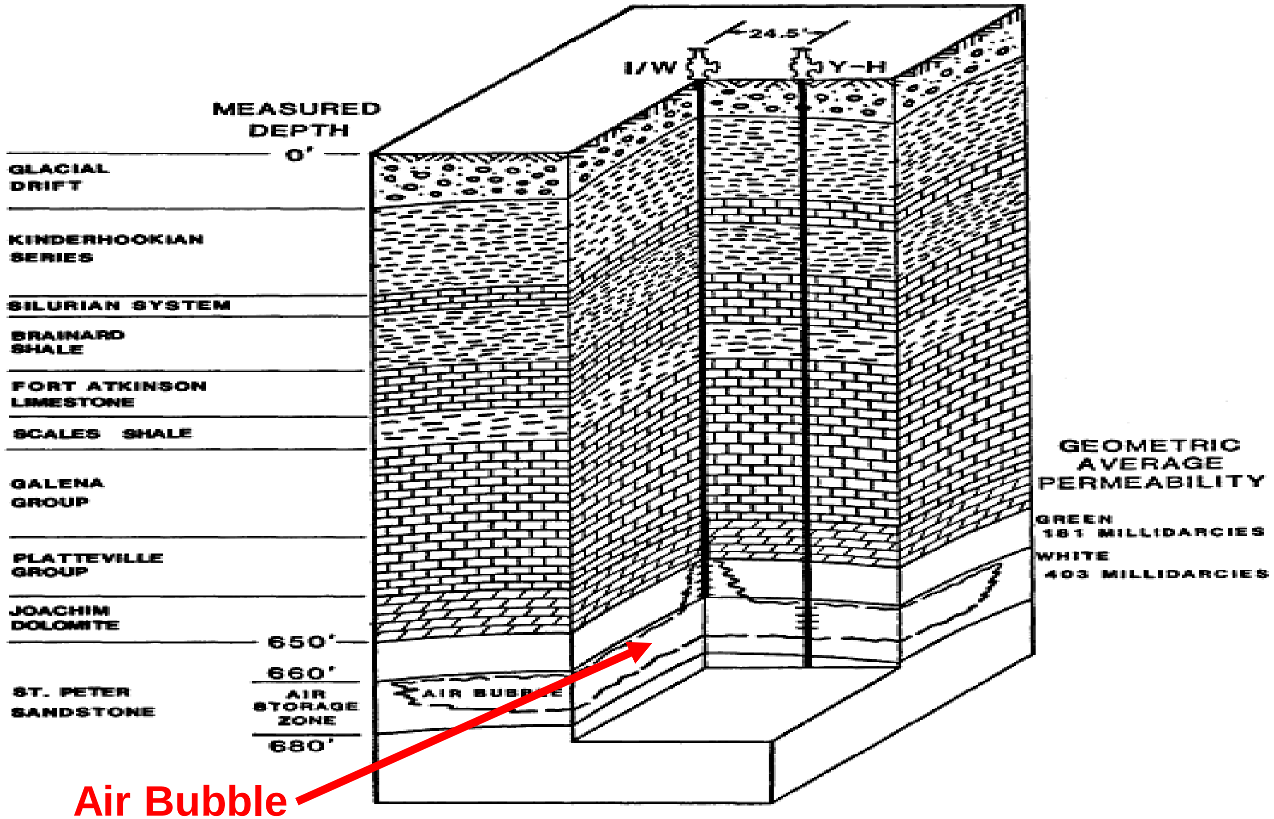
Underground Natural Gas Storage Facilities in the Lower 48 United States



CAES Porous Rock Sites/ Regions in USA



Generalized Structure and Cross-Section of Porous Rock Reservoir Showing Predicted Air Flow Path



Drawing Not to Scale
Source: EPRI

Geologic Properties Needed for CAES Air Store

- **General Requirements Depend on Size of CAES plant (in MW's and MWh's) and the type of turbomachinery used. Thus, the numbers on this slide are "guidelines".**
  - Good Cap rock (Should <less 0.1 md (milli-darcys)
  - Designed to Withstand Daily Cyclic Pressures (about 10% to 30%/day)
  - Geologic Formation Discovery Pressure Range: 500 psig to 3000 psig

- **Porous Rock Media / Depleted Gas Fields**
  - Porosity: > 10% [Higher porosity will reduce number of wells needed]
  - Permeability > 250 md [Higher permeability will reduce number of wells needed]

- **Salt Media**
  - Domal or bedded salt.
  - Void space needed is in range of 3000 CF/MWh to 7000 CF/MWh

- **Hard Rock Media**
  - For dry caverns, void space needed is same as Salt media.
  - If water compensation column is used, space is about 1/5 that of salt caverns, since pressure in cavern is almost constant.

Challenges for a Depleted Gas Reservoir Used for CAES

- **Oxygen Chemistry**
  - If chemical reactions occur in air-porous rock media, this could cause significant reduction in porosity and/or permeability, which will impact design and/or operation of plant.
  - CAES plant designs exist where air from reservoir does not go through combustion process. Thus, oxygen reduction in reservoir is not a critical concern.

- **No known depleted gas reservoir has yet been tested with air injection**
  - R&D is on-going in this area.

- **Buffer gas (i.e., air cushion gas) is planned to be 10-X, where "X" is the CAES plants working gas. This will mitigate potential water coning during compression and/or generation process.**

Appendix

Appendix

EPRI Pittsfield Porous Rock Reservoir CAES Field Test: Lessons Learned

- **Pittsfield, Illinois CAES Air Cycling Field Test by EPRI in 1980s**
  - Data Was Successfully Analyzed To Show Natural Gas Storage Industry Practices Apply To Air Storage for CAES Cyclic Operation.
  - Pressure–Volume Correlations Using Well Data Compared In Excellent Manner After Fluid Gas Properties Were Adjusted For Air Instead Of Natural Gas.

Appendix

EPRI Calgary University Air Gas Mixing Project: Objective and Key Results

- **Objective**
  - Perform the flammability and in-situ combustion tests with cores from PG&E's Thornton depleted gad field site.
  - Determine oxygen depletion due to hydrocarbons and Pyrites.
  - Perform reservoir simulation for simulated CAES plant operation.

- **Key Results**
  - Gas flammability widens with increased pressure and temperature and this property is reservoir specific, due to gas composition, permeability, porosity, moisture, minerals and Kerosene (a mixture of organic chemical compounds in sedimentary rocks with soluble portion known as Bitumen's).
  - Oxidation kinetics data suggested in-situ combustion and in-bore flammability are predictable.
  - Away from well bore, in-situ combustion is not possible.

EPRI Calgary University Air Gas Mixing Project: Lessons Learned

Appendix

- Canadian experience with air injection in a Bitumen reservoir to maintain pressure was successful in recovering natural gas for sale as air bubble is developed.
- Project operated for five years without any incidence of flammable mixture, explosion or in-bore combustion.
- PG&E can obtain this technology and experience from EPRI's contracts with the University of Calgary.
- Gas mixing test facility at the University of Calgary (cofunded by EPRI) is available to PG&E to test kinetics of potential gas-mixing issue and oxidation at reservoir conditions. Also, reservoir simulations can be performed to estimate the safe air injection/withdrawal rates and gas compositional changes during air storage for CAES application.

Appendix

Glossary/ Acronyms

Btu	British Thermal Units
CAES	Compressed Air Energy Storage
EPRI	Electric Power Research Institute
HP	High Pressure
LP	Low Pressure
MCF	Million cubic feet
MW	Mega Watt (one million Watts of power)
MWh	Mega Watt Hour (one million Watt hours of energy)
psi_a	Pounds per square inch, absolute
psi_g	Pounds per square inch, gauge (psi_a – 14.7 = psi_g)