Assessing Compressed Air Energy Storage (CAES) Potential in Kentucky to Augment Energy Production from Renewable Resources

J. Richard Bowersox, Kentucky Geological Survey, University of Kentucky

John B. Hickman, Kentucky Geological Survey, University of Kentucky

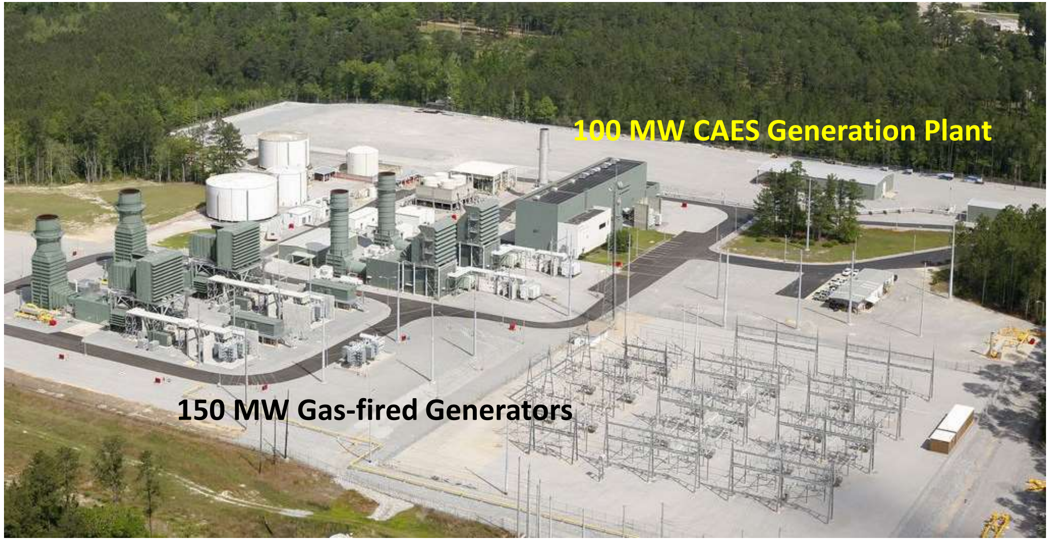
Kyle A. Skeese, Department of Earth and Environmental Sciences, University of Kentucky

Geological Society of America
2022 North-Central/Southeastern Joint Section Meeting
Cincinnati, Ohio, April 7, 2022

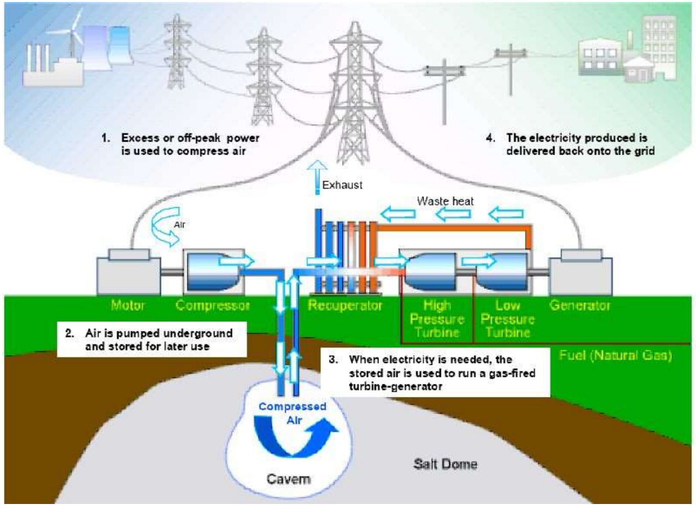
Compressed Air Energy Storage (CAES)

- CAES is an efficient way of generating electricity that can be totally green with the co-installation of a renewable energy source.
- The two commercial CAES power plants are a 290 MW plant at Huntorf, Germany, built in 1978, and a 110 MW plant at McIntosh, Alabama, built in 1991. Both powerplants store compressed air solution caverns developed in salt domes.
- Salt beds are not a part of Kentucky's subsurface geology, so other solutions were evaluated for their potential deployment in the bluegrass state assuming co-installed PV-Solar electricity generation:
  - Conversion of inactive and abandoned limestone mines
  - Acid-Solution caverns in limestones and dolomites below 2000 ft
  - Advanced-CAES by mining deep caverns, >2000 ft deep, in limestones and dolomites
  - Recompletion of abandoned oil and gas fields and completions in saline aquifers
  - Cased-Wellbore energy storage. **This storage technology is not limited by site geology.**
- I will be using oil industry terminology for volumes where Mcf is 1000 cubic feet and MMcf is 1 million cubic feet

Compressed Air Energy Storage (CAES) Power Generation



PowerSouth Energy Cooperative | Generation and Transmission Electric Cooperative

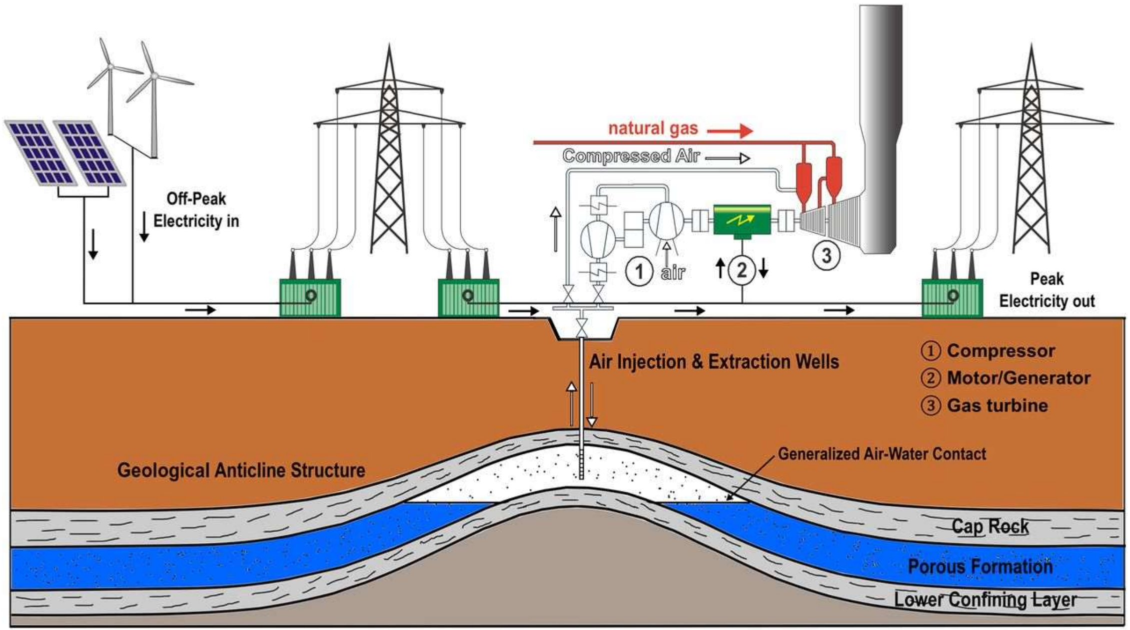


https://api.intechopen.com/media

This is the 110 MW PowerSouth plant at McIntosh, Alabama, built in 1991. It stores compressed air in a solution cavern constructed in a salt dome (above right). The compressed air storage capacity of the PowerSouth McIntosh plant is 19 MMcf at 1100 psi. Because of the potential impact of CAES on groundwater, CAES power plants will require EPA UIC permits.

CAES conceptual model has renewable energy sources, PV Solar in Kentucky, backed up by CAES and battery/capacitor electricity storage

Exhaust ("Waste") Heat can be Captured for Additional Applications



pg.lyellcollection.org

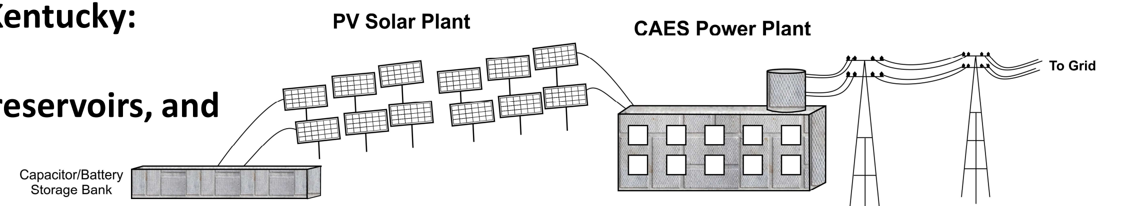
*University of Tennessee MS thesis, Engineering

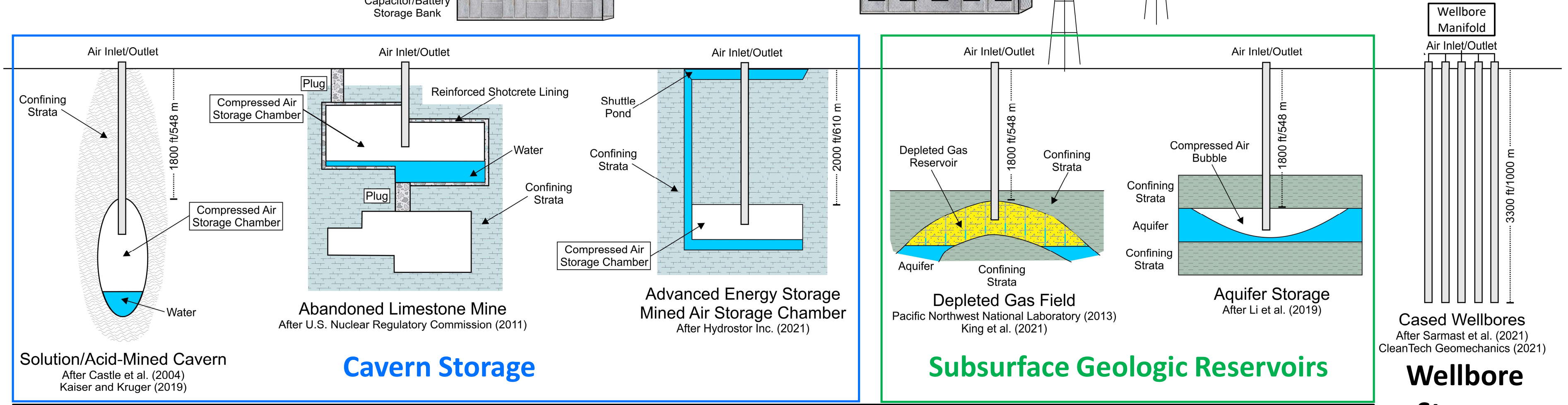
Rather than using natural gas to provide off-peak electricity in a conventional utility power plant, using co-installed PV solar as a PV-CAES plant has better economics by avoiding carbon capture and storage. This design can have close to 82% efficiency (Johnson, 2014*).

Summary of CAES models with co-installed PV-Solar for Kentucky electricity generation

Three CAES models were reviewed for potential application in Kentucky:

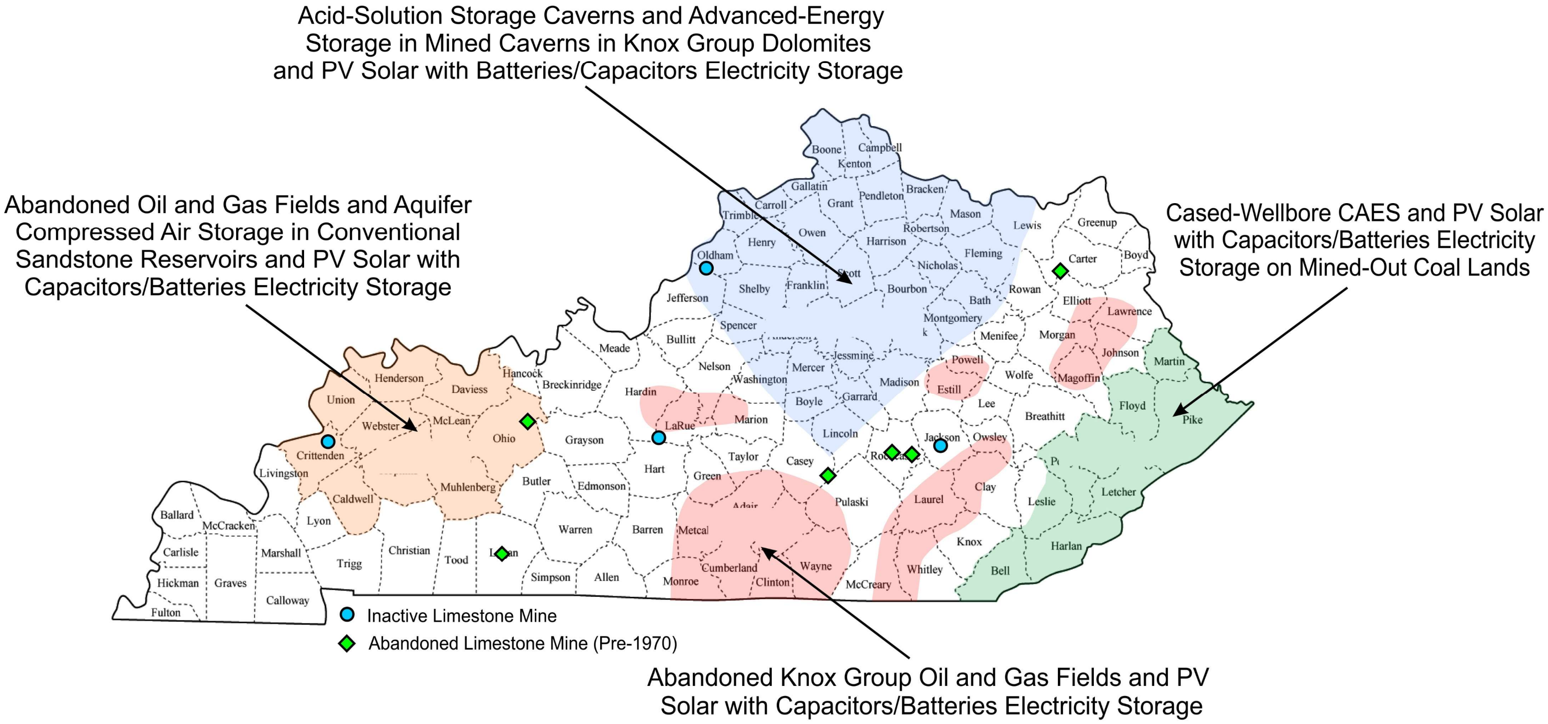
- ➢ **Caverns storage,**
- ➢ **Subsurface geologic reservoirs, and**
- ➢ **Cased wellbores.**





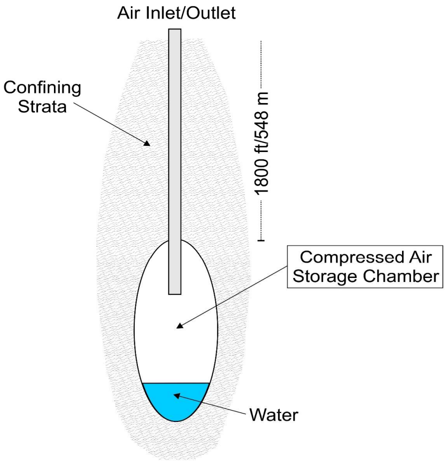
Co-installed PV-solar is part of the electricity grid and can be sited remotely from the CAES power plant

Kentucky areas suitable for CAES with co-installed PV solar electricity generation

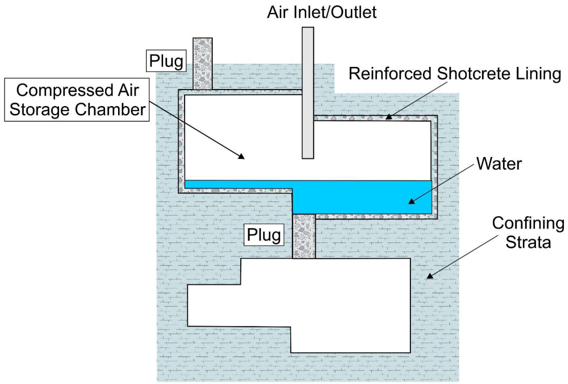


Compressed Air Storage in Caverns

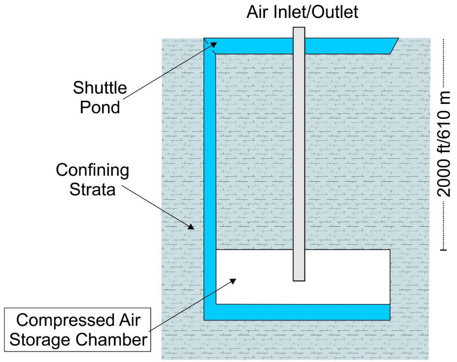
Advanced CAES model is where compressed air is stored in a 2000-ft deep mined cavern. Uniform compressed air pressure of 870 psi is maintained through hydrostatic connection to a surface pond.



Solution-Mined Cavern
After Castle et al. (2004), Kaiser and Kruger (2019)

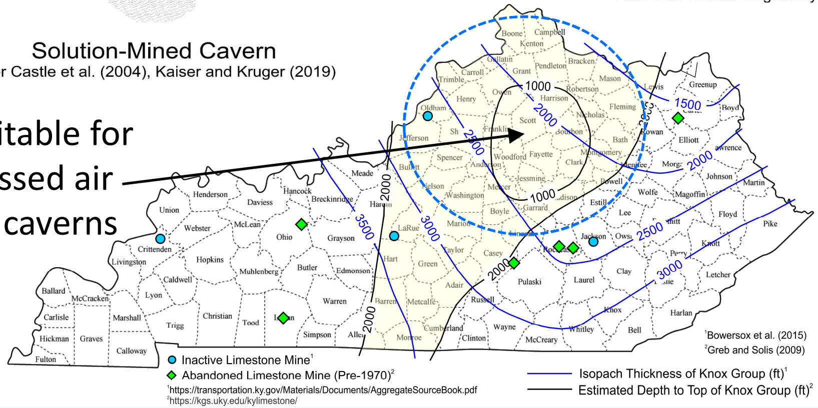


Abandoned Limestone Mine
After U.S. Nuclear Regulatory Commission (2011)



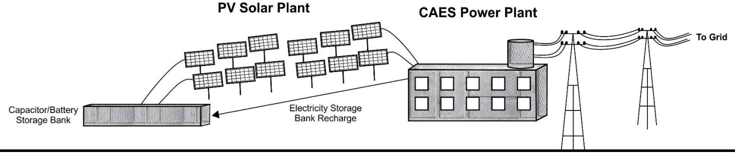
Advanced Energy Storage
After Hydrostor Inc. (2021)

Area suitable for compressed air storage caverns

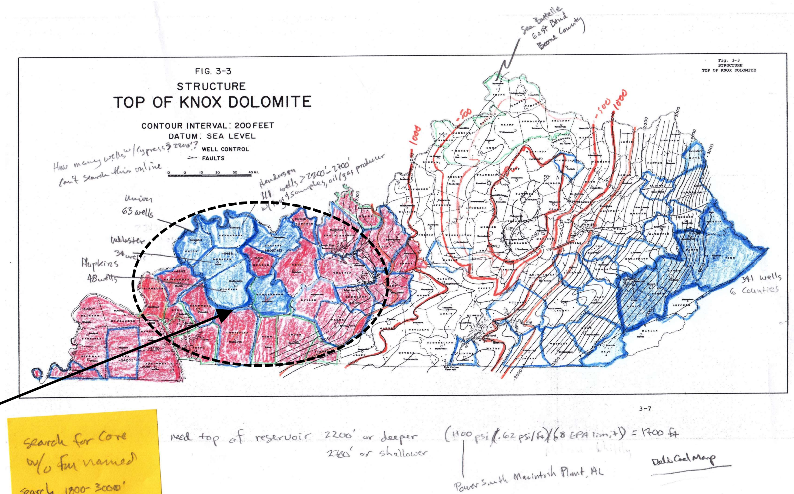


- Thick salt beds are not a part of Kentucky's subsurface geology.
- Kentucky has two alternatives:
  - Repurposed limestone mines, or
  - Deep acid-solution caverns or mined caverns in the Knox Dolomite.

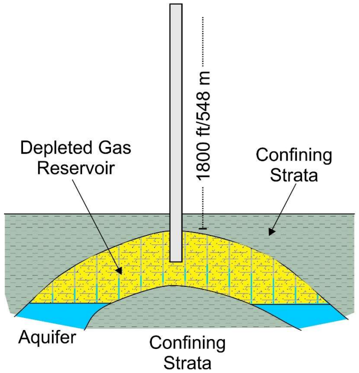
Depleted oil and gas fields and aquifer compressed air storage



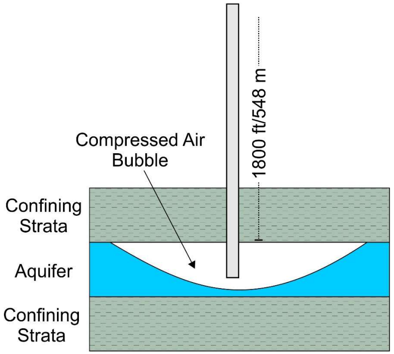
Kentucky's subsurface fracture gradient is ~0.62 psi/ft, so saline aquifers need to be >1800 ft deep to confine the compressed air storage reservoir.



My project work map



Depleted Gas Field
After King et al. (2021)

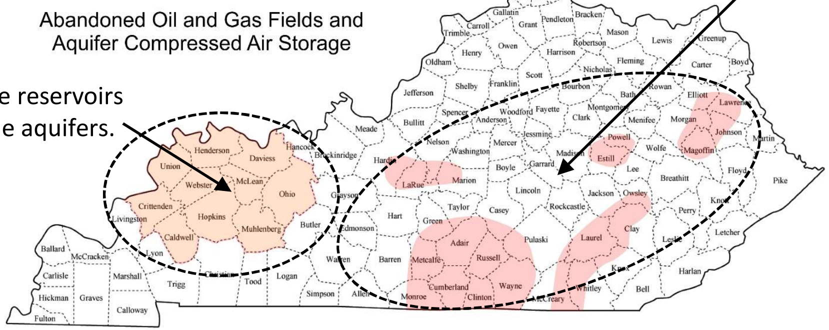


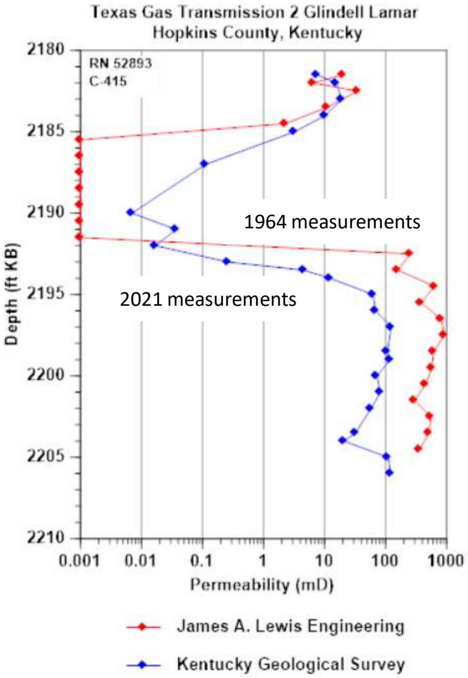
Aquifer Storage
After Li et al. (2019)

Areas for potential CAES development

Depleted reservoirs in Knox Group dolomites..

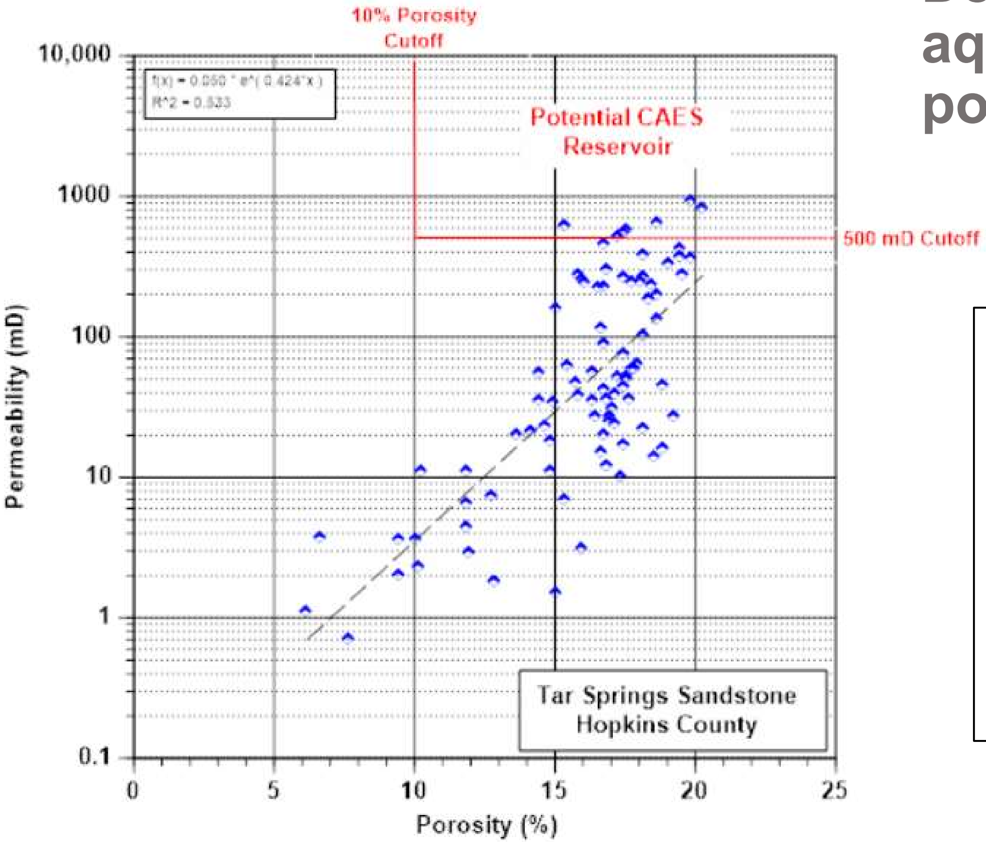
Sandstone reservoirs and saline aquifers.





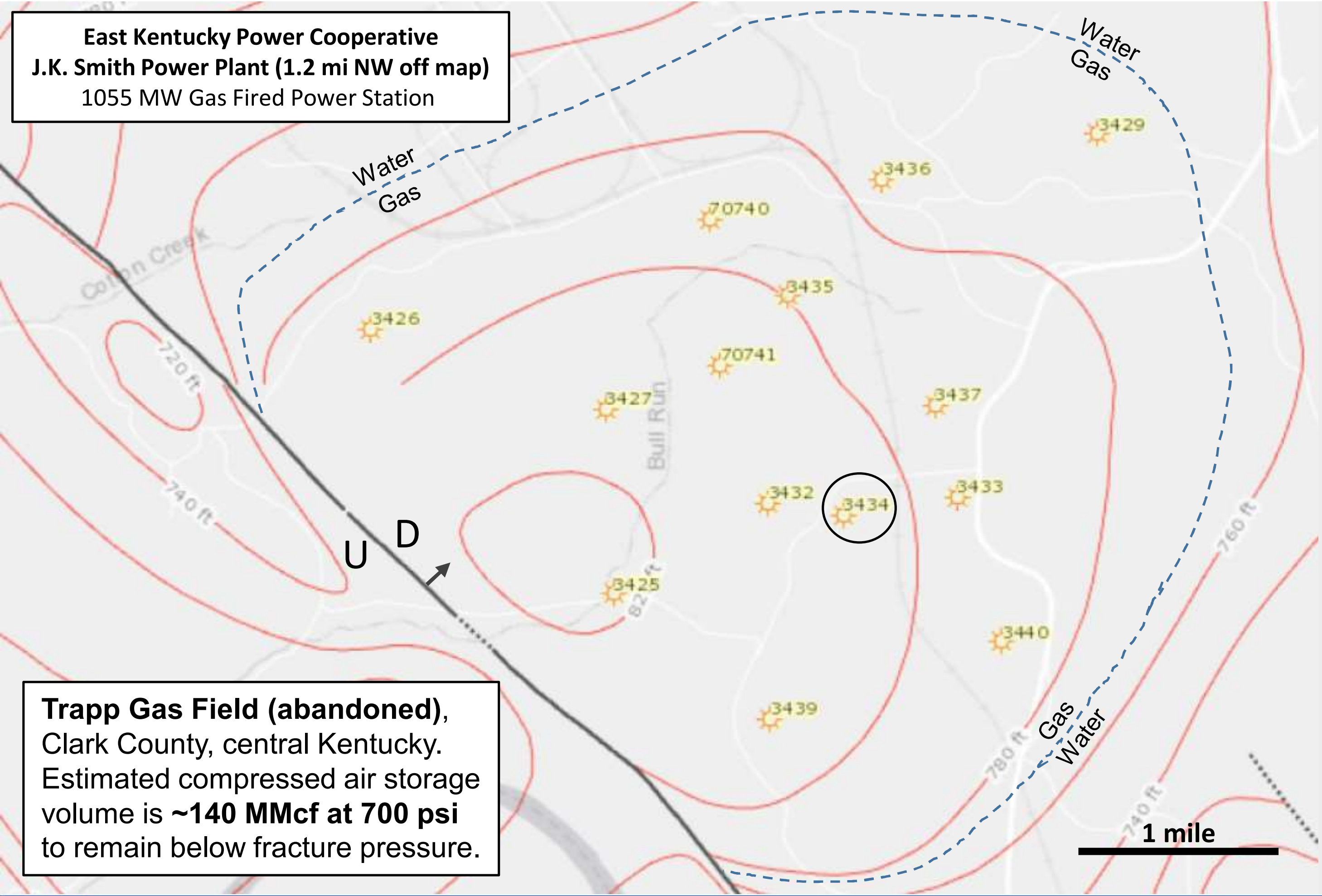
Kyle Skeese, student research assistant (left), measuring the permeability of a core from the Tar Springs Sandstone (center) from well TGT 2 Glindell Lamar, Hopkins County.

Depleted oil and gas fields and aquifer compressed air storage potential in western Kentucky

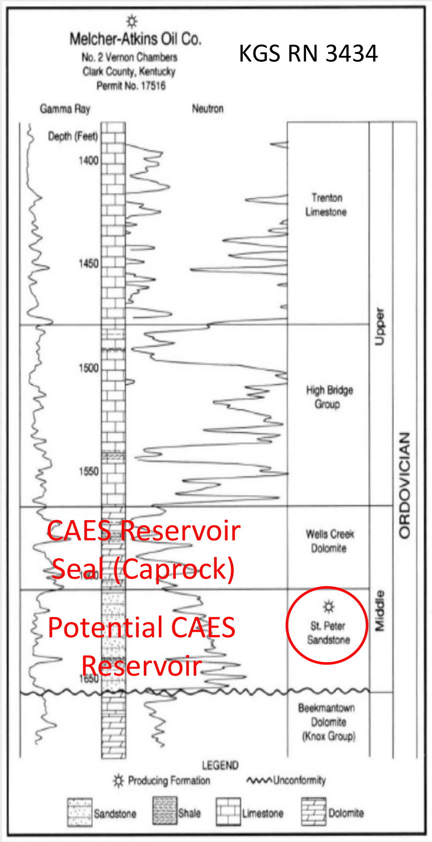


DOE NETL recommends CAES storage reservoirs have porosity >10% and permeability >500 mD. Measurements of eight cores from the Tar Springs Sandstone suggests that the reservoir does not meet these requirements. This may limit the potential for CAES in western Kentucky to saline aquifers.

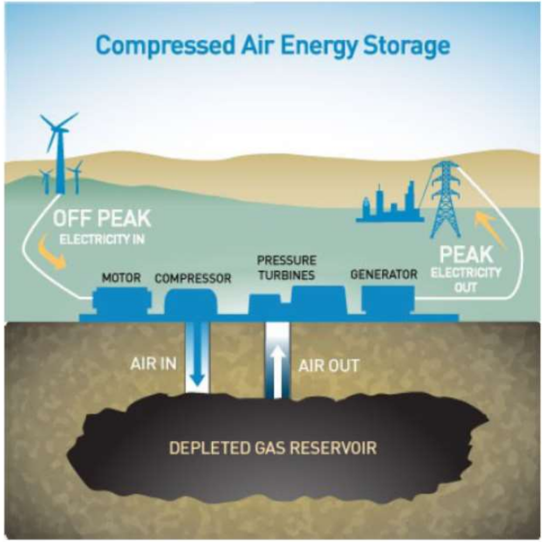
East Kentucky Power Cooperative
J.K. Smith Power Plant (1.2 mi NW off map)
1055 MW Gas Fired Power Station



Trapp Gas Field (abandoned), Clark County, central Kentucky. Estimated compressed air storage volume is **~140 MMcf at 700 psi** to remain below fracture pressure.



From Humphreys and Watson (1996) in "The Atlas of Major Appalachian Gas Plays" available from KGS

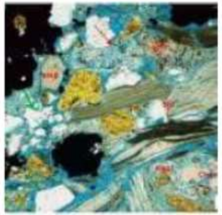


What happens to reservoir rock when air is injected into it?

PG&E, a major California utility, spent years trying to permit a CAES plant in a depleted gas field in central California. It didn't happen.

GEOCHEMICAL INVESTIGATION FOR CAES PROJECT IN A DEPLETED GAS RESERVOIR

San Joaquin County, CA



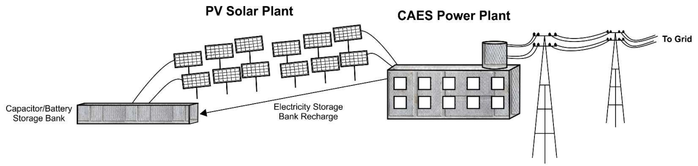
Compressed Air Energy Storage (CAES) in depleted gas fields is being investigated as a potential means to help store energy during times of excess electricity generation from wind and solar energy projects. Although depleted gas fields have been found to offer advantages for energy storage in California's power distribution grid, they also present unique challenges. Among these is the possibility of geochemical reactions when reservoir materials and contents are exposed to air for the first time in millions of years.

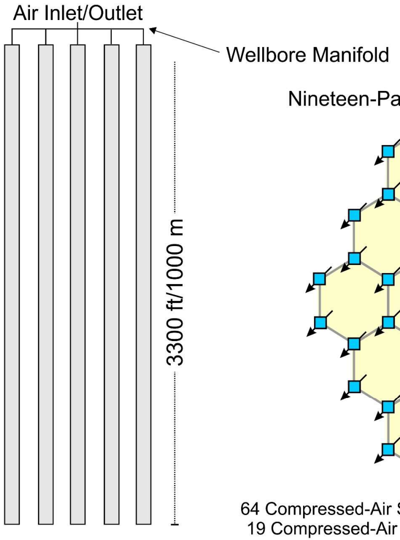
JJ&A provided recommendations to manage oxygen depletion and corrosivity effects, including further investigation, heat flow modeling and monitoring, and reservoir development and operating procedures.

Right Answer > **Significant porosity and permeability changes were not expected to occur.**

[Geochemical investigation for a CAES project | Jacobson James and Associates]

Cased-Wellbore CAES is independent of geology

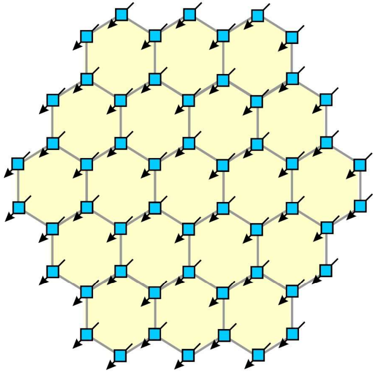




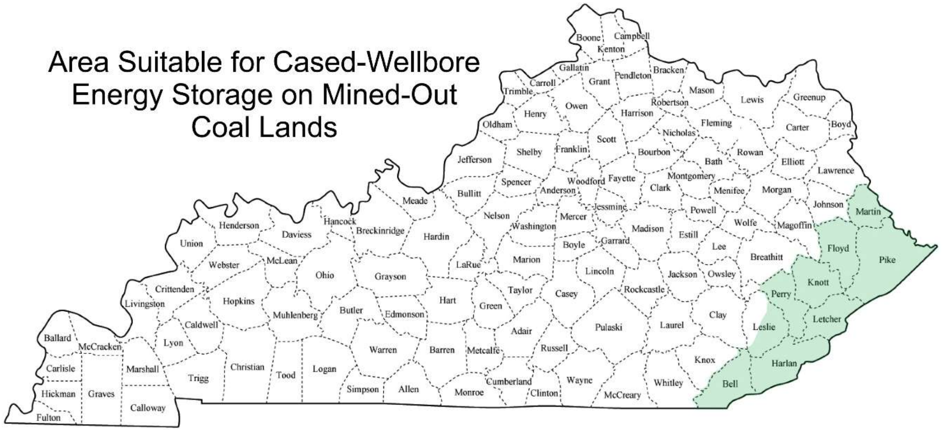
Cased Wellbores

After Sarmast et al. (2021)

Nineteen-Pattern Utility-Scale Storage Field



64 Compressed-Air Storage Wells, 362,300 ft^3 Storage Volume
19 Compressed-Air Storage Patterns, 4.4 acres Surface Area
Estimated Storage Capacity ~220 MW at 1300 psi



Cased-Wellbore CAES is a novel, non-geology limited, model where the compressed air is stored at high pressure in cased vertical storage wells. Just about anywhere in Kentucky with an available site and grid connection would be suitable for CW-CAES.

My hybrid Cased-Wellbore Advanced CAES Model

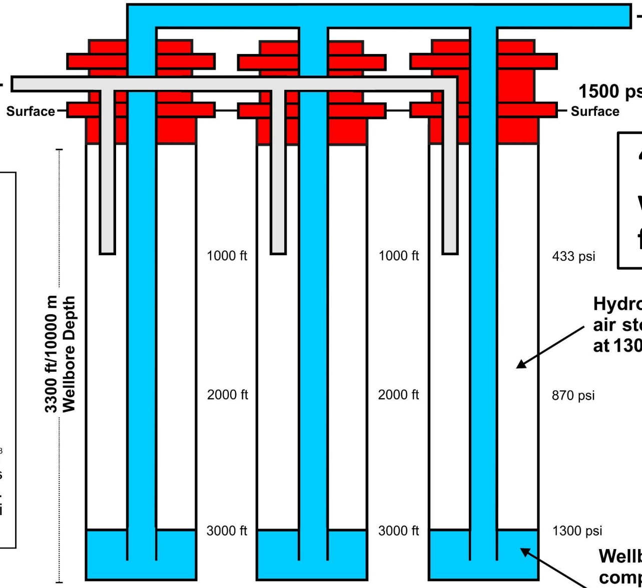
Cased-Wellbore Advanced Compressed Air Energy Storage (CWA-CAES)

Modified from Sarmast et al. (2021), CleanTech Geomechanics (2021), and Hydrostor Inc. (2021)

Water in tubing is discharged to storage pond (~2 acre-feet/MW, total ~89 acre-feet for the proposed pilot project.)

Compressed air in the casing annulus is discharged through tubing to the generator turbine at 1300 psi.

1500 psi wellheads

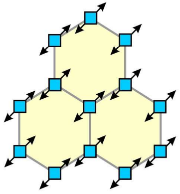


"A utility-scale CWA-CAES power plant would have ~220 MW generation capacity from 64 compressed-air storage wells."

Hydrostatically-compensated compressed air storage in the wellbore casing annulus at 1300 psi.

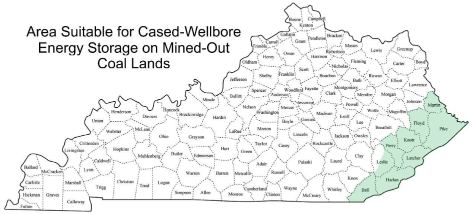
Wellbore water column maintains a constant compressed air storage pressure of 1300 psi at 3000 ft water level (fresh water, 0.433 psi/ft hydrostatic gradient).

Three-Pattern 13-Well ~44.5 MW Pilot CWA-CAES Storage Field



Pilot project has 13 CWA-CAES wells with a total of 73,590 ft^3 storage volume in three compressed-air storage patterns (requires ~0.45 acres surface area with 50-ft well spacing). Estimated energy storage capacity is ~44.5 MW at 1300 psi wellbore casing pressure at 3000 ft compensating water level.

Area Suitable for Cased-Wellbore Energy Storage on Mined-Out Coal Lands



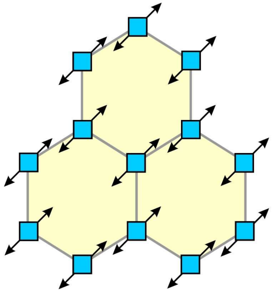
Casing Specifications

20-inch 133 lb/ft N80 LTC casing (nominal 19.124-in ID), 1600 psi collapse resistance, storage volume ~500Mcf/wellbore at 1300 psi. This can be re-scaled to meet any required project specifications.

The PowerSouth McIntosh Plant, Alabama, produces 110 MW from 19 MMcfa compressed air storage cavern at 1100 psi, thus it requires 172.73 Mcfa/MW of compressed air. At 1300 psi, McIntosh would produce ~130 MW, or require 146.2 Mcfa/MW. In the CWA-CAES model each cased wellbore stores 500 Mcfa compressed air at 1300 psi, or 3.42 MW energy storage capacity per wellbore. The 13-well compressed air storage well pilot project is estimated to be capable of generating ~44.5 MW, although actual generation capacity may be less. A utility-scale CWA-CAES power plant would have ~220 MW generation capacity from 64 compressed-air storage wells. Figure is not to scale.

Cased-Wellbore CAES Storage Wells Patterns
50-ft Well Spacings, 3300 ft Deep Wellbores
3000 ft Effective Depth Above Hydrostatic-Compensating Water Level

Three-Pattern Pilot Storage Field

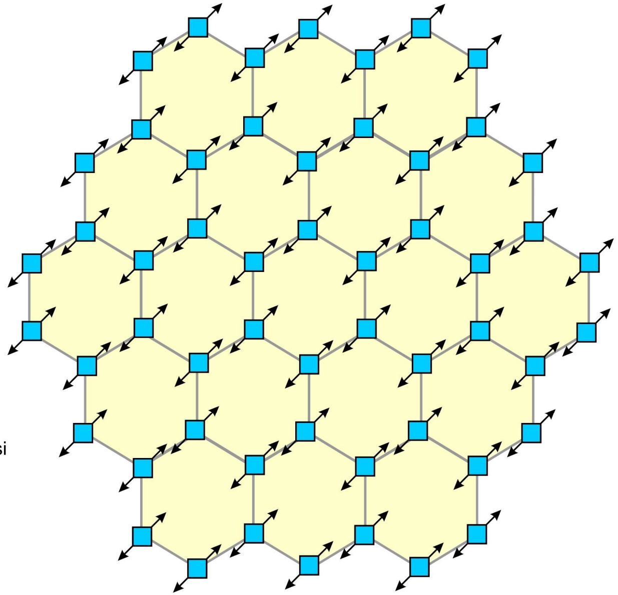


13 Compressed-Air Storage Wells, 73,590 ft^3 Storage Volume
3 Compressed-Air Storage Patterns, 0.45 acres Surface Area
Estimated Energy Storage Capacity ~44.5 MWh at 1300 psi
Single Pattern Energy Storage Capacity ~20.5 MWh at 1300 psi

Wellbore Specifications

- 24-inch Wellbore Drilled to 3300 ft TD
- 20-in, 133 lb/ft N80 LTC seamless casing cemented from TD to surface
- 1600 psi wellheads
- Insulated compressed air flow lines

Nineteen-Pattern Utility-Scale Storage Field



64 Compressed-Air Storage Wells, 362,290 ft^3 Storage Volume
19 Compressed-Air Storage Patterns, 4.4 acres Surface Area
Estimated Energy Storage Capacity* ~220 MWh at 1300 psi

Increasing the storage pressure in the 64 cased wellbores to 8500 psi would allow storage of **200 MMcf of hydrogen**. The only mechanical changes required to store hydrogen would be a non-reactive coating on the casing interiors and high-pressure 20-in casing and fittings. Required surface area remains 4.4 acres.

*www.technologycatalog.com, "Cased-Wellbore Compressed Air Storage for Renewable Energy". Estimated energy storage capacity up to 10 MWh per 3300-ft deep wellbore with 10¾-inch casing at 7250 psi and 392 °F. Capacity recalculated for 20-inch wellbore casing at 1300 psi and 77 °F.

Where do we go from here?

- Kentucky has three CAES options:
  - Caverns
  - Abandoned oil and gas fields and aquifers
  - Cased wellbores
- PV-Solar electricity generation, the source for producing heat for CAES power generation, can be co-installed but not necessarily on the same site.
- Cased-Wellbore CAES offers the greatest flexibility for siting the electricity generation plant

Acknowledgements:

This project was funded was by a grant from the University of Kentucky Energy Research Prioritization Partnership Seed Grant program, 2020. Our thanks for their patience because of delays completing this project during the lockdown period from the COVID-19 pandemic.

Thanks!

Bowersox, J.R., Hickman, J.B., and Skeese, K.A., 2022, Assessing Compressed Air Energy Storage (CAES) Potential in Kentucky to Augment Energy Production from Renewable Resources: Geological Society of America *Abstracts with Programs.* Vol. 54, No. 4, doi: 10.1130/abs/2022NC-374797.