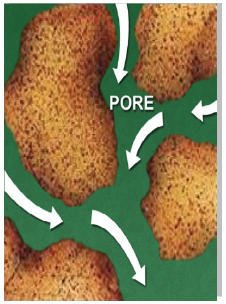


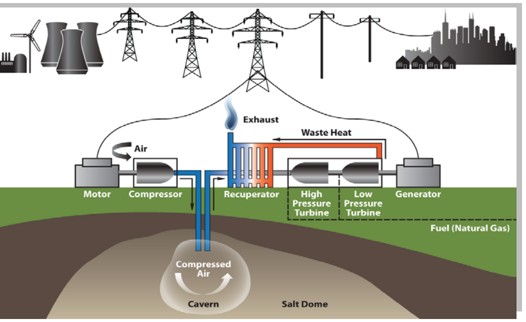


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# CAES Geo Performance for Natural Gas and Salt Reservoirs,

# Thermal-Mechanical-Hydraulic Response of Geological Storage Formations for CAES

27 September 2012

SJ Bauer, M Martinez, **W. Payton Gardner**, J Holland

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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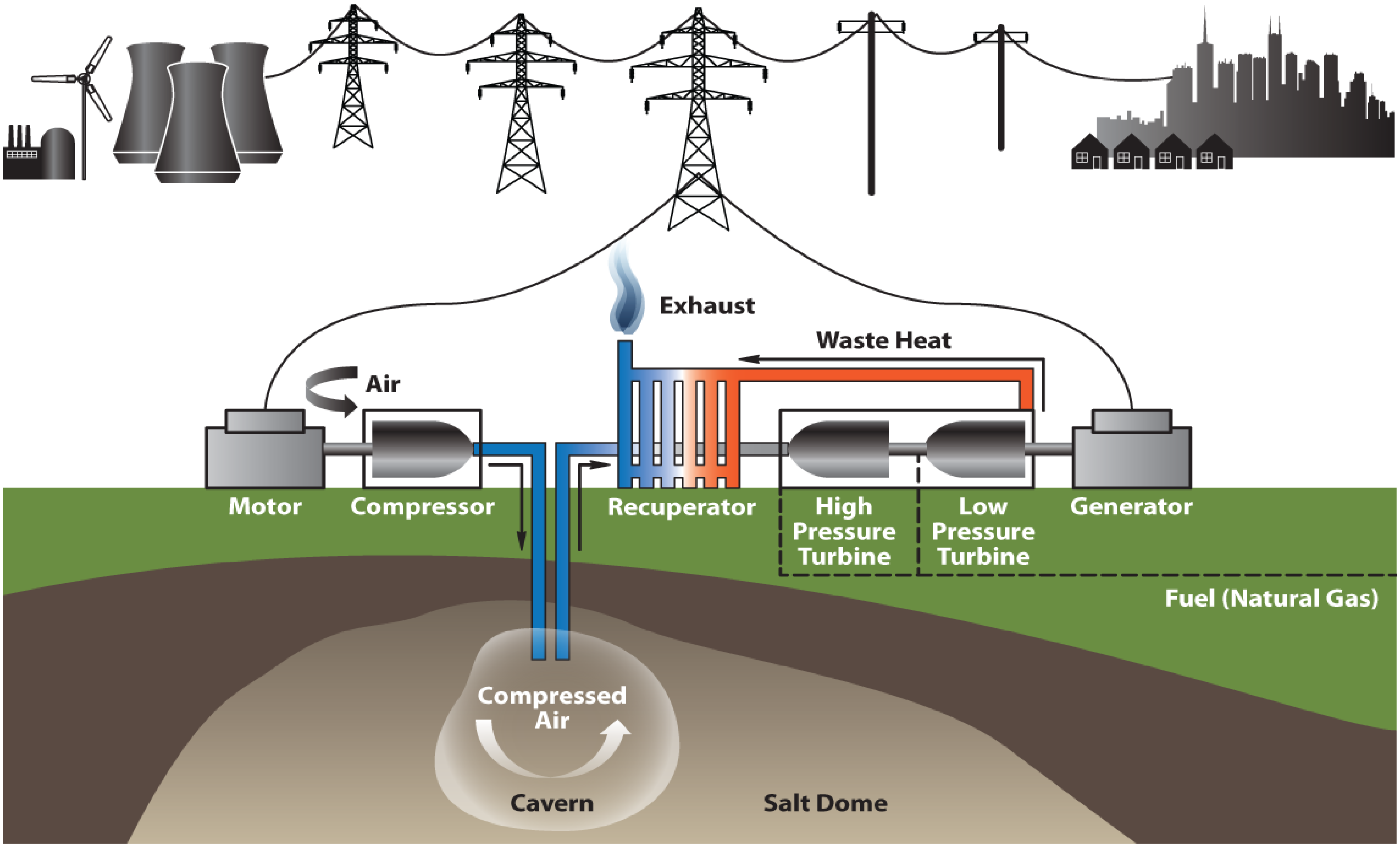
Exhaust
Waste Heat
Air
Motor
Compressor
Recuperator
High Pressure Turbine
Low Pressure Turbine
Generator
Fuel (Natural Gas)
Compressed Air
Cavern
Salt Dome

# CAES Geo Performance for Natural Gas and Salt Reservoirs / Thermal-Mechanical-Hydraulic (T-M-H) Response of Geological Storage Formations for CAES

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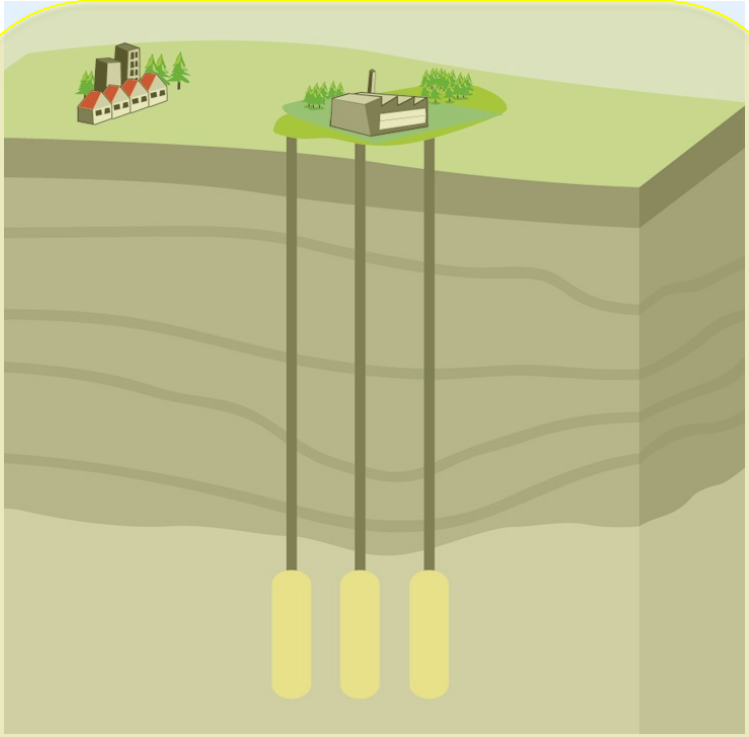
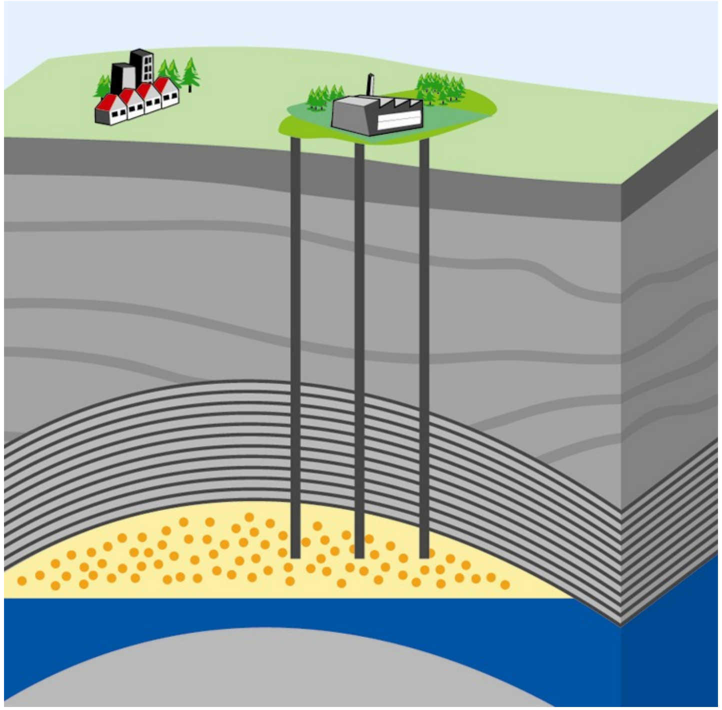
- **Problem**: Siting of CAES facilities may be limited by specific geologic conditions
- **Opportunity**: Fundamental understanding of T-M-H will enable/extend CAES siting potential throughout the US





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1. CAES in Mined Salt Caverns
- Model large scale salt cavern response to air pressure cycling
- Experimentally evaluate thermal cycling effect on domal salt

Images taken from: http://www.rwe.com/

2. CAES in Depleted Natural Gas Reserviors:
- Model multiphase flow in a depleted natural gas reservoir for CAES
- Experimentally evaluate pore pressure cycling effect on sandstone deformation

# Large scale salt cavern response to air pressure cycling

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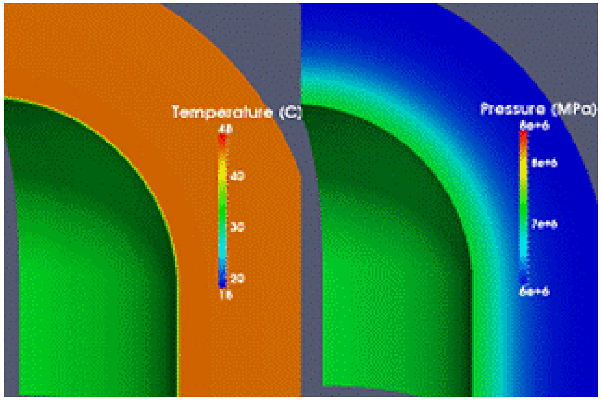
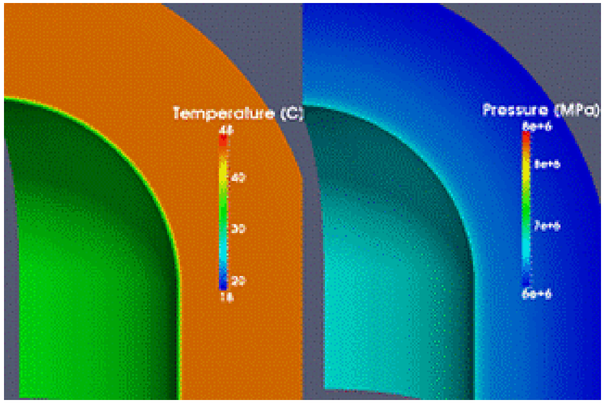
Coupled 3D simulation of cavern gas thermodynamics and heat/mass flow in salt

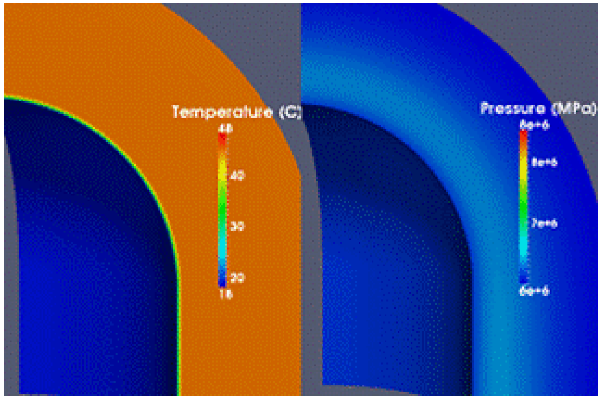
- Assess long term performance, efficiency and economics.
- Cavern gas thermodynamics is coupled with energy transfer to and from the salt formation.
- Minimize creep/damage of the cavern and minimize efficiency-reducing energy losses to and from the formation.



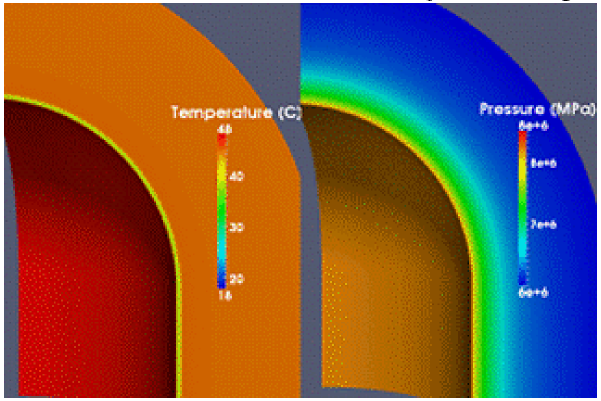

After 8 hours extraction




After 4 hours of subsequent injection




End of 16 hour extraction

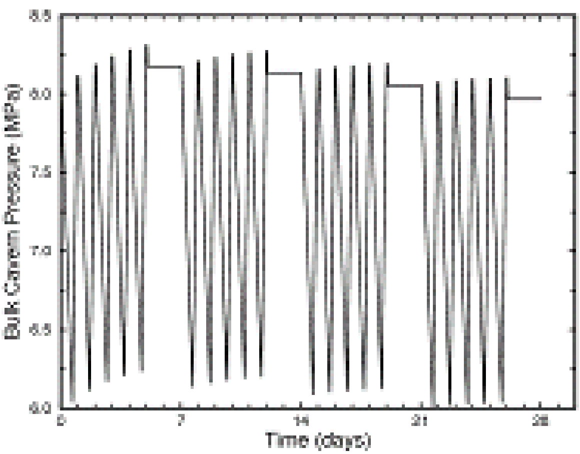



End of 24 hour cycle

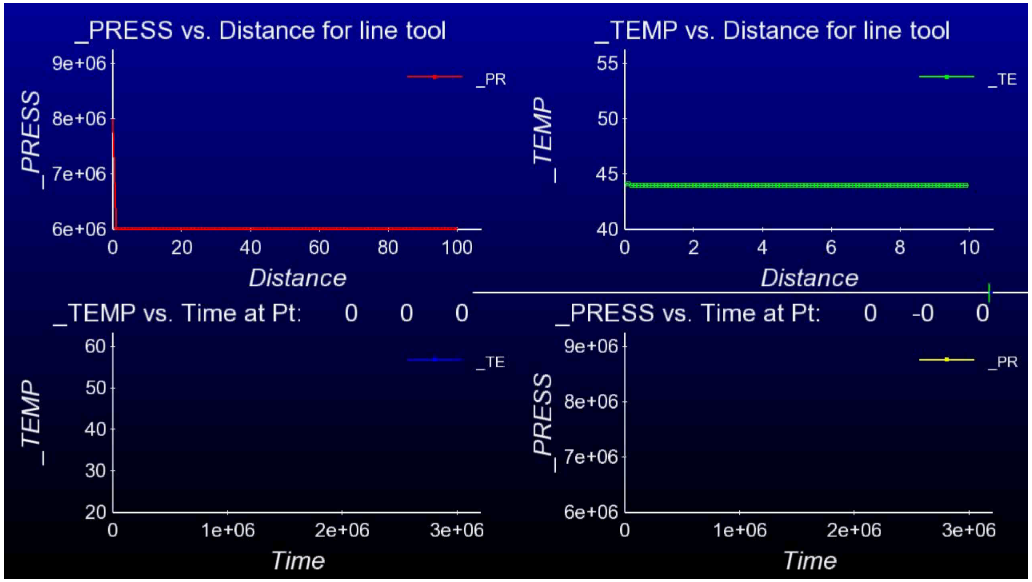
Walls are 30m thick. Cavern is made up of cylinder midsectio
(height=65m; radius 40m) with
hemispheres (radius=40m) at top and bottom

# Response of CAES to pressure/temperature cycling: Closeup

Cavern Gas Pressure




Pressure and Temperature in the Salt Formation




<u>Cycle:</u> 5 days on, 2 days off (weekend)

- Extract for 16 hours (154 kg/s)
- Inject for 7 hours (352 kg/sec , 40 $^{o}$C)
- Hold for 1 hour

Upper row of figures: Salt response

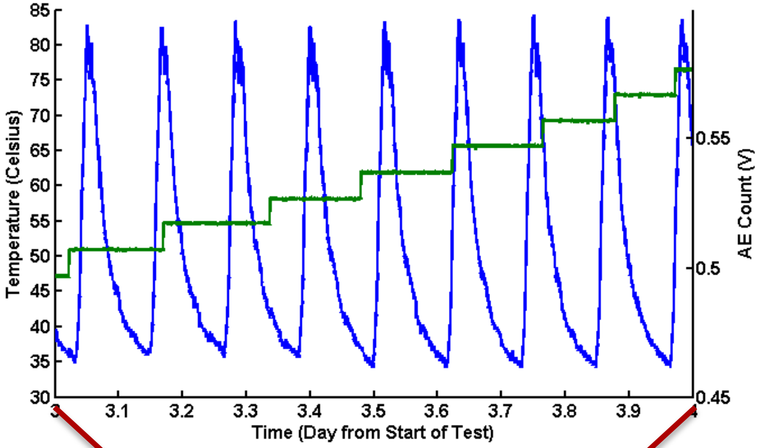
- temperature fluctuation ~ 1-2 m
- pressure fluctuation ~ 40 m

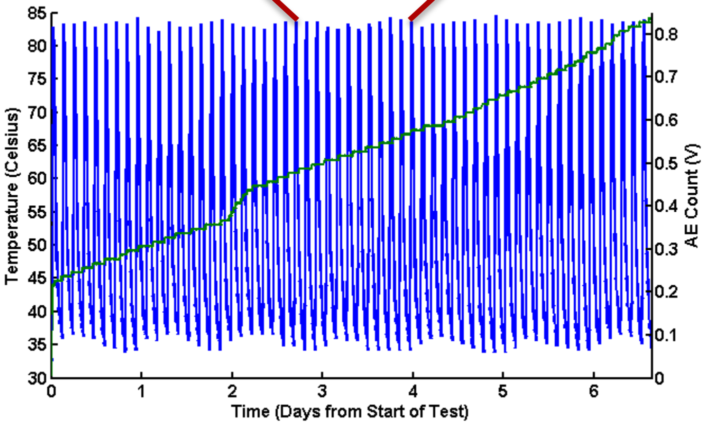
Lower row of figures: Cavern T & P response

- start-up transient

# Thermal Cycling of Salt

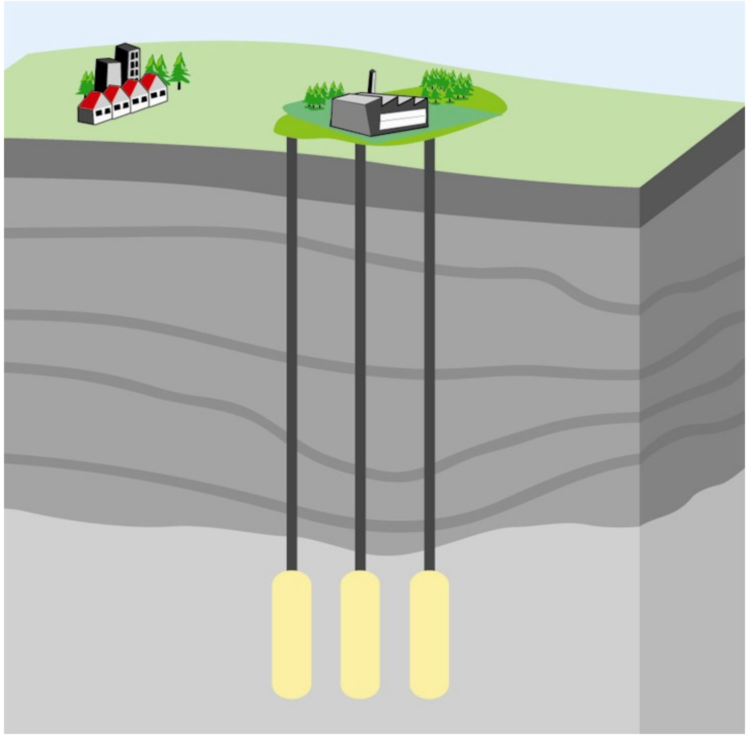
Experimental System Developed
to detect and record Acoustic Emissions
(cracking events)
in salt as it was heated and cooled

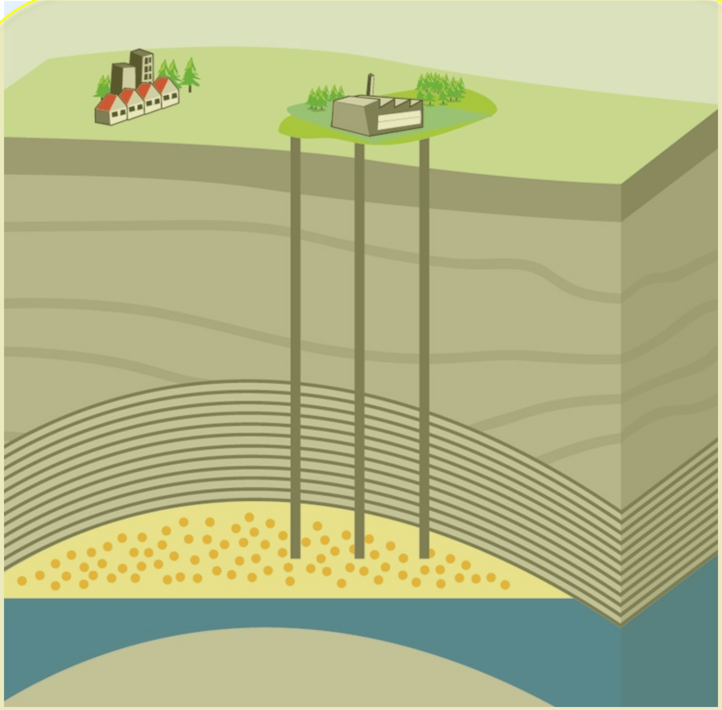



Observation: For this temperature range and slow heating and cooling rate, only a small amount of acoustic emissions (thermal cracking) are detected

Future work: thermally cycle rock salt at realistic heating and cooling rates





1. CAES in Mined Salt Caverns

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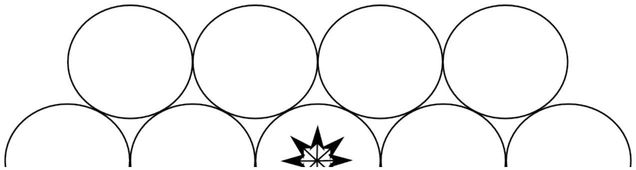
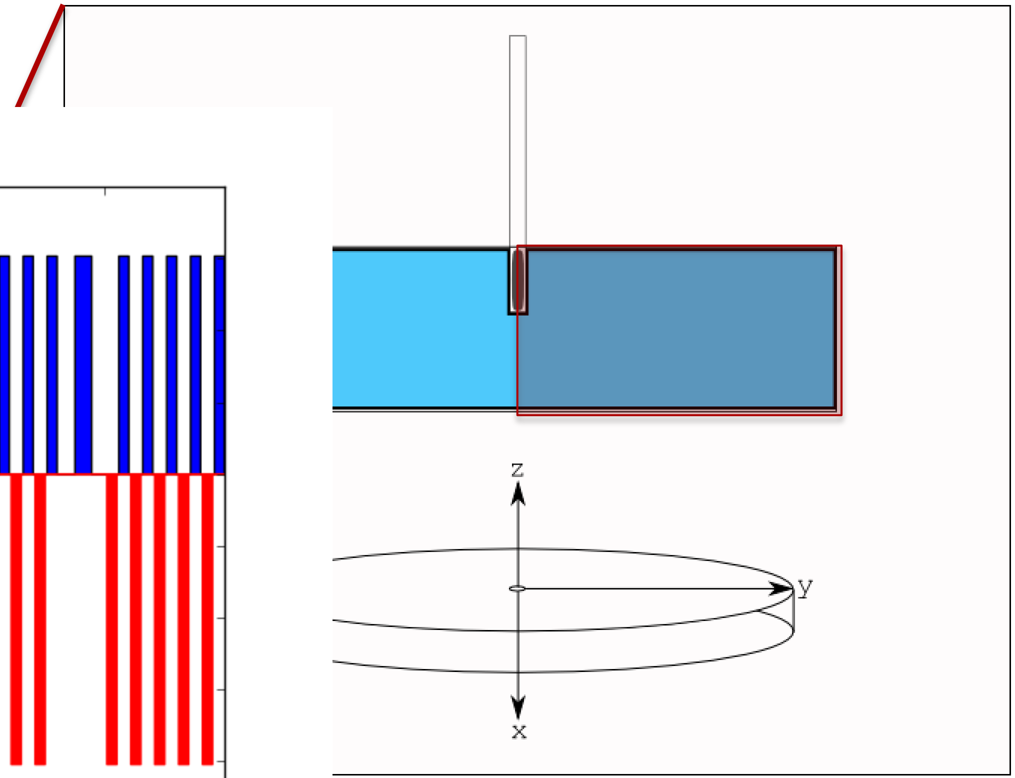
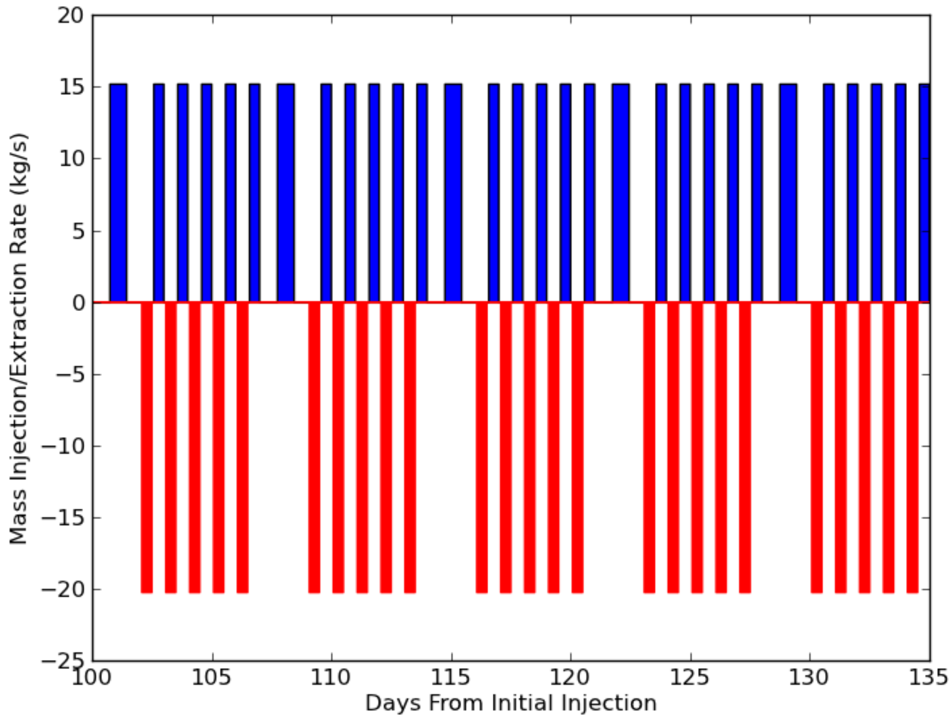
# Formation Analysis for CAES in Depleted Natural Gas Reservoirs



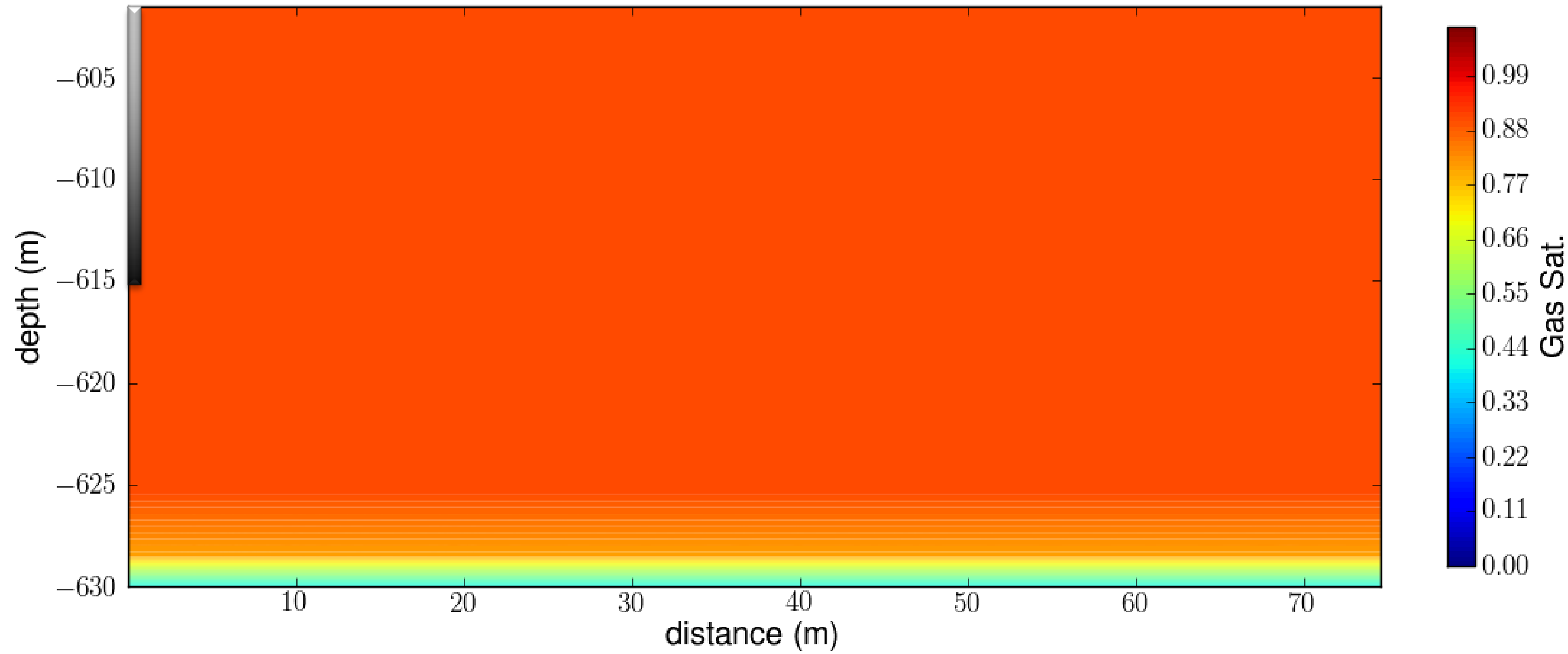


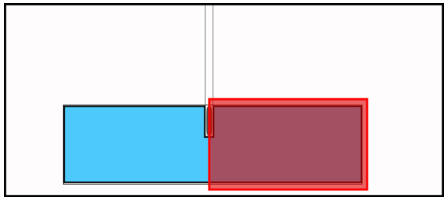

Ac




Cylindrical Region

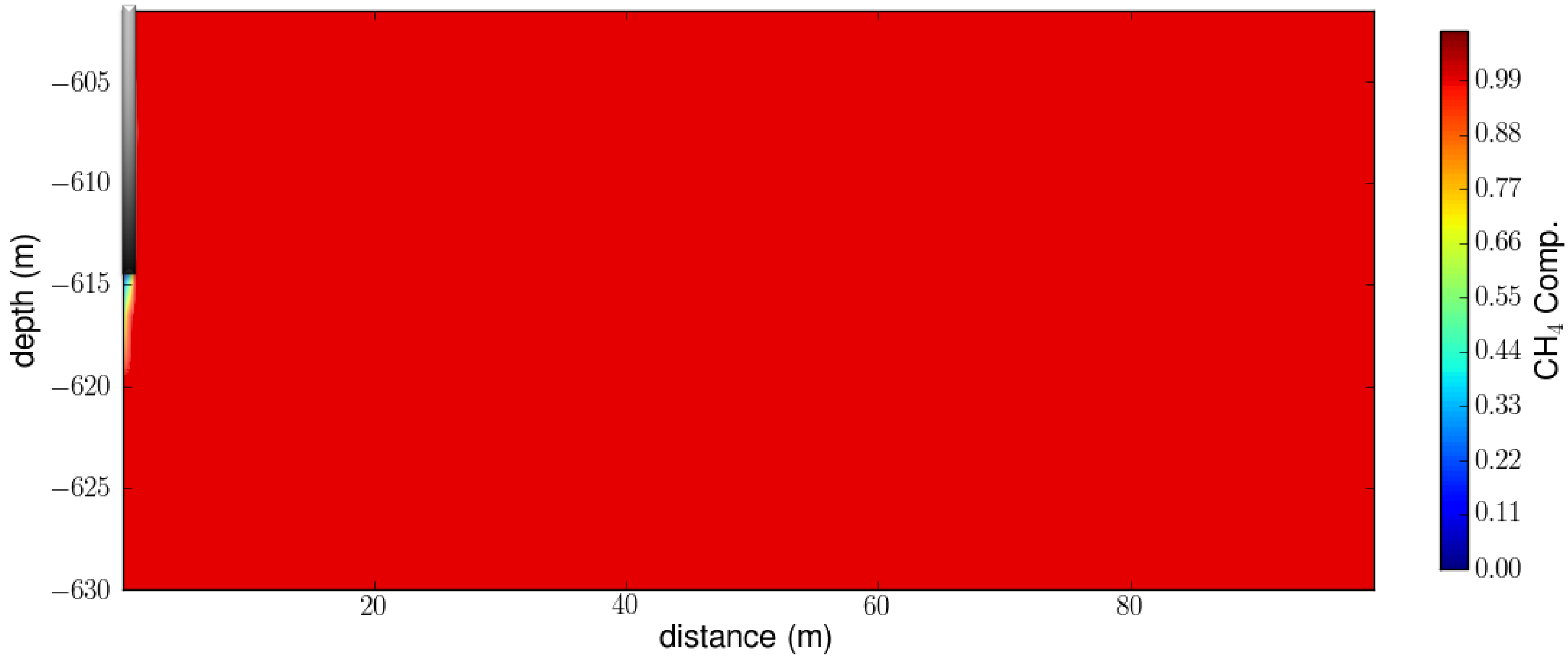
# The Initial Condition - Modeling a Depleted Natural Gas Reservoir



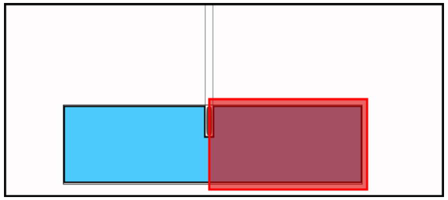



- After natural gas production, residual $CH_4$ is left behind
- Residual gas saturation for the given formation parameters is between 10-20% of the total porosity
- This gas phase is composed of 100% $CH_4$

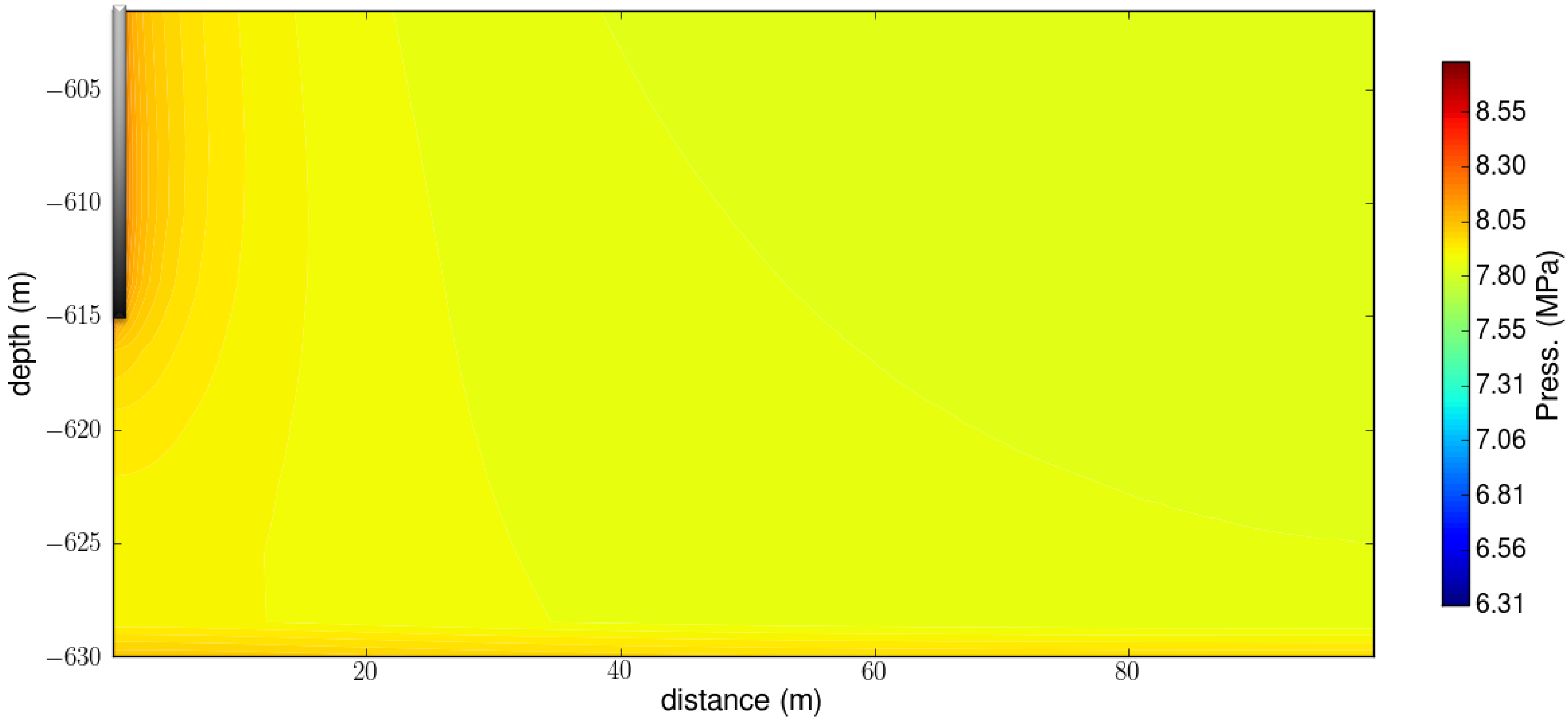
# Forming an Air bubble - Gas Composition During Bubble Formation

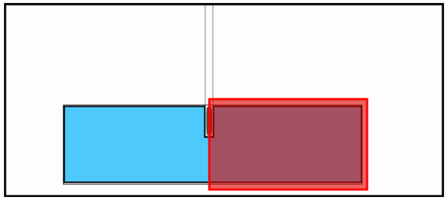



- $N_2$ bubble is formed and pushes the $CH_4$ to the fringes.
- Relatively little mixing during bubble formation.
- $N_2$ rich bubble next to bore

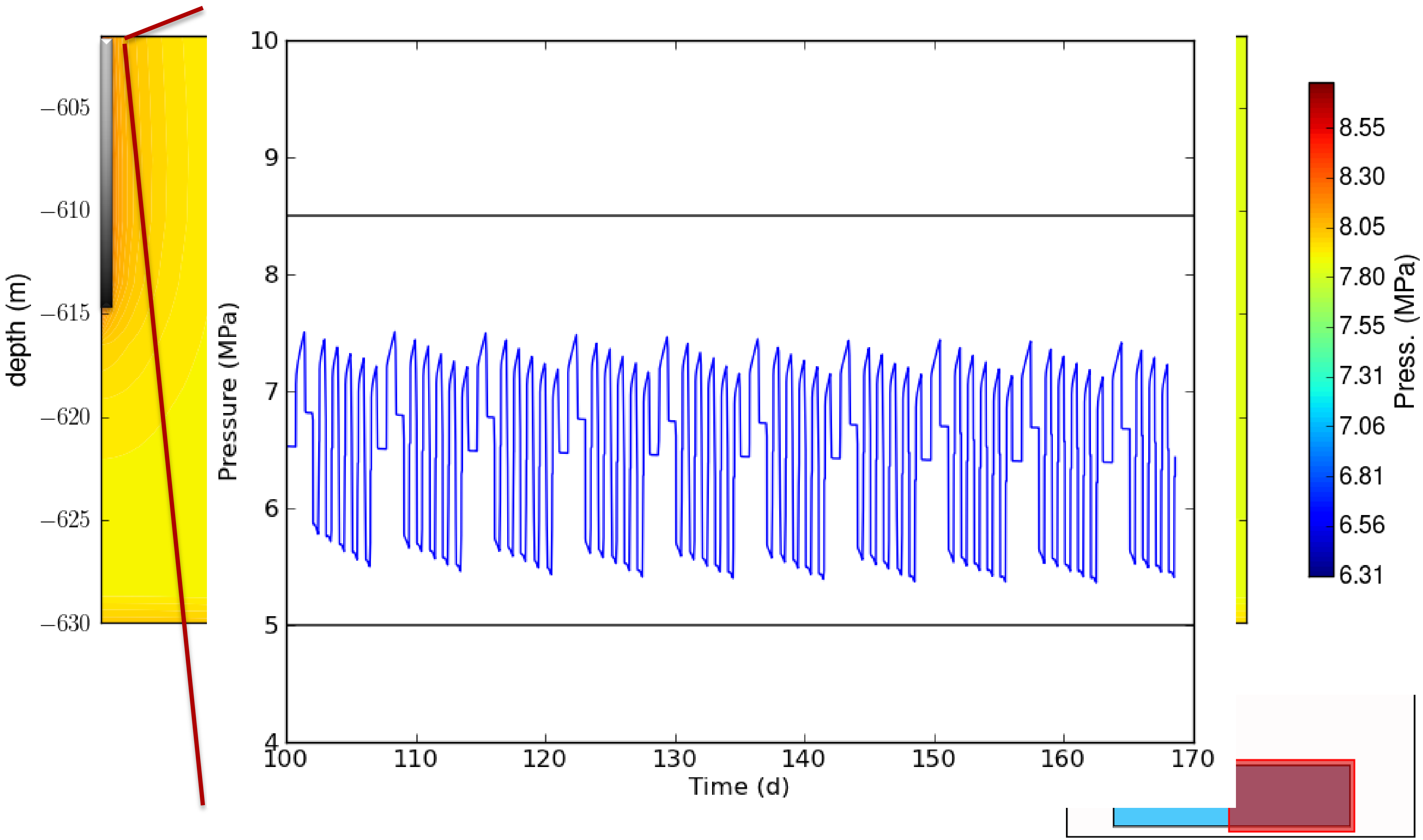


# Reservoir Pressure During Cycling

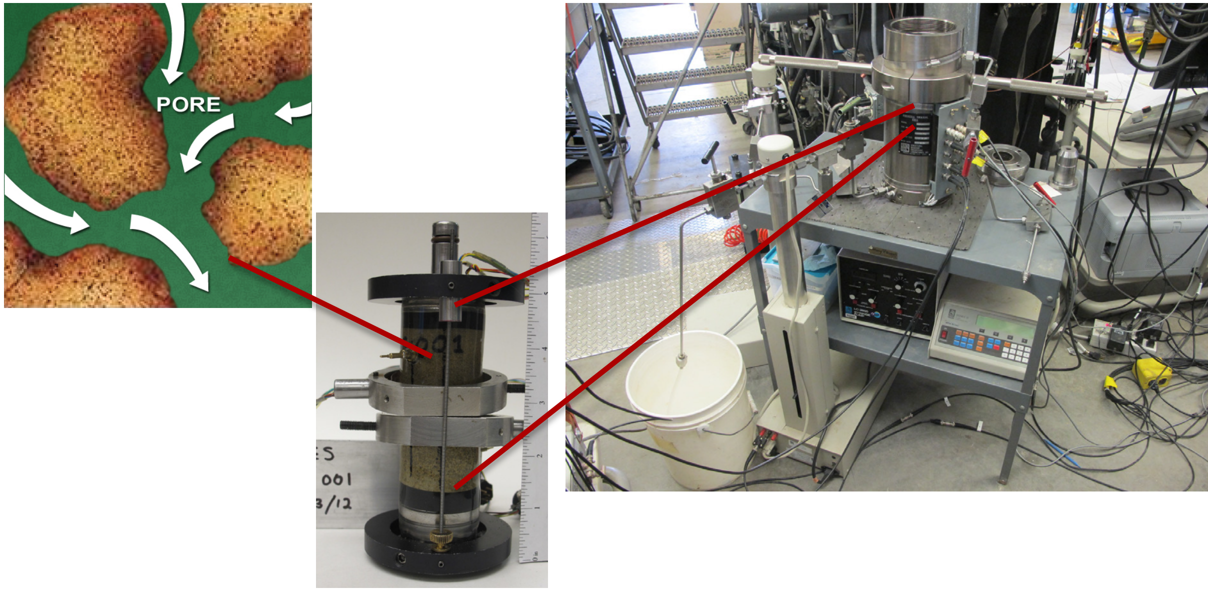


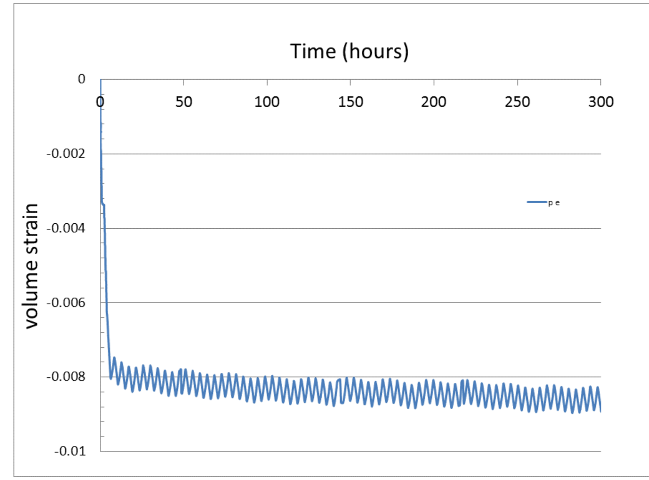
# Cycling – Pressure



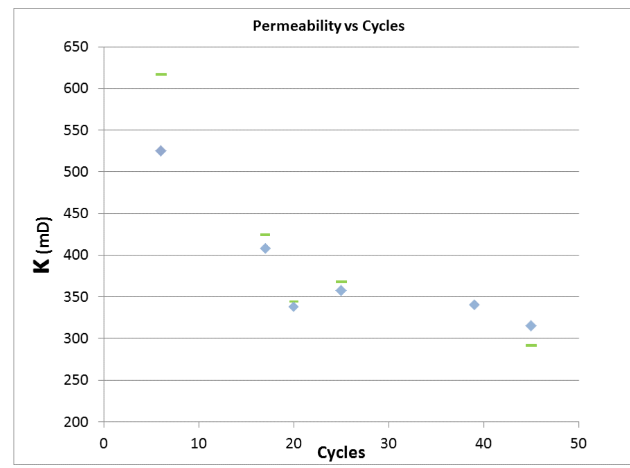
# Pore pressure cycling of sandstone




Experimental System Developed
to cycle pore pressure in a
sandstone in hydrostatic stress state




Volume strain versus time:
Compaction observed

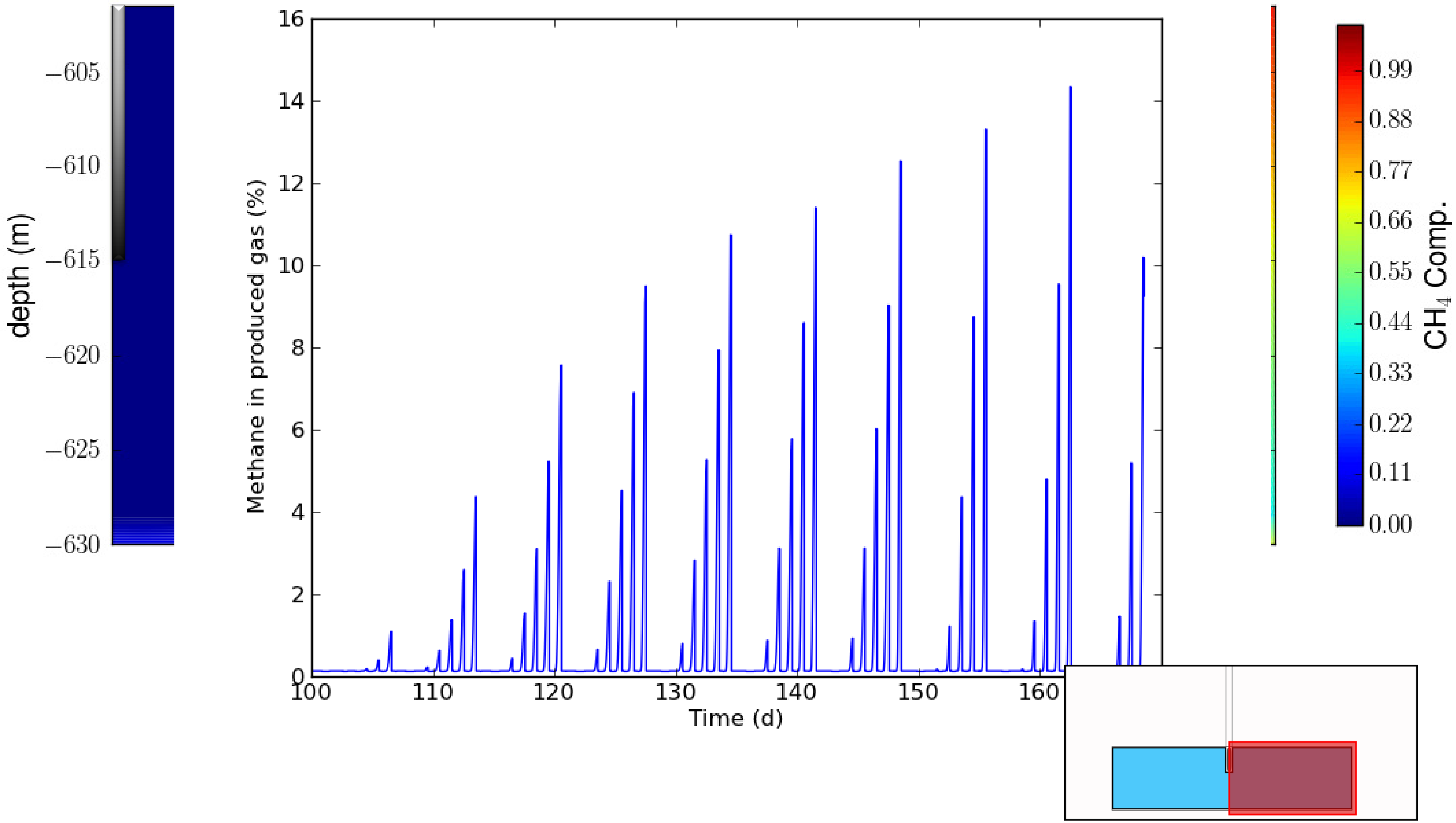



Decrease in permeability
with cycle/time

Observation: Sandstone compacts over time, repeated cycles: permeability decreases

Future work: Evaluate cycling effect on other stress state, additional sandstone lithologies
(rocks with different cement, porosity, permeability)

# Cycling – Methane in Produced Gas



# CAES in Depleted Natural Gas Reservoirs is a Viable Option

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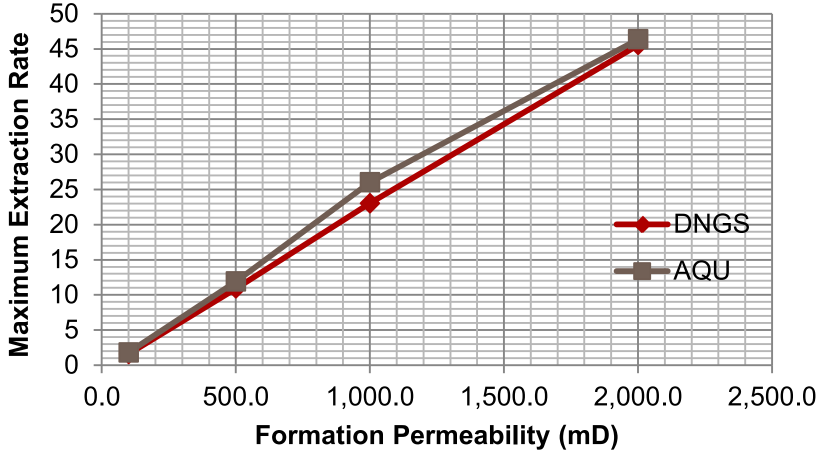
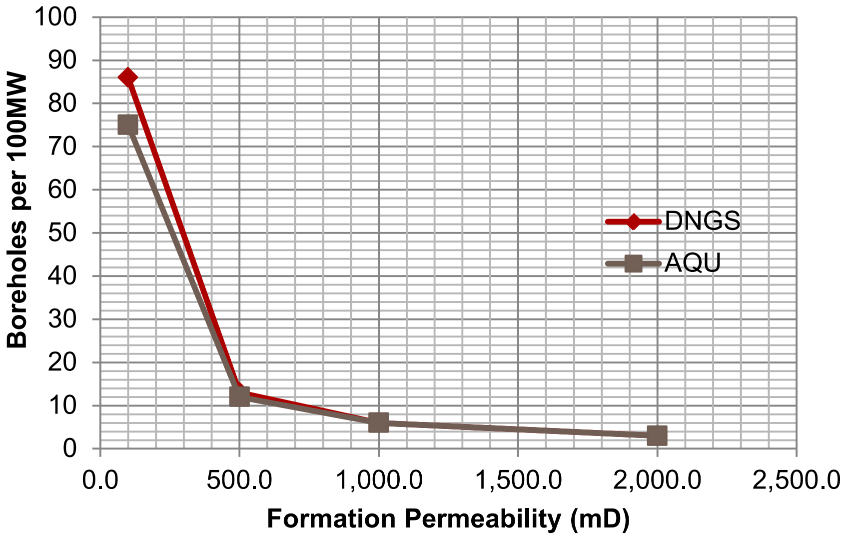
- Have a numerical framework in place to simulate air, methane and water movement in a porous reservoir
  - First CAES simulations in a depleted natural gas reservoir
- CAES in depleted natural gas reservoirs appears to be a viable option



# Summary/Conclusions

- Developed numerical analysis method to evaluate thermal and mechanical effects of air mass flow cycling in a salt cavern
- Developed experimental system to evaluate thermal cycling effect on rocksalt

- Developed numerical analysis method to model multiphase flow of air, H2O and methane for a CAES evaluation in a depleted natural gas reservoir
- Developed experimental system to evaluate pore pressure cycling effect on sandstone

# Future Tasks

- Evaluate thermal cycling effect on rocksalt using thermal cycles determined from analyses (below)
- Evaluate model comparing to actual real pressure/temperature cycling data from industry partner
- Develop operational (cycle variations) and geologic (i.e. depth) assessments to probe geo-system flexibility
- Evaluate pore pressure cycling effect for other stress conditions and reservoir rocks
- Improve on multiphase flow model for depleted natural gas reservoir; evaluate different cycles (i.e. wind generated), examine the effect of heterogeneity

# Publications

- Thermomechanical Model Development for CAES in Salt Caverns, 2012, M. Martinez, J. Holland, S. Bauer, P Hopkins, A Rinehart, Sandia National Laboratories, SAND report in prep
- Pore pressure cycling effects in a sandstone, 2012, S. Bauer, Sandia National Laboratories, SAND report in prep
- Formation Analysis for CAES in Depleted Natural Gas Reservoirs, 2012, P. Gardner, Sandia National Laboratories, SAND report in prep
- Compressed Air Energy Storage in Hard Rock Feasibility Study, 2012, S. Bauer, S. Webb, K. Gaither, Sandia National Laboratories , December 2012, SAND2012-0540
- Permeability and heterogeneity restrain compressed air energy storage in the Mount Simon Sandstone, Dallas Center structure, Iowa, 2012, J. Heath, and S. Bauer, Sandia National Laboratories, SAND report in prep
- Elasto-Plastic Constitutive Behavior in Three Lithofacies of the Cambrian Mt. Simon Sandstone, Illinois Basin, USA, 2012, T. Dewers, P. Newell, S, Broome, J. Heath, and S. Bauer, Sandia National Laboratories, SAND report in prep

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