Integrated Pre-Feasibility Study of a Commercial-Scale CCS Project in Formations of the Rock Springs Uplift, Wyoming

DE-FE0029302

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CMI/University of Wyoming

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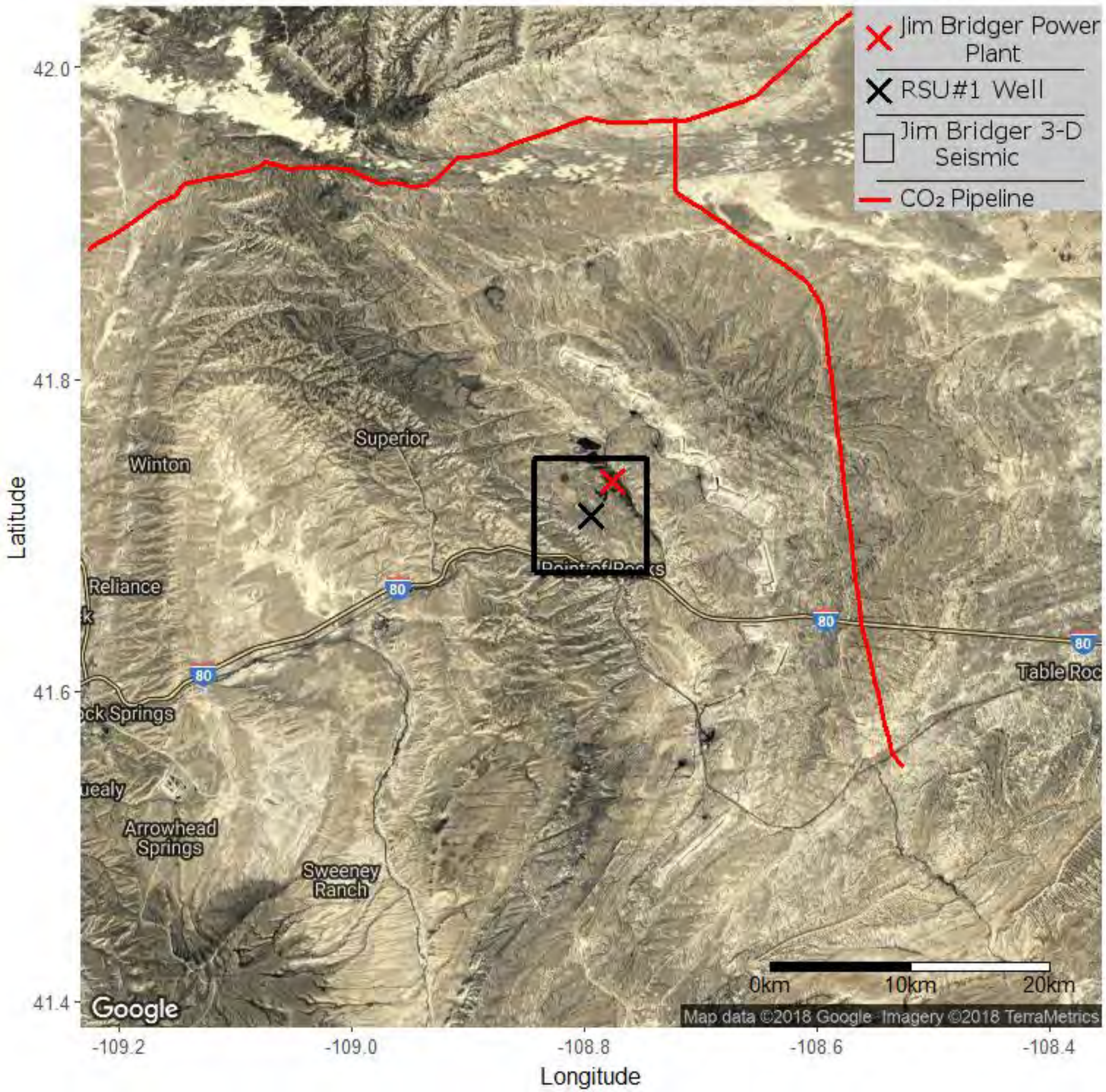
We appreciate the support.

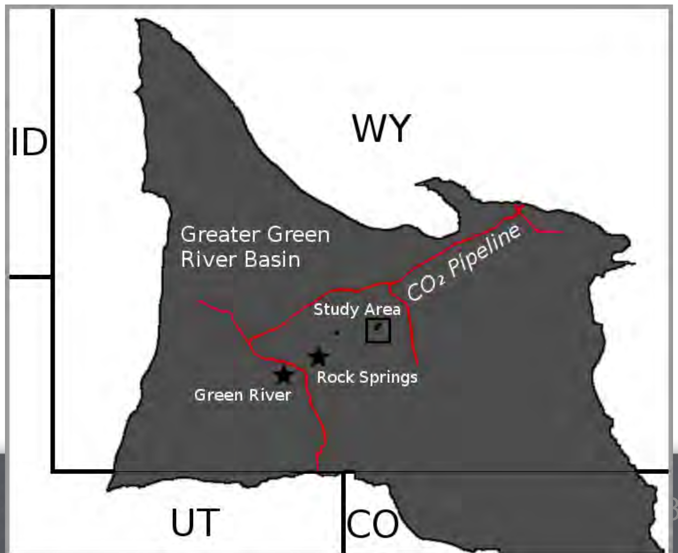
Presentation Outline

- Project Background and Objectives
- Technical Status
- Accomplishments to Date
- Lessons Learned
- Synergy Opportunities
- Project Summary

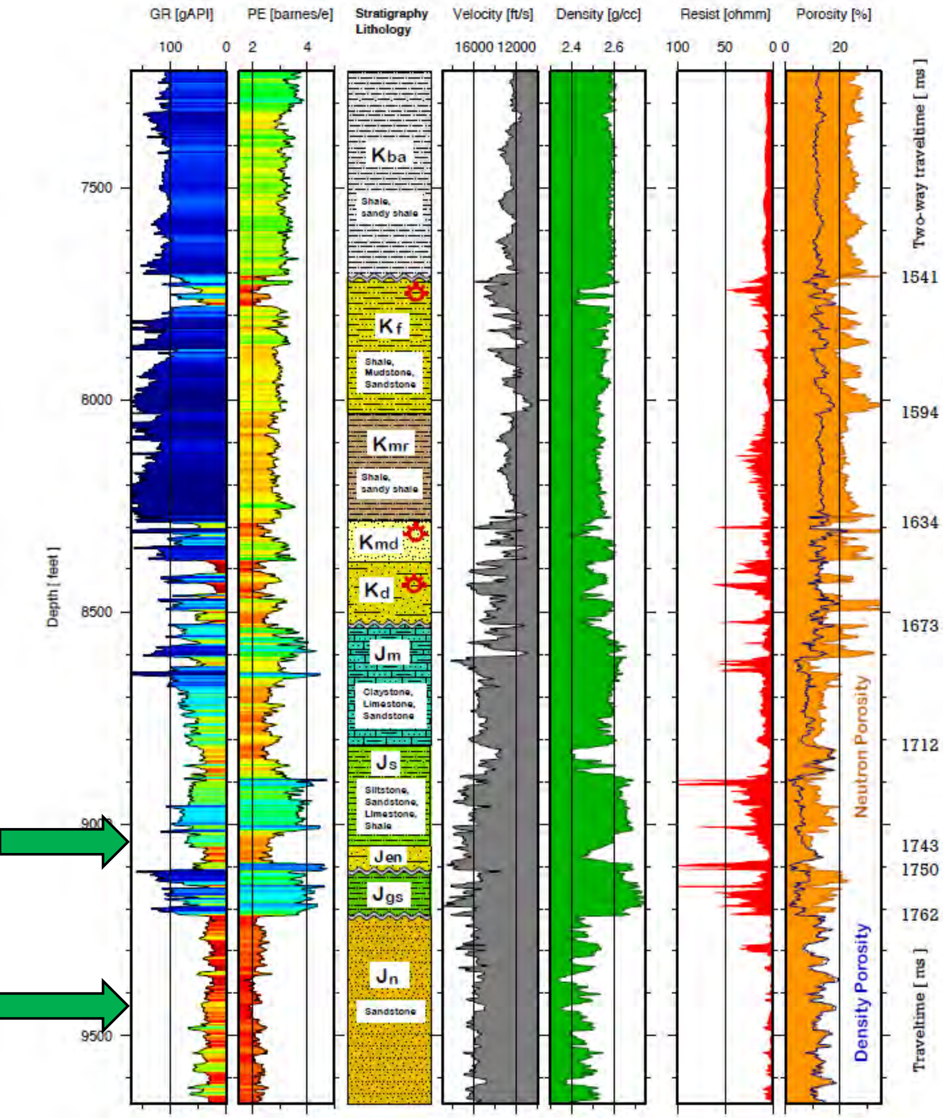
Project background

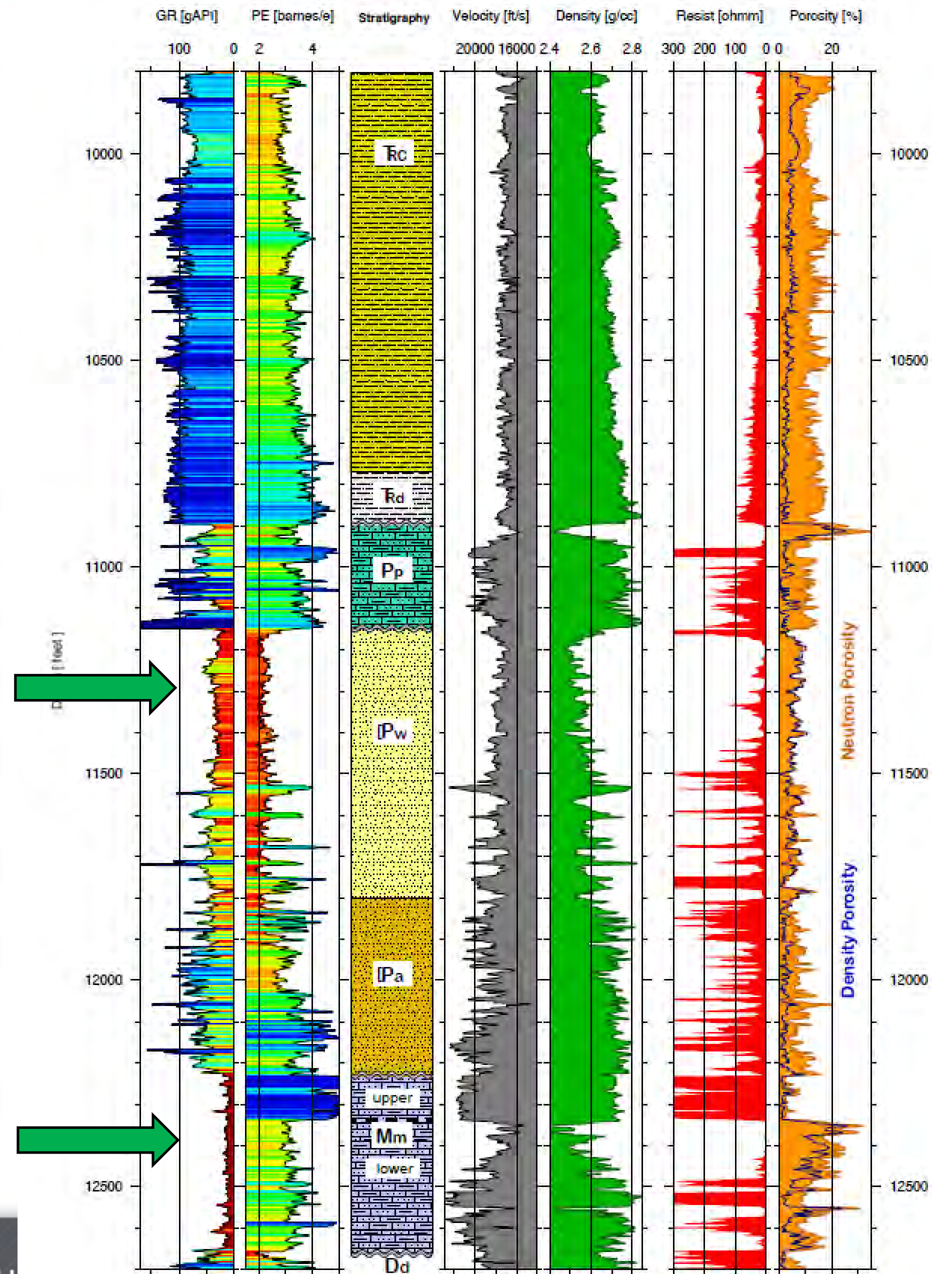


- Capture from the Jim Bridger Power Station (largest CO_2 source in State ~18 Mt/yr)
- Adjacent to CO_2 infrastructure



Project background



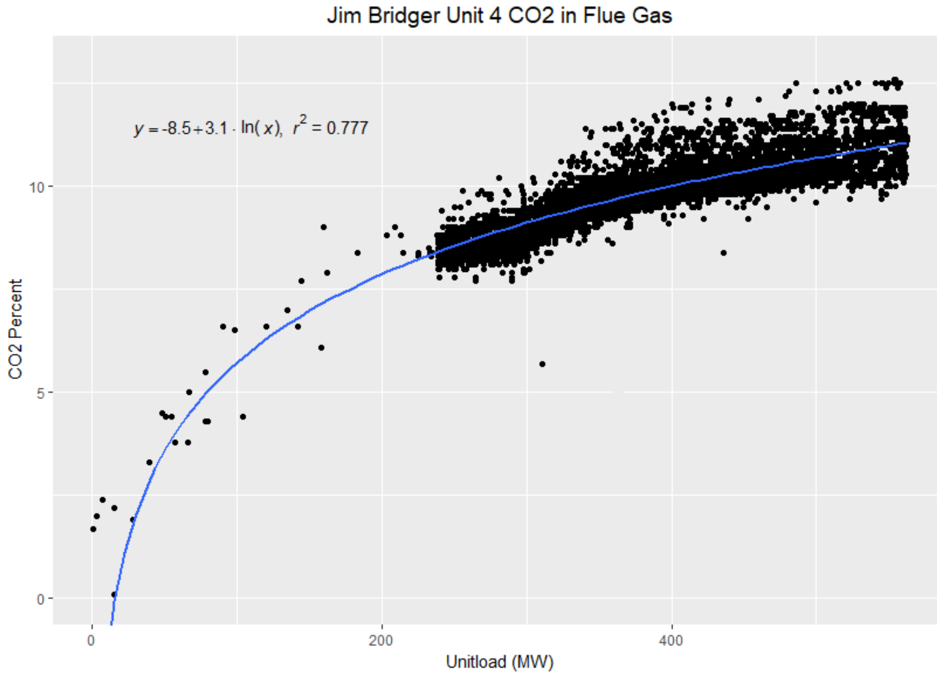


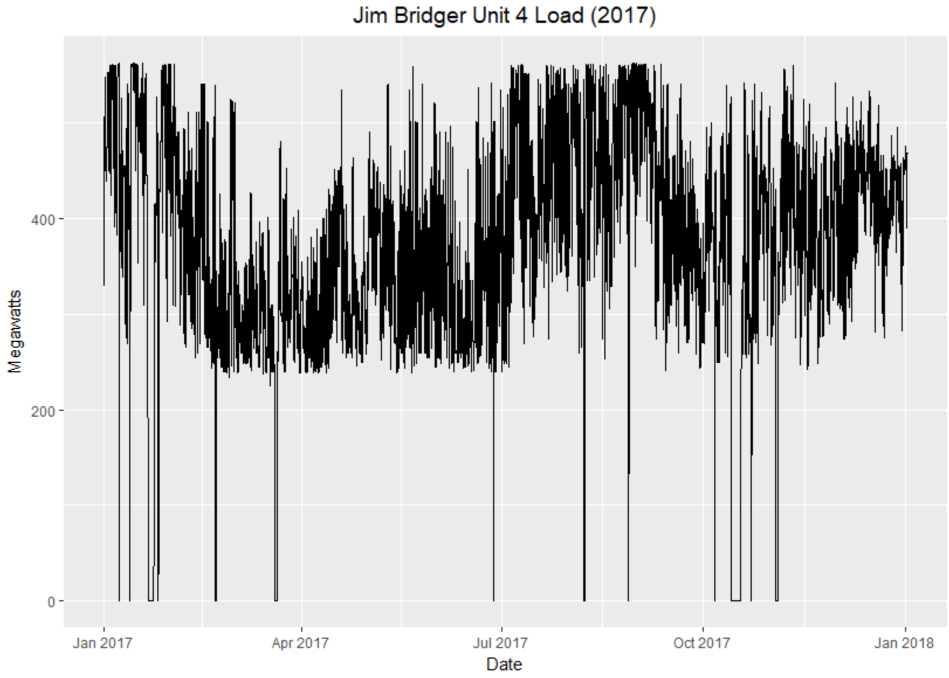
Objectives

- CCUS team development
- Outreach strategy
- Scenario assessment
- Business assessment
- Regulatory assessment
- Source assessment
- Stacked storage assessment
- NRAP evaluation

CO_2 Source

- Largest point source in Wyoming
- Feasibility study completed by Sargent & Lundy
  - Unit 4 typically averages 386 MW (~3.0 MMT of CO_2)
  - Assuming capture success similar to Petra Nova, then ~30% (18 MMT) of the CO_2 captured during project lifespan could be sold.





Estimated CAPEX & OPEX

Capital (CAPEX) and annual operating (OPEX) costs of implementing the preferred "JBP On-site" scenario are in the range of $758-$956 million and $54-$103 million, respectively, based upon the project's economic model (Petro Nova as base model).

Assumptions: (1) amine capture system sized for a 380 MW flue gas stream; (2) saline storage site within 2.5 miles of JBP; (3) 15-mile CO_2 pipeline for regional CO_2-EOR opportunities; (4) utilization of JBP's coal-based steam cycle per Sargent & Lundy, LLC's assessment; (5) power purchases at wholesale prices; and (6) deposition of funds for post-injection site care into trust accounts during the project's operating period.

Project financing assumes: (1) 30% of costs are financed by debt; (2) significant sales of CO_2 for CO_2-EOR; (3) revenues from tradable CO_2 can be earned for the saline storage share of capture; and (4) utilization of section §45Q (as amended) and §48A tax credits.

Economics

Potential Sources of Revenue

The project's economic model estimated that the following revenues collectively are sufficient to finance the project:

- ✓ Sales of CO_2 for EOR (approximately $69 million/year);
- ✓ Use of CO_2 tax credits such as amended §45Q and §48A (approximately $484 million total); and
- ✓ Sales of low-carbon electricity and marketable carbon offset/credits into carbon-constrained markets (approximately $11-$17 million/year).

These revenue estimates are broadly consistent with a 2013 Stanford University study (Stanford, 2013) that concluded arbitrage in JBPS retail electricity sales between California and Wyoming could help to support the cost of deploying CCS at JBPS.

Regulatory Issues

Legal Considerations

- ✓ ***The Big Picture***: Many legal issues are addressed through the State of Wyoming robust CCUS-related laws – to include, for example, pore space ownership.

- ✓ ***Federal Lands Considerations***: The proposed scenarios are located in an area of Wyoming where the land ownership pattern is referred to as the "checkerboard," meaning that every alternating section (≅640 acres) is federally owned. Potential impacts --

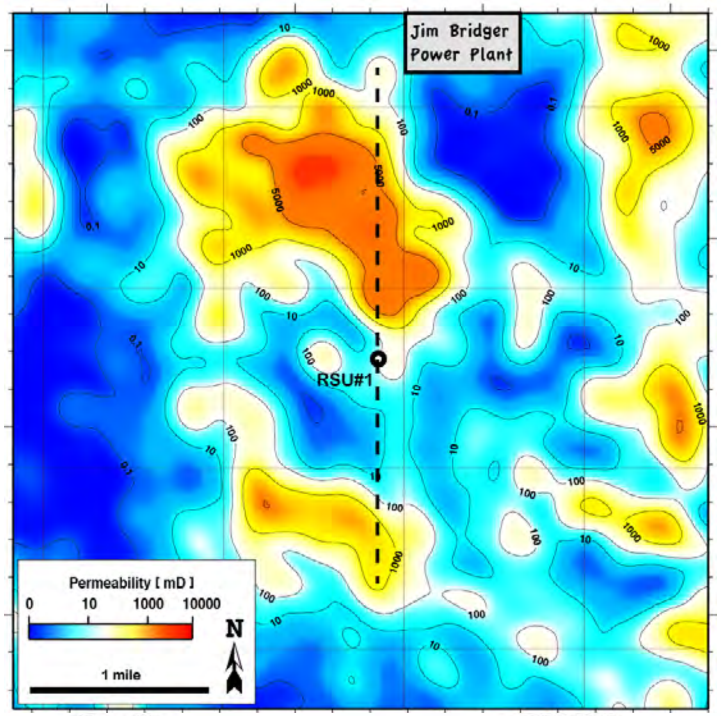
  - Federal pore space likely required to be acquired.

  - Rights of ways across federal lands for pipelines likely to be required.

Legal Considerations

- ✓ ***Liability for Stored CO_2***: Wyoming law provides that the injector, not the pore space owner, is generally liable and that the State is not liable (*see, e.g., Wyo. Stat. § 34-1-513*). The team intends to engage the State of Wyoming Legislature and Office of State Lands and Investments (OSLI) on potential clarifications and approaches. The team further intends to manage these risks by: (1) structuring the project to control plume extent and potentially impacted parties; (2) making use of Wyoming law that provides for post-closure MVA via a trust fund approach (*id. § 35-11-318*); and (3) entering into insurance and user fee-funded structured financial instruments that would be prepared with the assistance of Lindene Patton, Esq., former Chief Climate Product Officer at Zurich Financial Services and the author of the first CCS insurance policy put in use in the United States.

Modeling and Simulations



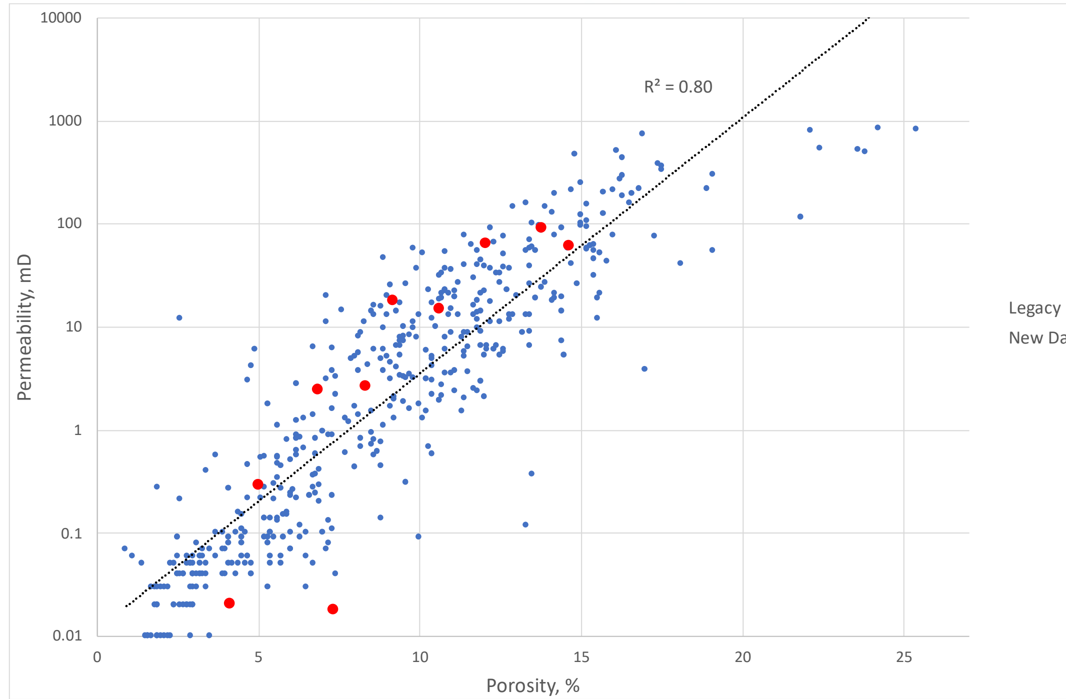
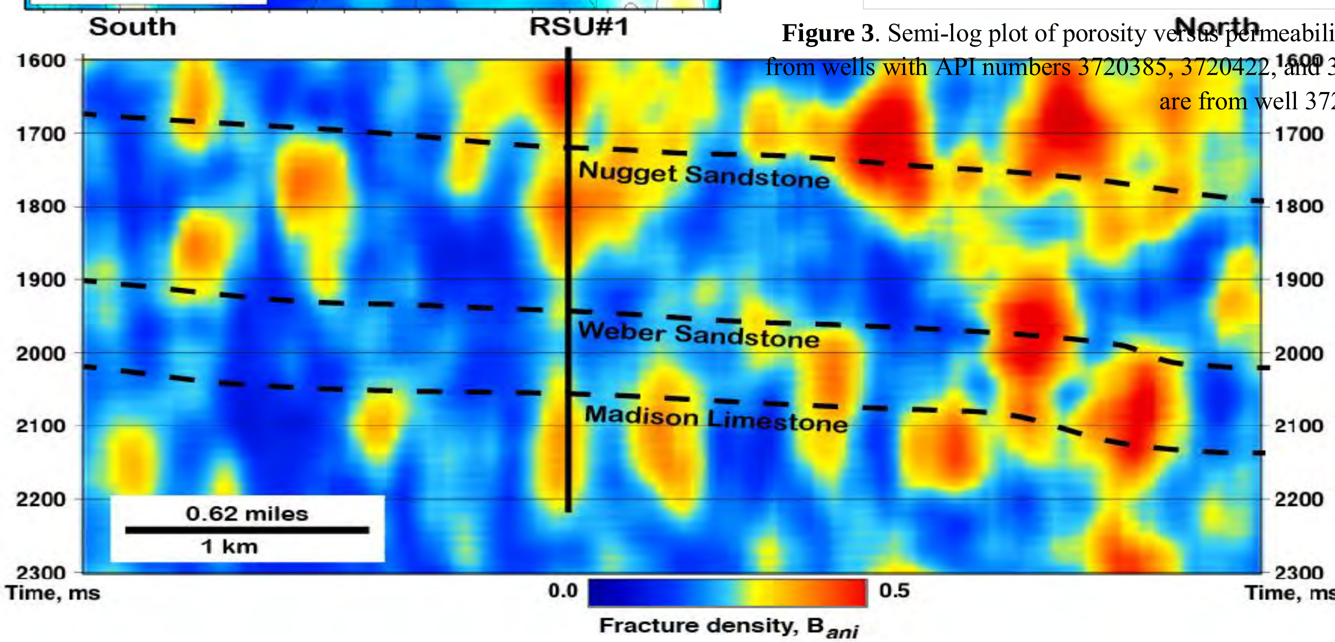
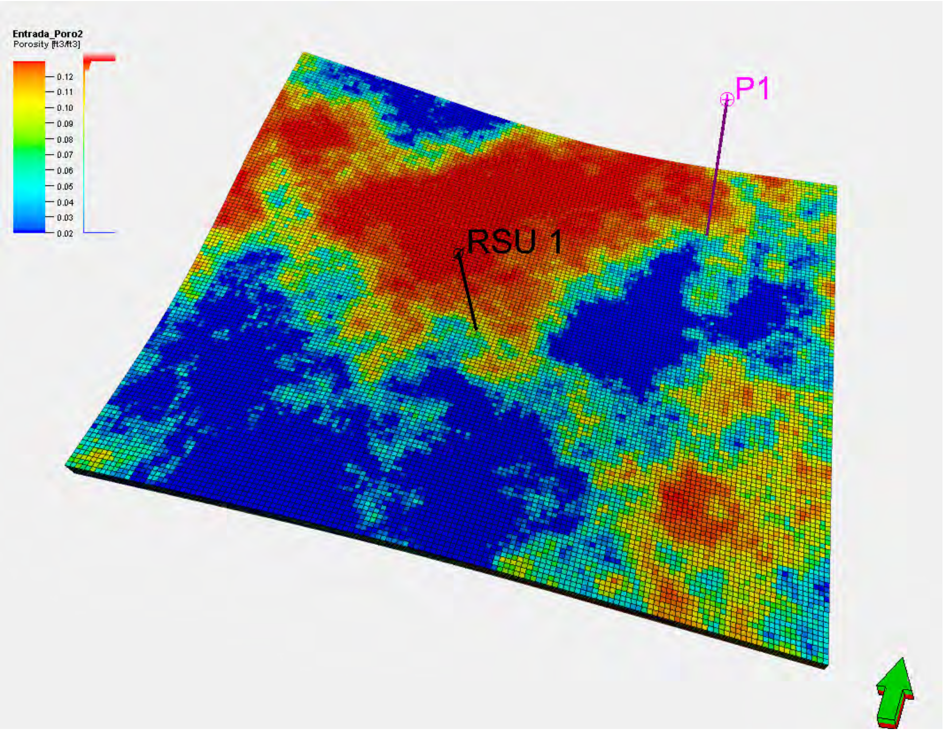


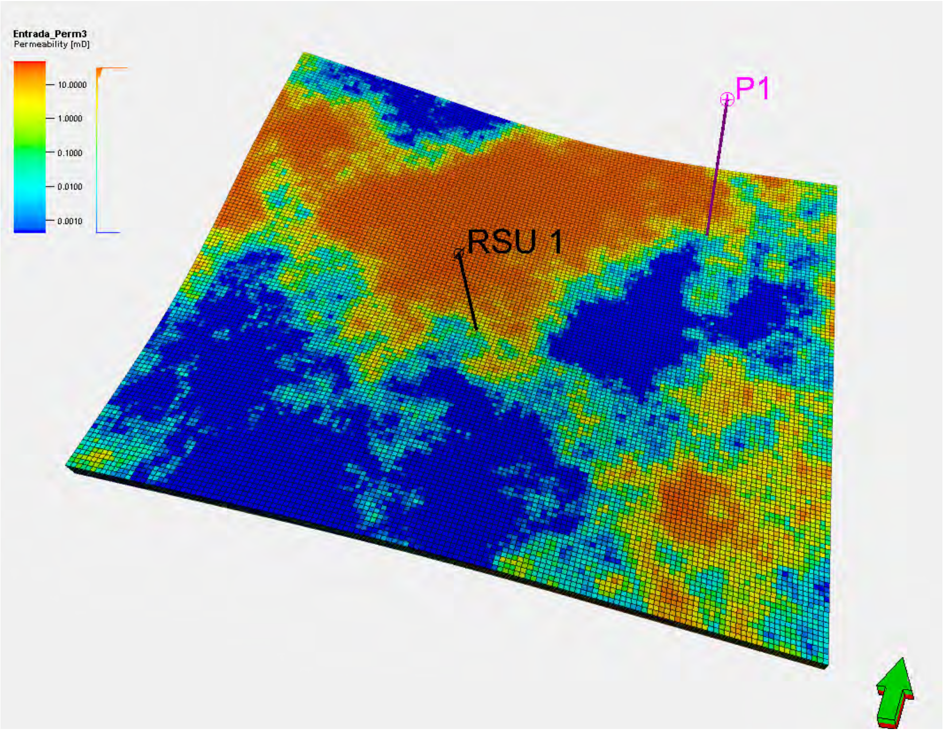
Figure 3. Semi-log plot of porosity versus permeability for the Nugget Sandstone. Published data (labeled "Le
from wells with API numbers 3720385, 3720422, and 3722344. Data collected from Phase 1 investigations (labe
are from well 3720422; data plotted are at 3570 psig.



Modeling and Simulations

Entrada Formation Properties





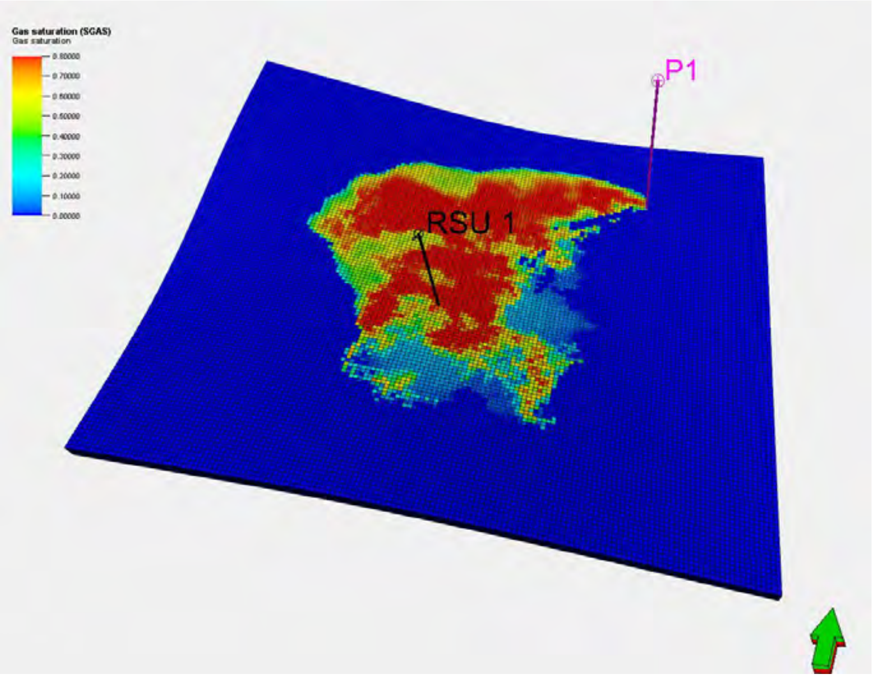
Porosity

Permeability

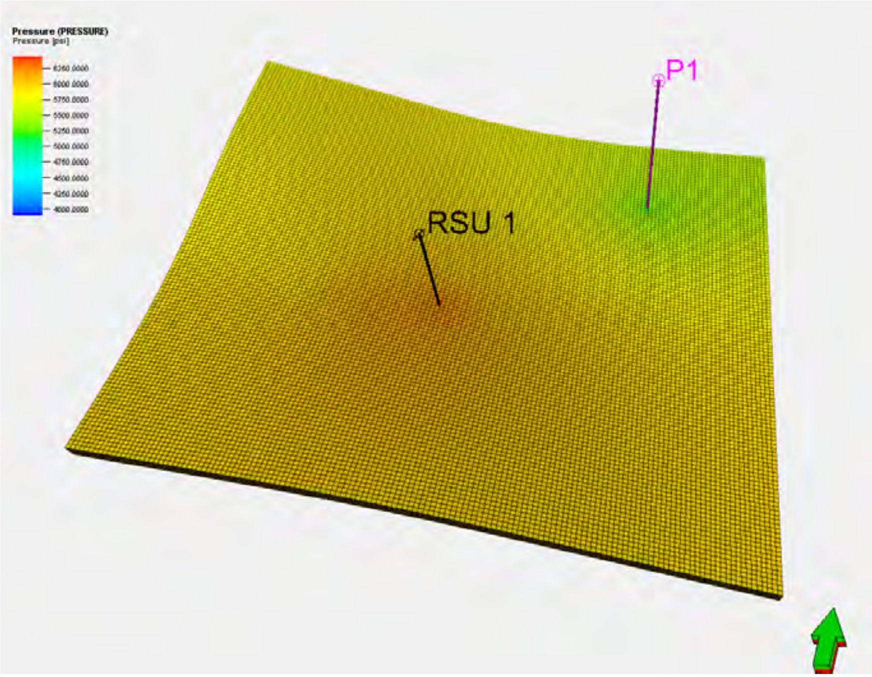
Modeling and Simulations

Entrada Sandstone Simulation Results

Pressure below 6000 psi, breakthrough (>1.6 MMT CO_2), >2.5 MMBBL of brine



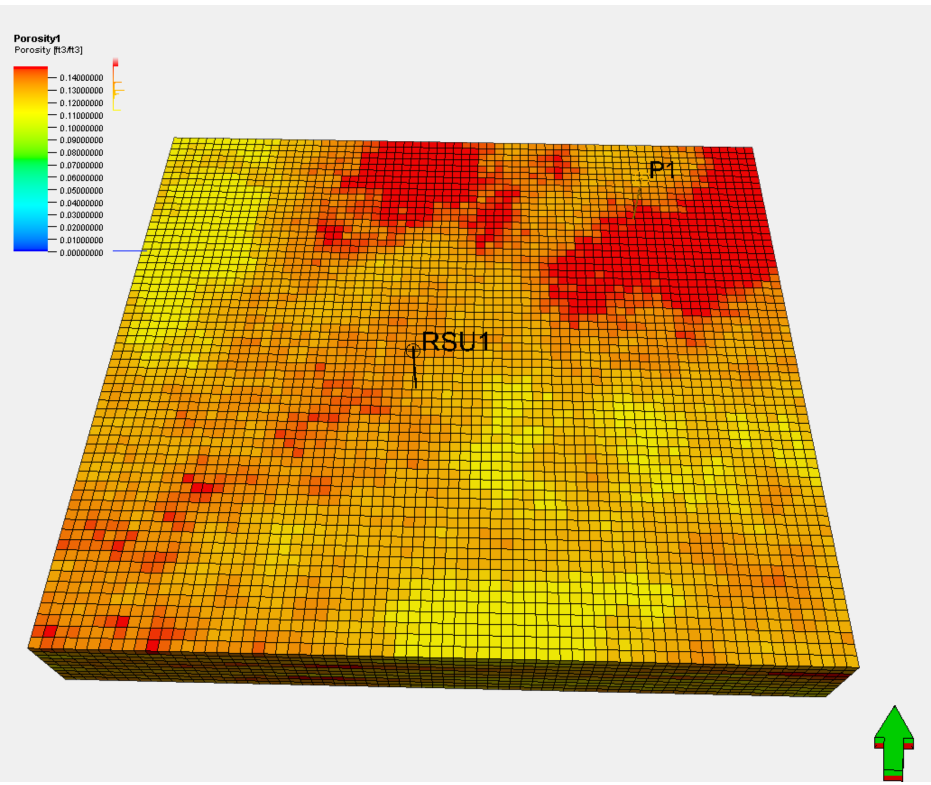
CO_2 Plume



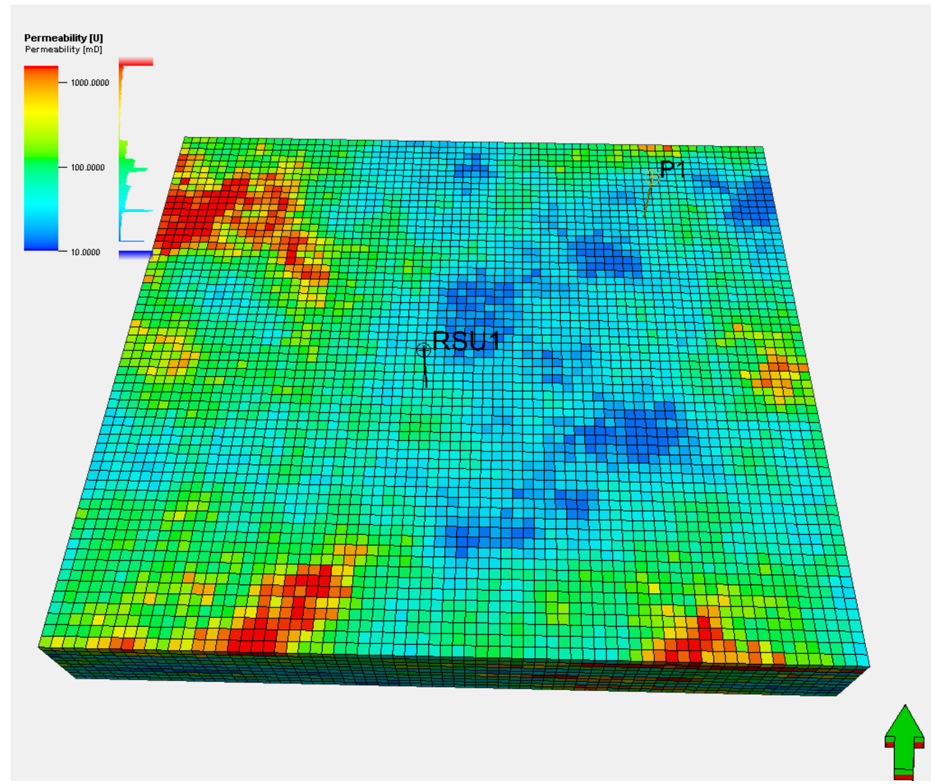
Pressure

Modeling and Simulations

Nugget Sandstone Properties



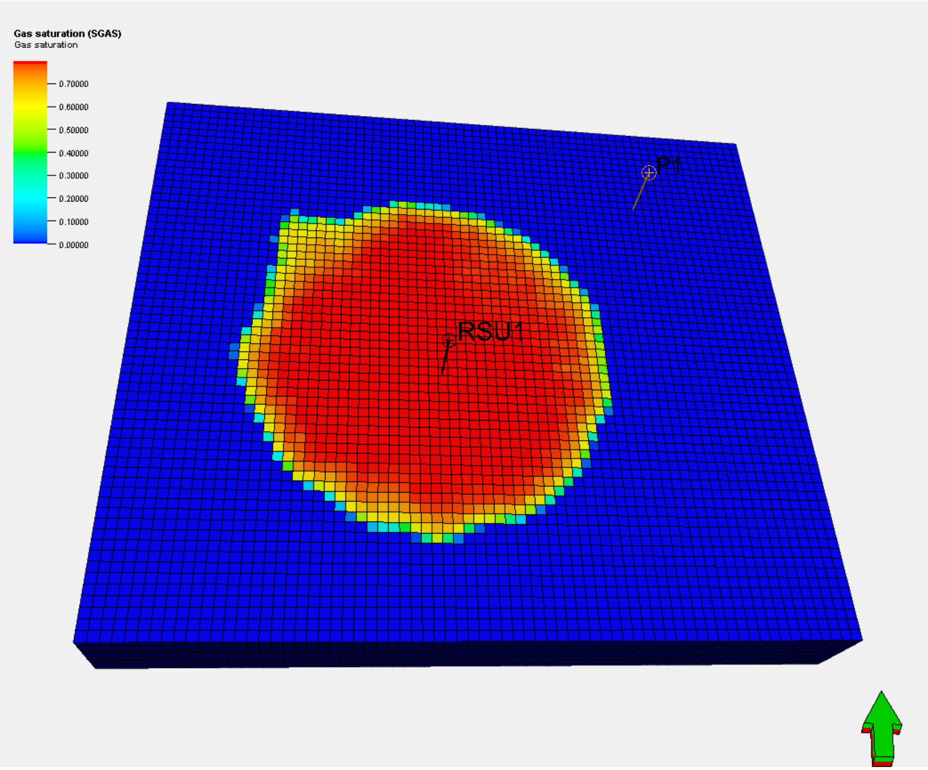
Porosity



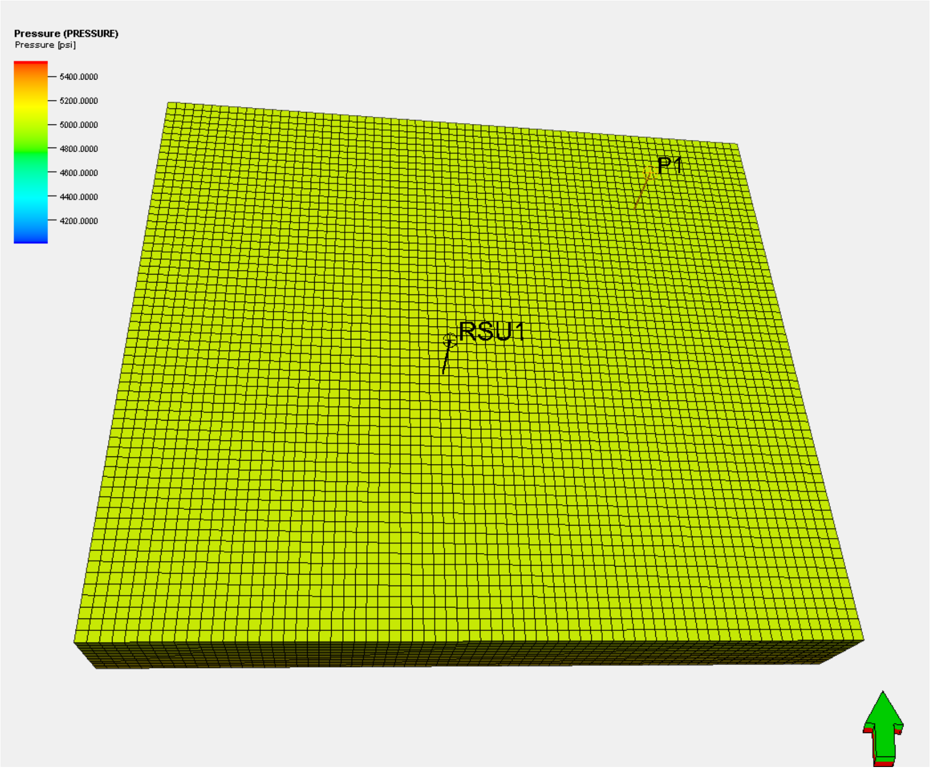
Permeability

Nugget Sandstone Simulation Results

Pressure below 5100 psi, no breakthrough (>15 MMT CO_2), >20 MMBBL of brine



CO_2 Plume



Pressure

Modeling and Simulations

Single Injection and Production Well Simulation Results

Formation	Model Area (mile^2)	CO_2 Plume Area (mile^2)	Total CO_2 injection (Mt/well/25year)
Entrada	14.7	5.10	3.75
Nugget	14.7	3.97	15
Weber	24.7	3.09	7.5
Madison	24.7	4.63	12.5
Total Storage			38.75

Modeling and Simulations

WLAT Results from Multisegmented Wellbore Model

Distance from Leaky Well to Injector

CO_2 Leakage

10m (33 Ft)

	Aquifer 1	Aquifer 2	Aquifer 3	Aquifer 4	Aquifer 5	Atmosphere	Total Leakage out of Reservoir
Total Leakage (Tonnes)	6043	2420	2250	46	0	0	10759
Total Percentage of Reservoir Leakage	0.12%	0.05%	0.04%	0.00%	0.00%	0.00%	0.21%

100 m (328 Ft)

	Aquifer 1	Aquifer 2	Aquifer 3	Aquifer 4	Aquifer 5	Atmosphere	Total Leakage out of Reservoir
Total Leakage (Tonnes)	4480	1550	1384	48	0	0	7461
Total Percentageof Reservoir Leakage	0.088%	0.030%	0.027%	0.001%	0%	0%	0.15%

500 m (1640 Ft)

	Aquifer 1	Aquifer 2	Aquifer 3	Aquifer 4	Aquifer 5	Atmosphere	Total Leakage out of Reservoir
Total Leakage (Tonnes)	3380	973	811	32	0	0	5195
Total Percentage of Reservoir Leakage	0.066%	0.019%	0.016%	0.001%	0%	0%	0.10%

1000 m (3280 Ft)

	Aquifer 1	Aquifer 2	Aquifer 3	Aquifer 4	Aquifer 5	Atmosphere	Total leakage out of Reservoir
Total Leakage (Tonne)	2912	738	577	21	0	0	4247
Total Percentage of Reservoir Leakage	0.06%	0.014%	0.011%	0.00041%	0%	0%	0.083%

Distance from Leaky well to Injector	Time for CO_2 breakthrough to Aquifer 1 (Day)
10m (33Ft)	0.001
100m (328 Ft)	0.1
500m (1640 Ft)	3
1000m (3280 Ft)	10

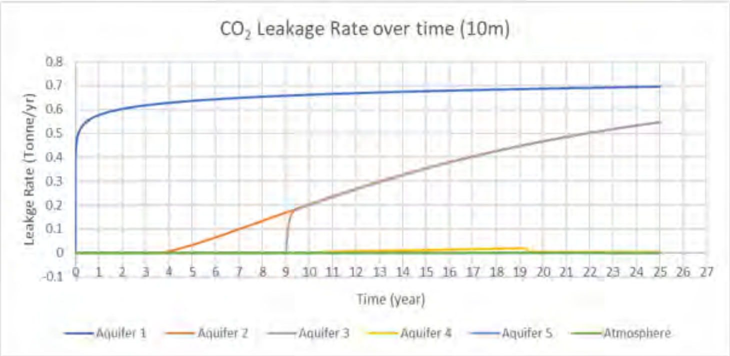
Time (year) it takes for CO2 leakage to begin

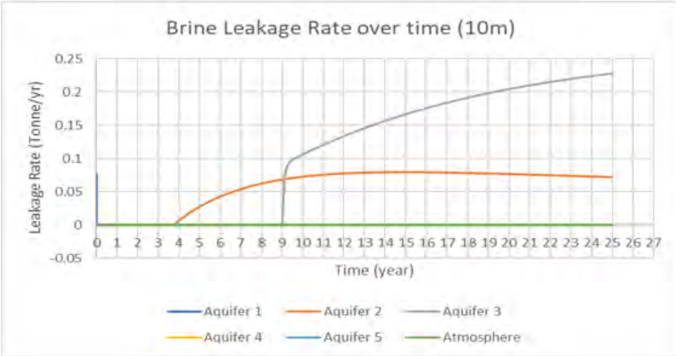
Distance From leaking well	Aquifer 2	Aquifer 3	Aquifer 4	Aquifer 5	Atmosphere
10 m (32 Ft)	3.7	9.0	10.3	Never	Never
100 m (328 Ft)	5.2	11.5	13	Never	Never
500 m (1,640 Ft)	6.8	14	15.7	Never	Never
1,000 m (3,280 Ft)	8	15.7	17.6	Never	Never

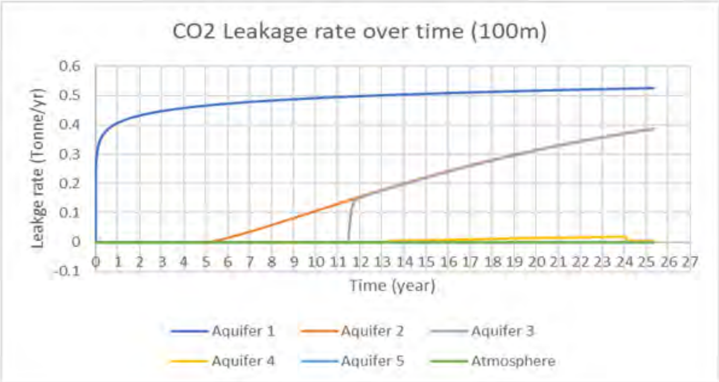
Nearly instantaneous breakthrough for all distances

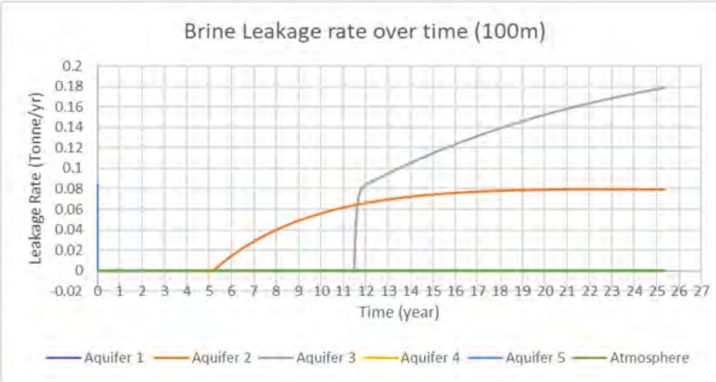
Modeling and Simulations

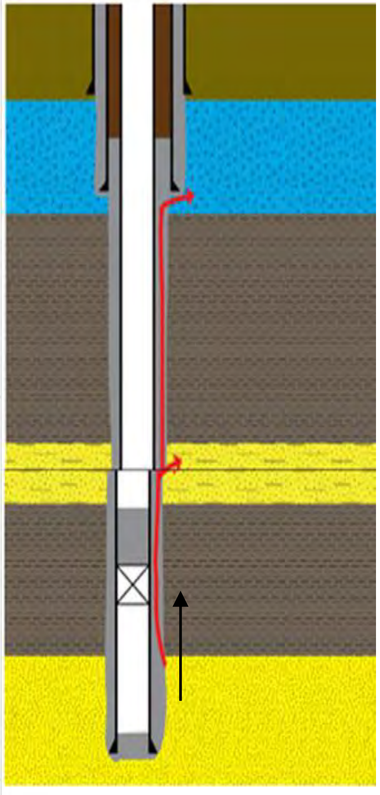
WLAT Results from Multisegmented Wellbore Model











Well Permeability along shale(m2)	10^-17, 10^-14, 10^-13, 10^-16, 10^-15, 10^-14
Well Permeability along shale(Darcy)	1.0E-5, 0.01, 1.01, 1E-4, 0.001, 0.01

Accomplishments to Date

- Established CCUS coordination team
- Complete outreach plan
- Complete environmental assessment
- Complete scenario assessment
- Complete economic analysis
  - Established techno-economic and unique business cases
- Complete regulatory/policy analysis
- Complete CO_2 source analysis assessment
- Complete CO_2 capture engineering assessment
- Complete geological property model
- Complete seismic attribute analysis
- Preliminary fluid injection simulations
- Preliminary site optimization plan
- Deployment of several NRAP tools
- 11 graduate students (law, economics, engineering, geology and geophysics)

Lessons Learned

- Excess CO_2 bolstered the business case, as did modeling low carbon markets
- Stacked storage is feasible, but not practical to use every reservoir
- Buoyancy could be an issue in the Nugget
- Defining heterogeneity in stacked systems needs to be a priority
- Pressure management, via co-produced formation fluid, will be necessary to meet target rates and volumes

Synergy Opportunities

- Other CarbonSAFE project team reservoir assessments
- Expanded business and regulatory collaborations
- Combining BEST and CarbonSAFE project objectives (produced water management)
- NRAP tool development and testing (ex: Los Alamos)
- Interoperability assessment with Dry Fork Station in Gillette, drawing upon existing CO_2 pipeline network and making use of Gillette-based attributes, such as the Integrated Test Center
- Regional injection well learning

Project Summary

- Potential business case due to excess CO_2, existing infrastructure, tax incentives and low carbon markets
- No identified regulatory impediments
- Proven capture technology could be utilized at JBPS
- Stacked storage would benefit project footprint, with a focus on two of the reservoirs (these two could provide CCUS archetypes, similar to the Mt. Simon)
- Pressure management will be necessary to optimize capacity, reduce risk, and lessen plume(s) size
- 50 MMT of storage is a feasible target adjacent the RSU

Appendix

Benefit to the DOE CCUS Program

- *Identify suitable saline aquifers, capable of sequestering 50 Mt (commercial-scale) of CO_2, adjacent to one of the largest coal-fired plants in the Rocky Mountain region*
- *Ensure storage permanence relative to seal/reservoir pairs*
- *Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness utilizing reservoir management techniques*

Additional Benefits

- Evaluation of the economics associated with coupling commercial-scale coal-based CCS with low-carbon energy sales
- Evaluation of the economics of coupling coal-sourced capture within existing EOR infrastructure
- Technical and economic evaluation of large-source capture and storage (~18Mt/year); 50 Mt before 25 years?

Project Overview

Goals and Objectives

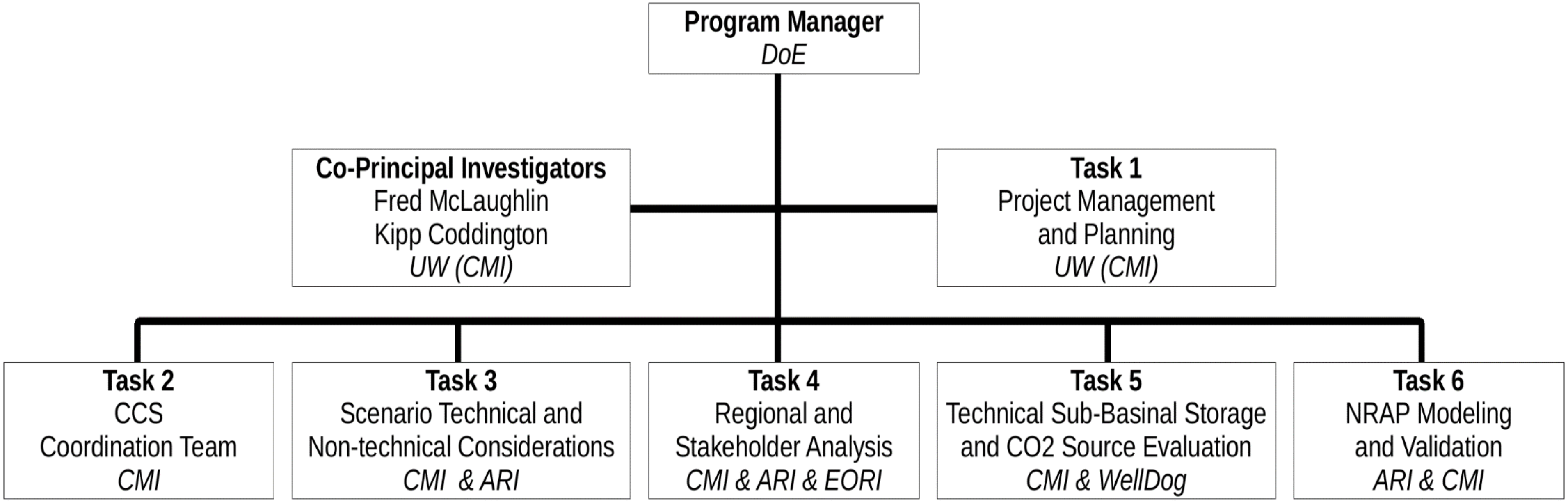
The objectives of this study involve a pre-feasibility assessment of an integrated carbon capture & storage (CCS) project (Project) at the Rock Springs Uplift (RSU), Wyoming. The RSU is a previously studied saline geologic storage complex with excellent sealing characteristics that has the potential to securely store well in excess of 50+ million metric tons of anthropogenic carbon dioxide (CO_2). The Project, which is realistic with respect to all relevant technical and economic factors, consists of the following initial scenario and related study objectives:

1. A CO_2 source assessment based on post-combustion capture of CO_2 from PacifiCorp's Jim Bridger Plant – which is located with the RSU study area, is the largest source of anthropogenic CO_2 in the State of Wyoming, is one of the largest CO_2 emitters in the Rocky Mountain region, and sells electricity into regional states such as California that have stringent restrictions on CO_2 emissions – as the preferred source.
2. Utilization of both the existing CO_2 pipeline network in the immediate vicinity of the RSU and the Wyoming Pipeline Corridor Initiative (WPCI), an ongoing effort by the State of Wyoming with the cooperation of the U.S. Department of the Interior's Bureau of Land Management (BLM) to connect via pipeline a broader array of CO_2 emitters and sinks within the state; and
3. The study, as part of a high-level sub-basinet evaluation, of additional storage reservoirs within the RSU beyond the two – the Madison and Weber formations – that were the subject of prior investigations.

An initial, fully capable CCS Coordination Team (CCT) is already in place, and the pre-feasibility assessment includes as an objective the potential expansion of the CCT to ensure the participation of all needed and impacted stakeholders. The CCT has a separate objective of further developing the preliminary implementation plan that already has been outlined for the Project's initial scenario. The preliminary implementation plan includes consideration of:

1. Additional CO_2 sources within the vicinity of the RSU and existing CO_2 pipeline network, including trona production facilities in the Greater Green River Basin; and
2. The use of CO_2 for enhanced oil recovery for economic purposes while still ensuring satisfaction of the Project's saline storage requirements.

Organization Chart



Team Members and Participants

University of Wyoming, EORI, KKR, ARI, Carbon GeoCycle/Welldog, Sargent & Lundy, Lindene Patton, and PacifiCorp

Gantt Chart

Timeline		Task Dependency						2017												2018					
Task	Description	1	2	3	4	5	6	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
1	**Project Management and Planning**																								
1.1	Project Management Plan							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
1.2	Reporting							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
1.3	Project Management							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
1.4	Data Management Plan							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
1.5	Collaborative Meetings							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
1.6	Kick-off Meeting							■																	
2	**CCS Coordination Team**																								
2.1	Internal Team Composition Assessment.	x						■	■																
2.2	Outreach to Potential CCT Members	x						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
2.3	Preparation of Project Background and Educational Materials.	x						■																	
2.4	Preparation of CCT Work Plan and Schedule.	x						■																	
3	**Scenario technical and non-technical considerations**																								
3.1	Source Factors Identification	x							■	■	■														
3.2	Transport Factors Identification	x							■	■	■														
3.3	Storage Factors Identification	x							■	■	■														
3.4	Competing Factors Assessment	x			x	x	x																■	■	■
3.5	Final Scenario Assessment	x			x	x	x																■	■	■
4	**Regional and Stakeholder Analysis**																								
4.1	Economic assessment	x		x						■	■	■	■	■	■	■	■								
4.2	Legal Assessment	x		x						■	■	■	■	■	■	■	■								
4.3	Environmental Assessment	x		x						■	■	■	■	■	■	■	■								
4.4	Community and Public Outreach/Assessment.	x	x	x							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
5	**Technical Sub-Basinal Storage and CO2 Source Evaluation**																								
5.1	CO2 Technical Evaluation	x		x						■	■	■	■	■	■	■	■								
5.2	Techno Economic Assessment	x		x						■	■	■	■	■	■	■	■								
5.3	Subsurface Description	x		x						■	■	■	■	■	■	■	■								
5.4	Hydrostratigraphy Description	x		x						■	■	■	■	■	■	■	■								
5.5	Geophysical Description	x		x						■	■	■	■	■	■	■	■								
5.6	Traditional Reservoir Modeling and Simulation	x		x												■	■	■	■	■	■	■	■		
5.7	Technical Risks Assessment	x		x												■	■	■	■	■	■	■	■		
5.8	3-D Visualization and Outreach	x	x	x	x							■	■	■	■	■	■	■	■	■	■	■	■	■	■
6	**NRAP Modeling, and Validation**																								
6.1	NRAP Modeling	x			x	x										■	■	■	■	■	■	■	■		
6.2	NRAP Comparison	x			x	x										■	■	■	■	■	■	■	■		

Bibliography

- Selected journal publications

  - Grana, D., Verma, S., Pafeng, J., Lang, X., Sharma, H., Wu, W., McLaughlin, F., Campbell, E., Ng, K., Alvarado, V. and Mallick, S., 2017. A rock physics and seismic reservoir characterization study of the Rock Springs Uplift, a carbon dioxide sequestration site in Southwestern Wyoming. *International Journal of Greenhouse Gas Control*, *63*, pp.296-309.
  - Mallick, S., Mukherjee, D., Shafer, L. and Campbell-Stone, E., 2017. Azimuthal anisotropy analysis of P-wave seismic data and estimation of the orientation of the in situ stress fields: An example from the Rock-Springs uplift, Wyoming, USA. *Geophysics*, *82*(2), pp.B63-B77.
  - Pafeng, J., Mallick, S. and Sharma, H., 2017. Prestack waveform inversion of three-dimensional seismic data—An example from the Rock Springs Uplift, Wyoming, USA3D prestack waveform inversion. *Geophysics*, *82*(1), pp.B1-B12.
  - Righetti, T.K., 2017. Correlative Rights and Limited Common Property in the Pore Space: A Response to the Challenge of Subsurface Trespass in Carbon Capture and Sequestration.
  - Righetti, T.K., 2017. Siting Carbon Dioxide Pipelines. *ONE J*, *3*, p.907.
  - Sharma, H.S., Mallick, S., Verma, S. and Campbell-Stone, E., 2018. AZIMUTHAL ANISOTROPY ANALYSIS OF MULTIAZIMUTH P-WAVE SEISMIC DATA–AN EXAMPLE FROM THE ROCK SPRINGS UPLIFT, WYOMING, USA. *Interpretation*, *6*(3), pp.1-53.