EERC | UND UNIVERSITY OF NORTH DAKOTA

Critical Challenges. Practical Solutions.

Energy & Environmental Research Center (EERC)

DEVELOPING AND VALIDATING PRESSURE MANAGEMENT AND PLUME CONTROL STRATEGIES IN THE WILLISTON BASIN THROUGH A BRINE EXTRACTION AND STORAGE TEST (BEST) (FE0026160)

Carbon Management and Oil and Gas Research Project Review Meeting
August 31, 2023

John Hamling
Assistant Vice President
for Strategic Partnerships

ACTIVE RESERVOIR MANAGEMENT

Active Reservoir Management

- Mitigate pressure interference between neighboring carbon capture and storage (CCS) projects.
- Improve storage efficiency/increase capacity of a permitted CO_2 storage site.
- Optimize geologic storage footprint and pore space.
- Reduce stress on sealing formation.
- Geosteer injected fluids (injection and/or extraction of brine).
- Divert pressure from potential leakage pathways.
- Improve injectivity, capacity, and storage efficiency.
- Reduce area of review (AOR).
- Accelerate pressure dissipation after injection.

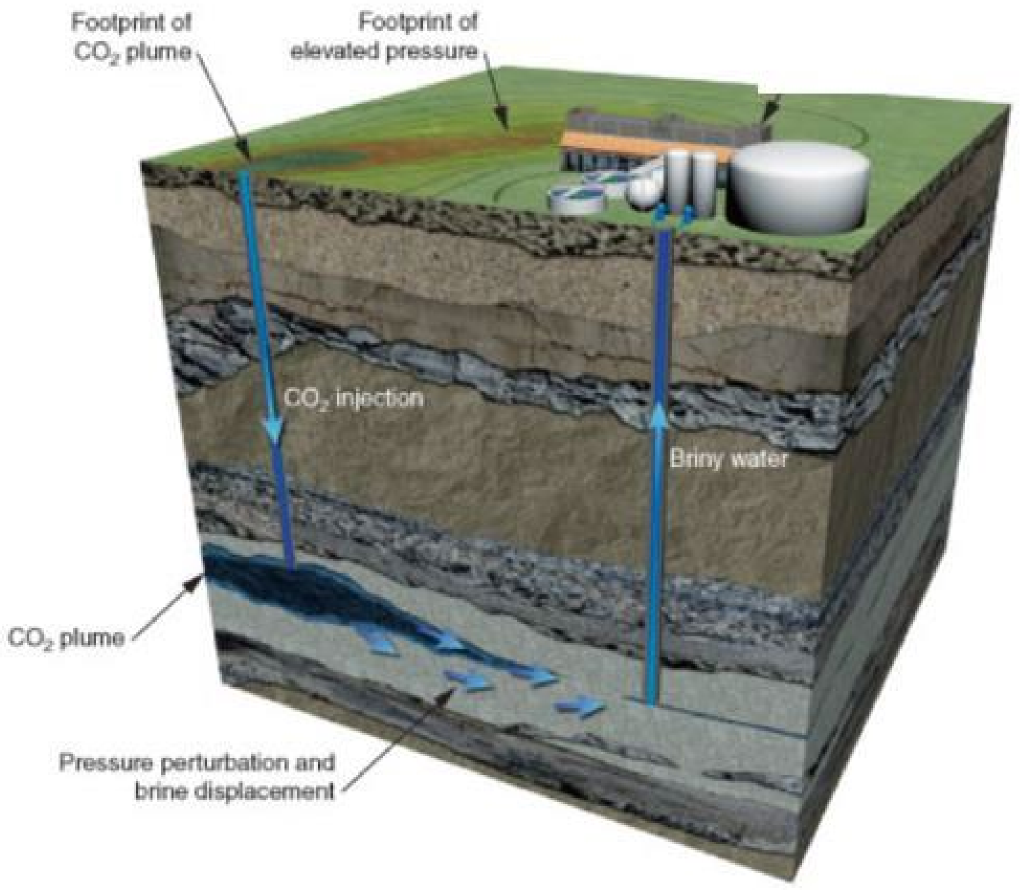


Illustration modified from Lawrence Livermore National Laboratory https://str.llnl.gov/Dec10/aines.html

Brine Treatment

- Alternative source of water.
- Reduced disposal volumes.
- Salable products for beneficial use.

PROGRAM OVERVIEW

Objectives:

- Validate efficacy of brine extraction as a means of active reservoir management (ARM) to enable geologic CO_2 storage through field testing and calibrated modeling.
- Implement and operate a brine treatment technology development and test facility to enable development of brine treatment technologies capable of treating high total dissolved solids (TDS) brines associated with geologic CO_2 storage formations.

Project Details:

- Phase II project: $22,573,604
  - DOE share: $18,103,044
  - Cost share: $4,470,560
- Period of performance: July 2016 – May 2024

PARTNERS

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

EERC

SELECT

CMG

slb

MAJOR CONTRACTORS

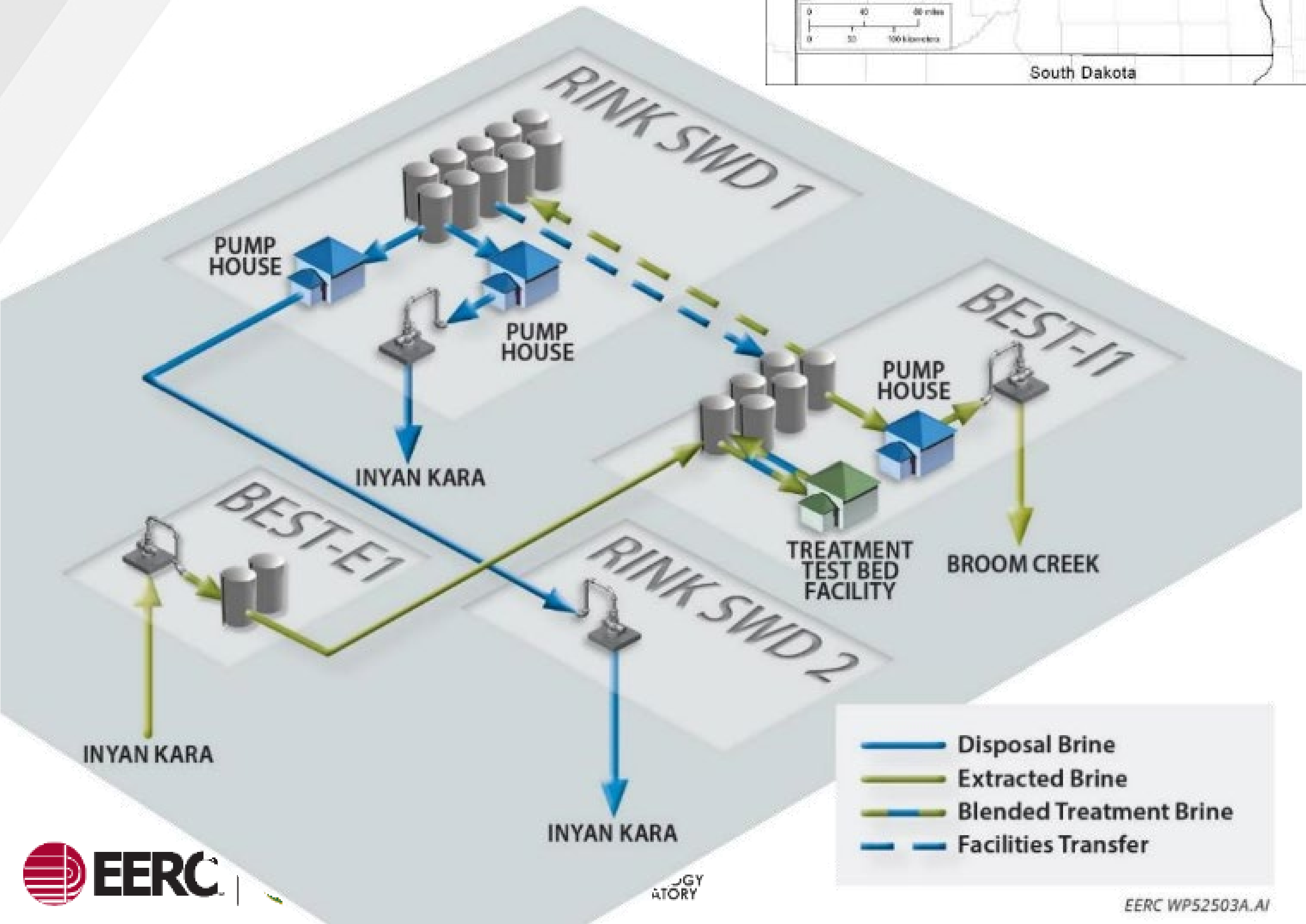
AE2S CONSTRUCTION

AE2S INDUSTRIAL

HAM'S WELL SERVICE WESTHOPE, ND

This material is based on work supported by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) under Award No. DE-FE0026160.

THE SITE



EERC

ACCOMPLISHMENTS

Designed and Implemented ARM Field Test (COMPLETE)

- Installed brine extraction well proximal to two saltwater injection wells.
- Installed deep injection well to reinject extracted water (proxy for ARM at a CCS site).
- Acquired reservoir and well data over short- and long-duration brine injection/extraction tests.
- Confirmed that a measurable pressure and injection response was achieved using brine extraction.

Simulation and Modeling (COMPLETE)

- Calibrated and validated ARM proxy models by integrating monitoring and operational data.
- Evaluated efficacy of ARM strategies for varying operating and deployment scenarios relevant to geologic CO_2 storage.

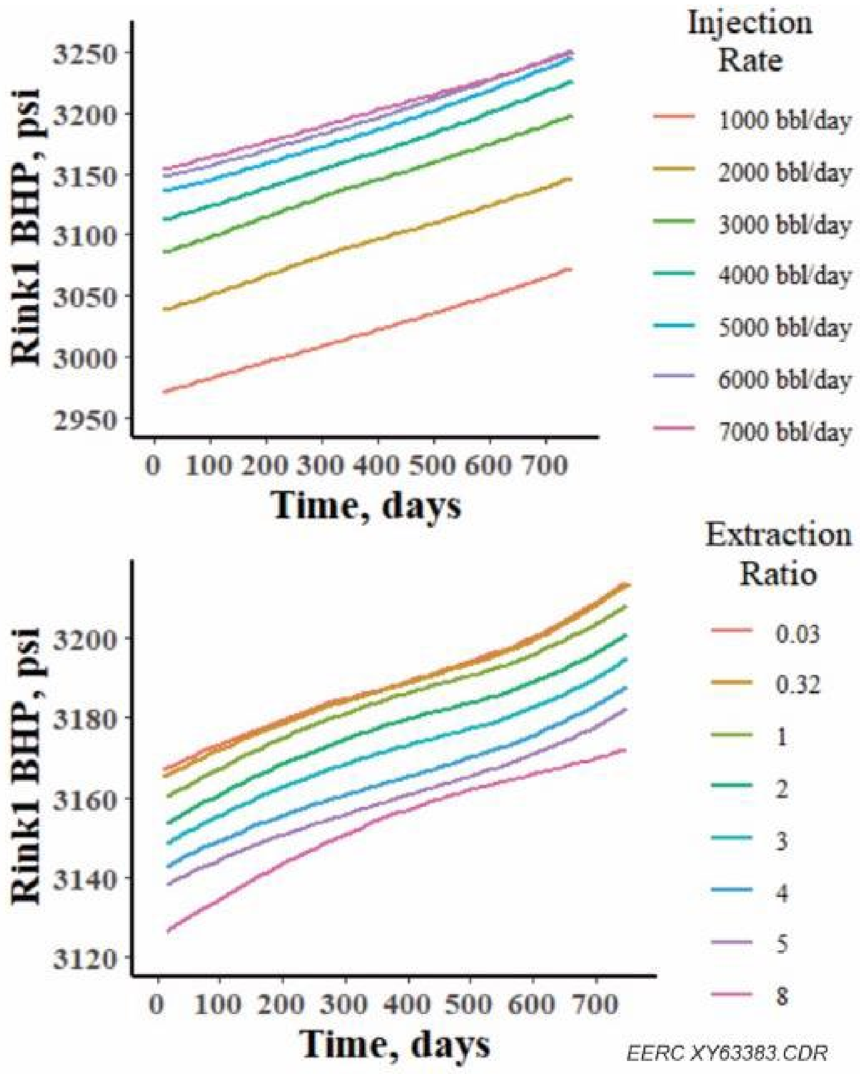
Machine Learning (ML) Analysis (COMPLETE)

- Developed a ML model to simulate reservoir pressure relative to injection and extraction rates.
- Applied the ML model to predict reservoir pressure at various scenarios of operation.
- Validated results against field data.

DEMONSTRATED BRINE EXTRACTION CAN POSITIVELY INFLUENCE INJECTION PERFORMANCE

- Extensive data processing
  - ML methods employed
  - Identified related variables and trends during active and inactive periods.
  - Addressed and conditioned noisy, variable, and imperfect data (commercial saltwater disposal [SWD] site)

- Effects of extraction
  - Influence injection well bottomhole pressure (BHP)
    - ♦ Lower operating pressure
    - ♦ Increased rate
  - Reduced rate of pressure buildup



Time series of the partial dependence effects of the injection and production on Rink1 BHPs.

CCS ARM PERFORMANCE

MODEL SCENARIOS

- History-matched model covering 36 mi^2 was used to test initial CO_2 injection scenarios to evaluate how production wells can increase total storage capacity of CO_2 through ARM.
  - These evaluations showed up to ~20% increase in storage.
- Expanded 900-mi^2 model developed to investigate application to large injection scenarios (up to 10 MMt/yr of CO_2) and associated ARM strategies.
  - Maintain geologic heterogeneity and history match.

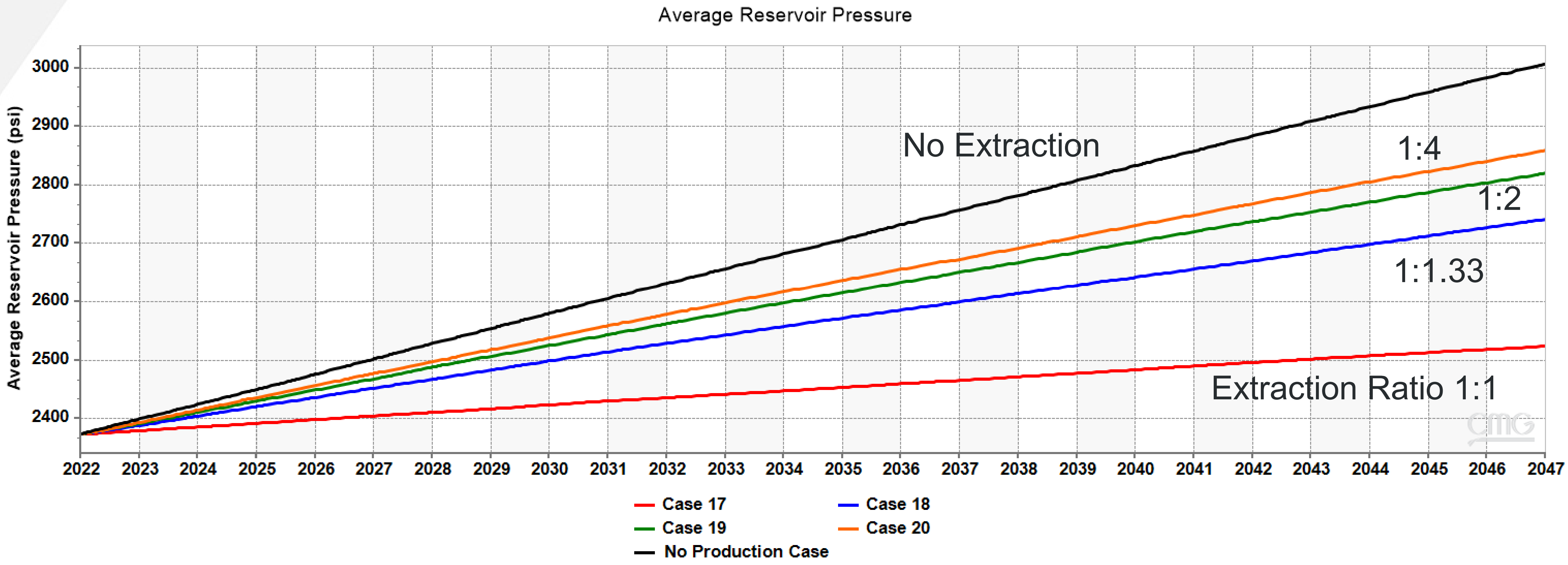
MODELED CCS ARM PERFORMANCE

Example

- History-matched model
- Injection rate equivalent of 1 MMt/yr.
- Extraction ratios (volume extracted to volume injected) of 1:1, 3:4, 1:2, and 1:4.
- Simulated two injection wells with one extraction well.
  - Offset distance of extraction well for half-mile increments (0.5 miles to 2.5 miles).
  - Extraction well shuts in when breakthrough is observed.

MODELED CCS ARM PERFORMANCE

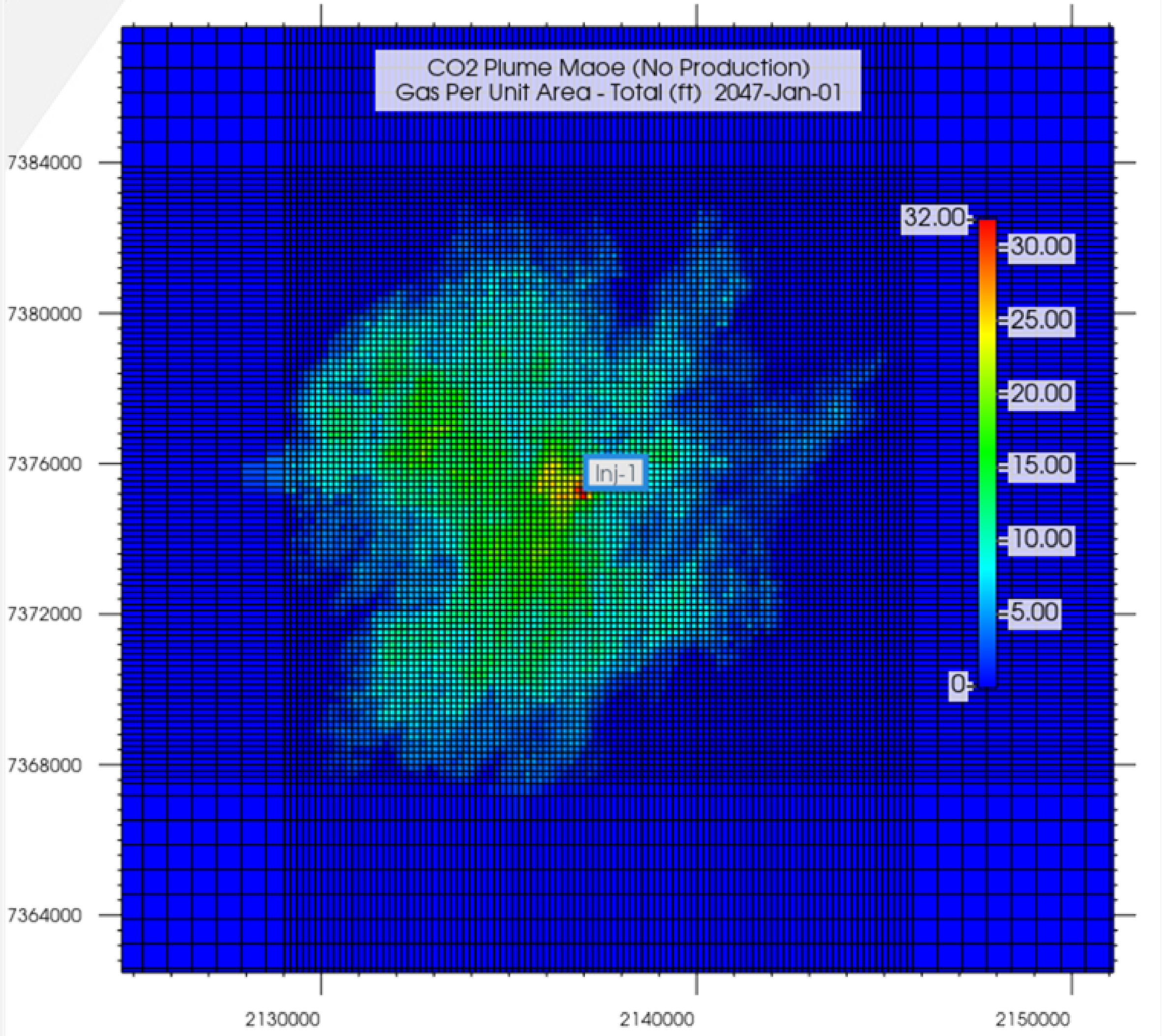
Example

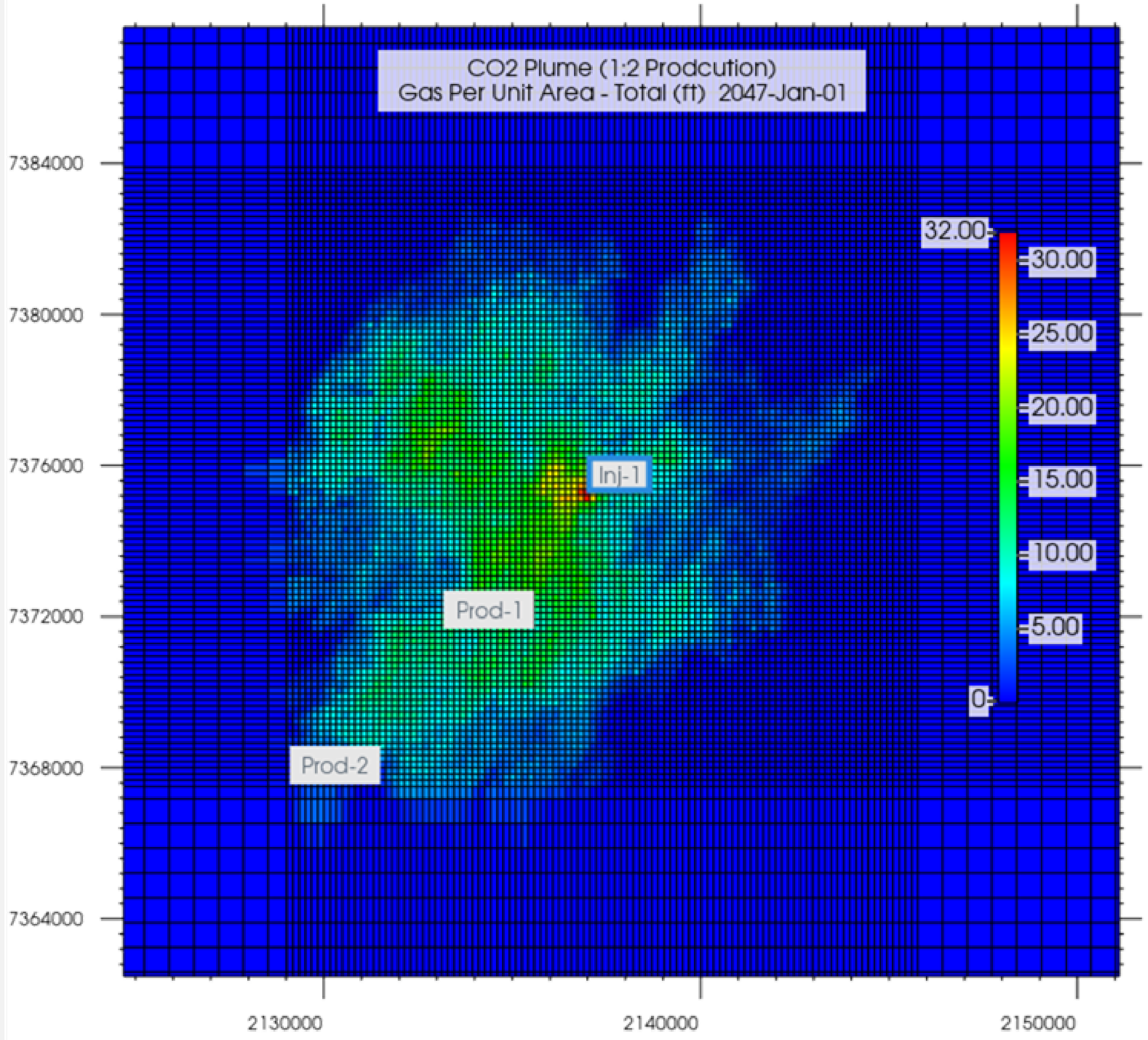


- Up to 500-psi decrease in average reservoir pressure and 20% increase in storage.

MODELED CCS ARM PERFORMANCE

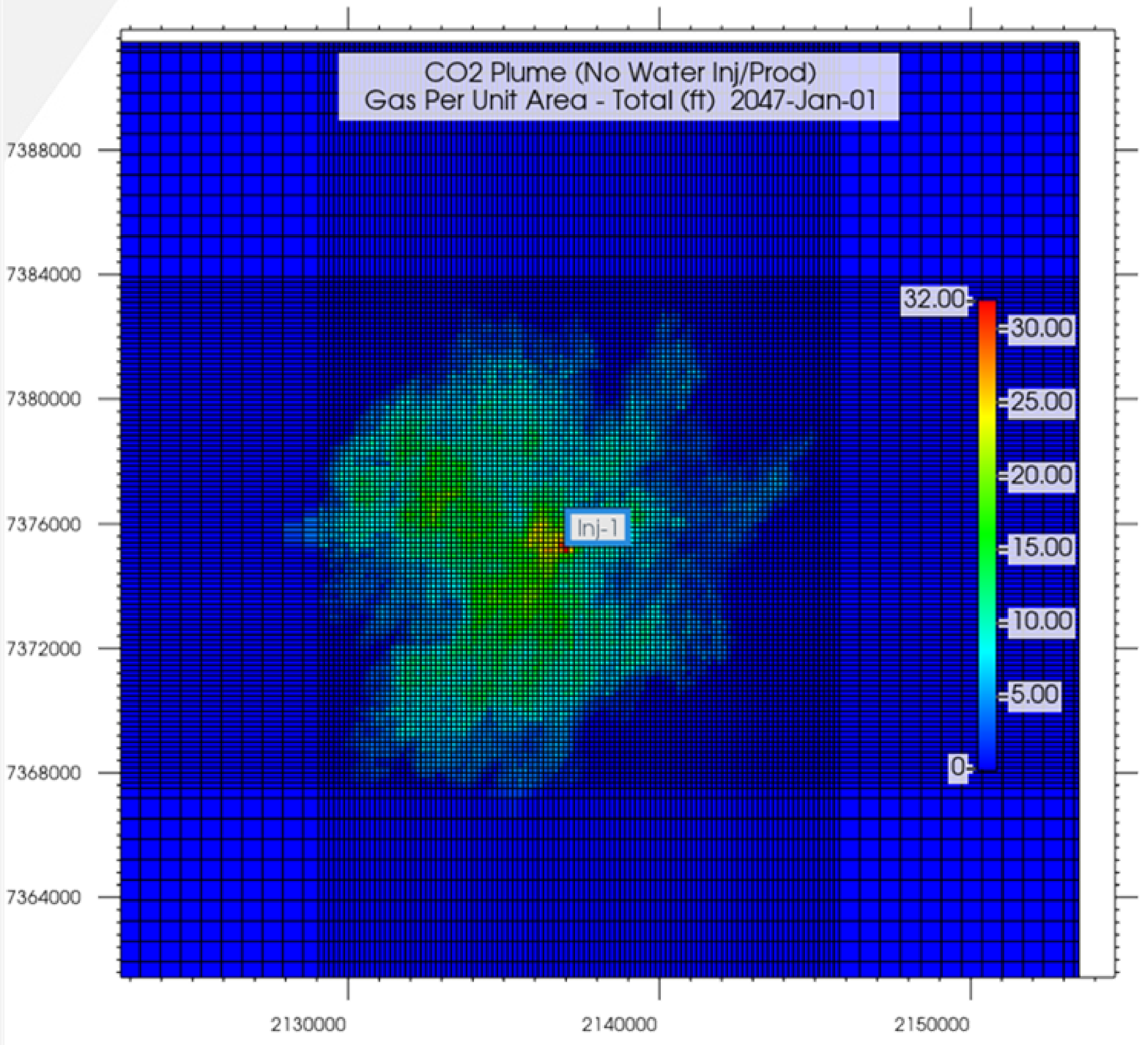
EXAMPLE GEOSTEERING – TWO WELLS, PROGRESSIVE

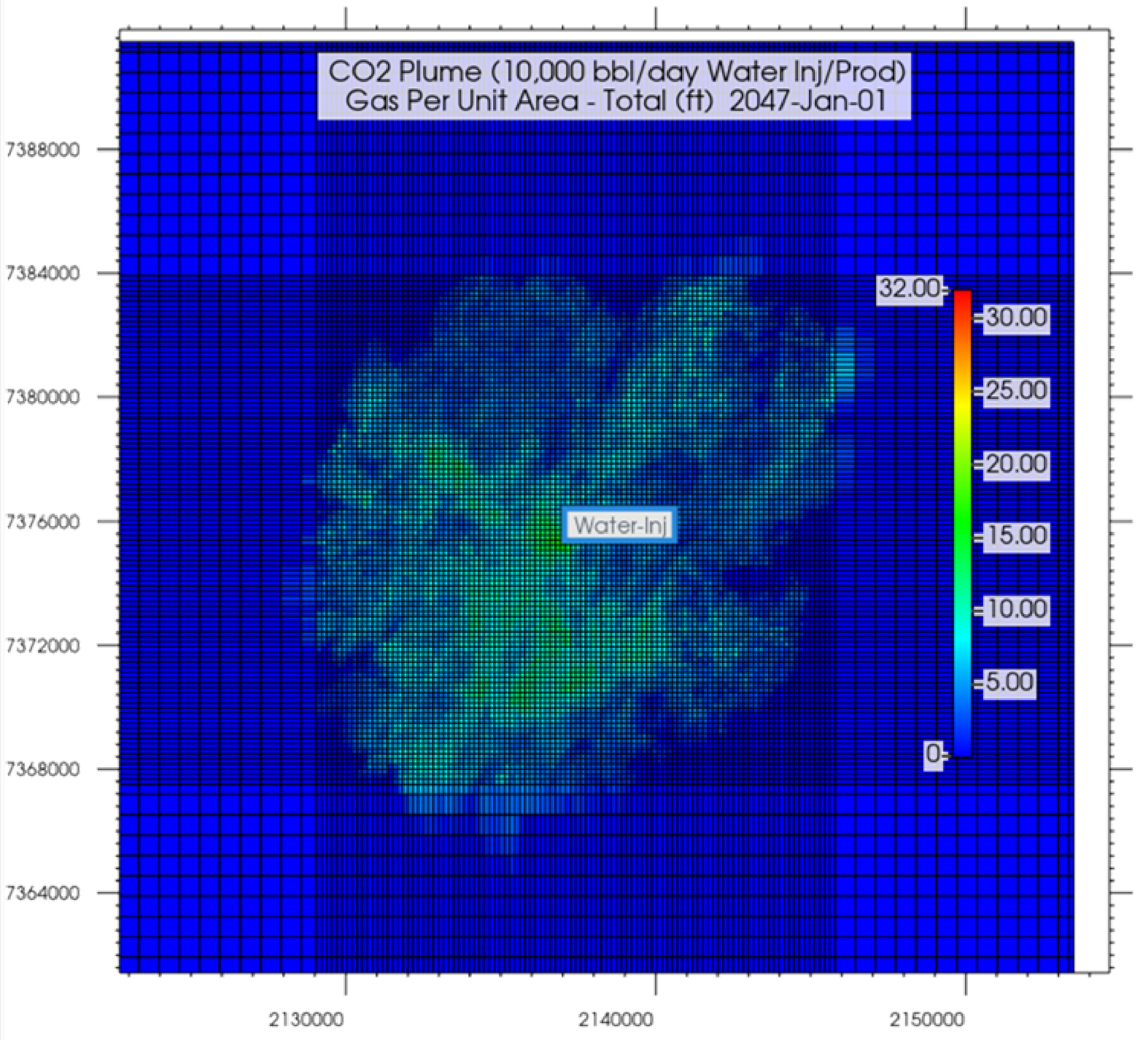




MODELED CCS ARM PERFORMANCE

EXAMPLE – WATER INJECTION ABOVE CO_2

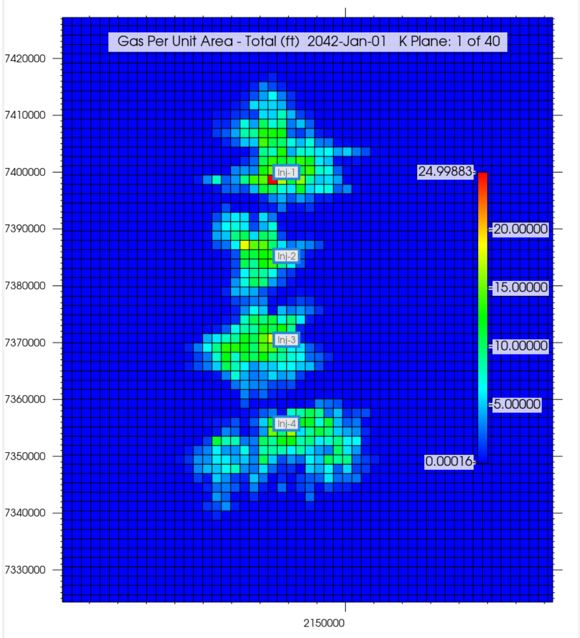




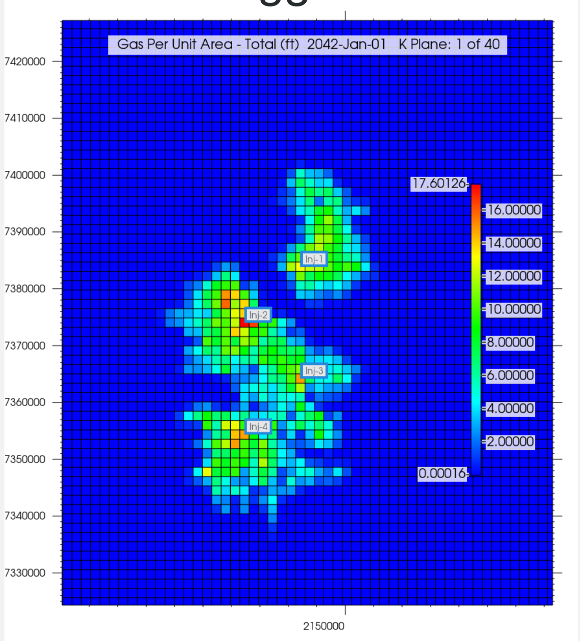
MODELED CCS ARM PERFORMANCE

How does well placement impact injection and storage performance?

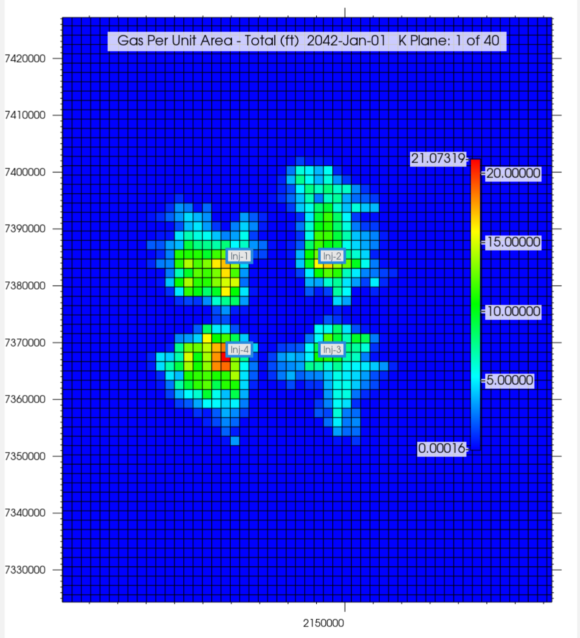
Linear



Staggered



Square



Well Pattern	Well Separation (miles)	Cumulative CO_2 Injected (MMt)	% Increase
Linear	3	149,759,792	5.5
Staggered	3	140,052,032	–1.3
Square	3	141,934,768	–

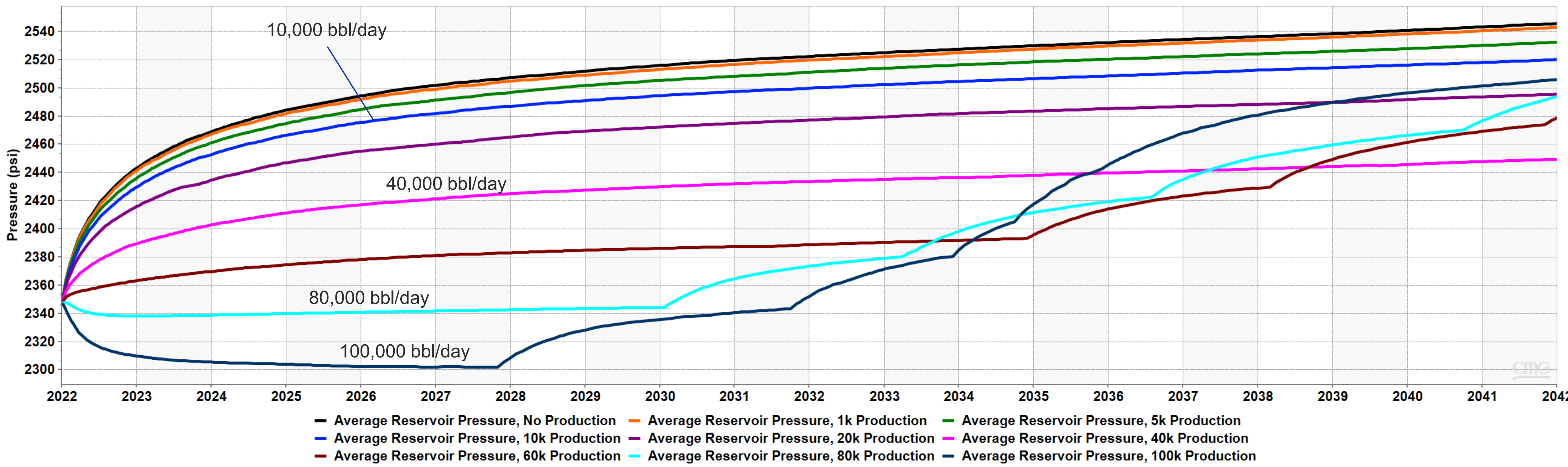
Linear: Less well interference and increased total storage

Staggered: More interference and decrease in total storage but a higher storage efficiency

Square (base case): Modest interference.

MODELED CCS ARM PERFORMANCE

How much extraction is needed to mitigate reservoir pressurization?



- Going beyond 80K, in this example, can improve pressure reduction but leads to earlier well shut-in
- Chosen rate dependent upon pressurization challenge faced by the operator

LESSONS LEARNED

- Proportionally larger volumes of water extraction are likely required to offset large CO_2 injection volumes to achieve a similar impact.
  - Performance does not proportionally scale to larger project areas and rates (other reservoir physics come into play).

- ARM is less effective at extraction ratios less than 1:1.
  - Lower extraction rations are perhaps more applicable at smaller scales and/or for applications seeking to influence localized impacts.

LESSONS LEARNED

- Extraction well placement determines effectiveness and the usable life span.
  - Too close and breakthrough occurs quickly
  - Too far and the impact is minimal

- ARM is particularly sensitive to reservoir permeability distribution and heterogeneity.

- Optimizing well placement, well patterns, extraction rate, and economics will be important.

- Effective CO_2 plume and pressure management demands a **highly nuanced understanding of the reservoir's heterogeneity** as well as a sophisticated approach to well placement and production management.
  - Requires a willingness to embrace dynamic, site-specific strategies that account for the unique complexities of each subsurface reservoir.

North Dakota Brine Treatment Facility – Watford City, North Dakota

ACCOMPLISHMENTS TO DATE

- Successfully conducted demonstrations evaluating four different pilot-scale technologies.
- Limited technologies are targeting high TDS brines; however, demonstrations of innovative approaches are critical for technology scale-up and development.
- Economics may be enhanced through collaborative approaches, such as coupled resource recovery from concentrated brines.

Technologies Tested

- **Mechanical Vapor Recompression**
  - Achieved brine concentration of 40%–60% and produced near-drinking-water-standard water.
  - Performance data were used as a baseline for evaluation of competing innovative technologies.

NETL Laboratories

- **Air Gap Membrane Distillation**
  - Achieved >99% salt rejection with the membrane, and tests were conducted under 30% and 50% clean water recovery at 1-gpm brine feed rates.

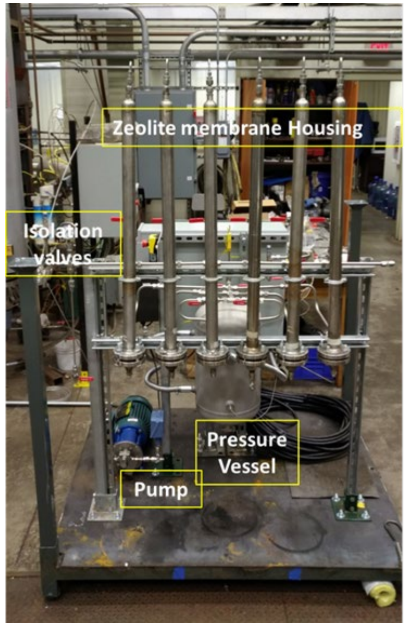
University of Pittsburgh

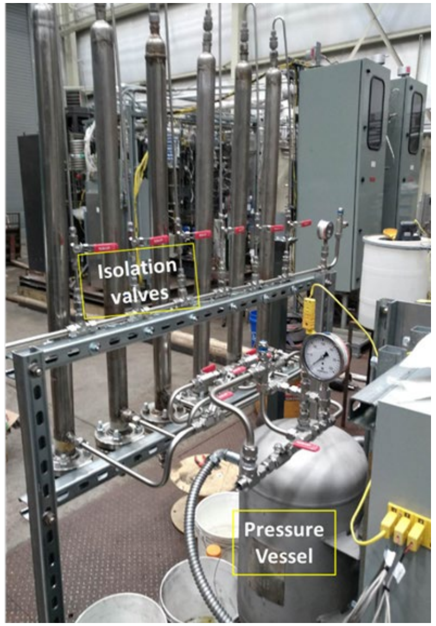
Technologies Tested, Cont.

- **Supercritical Water Desalination**
  - Achieved clean water recovery of 30% and 50% at each inlet salinity tested.
  - Crucial engineering insight was gained on inlet chemistry impacts of undesired precipitation on particulate filters at high pH conditions.


Ohio University

- **Zeolite Membrane Dewatering**
  - Laboratory-scale testing achieved 30% water recovery using 180,000 mg/L TDS brines.
  - Knowledge gained from field testing was key to understanding engineering issues related to technology scale-up.





University of Kentucky

Synergistic Demonstration Activities

Near-Future Plans

- Supporting NETL to conduct a "treatment train" approach technology demonstration for treating high TDS brines and develop database of brine chemistry at various stages of treatment.
  - Multiple technologies
    - ♦ Reverse osmosis
    - ♦ Membrane distillation
    - ♦ Mechanical vapor recompression
  - Multiple brines from across United States
    - ♦ DJ Basin
    - ♦ Eagle Ford Basin
    - ♦ Permian Basin
  - Multiple partner approach
    - ♦ NETL/Leidos
    - ♦ University of Pittsburgh
    - ♦ Colorado School of Mines
    - ♦ EERC BEST Facility

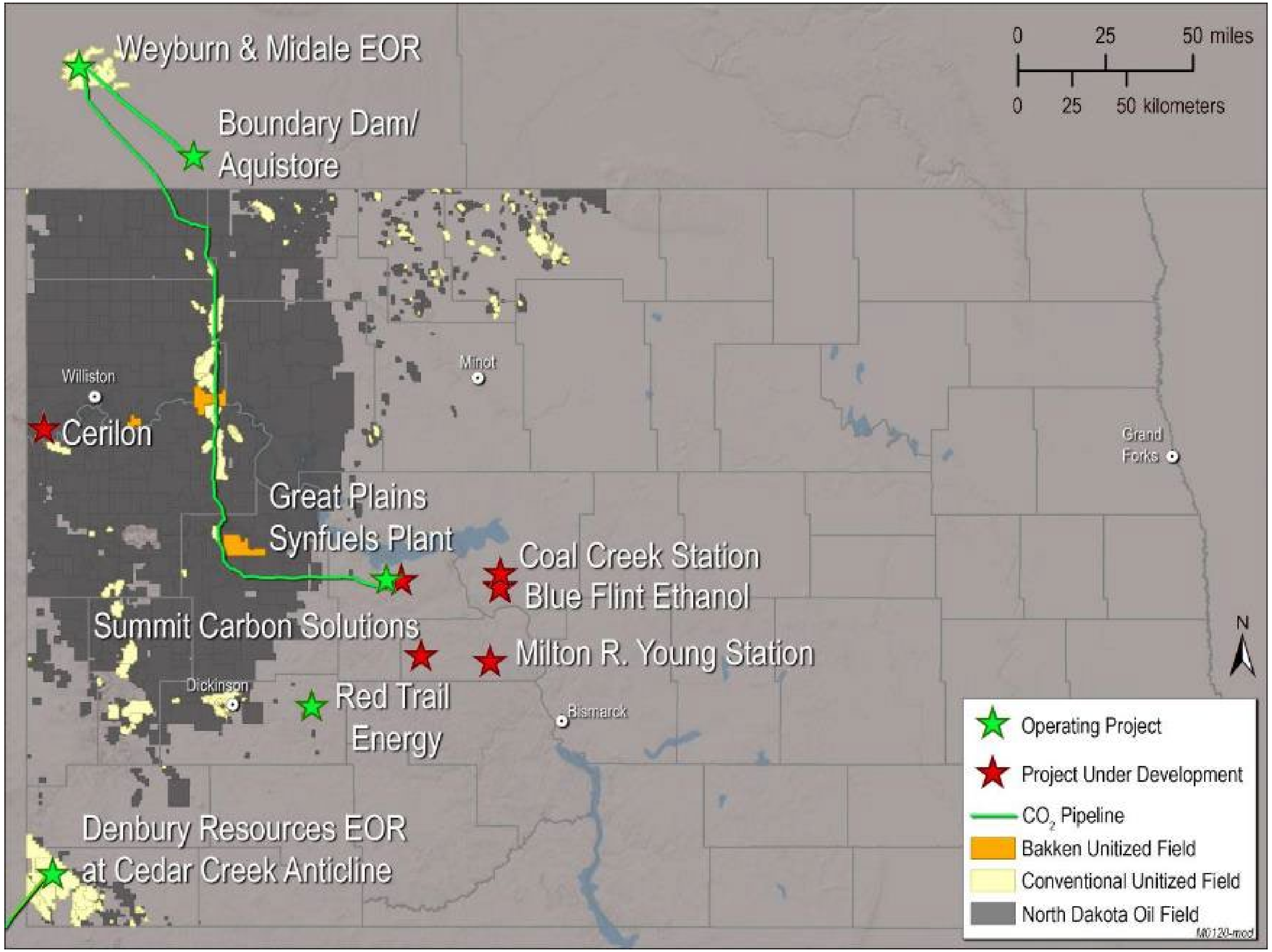
Possible Follow-On

- The EERC hopes to facilitate the continued operation of the BEST facility as a unique national demonstration location with opportunities to evaluate innovative approaches to water/brine treatment and carbon management and storage practices.
- Possible activities include:
  - Carbonated brine injection approaches
    - ♦ Commingled brine/CO_2 injection evaluations
  - Carbon mineralization process using CO_2-infused extracted brines
    - ♦ Semplastics, Inc.
    - ♦ Carbon sequestration coupled with resource recovery and reduced injection disposal
  - Evaluation of coupled technologies for resource recovery
    - ♦ Critical mineral extraction
    - ♦ HCl and NaOH production

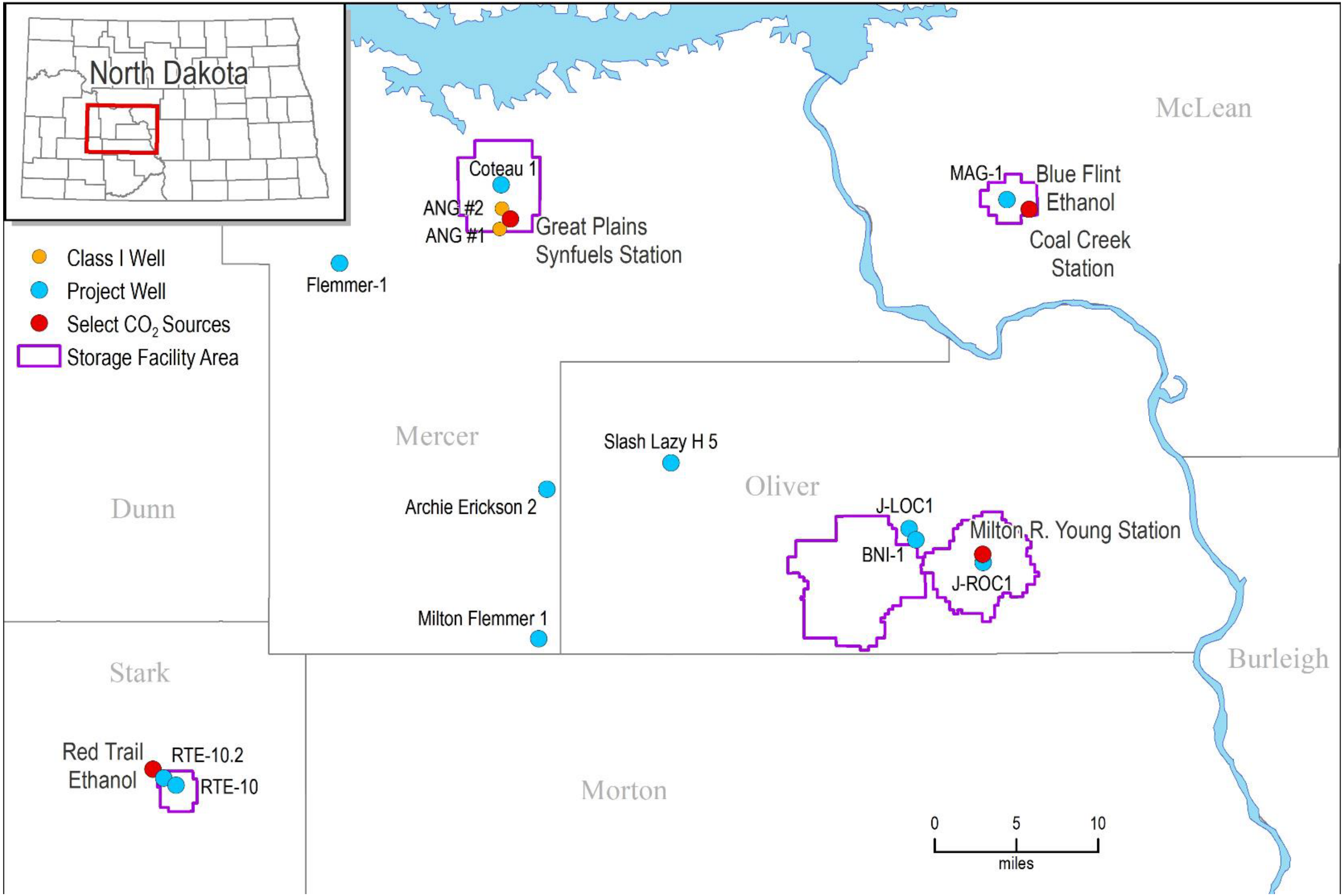
North Dakota CCUS Activity

Approved permits:
- Red Trail Energy
- Minnkota – Milton R. Young Station (two permits)
- Great Plains Synfuels Plant
- Blue Flint Ethanol

Pending permits:
- DCC West Project LLC



North Dakota has permitted over 100,000,000 metric tons of CO_2 storage.



North Dakota
McLean
Mercer
Oliver
Dunn
Stark
Morton
Burleigh
Class I Well
Project Well
Select CO_2 Sources
Storage Facility Area
Coteau 1
ANG #2
ANG #1
Great Plains Synfuels Station
Flemmer-1
MAG-1
Blue Flint Ethanol
Coal Creek Station
Slash Lazy H 5
Archie Erickson 2
J-LOC1
BNI-1
Milton R. Young Station
J-ROC1
Milton Flemmer 1
Red Trail Ethanol
RTE-10.2
RTE-10
0
5
10
miles

ACTIVE RESERVOIR MANAGEMENT

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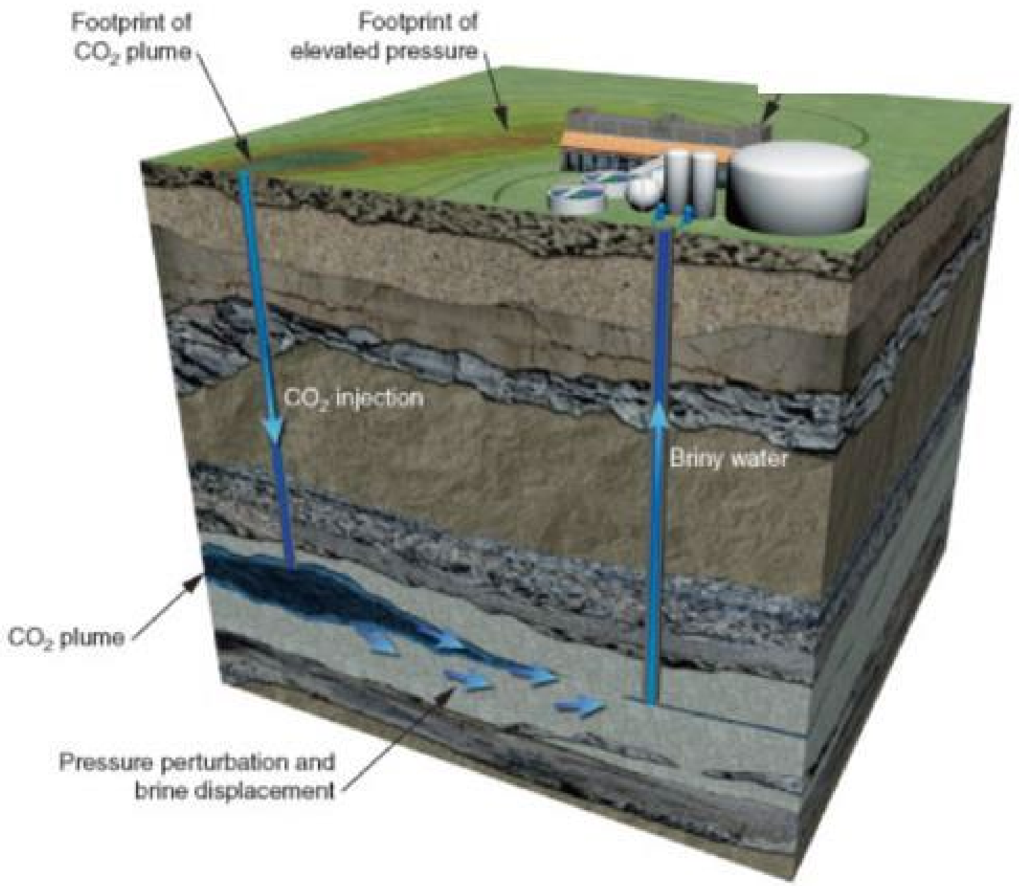

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Brine Treatment

- Alternative source of water.
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DISCLAIMER

This material is based on work supported by DOE NETL under Award No. DE-FE0026160.

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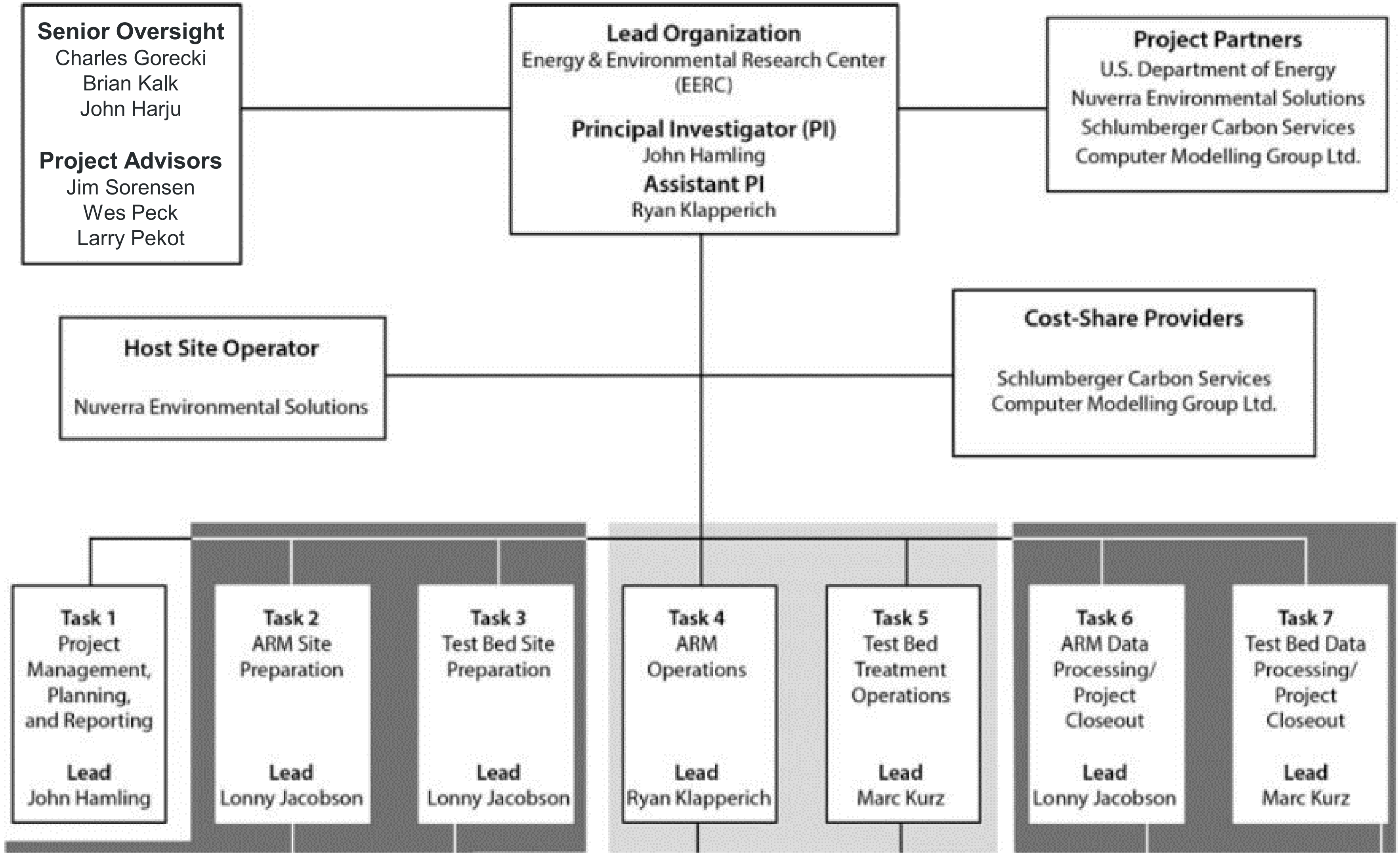
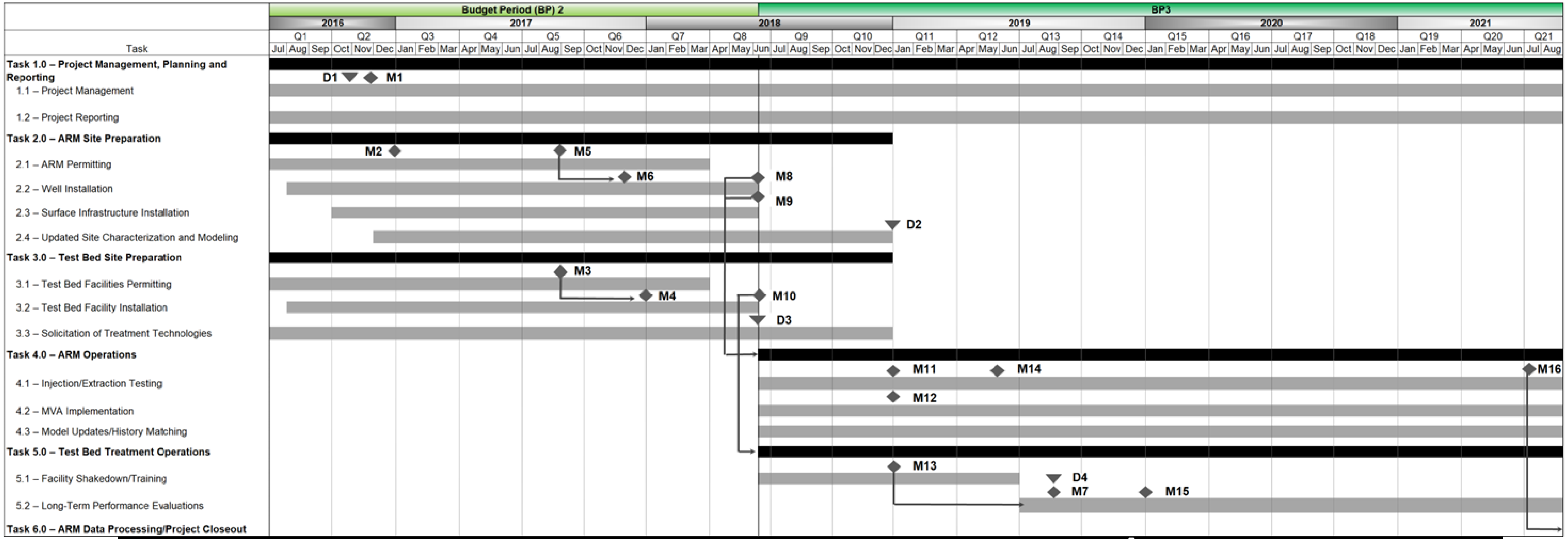
THANK YOU

Critical Challenges. Practical Solutions.

APPENDIX

ORGANIZATION CHART

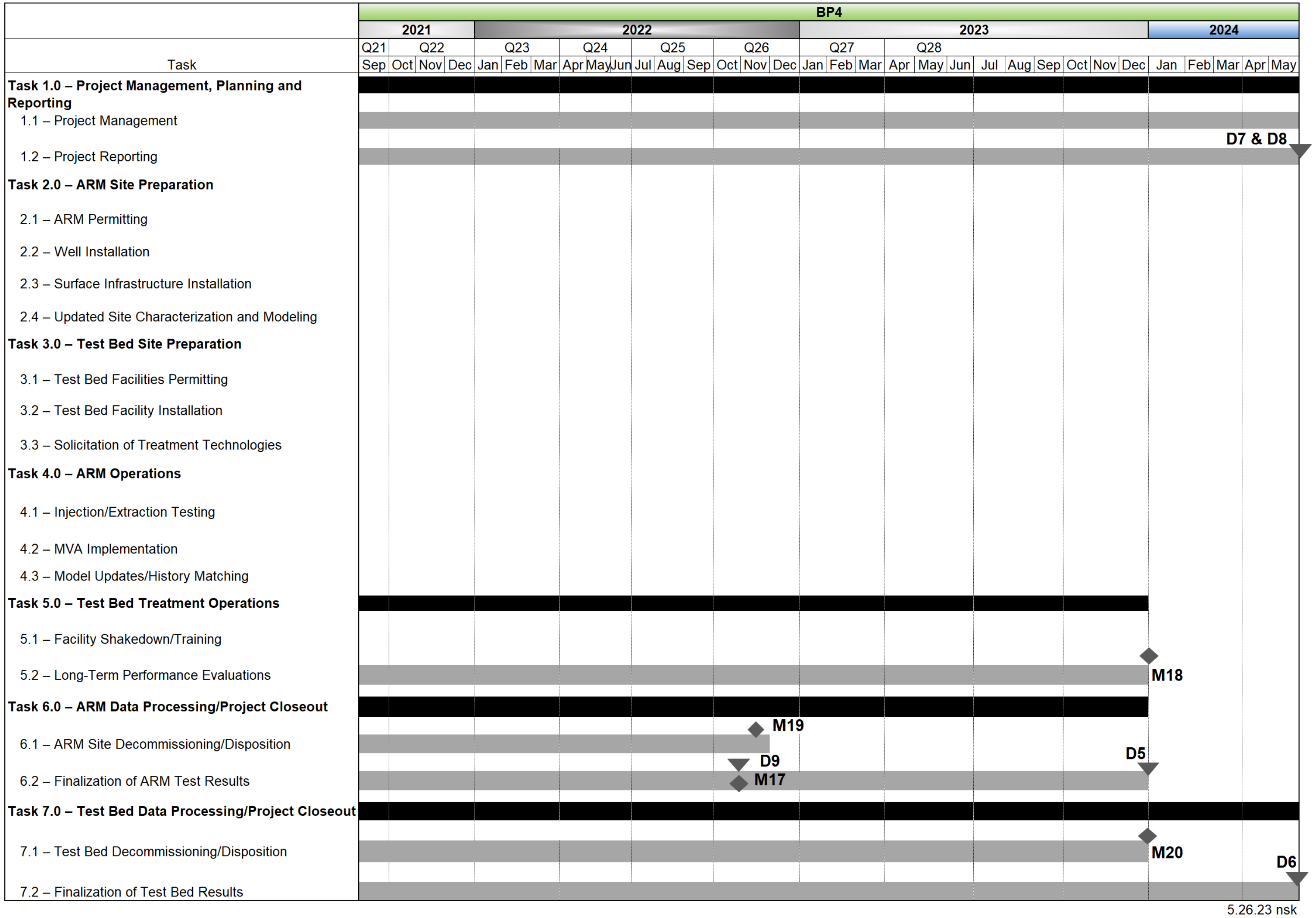




Deliverables	Milestones (M)	
D1 – Updated PMP	M1 – Project Kickoff Meeting	M9 – Surface Installation Complete
D2 – Field Implementation Plan (FIP) Finalized	M2 – Permit to Drill Submitted	M10 – Water Treatment Facilities Complete
D3 – Water Treatment Technology Selection Process Summary	M3 – Water Treatment Test Bed Permit Received	M11 – Initiate Stage 1 of Experimental Scenario
D4 – Preliminary Schedule of Technologies	M4 – Start Water Treatment Facilities Construction	M12 – Initiate Collection of Operational Data
	M5 – Permit to Drill Received	M13 – Water Treatment Test Bed Fully Operational
	M6 – Start Site Preparation	M14 – Initiate Stage 2 of Experimental Scenario
	M7 – First Treatment Technology Selected	M15 – First Treatment Technology Evaluated
	M8 – Well Installation Complete	M16 – Completion of ARM Operations

Gantt Chart, Deliverables, and Milestones

Gantt Chart, Deliverables, and Milestones cont'd



Deliverables	Milestones (M)
D5 – Vol. 1 – ARM Engineering and Evaluation Summary	M17 – BSEM Time-Lapse Sensitivity Study Complete
D6 – Vol. 2 – Technology Evaluation Report	M18 – Completion of Water Treatment Technology Demonstration
D7 – Data Submission to EDX	M19 – ARM Site Decommissioning/Disposition Completed
D8 – Lessons Learned Document	M20 – Water Treatment Test Bed Decommissioning/Disposition Completed
D9 – Time-Lapse BSEM Sensitivity Study Results	

BENEFITS TO THE PROGRAM

This project is expected to result in the development of engineering strategies/ approaches to quantitatively effect changes in differential formation pressure and to monitor, predict, and manage differential pressure plume movement in the subsurface for future CO_2 saline storage projects. Additionally, the brine treatment technology evaluation is expected to provide valuable information on the ability to produce water for beneficial use. The results derived from implementation of the project will provide a significant contribution to the U.S. Department of Energy's (DOE's) Carbon Storage Program goals. Specifically, this project will support **Goals 1 and 2** by validating technologies that will improve reservoir storage efficiency, ensure containment effectiveness, and/or ensure storage permanence by controlling injected fluid plumes in a representative CO_2 storage target. Geologic characterization of the target horizons will provide fundamental data to improve storage coefficients related to the respective depositional environments investigated, directly contributing to **Goal 3**. In addition, this project will support **Goal 4** by producing information that will be useful for inclusion in DOE best practices manuals.

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SUCCESS CRITERIA

Validate efficacy of ARM applications to industrial CO_2 storage projects (through a field test).

Demonstrate the steps necessary to design and implement ARM for industrial CCS projects.

Enable development of water treatment technologies with application to treating high TDS brines associated with geologic CO_2 storage targets.

CHALLENGES

SITE OPERATIONS

Hot Weather

HEAT!!

Electric motor upgrade

Stock Tank Repairs

Stock tank cracked

Stock tank repaired

Water Treatment Facility Corrosion

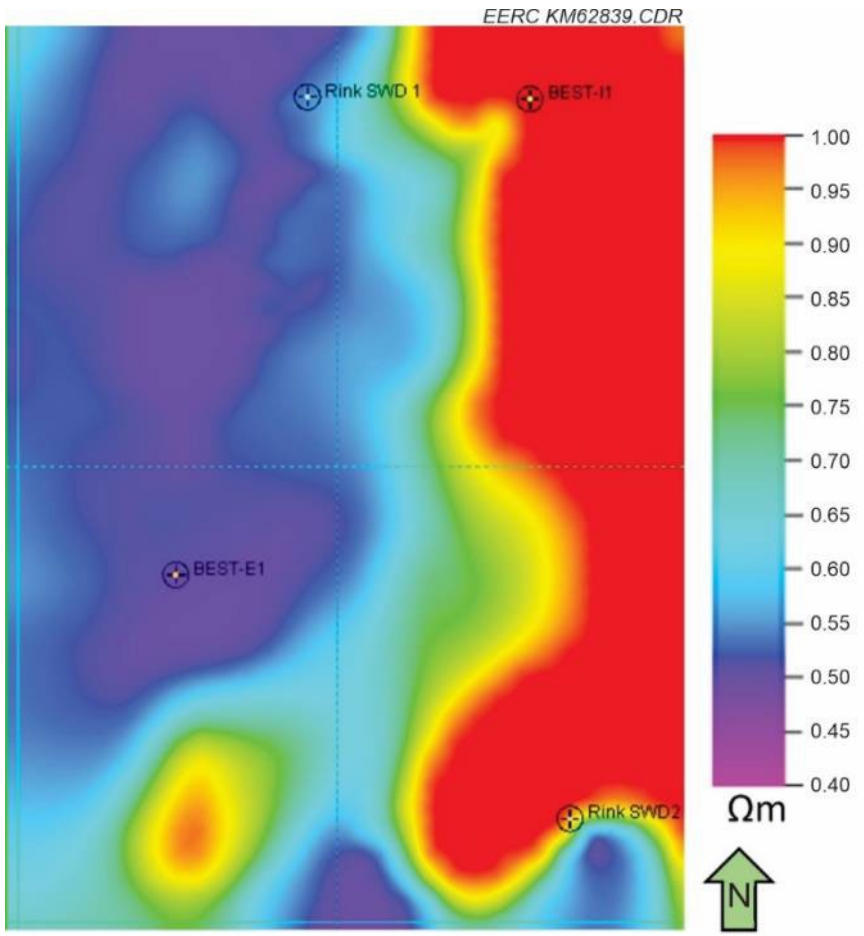
High-salinity waters accelerate corrosive processes

Free Water Knockout (FWKO) Issues

Water dump and pop-off valves damaged

BOREHOLE-TO-SURFACE ELECTROMAGNETIC SURVEY (BSEM) EXPERIMENT IN MONITORING

- Geophysical method of subsurface investigation using a borehole-deployed electrical source.
  - Receivers deployed at surface to create a 3D map of resistivity within a target reservoir(s).
- Baseline survey conducted in September 2018.
  - Repeat survey could not be conducted.
- Analysis of the baseline survey was able to resolve salinity variations resulting from brine injection into the Inyan Kara Formation.
  - Subsequent evaluation suggests this method could be effective for CO_2 injection monitoring.
  - Results published at GHGT-16.



CARBONATED BRINE STORAGE

SYNERGY – NRAP COLLABORATION

- **Hypothesis –** Coinjection of dissolved CO_2 into saltwater disposal (SWD) wells could accommodate meaningful quantities of geologic CO_2 storage with a significantly reduced risk profile that is easier to permit that could enable a distributed CO_2 storage model.
  - Screening-level techno-economic feasibility assessment shows potential for implementation.
  - A significantly reduced risk profile of carbonated brine storage can be achieved versus supercritical CO_2 injection.
  - Uncertain regulatory environment is a significant barrier to implementation.
  - Reporting in progress.

TIMELINE

2017 – Construction permits approved; construction begins in December

2018 – Two new project wells drilled in spring

– Arm site infrastructure (tanks, flowlines, pumps, etc.) installed throughout the year

2019 – Site and wells tested and commissioned in May

– Short-term extraction testing conducted in late summer and fall months (correlative tests)

– First water treatment technology test conducted

2020 – Submersible pump removed in February

– Long-term extraction testing commenced in February

2021 – Long-term extraction testing completed in July

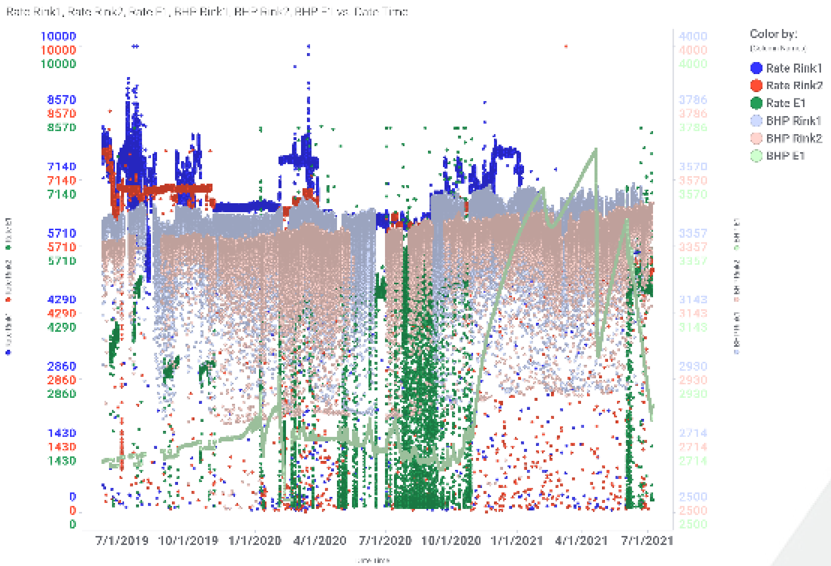
– Data analysis underway (challenging data sets)

– Additional water treatment technology tests conducted

2022 – Data analysis continued; CO_2 injection simulated based on field site performance

2023 – CO_2 injection model and simulations scaled up to “commercial” scales (1-10 MMt/yr of CO_2)

– Additional water treatment technology tests planned (fall)

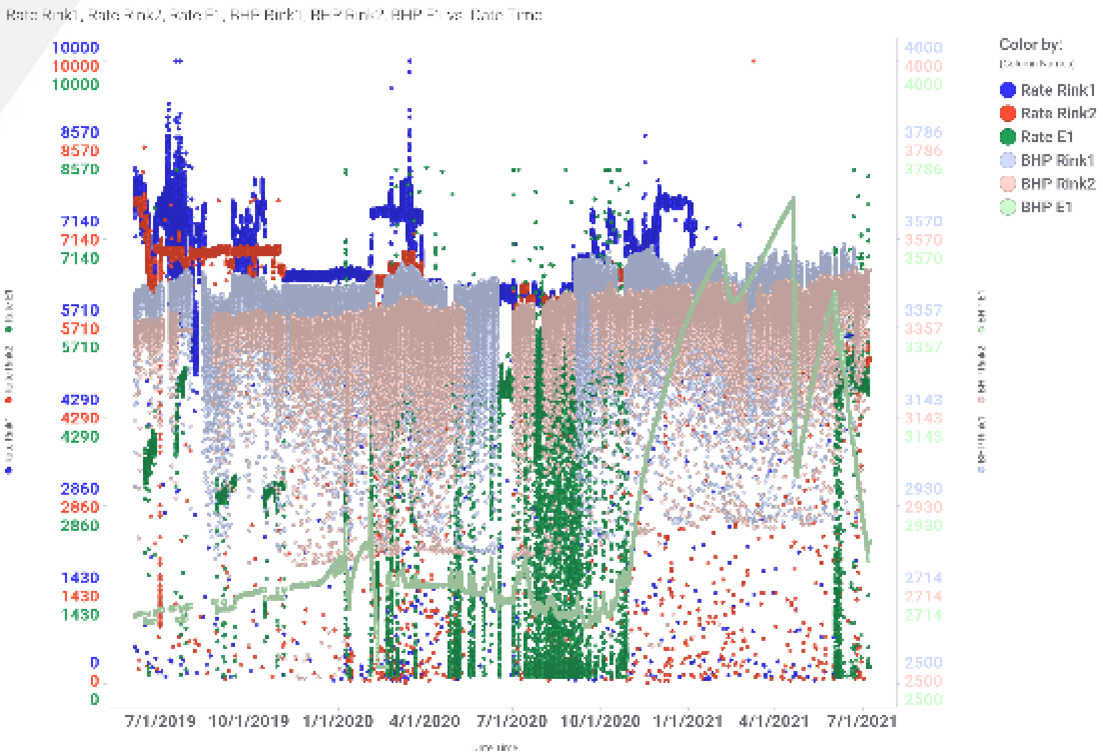


PROJECT SUMMARY

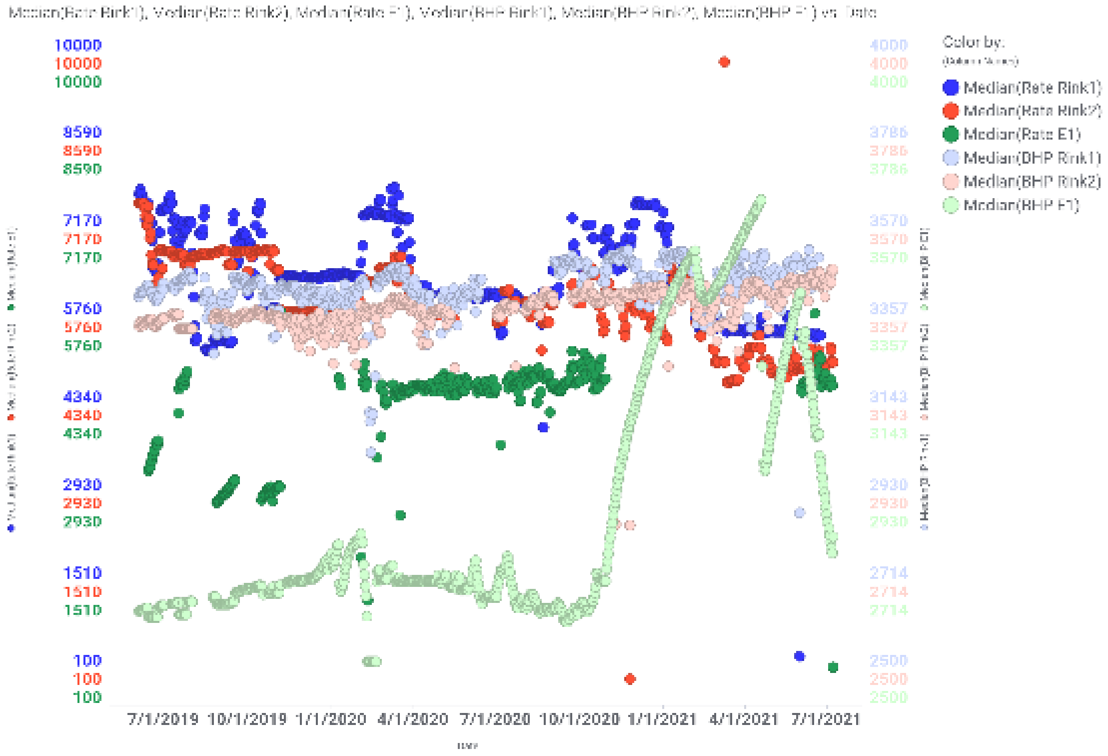
- Key findings:
  - The field trials demonstrated that injection is a greater contributor to reservoir pressure than extraction, but extraction can reduce reservoir pressure in certain scenarios.
  - Machine learning techniques can be applied to complex injection data sets to identify trends.
  - Modeling suggests a 20% increase in storage potential could be achieved with comparable volumetric injection and extraction rates.
  - Multiple variables of impact – optimization is key.
  - Large injection projects need to move similarly large volumes of water to see similar overpressurization reductions. Scenarios where reservoir fluids are naturally trapped in portions of a reservoir may be best suited for these types of management systems.
  - Experimental brine treatment technologies exist that are capable of treating the saline waters that are likely to be associated with CO_2 storage sites applying ARM. Additional technology development is needed to enable and produce commercialized solutions.
    - ♦ Field-based demonstrations provided extremely valuable insight on technology scale-up.

Supplemental Slides

RAW DATA PROCESSING FOR SIMULATION INPUT



Recorded SCADA Data



Processed Daily Pressure/Rate

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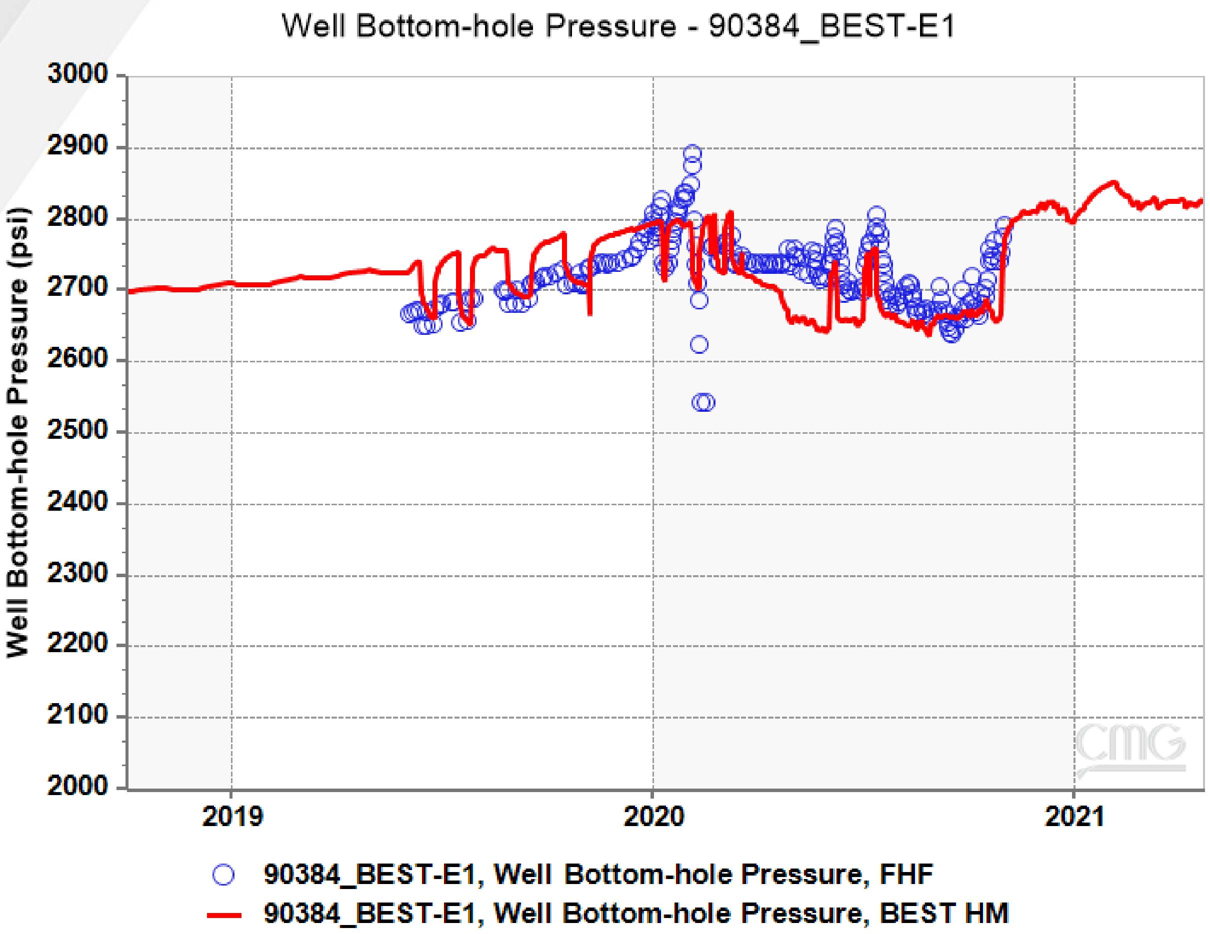
Critical Challenges. Practical Solutions.

HISTORY MATCH RESULTS



- Red line illustrates the history match results.
  - Real-world sites introduce significant complexities to the data set. We observed regular well shut-ins and opening of the wells as well as changing fluid properties throughout the experimental duration.
  - We were able to achieve a usable history match to explore predictive cases.

CO_2 INJECTION RESULTS

IMPROVED DISSOLUTION – WATER INJECTION ABOVE CO_2