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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 Project Review Meeting

August 16, 2022

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Principal Geoscientist

PARTNERS

MAJOR CONTRACTORS

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PROGRAM OVERVIEW

Objectives:

- Validate efficacy of brine extraction as a means of active reservoir management (ARM)
  - Applications that can enable the implementation and improve the operability of industrial carbon capture and storage (CCS) projects.
  - Manage injection performance and formation pressure.
  - Model, predict, monitor, and validate movement of fluids and pressure.
  - Provide data set to enable evaluation and design of ARM applications at compatible CCS sites.
  - Improve use and efficiency of geologic CO_2 storage resources.

- Implement and operate a brine treatment technology development and test bed facility
  - Enable development of brine treatment technologies capable of treating high-total dissolved solids (TDS) brines associated with geologic CO_2 storage target.

Project Details:

- Phase II project: $22,573,604
  - DOE share: $18,103,044
  - Cost share: $4,470,560
    - ♦ Schlumberger: $3,760,280
    - ♦ CMG: $ 710,280

- Period of Performance:

  July 2016 – May 2023

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.

GEOLOGIC CO_2 STORAGE

CONSIDERATIONS FOR INDUSTRIAL PROJECTS

- Buoyant fluid
- Large volumes = large footprint
- Access to pore space
  - Leasing, unitization/amalgamation, trespass
- Compliance with regulatory and incentive programs
- Assuring permanence for incentives or credits
  - Conformance and storage efficiency

Because of a host of technical, social, regulatory, environmental, and economic factors, brine disposal tends to be more accessible and generally quicker, easier, and less costly to implement compared to dedicated CO_2 storage.

TWO COMPLEMENTARY COMPONENTS

ARM Test

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

Brine Treatment Test Bed

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

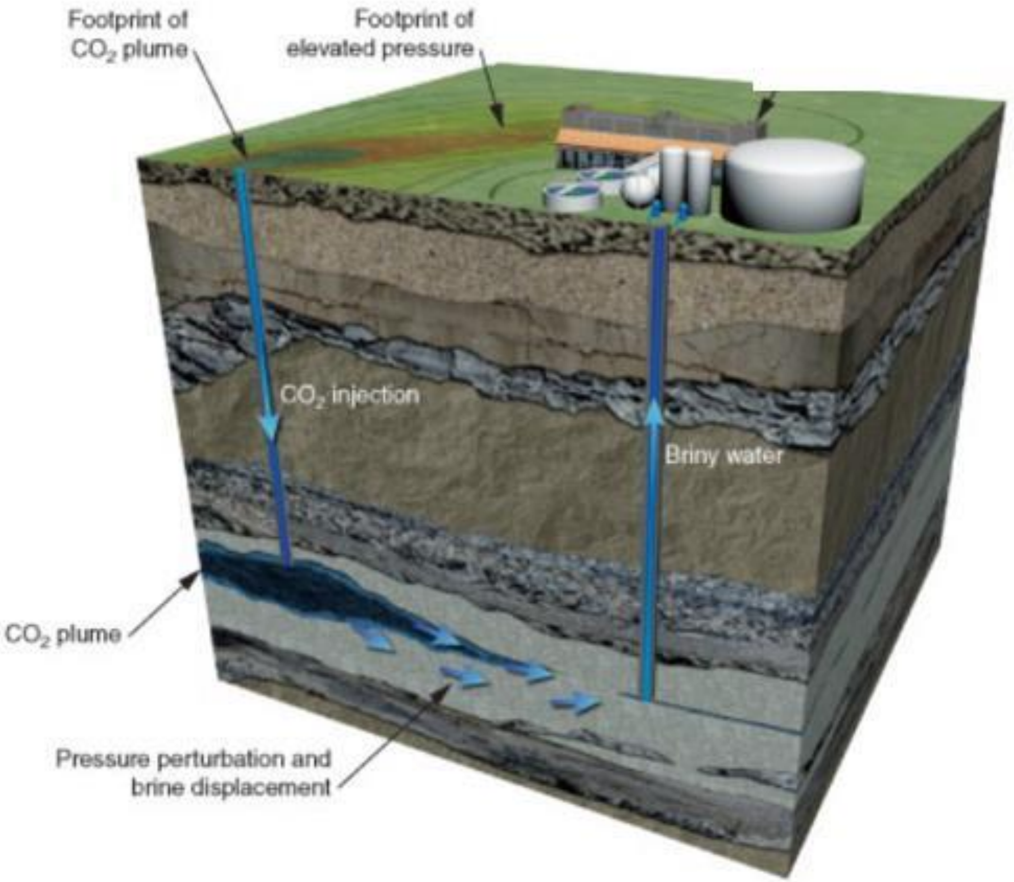
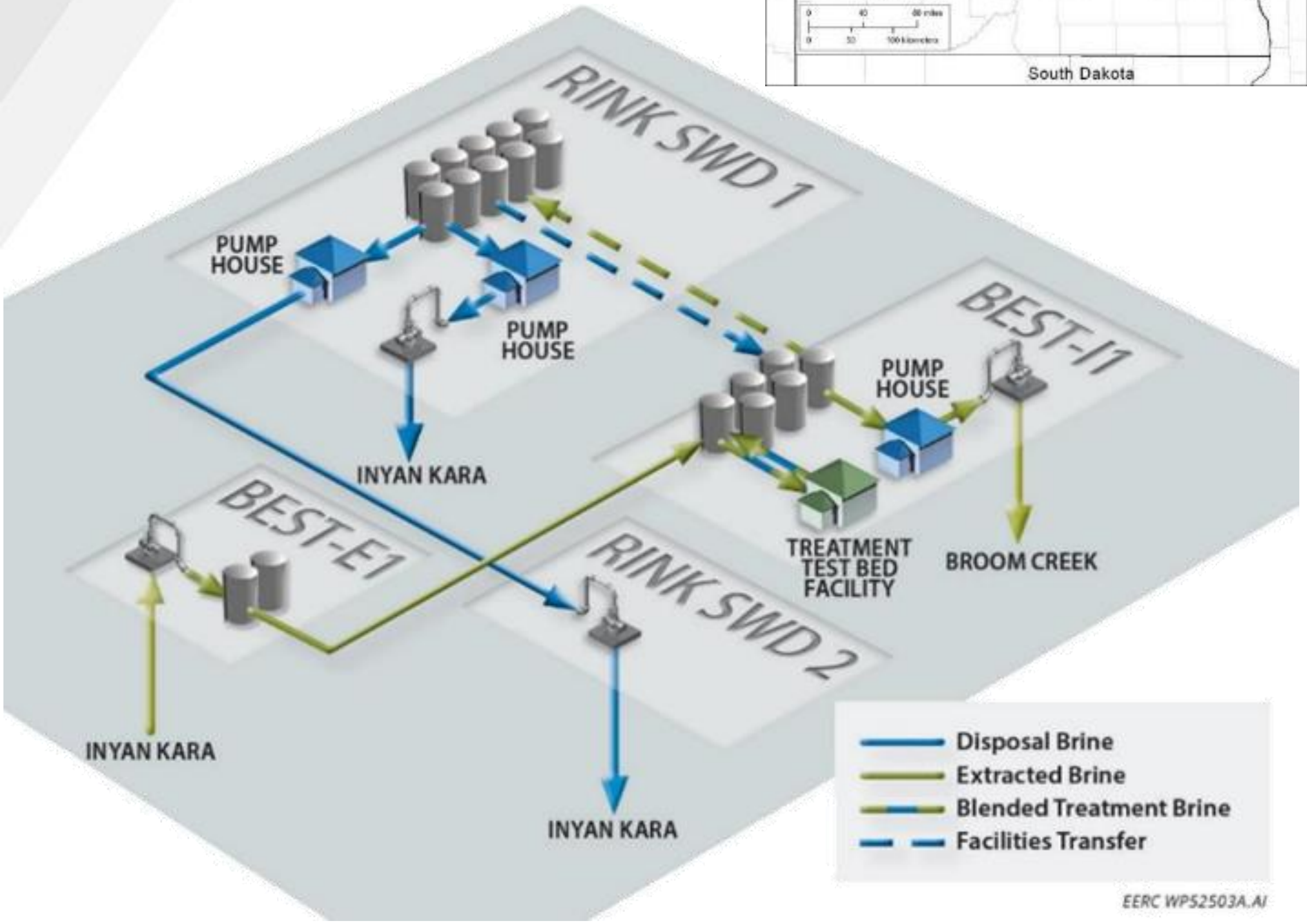


Illustration modified from Lawrence Livermore National Laboratory https://str.llnl.gov/Dec10/aines.html

THE SITE


Saskatchewan
Manitoba
CANADA
UNITED STATES
Williston
Minot
BEST Site
North Dakota
Grand Forks
Minnesota
Montana
Bismarck
Dickinson
Fargo
South Dakota


RINK SWD 1
PUMP HOUSE
PUMP HOUSE
BEST-I1
PUMP HOUSE
INYAN KARA
BEST-E1
TREATMENT TEST BED FACILITY
BROOM CREEK
RINK SWD 2
INYAN KARA
INYAN KARA
Disposal Brine
Extracted Brine
Blended Treatment Brine
Facilities Transfer
EERC WP52503A.AI


McKenzie County Rural Water System
23
N
Existing Disposal Facility
Existing Bermed Pad
BEST - I1
RINK SWD 1
Command Center
Brine Treatment Facility
1372 ft
2035 ft
Approximate Site Boundary
Proposed Well Pad
BEST - E1
Proposed Road
1426 ft
Existing Pipeline Route
Site Infrastructure:
Existing
Saltwater Disposal Well
Proposed
Wells
Tank Farm
Pipeline Route
Freshwater Supply
Overhead Electric Lines
Buried Electric Lines
Structures
RINK SWD 2
feet
0
250
500
1000

ACCOMPLISHMENTS TO DATE

Designed and Implemented ARM Field Test (COMPLETE)

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

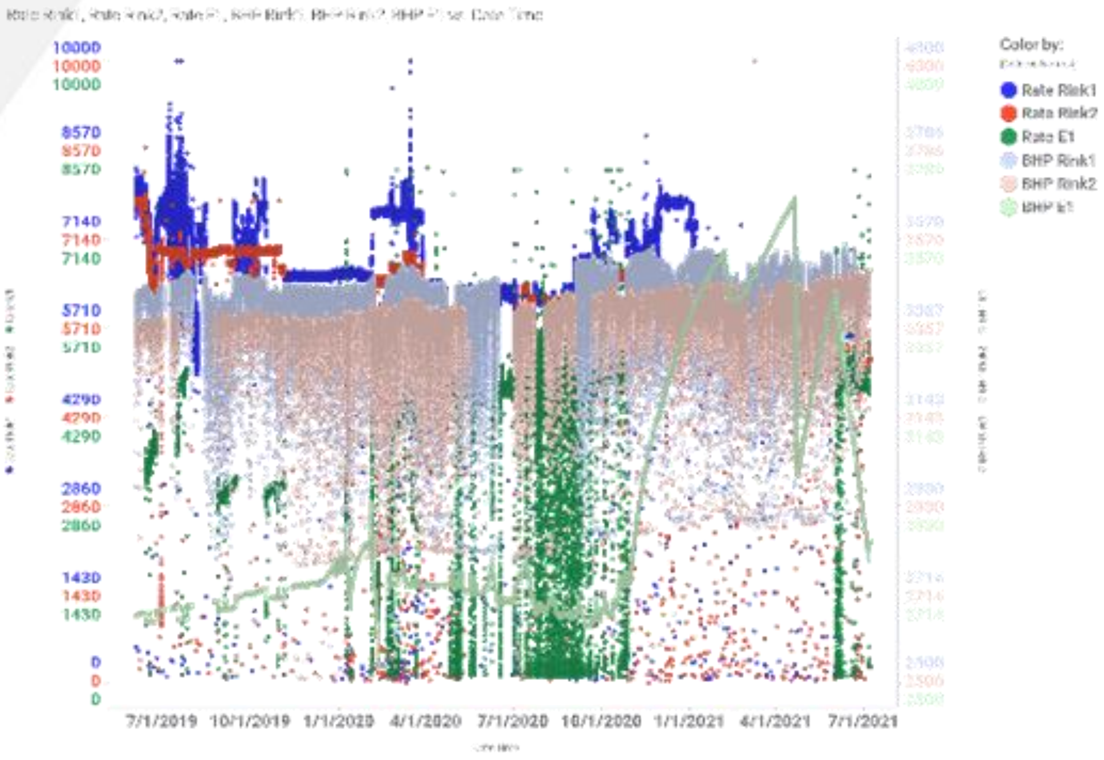
Geophysical Simulation and Modeling (in progress)

- Calibrate and validate performance of ARM proxy models by integrating monitoring data.
- Evaluated efficacy of ARM strategies for varying operating and deployment scenarios relevant to geologic CO_2 storage.
- Evaluating revised injection/extraction scenarios with increased scaling to better represent potential commercial CO_2 injection scenarios.

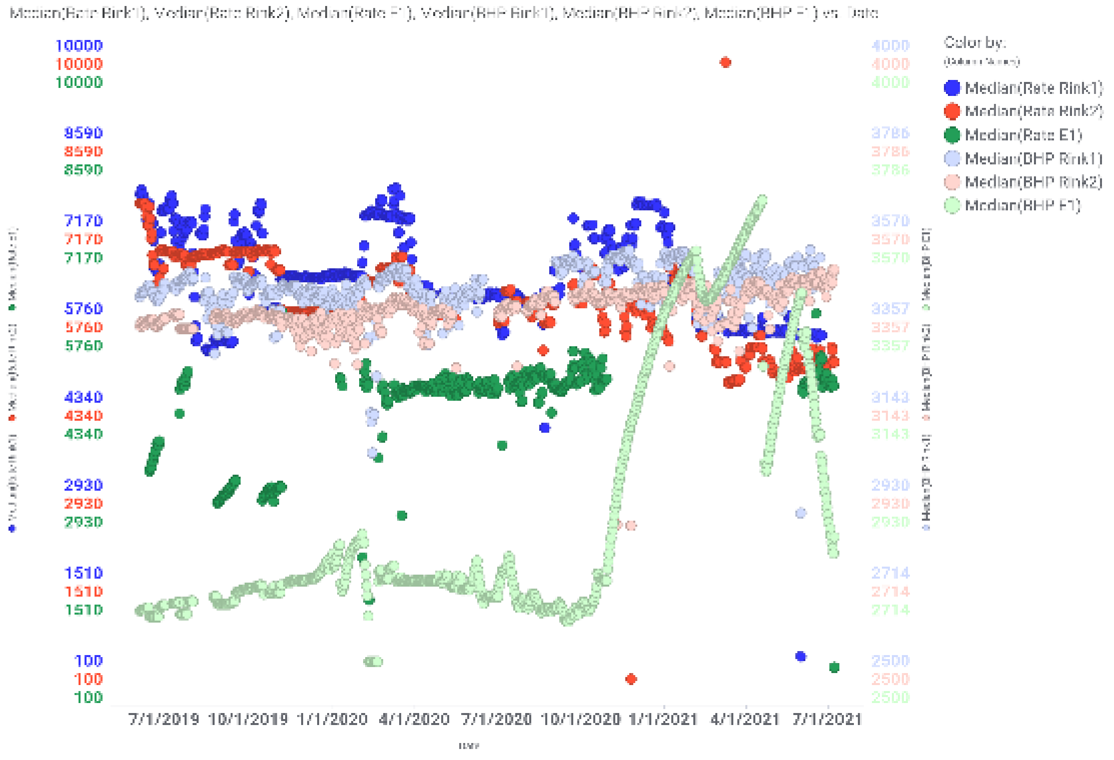
Machine Learning (ML) Analysis (COMPLETE)

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

RAW DATA PROCESSING FOR SIMULATION INPUT

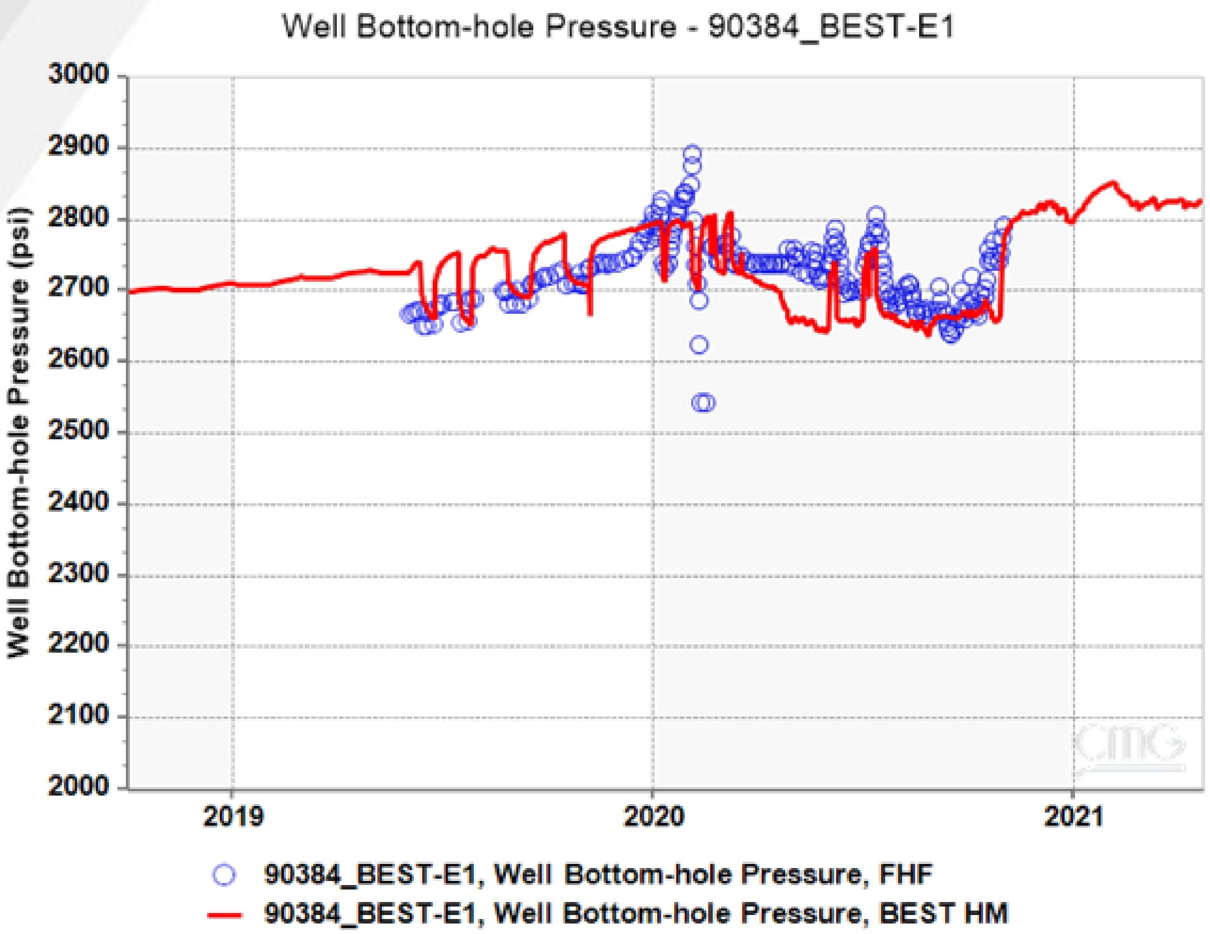


Recorded SCADA Data



Processed Daily Pressure/Rate

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 SIMULATION

- Use history-matched model to test initial CO_2 injection scenarios to evaluate how production wells can increase total storage capacity of CO_2 through ARM.
  - Used preliminary modeling to ascertain the scale of impact that brine extraction can have on CCS performance with relation to positioning of extraction wells relative to injection wells and injection/extraction rates.
  - Results inform a matrix of simulation cases to explore the impact of well position, injection/extraction rate, and various operational and development strategies relative to ARM applications to CCS.

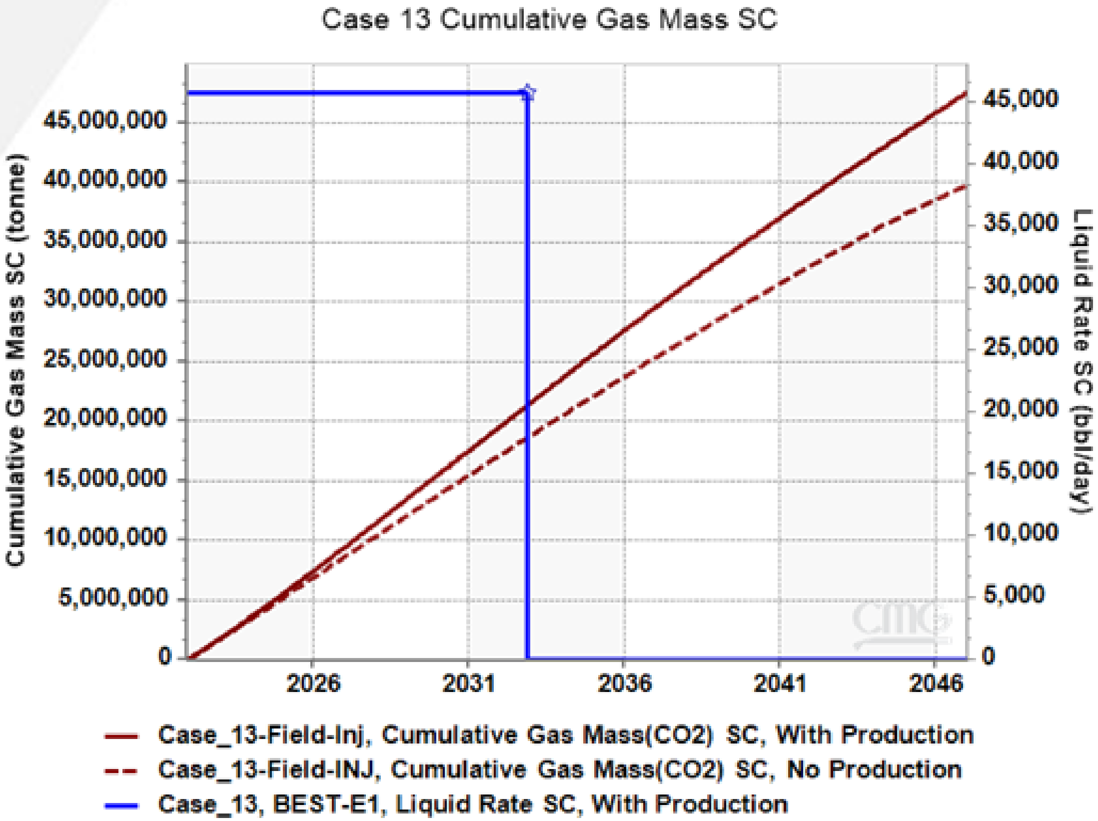
- Influential parameters to bottomhole pressure responses:
  - Permeability near extraction and injection wells.
  - Offset injection wells outside the study area have an impact.
  - Appropriate permeability and volume modifiers and boundary conditions for subsequent case studies.

CO_2 INJECTION SIMULATION – TEST VARIABLES

- Injection rate equivalent of 1 MMt/yr.
  – Injected at reservoir conditions.
- 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.
- 20 cases were evaluated.

CO_2 INJECTION RESULTS

A HYPOTHETICAL CCS SCENARIO

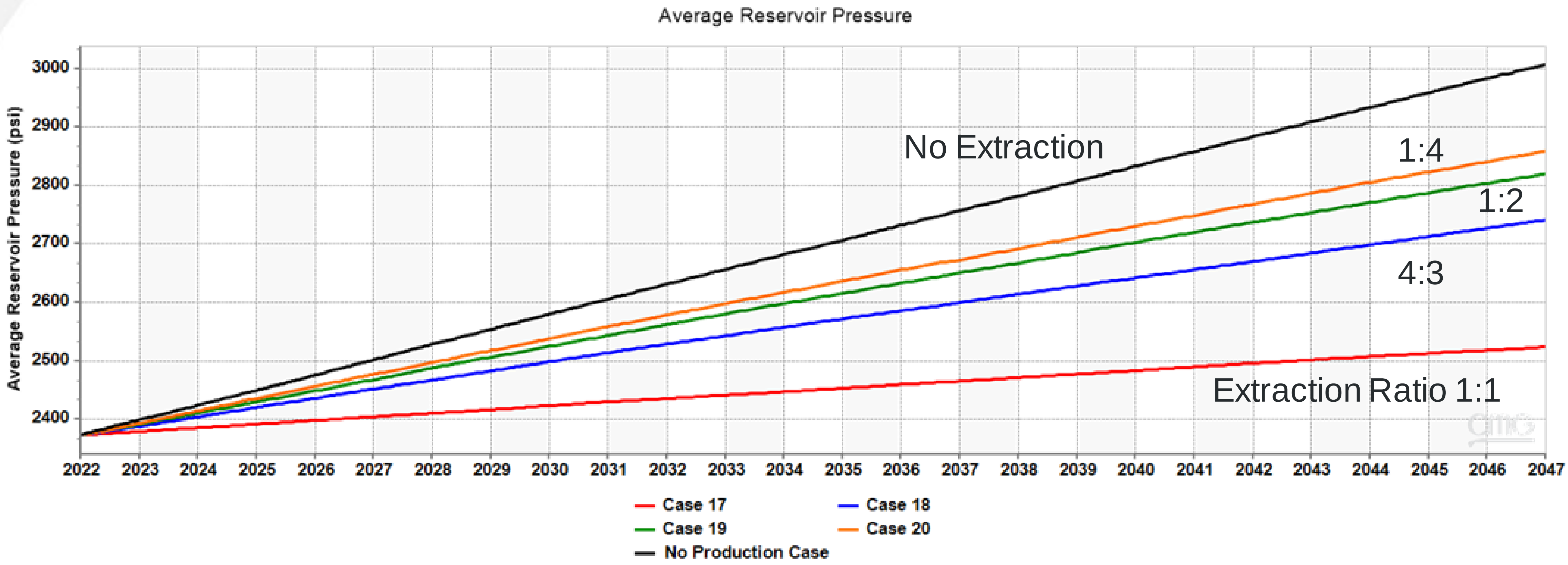


Case #	Inj Rate (RC ft3/d)	Prod Rate (RC bpd)	Ratio	Distance
13	~130,000	~46,000	1:1	2-Mile

- The drop of the liquid production rate (blue line) represents the point where injected gas broke through to the extraction well.
  - Extraction well was shut in.
- At the breakthrough point (~10 years), the difference in injected gas is ~2.7 MMt.
  - ~15% volume increase compared to the nonextraction base case.
- At end of simulation (25 yr), difference grows to ~7.8 MMt.
  - ~20% volume increase compared to the nonextraction base case.

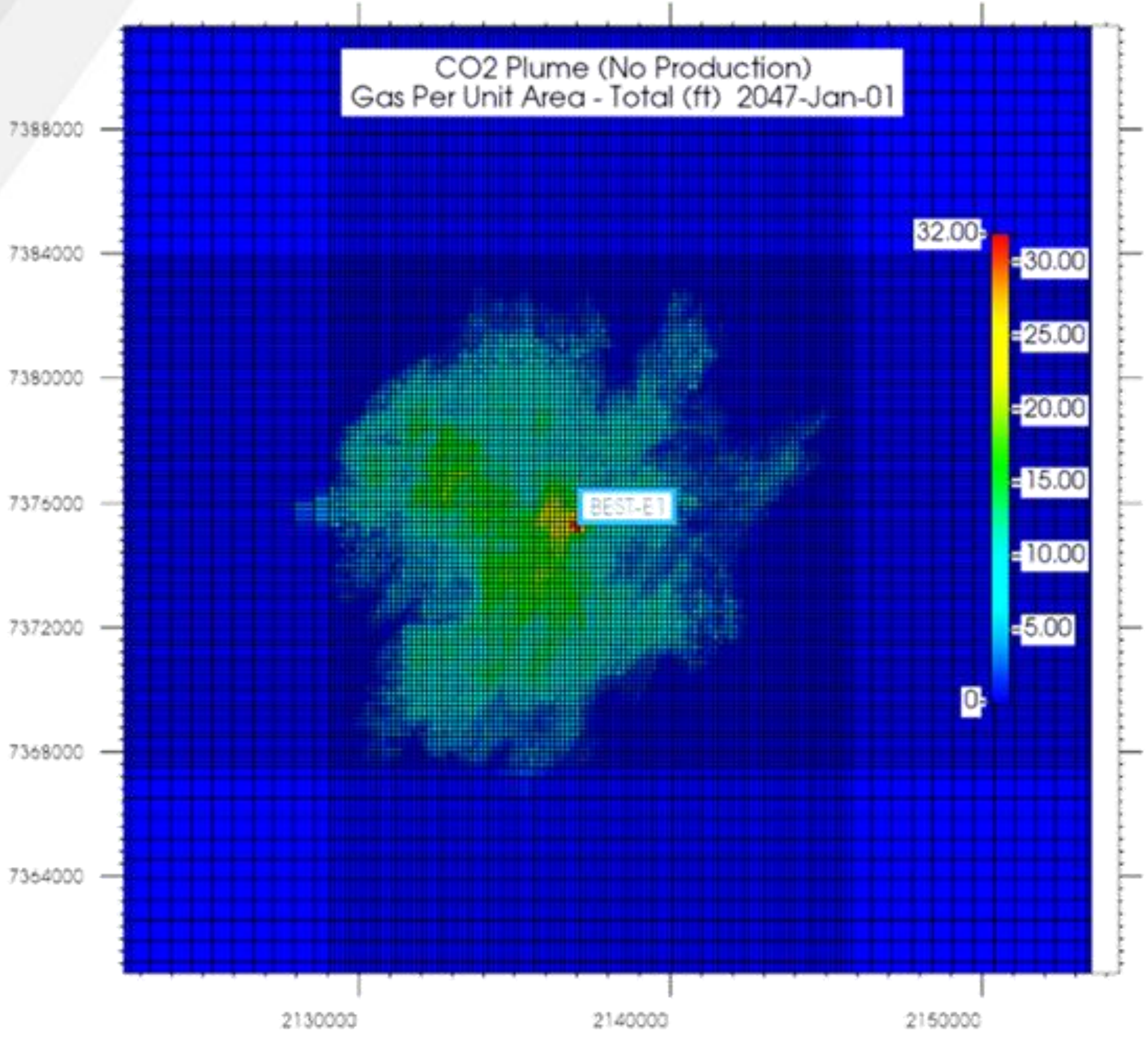
CO_2 INJECTION RESULTS

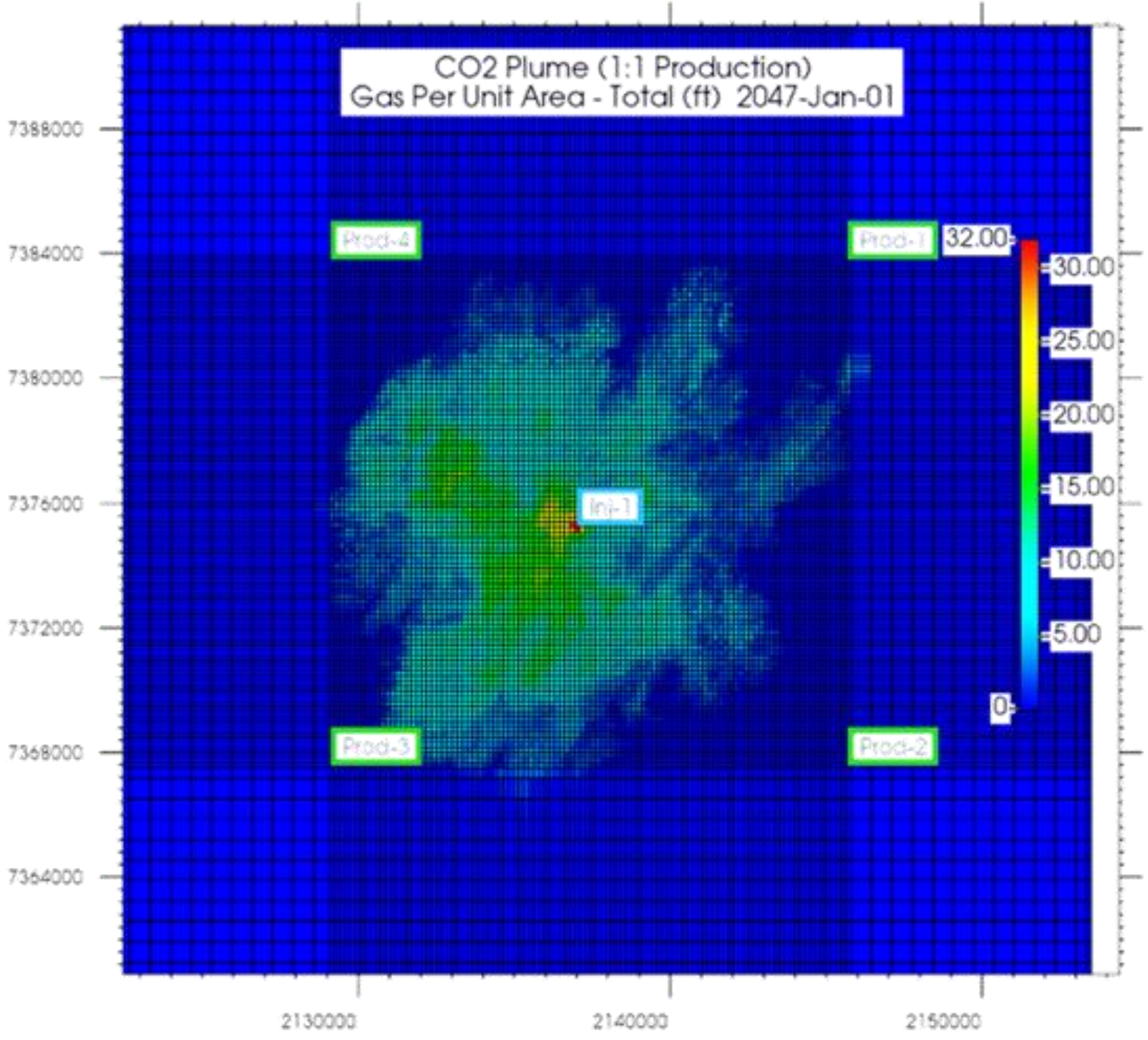
A HYPOTHETICAL CCS SCENARIO – RESERVOIR PRESSURE DECREASE



CO_2 INJECTION RESULTS

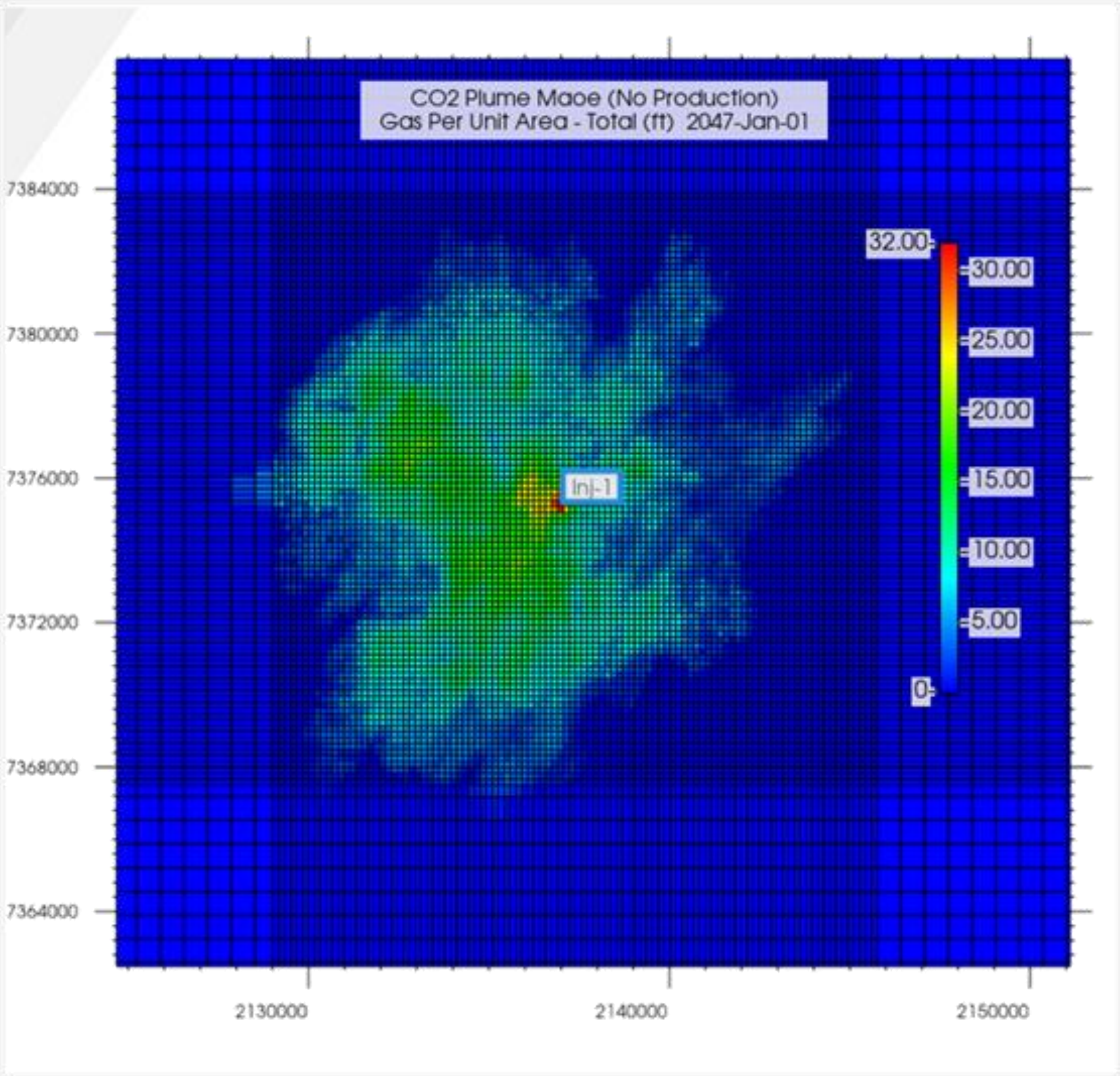
GEOSTEERING – OFFSET WELLS

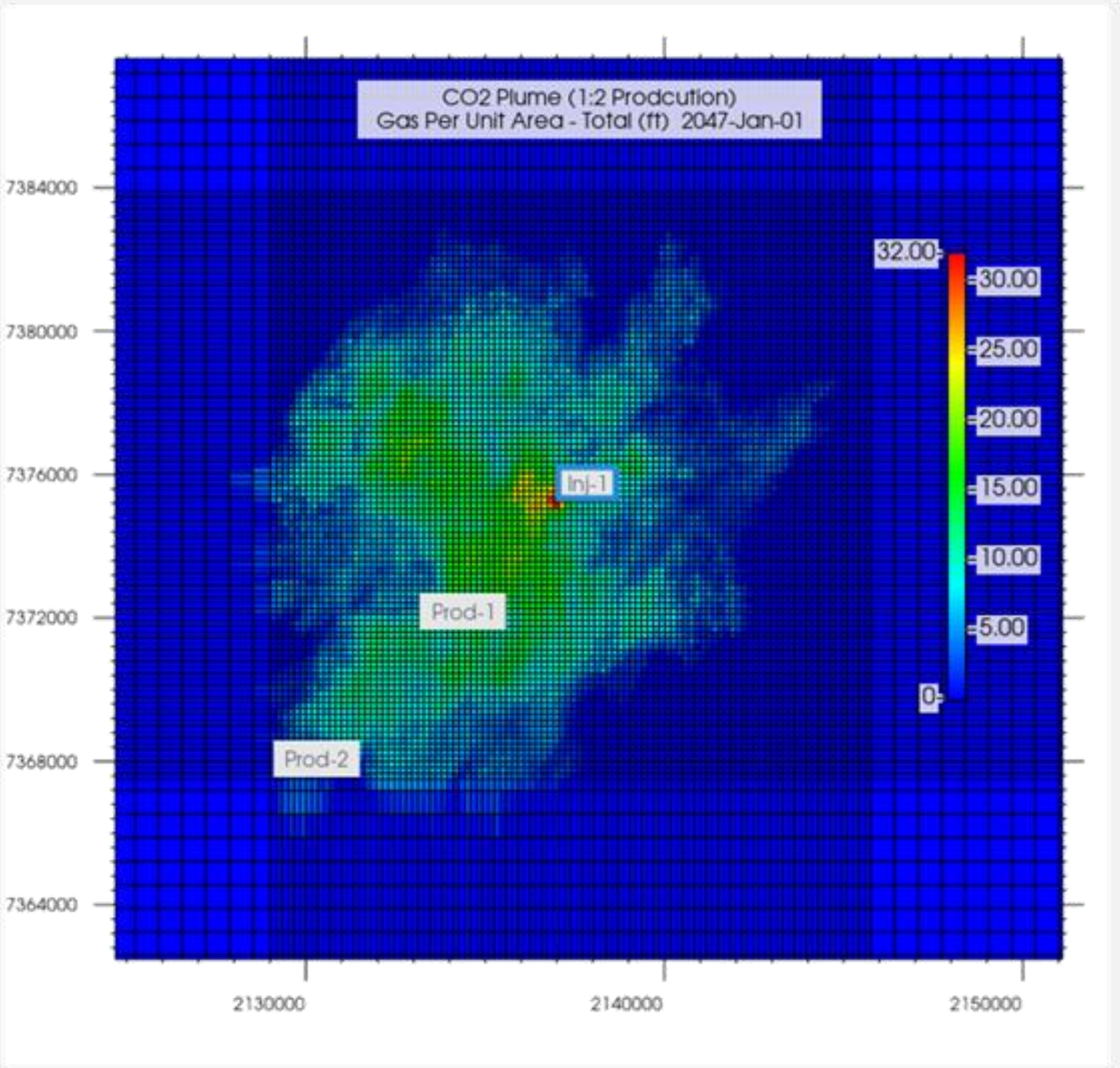




CO_2 INJECTION RESULTS

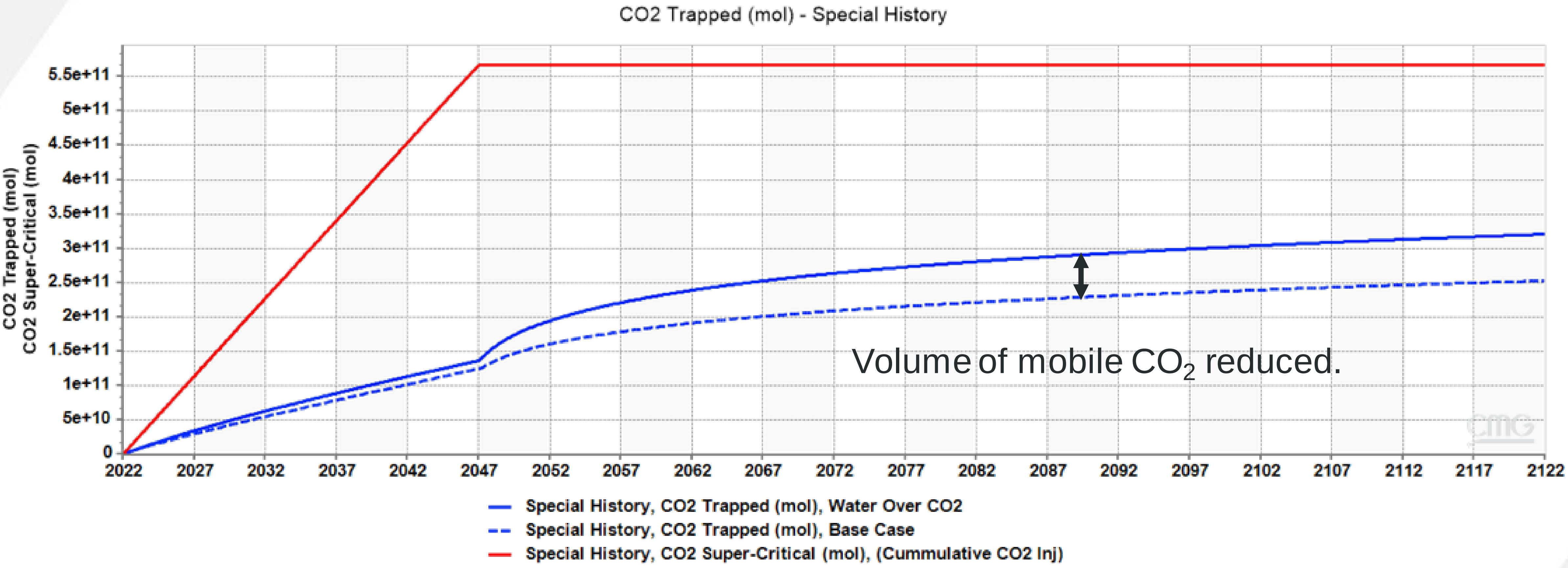
GEOSTEERING – TWO WELLS, PROGRESSIVE





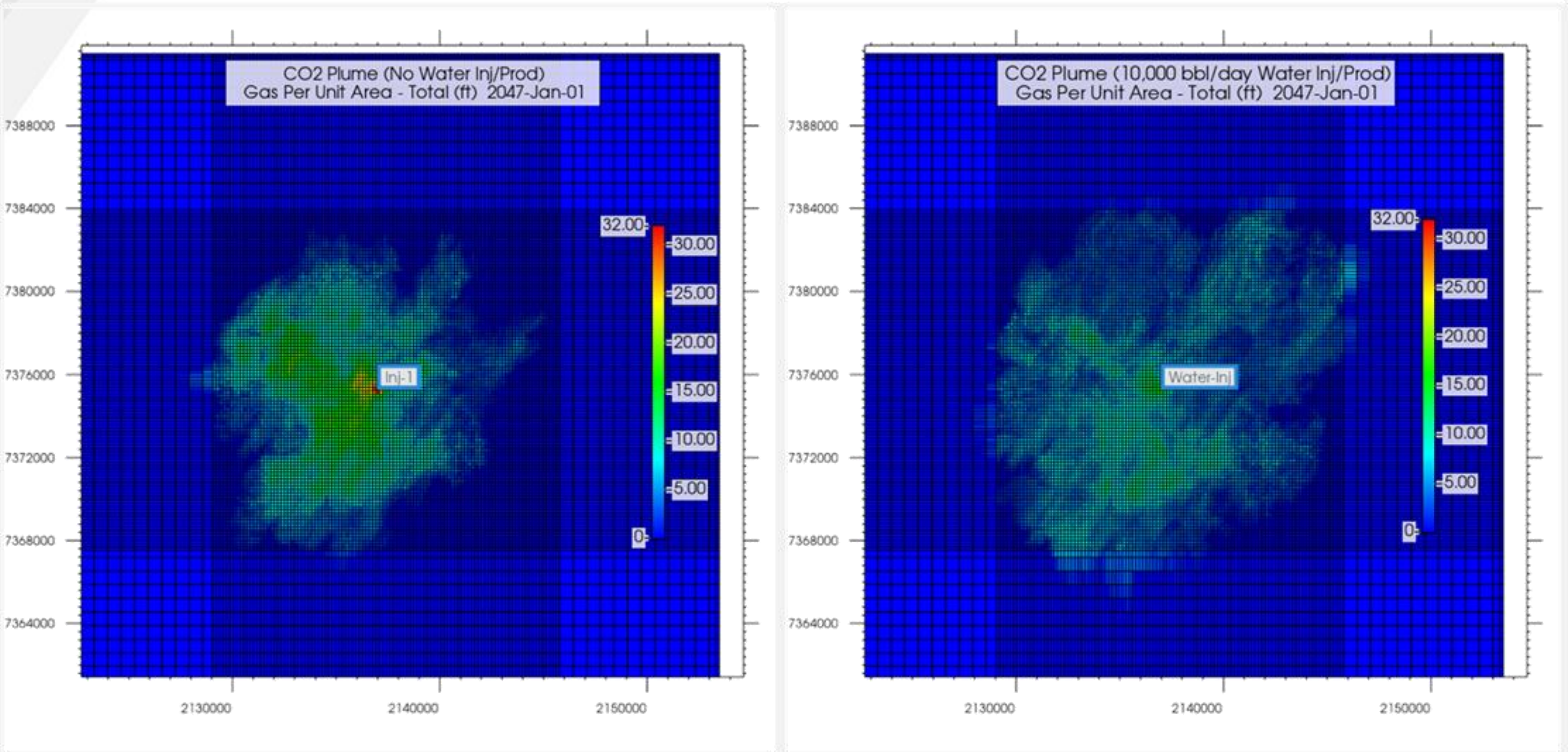
CO_2 INJECTION RESULTS

IMPROVED DISSOLUTION – WATER INJECTION ABOVE CO_2



CO_2 INJECTION RESULTS

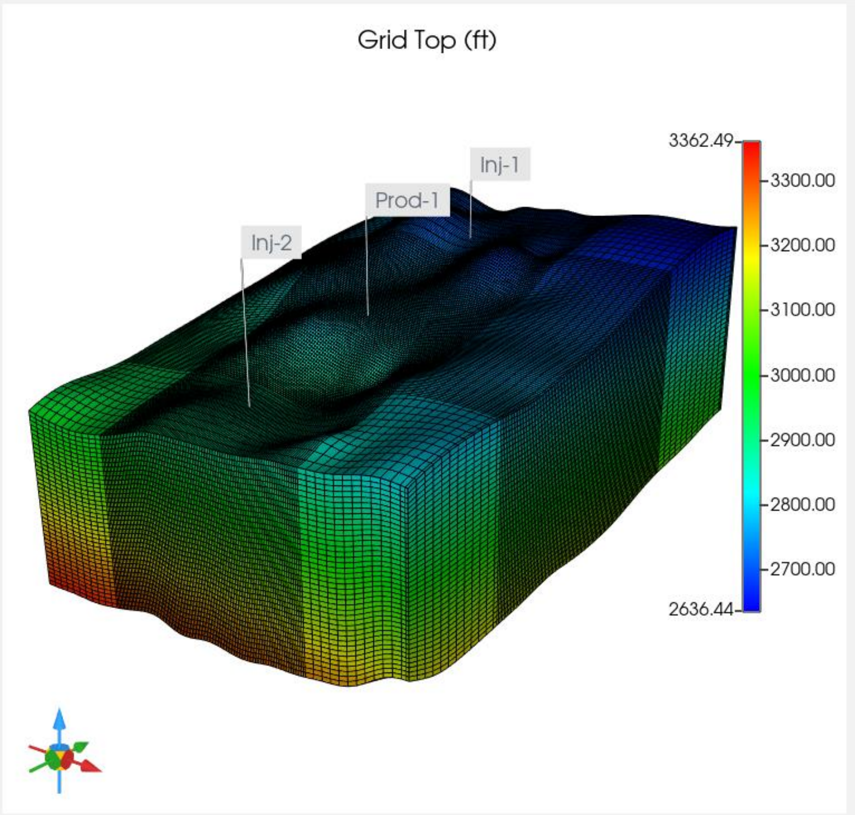
IMPROVED DISSOLUTION – WATER INJECTION ABOVE CO_2



FUTURE MODELING

DO TRENDS SCALE?

- Increase size of modeled region
  - 36 mi^2 to 900 mi^2
- Increase injection volumes
  - 1–10 MMt/yr
- More complex injection and extraction arrangements
  - Multiple patterns to be investigated
- Maintain geologic heterogeneity from original site



MOTIVATION FOR USING ML

- Complex system of injection and extraction.
  - Dynamic and variable rates, pressures, and fluid densities observed throughout the course of the field tests.
  - Inherent noisiness of field data is challenging to evaluate using traditional techniques.
- Power of ML methods in data mining and prediction.
  - Helps with automation and provides savings in data processing.
- **Predicted reservoir pressure could be used to monitor reservoir response to brine/CO_2 injection.**

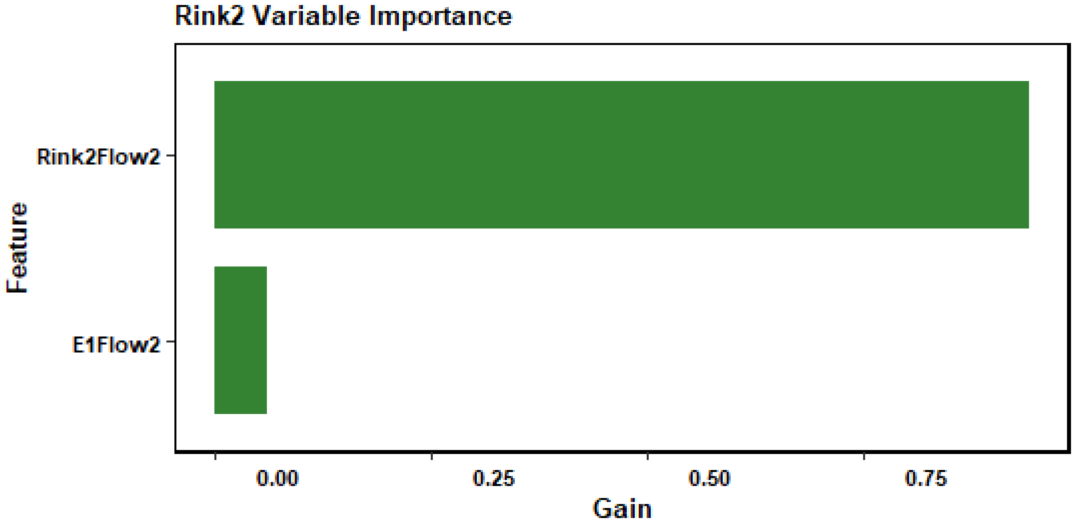
XGBOOST MODEL PERFORMED WELL IN PREDICTING RESERVOIR PRESSURE

Modeling Evaluation

	Train	Test
R-square	0.9204	0.9202
RMSE	46.71	31.14
MAE	46.80	31.17

- XGBoost model performed very well with both the training and test data sets.

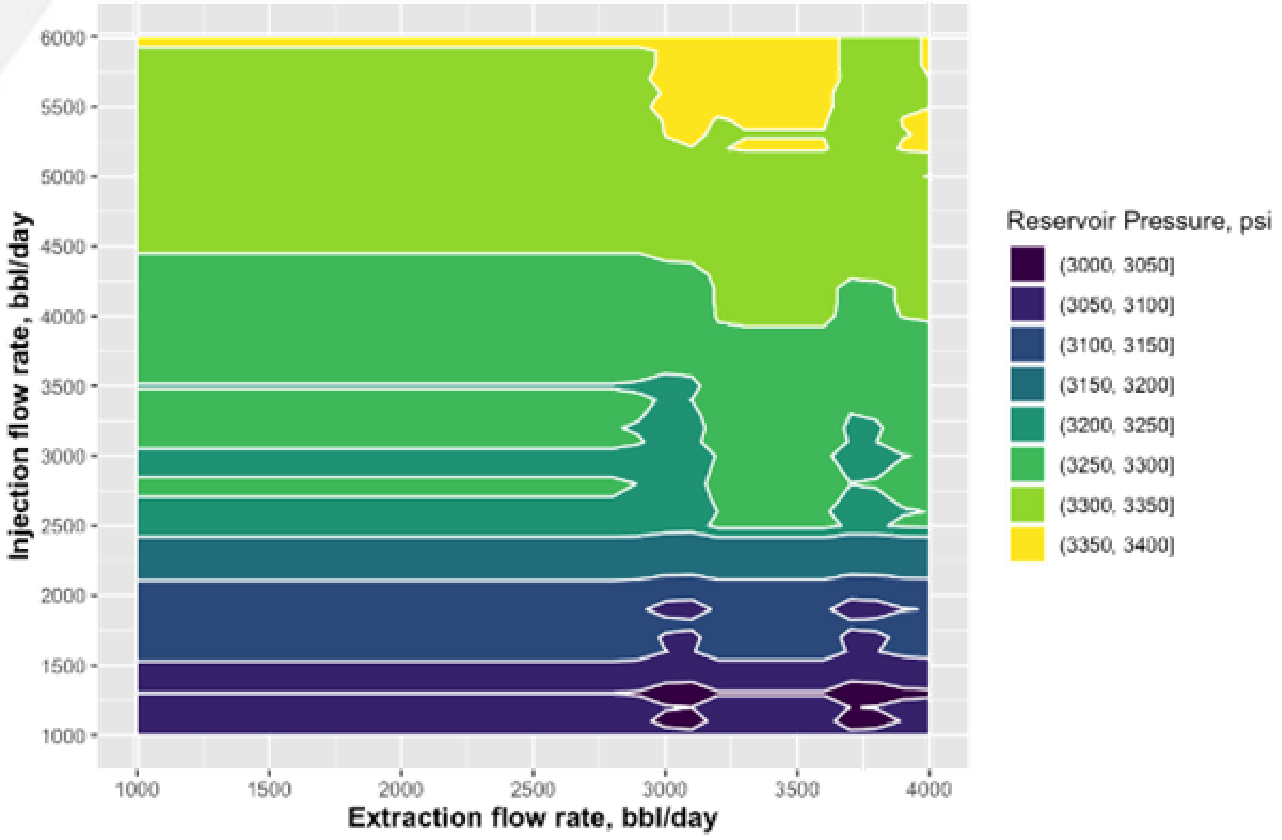
Variable Importance Plot



- Reservoir pressure was more greatly influenced by injection than extraction.

MODELED RESERVOIR PRESSURE RESPONSE TO INJECTION AND EXTRACTION OPERATIONS

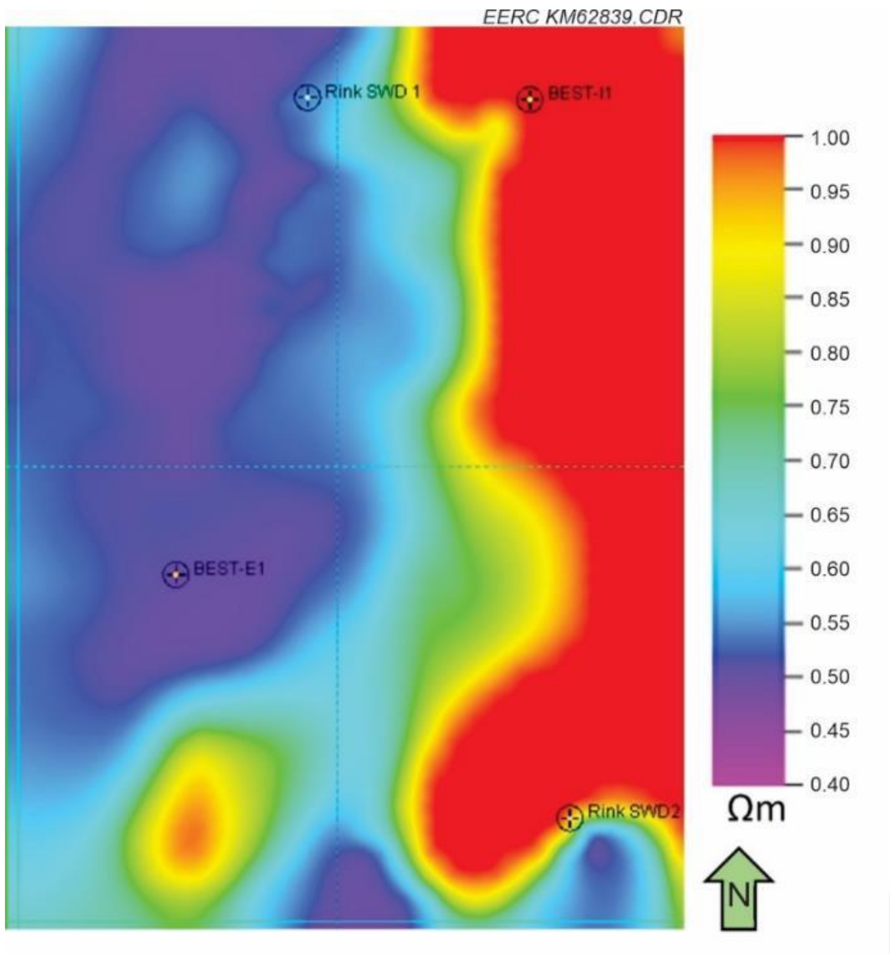
Contour Plot of Reservoir Pressure Response to Injection and Extraction Modeled by XGBoost



- The contour plot was created to model reservoir pressure response to different scenarios of injection and extraction operations.
- Higher injections always correspond to higher pressure.
  - E.g., pressure can increase ~200 psi when injection rate increased from 2000 to 5000 bbl/day.
- Under some conditions, extraction could decrease reservoir pressure (<100 psi).

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 to be published at GHGT-16.



NORTH DAKOTA BRINE TREATMENT FACILITY – WATFORD CITY, NORTH DAKOTA

BRINE TREATMENT TECHNOLOGY SELECTION AND TESTING

- Over 30 different technologies and providers of brine treatment/management technologies were solicited and reviewed for applicability to high-TDS brines.
    - Technologies were reviewed and ranked according to selection criteria, including **1) project benefits** (reduction of injection costs, etc.), **2) technology strengths** (scientific soundness, readiness level), and **3) organizational strengths** (IP, capability for further development, etc.).
    - Four technologies were identified and recommended for pilot-scale demonstration.
    - An inaugural demonstration of a mechanical vapor recompression (MVR) technology provided benchmark testing for comparison.

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ACCOMPLISHMENTS TO DATE

BRINE TREATMENT DEVELOPMENT FACILITY

- Four additional demonstrations to occur in late 2021 and 2022.
  - Demonstrations include a second extended steady-state evaluation of the MVR technology and three other innovative technologies.
    - ♦ MVR technology to acquire data under extended steady-state operation (August 2021) – equipment failure
    - ♦ Internally heated supercritical water desalination technology (September 2021)
    - ♦ Thermally assisted membrane distillation technology (October 2021)
    - ♦ Zeolite-derived membrane technology (pending)

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.

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

LESSONS LEARNED

Public–private partnership is key.

Adaptability.

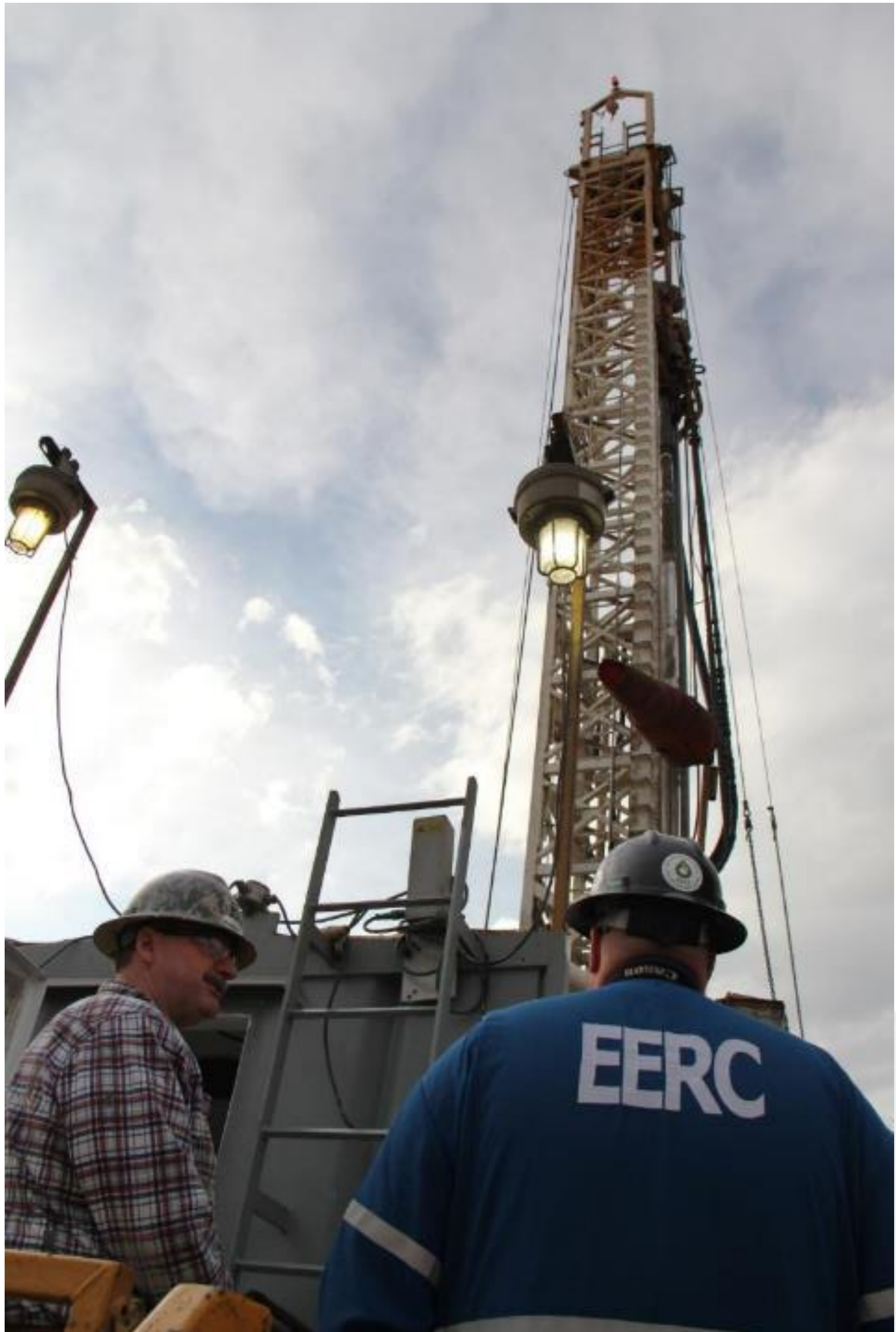
Committed partners, leverage stakeholder experience.

Maintain an up-to-date risk register, mitigate risks where prudent, incorporate flexibility where possible, robust designs and contingency plans, be adaptive as conditions change.

Large field tests have elevated risks and dynamic conditions.

Risk, cost, and objectives must be managed together.

Field data should be expected to be complex; traditional strategies for data management and interpretation may not be sufficient.



PROJECT SUMMARY

- Key Findings:
  - The field trials showed injection is a greater contributor to reservoir pressure than extraction, but extraction can reduce reservoir pressure in certain scenarios.
  - 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.
    - ♦ Additional simulation to pursue scalability is being evaluated.
  - 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.

- Next Steps:
  - Evaluation of varying ARM implementation and optimization steps for CO_2 injection guided by preliminary results using the history-matched model.
  - Complete field trials and analysis of brine treatment technologies.
  - Project reporting and knowledge sharing.

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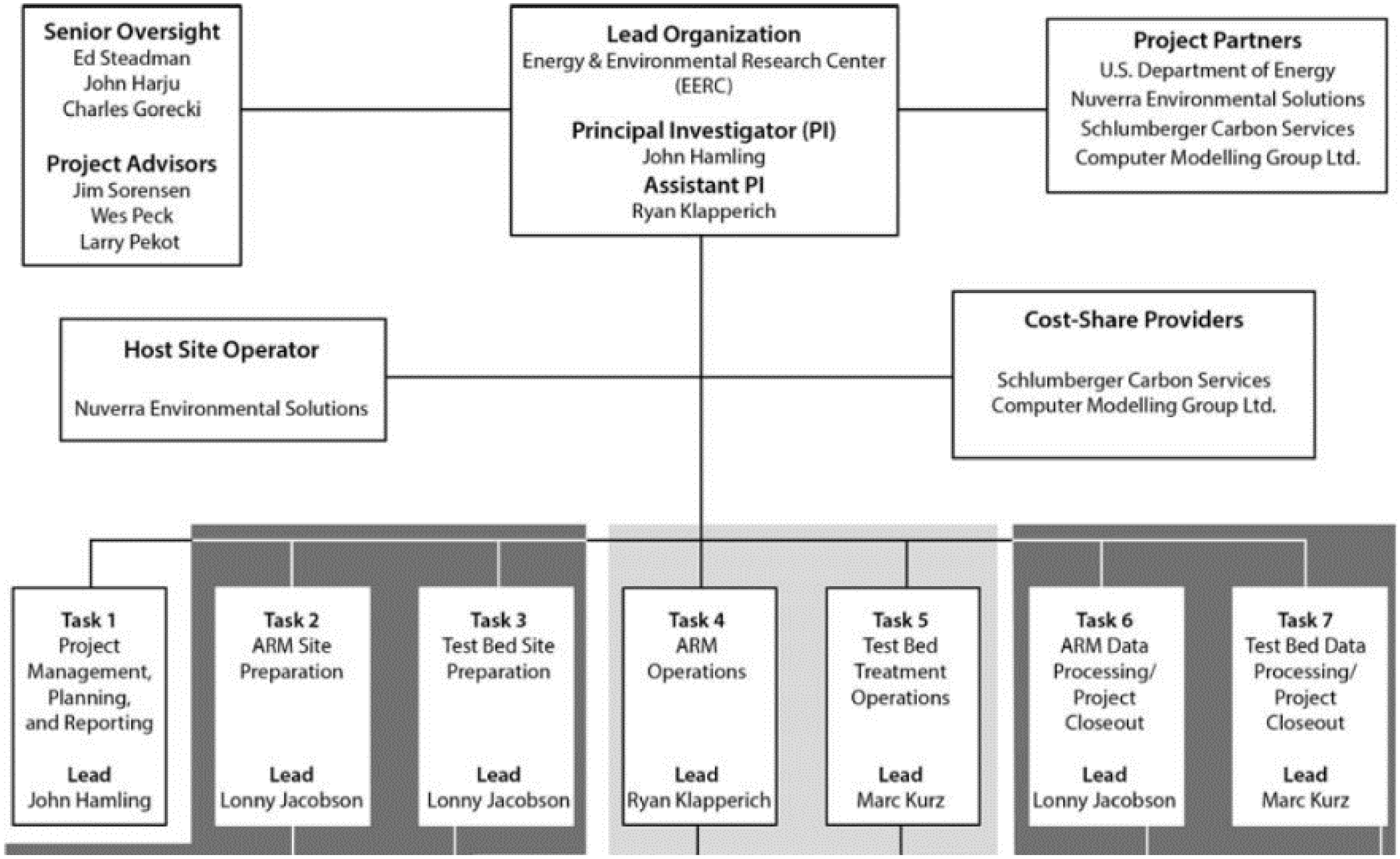
APPENDIX

BENEFITS TO THE PROGRAM

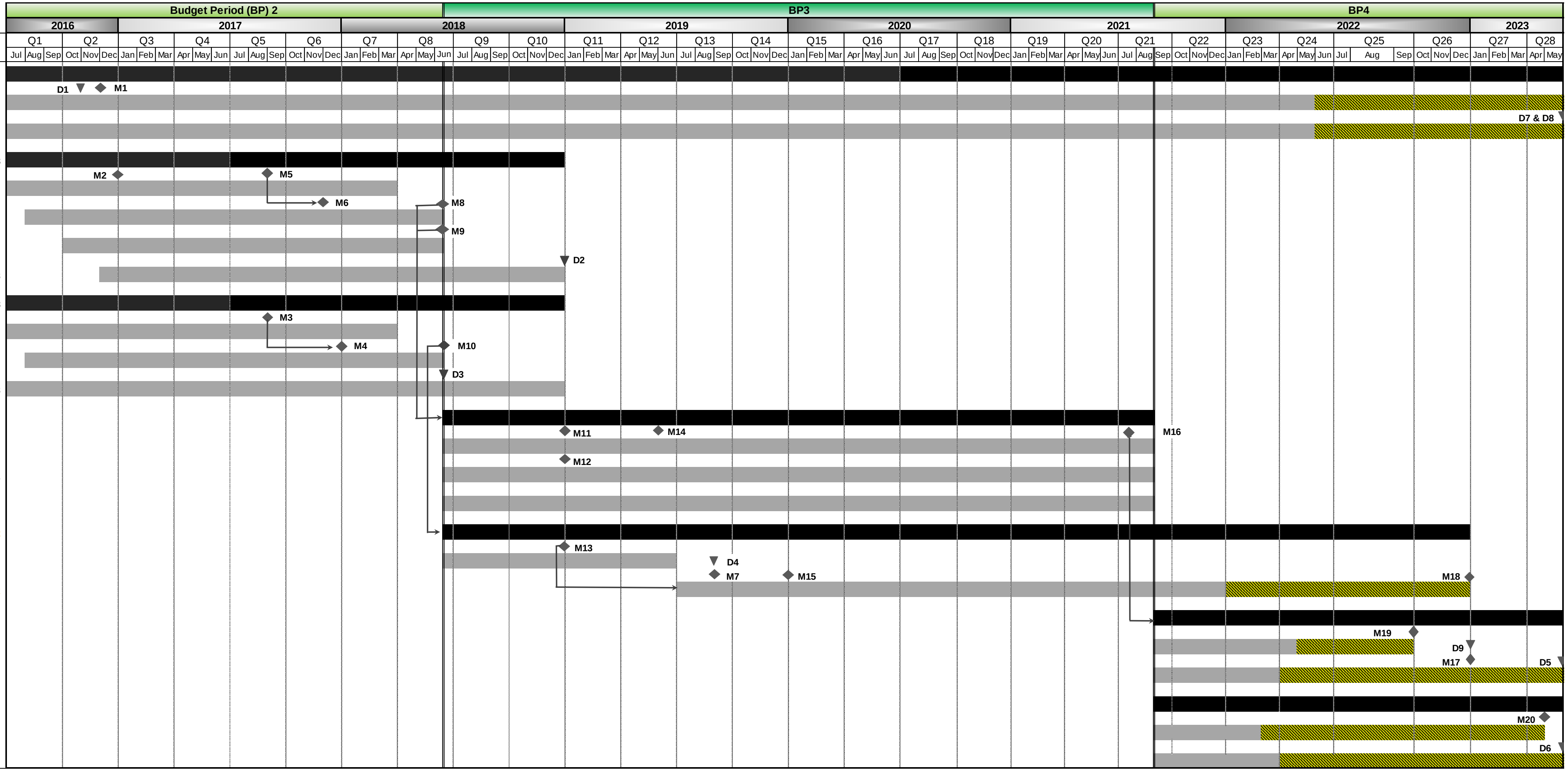
This project is expected to result in the development of engineering strategies/ approaches to quantitatively effect changes in differential formation pressure and to monitor, predict, and manage differential pressure plume movement in the subsurface for future CO_2 saline storage projects. Additionally, 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.

ORGANIZATION CHART



Gantt Chart, Deliverables, and Milestones

Task	Start Date	End Date
Task 1.0 – Project Management, Planning and Reporting	**7/7/16**	**5/31/23**
1.1 – Project Management	7/7/16	5/31/23
1.2 – Project Reporting	7/7/16	5/31/23
Task 2.0 – ARM Site Preparation	**7/7/16**	**12/31/18**
2.1 – ARM Permitting	7/7/16	3/31/18
2.2 – Well Installation	8/1/16	6/15/18
2.3 – Surface Infrastructure Installation	10/1/16	6/15/18
2.4 – Updated Site Characterization and Modeling	12/1/16	12/31/18
Task 3.0 – Test Bed Site Preparation	**7/7/16**	**12/31/18**
3.1 – Test Bed Facilities Permitting	7/7/16	3/31/18
3.2 – Test Bed Facility Installation	8/1/16	6/15/18
3.3 – Solicitation of Treatment Technologies	7/7/16	12/31/18
Task 4.0 – ARM Operations	**6/16/18**	**8/31/21**
4.1 – Injection/Extraction Testing	6/16/18	8/31/21
4.2 – MVA Implementation	6/16/18	12/31/21
4.3 – Model Updates/History Matching	6/16/18	8/31/21
Task 5.0 – Test Bed Treatment Operations	**6/16/18**	**12/31/22**
5.1 – Facility Shakedown/Training	6/16/18	6/30/19
5.2 – Long-Term Performance Evaluations	5/1/19	12/31/22
Task 6.0 – ARM Data Processing/Project Closeout	**9/1/21**	**5/31/23**
6.1 – ARM Site Decommissioning/Disposition	9/1/21	9/30/22
6.2 – Finalization of ARM Test Results	9/1/21	5/31/23
Task 7.0 – Test Bed Data Processing/Project Closeout	**9/1/21**	**5/31/23**
7.1 – Test Bed Decommissioning/Disposition	9/1/21	4/30/23
7.2 – Finalization of Test Bed Results	9/1/21	5/31/23



Note: The contract modification for Phase II was fully executed on September 9, 2016.

Deliverables ▼

- D1 – Updated PMP
- D2 – Field Implementation Plan (FIP) Finalized
- D3 – Water Treatment Technology Selection Process Summary
- D4 – Preliminary Schedule of Technologies
- D5 – Vol. 1 – ARM Engineering and Evaluation Summary
- D6 – Vol. 2 – Technology Evaluation Report
- D7 – Data Submission to EDX
- D8 – Lessons Learned Document
- D9 – Time-Lapse BSEM Sensitivity Study Results

Milestones (M) ◆

- M1 – Project Kickoff Meeting
- M2 – Permit to Drill Submitted
- M3 – Water Treatment Test Bed Permit Received
- M4 – Start Water Treatment Facilities Construction
- M5 – Permit to Drill Received
- M6 – Start Site Preparation
- M7 – First Treatment Technology Selected
- M8 – Well Installation Complete
- M9 – Surface Installation Complete
- M10 – Water Treatment Facilities Complete
- M11 – Initiate Stage 1 of Experimental Scenario
- M12 – Initiate Collection of Operational Data
- M13 – Water Treatment Test Bed Fully Operational
- M14 – Initiate Stage 2 of Experimental Scenario
- M15 – First Treatment Technology Evaluated
- M16 – Completion of ARM Operations
- M17 – BSEM Time-Lapse Sensitivity Study Complete
- M18 – Completion of Water Treatment Technology Demonstration
- M19 – ARM Site Decommissioning/Disposition Completed
- M20 – Water Treatment Test Bed Decommissioning/Disposition Completed

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