Chemically Enabled CO_2-Enhanecd Oil Recovery in Multi-Porosity, Hydrothermally Altered Carbonates in the Southern Michigan Basin

DE-FE-0031792

DOE FOA-1988

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October 13, 2020. DOE Annual Review

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Outline

- Program Overview, Goals, and Objectives
- Technology Background
- Technical Approach
- Progress and Current Status of Project
- Plans for Future Testing/Development/Commercialization
- Summary

Project Overview

- Project Cost:
  - DOE Funds- $7,999,659
  - Cost Share- $2,153,668
  - **Total Cost- $10,153,327**

- Period of performance: October 2019-March 2024

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INNOVA EXPLORATION, INC.

CORE ENERGY, LLC

WESTERN MICHIGAN UNIVERSITY

THE UNIVERSITY OF TEXAS AT AUSTIN

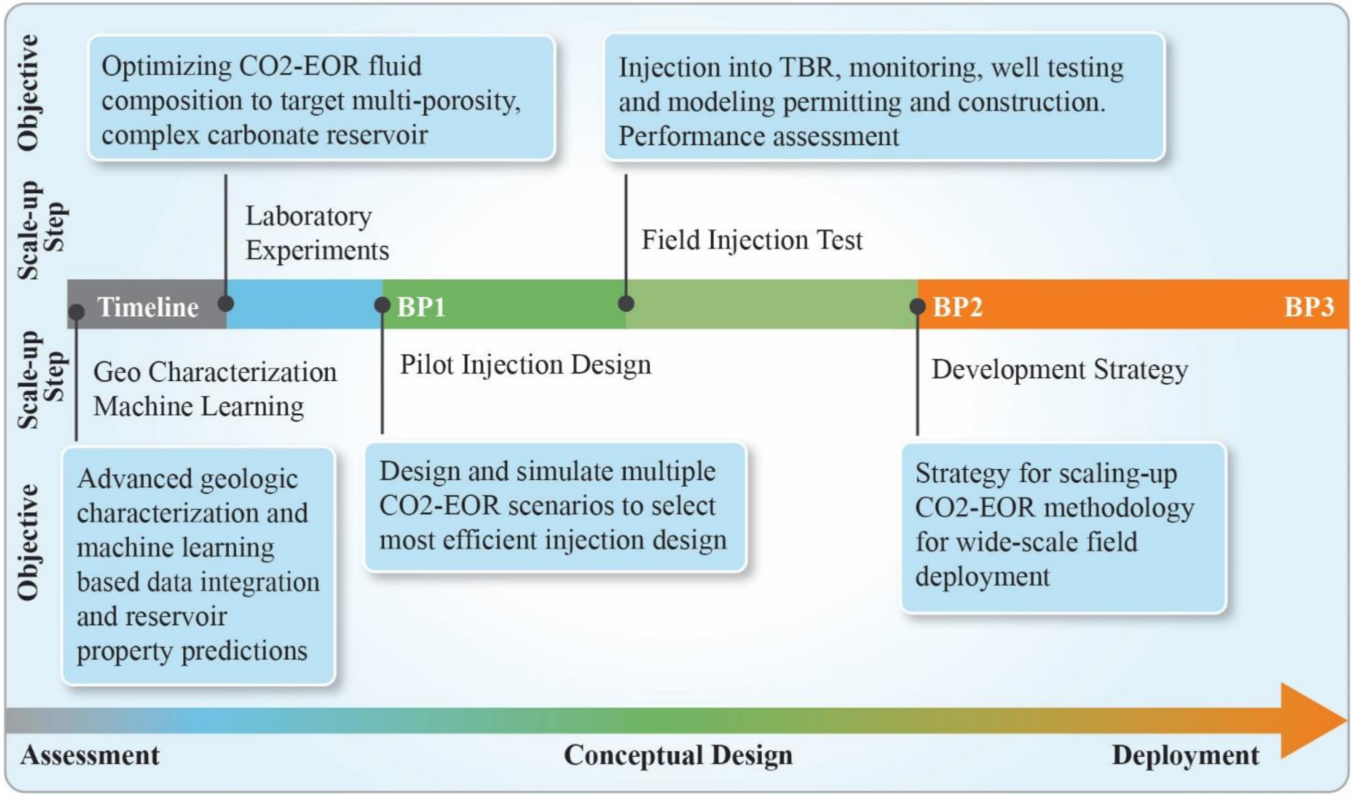
sasol

DTE Energy

Valero

Project Goals and Objectives

- Carry out a **comprehensive laboratory experiment, computer modeling, and field testing-based evaluation** of **chemically enabled CO_2-EOR** in the **Southern Michigan Basin conventional Trenton/Black River play** to **optimize recovery in a complex, multi-porosity, hydrothermally altered carbonate**



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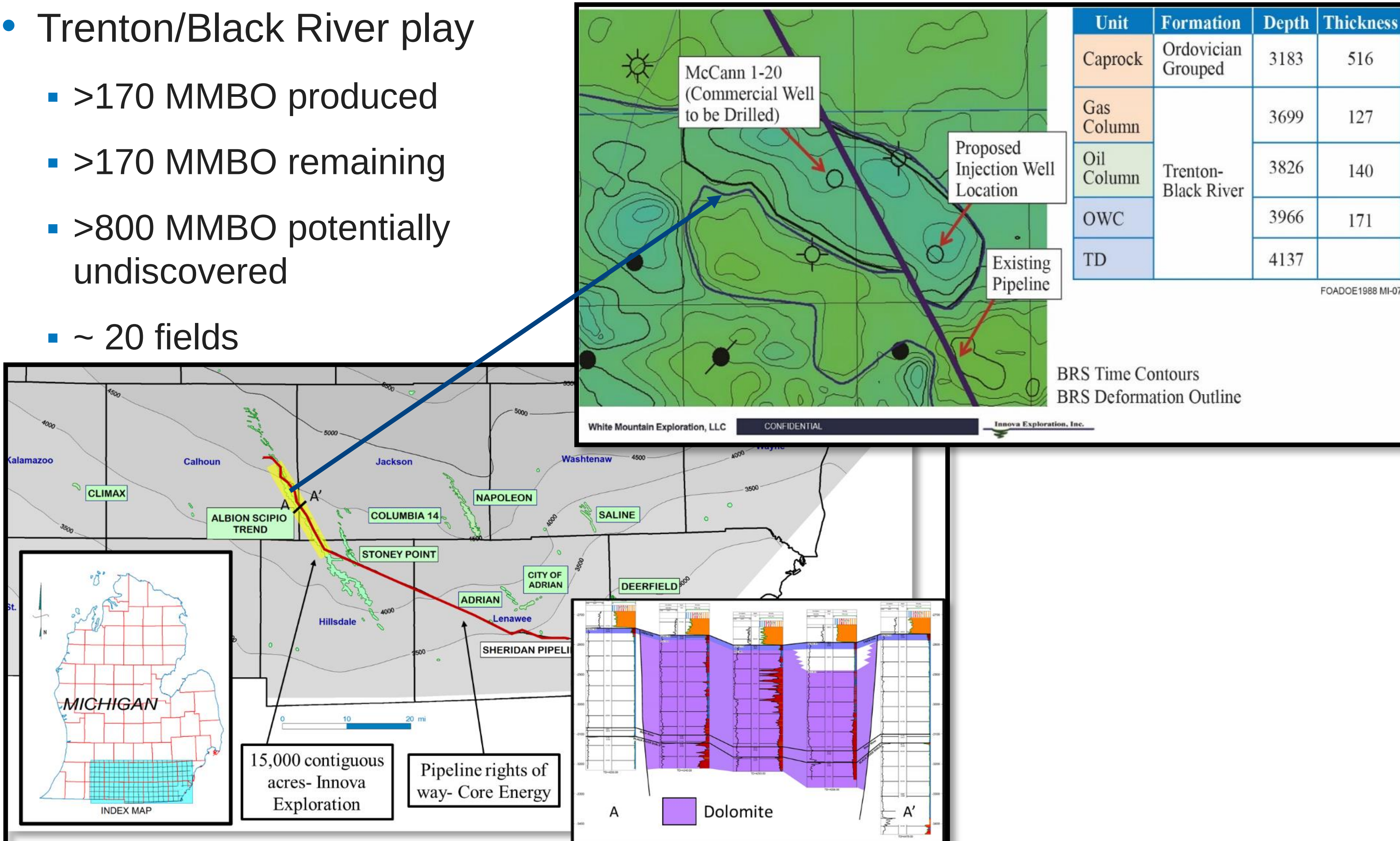
Project Setting- Significant Oil Potential

- Trenton/Black River play
  - >170 MMBO produced
  - >170 MMBO remaining
  - >800 MMBO potentially undiscovered
  - ~ 20 fields



Unit	Formation	Depth	Thickness
Caprock	Ordovician Grouped	3183	516
Gas Column	Trenton-Black River	3699	127
Oil Column		3826	140
OWC		3966	171
TD		4137	

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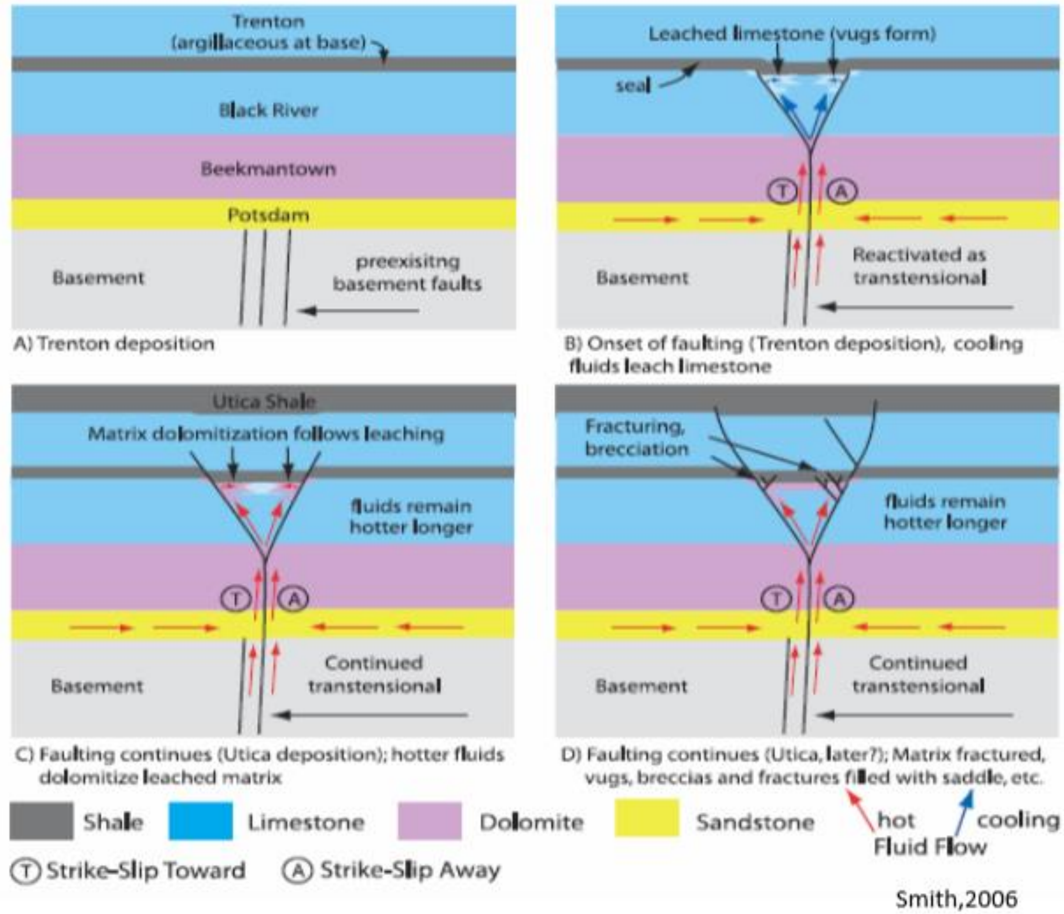
Project Setting- Complex Carbonate System

- Facies heterogeneity
- Dolomitization from hydrothermal fluids
- Zones of enhanced porosity and permeability from vugs and fractures



Albion-Scipio Field Information

Depth	OOIP	Total Production	Discovery Pressure	Current Pressure	Avg. Porosity	Avg. Permeability
3,550-4,000 ft	290 MMBO	135 MMBO	1593 psig	100-150 psig	4.8%	84.5 mD

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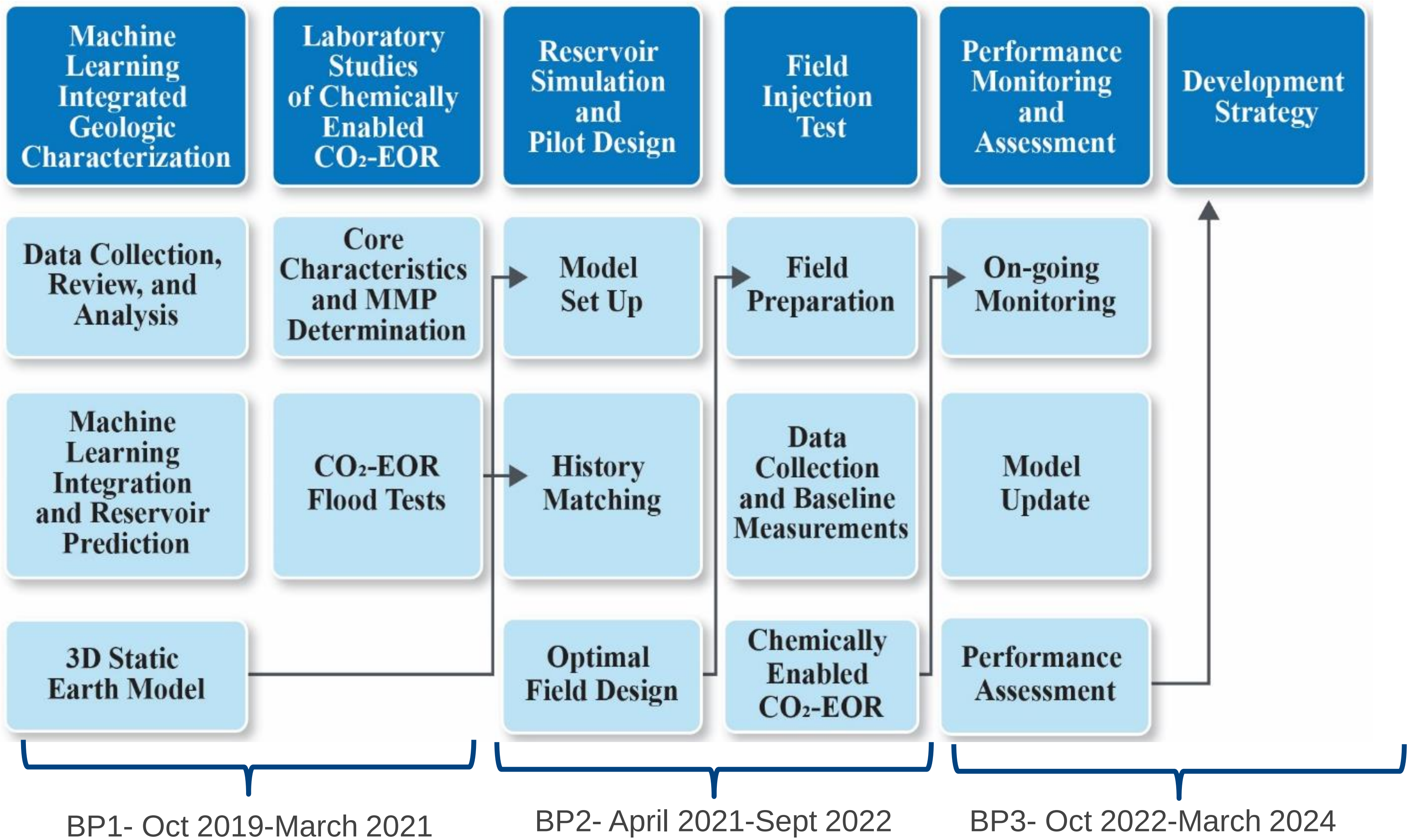
Project Setting - Rich, Extensive Database

- Detailed, digitized well records for all wells in the field
  - Construction, plugging, logging, etc.
- Digitized wireline log data for 1000+ wells
- Custom porosity & lithology logs for all wells in study area
- 13 mi^2 high resolution 3D seismic covering study area
- Core measured data available for ~60 wells across the TBR in Michigan
  - Porosity and permeability
  - Thin sections

Technical Approach



Project Success and Impacts

- We anticipate the following key outcomes and impacts:
  - First-of-a-kind comprehensive database and TBR characterization in southern Michigan
  - Understanding of the distribution and extent of vugs and fractures in the TBR reservoir using traditional ML and deep learning techniques
  - Laboratory experiment driven improved design of chemically-enabled CO_2 EOR which targets multi-porosity, complex carbonate reservoirs and improves flood efficiency
  - Modeling and field testing-based evaluation of the viability of chemically CO_2-EOR for stranded oil recovery in the TBR & similar HTD plays, along with field development plan.
- EOR advancements in the TBR in southern Michigan would be applicable to numerous fields and improved methodologies for enhancing oil recovery in complex carbonate systems.
- Project funding will initiate CO_2-EOR infrastructure in the Midwest, which will also lay the groundwork for future work and demonstrate the path forward in re-evaluating historical plays.
- This work will greatly benefit local oil and gas operators, CO_2 emitters and providers, and other industrial businesses.

Progress and Current Status

Task 2- Machine Learning Integrated Geologic Characterization

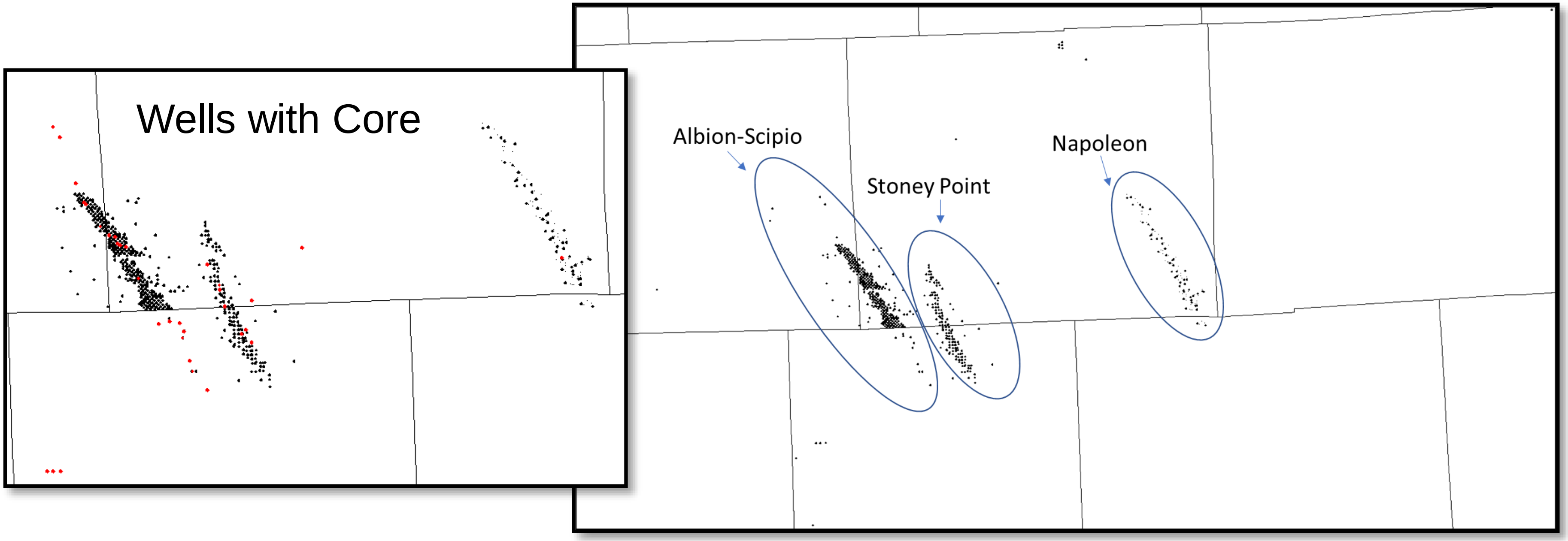
- Data collection, cleaning, and analysis→ integrated database
- Core workshop
- Development of petrophysical workflows
- Preliminary 3D seismic analysis
- Risk Assessment over AOI
- Development of data cleaning and exploration workflows
- Preliminary machine learning applications and results

Task 3- Laboratory Studies of Chemically Enabled CO_2-EOR

- Collection of oil samples from analog wells
- Review of existing PVT data
- Minimum miscibility pressure tests
- Chemical additive screening

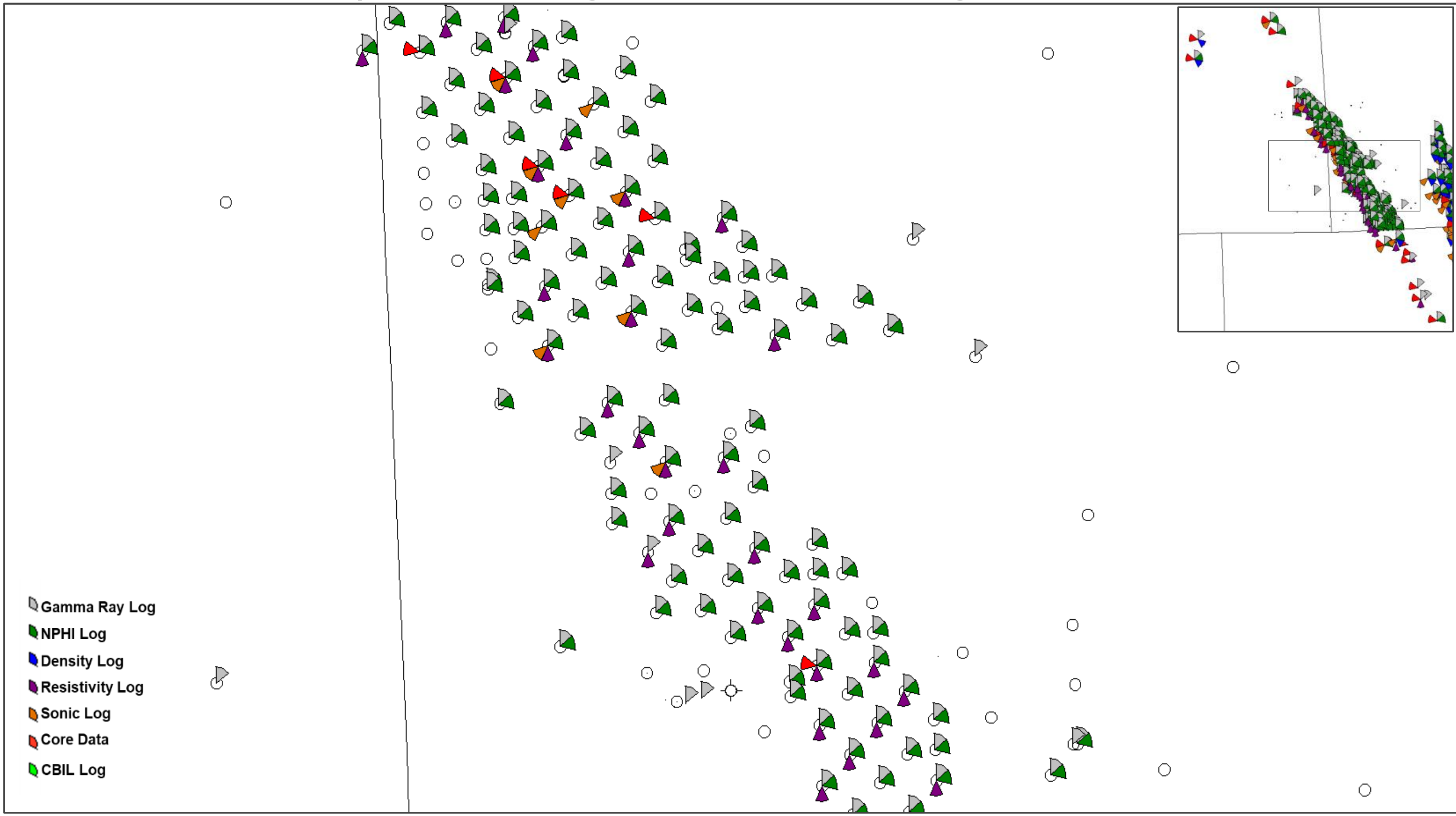
Data Compilation

- Focused on three main fields: Albion-Scipio, Stoney Point, and Napoleon
  - Albion-Scipio is the location of field test while Stoney Point and Napoleon are great analogs with modern data



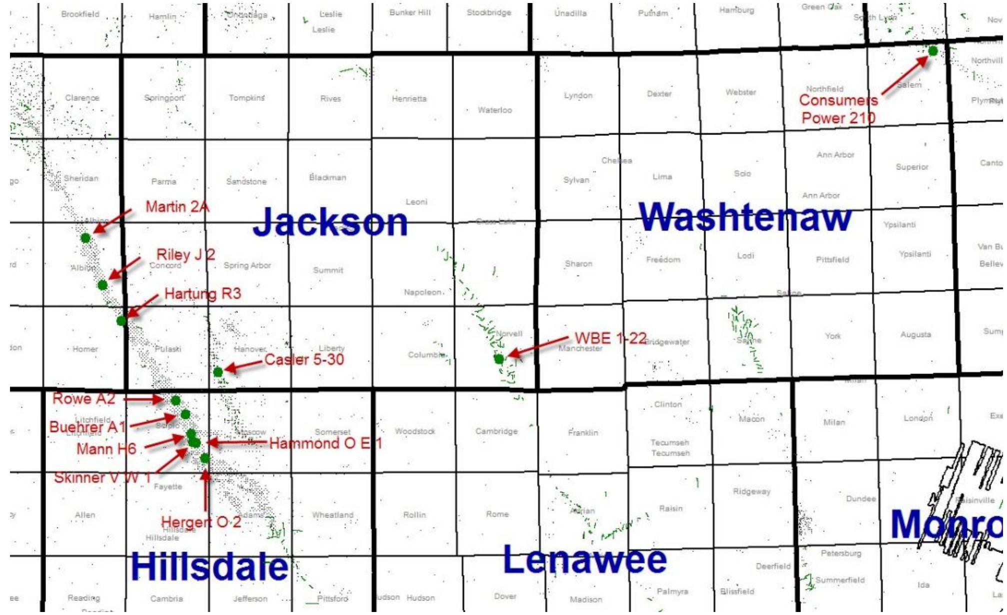
Data Compilation

Central Albion-Scipio Field Log and Core Coverage



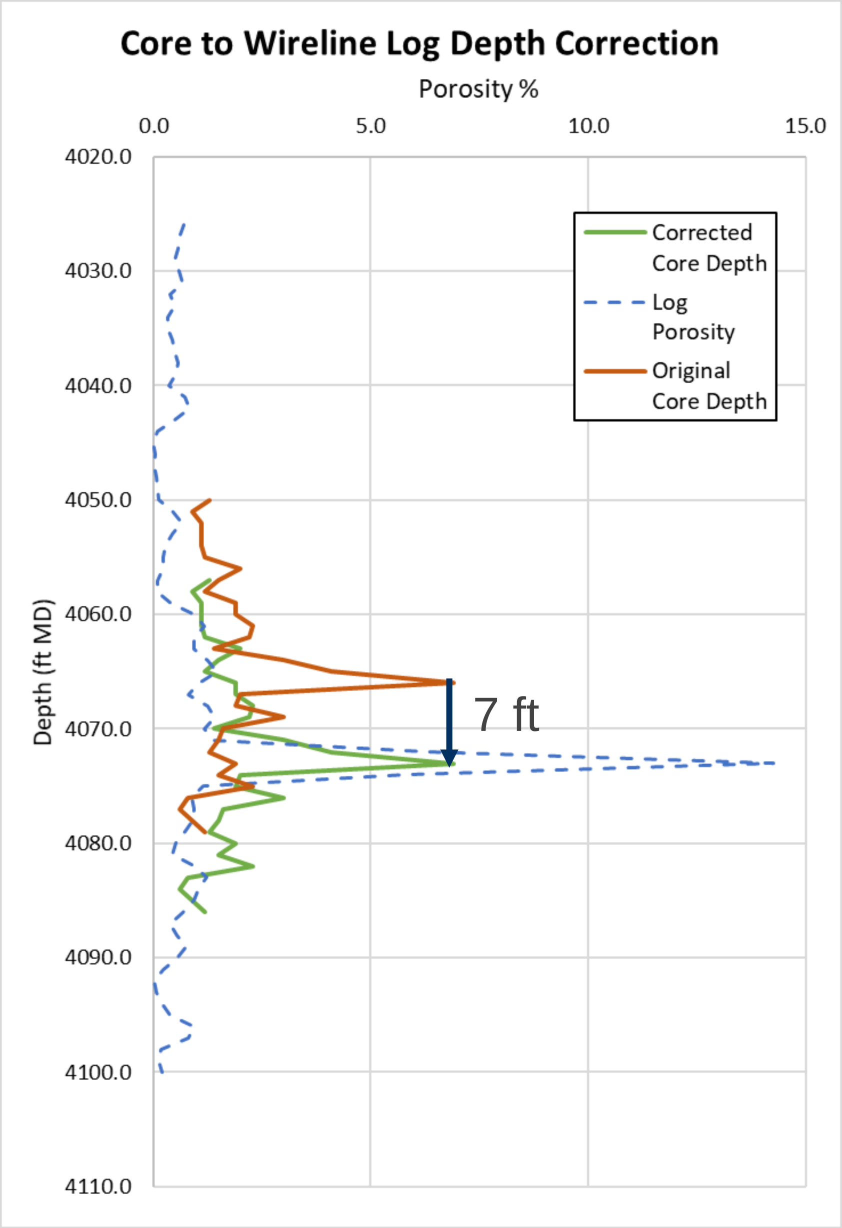
Core Workshop

- Examined 13 wells with core data
- Compared to facies descriptions, logs, and measured porosity/permeability
- Developed guidelines for consistent formation picks
- Began catalog of observable features (vugs, fractures, lithology, etc)



Depth Correction

- Correcting core depth to log depth for reliable correlations
- Example well shows improved correlation from .0004 to .85 by shifting depths by 7 feet
- Core data will be used in machine learning applications to better predict reservoir properties



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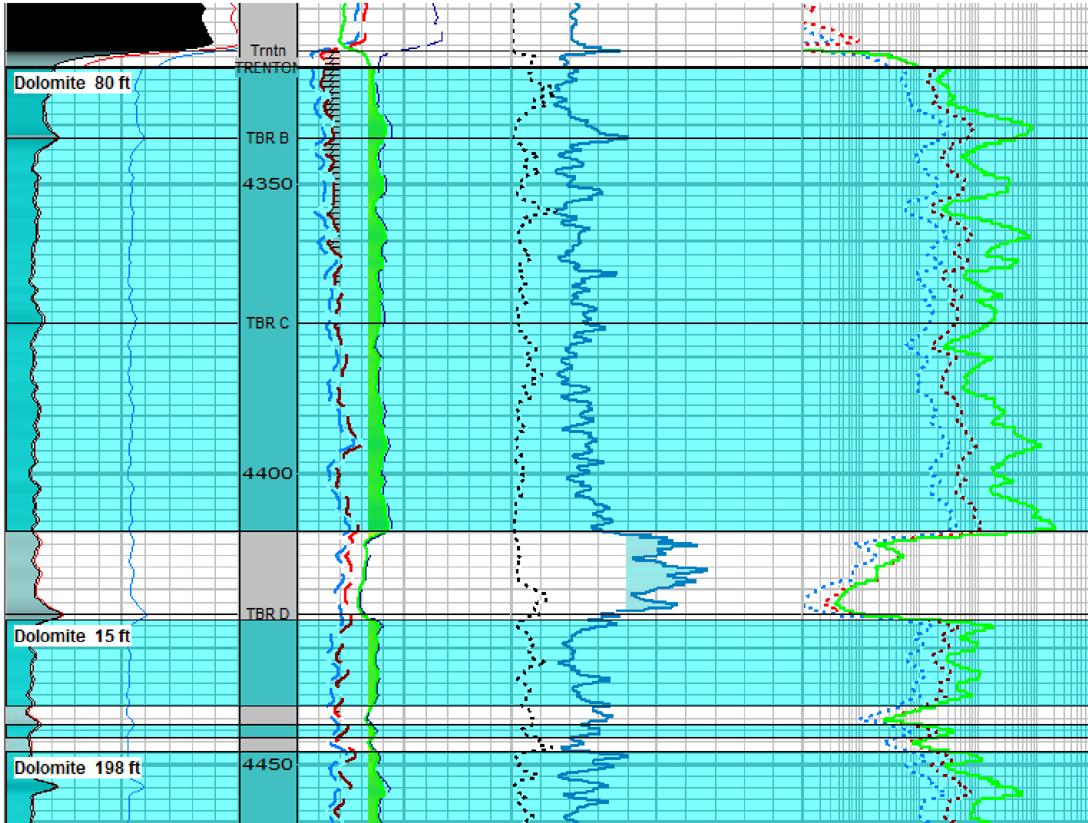
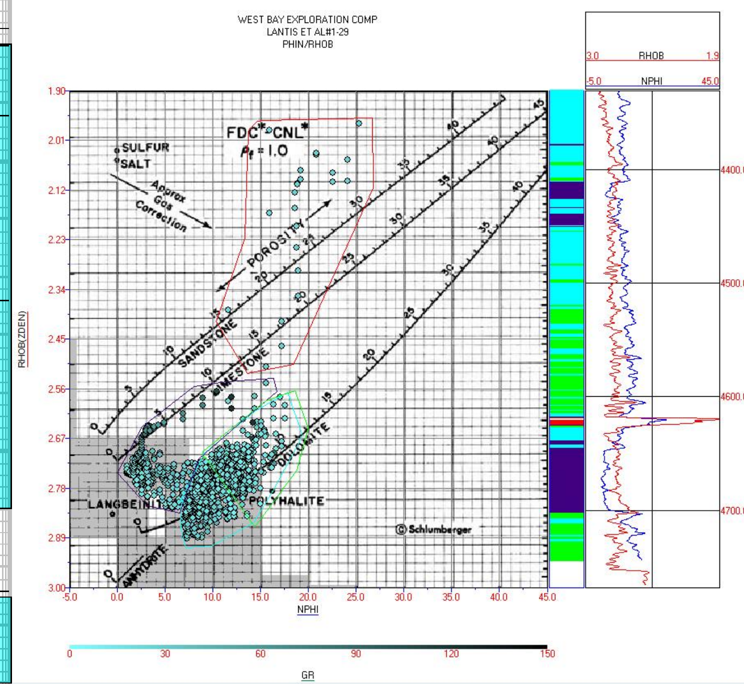
Petrophysical Calculations

- Finalized Vshale, effective porosity, and water saturation
- Applying permeability bulk transform from core, and Timur method of estimating permeability from logs





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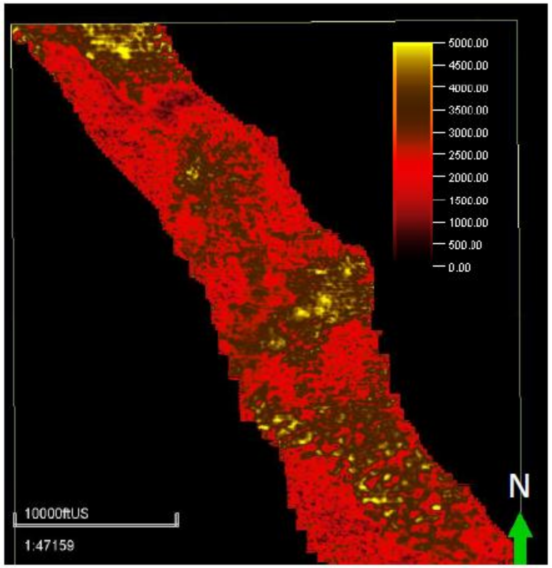
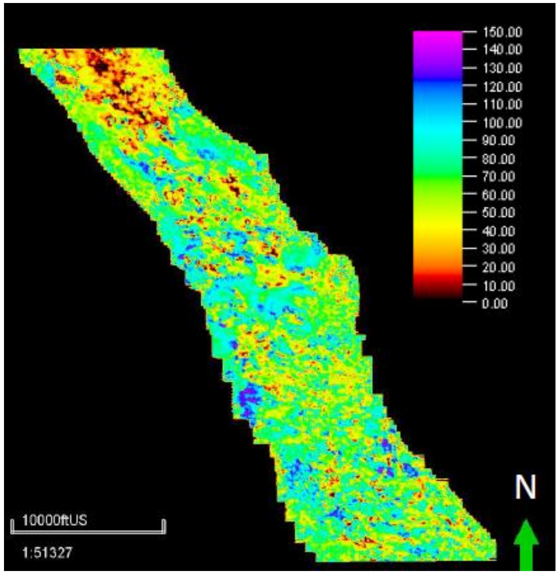
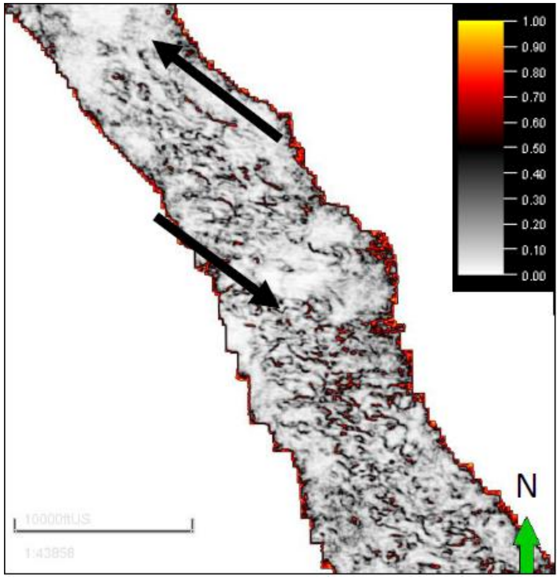
Seismic Analysis

- Preliminary analysis completed including:
  - Well ties
  - Horizon mapping
  - Attribute analysis
  - Fault identification
  - Inversion







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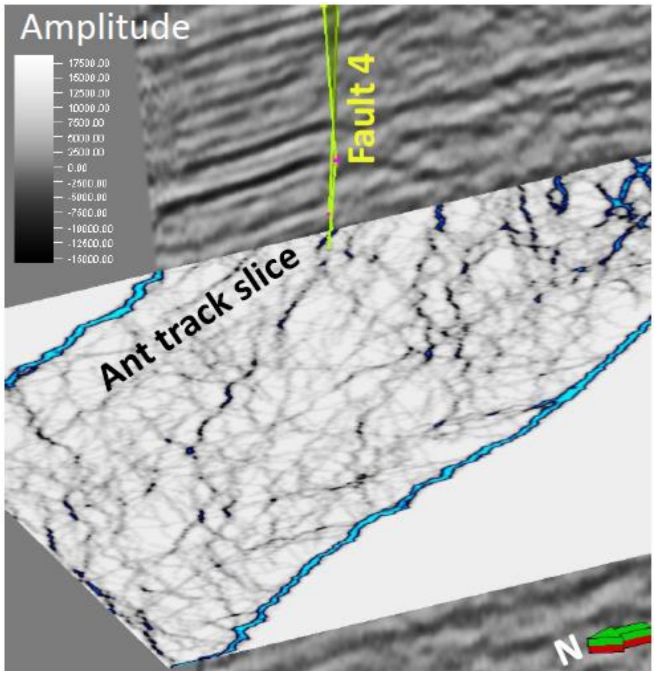
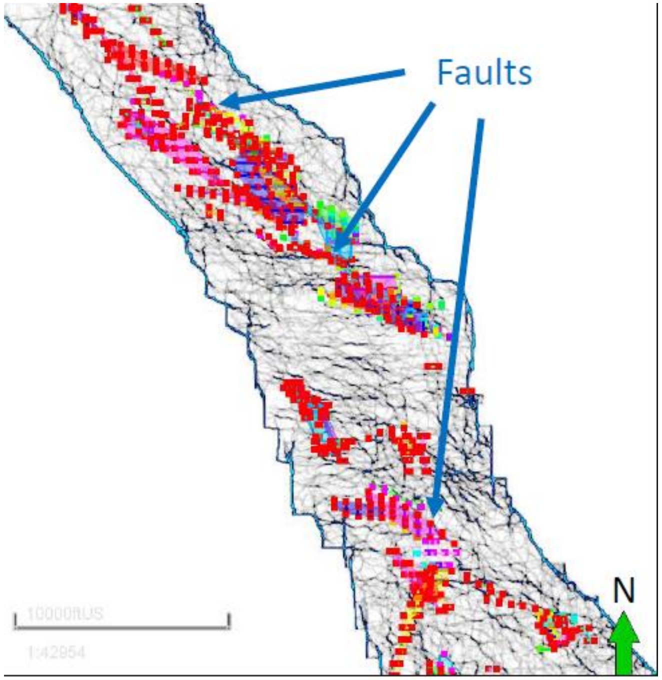
Seismic Analysis

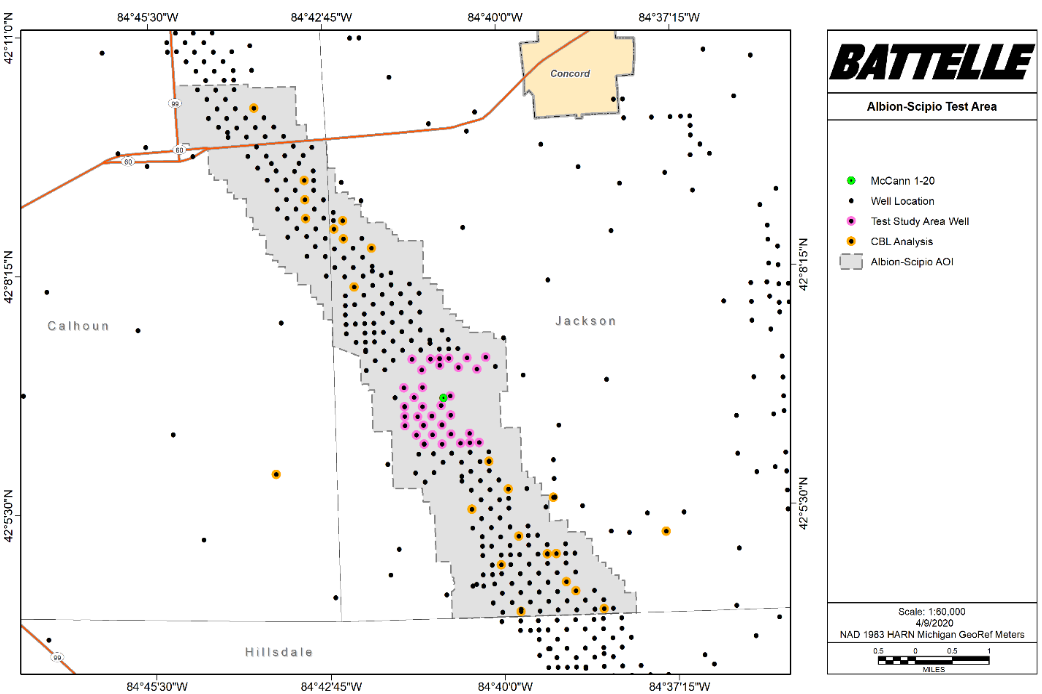
- >50 faults interpreted in the volume
  - Few large faults with several smaller faults

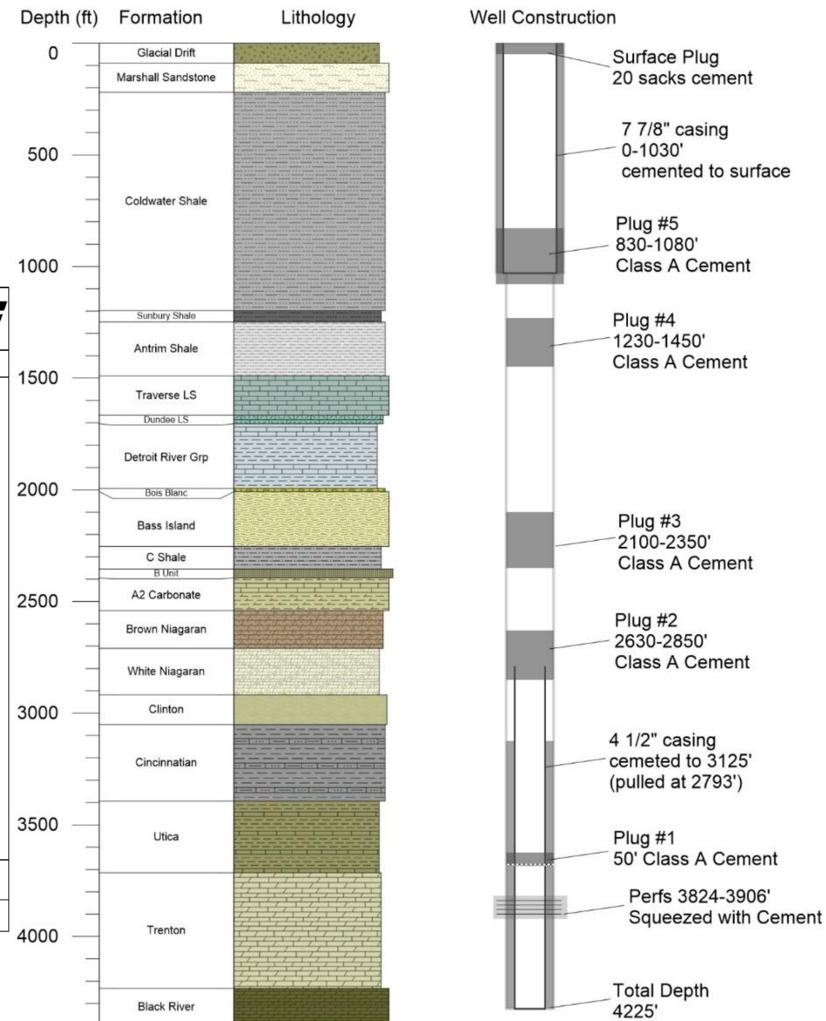




Risk Assessment- Wellbore Integrity

- Review of well records and cement bond logs to screen wells for potential WBI issues





Risk Assessment- Site Risk Screening

- Features, Events, and Processes (FEPs) review and activity-based analysis of project tasks

Description	Rating	Description	Rating	Description	Rating
Assessment Basis		*CO2 Interactions*		*Terrestrial Environment*	
Purpose of the assessment		Effects of Pressurisation of reservoir on caprock		Topography and Morphology	
Endpoints of Interest		Effects of Pressurization on reservoir fluids		Soils and Sediments	
Spatial Domain of Interest		Interaction with Hydrocarbons		Erosion and Deposition	
Timescale of Interest		Displacement of saline formation fluids		Atmosphere and meterology	
Sequestration Assumptions		Mechanical Processes and conditions	+	Hydrological regime and water balance	
Future Human Action Assumptions		Induced seismicity	++	Near-surface aquifers and surface water bodies	
Legal and Regulatory Framework		Subsidence or uplift		Terrestrial Flora and Fauna	
Model and Data Issues		Thermal effects on injection point		Terrestrial Ecological Systems	
Geological Factors		Water Chemistry		*Marine Environment*	
Neotectonics		Interaction of CO2 with chemical barriers		Coastal Features	
Volcanic and Magmatic Activity		Sorption and Desorption of CO2		Local Oceanography	
Seismicity		Heavy metal release		Marine Sediments	
Hydrothermal Activity	+	Mineral phase		Marine flora and fauna	
Hydrological and Hydrogeological Response		Gas Chemistry		Marine ecological systems	
Large Scale Erosion		Gas Stripping		*Human Behavior*	
Bolide Impact		Gas Hydrates		Human Characteristics	
Climatic Factors		Biogeochemistry		Diet and Food Processing	
Global Climate Change		Microbial Processes		Lifestyles	
Regional and Local Climate Change		Biomass Uptake of CO2		Land and water Use	
Sea Level Change		*CO2 Transport*		Community Characteristics	
Periglacial Effects		Advection of free CO2		Buildings	
Glacial and ice sheets effects		Buoyancy-driven flow	+	System Performance	
Warm Climate Effects		Displacement of formation fluids		Loss of Containment	
Hydrological and Hydrogeological Response to Climate Chan		Dissolution in formation fluids			
Responses to Climate Changes		Water mediated transport			
Future Human Actions		CO2 release processes			
Human Influences on Climate		Co-migration of other gases			
Motivation and Knowledge Issues		*Geology*			
Social and Institutional Developments		Geographical Location			
Technological Developments		Natural Resources			
Drilling Activities		Reservoir Type			
Mining and other underground activities		Reservoir geometry			
Human Activities in the surface Environment		Reservoir exploitation			
Water Management		Cap rock or sealing formation			
CO2 presence influencing future operations	++	Additional Seals			
Explosions and crashes		Lithology			
CO2 Storage Pre-Closure		Unconformities			
Storage Concept		Heterogeneities			
CO2 quantities, injection rate	+	Faults and Fractures			
CO2 composition		Undetected features			
Microbiological Contamination		Vertical Geothermal Gradient			
Schedule and Planning	+	Formation Pressure			
Pre-closure administrative control	+	Stress and Mechanical Properties			
Pre-closure monitoring of storage	+	Petrophysical Properties			
Quality Control	+	*Fluids*			
Accidents and unplanned events	+	Fluid Properties			
Over-pressuring	++	Hydrogeology			
CO2 Storage Post-Closure		Hydrocarbons			
Post-closure administrative control	+	*Drilling and Completion*			
Post-closure monitoring of storage	+	Formation Damage			
Records and markers	+	Well lining and completion			
Reversibility	+	Workover			
Remedial Actions	+	Monitoring wells			
CO2 Properties		Well Records			
Physical Properties of CO2		*Borehole Seals and Abandonments*			
CO2 phase behavior		Closure and Sealing of Boreholes			
CO2 solubility and aqueous speciation		Seal Failure			
		Blowouts			
		Orphan wells			
		Soil Creep around Boreholes			

Node 01: Well Preparation

NA

Prepare wells for characterization data gathering, hydrogeologic formation testing, fluid sample gathering and CO2 injection and monitoring.
Note: All workover and well preparation activities will be performed by Innova and its vendors. Battelle will be onsite periodically to observe and confirm that the wells are proper configuration for characterization activities.

During the well workover and preparation activities there are inherent HSE hazards. These hazards and mitigation measures will be addressed through Innova and its contracted vendors' HSE plans. Throughout these activities, Battelle representatives will be present periodically onsite as observers to track progress, performance and condition of wells. As an observer, the Battelle representatives need to be constantly aware of onsite conditions and remain clear of well preparation and workover operations.

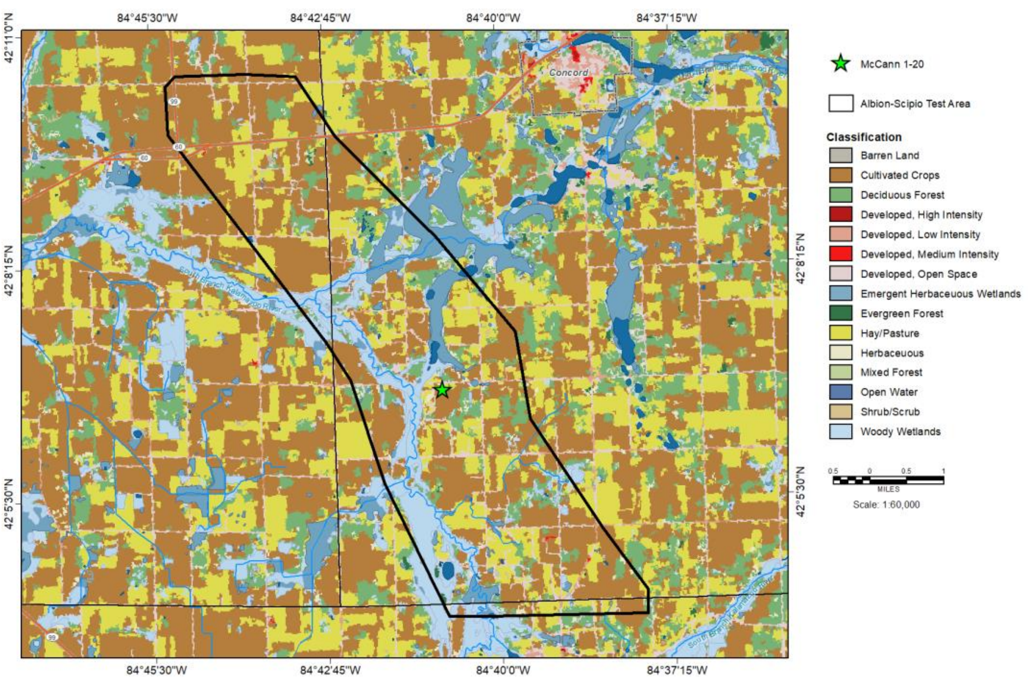
What If	Cause	No Safeguards					Safeguards		With Safeguards				Remarks/Findings
		Prob	Consequence	Severity	RAC		Admin	Engineering	Prob	Severity	RAC		
Can't pull rods out of well	Rods stuck in tubing	D – Remote	Strip tubing and rods out of well	IV – Negligible	D-IV	Low					-	?	
Can't pull rods out of well	Rods parted	C – Occasional	Fish rods or strip tubing and rods out of well	IV – Negligible	C-IV	Low					-	?	
Can't pull rods out of well	Down hole pump stuck	C – Occasional	Fish rods or strip tubing and rods out of well	IV – Negligible	C-IV	Low					-	?	
Can't pull tubing out of well	Salt or other type of bridge	C – Occasional	Shoot off tubing and mill over bridge – requiring additional time and expense	III – Marginal	C-III	Medium	Intermittent treatments on the well to dissolve the salt		D – Remote	III – Marginal	D-III	Medium	Risk level due to financial impact.
Can't pull tubing out of well	Casing collapse	D – Remote	Mill casing and install casing patch or plug well – requiring additional time and expense	III – Marginal	D-III	Medium	Run casing inspection logs		D – Remote	III – Marginal	D-III	Medium	Risk level due to financial impact.
Well blows out	Fluid level too low in well	C – Occasional	Loss of well control, release of CO2, possible release of brine and oil, possible personal injury	III – Marginal	C-III	Medium	Procedural requirements to maintain proper fluid level; Michigan DEQ requirements; SPCC plan and equipment; PPE		D – Remote	IV – Negligible	D-IV	Low	
Well blows out	Tubing BOP malfunction	D – Remote	Loss of well control, release of CO2, possible release of brine and oil, possible personal injury	III – Marginal	D-III	Medium	Daily function test on BOP; Michigan DEQ requirements; SPCC plan and equipment, PPE		D – Remote	III – Marginal	D-III	Medium	Amount of CO2 available for release is minimal.
Well is flowing	CO2 and other fluids migrating to surface	C – Occasional	Unable to log well. Possible loss of control, release of CO2, possible release of brine or oil.	IV – Negligible	C-IV	Low	Michigan DEQ requirements; SPCC plan and equipment				-	?	Amount of CO2 available for release is minimal.
Drop tubing in well	Elevators not properly latched	D – Remote	Possible damage to well, mill and/or fish to retrieve tubing, potential injury and/or property damage	III – Marginal	D-III	Medium	JHA, JSA, training; assign worker to double-check that they are properly latched; PPE		E – Improbable	III – Marginal	E-III	Medium	
Drop tubing in well	Slips not properly set or malfunctioned	C – Occasional	Possible damage to well, mill and/or fish to retrieve tubing, potential injury and/or property damage	III – Marginal	C-III	Medium	JHA, JSA, training; assign worker to keep an eye on the slips; PPE		E – Improbable	III – Marginal	E-III	Medium	
Tubing separates	Bad or cross-threaded tubing connection	D – Remote	Possible damage to well, mill and/or fish to retrieve tubing	III – Marginal	D-III	Medium	Visual inspection; proper handling of tubing		E – Improbable	III – Marginal	E-III	Medium	Risk level due to financial impact.
Drop something down well	Accident	C – Occasional	Cause delay in project, fish or mill out object or push to bottom of well. For source, fish source out of well or plug and abandon well by filling from top to bottom with cement (NRC requirement)	III – Marginal	C-III	Medium	Good housekeeping; tool insurance	Cement the borehole in place (if backfilling).	E – Improbable	IV – Negligible	E-IV	Low	
Acid spills (HCl)	Break in line or leak at connection	C – Occasional	Possible personal injury and environmental damage	III – Marginal	C-III	Medium	Perform pressure test and visual inspection; Maintain safe pressure; PPE (face shield, gloves); Michigan DEQ requirements, SPCC plan and equipment		D – Remote	IV – Negligible	D-IV	Low	15% HCl. 500-1000 gallons onsite to pump into the well to dissolve debris
An obstruction is encountered in the casing	Bridge, foreign obstacle or collapse in casing	D – Remote	Unable to run tubing or packer, set bridge plugs, log, or swab or perform reservoir tests	IV – Negligible	D-IV	Low					-	?	
Set bridge plug at wrong depth in well	Incorrect depth correlation, premature set from stray current or human error.	D – Remote	Mill or retrieve bridge plug	IV – Negligible	D-IV	Low					-	?	
Bridge plug not holding pressure	Malfunction in bridge plug, set in bad spot in casing, set in casing collar,	D – Remote	Cause delay in project, mill out or retrieve bridge plug	IV – Negligible	D-IV	Low					-	?	
Tubing handling equipment malfunctions	Equipment worn out, not properly spec'd, not properly inspected	C – Occasional	Could result in worker injury due to impact of flying equipment	III – Marginal	C-III	Medium	Inspect handling equipment; Follow safe operation practices; JSA, PPE		D – Remote	IV – Negligible	D-IV	Low	
We incur a gas (methane) kick (pocket)	Naturally occurring	C – Occasional	Possible fire/explosion – fatality	III – Marginal	C-III	Medium	Ignition control practices; Make sure flow lines are properly constructed and secured; PPE, JSA, pressure readings	Well control devices (BOP, pressure control (lubricator)).	E – Improbable	IV – Negligible	E-IV	Low	

- No significant items found that would affect system safety/performance
- Wellbore integrity, geomechanical issues, and injection performance due to fractures highlighted

- No extremely high- or high-risk scenarios identified
- Typical oil field risk items which can be mitigated through safe drilling practices

Risk Assessment- Geohazards Analysis

- Review of environmental areas and potential geohazard risks such as seismicity and geomechanics
- Test area is mostly cropland, pasture, and mixed with forest and wetlands.
- Fractured reservoir has geomechanical risks which will be considered during modeling



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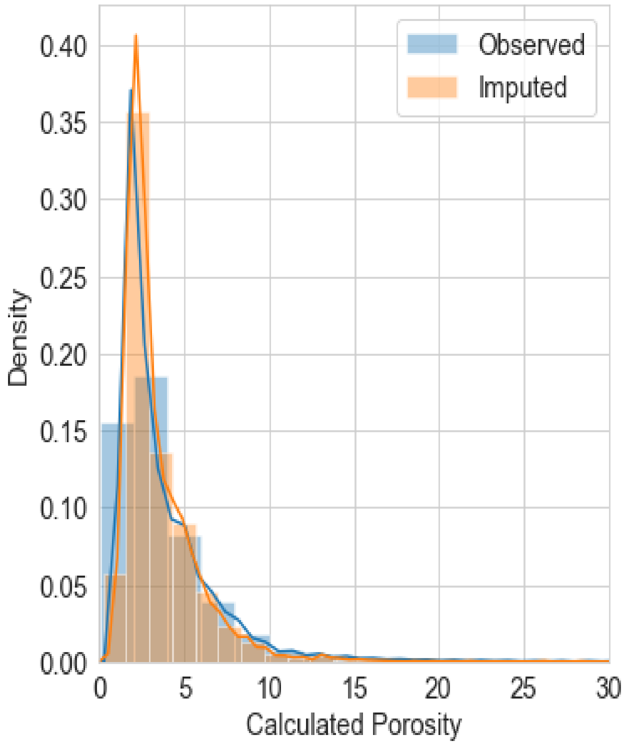
Data Analytics & Machine Learning

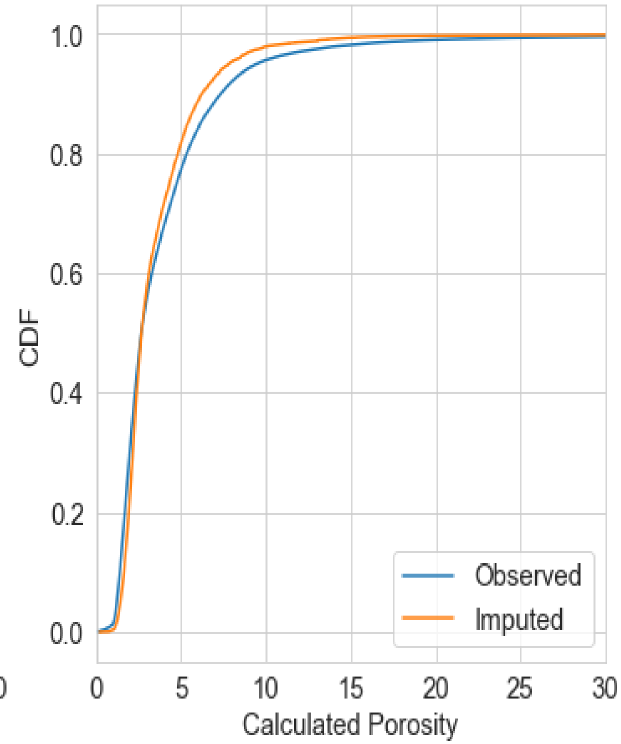
- Objective: Integrate multiple data types to predict key reservoir properties such as porosity, permeability, and fractures.
  - **Defining reservoir facies -** experienced based reservoir facies have traditionally been applied to interpret the TBR. ML techniques, such as principle component analysis and cluster analysis will be used to **identify and predict statistically significant facies** at all well locations
  - **Developing correlations and predictive model for acoustic properties-** Vintage log data only records Vp, so laboratory measurements will be used to develop correlations between Vs and Vp to **predict Vs from vintage acoustic logs**
  - **Identifying fracture network:** Deep learning **methods will be used to train and identify fractures and faults on 3D seismic slices** to develop a full fracture network across the study area. **In the absence of seismic dat**a, ML methods will be used to predict fractures from available wireline log data

Machine Learning

Filling in Missing Values (Data Imputation)

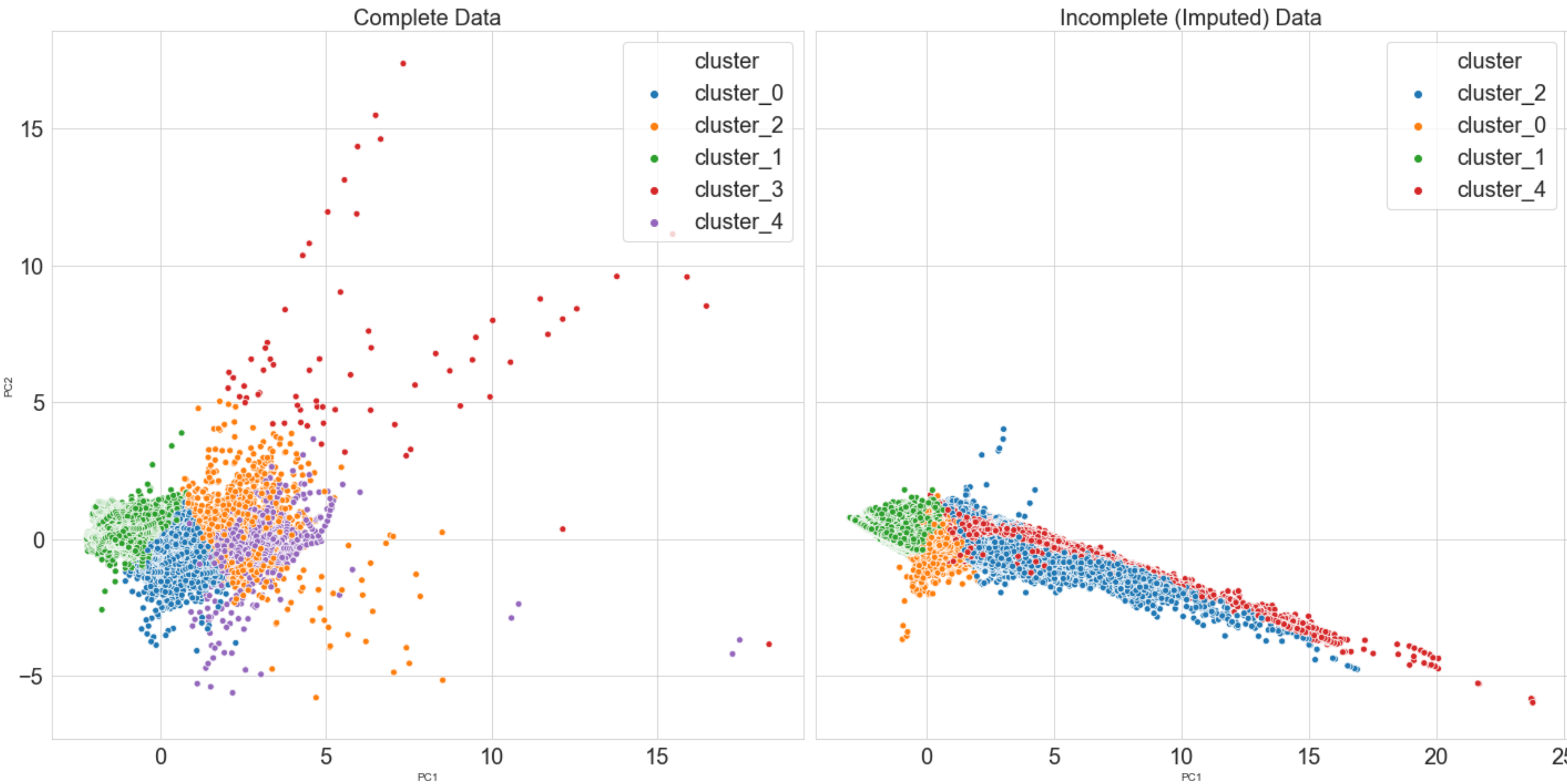
- Values for missing data are inferred using kNN (nearest neighbor interpolation with a moving window)
- The distributions of the imputed and observed values are consistent as shown in the histogram and CDF plots
- This creates a rich data set where all of the samples can be utilized for identifying electrofacies or building predictive models





Machine Learning

Cluster Analysis to Define Electrofacies



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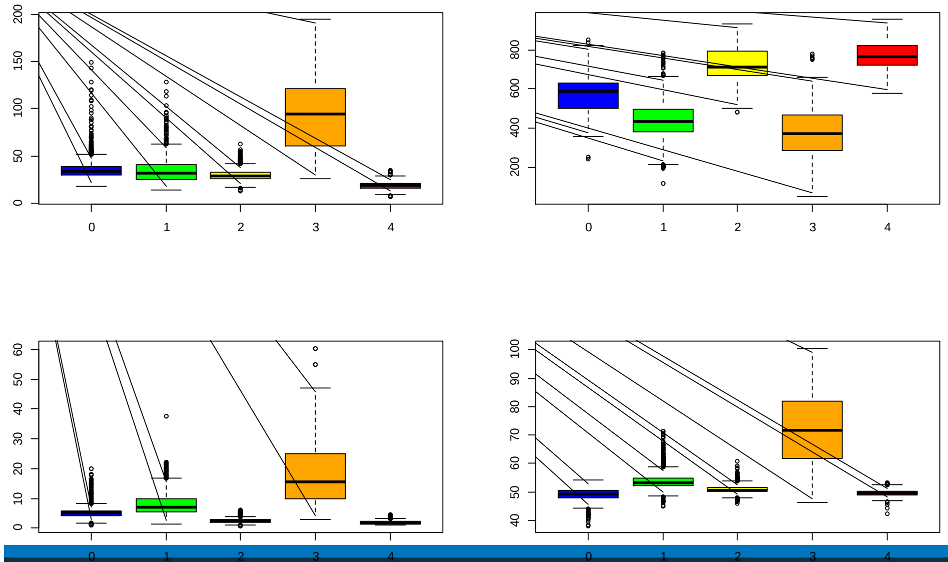
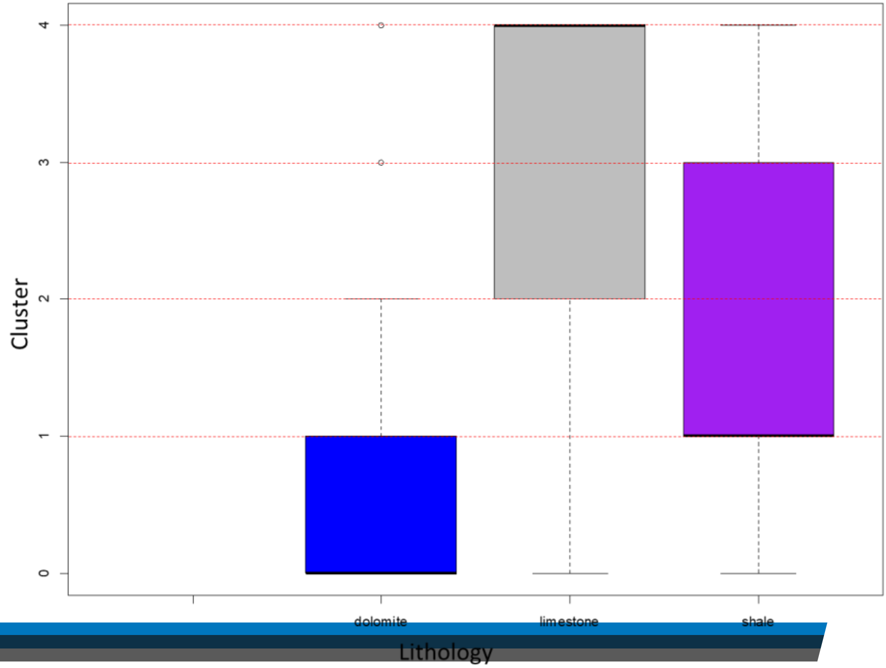
Machine Learning

Cluster Analysis Geologic Validation

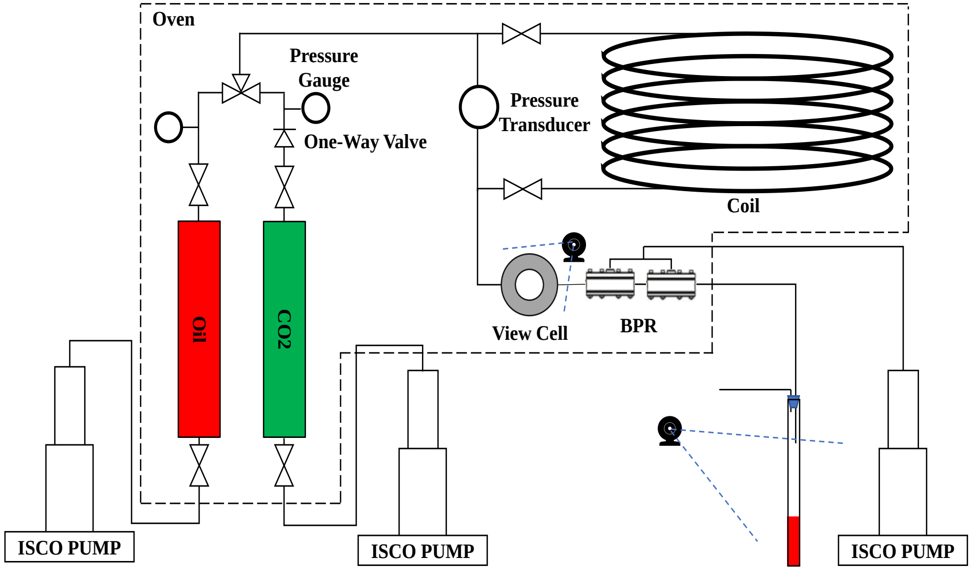
- Cluster 3 (orange) correlates with shaley intervals
- Cluster 2 and 4- tight limestone
- Cluster 0- moderate porosity (blue)
- Cluster 1- high porosity (green)





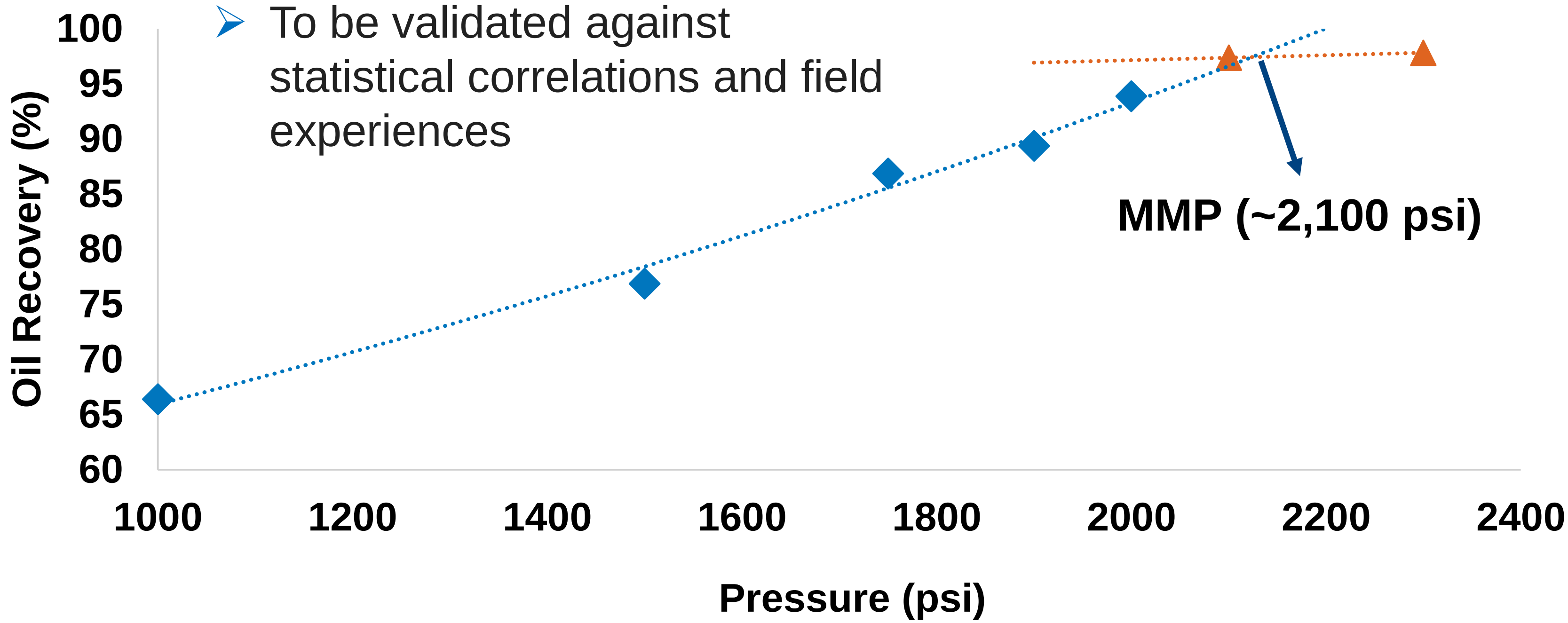
Task 3 MMP Test

- Minimum Miscibility Pressure (MMP) test parameters:
  - Type – Slim tube
  - Diameter: 0.26 in
  - Length: 20 ft
  - Porosity: 37.4%
  - Sand Mesh: 100-150
  - Temperature: 40°C
  - Pressure: 1000-3000 psi
  - Flow rate: 0.014 ml/min
  - Injection volume: 1.2-1.3 PV

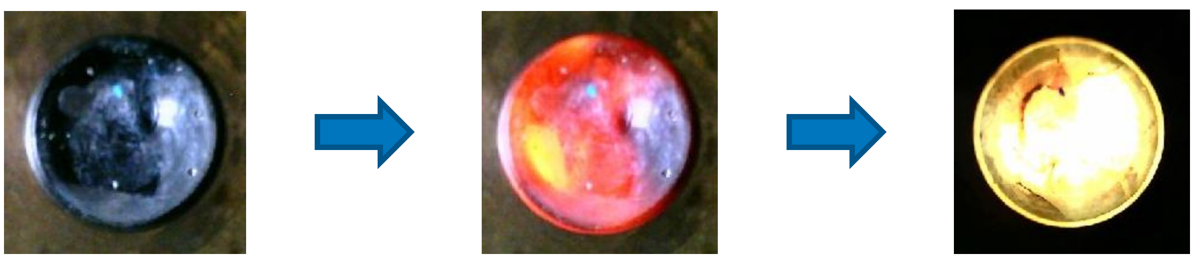


MMP Results

➢ To be validated against statistical correlations and field experiences

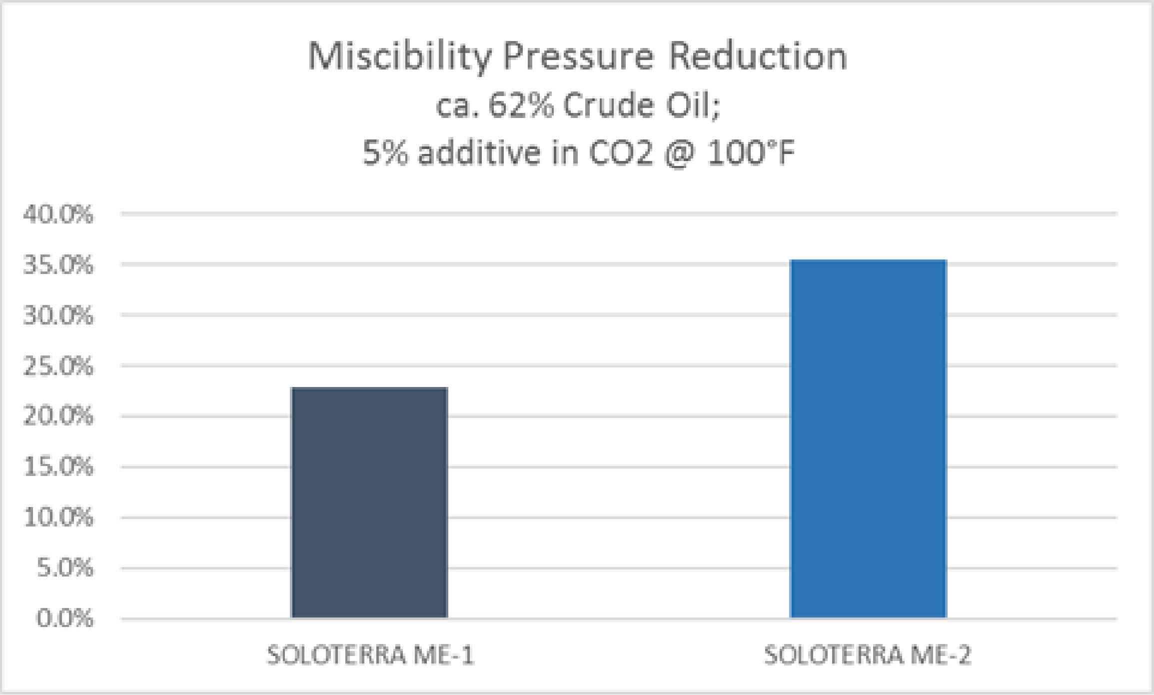


Oil cell visuals at 2,100 psi



Task 3 Chemical Additive Screening

- Sasol conducted testing of the crude oil for chemical additives
  - Identified two potential additives Soloterra ME-1 and ME-2 for further testing with UT



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Task 3- Testing Chemical Additives

- UT also tested Sasol’s Soloterra 843 as a foaming agent (surfactant plus brine)
- Produced stable foam with a half-life of 0.5 hours
- Foam stability increased with salinity (desired)
- Half-life was higher at higher salinities (desired)
- Addition of oil didn’t impact foam stability vs. salinity (positive sign)

Plans for Future Testing/Development/Commercialization

- Drilling of the monitoring/production well
  - Will collect modern logs, core samples, oil samples, and baseline monitoring data
- Preparing for field injection test
  - Develop plans/permits/etc to drill injection test well near the monitoring/production well
  - To be conducted in BP2
- Evaluation of test success and impact it could have on Albion-Scipio field
- Evaluation of potential impact on multiple TBR fields
- Integration of results into development plan

Project Summary

- Experienced unexpected delays due to changes in oil prices and COVID-19
- Project remained on track and focused on database compilation, analysis, and machine learning workflows
  - Extensive database of well information, wireline logs, core data, historical records, maps, etc
  - Workflows in place for consistent and efficient analyses
- Monitoring/production well to be drilled by end of the month

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It can be done

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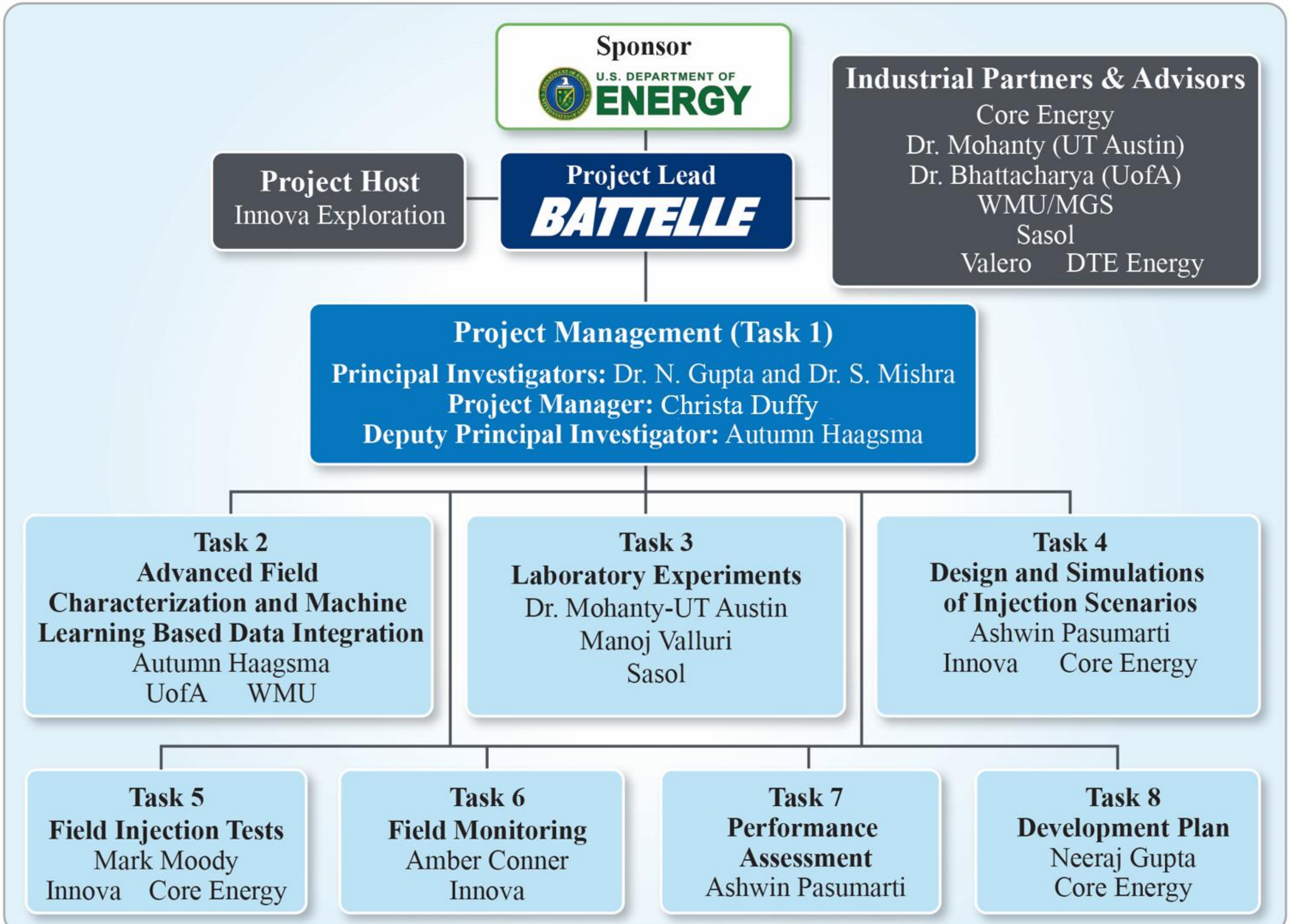
Appendix

Project Team



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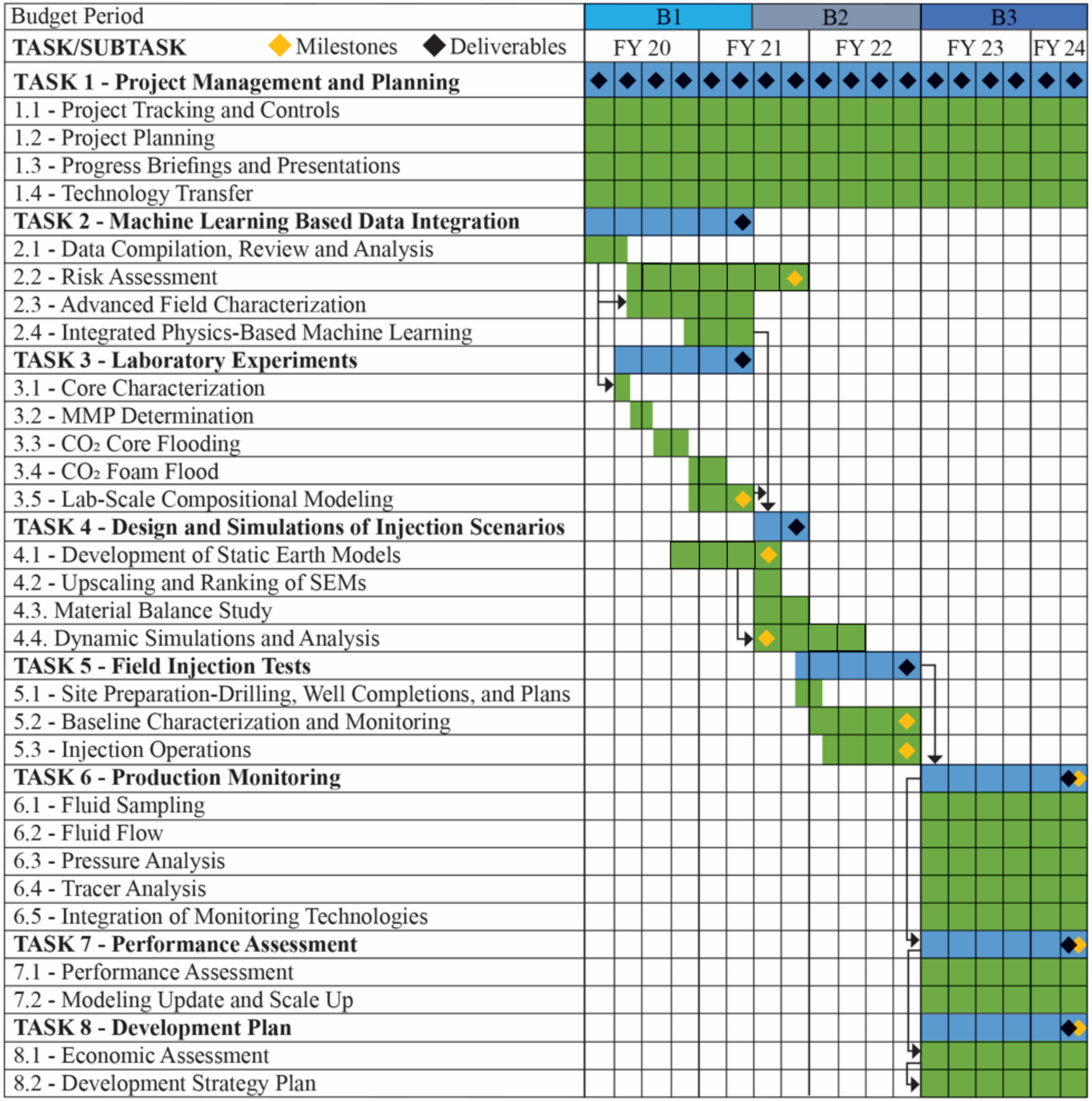
Project Schedule and Deliverables

- 3, 18-month budget periods spanning 4.5 years
- 8 tasks



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Project Risks

- Familiar with project risks and mitigations from previous project experiences
- Low to medium overall risks
- Multiple contingency plans to ensure project success

Perceived risk	Risk rating (Low, Med, High): Probability	Impact	Overall	Mitigation/response strategy
Financial risks:				
Field costs	M	M	M	Closely monitor field costs to stay within budget and scope
Cost share	L	L	L	Provide well use cost share; existing well and new wells planned, additional cost share available
Cost/schedule risks:				
Well availability	L	H	L	Engage committed operator: Innova Exploration
CO_2 source arrangements	L	H	M	Work with experienced and available vendor for CO2 sourcing
Operator schedule	L	M	M	Coordinate with operator; provide large time span for testing
Technical/scope risks:				
CO_2 injectivity in the TBR	M	H	M	Conduct core analysis and injection simulations; side-track well as needed; prolong test
Inability to fully monitor CO_2 flood	M	M	M	Deploy multiple monitoring methodologies
Lost circulation and wellbore integrity	L	M	L	Use comprehensive field characterization and well construction and completion plans
Management, planning, and oversight risks:				
Managing field work schedule, vendors, supplies	M	M	M	Work with operator to streamline field work

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Machine Learning

Data Imputation – Comparison of Methods

Boxplots highlighting the D-statistic using several machine learning models to impute data (note: the rightmost boxplots use an iterative process to impute data, the left boxplot is filling in points by using the k nearest points utilizing a distance metric which accounts for missing data).
The points in each boxplot are the D-statistic as a function of selected hyperparameters for each model.