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Critical Challenges. Practical Solutions.

Energy & Environmental Research Center (EERC)

SUBTASK 3.1 – BAKKEN RICH GAS ENHANCED OIL RECOVERY

DE-FE0024233

U.S. Department of Energy National Energy Technology Laboratory
Carbon Storage Virtual Project Review Meeting
October 13, 2020

Jim Sorensen
Director for Subsurface R&D

PRESENTATION OUTLINE

- **Background**
- **Subtask 3.1 – Bakken Rich Gas EOR Project**
  - **Activities and Status**
  - **Key Lab-Based Results**
  - **Stomping Horse Field Test Results**
  - **Advanced Modeling of Alternative EOR Strategies**
  - **Next Steps**

PARTNERS

ConocoPhillips

equinor

HESS

LIBERTY RESOURCES

Marathon Oil

OASIS PETROLEUM

PETRO - HUNT L.L.C.

WPXENERGY

XTO ENERGY

North Dakota oil & gas research program

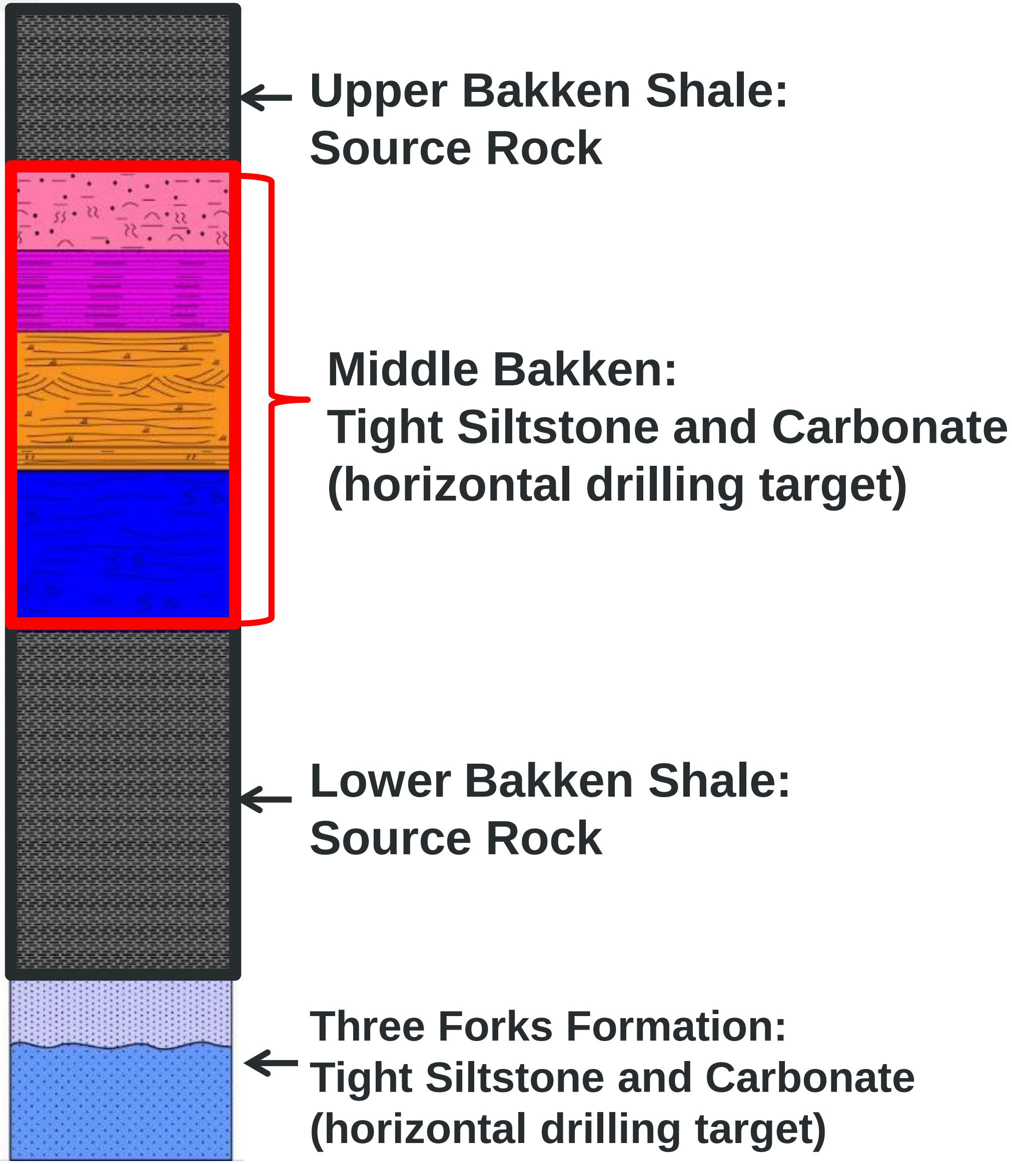
U.S. DEPARTMENT OF ENERGY

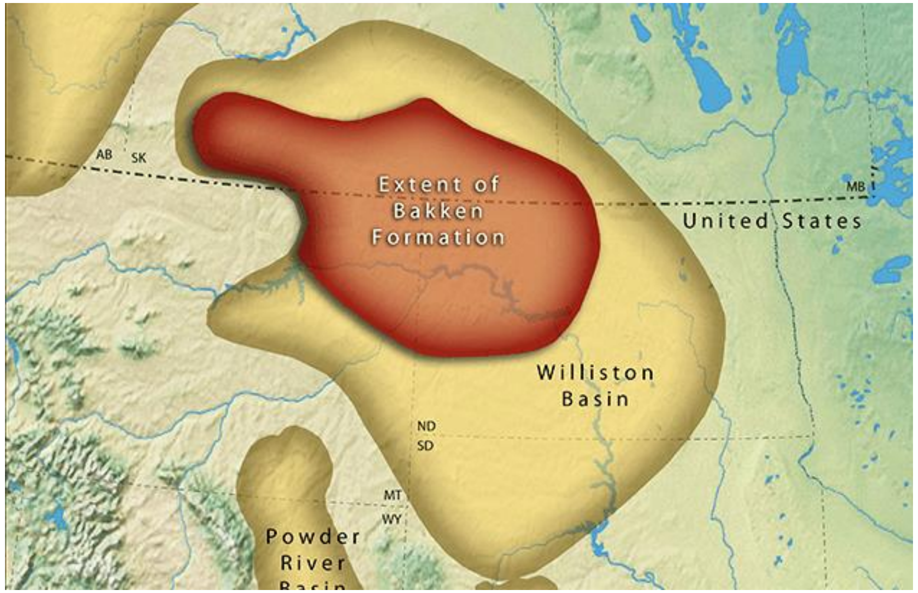
NATIONAL ENERGY TECHNOLOGY LABORATORY

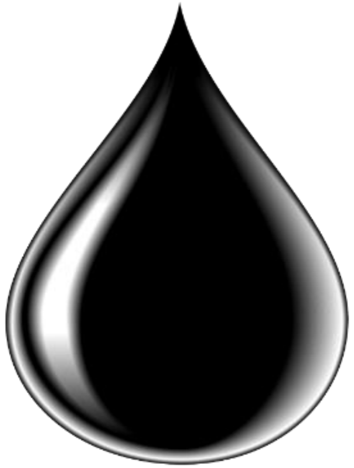
NORTH DAKOTA OIL AND GAS DIVISION

NORTH DAKOTA PETROLEUM COUNCIL

BAKKEN PETROLEUM SYSTEM





OOIP Estimate	Technically Recoverable Reserve Estimate
	
600 Bbbl (NDGS, 2011)	7.4 Bbbl (USGS, 2013)

LIBERTY'S STOMPING HORSE OIL & GAS COMPLEX

LIBERTY RESOURCES

NETL

North Dakota oil & gas research program

- Liberty Resources (LR) approached the EERC in December 2016 to explore partnering on an enhanced oil recovery (EOR) pilot test.

- In 2017, DOE NETL and the North Dakota Oil & Gas Research Program provided funding.

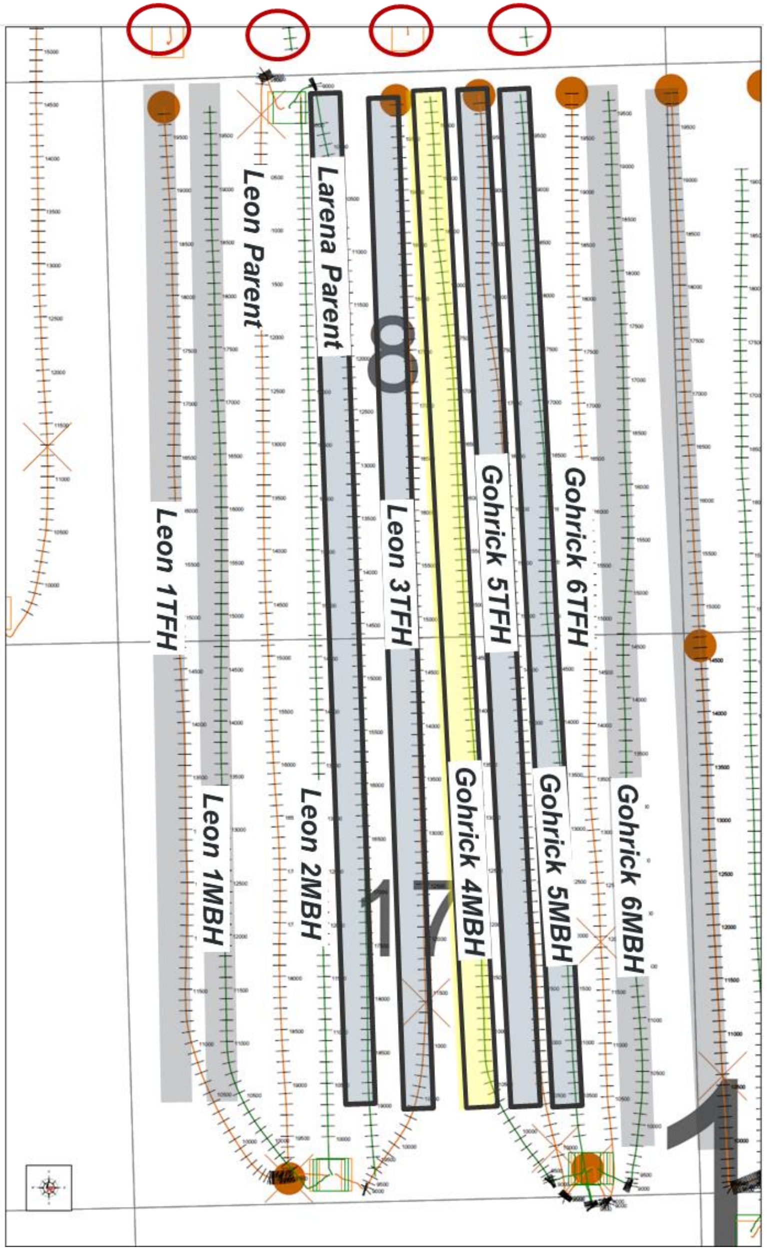
Boundary Well

Injection Well

Monitor Well BHP Gauge

Monitor Well Gas Chromatograph

Offset Operator Notification

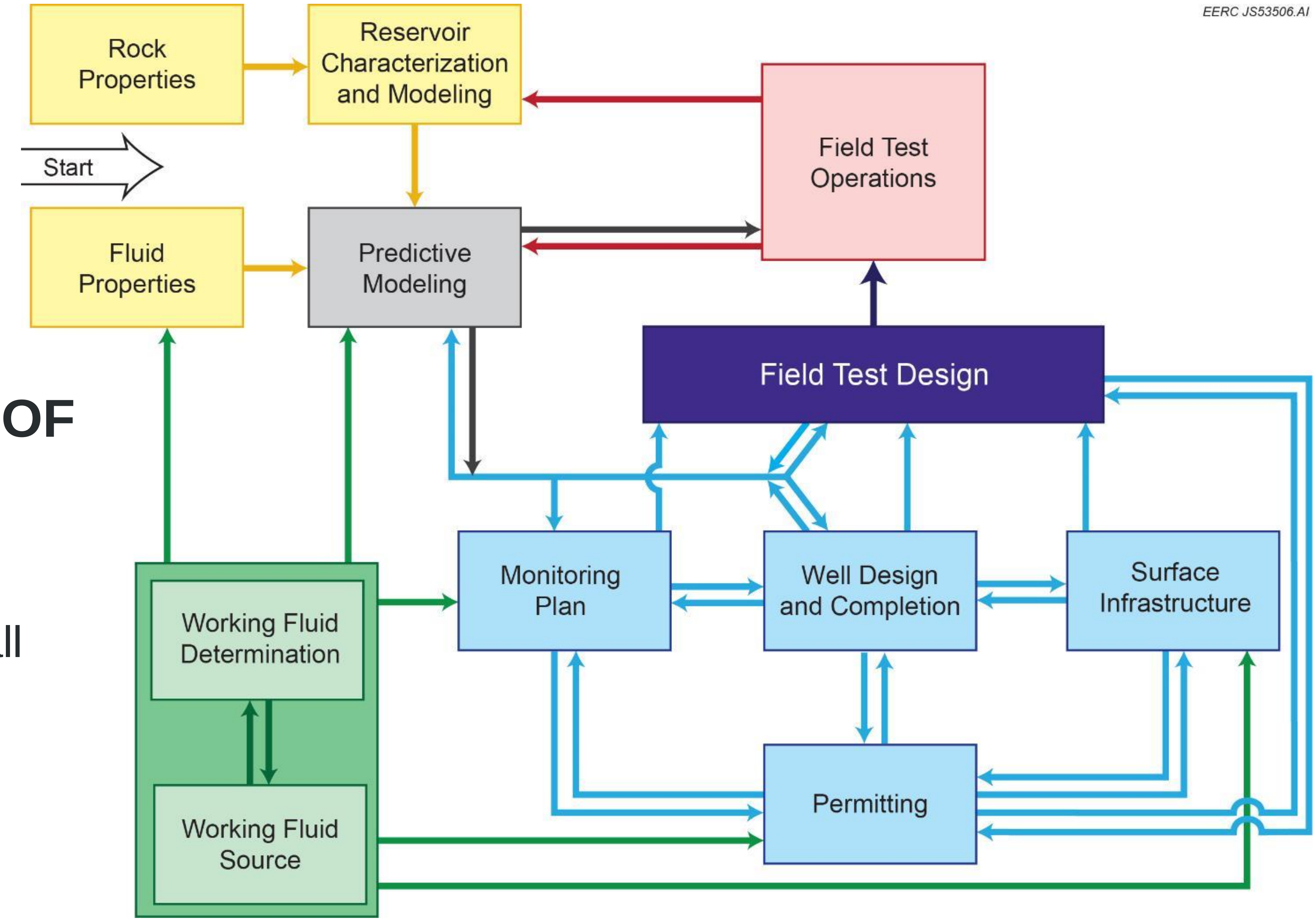


GOALS AND OBJECTIVES OF SUBTASK 3.1 PROJECT

Develop lessons learned to demonstrate how reinjecting captured produced gas can be used to increase ultimate recovery of the Bakken resource and reduce greenhouse gas emissions associated with flaring.

COMPONENTS OF AN EOR PILOT

The Subtask 3.1 project touches on all of these elements.

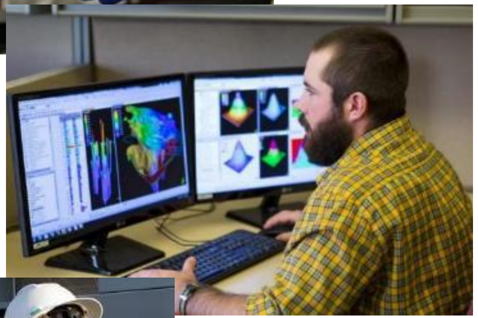


BUDGET

Sponsors	Budget	Actual Expenses Through September 2020	Notes
DOE (O&G Program)	$5,000,000	$3,337,847	Awarded.
NDIC (BPOP 2.0)	$1,565,891	$1,565,831	Awarded (completed).
NDIC (BPOP 3.0)	$375,000	$48,100	Request submitted to DOE on 9/20/2020 to recognize this additional cost share.
CMG (in-kind)	$334,400	$167,200	Commitment provided.
Total	$7,275,291	$5,118,978	

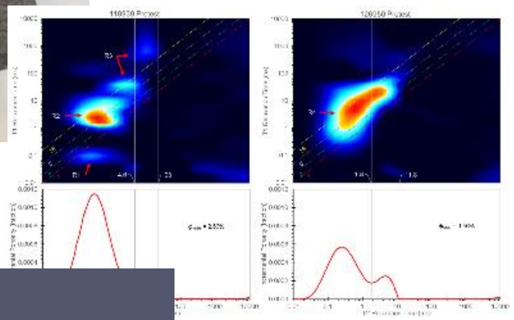
PROJECT TECHNICAL ACTIVITIES (2017–2020)

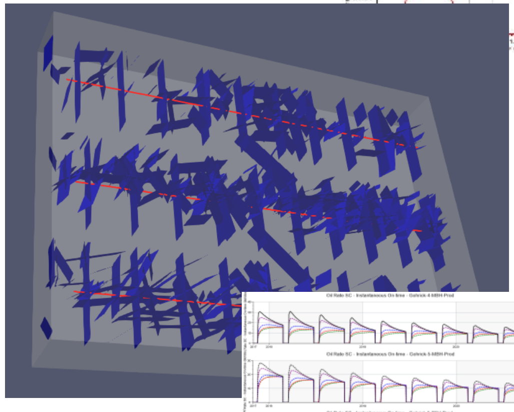
- Rich Gas Interactions with Reservoir Fluids and Rocks
  - Rich gas permeability and sorption studies in organic-rich Bakken shale
- Bakken Rich Gas Characterization for EOR Operations
  - Characterization of the rich gas streams being considered for the pilot
- Iterative Modeling of Surface & Subsurface EOR Components
  - Modeling to specifically support the Stomping Horse EOR pilot
- Pilot Performance Assessment
  - Design, implementation, analysis, and interpretation of reservoir surveillance activities at Stomping Horse

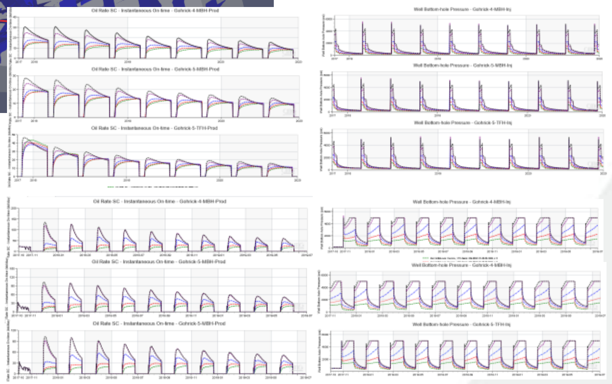


TECHNICAL ACTIVITIES ADDED IN 2019 TO BE COMPLETED 2021

- Advanced Reservoir Characterization for Rich Gas EOR
  - Wettability and relative permeability studies using rich gas mixtures
  - Cuttings characterization for geomechanical properties
- Modeling Conformance Treatments and EOR Strategies
  - Development of a ten-component equation of state for Bakken oil based on analysis of multiple PVT data sets
  - Application of EDFM approach to Bakken EOR simulations
- Machine Learning and Big Data Analytics for Unconventional EOR Strategies
  - Application of ML and BDA techniques for improving EOR design, operations, and results analysis

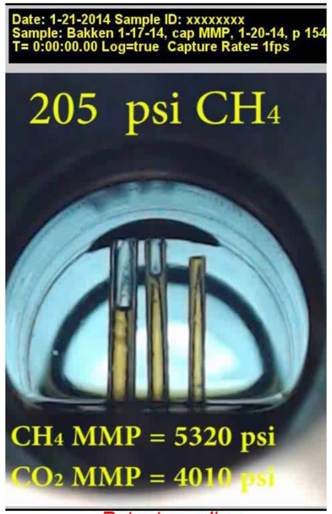






RICH GAS–OIL FLUID BEHAVIOR AND ROCK EXTRACTION STUDIES

MMP Studies



Patent pending

Minimum miscibility pressure (MMP) of crude oil with rich gas components and different rich gas mixtures.

– Methane, ethane, and propane.

~ Eighty MMP determinations done.

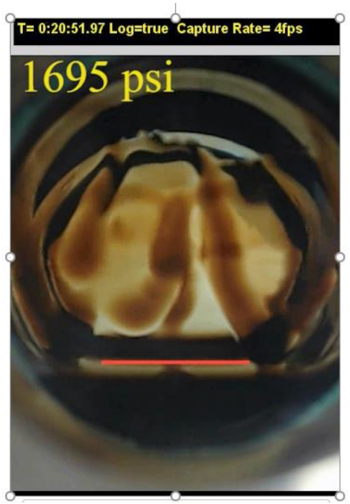
(Capillary-rise, vanishing interfacial tension measurements of MMP, EERC patent US 9851339)

Rock Extraction Studies

Determine ability of rich gas components to mobilize oil from the Bakken matrix.

– Methane, ethane, and propane at reservoir conditions.
– *(2018 URTeC 2671596)*

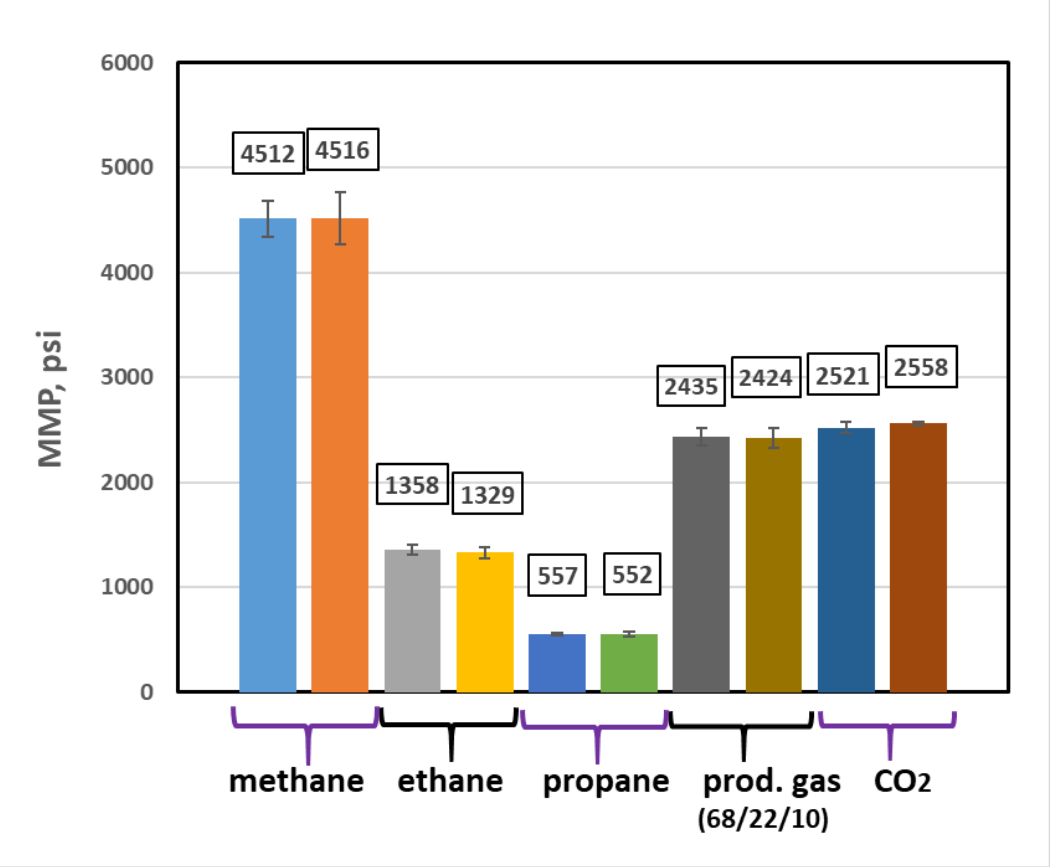
Miscible Behavior Studies



Which hydrocarbons partition into this “miscible” upper phase?

Which hydrocarbons are lost as pressure drops?

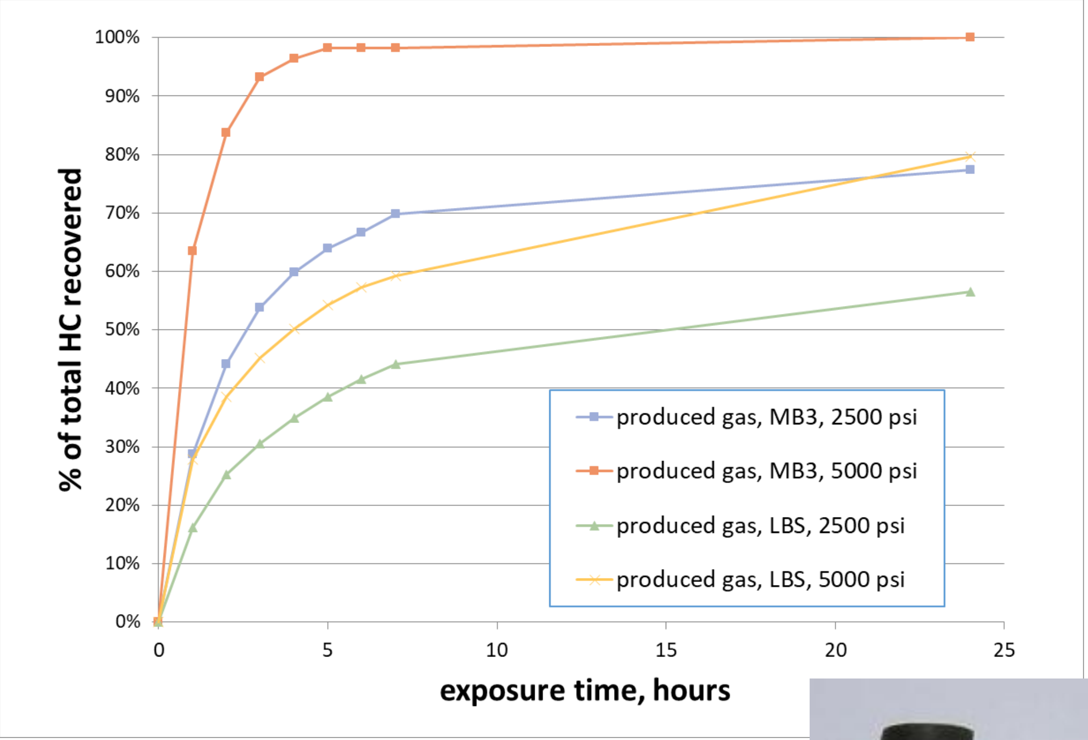
BAKKEN CRUDE OIL MMP AND ROCK EXTRACTIONS



The richer the gas, the lower the MMP!!

* CO_2 MMPs were determined as part of a previous project under separate funding from the DOE and are presented only for comparison purposes.

Total hydrocarbon recovery from Middle Bakken and Lower Bakken Shale with produced gas is <u>best with higher pressures</u>.



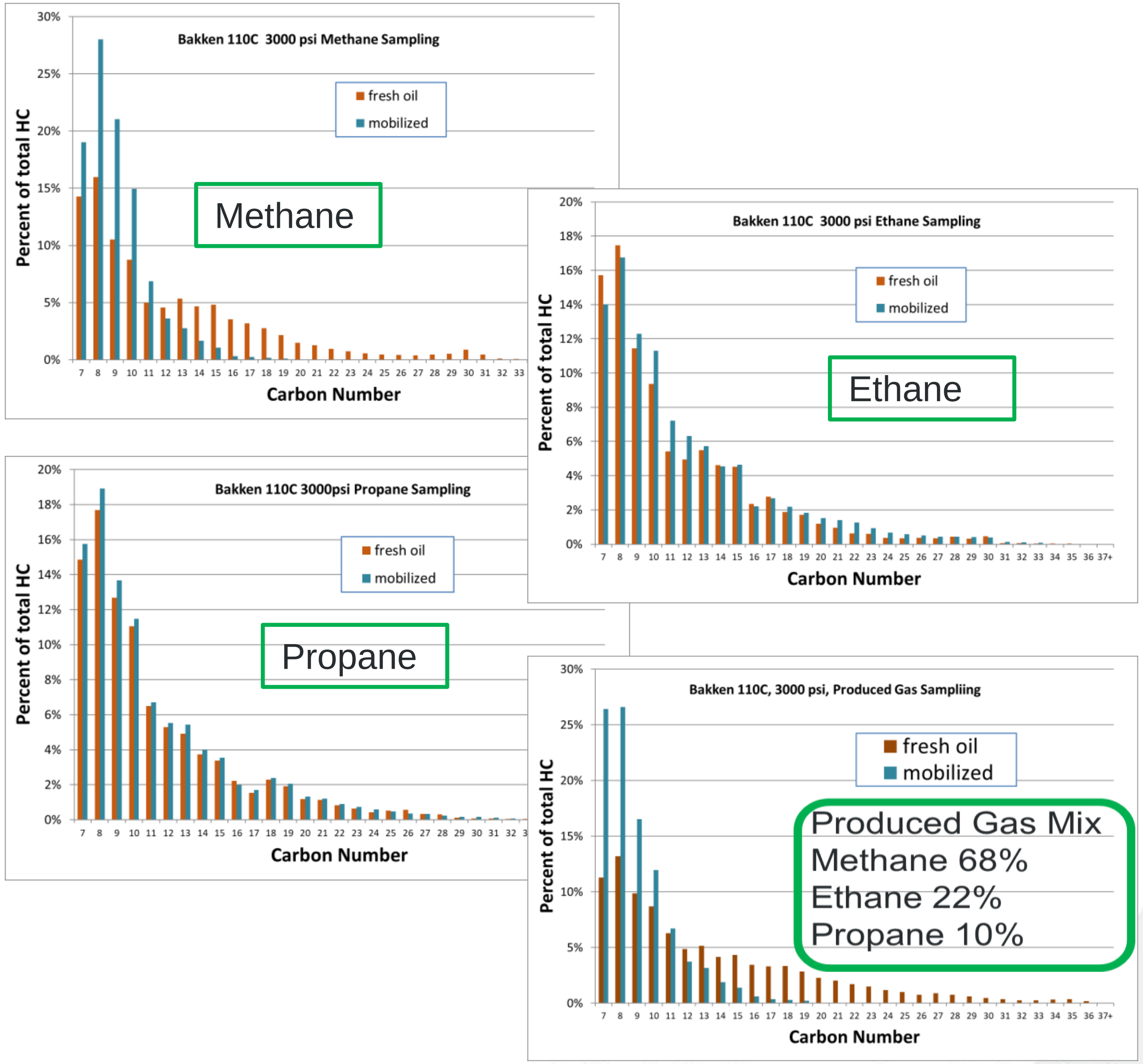
Detailed description of method and results can be found in URTeC 2671596.

"MISCIBLE" BEHAVIOR STUDIES

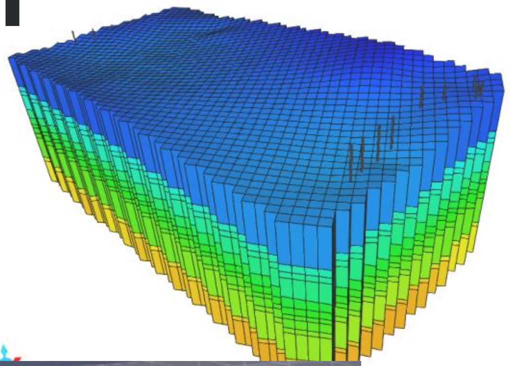
At 3000 psi, ethane and propane efficiently mobilize the heavier hydrocarbons effectively, but ethane is less efficient at lower pressures.

Methane ONLY mobilizes low-MW hydrocarbons at any pressure, leaving most mid- and higher-MW hydrocarbons in the reservoir.

Produced gas is better than methane at 3000 psi.

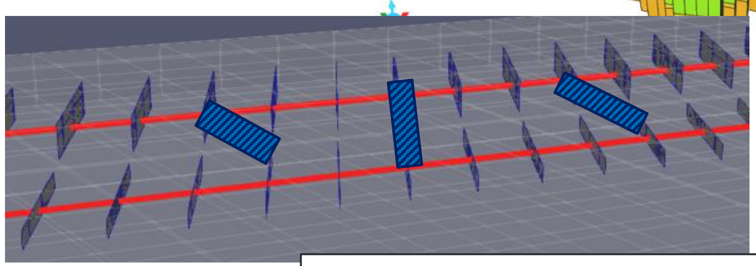


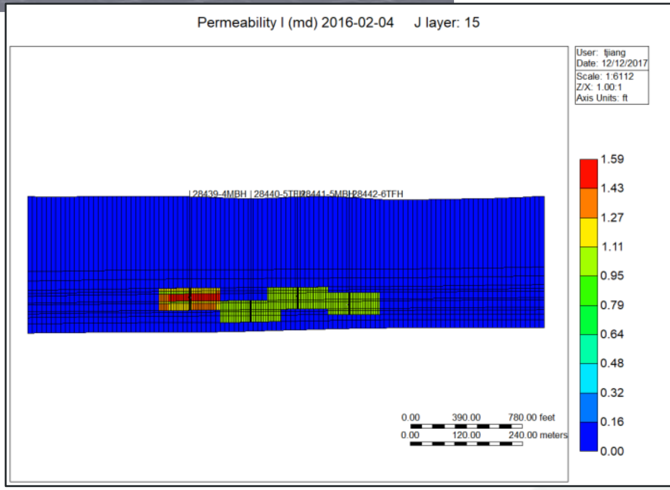
STATIC AND DYNAMIC MODELING TO SUPPORT DESIGN OF STOMPING HORSE PILOT TEST



Bakken Reservoir Modeling and Simulations

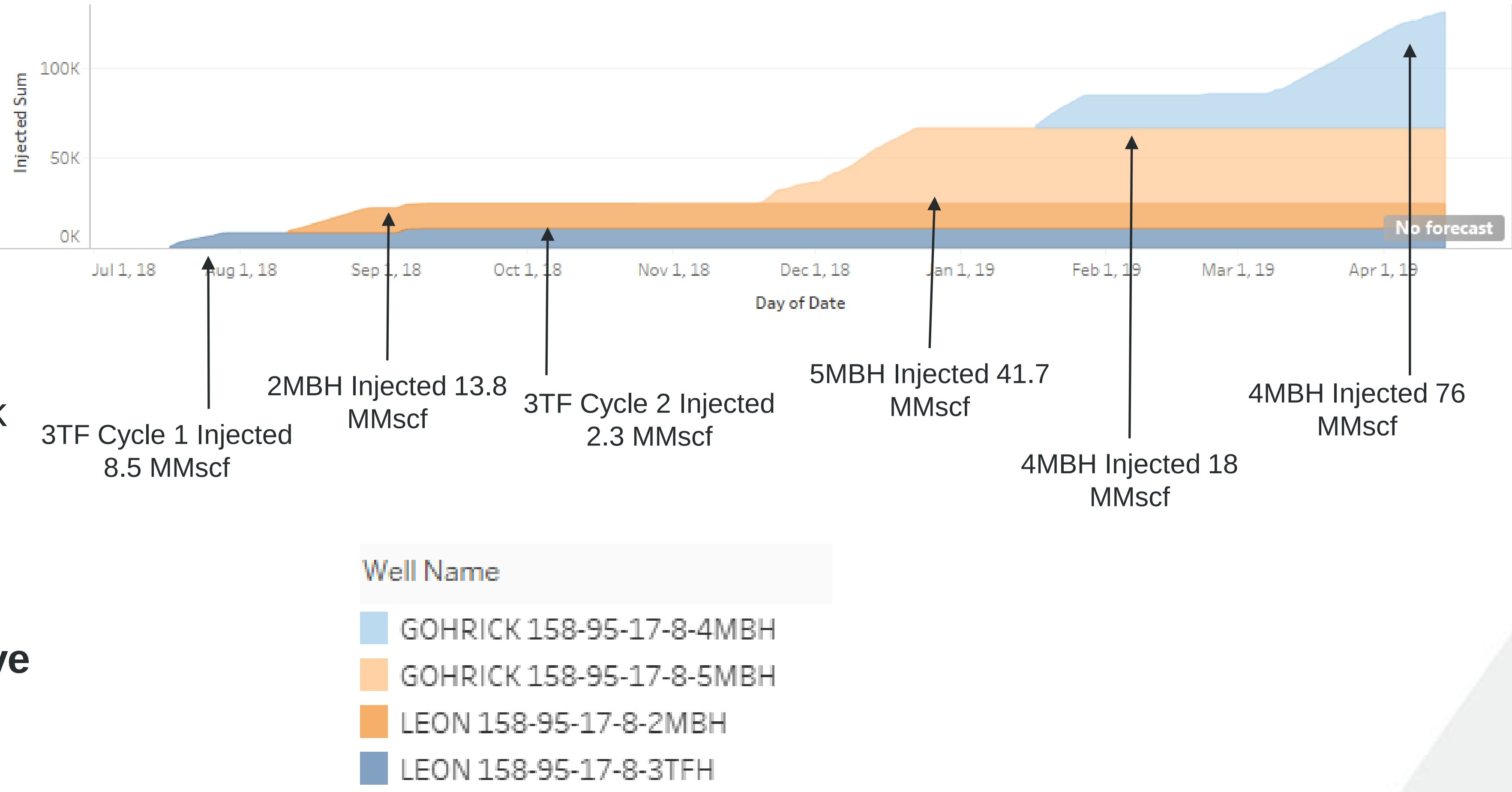
- The EERC worked closely with the LR geoscience team to build static geocellular models of the Bakken petroleum system at Stomping Horse.
- Dynamic simulations of potential EOR schemes:
  - Different injection–production scenarios with an emphasis on cyclic multiwell huff ‘n’ puff (CMWHP) to help LR design pilot.
  - **Surface infrastructure modeling predicts rich gas EOR will not adversely affect Stomping Horse surface facility operations.**



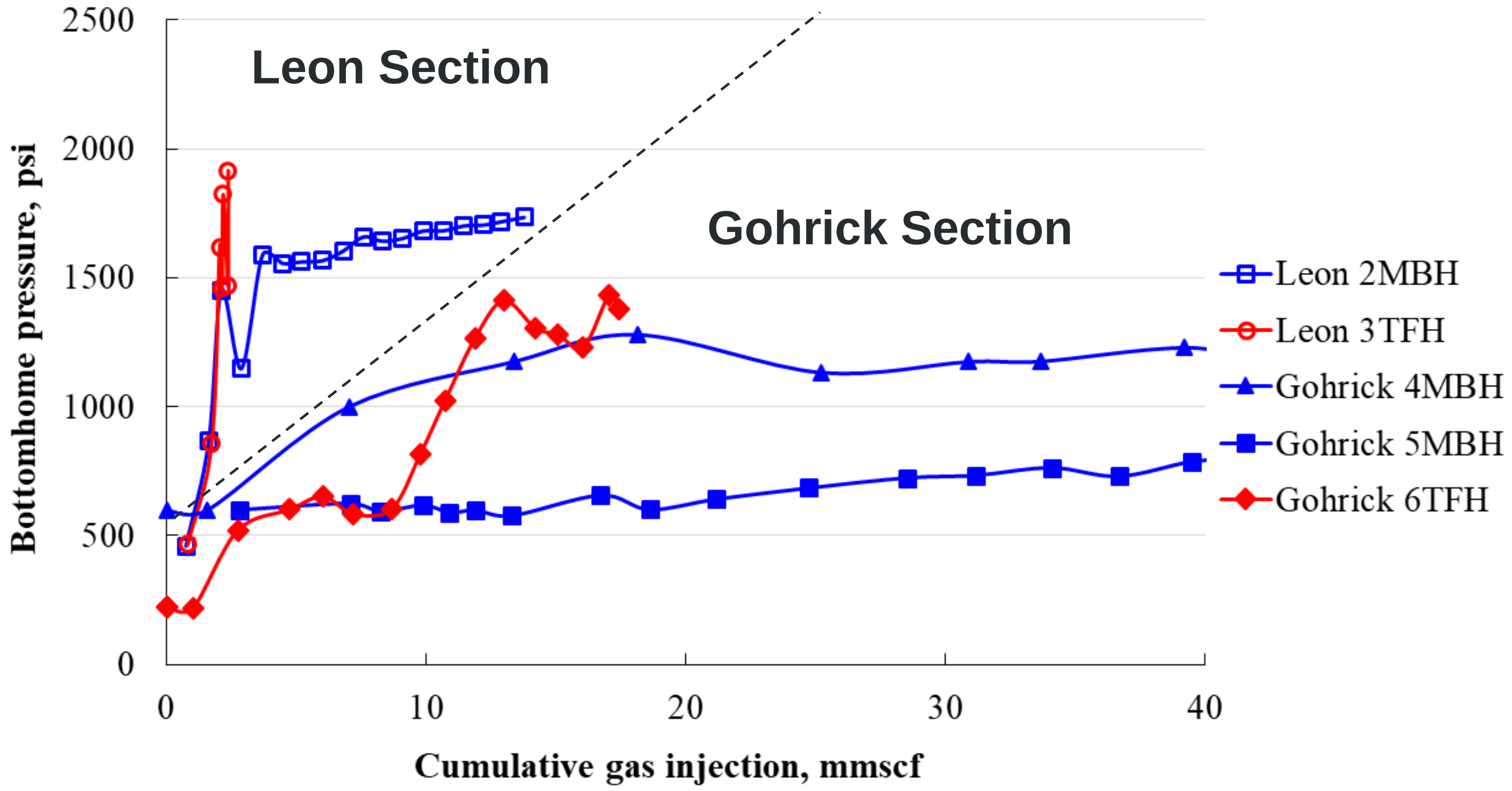


STOMPING HORSE PILOT TEST

- Pilot goals were to determine injectivity, build pressure & manage conformance using multiwell cyclic huff ‘n puff approach.
- Initial small-scale tests in Leon wells largely to investigate injectivity.
- Larger-scale injection in Gohrick wells to investigate pressure buildup and conformance.
- **By end of May 2019, total of ~160 MMscf gas injected in five wells during six different injection periods.**



RESERVOIR RESPONSE TO GAS INJECTION IN THE LIBERTY WELLS



Lessons from Tracer Tests:

Breakthrough between offset wells occurred quickly.

However, tracer testing showed injected gas remained within the DSU.

Indicates the pilot was effective at maintaining conformance within the reservoir.

- Leon wells are easier to pressure up than the Gohrick wells.
- Three Forks wells are easier to pressure up than the Middle Bakken wells.
- Two stages of pressure lifting: fracture filling and produced volume filling with different slopes.

LESSONS FROM THE FIELD TESTS

- **Injectivity is readily established and has not been a constraint on operations.**
- **Reservoir surveillance demonstrate the injected gas can be controlled and has been contained within the DSU.**
- **Pressure buildup can be achieved.**

KEY LESSONS FOR FUTURE PILOTS IN THE BAKKEN

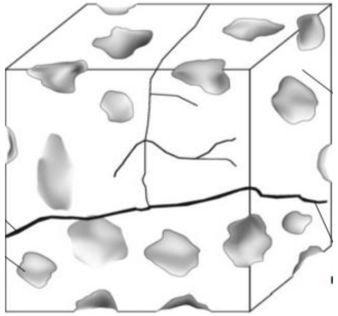
- **Adequate supply of working fluid is essential.**
- **Start with reservoirs that are less pressure depleted.**
- **The lab work has made valuable contributions to pilot design and operation.**
- **Use of EDFM models can improve accuracy and efficiency of modeling.**

ADVANCED MODELING - THE EDFM APPROACH

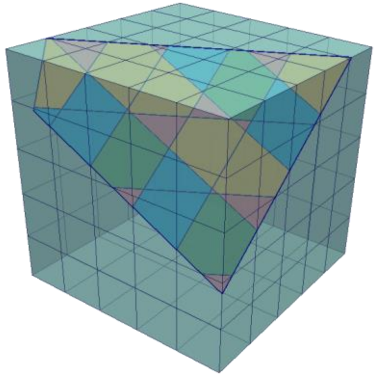
The embedded discrete fracture model (EDFM) combines the advantages of traditional simulation methods for fractured reservoirs but achieving a better balance between calculation cost and simulation accuracy.

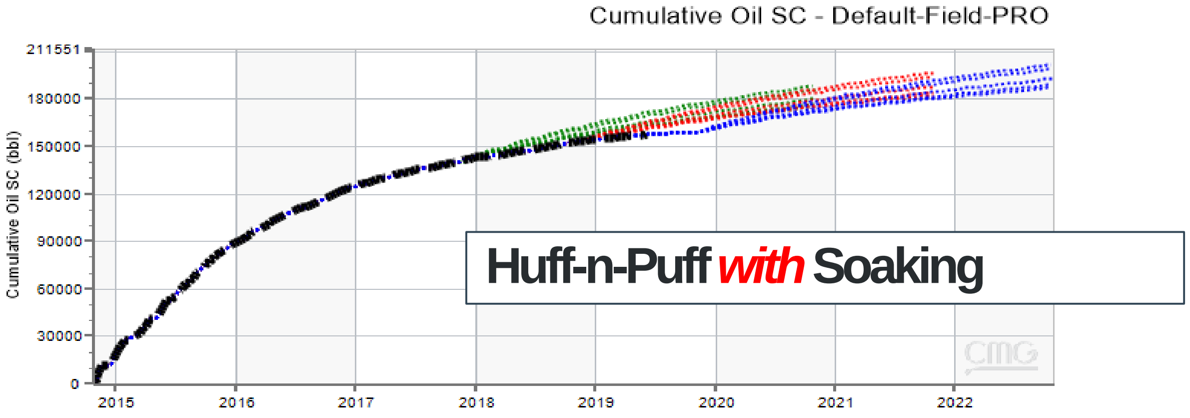
- Achieved improved history match
- Investigating alternative injection scenarios

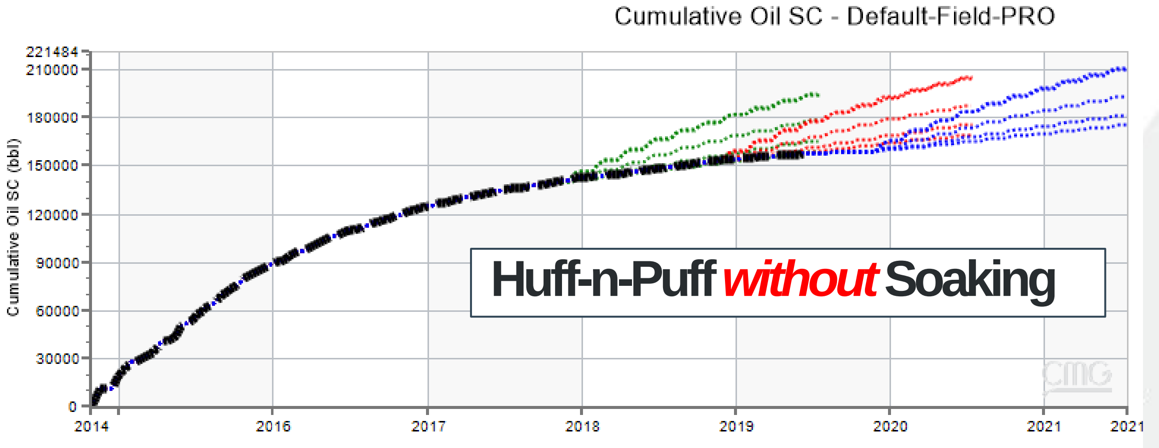
Discrete Fracture Network (DFN)



EDFM







DETERMINATION OF BRITTLENESS INDEX FROM WELL CUTTINGS

1. New samples collected for the validation.
   – Representative samples from each **lithofacies** in Middle Bakken formation.
   – Validate each sub-member.
2. Actively explore big dataset and the machine learning approach.

Dataset overview:

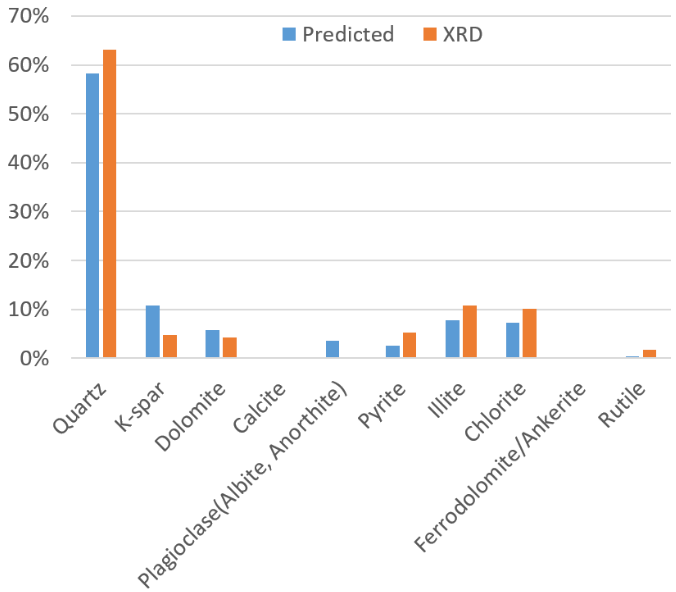
– Publically available data through NDGS Core Library
– 635 “samples” available with dynamic geomechanical properties (E, v). 565 samples with static geomechanical properties.
– 2390 XRD measurements. 88 samples tested by XRF.

DETERMINATION OF BRITTLENESS INDEX FROM WELL CUTTINGS

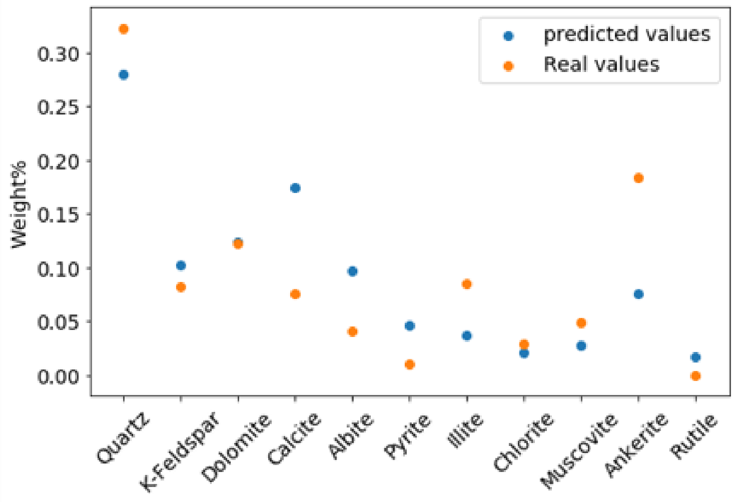
Mineral Predictions from XRF

Modeled Elastic Properties

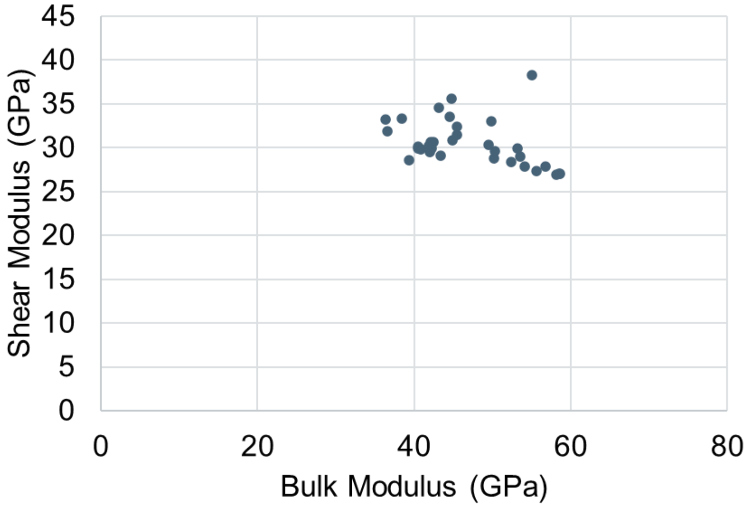
Modeling mineral composition from XRF
Method 1: SEDMIN method



Modeling mineral composition from XRF
Method 2: Machine learning method



Results by rock physics modeling - (Assumption: isotropic, homogeneous)



WETTABILITY AND MACHINE LEARNING STUDIES

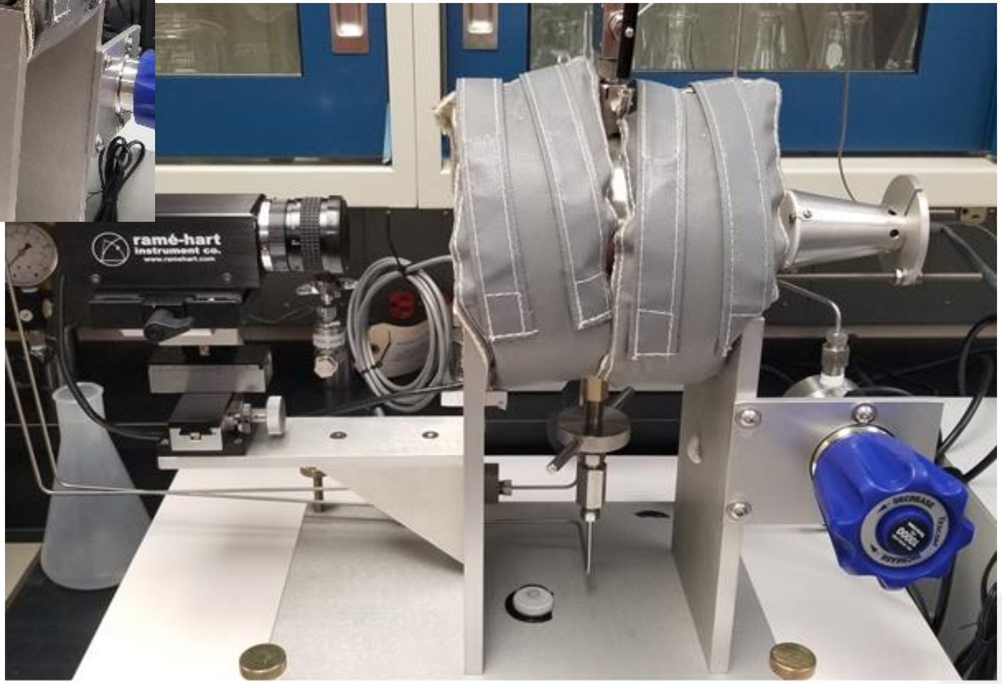
Wettability

- EERC recently acquired new Interfacial Tension/Contact Angle Instrument
- Wettability and Relative Permeability studies are being initiated.
- Oil/Gas pairs will be tested in the context of Bakken Reservoir conditions
- Rock interactions to determine wettability will be tested for shale and middle member samples

Machine Learning

- Machine learning studies are ongoing
- Simulation outputs from field tests are to be used as inputs for ML/AI development.

Reservoir condition Tensiometer to determine IFT and contact angle of reservoir fluid and rock pairs.



NEXT STEPS

- Subactivity 6.1 will begin testing rock/fluid pairs to determine wettability and potential impacts to relative permeability.
- A ML approach will be implemented in Subactivity 6.2 on a large data set of x-ray fluorescence (XRF), x-ray diffraction (XRD), and geomechanical tests. Brittleness index evaluation and cross-validation will be performed using multiple approaches. M14, XRD–XRF Calibration Completed, will be completed.
- Reservoir simulation models with different scales will be developed based on the large-scale geologic model. Fractures will be integrated into the simulation models and dynamic simulations will be conducted to get the models ready for EOR and conformance control studies under Activity 7.
- The reservoir database developed in M11 will be used to explore ML-based approaches for accelerating physics-based reservoir simulations to increase the computational speed associated with solving complex EOR process problems. These ML-based techniques will be used in subsequent work under Subactivity 8.1 to rapidly explore and test various strategies for optimizing reservoir development and management. M15, Initiate Virtual Learning Based Modeling, will be completed.
- Subactivity 8.2, ML techniques for time-series data will be applied to the Pilot Database (M12) to evaluate different techniques for RTVFC, with a primary focus on developing cost-effective approaches to reservoir surveillance for monitoring injection conformance.

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THANK YOU

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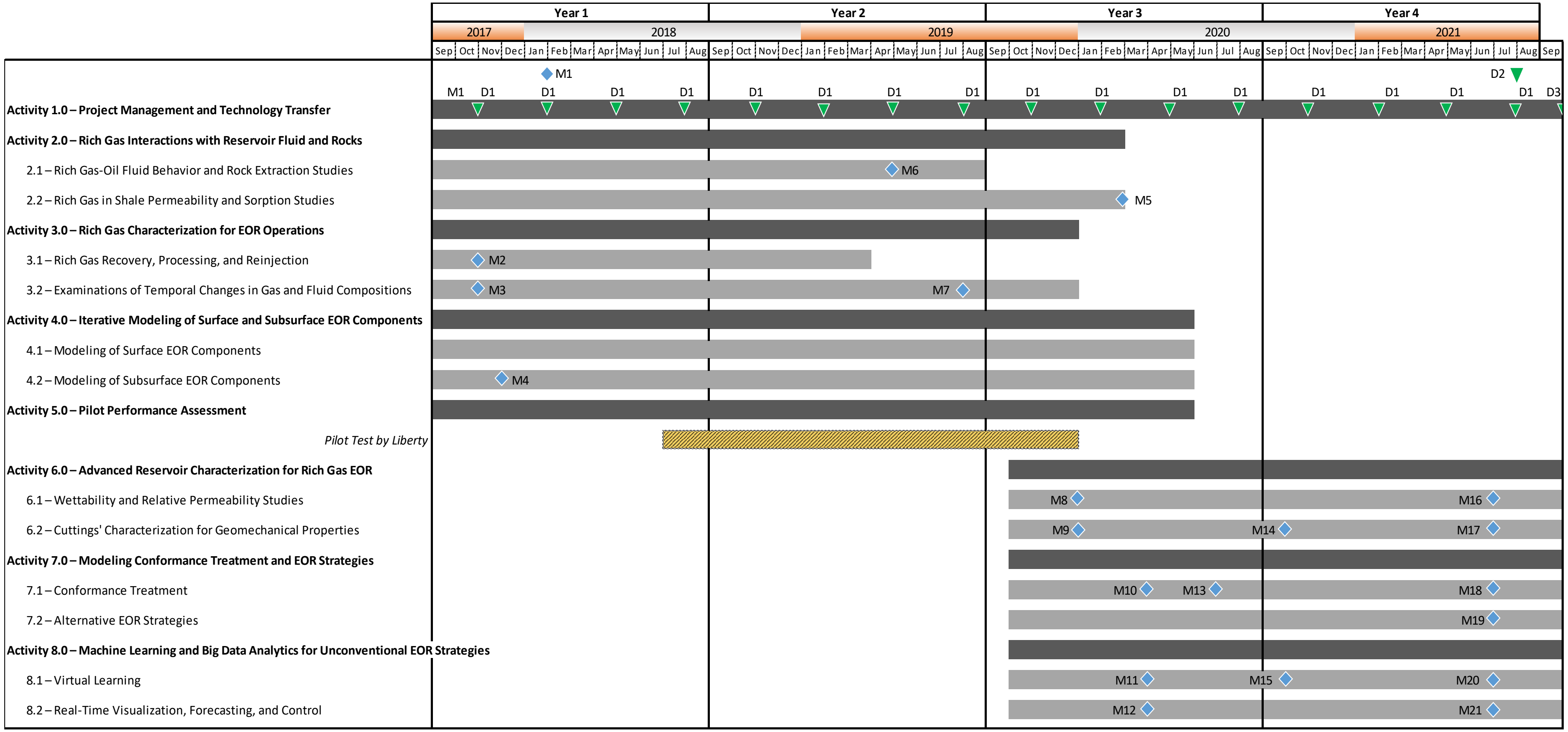
APPENDIX

GANTT CHART



Milestones			Deliverables
M1 – Conduct Project Kickoff Meeting	M8 – Samples for Wettability and Relative Permeability Testing Collected	M15 – Initiate Virtual Learning-Based Modeling	D1 – Quarterly Progress Report
M2 – Complete Initial Assessment of Test Site Rich Gas Quality and Quantity	M9 – Samples for Brittleness Testing Collected	M16 – Wettability and Relative Permeability Studies Complete	D2 – Draft Final Report
M3 – Finalize Fluids Sampling Collection and Analysis Plan	M10 – Initial EDFM Model Complete	M17 – Brittleness Studies Complete	D3 – Final Report
M4 – Complete Initial Reservoir Geocellular Model	M11 – Reservoir Characterization and Performance Database Complete	M18 – Conformance Treatment Modeling Studies Complete	
M5 – Complete Rich Gas in Shale Permeability and Sorption Studies	M12 – Pilot Test Database Complete	M19 – Large-Scale EOR Modeling Studies Complete	
M6 – Complete Minimum Miscibility Pressure and Rock Extraction Studies	M13 – Initial Large-Scale Model Complete	M20 – Virtual Learning Method Development Studies Complete	
M7 – Complete Temporal Changes in Gas and Fluid	M14 – XRD-XRF Calibration Complete	M21 – RTVFC Method Development Studies Complete	

LR 10/23/19

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