Demonstration of Proof of Concept of a Multi-Physics Approach for Near Real-Time Remote Monitoring of Dynamic Changes in Pressure and Salinity in Hydraulically Fractured Networks ©

DE-FE0031785

PI: Mohsen Ahmadian

UT Austin – Bureau of Economic Geology

Subcontractors: UNC and Duke University

U.S. Department of Energy
National Energy Technology Laboratory
Oct, 14, 2020
Virtual Annual Review Meeting
Research Challenges and Project Objectives

**Problem Statement:** Current geophysical methods are weakly sensitive to identifying stimulated reservoir volume (SRV) and dynamic changes that occur in SRV during the life time of a hydraulically-fractured (HF) reservoir.

**Project Objectives:**

1. To demonstrate Electromagnetic (EM) and Acoustic Contrast Agent (CA)-based method for direct in situ monitoring of relative physio-chemical changes that are commonly encountered during HF production remotely.

2. Advance utility of high sampling rate, surface-deployable tools to achieve objective #1 in near real time at the UT/BEG’s Devine Field Test Site (DFTS).
Persistence Pays Off

• Current project was first proposed to DOE/NETL in May 2016:

Project Narrative - Area of Interest 2

AOI2: Demonstration of Proof of Concept of Coupled Geophysical Methods for High Resolution Illumination of Fracture Networks

May, 4, 2016

SUBMITTED UNDER FUNDING OPPORTUNITY ANNOUNCEMENT

DE-FOA-0001445
Unique Aspects of Current Work

• It leverages the AEC’s previous investment in contrast agents for fracture and water flood mapping, payload delivery and micro-sensor research programs, as well as a well-characterized testbed at the UT’s DFTS

• The scale of the proposed demonstration is large enough to be representative of the reservoir scale but still allow us to perform verification of the proposal economically

• It combines multiple geophysical techniques, configurations, and models

• It lays the foundation for future consideration in an actual HF field
### AEC Prototypes and Applications

<table>
<thead>
<tr>
<th>Class</th>
<th>Contrast Agents</th>
<th>Nano-material Sensors and Payload Delivery</th>
<th>Microfabricated Sensors</th>
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- Sensors and materials will be used individually or combined to interrogate the subsurface and other inaccessible environments
- Size can range from nano to milli scale and for small to meso applications: (e.g. CCUS, EGS, Hydrology, Environmental, Pipes, Cement, etc..)
Leveraging Prior Work by UT’s/AEC/BEG
Developed Validated Methods to Accurately Map SRV at DFTS

6 Verification and 4 Existing OB Wells Logged, Plus 2 Cored, Excellent agreement between logs and inversion results at the predicted depth and locations- ~5ft Lateral Precision!
Project Partners

- U.S. Department of Energy
- Bureau of Economic Geology
- Texas
- ADVANCED ENERGY CONSORTIUM
- Duke University
- THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL
- ExxonMobil
- Repsol
- Shell
- Total
- Sandia National Laboratories
# Funding (DOE and Cost Share)

<table>
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<th>FY 2019</th>
<th>FY 2020</th>
<th>Total</th>
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<tr>
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<td>DOE</td>
<td>Cost Share</td>
<td>DOE</td>
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<tr>
<td>Applicant-UT</td>
<td>$414,841.00</td>
<td>$105,030.78</td>
<td>$535,551.00</td>
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<td>Includes Services for Field Work</td>
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<tr>
<td>Sub-recipient A-UNC</td>
<td>$99,999.00</td>
<td>$20,075.00</td>
<td>$100,000.00</td>
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<tr>
<td>Sub-recipient B-Duke</td>
<td>$172,485.00</td>
<td>$43,121.00</td>
<td>$177,122.00</td>
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<td>Total ($)</td>
<td>$687,325.00</td>
<td>$168,226.78</td>
<td>$812,673.00</td>
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<tr>
<td>Total Cost Share %</td>
<td>20%</td>
<td>21%</td>
<td>20%</td>
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Technical Approach/Project Scope

1. Project Management and Planning
2. Workforce Readiness for Technology Deployment

3. Calibration of CA Response in Laboratory Fracture Models
   *BP1-Go-no-Go

4. Model Development and Validation with Synthetic Data
5. Sensitivity Analysis
   *BP1-Go-no-Go

6. Design of Field Experiments
   Formation Well Testing
   Field Construction/Work Surveys

7. Data Processing/Interpretation

BP1

BP2
Progress and Current Status of Project
3.0: Core and Material Characterization

- Described 249 ft (76 meters) of core for DFTS
- Selected intervals from the DMW1 and DMW3 cores were slabbed and photographed to document lithology and stratification
- Facies and depositional-systems interpretations have been made
- Based on stratification and vertical facies relationships, a tidally influenced deltaic interpretation has been proposed.
3.0: Electrical Measurements in the Lab*- Salinity

Measurement models built to mimic scale down version of the Devine test site

- Relative change in conductivity is large for all electrode configurations probed when salinity is changed:
  - All passes the Go-No-Go criteria for BP1
3.0: Electrical Measurements in the Lab*- Pressure

Two pressure dependent properties of CA probed

- Relative change in conductivity is large when either lithostatic or hydrostatic pressure is applied to the CA in a confined space.

- Hypothesis:
  a) Lithostatic Pressure causes CA grain to compact,
  b) Hydrostatic Pressure caused CA grain separation

All passes the Go-No-Go criteria for BP1
Field Study Plan-Expected Results

Work Plan:
Baseline Packed CA
Low salinity/HLP
Inject with fresh H2O HHP
Inject with HS brine HHP
Rest Period / Extraction / leak-off
Low Salinity/HLP

Expected Outcome:
High e- conductivity
Decrease e- conductivity
Increase e- conductivity

Increase e- conductivity

e- conductivity of undisturbed CA under HLP >
e- conductivity of CA in fresh H2O <
e- conductivity of CA in high salinity (HS) + HHP (assumed -TBD)
Proposed Study Leverages the Existing Infrastructure at the UT/BEG’s Devine Test Site

- Injection via Huff-n-Puff from existing injection well
- Fluid migration and pressure will be validated by downhole Pressure/Salinity gauges in DMW1-2 and possibility in a new monitoring well at distal end of the HF

### Table: Well Information

<table>
<thead>
<tr>
<th>Well ID</th>
<th>Distance to Inj well (ft)</th>
<th>Total Depth (ft)</th>
<th>Screen/Perf Depth (ft)</th>
<th>Completion Type-Equipment</th>
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</thead>
<tbody>
<tr>
<td>Inj well</td>
<td>0</td>
<td>267</td>
<td>175</td>
<td>Steel/4&quot;/Perf</td>
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<tr>
<td>DMW1</td>
<td>10</td>
<td>267</td>
<td>170-77</td>
<td>PVC/2&quot;-ERT</td>
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<tr>
<td>DMW2</td>
<td>20</td>
<td>190</td>
<td>170-180</td>
<td>PVC/2&quot;</td>
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<td>DMW3</td>
<td>45</td>
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<td>DMW4</td>
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<td>190</td>
<td>130-135</td>
<td>PVC/2&quot;</td>
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<tr>
<td>DMW5</td>
<td>107</td>
<td>190</td>
<td>NA</td>
<td>PVC/2&quot;</td>
</tr>
<tr>
<td>DMW6</td>
<td>91</td>
<td>190</td>
<td>NA</td>
<td>PVC/2&quot;</td>
</tr>
</tbody>
</table>
5.1: Fluid Flow Modeling-Field Test Plan

Layer Cake Model-CMG

History Matching to Fracturing Pressure Data- from 2017

History Matching to Validation Well Drilling Pressure Data – from 2018

Pressure Modeling- 180BPD/30bbl Injected/4 hours

Salinity Modeling- 180BPD/30bbl Injected / 4 hours

Cumulative Injection and Extraction Volume_180 BPD

Ahmadian et.al. Q3BP1 Report
5.1: Fluid Flow Modeling

180 BPD Injection Case - Movie

- Simulation start date: July 1st.
- Injection Start Date: July 4th 0:00 am
- Resting time start after 4 hours of injection, and lasting 12 hours.
- Extraction started at July 4th 16:00 pm.
- The video ends at July 11th, 0:00 am

Salinity Modeling - 180BPD/30bbl Injected / 4 hours
20,000ppm injection

Pressure Modeling - 180BPD/30bbl Injected/4 hours
mini Pilot : 9/21-9/26/20 at DFTS
Monitoring Dilation, Closure and Compaction Mapping

Fracture Dilation

Failure attempts

1st successful injection

Instantaneous shut-in pressure (ISIP)

In between pressure after closure (i.e. compaction)

Will be correlated to real time geophysics
Flow rate mapping with EM Contrast Agents

Correlation of BHP and flow rate, which will impacts EM signature on Surface
DE-FE0031785 Q4BP1/BP2 Work and Beyond

Q1-Q4 BP2

- Calibration of Fluid Modeling
- Design of Field Experiments,
- Field Work, Construction
- Surveys
- Data Processing/Interpretation
- Publication and Reporting

CY2021:

Collaborate with the NETL and the AEC to perform a reservoirs scale demo:

- Field test partner has been identified to demo CA based HF mapping ASAP
- Material, tool, validated models are available
- Well is pre-drilled and available
- Commercial partner has been identified
- We will be combining multiple CA properties (acoustic, EM) and microsensors to build more resolution for subsurface monitoring
Summary and Future Plans

- A patent-pending sensor system for remote monitoring of *in situ* properties of HF has been proposed, developed and is being demonstrated.
- We have successfully passed the major Go-no-Go milestones for BP1.
  - CA-based sensors system displays a significant and measurable change under both pressure and salinity.
- A machine learning based inversion approach is under development, which promises to reduce analysis time from days to minutes.
- Fluid flow modeling and recent injections at DFTS is informing a number of injection scenarios to enable perturbations of the HF at DFTS for the proposed study.
- Various geophysical modalities (EM, Acoustic, Seismic) and detection configurations will be combined to monitor the extent and geophysical properties of subsurface HF environment dynamically in near real time.
Appendix

– These slides will not be discussed during the presentation, but are mandatory.
Organization Chart

Dr. Fomel (Seismic) UT

Dr. Hassan (Fluid Studies) UT

EM Geophysics Co.

Dr. Ahmadian (PI) UT-Austin

UT And DFPS Administration

Gary Covatch DOE/NELT

Dr. Kleinhammes (Co-PI) UNC

Dr. Liu (Co-PI) Duke

Dr. Ogiesoba (VSP/SS Survey Design)

Mr. Ambrose (Rock Characterization)

Mr. DeAngelo (VSP/SS Field Survey)

Dr. Mezallikin (VSP/SS Modeling and Processing)

Dr. Nicot (Fluid Flow Model and OPT)

Technician (Fluid Sampling)

GRA (Modeling)

Geophysicist

Programmer

GRA (Mixing Rules)

GRA1

GRA2

GRA3

Dr. Yue Wu

UNC Administration

Mechanical Engineer

Duke Administration

Confidential Slide
### Tasks and Status as of 7/30/20

<table>
<thead>
<tr>
<th>Task</th>
<th>Subtask/Milestone Description</th>
<th>Planned Completion Date</th>
<th>Percent Complete as of 6/30/2020</th>
<th>Verification Method/ Deliverables</th>
<th>Comments</th>
</tr>
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<tbody>
<tr>
<td>1.0</td>
<td>Project Coordination and Communication and Reporting</td>
<td>9/30/2020</td>
<td>75%</td>
<td>PMP, DMP, TMP Quarterly Reports, Continuation Application</td>
<td>1. PMP and DMP was updated.  2. TMP will be updated and will be submitted in BP2  3. Q2 BP1 reports were submitted to DOE. Two more reports remain.</td>
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<td>2.0</td>
<td>Workforce Readiness for Technology Deployment</td>
<td>10/31/2020</td>
<td></td>
<td>Presentation file BP2 deliverable</td>
<td>1. BP2 deliverable will be submitted in Q1BP2.</td>
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<td>3.0</td>
<td>1. Initial Lab Studies for HP/HS Responsive EAP  2. Lithology and Cores Studies</td>
<td>09/30/2020</td>
<td>75%</td>
<td>Q2 &amp; 3 Reports  Q1, 2, &amp; 3 Reports</td>
<td>1. Initial lab studies have demonstrated that both pressure and salinity cause a marked impact on electric response.  2. We completed an extensive core characterization report describing 249ft (76m) of core from the DFPS.</td>
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<td>4.0</td>
<td>1. VSP/seismic RTM Validation  2. Joint VSP/Seismic and EM Inversion</td>
<td>06/30/2020</td>
<td>630/20</td>
<td>Year 1 Topical Report</td>
<td>1. RTM code has been validated.  2. We tested our seismic modeling software for generating synthetic data for assessing the feasibility of the proposed workflow using a 12.5- to 2 - cm fracture. Fracture is detectable at 200 Hz.</td>
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<td>5.0</td>
<td>1. Field Design: Fluid Flow Modeling  2. EM Sensitivity Analysis  3. VSP or Seismic Sensitivity Analysis</td>
<td>09/30/2020</td>
<td>80%</td>
<td>Year 1 Topical Report</td>
<td>1. A fluid flow model has been built and refined using prior fluid injection history from DFPS. Multiple simulations will be completed for different field injection scenarios.  2. Our EM sensitivity analysis has shown that even a 5% change in conductivity of the EAP-filled fracture can result in &gt;1% contrast in the signal.  3. We created velocity and density models for seismic modeling and examined the seismic response to the fracture.</td>
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