Quarterly Research Performance Progress Report

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Project Title	**THE EAGLE FORD SHALE LABORATORY: A FIELD STUDY OF THE STIMULATED RESERVOIR VOLUME, DETAILED FRACTURE CHARACTERISTICS, AND EOR POTENTIAL**
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1. INTRODUCTION

This quarterly research progress report is intended to provide a summary of the work accomplished under this project during the fourth quarter of the first budget period (January 1st, 2019 – March 31st, 2019). Summarized herein is a description of the project accomplishments to date, along with the planed work to be conducted in the next quarter.

2. ACCOMPLISHMENTS

2.1. Project Goals

The ultimate objective of this project is to help improve the effectiveness of shale oil production by providing new scientific knowledge and new monitoring technology for both initial stimulation/production as well as enhanced recovery via re-fracturing and EOR. This project will develop methodologies and operational experience for optimized production of oil from fractured shale, an end result that would allow for more production from fewer new wells using less material and energy. While aspects of the proposed project are site-specific to the Eagle Ford formation, there will be many realistic and practical learnings that apply to other unconventional plays, or even apply to other subsurface applications such as unconventional gas recovery and geologic carbon sequestration and storage. The main scientific/technical objectives of the proposed project are:

- Develop and test new breakthrough monitoring solutions for hydraulic fracture stimulation, production, and EOR. In particular, for the first time in unconventional reservoirs, use active seismic monitoring with fiber optics in observation wells to conduct: (1) real-time monitoring of fracture propagation and stimulated volume, and (2) 4D seismic monitoring of reservoir changes during initial production and EOR from the re-fractured well.
- Improve understanding of the flow, transport, mechanical and chemical processes during and after stimulation (both initial and re-fracturing) and gain insights into the relationship between geological and stress conditions, stimulation design, and stimulated rock volume.
- Assess spatially and temporally resolved production characteristics and explore relationship with stimulated fracture characteristics.
- Evaluate suitability of re-fracturing to achieve dramatic improvements in stimulation volume and per well resource recovery.
- Evaluate suitability of gas-based EOR Huff and Puff methods to increase per well resource recovery.
- Optimize drilling practices in the Eagle Ford shale based on surface monitoring and near-bit diagnostic measurements during drilling.
- Conduct forward and inverse modeling to test reservoir and fracture models and calibrate simulations using all monitored data. Ultimately, provide relevant guidance for optimized production of oil from fractured shale.
- Disseminate research and project results among a broader technical and scientific audience, and ensure relevance of new findings and approaches across regions/basins/plays.

The project will start with the re-fracturing of a legacy well that was initially stimulated using now outdated fracturing technology (Task 2). The recipient will drill, complete, and instrument one vertical and one horizontal observation strategically located on both sides of the legacy well to allow for real-time cross-well monitoring of evolving fracture characteristics and stimulated volume. These observation wells will also be used for the other two main project stages, involving a new state-of-the art stimulation effort (Task 3) and a Huff and Puff EOR test (Task 4). Task 3 will be conducted in two new wells of opportunity drilled; these wells will be situated parallel to the horizontal observation well on the other side of the re-fracturing well. Task 4 will be conducted in the re-fractured legacy well, testing the efficiency of a Huff and Puff process with natural gas injection for EOR. As described below, each main task comprises various field activities complemented by laboratory testing and coupled modeling for design, prediction, calibration, and code validation. In addition to the three main tasks aligned with re-fracturing, new stimulation, and EOR, the work plan also comprises Task 1 (Project Management and Planning) and Task 5 (Integrated Analysis, Lessons Learned, Products, and Reporting). The project milestones, description of tasks and subtasks, and current milestone status are shown in **Table 1**.

2.2. Accomplishments

This section summarizes the accomplishments for the current reporting quarter (January 1st, 2019 – March 31st, 2019).

2.2.1. Surface Orbital Vibrator (SOV) Acquisition Planning & Test Design

The original EFSL project plan proposed the use of crosswell Continuous Active Source Seismic Monitoring (CASSM; Daley et al., 2007, Geophysics, 72, A57-A61), a permanent borehole seismic monitoring system developed at LBNL over the past decade. CASSM was to be deployed between horizontal wells using an array of semi-permanent piezoelectric borehole seismic sources and semi-permanent borehole seismic receivers (3C geophones and DAS). The primary goal of CASSM at the EFSL was to track hydraulic fractures, re-fractures and the EOR fracture stimulation processes at reservoir depths and out to distances of 100's of meters between boreholes with high spatial and temporal resolutions. However, during the planning stage, it was determined by the operator (WildHorse Resource Development) that it would not be operationally feasible to emplace permanent seismic sources or sensors (geophones or DAS) behind casing in either of the two horizontal re-fracturing wells (Bronco A2H and A3H wells) because of casing size restrictions.

Recognizing the unique opportunity afforded by this field project to observe the evolution of re-fracturing, fracturing and EOR processes, the project team decided to exercise the backup option of replacing the borehole piezoelectric CASSM source array with a surface array of SOVs. SOVs also utilize permanent source emplacement to achieve high repeatability. Utilizing a linear array of 10 SOVs mounted above the Horizontal Observation Well (HOW) as illustrated in **Figure 1**, LBNL (Jonathan Ajo-Franklin) performed a synthetic traveltime tomography imaging analysis that supported the use of SOVs for imaging the vertical growth of the fractures generated during the re-fracturing of the Bronco A3H well (previous section). The use of stationary surface source acquisition as a monitoring tool for monitoring hydraulic fracture growth was highlighted in a recent study by Byerley et al. (2018, The Leading Edge, 802-810). In this field study, Apache Corp monitored 78 individual hydraulic frac stages using DAS in a horizontal shale well and two fixed vibroseis sources off the two ends of the monitoring well. A key finding from this study was that the continuous monitoring data recorded changes in the stimulated rock that diminished over a period of days. These changes, which included subtle changes in the P-wave velocity and the generation of P-to-S converted waves by the hydraulically-induced fractures, would have "been completely missed using the conventional approach of having a single monitor survey acquired after the well was treated.” The 10 source SOV array that will be used in the EFSL field program will allow our program to go beyond fracture characterization, as in the 2 source Apache study, to fracture imaging.

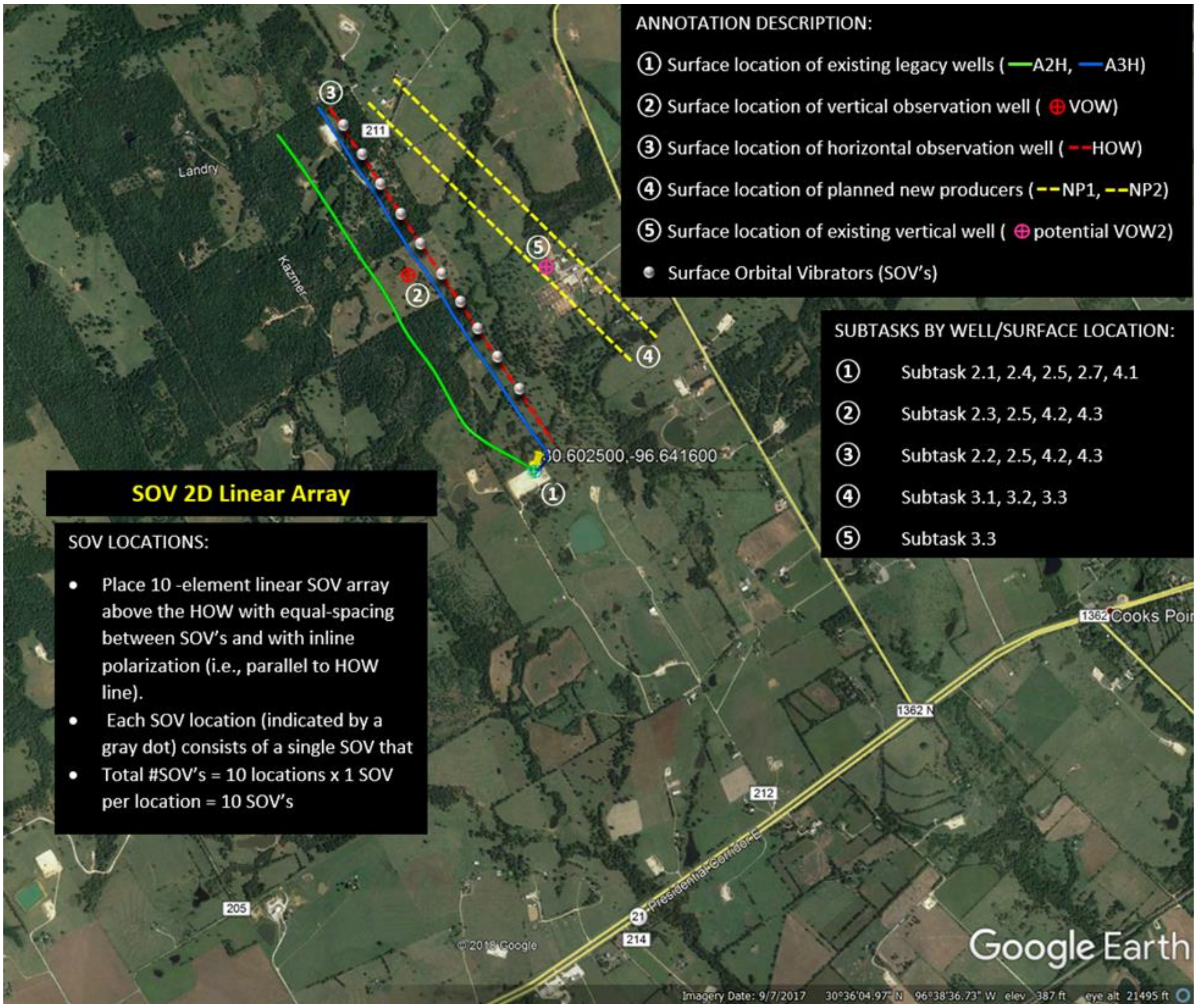

Figure 1. Proposed Surface Orbital Vibrator 2D Linear Array.

To validate the utility of SOV’s for monitoring hydraulic fractures in the Bronco site and a removable SOV foundation design a single SOV pilot test was designed for the WRD Harden CP3 well pad located south of Caldwell, TX off of FM975. This feasibility test will test a new modular foundation design that allows for easy construction, removal and remediation. The design and construction of the modular foundation has been completed and is awaiting site access approval by Chesapeake to conduct testing. This test will also validate the use of a new slewing bearing mount that allows the SOV to be rotated over 360 degrees. This new capability will provided a full angular range of horizontally-polarized shear waves to be used in the fracture imaging. **Figure 2** (A) shows a past SOV deployment on a fixed concrete pad; in this situation, extraction of the pad, which has a 1 m depth extent, is challenging and the SOV is oriented in a single direction. **Figure 2** (B) shows the slewing bearing to be tested which will allow arbitrary shear orientation of the SOV.

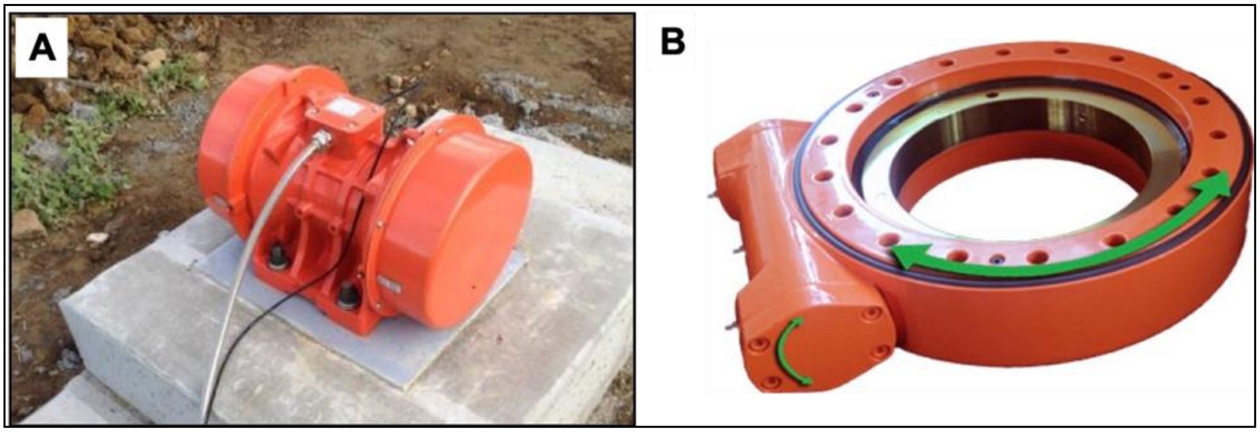

Figure 2. *Example of past SOV installation (A) installed at a fixed orientation on a concrete pad; (B) shows the slewing bearing which allows orientation of the SOV in an arbitrary direction for rotating shear wave polarization.*

To date, we have procured the SOV motors and associated electronics for this test as well as fabricated a metal cage for mounting the SOV and rotatable bearing on the transportable concrete pad. A single cage has been cast in a concrete form and is now ready for testing at the Harden site where an existing well has fiber optics behind casing, appropriate for recording DAS data during a surface-to-borehole SOV test. **Figure 3** shows the design for the mounting assembly and cage as well as the completed system after welding. The slewing bearing (**Figure 2** (B)) will be mounted on the top circular bolt pattern (**Figure 3** (B)) with the SOV shaker (**Figure 2** (A)) mounted above. The resulting system will be the first semi-permanent seismic source with controlled polarization capabilities, a feature which should improve our ability to detect the orientation of induced fractures. The first tests of this system are currently slated for late April 2019.

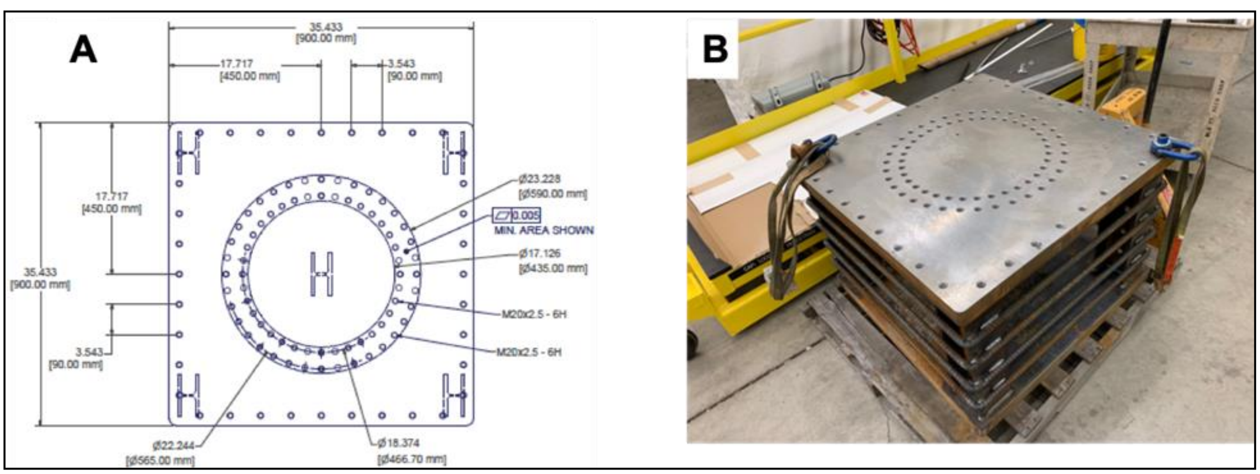

Figure 3. *The design of the mounting plate and pad (A, left) and the corresponding assembly after welding and integration. The slewing bearing will be mounted on the circular bolt pattern.*

2.2.2. **Surface Orbital Vibrator (SOV) Modular Foundation Design and Construction**

A modular steel reinforced concrete foundation for installing SOV's has been designed. The modular foundation's design facilitates construction, transportation, installation, and subsequent site remediation with the minimal cost associated with each operation. Construction of the modular SOV concrete foundation has been completed. Utilizing the modular foundation design shown above, a steel SOV mounting reinforcement (designed, fabricated, and provided by LBNL) was integrated on the top block component, and further reinforced with 2 mats of steel rebar as shown in **Figure 4**.

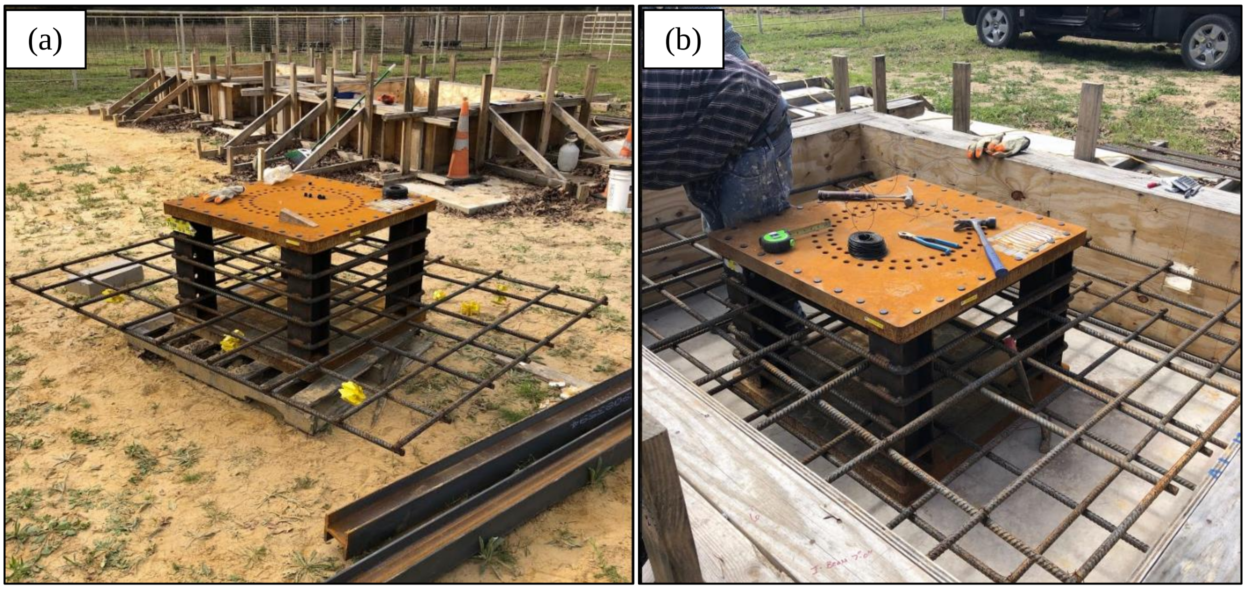

Figure 4. *Surface orbital vibrator (SOV) foundation mounting reinforcement. (a) SOV mounting reinforcement being tied in with steel rebar mats; (b) SOV mounting reinforcement with 2 rebar mats placed within the foundation forms.*

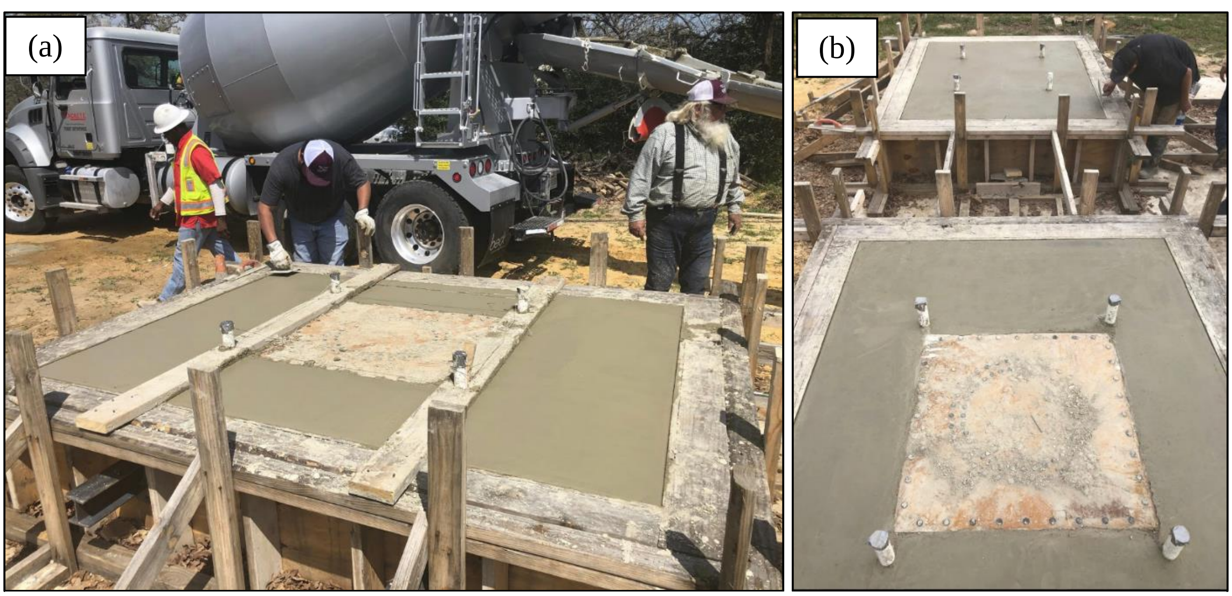

Figure 5. *Completed surface orbital vibrator (SOV) steel reinforced modular concrete foundation. (a) Top foundation block with SOV mounting reinforcement; (b) Top and bottom SOV foundation blocks (to be assembled together to form complete SOV foundation).*

The bottom block component was also reinforced with 2 steel rebar mats, and both blocks of the assembly were completed on March 19th, 2019, as shown in **Figure 5**. Both foundation assembly blocks reached full cure strength by April 16th, 2019 and were ready to be transported to the field test site.

2.2.3. Surface Orbital Vibrator (SOV) Test on Marjorie-Bartlett Well Pad

The design concept for the modular SOV foundation required an excavating the specific location for the SOV foundation blocks. The excavation was designed to be 8 ft. wide by 10 ft. long, and 4 ft. deep. The procedure for installing the modular blocks was to mobilize a crane and lower one block at a time into the excavation, allowing for high strength steel all-thread rods to be placed through both blocks in order to couple them together as to act as one cohesive mass. The installation of the blocks is shown in **Figure 6**.

Figure 6. *Field installation of surface orbital vibrator (SOV) steel reinforced modular concrete foundation. (a) Crane lowering bottom block into excavation; (b) Top and bottom SOV foundation blocks being assembled together.*

Once the concrete foundation blocks were placed within the excavation, they were bolted together and the excavation was backfilled. The next step was to install the slewing bearing onto the steel mounting base on the top of the concrete foundation, followed by mounting of the vibrator motor on top of the slewing bearing. The completed assembly is shown in **Figure 7**.

Figure 7. *Completed Surface Orbital Vibrator (SOV) installation on Marjorie-Bartlett well pad.*

After initial testing, it was determined that the exiting SOV installation was not sufficiently coupled to the ground in order to properly transmit the generated shear waves. A subsequent retrofit of the concrete foundation was conducted by re-excavating any loose soil around the concrete blocks as well as extending the excavation 2 ft. beyond the bottom of the blocks to a total depth of 6 ft. After the foundation was re-excavated, steel reinforcement was then lowered into the surrounding excavation and welded to the I-beams on the original blocks. Concrete was then poured to fill the surrounding excavation, directly coupling the two foundation blocks to competent soil as illustrated in **Figure 8**.

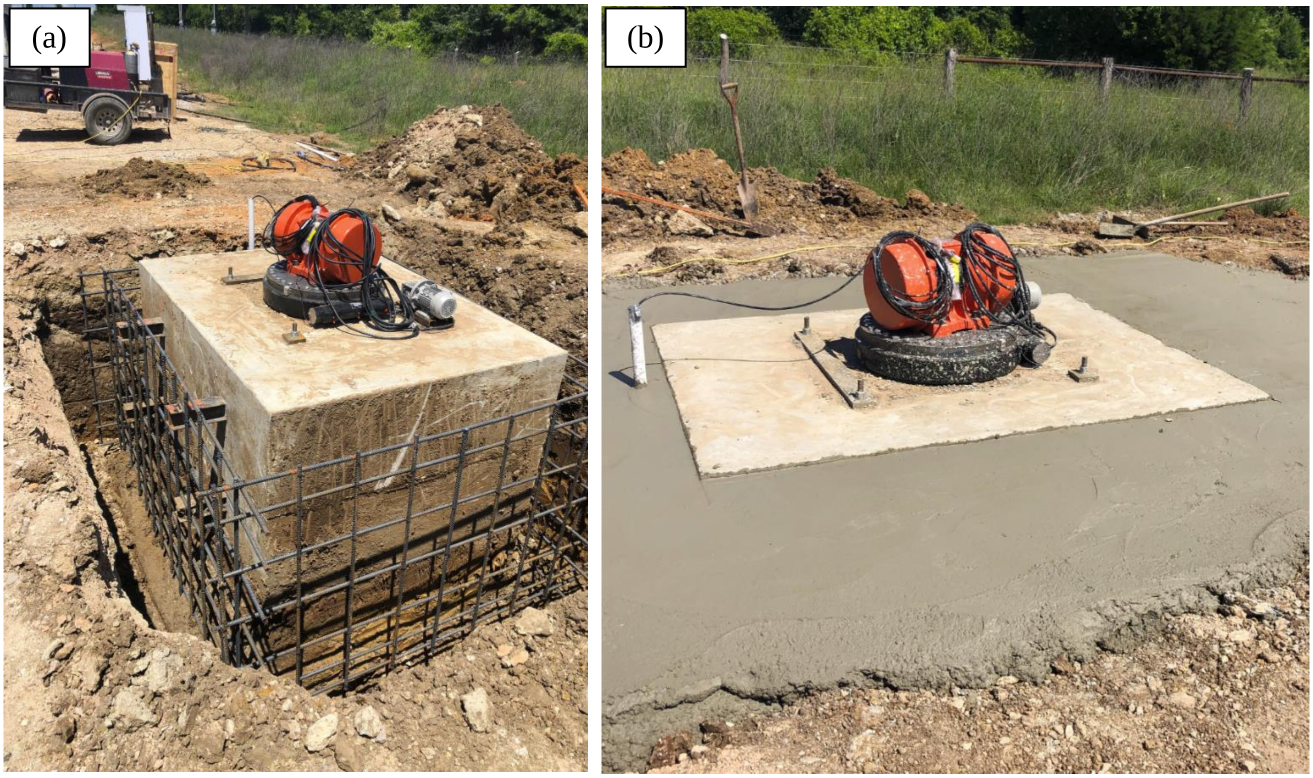

Figure 8. *Retrofit to SOV foundation: (a) Surrounding re-excavation of existing foundation; (b) Completed retrofit of existing foundation.*

2.3. Opportunities for Training and Professional Development.

Nothing to Report.

2.4. Dissemination of Results to Communities of Interest

Nothing to Report.

2.5. Plan for Next Quarter (BP1-Q5 NCTE: April – June, 2019)

Building on the current progress achieved by the research team, work planned for the next quarter will include, but is not limited to, the following:

- Continue work related to the HOW and the VOW in support of Subtask 2.2, 2.3, and 2.5:
  - ✓ Surface location selection.
  - ✓ Planning for permitting.
  - ✓ Vertical pilot and well path design (for HOW).
  - ✓ Casing design to accommodate coring and subsequent instrumentation.
- Continue ongoing design and planning for surface monitoring in support of Subtask 2.5:
  - ✓ Continue SOV pilot test on Harden CP3 well pad.
  - ✓ Procure SOV components for linear surface array.
  - ✓ SOV linear surface array location determination, planning, and permitting.
  - ✓ Initiate development of EFSL-specific seismic data processing and interpretation tools.
  - ✓ Procure CASSM source components and begin assembly of CASSM sources.
  - ✓ Complete DSS fiber optic cable design and testing, along with constructing a custom BOTDR in support of the DSS measurements.
- Select DAS/DTS fiber optic cable and interrogator supplier.
- Finalize proppant tracing program and contract with tracing supplier/service company.
- Design of geomechanical testing experiments to be conducted on core and cuttings.
- Continue simulation and modeling efforts in support of Subtask 3.5.

2.6. Summary of Tasks for Next Quarter (BP1-Q5 NCTE: April – June, 2019)

The following provides a summary of the tasks, subtasks, and activities planned in BP1-Q5:

- Task 1 – Project Management and Planning

  Activity is ongoing.
- Task 2 – Phase 1: Evaluation of Re-fracturing
  - ✓ Subtask 2.1 – Evaluation of Existing Data and Design of Observation Wells
    - *Activity 2.1.2 Design of the Active Source and Passive Monitoring Arrays*

      Activity is ongoing.
    - *Activity 2.1.3 Engineering of Integrated Monitoring Completion*

      Activity is ongoing.
- Special Reporting Requirements
  - ✓ An additional time extension request for Budget Period 1 (BP1) is anticipated pending the outcome of the summit meeting with Chesapeake in Oklahoma City on May 13-14, 2019.

Table 1. Summary of Milestone Status

Milestone	Task	Sub-task	Title/Description	Planned Completion Date	Actual Completion Date	Verification Method	Comments
A	1	1	Project Management & Planning	3/31/2021	Ongoing	Report	See description in CA
A	2 - Phase 1: Re-Fracturing Evaluation	2.1	Evaluation of Existing Data and Design of Observation Wells	9/30/2018	Ongoing	Report	See description in CA
B	2 - Phase 1: Re-Fracturing Evaluation	2.2	Drill, Complete, & Instrument Horizontal Observation Well	9/30/2018	*Pending	Report	Delayed due to change in operator
B	2 - Phase 1: Re-Fracturing Evaluation	2.3	Drill, Complete, & Instrument Vertical Observation Well	9/30/2018	*Pending	Report	Delayed due to change in operator
B	2 - Phase 1: Re-Fracturing Evaluation	2.4	Recomplete Well to be Re-Fractured	9/30/2018	*Pending	Report	Delayed due to change in operator
C	2 - Phase 1: Re-Fracturing Evaluation	2.5	Monitoring of Re-Fracturing	12/31/2018	*Pending	Report	Delayed due to change in operator
C	2 - Phase 1: Re-Fracturing Evaluation	2.6	Analysis of Re-Fracturing Monitoring	12/31/2019	*Pending	Report	Delayed due to change in operator
D	2 - Phase 1: Re-Fracturing Evaluation	2.7	DTS/DAS/DSS & Seismic Monitoring During Production	12/31/2019	*Pending	Report	Delayed due to change in operator
D	2 - Phase 1: Re-Fracturing Evaluation	2.8	Laboratory Evaluation of EOR Potential	6/30/2020	Ongoing	Report	See description in CA
E	2 - Phase 1: Re-Fracturing Evaluation	2.9	Coupled Modeling for Design, Prediction, Calibration & Code Validation	9/31/2020	Ongoing	Report	See description in CA
E	3 - Phase 2: Fracturing Evaluation	3.1	Drill, Complete & Instrument Two New Producing Wells	6/30/2019	Not Started	Report	None
F	3 - Phase 2: Fracturing Evaluation	3.2	Drilling Optimization	6/30/2020	Not Started	Report	None
F	3 - Phase 2: Fracturing Evaluation	3.3	Monitoring of Fracturing of Two New Producing Wells	12/31/2019	Not Started	Report	None
F	3 - Phase 2: Fracturing Evaluation	3.4	Analysis of Fracturing Monitoring of Two New Producing Wells	12/31/2020	Not Started	Report	None
F	3 - Phase 2: Fracturing Evaluation	3.5	Coupled Modeling for Design, Prediction, Calibration & Code Validation	12/31/2020	Not Started	Report	None
F	4 - Phase 3: EOR Pilot Test	4.1	Conduct Huff & Puff EOR Pilot Test	6/30/2020	Not Started	Report	None
F	4 - Phase 3: EOR Pilot Test	4.2	Monitor Injected Gas Placement with Active & Passive Seismic Monitoring	12/31/2020	Not Started	Report	None
F	4 - Phase 3: EOR Pilot Test	4.3	Monitor Injected Gas Distribution with DTS/DAS in Pilot Well	12/31/2020	Not Started	Report	None
G	4 - Phase 3: EOR Pilot Test	4.4	Modeling of the Huff & Puff EOR Pilot Test	12/31/2020	Not Started	Report	None
G	5 - Final Report	5.1	Multi-Purpose Optimization & Lessons Learned	3/31/2021	Not Started	Report	None
G	5 - Final Report	5.2	Products & Reporting	3/31/2021	Not Started	Report	None

3. PRODUCTS

Nothing to Report.

4. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

The acquisition of WildHorse Resource Development by Chesapeake Energy Corporation, which was announced on October 30th, 2018, has led to a change in the industry partner for the project. The acquisition officially closed on February 1st, 2019, at which point Chesapeake Energy Corporation became the new industry partner and EFSL field test site operator.

The project PI, Dr. Dan Hill, and the supporting project team at TAMU, has been in constant communication with WildHorse Resource Development's management team as well as upper level management at Chesapeake Energy Corporation to manage this transition and the possible impact on the EFSL project. This transition in industry partners has caused a delay in the performance of field test site activities planned during this reporting quarter (BP1-Q4).

The EFSL team at Texas A&M will be meeting with Chesapeake management and the respective EFSL project team leads on May 13th and 14th, 2019, at Chesapeake's main office in Oklahoma City, OK. This meeting is intended to finalize the scheduling of all field test site activities.

5. IMPACT

Nothing to Report.

6. CHALLENGES/PROBLEMS

A change in industry partner for the project has caused a delay to field test site activities as described in **Section 4** of this report. The team is actively managing this transition and has submitted a No-Cost Time Extension (NCTE) request to DOE which has been approved to extend Budget Period 1 to June 30th, 2019, in order to complete all activities originally planned for BP1.

An additional time extension request and funding profile adjustment is anticipated to be required for Budget Period 1, pending the outcomes of the meeting with Chesapeake on May 13th and 14th, 2019.

7. SPECIAL REPORTING REQUIREMENTS

7.1. Continuation Application and Funding (CA)

A Continuation Application and Funding (for Budget Period 2) was submitted on 03/31/2019. Reported within the Continuation Application and Funding is a comprehensive summary of the progress towards meeting the project objectives, a detailed budget justification, and a discussion on the Budget Period 2 plans for the project.

8. BUDGETARY INFORMATION

A summary of the budgetary information for Q1-Q4 of BP1 for the project is provided in **Table 2**. This table shows the original planned costs, the actual incurred costs, and the variance. The costs are split between federal share and non-federal share.

Table 2. Budgetary Information for Budget Period 1, Q1- Q4

Baseline Reporting Quarter	EFSL Budget Period 1 (04/01/2018 - 03/31/2019)									
	Q1		Q2		Q3		Q4		Total	
	04/01/2018 - 06/30/2018		07/01/2018 - 09/30/2018		10/01/2018 - 12/31/2018		01/01/2019 - 03/31/2019		04/01/2018 - 03/31/2019	
	Federal Share	Non-Federal Share	Federal Share	Non-Federal Share	Federal Share	Non-Federal Share	Federal Share	Non-Federal Share	Federal Share	Non-Federal Share
Baseline Cost Plan										
TAMU	$182,670	$0	$182,670	$0	$182,670	$0	$182,670	$0	$730,678	$0
Chesapeake	$850,001	$500,000	$850,001	$500,000	$850,001	$500,000	$850,001	$500,000	$3,400,003	$2,000,000
LBNL	$166,750	$0	$166,750	$0	$166,750	$0	$166,750	$0	$667,000	$0
Stanford	$31,456	$0	$31,456	$0	$31,456	$0	$31,456	$0	$125,825	$0
Total Planned	$1,230,877	$500,000	$1,230,877	$500,000	$1,230,877	$500,000	$1,230,877	$500,000	$4,923,506	$2,000,000
Actual Incurred Cost										
TAMU	$119,579	$0	$152,177	$0	$108,898	$0	$110,749	$0	$491,404	$0
Chesapeake	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
LBNL	$57,679	$0	$104,547	$0	$168,294	$0	$303,022	$0	$633,542	$0
Stanford	$29,084	$0	$4,847	$0	$16,552	$0	$34,659	$0	$85,143	$0
Total Incurred Cost	$206,342	$0	$261,572	$0	$293,745	$0	$448,430	$0	$1,210,089	$0
Variance										
TAMU	$63,090	$0	$30,492	$0	$73,771	$0	$71,920	$0	$239,274	$0
Chesapeake	$850,001	$500,000	$850,001	$500,000	$850,001	$500,000	$850,001	$500,000	$3,400,003	$2,000,000
LBNL	$109,071	$0	$62,203	$0	($1,544)	$0	($136,272)	$0	$33,458	$0
Stanford	$2,372	$0	$26,609	$0	$14,904	$0	($3,203)	$0	$40,682	$0
Total Variance	$1,024,534	$500,000	$969,305	$500,000	$937,132	$500,000	$782,446	$500,000	**$3,713,417**	**$2,000,000**

9. PROJECT OUTCOMES

Nothing to Report