Quarterly Research Performance Progress Report

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Name, Title, Email Address, and Phone Number for the Prime Recipient	**Technical Contact (Principal Investigator):** Griffin Beck Group Leader-R&D, griffin.beck@swri.org 210-522-2509 SwRI Project No. 20758 **Business Contact:** Robin Rutledge, Senior Specialist, robin.rutledge@swri.org, 210-522-3559
Prime Recipient Name and Address	Southwest Research Institute 6220 Culebra Road, San Antonio, TX 78238-5166
Prime Recipient type	Not for profit organization
Project Title	**Development and Field Testing Novel Natural Gas Surface Process Equipment for Replacement of Water as Primary Hydraulic Fracturing Fluid**
Principal Investigator(s)	Griffin Beck – *SwRI* SwRI Project No. 20758 **Subcontractors/Co-Funding Partners**: Sandeep Verma, Ph.D. – *Schlumberger* Leo Chaves – *Chevron*
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Signature of Principal Investigator:	Griffin Beck

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1. INTRODUCTION

Southwest Research Institute® (SwRI®), Schlumberger Technology Corporation (SLB), and Chevron Corporation® (Chevron) are working to jointly develop a novel, optimized, and lightweight modular process for natural gas (NG) to replace water as a low-cost fracturing medium with a low environmental impact. Hydraulic fracturing is used to increase oil and NG production by injecting high-pressure fluid, primarily water, into a rock formation, which fractures the rock and releases trapped oil and NG. This method was developed to increase yield and make feasible production areas that would not otherwise be viable for large-scale oil and NG extraction using traditional drilling technologies.

Since the fracturing fluid is composed of approximately 90% water, one of the principal drawbacks to hydraulic fracturing is its excessive water use and associated large environmental footprint. According to recent data, fracturing applications in North America can consume as much as 11 million gallons of water per well. During the fracturing process, some of the fracturing fluid is permanently lost and the portion that is recovered is contaminated by both fracturing chemicals and dissolved solids from the formation. The recovered water or flow-back represents a significant environmental challenge, as it must be treated before it can be reintroduced into the natural water system. Although there is some recycling for future fracturing, the majority of the flow-back water is hauled from the well site to a treatment facility or to an injection well for permanent underground disposal.

To mitigate these issues, an optimized, lightweight and modular surface process using NG to replace a majority of the water is being developed as a cost-effective and environmentally clean fracturing fluid. Using NG will result in significantly less consumption since the gas that is injected as a fracturing fluid will be mixed with the formation gas and extracted as if it were from the formation itself. This process will minimize the collection, waste, and treatment of large amounts of water and reduces the environmental impact of transporting and storing the fracturing fluid.

There are two major steps involved in utilizing NG as the primary fracturing medium: (1) increasing the supply pressure of NG to wellhead pressures suitable for fracturing and (2) mixing the required chemicals and proppant needed for the fracturing process at these elevated pressures. The second step (NG-proppant mixing at elevated pressures) still requires technology advancements but has previously been demonstrated in the field with other gases such as nitrogen (N_2) and carbon dioxide (CO_2). However, the first step (a compact, on-site unit for generating high-pressure NG at costs feasible for fracturing) has not been developed and is currently not commercially available. Due to the inherent compressibility of NG, more energy is required to compress the gas than what is required to pump water (or other incompressible liquids) to the very high pressure required for downhole injection. This project aims to develop a novel, hybrid method to overcome this challenge.

The project work is being performed in five sequential phases. The first phase included a thorough thermodynamic, economic, and environmental analysis of potential process concepts, as well as detailed design of three top-performing processes. The work completed in the first phase allowed the selected thermodynamic pathway of direct compression to be optimized for the intended application. In the second phase, the Pilot-Scale Foam Test Facility (PFTF) was constructed at the SwRI facilities in San Antonio, Texas. The PFTF was used to generate NG foam at elevated pressures similar to those found in a field application. The facility was used to investigate various properties of NG foam; such data are not available in the literature. In the third phase, the PFTF was used to further explore the feasibility of this novel technology and provided a more substantial data set that can be used to implement the technology in the field. In the fourth phase (the current phase), laboratory tests, process models, and pilot-scale tests were expanded to investigate the effects of realistic fluids and operating conditions. Specifically, the effects of multi-constituent NG mixtures, water impurities, and elevated operating temperatures on foam stability are being investigated. Furthermore, the impact of NG mixtures on the compression process efficiency and equipment footprint was identified. In the fifth phase, the potential for NG foam to enhance oil and gas recovery will be investigated in a series of laboratory fracture network tests.

The first budget period (BP1) for this project was completed in December 2015. Work from this first effort demonstrated that the use of a direct-compression system for fracturing is commercially viable and has economic potential. Work for the second budget period (BP2) was completed on March 31, 2017, and included pilot-scale investigations that demonstrated that stable NG foam can be generated at elevated pressure. The third budget period (BP3) was completed December 31, 2018, and included expanded pilot-scale tests to further investigate the fluid properties of NG foam using a range of base fluid mixtures. The fourth budget period (BP4), began January 1, 2019. This report covers work completed during the fourth and final quarter of BP4. The project goals and accomplishments related to those goals are discussed. Details related to any products developed in the quarter are outlined. Information on the project participants and collaborative organizations is listed and the impact of the work done during this quarter is reviewed. Any issues related to the project are outlined and, lastly, the current budget is reviewed.

2. ACCOMPLISHMENTS

2.1 Project Goals

The primary objective of this project is to develop and test a novel approach to use readily available wellhead (produced) NG as the primary fracturing fluid. This includes development, validation, and demonstration of affordable non-water-based and non-CO_2-based stimulation technologies, which can be used instead of, or in conjunction with, water-based hydraulic fracturing fluids to reduce water usage and the volume of flow-back fluids. The process will use NG at wellhead supply conditions and produce a fluid at conditions suitable for injection.

The project work is split into five budget periods. The milestones for each budget period are outlined in Table 6-1. This table includes an update on the status of each milestone in relation to the initial project plan. Explanations for deviations from the initial project plan are included.

2.2 Accomplishments

In the past quarter, the design of a small scale foam generator was further developed. This foam generation apparatus will be used to conduct experiments of fracture propagation when compressible fluids (e.g., foam) are used to initiate fractures.

Additionally, the Schlumberger Reservoir Laboratory investigated the effects of water and natural gas composition on the stability of natural gas foam. These and other accomplishments are discussed in the confidential appendix to this report.

2.3 Opportunities for Training and Professional Development

No opportunities for training and professional development occurred during the last quarter.

2.4 Dissemination of Results to Communities of Interest

No publications or presentations were released in the past quarter.

2.5 Plan for Next Quarter

In the second quarter of BP5, work will focus on finalizing the design for the small-scale foam generator and construction will begin. The project team will work to define appropriate rock samples to target with the tests at SRL. Additionally, work on the Duvernay reservoir model will continue.

2.6 Summary of Tasks for Next Quarter

The following tasks are expected in the next quarter:

- Complete the final design of the small, portable foam generator
- Begin construction of the SCFG
- Define preliminary test matrix for fracture network tests at SRL

3. PRODUCTS

With any technical work, results will be documented and reported to the appropriate entities. In addition, the work may produce new technology or intellectual property. This section provides a summary of how the technical results of this project have been disseminated and lists any new technology or intellectual property that has been produced.

3.1 Publications

No new publications were generated during the last quarter.

3.2 Technologies or Techniques

No new techniques or technologies have been developed during the last quarter.

3.3 Intellectual Property

No intellectual property, such as patents or inventions, has been submitted or developed in the last quarter.

4. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

The work required to develop the high-pressure NG processing system for fracturing requires the technical knowledge and effort of many individuals. SwRI, SLB, and Chevron are collaborating to complete the work. This section provides a summary of the specific individuals and organizations who have contributed in the last quarter.

4.1 SwRI – Prime Contractor

The following list provides the name of the Principal Investigator (PI) and each person who has worked approximately one person-month per year during the last quarter.

- Griffin Beck
  - Project role: PI
  - Nearest person-month worked: 0.2
  - Contribution to project: BP5 test design and project management
  - Funding support: DOE
  - Collaborated with individual(s) in foreign country(ies): No
  - Country(ies) of foreign collaborator(s): None
  - Traveled to a foreign country(ies): No
  - If traveled to a foreign country(ies), duration of stay: N/A

4.2 Other Organizations

For this project, SwRI is collaborating with SLB and Chevron. SLB is a subcontractor and cost-share supporter for this project. Chevron is a cost-share supporter for this project. More information about their participation is listed below.

- SLB
  - Location of organization: United States
  - Partner’s contribution to the project: Analysis and design support, laboratory testing, reservoir modeling
  - Financial support: N/A
  - In-kind support: Labor hours in the first budget period
  - Facilities: N/A
  - Collaborative research: SLB staff supported reservoir modeling tasks during the first quarter
  - Personnel exchanges: N/A
- Chevron
  - Location of organization: United States
  - Partner’s contribution to the project: Analysis and design support
  - Financial support: N/A
  - In-kind support: Labor hours in the first budget period
  - Facilities: N/A
  - Collaborative research: Chevron staff provided technical expertise for the project
  - Personnel exchanges: N/A

5. IMPACT

The use of NG foam is expected to have a smaller environmental footprint and may enhance gas and oil recovery compared to traditional, water-based fluids. Despite these potential benefits, fracturing with NG foams has not been widely adopted due in part to limited fluid property data. This project has provided much-needed information to the industry to advance fracturing with NG foams.

As noted in previous reports, past research efforts by others have investigated the rheological properties of foams generated with nonflammable gases, namely nitrogen and carbon dioxide. However, published literature is not available for the rheological properties of NG foam. The data generated by this project will be critical in future design work, particularly in understanding the impact of the gas compression machinery.

6. CHANGES/PROBLEMS

There are no changes to the milestone completion dates to report at this time. The project milestones and delivery dates are shown in Table 6-1.

At the time of this report, the project has not experienced any significant delays caused by the COVID-19 pandemic. However, several project members from the Schlumberger team have been placed on mandatory furloughs for 25% of their normal time (i.e., they are working 75% of normal time). With such reductions, it is possible that milestone schedules may be affected. The project team will continue to monitor the situation closely and will report any delays to DOE in a timely manner.

Table 6-1: Summary of Milestone Completion Status

Budget Period	Milestone Letter	Milestone Title/Description	Planned Completion Date	Actual Completion Date	Verification Method	Comments (Progress towards achieving milestone, explanation of deviations from plan, etc.)
1	A	Top 2 to 3 Thermodynamic Cycles Identified	January 2, 2015 **New: June 9, 2015**	Complete June 9, 2015	At least two combinations of thermodynamic paths and sets of equipment have been identified as being capable of accomplishing natural gas compression from approximately 200-1,000 psi inlet to 10,000 psi outlet.	Completion of this milestone has been delayed by execution of full contract. Actual completion date was June 9, 2015.
	B	Top Thermodynamic Cycle Identified	May 1, 2015 **New: September 30, 2015**	Complete September 30, 2015	At least one combination of thermodynamic paths and sets of equipment has been identified as being capable of accomplishing natural gas compression from approximately 200-1,000 psi inlet to 10,000 psi outlet in an economically feasible fashion. This is considered a critical path milestone.	Start of this work was delayed due to delay in execution of full contract. Actual completion date was September 30, 2015.
	C	Finalized Detailed Design	September 30, 2015 **New: December 31, 2015**	Complete, December 31, 2015	A laboratory-scale compression/pump test train will be designed to accomplish natural gas compression from approximately 200-1000 psi inlet to 10,000 psi outlet in an economically feasible fashion. This is considered a critical path milestone.	With the delay in execution of the full contract, this milestone was completed on December 31, 2015.
2	D	Compressor/Pump Train Set-up Complete	March 17, 2016 **New: December 30, 2016**	Complete, December 30, 2016	The laboratory-scale compression/pump test train will be assembled/constructed. This is considered a critical path milestone.	Due to a delay in contract execution, delays with component deliveries, and delays related to commissioning, the construction was completed Dec. 30, 2016.
	E	Test Data Acquired and Analyzed	September 30, 2016 **New: March 31, 2017**	Complete, March 31, 2017	Measured data will confirm that the laboratory-scale compression/pump test train is able to accomplish natural gas compression from approximately 200-1000 psi inlet to 10,000 psi outlet in an economically feasible, compact, and portable fashion. This is considered a critical path milestone.	With the delayed completion of the test stand, testing and data analysis was completed March 31, 2017.
3	F	Test Facility Modifications Complete	October 31, 2017 **New: March 31, 2018**	Complete March 30, 2018	Modifications to the BP2 test stand are complete and the test matrix has been generated.	The test stand modifications were completed on March 30, 2018.
	G	Test Data Acquired and Analyzed	3/31/2018 **New: December 31, 2018**	Complete December 31, 2018	Measured data will provide detailed information about the rheology properties of NG foam.	Initial data processing is complete. Further processing will occur as needed.
4	H	Test Facility Modifications Complete	August 13, 2019	Complete October 8, 2019	Modifications to support high-temperature stability tests are complete	Facility upgrades were completed and tests were executed.
	I	Test Data Acquired and Analyzed	12/31/2019 **New: June 30, 2020**	In Progress	Data collected on the pilot-scale foam test facility and the closed-loop rheometer will be used to determine the effect of water quality, gas composition, and operating temperature on the stability of natural gas- based foam	Tests with produced water and natural gas mixtures were conducted and a majority of the data was analyzed.
	J	Compression Cycle Models Updated	September 30, 2019	Complete December 31, 2019	Cycles have been modeled with realistic natural gas compositions	
	K	Initial Reservoir Model Complete	September 30, 2019	Complete December 31, 2019	Initial reservoir models will be used to explore potential production benefits related to natural gas-based foam	
5	L	Portable Foam System Complete	June 30, 2020	In Progress	The portable foam system has been designed, built, and commissioned	Design work for the system is nearly complete and numerous system components have been ordered.
	M	Test Data Acquired and Analyzed	December 31, 2020		Fracture network data has been generated and analyzed	
	N	Final Reservoir Model Complete	September 30, 2020	In Progress	The reservoir model has been updated with additional information generated by the fracture network tests	

7. BUDGETARY INFORMATION

Summaries of the budgetary data for BP4 and BP5 portions of the project are provided in Table 7-1 and Table 7-2. These tables show planned costs over, the actual incurred costs to date, and the variance for the current budget period. The costs are split between the Federal and Non-Federal share.

As detailed in previous reports, a portion of the Schlumberger BP4 scope of work was delayed until the first quarter of this year. This work was conducted concurrently with the BP5 activities due to the removal of the funding by budget period requirement of the contract. Though that work is almost entirely complete, the invoice for that work has not yet been reported. Once that final invoice is received and the Chevron cost share is accounted for, the variance of $122,770 will be resolved. For the BP5 work, a variance of $168,076 currently exists but will be resolved as SwRI continues to purchase components for the SCFG and as subcontract and cost share invoices are reported.

Table 7-1: Budgetary Information for Budget Period 4

Budget Period 4					
Reporting Quarter	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**
Start	**1/5/2019**	**3/30/2019**	**7/6/2019**	**9/28/2019**	**1/4/2020**
End	**3/29/2019**	**7/5/2019**	**9/27/2019**	**1/3/2020**	**3/27/2020**
Baseline Cost Plan	$148,932	$406,734	$658,888	$804,755	$804,755
Federal Share	$106,721	$322,311	$532,253	$635,909	$635,909
Non-Federal Share	$42,211	$84,423	$126,634	$168,846	$168,846
Total Planned	***$148,932***	***$406,734***	***$658,888***	***$804,755***	***$804,755***
Actual Incurred Cost	$25,305	$94,200	$334,066	$539,037	$681,985
Federal Share	$25,305	$94,200	$334,066	$539,037	$564,385
Non-Federal Share	$0	$0	$0	$0	$117,600
Total Incurred Costs	***$25,305***	***$94,200***	***$334,066***	***$539,037***	***$681,985***
Variance	$123,628	$312,533	$324,821	$265,718	$122,770
Federal Share	$81,416	$228,110	$198,187	$96,872	$71,524
Non-Federal Share	$42,211	$84,423	$126,634	$168,846	$51,246
Total Variance	***$123,628***	***$312,533***	***$324,821***	***$265,718***	***$122,770***

Table 7-2: Budgetary Information for Budget Period 5

Budget Period 5				
Reporting Quarter	**Q1**	**Q2**	**Q3**	**Q4**
Start	**1/4/2020**	**3/28/2020**	**7/4/2020**	**9/26/2020**
End	**3/27/2020**	**7/3/2020**	**9/25/2020**	**1/1/2021**
Baseline Cost Plan	$197,889	$512,471	$718,731	$888,422
Federal Share	$151,492	$419,679	$579,542	$702,836
Non-Federal Share	$46,396	$92,793	$139,189	$185,585
Total Planned	***$197,889***	***$512,471***	***$718,731***	***$888,422***
Actual Incurred Cost	$29,813			
Federal Share	$29,813			
Non-Federal Share	$0			
Total Incurred Costs	***$29,813***			
Variance	$168,076			
Federal Share	$121,679			
Non-Federal Share	$46,396			
Total Variance	***$168,076***			