Quarterly Research Performance Progress Report

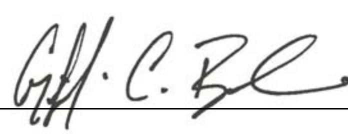
Federal Agency to which the report is submitted	Office of Fossil Energy
FOA Name	Environmentally-Prudent Unconventional Resource Development
FOA Number	DE-FOA-0001076
Nature of the Report	Research Performance Progress Report (RPPR)
Award Number	DE-FE0024314
Award Type	Cooperative Agreement
Name, Title, Email Address, and Phone Number for the Prime Recipient	**Technical Contact (Principal Investigator):** Griffin Beck Research Engineer, griffin.beck@swri.org 210-522-2509 **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	**TA2 Development and Field Testing Novel Natural Gas Surface Process Equipment for Replacement of Water as Primary Hydraulic Fracturing Fluid**
Principal Investigator(s)	Griffin Beck, Klaus Brun, Ph.D., and Kevin Hoopes – *SwRI* **Subcontractor and Co-funding Partner**: Sandeep Verma, Ph.D. – *Schlumberger*
Prime Recipient's DUNS number	00-793-6842
Date of the Report	January 27, 2017
Period Covered by the Report	October 1, 2016 – December 31, 2016
Reporting Frequency	Quarterly
Signature of Principal Investigator:	 Griffin Beck

TABLE OF CONTENTS

1 INTRODUCTION

Southwest Research Institute® (SwRI®) and Schlumberger Technology Corporation (SLB) are working to jointly develop a novel, optimized, and lightweight modular process for natural gas to replace water as a low-cost fracturing medium with a low environmental impact. Hydraulic fracturing is used to increase oil and natural gas production by injecting high-pressure fluid, primarily water, into a rock formation, which fractures the rock and releases trapped oil and natural gas. This method was developed to increase yield and make feasible production areas that would not otherwise be viable for large-scale oil and natural gas 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. Each application of fracturing can consume as much as three to seven million gallons of water. 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 natural gas to replace water will be developed and field-tested as a cost-effective and environmentally-clean fracturing fluid. Using natural gas will result in a near zero consumption process, 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 eliminates 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 natural gas as the primary fracturing medium: (i) increasing the supply pressure of natural gas to wellhead pressures suitable for fracturing and (ii) mixing the required chemicals and proppant that are needed for the fracturing process at these elevated pressures. The second step (natural gas-proppant mixing at elevated pressures) still requires technology advancements, but has previously been demonstrated in the field. However, the first step (a compact on-site unit for generating high-pressure natural gas (supercritical methane (sCH_4)) at costs feasible for fracturing) has not been developed and is currently not commercially available. The inherent compressibility of natural gas results in significantly more energy being required to compress the gas than is required for pumping 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. Several processes will be evaluated to identify the optimal process for producing high-pressure natural gas (sCH_4). Initial calculations have shown a substantial reduction in the total topside process energy requirements if a low-yield Liquefied Natural Gas (LNG) expansion, instead of a refrigeration production process, is utilized and treatment is limited to removal of only the minimal amount of impurities. The project will develop, optimize, and test this process both in the lab and in the field.

The project work will be performed in three sequential phases. The first phase will start with a thorough thermodynamic, economic, and environmental analysis of potential concepts, as well as detailed design. This will allow the selected thermodynamic pathway to be optimized for the intended application. The second phase will consist of the assembly and testing of a reduced-scale model in a SwRI laboratory to measure the overall efficiency and cost savings of the developed process. The third and final phase will be an on-site demonstration conducted in close partnership with SLB. This will allow the real world benefits of the technology to be demonstrated and quantified.

This report covers the work completed in this budget quarter. 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 field test a novel approach to use readily available wellhead (produced) natural gas 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 tandem with, water-based hydraulic fracturing fluids to reduce water usage and the volume of flow-back fluids. The process will use natural gas at wellhead supply conditions and produce a fluid at conditions needed for injection.

The project work is split into three budget periods. Each budget period consists of one year. The milestones for each budget period are outlined in Table 7-2. This table includes an update on the status of that milestone in relation to the initial project plan. Explanations for deviations from the initial project plan are included.

2.2 *Accomplishments*

In the fourth quarter of budget period 2 (BP2), the project team finalized the construction of the BP2 test stand (milestone D in Table 7-2) and completed several tasks to commission the test stand. That work included receiving and installing all of the major equipment used for the BP2 test stand.

Some significant delays were experienced during the commissioning of the water pump. Nevertheless, it is anticipated that there will be no additional delay to BP2 project completion date of March 31, 2017. The work completed in the fourth quarter of BP2 is discussed in detail in the confidential appendix of this report.

2.3 *Opportunities for Training and Professional Development*

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

2.4 *Dissemination of Results to Communities of Interest*

No results have been disseminated to communities of interest during this quarter.

2.5 *Plan for Next Quarter*

In the next quarter, the planned tests will begin. As the tests are completed, the collected data will be analyzed and the results will be documented.

Summary of tasks for next quarter

- Test stand commissioning
    - Commission high-flow LNG pumps, once LNG is received
- Testing
    - Perform tests outlined in the test matrix
- Data analysis & reporting

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*

In November 2016, a presentation was given at the 2016 AIChE Annual Meeting held in San Francisco, CA (https://www3.aiche.org/proceedings/Abstract.aspx?PaperID=474557).

3.2 *Websites or Other Internet Sites*

The results of this project have not been published on any websites or other internet sites during the last quarter.

3.3 *Technologies or Techniques*

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

3.4 *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 natural gas (sCH_4) processing system for fracturing requires the technical knowledge and effort of many individuals. In addition, two companies, SwRI and SLB, 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 *Southwest Research Institute (SwRI) – Prime Contractor*

The following list provides the name of the Principal Investigator (PI) and each person who has worked at least one person-month per year (160 hours of effort) in the last quarter.

- Griffin Beck
    - Project role: Principal Investigator
    - Nearest person-month worked: 1
    - Contribution to project: identification of commercially-available equipment, test design, test system simulations, hardware selection, technical project management, test stand construction, test stand commissioning
    - Funding support: DOE
    - Collaborated with individual in foreign country: No
    - Country(ies) of foreign collaborator: None
    - Traveled to foreign country: Yes, Mexico
    - If traveled to foreign country(ies), duration of stay: 4 days

- Craig Nolen
    - Project role: Project Engineer
    - Nearest person month worked: 1
    - Contribution to project: test design, test system simulations, hardware selection, test stand construction, test stand commissioning
    - Funding support: DOE
    - Collaborated with individual in foreign country: No

- Country(ies) of foreign collaborator: None
- Traveled to foreign country: No
- If traveled to foreign country(ies), duration of stay: None

- James Donnelly
  - Project role: Project Technician
  - Nearest person month worked: 1
  - Contribution to project: test stand construction, test stand commissioning
  - Funding support: DOE
  - Collaborated with individual in foreign country: No
  - Country(ies) of foreign collaborator: None
  - Traveled to foreign country: No
  - If traveled to foreign country(ies), duration of stay: None

4.2 *Other Organizations*

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

- Schlumberger
  - 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 second budget period
  - Facilities: n/a
  - Collaborative research: SLB staff supports the design and testing tasks for the second budget period
  - Personnel exchanges: n/a

5 IMPACT

The use of natural gas foam is expected to have a smaller environmental footprint and may also enhance gas and oil recovery compared to traditional, water-based fluids. Despite these potential benefits, fracturing with natural gas foams has not been widely adopted due in part to limited fluid property data. The BP2 tests will provide much needed information to industry to advance fracturing with natural gas foams.

As noted in previous reports, past research efforts by others have investigated the rheological properties of foams generated with inert gases, namely nitrogen and carbon dioxide. However, published literature is not available for the rheological properties of natural gas foam. The data generated by the BP2 tests will provide the first set of publically-available natural gas foam rheology data. Also, the BP2 tests will provide key details on the response of the foam fluid in a fracture-type event. These data will be critical in future design work, particularly in understanding the impact on the gas compression machinery.

6 CHANGES/PROBLEMS

In the past quarterly report, updates were made to the BP2 milestone completion dates to reflect a No-Cost Time Extension request submitted to DOE. The request was to extend the BP2 project deadline to March 31, 2017, a three-month delay from the original completion date. As described in this report, delays encountered with commissioning the BP2 test stand delayed the anticipated construction completion date to December 30, 2016. A summary of all the milestones and their status is shown in Table 7-2.

- Milestone D – Compressor/Pump Train Setup Complete
  - Original Completion Date: March 17, 2016
  - New Completion Date: December 30, 2016
- Milestone E – Test Data Acquired and Analyzed
  - Original Completion Date: September 30, 2016
  - New Completion Date: March 31, 2017

7 BUDGETARY INFORMATION

A summary of the budgetary data for the project is provided in Table 7-1. This table shows the initial planned cost, the actual incurred costs, and the variance for the current budget period. The costs are split between the Federal and Non-Federal share.

In the fourth quarter of BP2, $199,074 was spent. These costs included labor charges for the technical work completed, costs related equipment purchases, and costs related to the BP2 test stand installation. As indicated in past reports, the overall project cost variance was decreased significantly again in Q4 due to significant level of effort required to install the test stand.

Table 7-1. Budgetary Information for Period 4

Baseline Reporting Quarter	Budget Period 2				
	Q1	Q2	Q3	Q4	Cumulative Total
	1/1/2016 - 4/01/2016	4/2/2016 - 7/08/2016	7/08/2016 - 9/30/2016	10/1/2016 - 12/31/2016	
Baseline Cost Plan	$141,000	$157,000	$141,000	$125,445	$564,445
Federal Share	$112,800	$125,600	$112,800	$100,356	$451,556
Non-Federal Share	$28,200	$31,400	$28,200	$25,089	$112,889
Total Planned	$141,000	$157,000	$138,000	$125,445	$561,445
Actual Incurred Cost	$10,200	$107,904	$201,003	$199,074	$518,182
Federal Share	$10,200	$75,663	$167,466	$166,833	$420,163
Non-Federal Share	$0	$32,241	$33,537	$32,241	$98,019
Total Incurred Costs	$10,200	$107,904	$201,003	$199,074	$518,182
Variance	$130,800	$49,096	($63,003)	($73,629)	$43,263
Federal Share	$102,600	$49,937	($54,666)	($66,477)	$31,393
Non-Federal Share	$28,200	($841)	($5,337)	($7,152)	$14,870
Total Variance	$130,800	$49,096	($60,003)	($73,629)	$46,263

Table 7-2. 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 is 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 have 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. (see Milestones NOTE below). This is considered a critical path milestone.	Start of this work was delayed due to delay in execution of full contract. Actual completion date is 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. (see Milestones NOTE below). 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 comissioning, the construction was completed Dec. 30, 2016
	E	Test Data Acquired and Analyzed	September 30, 2016 **New: March 31, 2017**	In Progress	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 (see Milestones NOTE below). This is considered a critical path milestone.	With the delayed completion of the test stand, testing and data analysis is now scheuled for completion by March 31, 2017
3	F	Field Test Set-up Complete	April 17, 2017	Not Started	The equipment for the field testing has been set-up and commissioned at the test site. The test set-up is ready for the start of operation.	none
	G	Field Test Data Acquired and Analyzed	September 29, 2017	Not Started	Measured data will show that the field-tested, laboratory-scale compression/pump 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 (see Milestones NOTE below). This is considered a critical path milestone.	none