Quarterly Research Performance Progress Report

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Name, Title, Email Address, and Phone Number for the Prime Recipient	**Technical Contact (Principal Investigator):** Melissa Poerner, P.E., Senior Research Engineer, melissa.poerner@swri.org, 210-522-6046 **Business Contact:** Mary Lepel, Senior Specialist, mary.lepel@swri.org, 210-522-3026
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)	Melissa Poerner, P.E., 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
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Signature of Principal Investigator:	 Melissa Poerner, P.E.

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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 onsite 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 this last budget period, there were several accomplishments made. First, the search for commercially available equipment for the three thermodynamic cycles was completed. The models for each cycle were updated to reflect the availability and limitations of the equipment. In addition, site layouts for each of the cycles were created. This included determining how the equipment could be mounted on a trailer, if there are limitations for mounting the equipment on trailers, looking at where the equipment would be placed around the wellhead, and estimating the number of trailers required for each cycle. After the identification of commercial equipment and site layouts were completed, the cost for each cycle was estimated. Lastly, the results of the assessments described above were used to assign a score to the cycles to select the optimal system. The top cycle selected was the direct compression cycle. The details of the work performed in this last quarter are considered confidential and therefore are not included in this report.

2.3 *Opportunities for Training and Professional Development*

During this last quarter, several of the team members attended the Turbomachinery Symposium. These team members attended presentations and spoke with vendors on equipment related to this project. This allowed the team members to gain more knowledge about the commercially available equipment for the project and learn about what research is being done in the area of LNG cycle optimization. In addition, one team member attended the “Aspen HYSYS: Process Modeling” course.

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*

During the next quarter, several tasks will be completed. The list below outlines the planned work. First, design of the laboratory and field demonstration scale systems will be completed. This includes the equipment selection for these tests, simulation of the test system, development of the test matrix, and identification of safety consideration for testing. Lastly, the LNG rheology study will be completed.

Summary of tasks for next quarter

- Complete design of laboratory and field demonstration scale systems
  - Equipment selection
  - System simulation
  - Development of test matrix
  - Safety considerations
- Complete LNG rheology literature review

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 written works have been published during this last quarter. In addition, no abstracts for future papers or conferences have been submitted for this project.

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*

During this last quarter, invention disclosures were submitted for the Pre-Compressed Methane Liquefaction Cycle and the Mixed Refrigerant Cycle with High Pressure Cooling. SwRI notified DOE through the appropriate measures about the filing of these invention disclosures.

4 PARTCIPANTS & 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 PI and each person who has worked at least one person-month per year (160 hours of effort) in the last quarter.

- Melissa Poerner, P.E.
  - Project Role: Principal Investigator
  - Nearest person month worked: 1

  - Contribution to Project: Project management, thermodynamic cycle review, identification of commercially available equipment, metric scoring
  - 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

- Griffin Beck
  - Project Role: Project Engineer
  - Nearest person month worked: 1
  - Contribution to Project: thermodynamic cycle analysis, identification of commercially available equipment
  - 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 Schlumberger (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 first budget period
  - Facilities: n/a
  - Collaborative Research: SLB staff supports the analysis and design tasks for the first budget period
  - Personnel Exchanges: n/a

5 IMPACT

During this quarter, it was determined that the direct compression system is the optimal cycle for fracturing with natural gas. This has a significant impact. Many groups throughout industry are looking into various methods to fracture wells to minimizing the use of water. Some groups are using LNG or other liquefied hydrocarbons for the process. The results of the analysis can assist groups looking at new fracturing technology development by clearly showing the advantages and disadvantages of fracturing with natural gas or LNG. The results of this project also provide a clear picture of what equipment is commercially available for use in natural gas fracturing and the current limitations.

6 CHANGES/PROBLEMS

During the first quarter, the full contract was not completed. Therefore, this delayed the start of the technical work. During the second quarter, the technical work was started and attempts were made to accelerate the work pace. Based on the work completed during the second quarter and the workload anticipated for the rest of the first budget period, the schedule for the project was adjusted. The completion date for the milestones in the first budget period were shifted as outlined below and in Table 7-2. It is anticipated that the project work for the first budget period will be completed on December 31, 2015, which is three months after the original due date (September 30, 2015). A No-Cost Time Extension request was submitted and approved by DOE in order to extend the project deadline.

- Milestone A – Top 2 to 3 thermodynamic cycles identified
  - Original Completion Date: January 2, 2015
  - New Completion Date: June 9, 2015
- Milestone B – Top thermodynamic cycle identified
  - Original Completion Date: May 1, 2015
  - New Completion Date: September 30, 2015
- Milestone C – Finalized Detailed Design
  - Original Completion Date: September 30, 2015
  - New Completion Date: December 31, 2015

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. The costs are split between the Federal and Non-Federal share.

For the fourth quarter in budget period 1, $120,096 was spent. The cost included labor charges and charges for travel for the face-to-face meeting in September at the Schlumberger office in Boston, MA. Since the technical work began in February 2015, the cost variance on the overall project costs is high. The schedule for the project was shifted approximately 4.5 months. A review of the planned costs for Q3 show that the spend rate from Q3 closely matches the actual spend rate in Q4. This indicates that the technical work is progressing as planned with an offset because of the delayed start in technical work.

Table 7-1. Budgetary Information for Period 1

Baseline Reporting Quarter	Budget Period 1				
	Q1	Q2	Q3	Q4	Cumulative Total
	10/1/2014 - 12/31/2014	1/1/2015 - 3/31/2015	4/1/2015 - 6/30/2015	7/1/2015 - 9/30/2015	
Baseline Cost Plan	$112,000	$103,000	$138,000	$133,998	$486,998
Federal Share	$89,600	$82,400	$110,400	$107,198	$389,598
Non-Federal Share	$22,400	$20,600	$27,600	$26,800	$97,400
Total Planned	$112,000	$103,000	$138,000	$133,998	$486,998
Actual Incurred Cost	$15,754	$49,772	$95,650	$120,096	$281,271
Federal Share	$15,754	$37,203	$64,228	$89,803	$206,988
Non-Federal Share	$0	$12,569	$31,422	$30,293	$74,284
Total Incurred Costs	$15,754	$49,772	$95,650	$120,096	$281,271
Variance	$96,246	$53,228	$42,350	$13,902	$205,727
Federal Share	$73,846	$45,197	$46,172	$17,395	$182,611
Non-Federal Share	$22,400	$8,031	($3,822)	($3,493)	$23,116
Total Variance	$96,246	$53,228	$42,350	$13,902	$205,727

Table 7-2. Summary of Milestone 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. Planned completion date is extended to 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. Planned completion date is extended to September 30, 2015.
	C	Finalized Detailed Design	September 30, 2015 **New: December 31, 2015**	In Progress 35% Complete	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, it is anticipated that this milestone will be completed on December 31, 2015
2	D	Compressor/Pump Train Set-up Complete	March 17, 2016	Not Started	The laboratory-scale compression/pump test train will be assembled/constructed. This is considered a critical path milestone.	none
	E	Test Data Acquired and Analyzed	September 30, 2016	Not Started	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.	none
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