Development and Field Testing Novel Natural Gas Surface Process Equipment for Replacement of Water as Primary Hydraulic Fracturing Fluid

Project # DE-FE0024314

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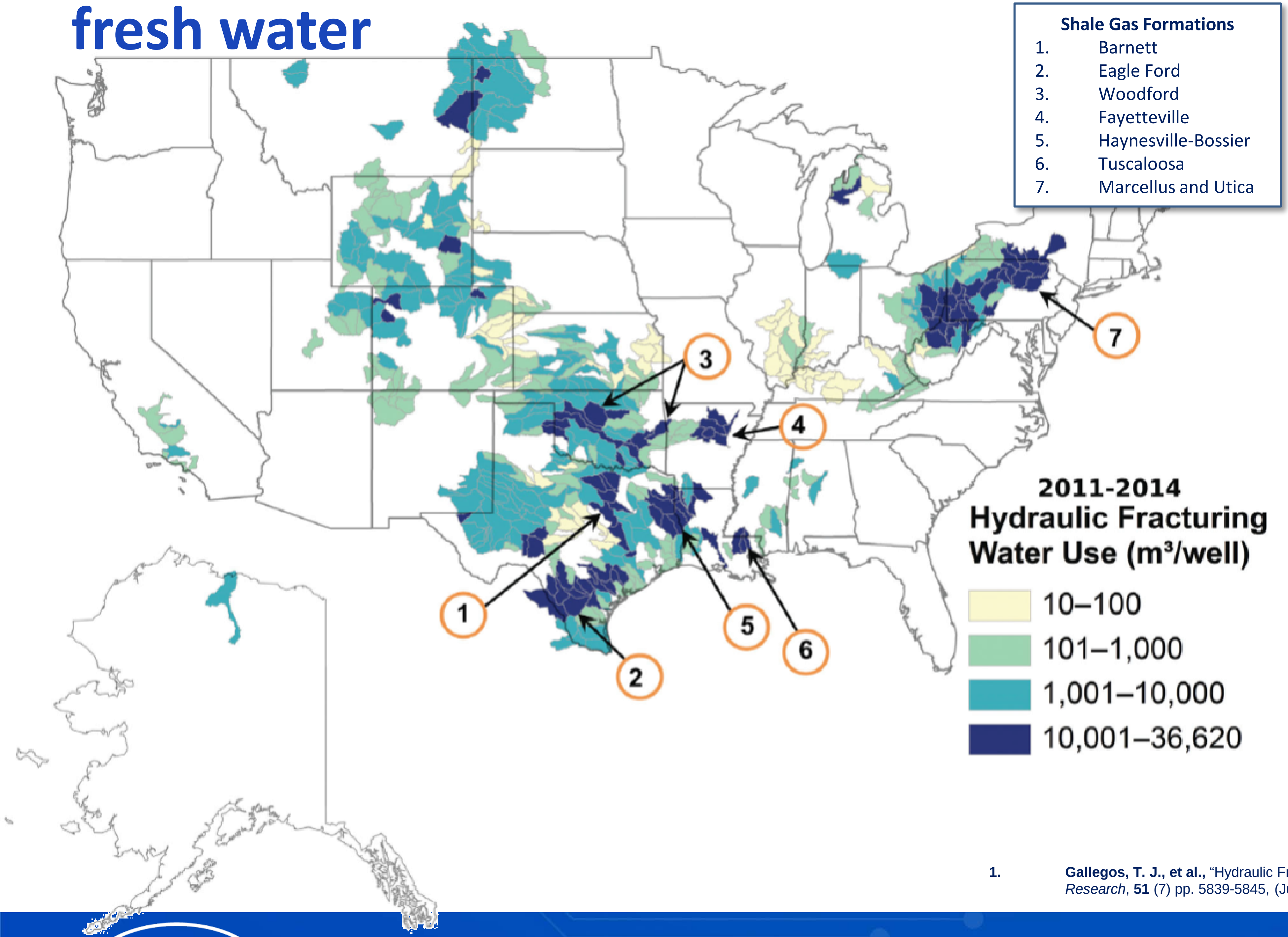
This presentation provides an overview of recent work to develop a hydraulic fracturing technique that uses natural gas-based foam

1. Project motivation
2. Technical Status & Accomplishments
    1. Process models
    2. Pilot-scale foam test facility
    3. Foam test results
    4. Current work
3. Synergy Opportunities
4. Future work

Pilot Scale Foam Test Facility

Typical hydraulic fracturing treatments consume a significant volume of fresh water

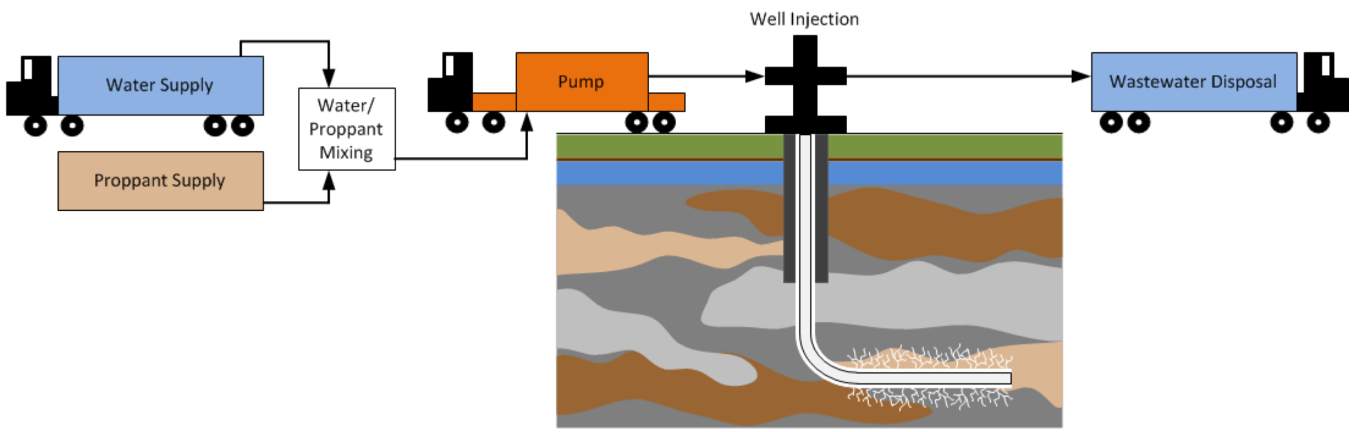


- Water combined with various chemicals is used to initiate fracture and carry proppant
- As much as 9.7 million gal/well[1]
- Significant transportation required
- Recovered water must be either cleaned or disposed

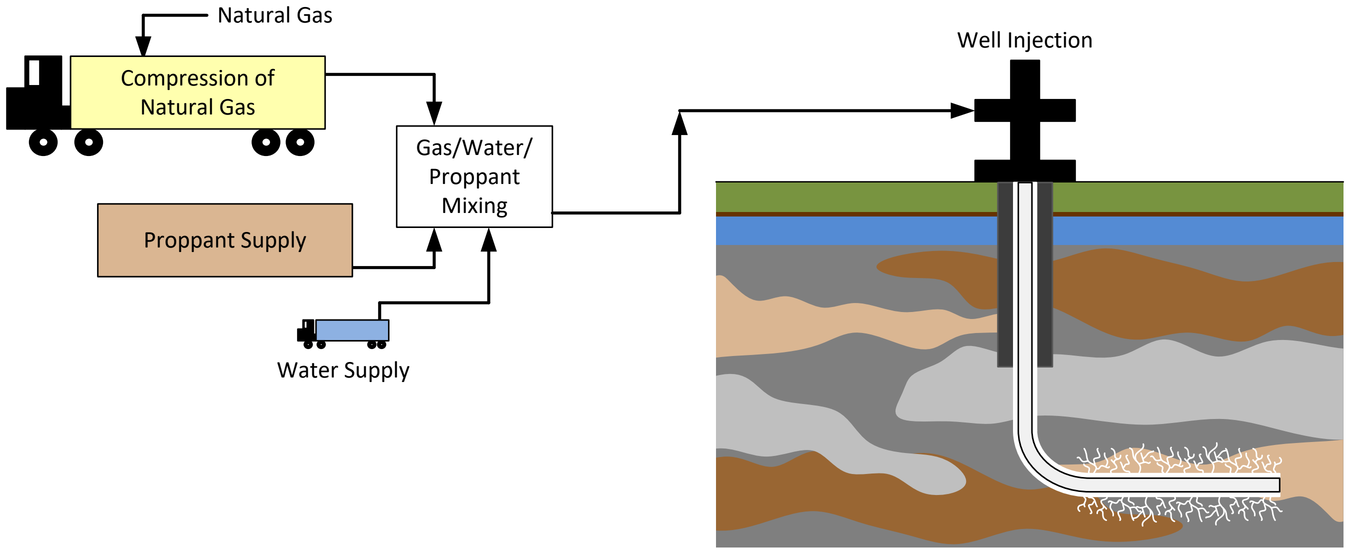
1. **Gallegos, T. J., et al.**, “Hydraulic Fracturing Water Use Variability in the United States and Potential Environmental Implications,” *Water Resources Research*, **51** (7) pp. 5839-5845, (July 2015).

SwRI, Schlumberger, and Chevron are working to develop a novel process that uses natural gas-based foam as the fracturing fluid

Current Fracturing Process



Proposed Natural Gas Fracturing Process



- The proposed process uses NG foam for hydraulic fracture treatment
- This could reduce water consumption by as much as 80%
- Natural gas is readily available at well site
- The recovered natural gas would be processed

A key challenge with using natural gas relates to the processing equipment

Typical Hydraulic Fracturing Pump Trailer

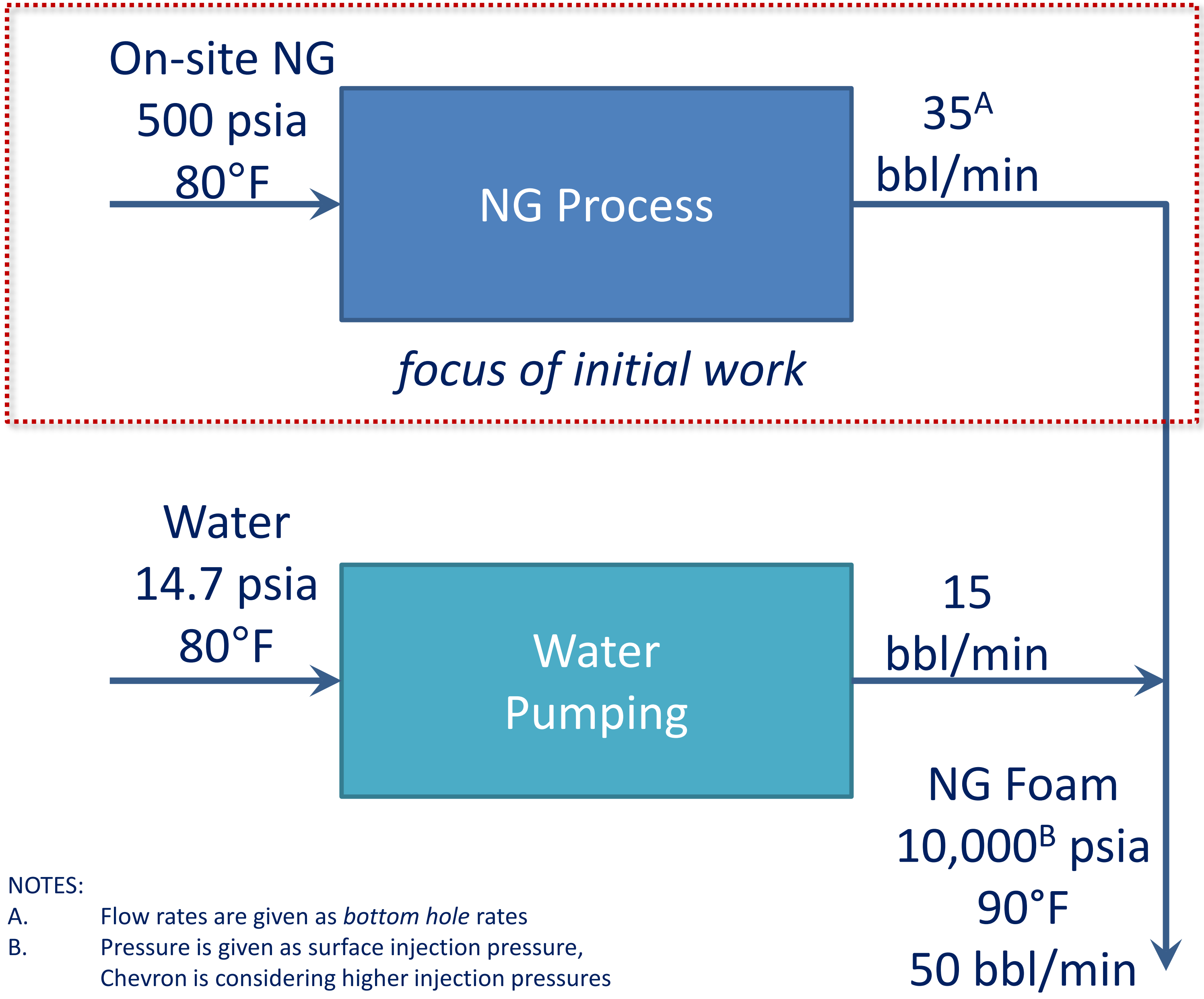
Retrieved from http://www.stewartandstevenson.com/markets/oil-gas/frac-well-stim-equipment/frac-pumps

Liquid Nitrogen (LN_2) Pump Trailer

Retrieved from http://cvatanks.com/products/oilfield-equipment/trailer-mounted-nitrogen-pumper/

- All hydraulic fracturing processes pump liquids to achieve high pressures
  - Typical fracture treatments use water pumps only
  - CO_2 and N_2 foam treatments use cryogenic pumps
- The natural gas foam process uses on-site natural gas

Initial project work focused on identifying an efficient mobile process capable of generating high pressure natural gas

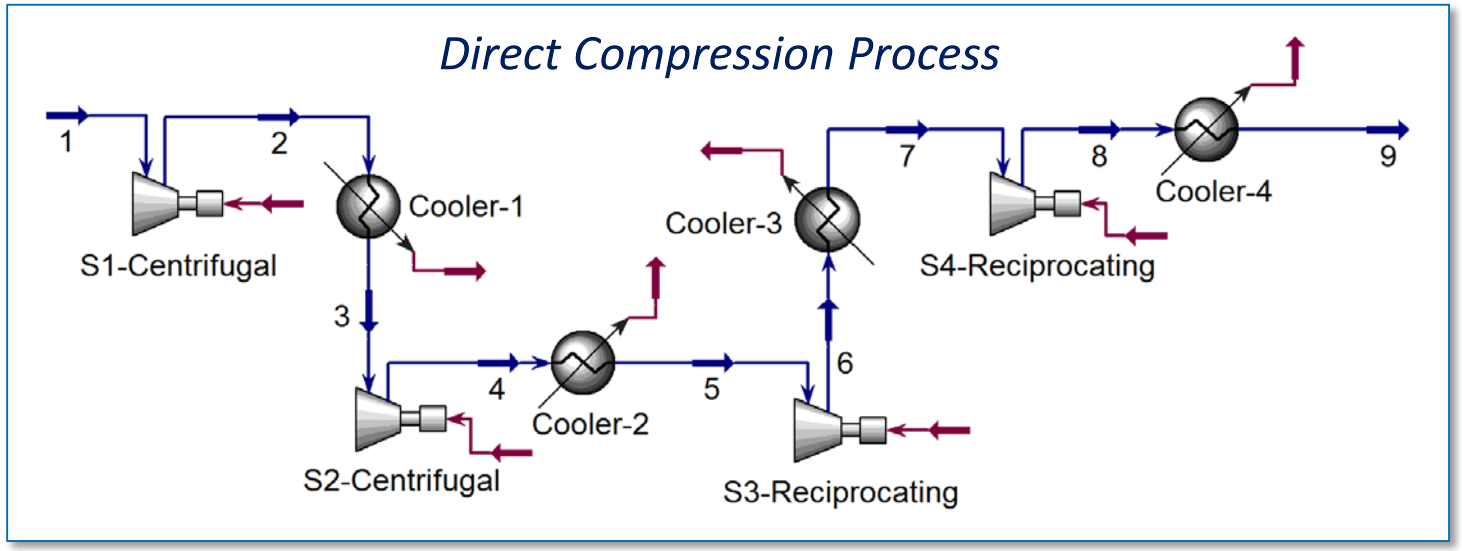


NOTES:
A. Flow rates are given as *bottom hole* rates
B. Pressure is given as surface injection pressure, Chevron is considering higher injection pressures

- On-site processes were considered (e.g., offsite liquefaction/ trucking LNG to site not considered)
- On-site storage of CNG or LNG was not considered
- Six (6) processes modeled[2-4]
  - 1 compression process
  - 5 liquefaction processes
- Inlet assumptions:
  - NG supply at 500 psia and 80°F
  - Surrounding wells and/or nearby processing plants to supply required flow rates
  - Pure methane (CH_4) assumed for thermodynamic analyses
- Outlet assumptions:
  - NG discharge at 10,000 psia and 90°F
  - 35 bbl/min (approximately 3700 lb/min)

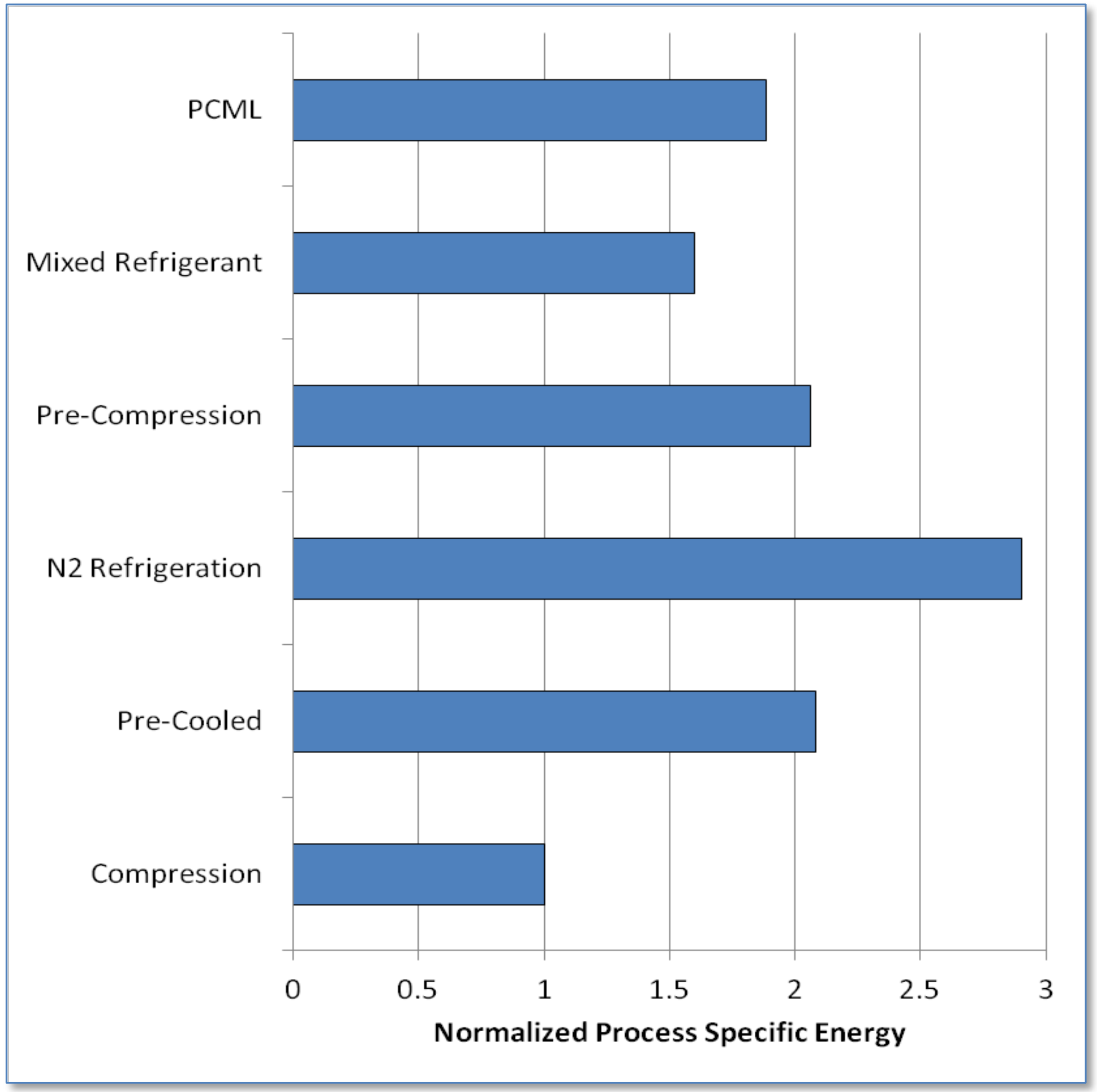
2. **Verma, S., et al.,** 2016. Novel Fracturing Process Utilizing Natural Gas. Presented at the AIChE Annual Meeting, San Francisco, CA, November 13-18, 2016.
3. **Beck, G. and Verma, S.,** 2016. Development and Field Testing Novel Natural Gas (NG) Surface Process Equipment for Replacement of Water as Primary Hydraulic Fracturing Fluid. Presented at the 2016 Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh, PA, August 16-18, 2016.
4. **Beck, G., et. al.,** 2016. Development and Evaluation of a Mobile Plant to Prepare Natural Gas for Use in Foam Fracturing Treatments. Paper GT2017-64689 presented at the 2017 ASME Turbo Expo, Charlotte, NC, June 26-30, 2017.

A compression cycle is the most appropriate process to produce high-pressure natural gas *on-site*

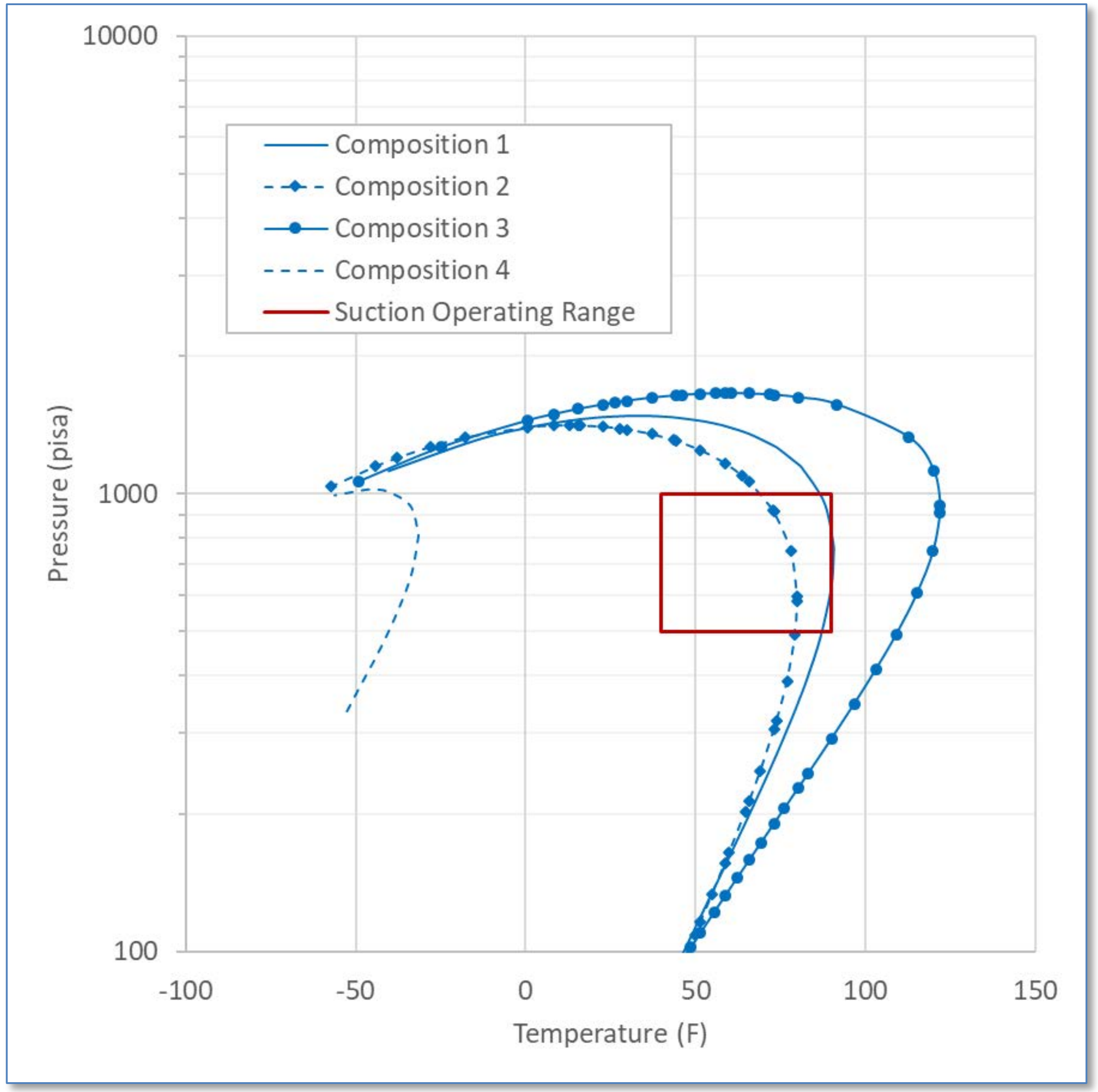


Key Findings from Process Development

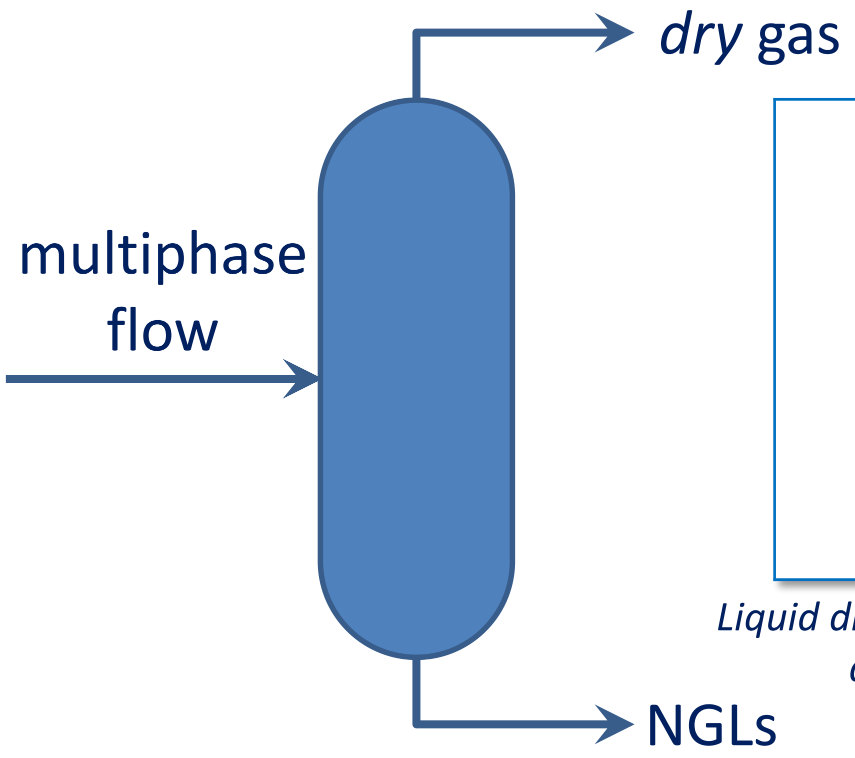
- The optimal process to produce high pressure NG is through direct compression
- Equipment needed to compress gas is commercially available
- A *mobile* compression fleet is feasible but requires more development



Current work is exploring the impact of natural gas mixtures on the efficiency and equipment footprint of the compression cycle



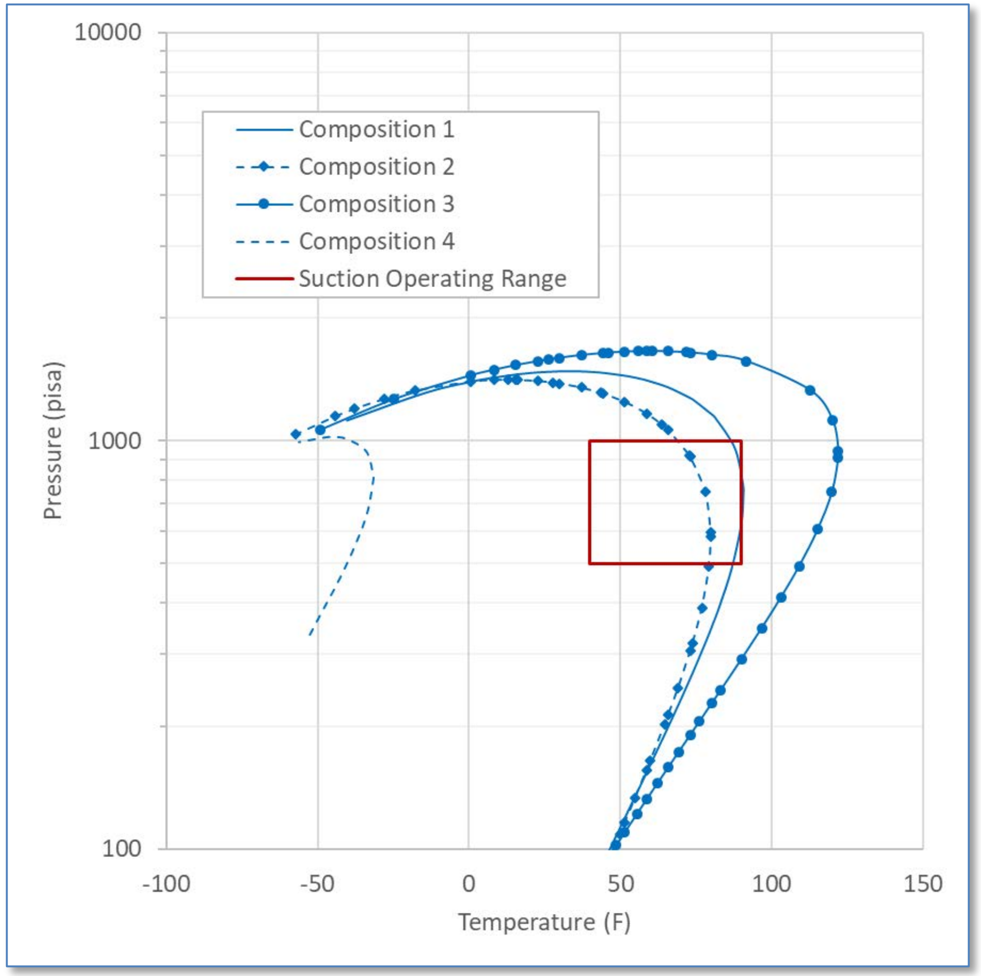
- Field gas and processed natural gas mixtures may contain heavy hydrocarbon and/or water components
- Gas-liquid separation equipment may be necessary to collect water and natural gas liquids (NGL)

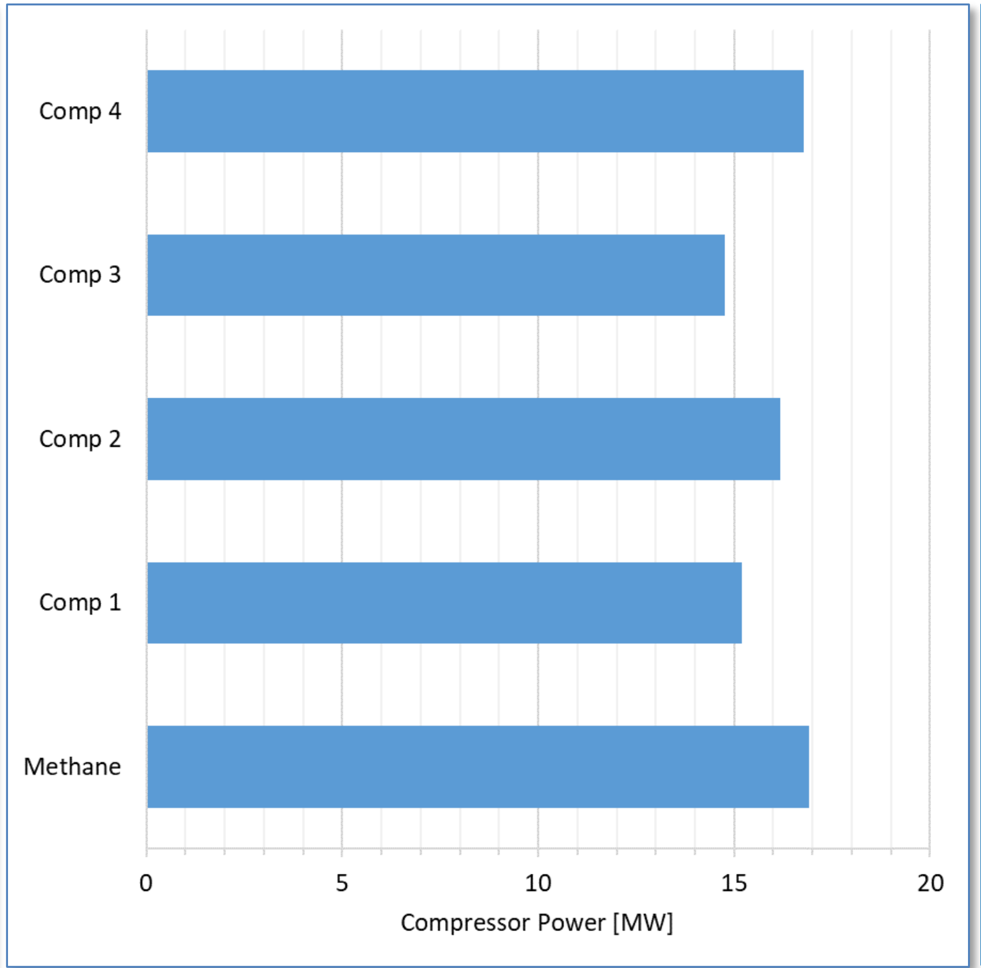


	Liquid Flow Rate (gpm)
Comp 1	7.3
Comp 2	3.2
Comp 3	123.5
Comp 4	0.0

Liquid dropout rates at 500 psi, 80°F for 35 bbl/min dry gas flow at 10,000 psi discharge

Natural gas composition impacts cycle performance

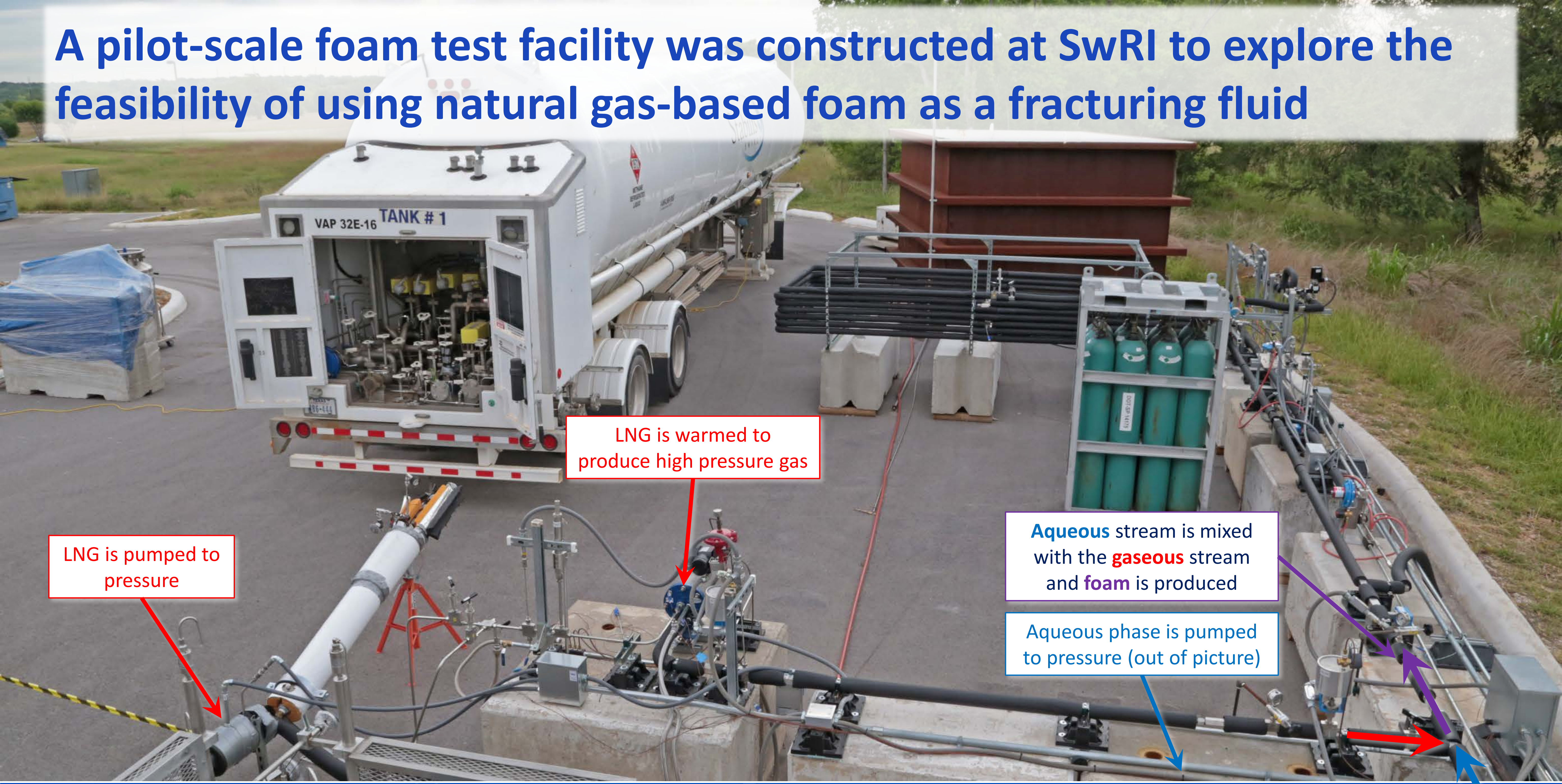




Compressor power required to compress different natural gas compositions from 500 psi to 10,000 psi at an outlet flow rate of 35 bbl/min

- Constant volumetric flow at outlet conditions
  - 35 bbl/min at 10,000 psi
- Peng Robinson EOS for natural gas mixtures and REFPROP for pure methane
- Models include inlet separation such that only dry gas is compressed
- Mixtures with higher concentrations of *heavy* hydrocarbons require less power to compress for equivalent volumetric flow rates
  - CH4 16.9 MW
  - Comp 3 14.8 MW

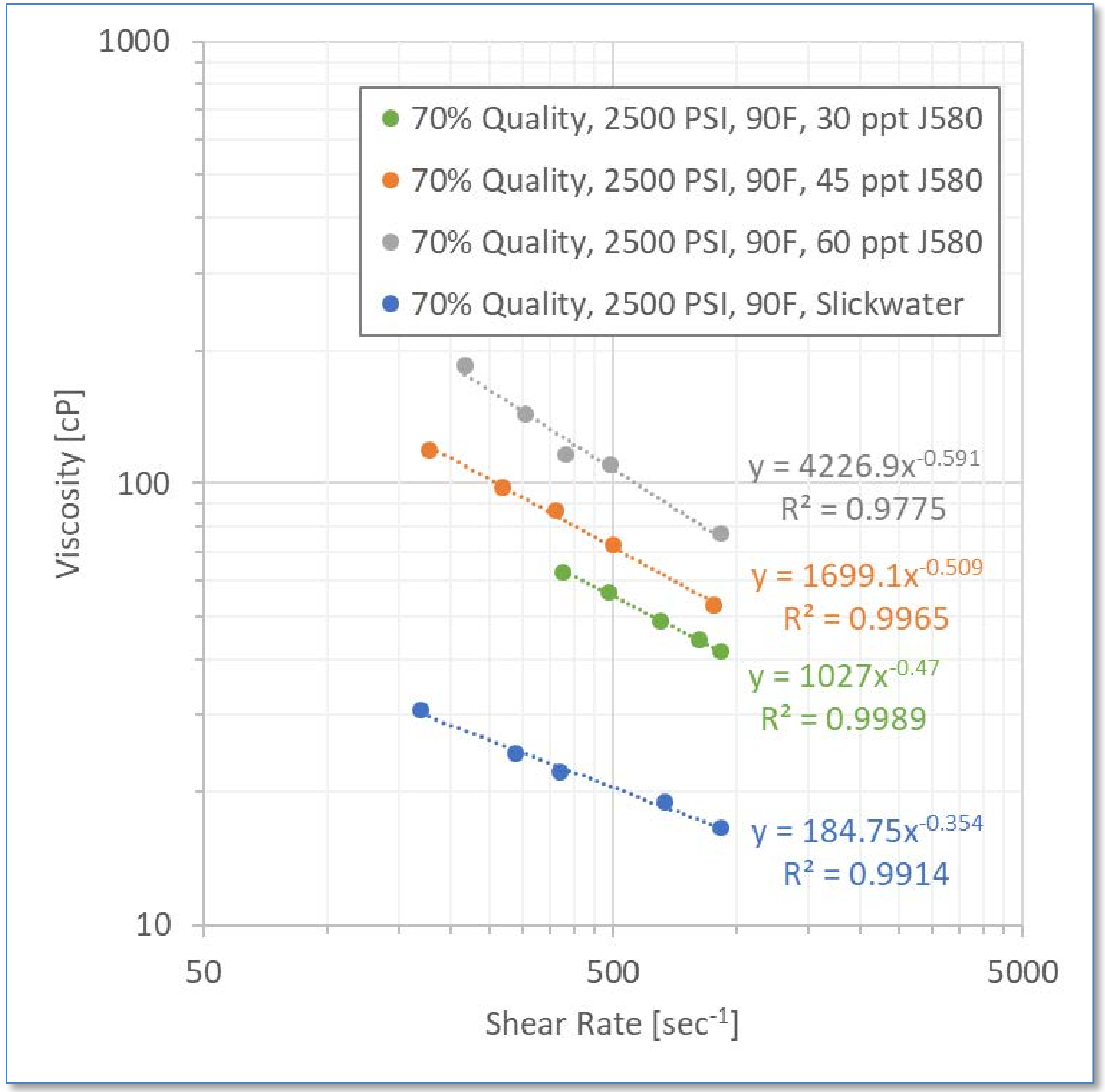
A pilot-scale foam test facility was constructed at SwRI to explore the feasibility of using natural gas-based foam as a fracturing fluid



Stable natural gas-based foam was generated using the pilot-scale test facility

Key Findings from Pilot-Scale Tests[5-6]

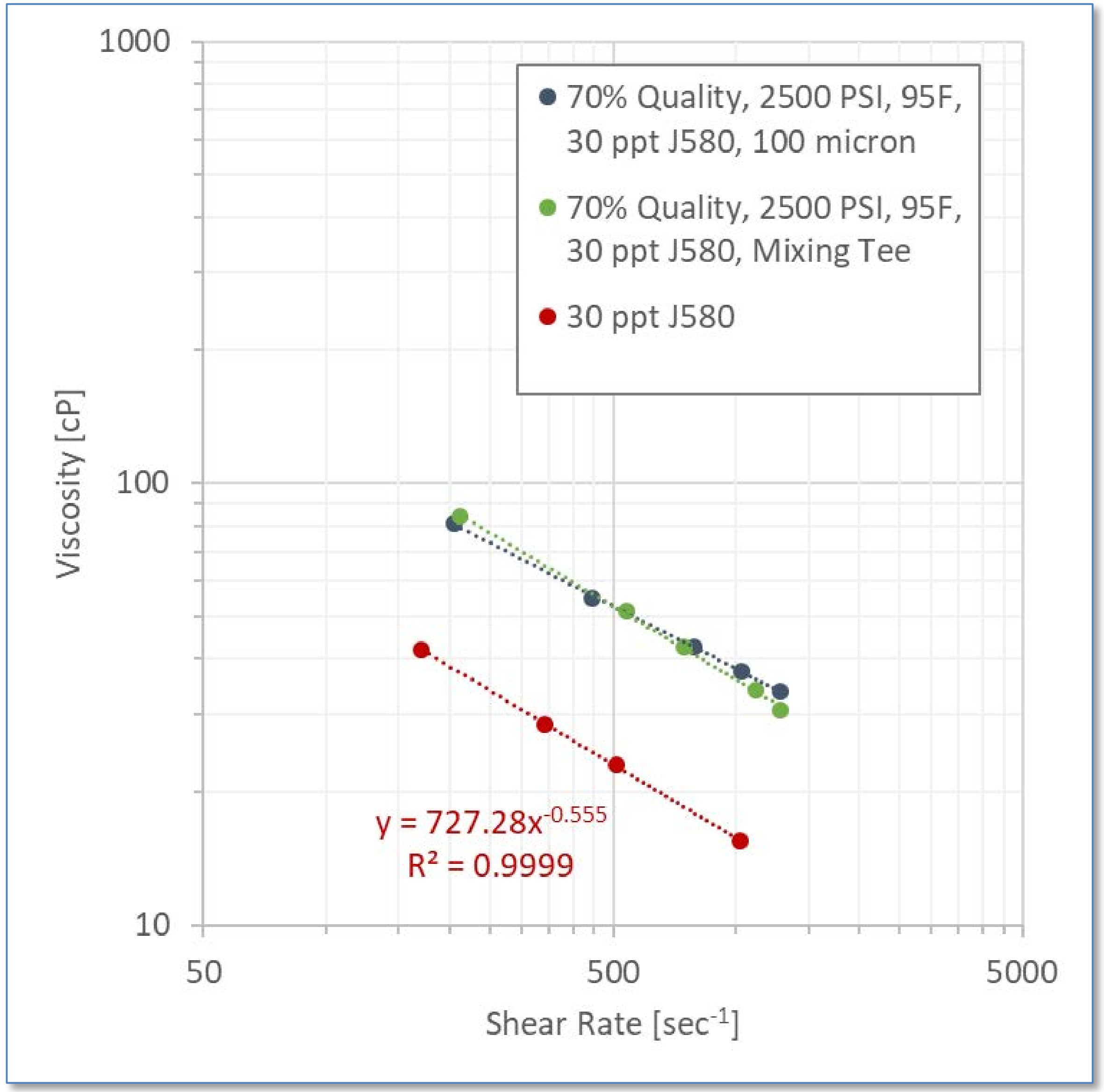
- Single-pass, pilot scale facility was designed, built, and operated.[5-6]
- Stable NG foam was generated at 5500 psi using commercially available viscosifiers and surfactants.
- Four base fluid mixtures were used to generate NG foam
- NG foam is qualitatively similar to other foams observed in literature:
  - Shear thinning, power law fluid
  - Increased viscosity with foam quality



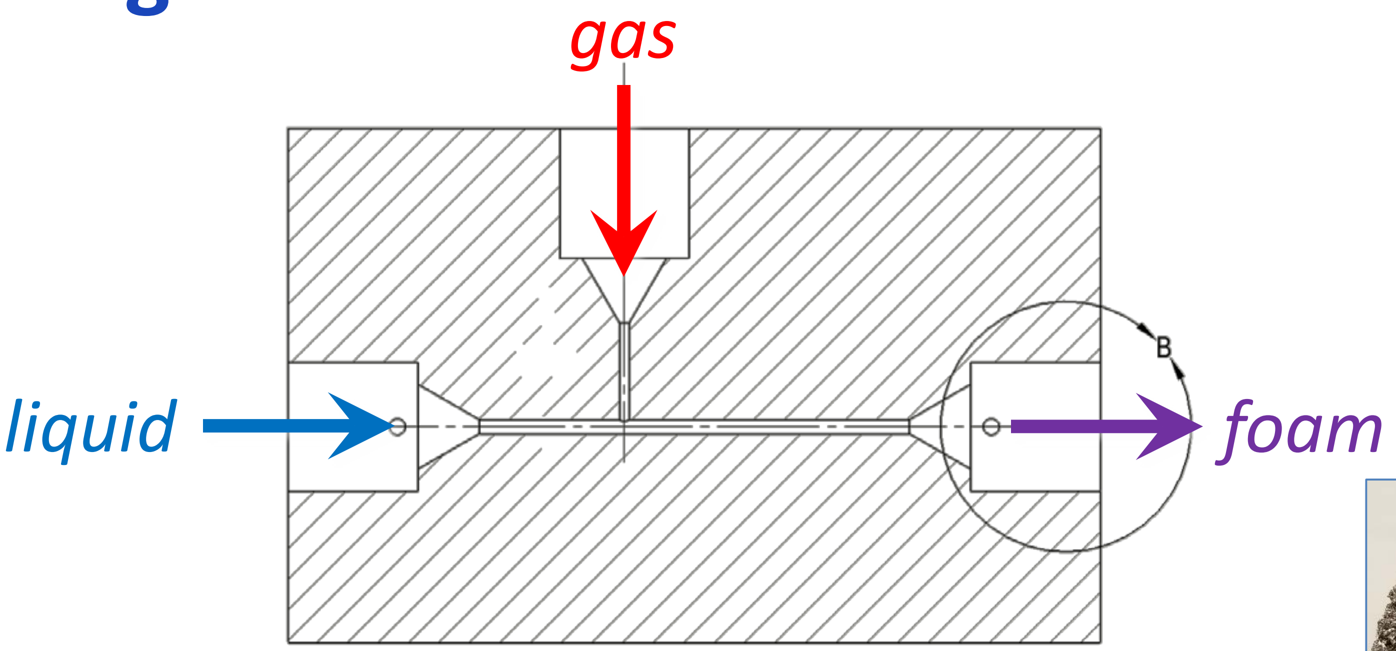
Four different base fluids were tested: slickwater and guar at three different concentrations

5. **Beck, G.,** "Development and Field Testing Novel Natural Gas (NG) Surface Process Equipment for Replacement of Water as Primary Hydraulic Fracturing Fluid," presented at the 2017 Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh, PA (August 1-3, 2017).
6. **Beck, G., et. al.** "Laboratory Evaluation of a Natural Gas-Based Foamed Fracturing Fluid," presented at the 2017 SPE ATCE, San Antonio, TX (October 9-11, 2017).

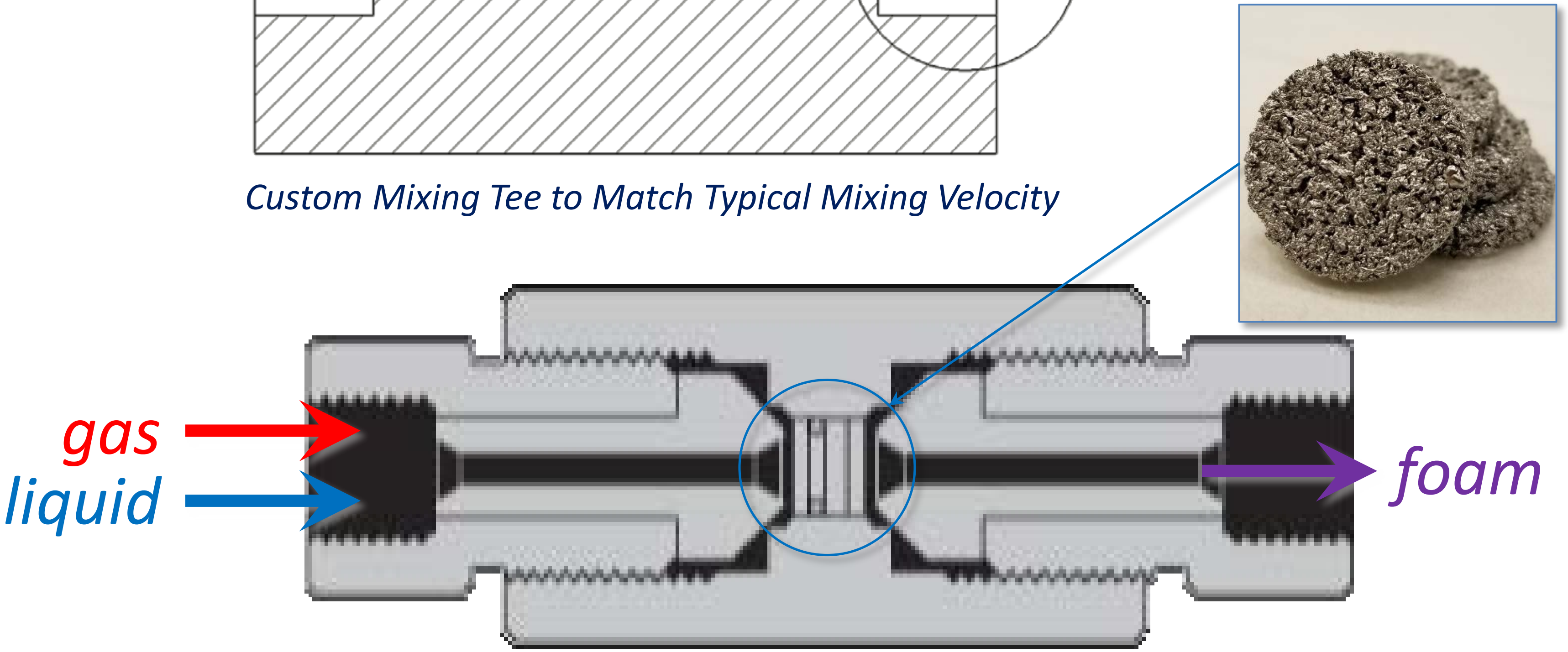
Two mixing methods were explored and results indicate that *field* mixing methods are sufficient to generate stable foam



Foam mixed in a 100 µm filter and in a custom mixing tee had nearly identical viscosity

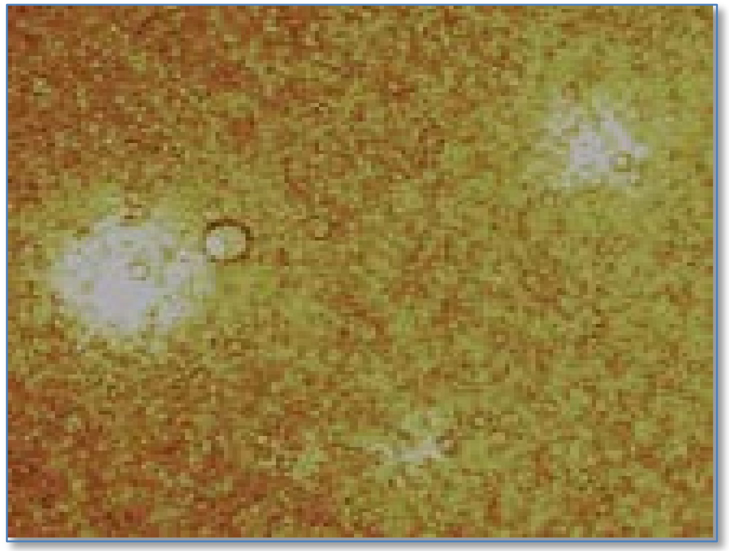


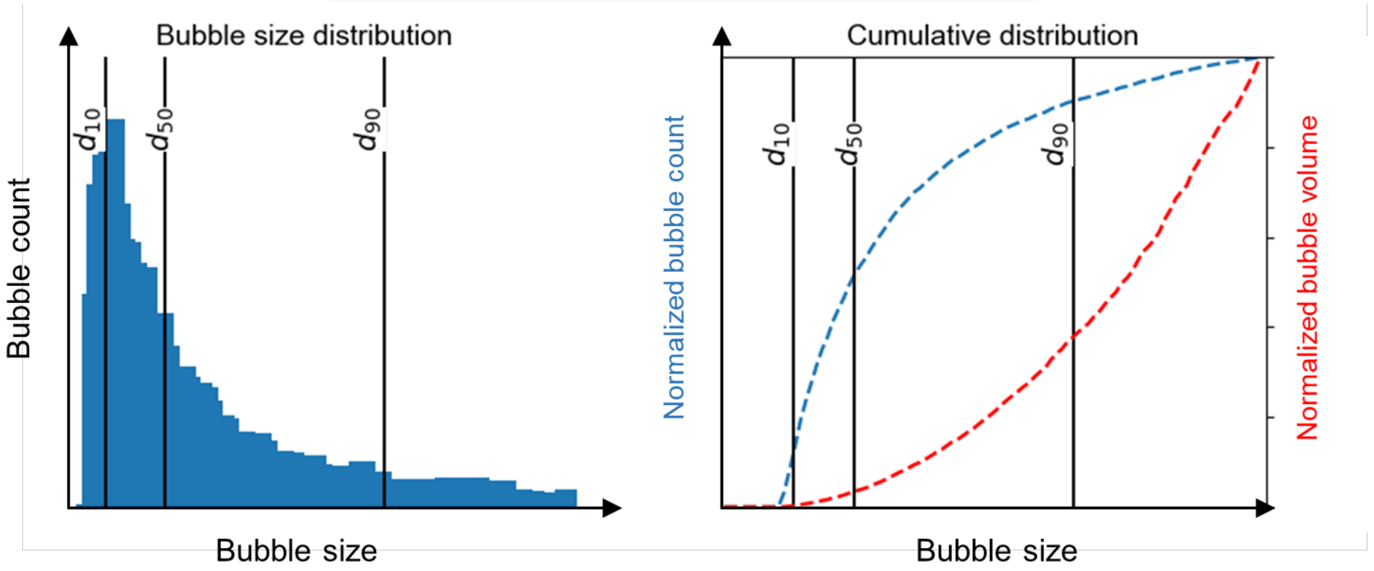
Custom Mixing Tee to Match Typical Mixing Velocity



100 µm Filter (20-51LF9 High Pressure Equipment Co.)

Current work is focused on quantifying the effects of gas composition and elevated operating temperature on foam stability





Enhanced visualization capability allows for detailed analyses of foam texture

- The effect of elevated temperature on foam stability will be evaluated in the pilot-scale test facility
- Recent facility upgrades include:
  - Enhanced visualization capability to quantify foam texture parameters (e.g., bubble sizes, size distributions) as a function of time and temperature
  - Foam heating capability to 300°F or more
- Additional laboratory tests at Schlumberger to investigate the impact of natural gas composition on foam stability

There are several opportunities for collaboration between the natural gas foam hydraulic fracturing project and other projects

Foam/Fracture Fluid Test Stand

- Pilot-scale foam test facility can be used to investigate a variety of foams and other fracturing fluids at relevant operating conditions
- Such tests can bridge the gap between bench-top and field demonstrations

Enhanced Oil Recovery (EOR)

- Use of natural gas as a fracturing fluid could enhance recovery
- Present and future research of EOR using natural gas can be leveraged to improve the NG foam fracturing methods

Foam Fluid Data

- Limited NG foam rheology data published
- Foam rheology results from current work can be used in multiple simulation codes

Current results indicate that natural gas foam is a viable hydraulic fracturing fluid and future work will explore production benefits

Results of Completed Project Work

- Compression cycle is the most efficient means of generating high pressure natural gas stream
- Equipment is commercially available but requires more development to mobilize
- Single-pass, pilot scale facility was designed, built, and operated.
- Stable NG foam was generated at 5500 psi using a commercially available viscosifier and surfactant.
- Relevant mixing methods were explored
- NG foam is qualitatively similar to other foams.
  - Shear thinning, power law fluid
  - Increased viscosity with foam quality
  - Laminar and turbulent regimes

Current and Future Work

- The impact of elevated temperature is being explored in pilot-scale tests
- The impact of natural gas composition on foam stability and rheology is being tested
- Process and reservoir models are being generated
- Work in the next budget period will determine if compressible foams generate improved fracture networks

Acknowledgement

This work was funded by the Department of Energy under award DE-FE0024314, ''Development and Field Testing Novel Natural Gas Surface Process Equipment for Replacement of Water as Primary Hydraulic Fracturing Fluid''. Co-funding for this work was provided by Schlumberger Technology Corporation and Chevron Energy Technology Company.

Questions?

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The work accomplished during this project supports the Department of Energy program goals

The work to develop an alternative hydraulic fracturing process that uses natural gas-based foam supports a "critical component of the DOE portfolio to advance the environmentally-sound development of unconventional domestic natural gas and oil reserves" (as stated in DE-FOA-0001076). The process being developed will help to "ensure these resources are developed safely and with minimal environmental impact" by minimizing the usage of fresh water in the hydraulic fracturing process. The process being developed could decrease water usage by 70% or more compared to typical, water-based hydraulic fracturing techniques.

The overall goals and objectives of this project are…

Project Objective

The objective of this project is to develop a rugged, mobile, and economic system that can take natural gas and prepare it for use in fracturing of gas shale to significantly reduce water usage from traditional fracturing methods

Project Goals by Budget Period (BP)

- **BP1** - Identify optimal process for bringing the wellhead gas to injection pressure (10,000 psia) and temperature (ambient ±20 °F)
- **BP2** - Complete a laboratory scale test to validate fracturing concept
- **BP3** - Determine if typical hydraulic fracturing fluids (i.e., base fluids) can be used to generate stable NG foam
- **BP4** - Quantify NG foam stability with multi-component natural gas mixtures and at elevated operating temperatures
- **BP5** - Investigate production benefits of using compressible foam fracturing fluids

The current project team includes members from SwRI, Schlumberger, and Chevron

SwRI

Griffin Beck	*Principal Investigator, Project Manager*
Carolyn Day	*Pilot-Scale Test System Lead*
Swanand Bhagwat, Ph.D.	*Visualization Lead, Testing Support*
James Donnelly	*Technical and Testing Support*
Nathan Poerner	*Data Acquisition Lead*
Brandon Ridens	*Process Model Lead, Testing Support*
Robin Rutledge	*Contracts*
Ellen Smith	*Data Acquisition and Testing Support*
John Stubbs	*Technical and Testing Support*

Schlumberger

Sandeep Verma, Ph.D.	*Principal Investigator*
Chris Daeffler, Ph.D.	*Foam Rheometer Lead*
Raj Malpani	*Reservoir Simulation Lead*
Rohit Shukla	*Fracture Network Test Advisor*
Ashwani Zutshi	*Fracture Network Test Advisor*

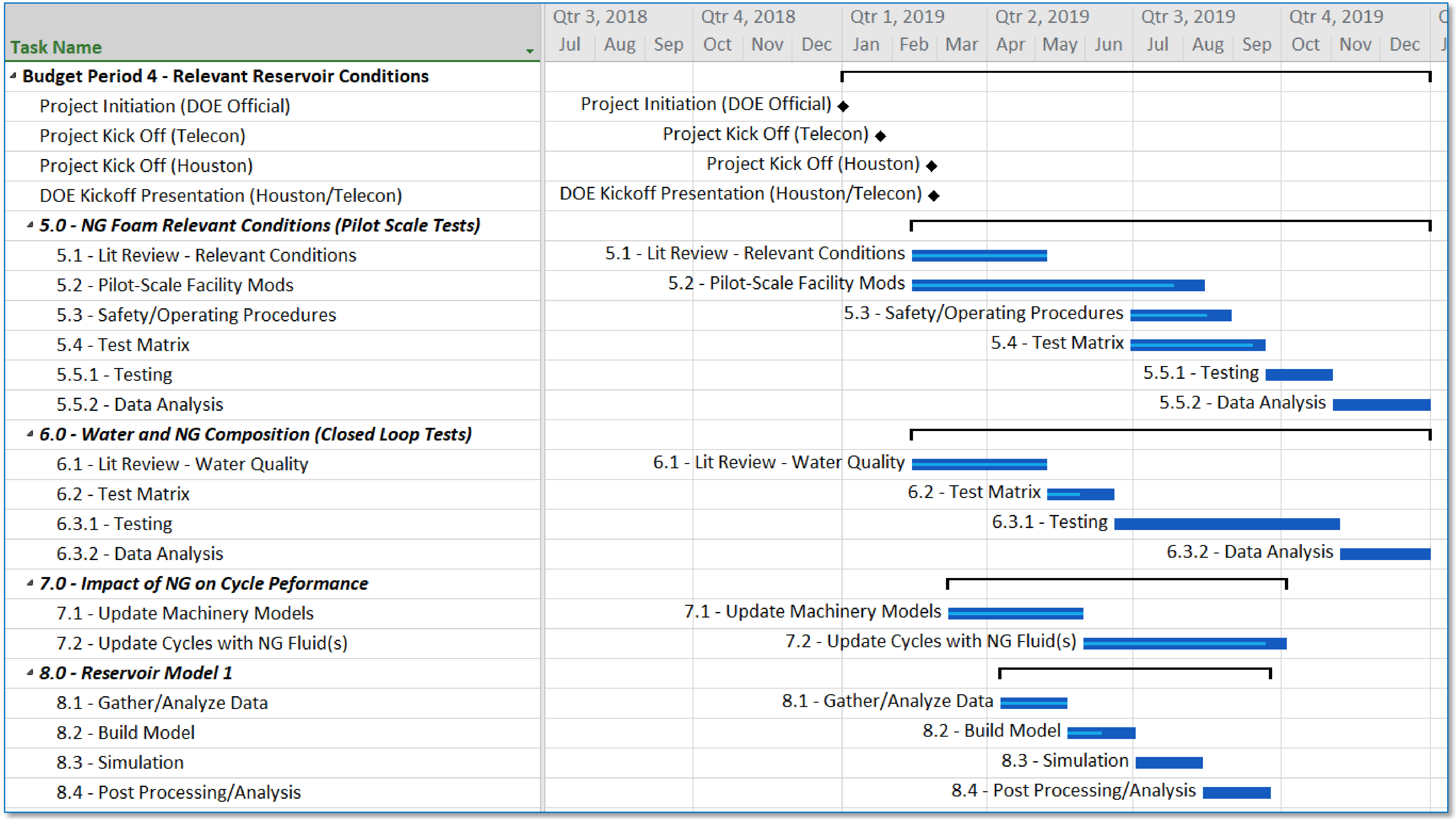
NATIONAL ENERGY TECHNOLOGY LABORATORY

Joseph Renk	*Federal Project Manager*

Chevron

Leo Chaves	*Principal Investigator*
Sarvesh Naik, Ph.D.	*Technical Advisor*

Work for the current budget period is on track with the projected schedule



Results and key findings have been presented to scientific and industry communities through the following publications and presentations

1. **Beck, G. and Verma, S.,** "Development and Field Testing Novel Natural Gas (NG) Surface Process Equipment for Replacement of Water as Primary Hydraulic Fracturing Fluid," presented at the 2016 Carbon Storage and Oil and Natural Gas Technologies Review Meeting, Pittsburgh, PA (August 16-18, 2016).
2. **Verma, S., et al.,** "Novel Fracturing Process Utilizing Natural Gas," presented at the AIChE Annual Meeting, San Francisco, CA (November 13-18, 2016).
3. **Beck, G., et. al.,** "Laboratory Evaluation of a Natural Gas-Based Foamed Fracturing Fluid," presented at the 2017 AIChE Spring Meeting, San Antonio, TX (March 26-30, 2017)
4. **Beck, G., et. al.,** "Development and Evaluation of a Mobile Plant to Prepare Natural Gas for Use in Foam Fracturing Treatments," presented at the 2017 ASME Turbo Expo, Charlotte, NC (June 26-30, 2017).
5. **Verma, S., Pankaj, P., and Phatak, A.,** "Application of Natural Gas for Foamed Fracturing Fluid in Unconventional Reservoirs", AAPG International Conference and Exhibition, Cape Town, South Africa, November 4-11, 2018.
6. **Pankaj, P., Phatak, A., & Verma, S.** (2018, October 19). Evaluating Natural Gas-Based Foamed Fracturing Fluid Application in Unconventional Reservoirs. Society of Petroleum Engineers. doi:10.2118/192042-MS. https://www.onepetro.org/conference-paper/SPE-192042-MS
7. **Pankaj, P., Phatak, A., & Verma, S.** (2018, August 13). Application of Natural Gas for Foamed Fracturing Fluid in Unconventional Reservoirs. SPE Argentina Exploration and Production of Unconventional Resources Symposium, 14-16 August, Neuquen, Argentina. doi:10.2118/191863-MS.