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

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National Energy Technology Laboratory
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Carbon Storage and Oil and Natural Gas Technologies Review Meeting
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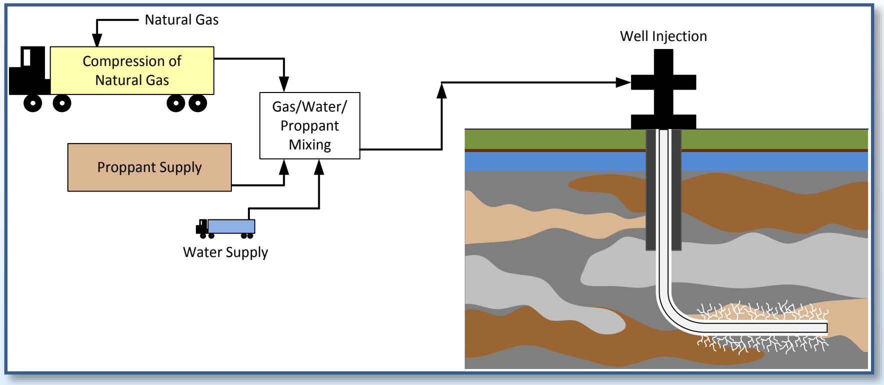
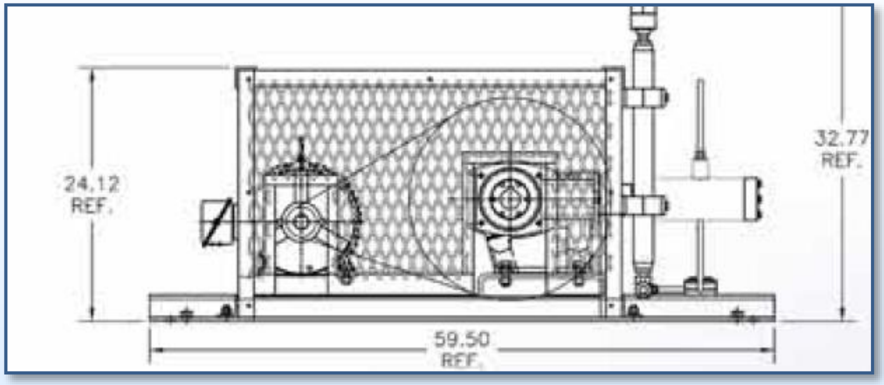
This presentation provides an overview of work to design and test a novel NG fracturing process

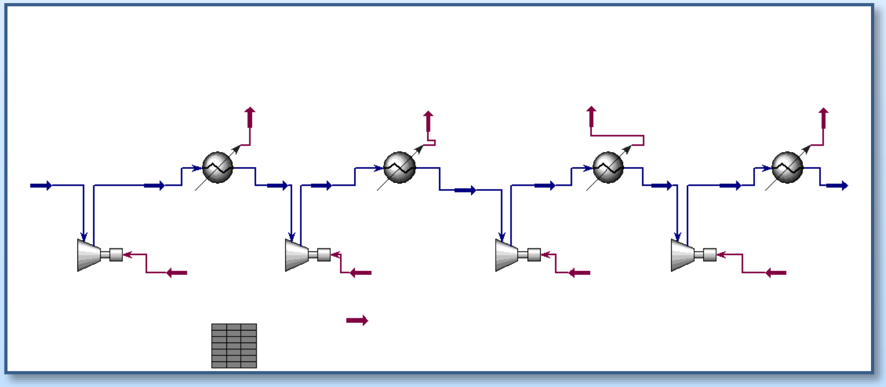
Project Overview, Benefit, & Goals



Lab-Scale Test Design



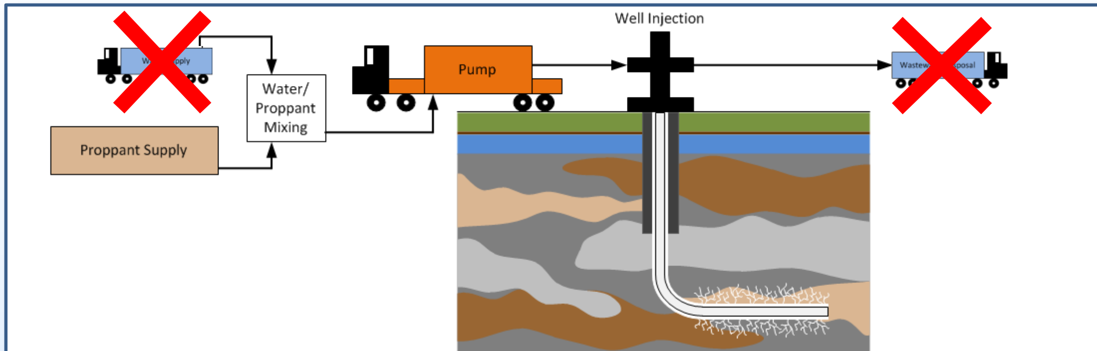
Process Development & Optimization



Future Work

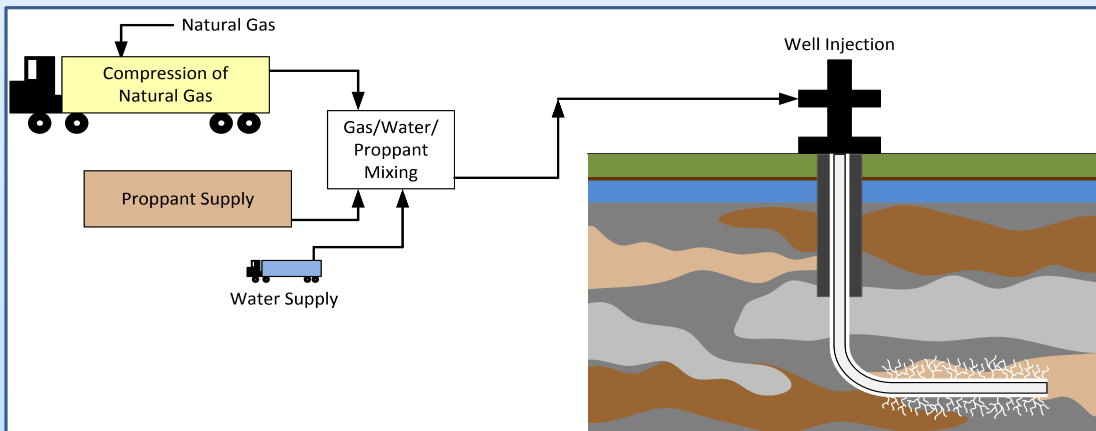
Most hydraulic fracturing treatments use a significant volume of water

Current Fracturing Process



- *Significant volume of water used to initiate fracture and carry proppant*
- *3 to 7 million gal / application*
- *Recovered water must be either cleaned or disposed*
- *How to reduce or eliminate?*

Proposed Natural Gas Fracturing Process



- *Proposed process uses NG foam for hydraulic fracture treatment*
- *Natural gas is readily available at well site*
- *Reduce water consumption by as much as 80%*
- *Recovered natural gas would be processed*

This projects supports a "critical component of the DOE portfolio to advance the environmentally-sound development of unconventional domestic natural gas and oil reserves" by "[developing] improved technologies and engineering practices to ensure these resources are developed safely and with minimal environmental impact" *DE-FOA-0001076*

Work to develop the NG fracturing process is scheduled to occur over a three-year period

Project Objective

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

Year 1 (2015)

Identify optimal process for bringing the wellhead gas to injection pressure (10,000 psia) and temperature (ambient ±20 °F)

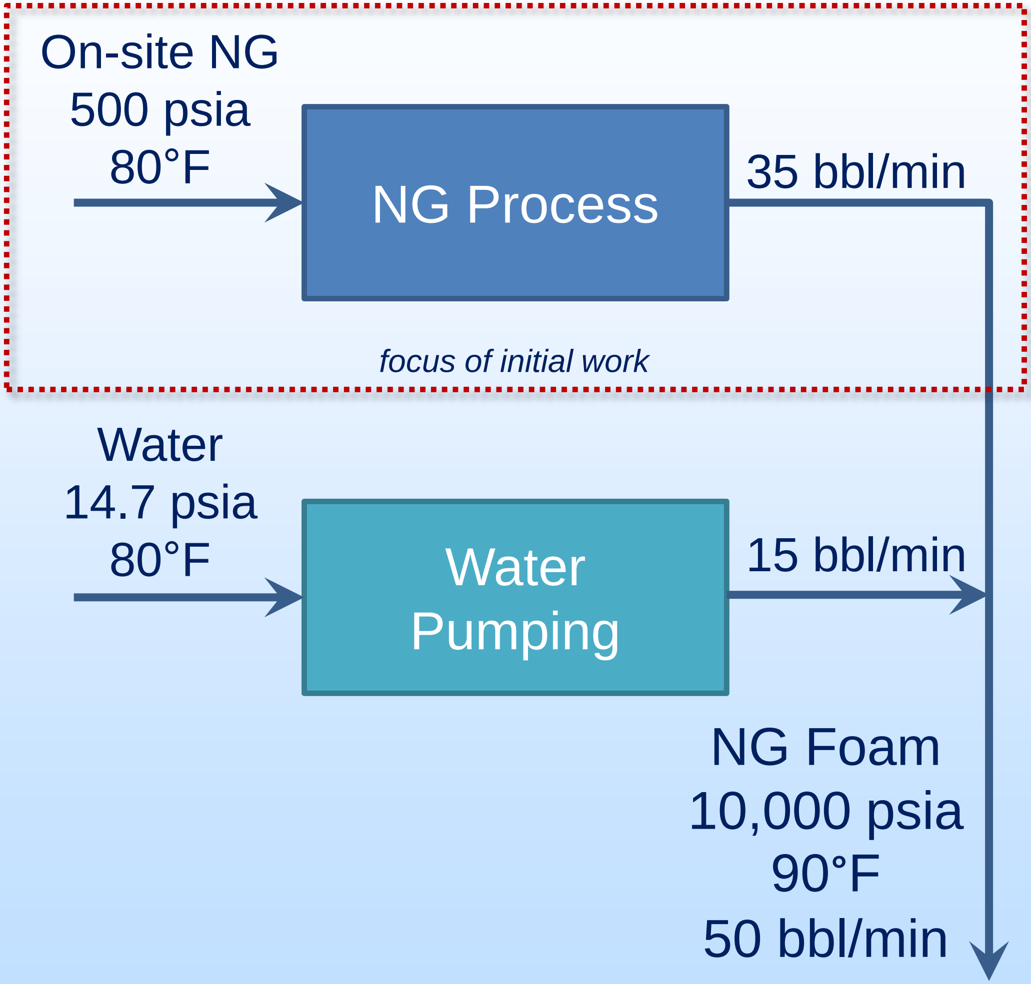
Year 2 (2016)

Complete a laboratory scale test to validate fracturing concept

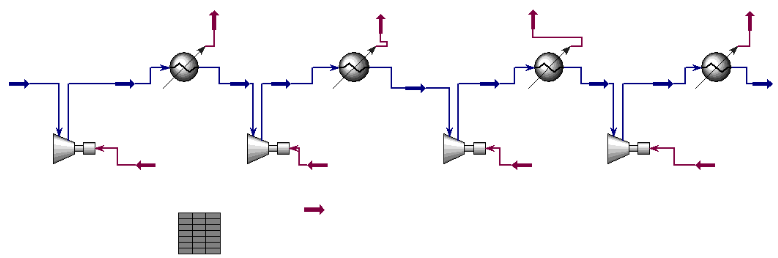
Year 3 (2017)

Complete a field test to validate the ability of the system to operate at field conditions

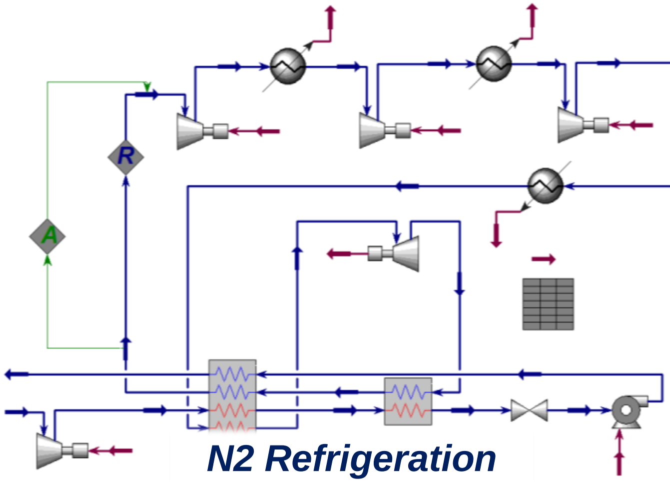
Initial work in 2015 focused on brainstorming processes to generate high pressure NG



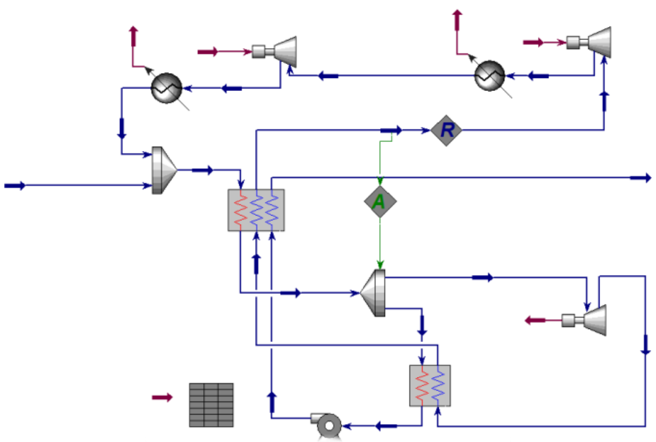
Six processes, including direct compression and multiple refrigeration cycles, were considered



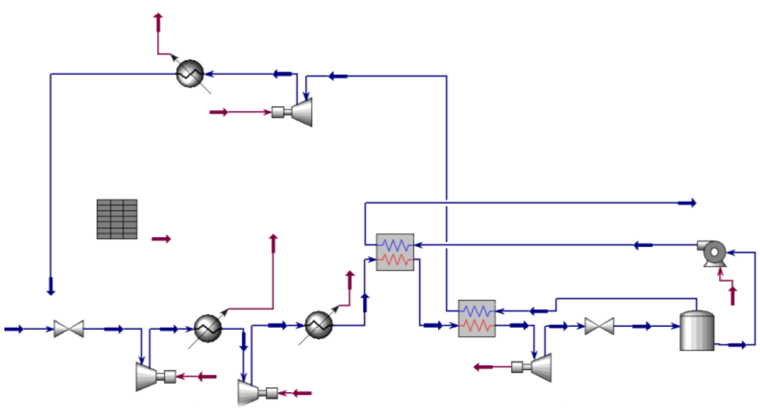
Direct Compression



N2 Refrigeration



Pre-Cooled

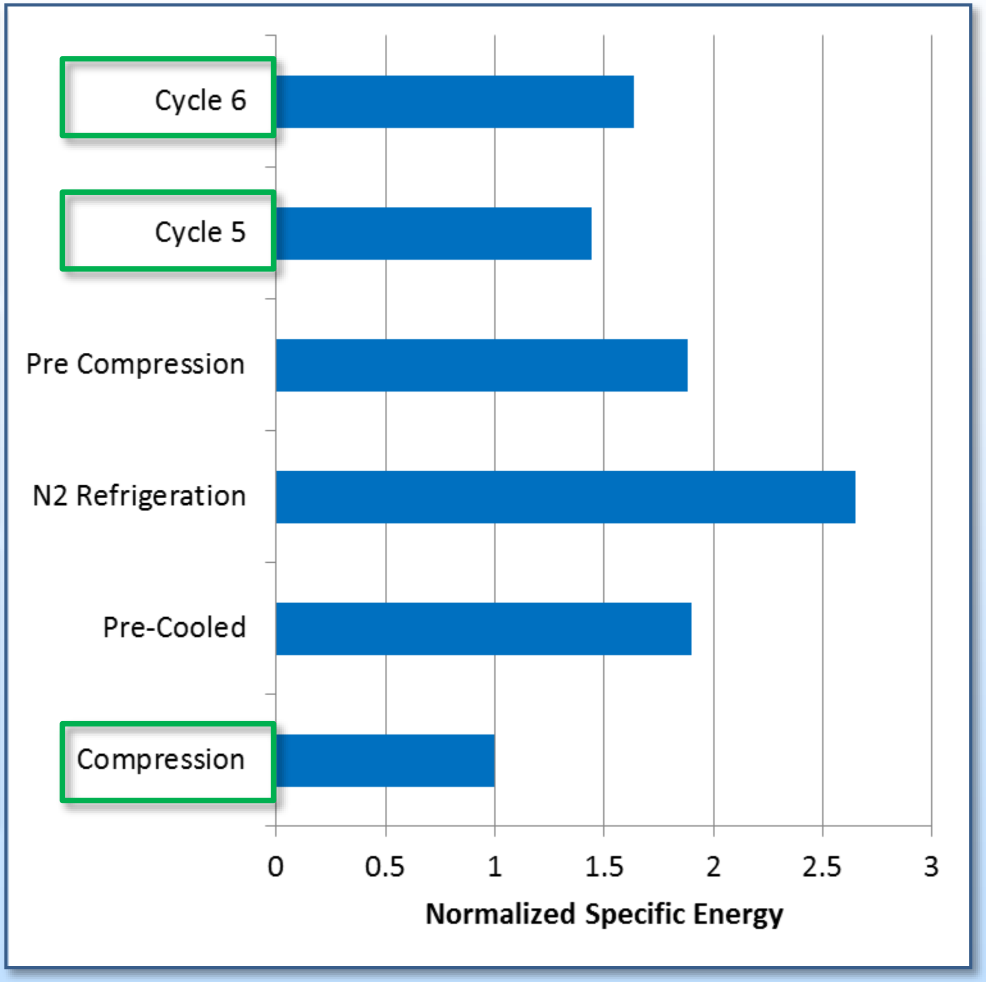


Pre-Compressed

- *Two additional liquefaction cycles developed (Cycles 5 & 6)*
- *Patent applications being explored*

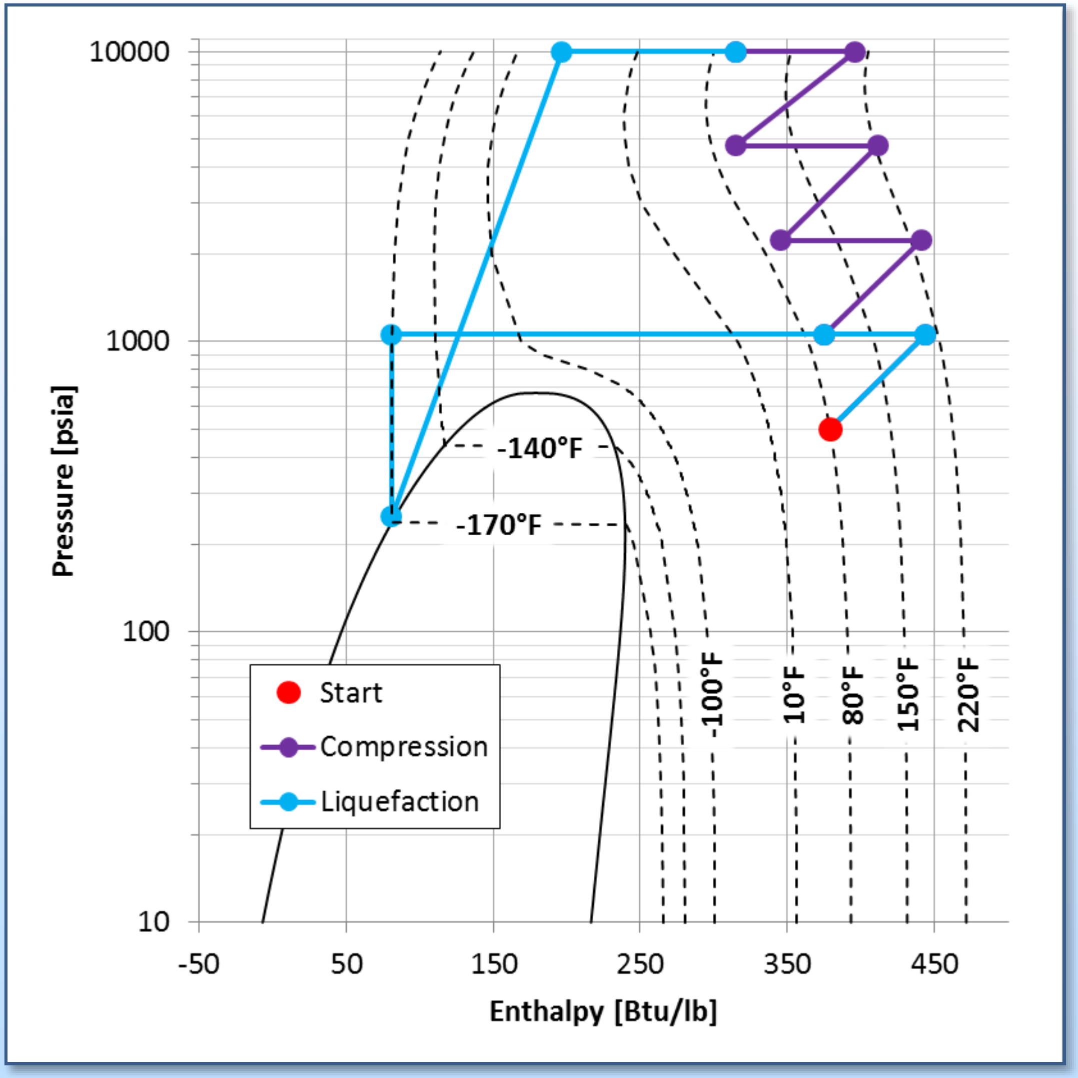
The cycles were modeled and specific energy was estimated

- *HYSYS® models used to estimate specific energy (energy required to produce unit mass of compressed NG)*
- *Specific energy is a function of gas composition and pressure / temperature*
- *Equipment footprint for liquefaction cycles (e.g., coolers to reject heat) found to be very large*



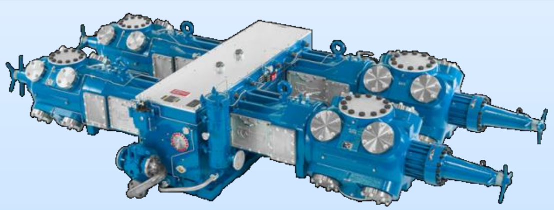
***all values normalized to direct compression specific energy**

In general, the amount of energy required for liquefaction cycles is very high

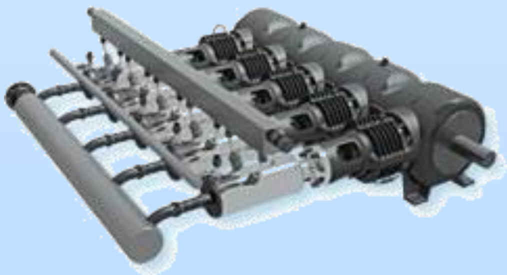


With the top three cycles selected, additional work focused on preliminary design and optimization

- *Quotations & specs were obtained for commercially available equipment*
- *Equipment included: centrifugal and reciprocating compressors, cryogenic liquid pumps, PCHE, companders, air coolers*

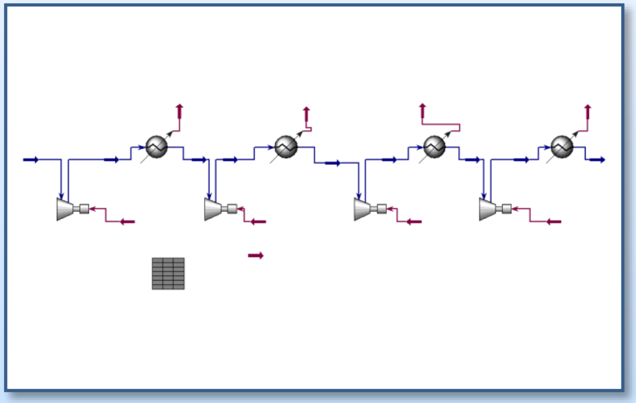


Ariel JGC Compressor [1]

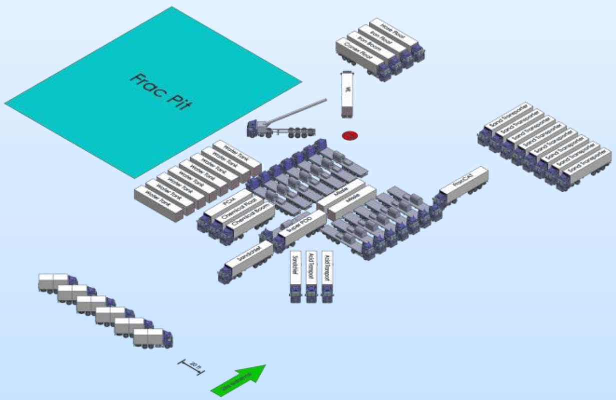


Cryostar HPP Quintuplex Pump [2]

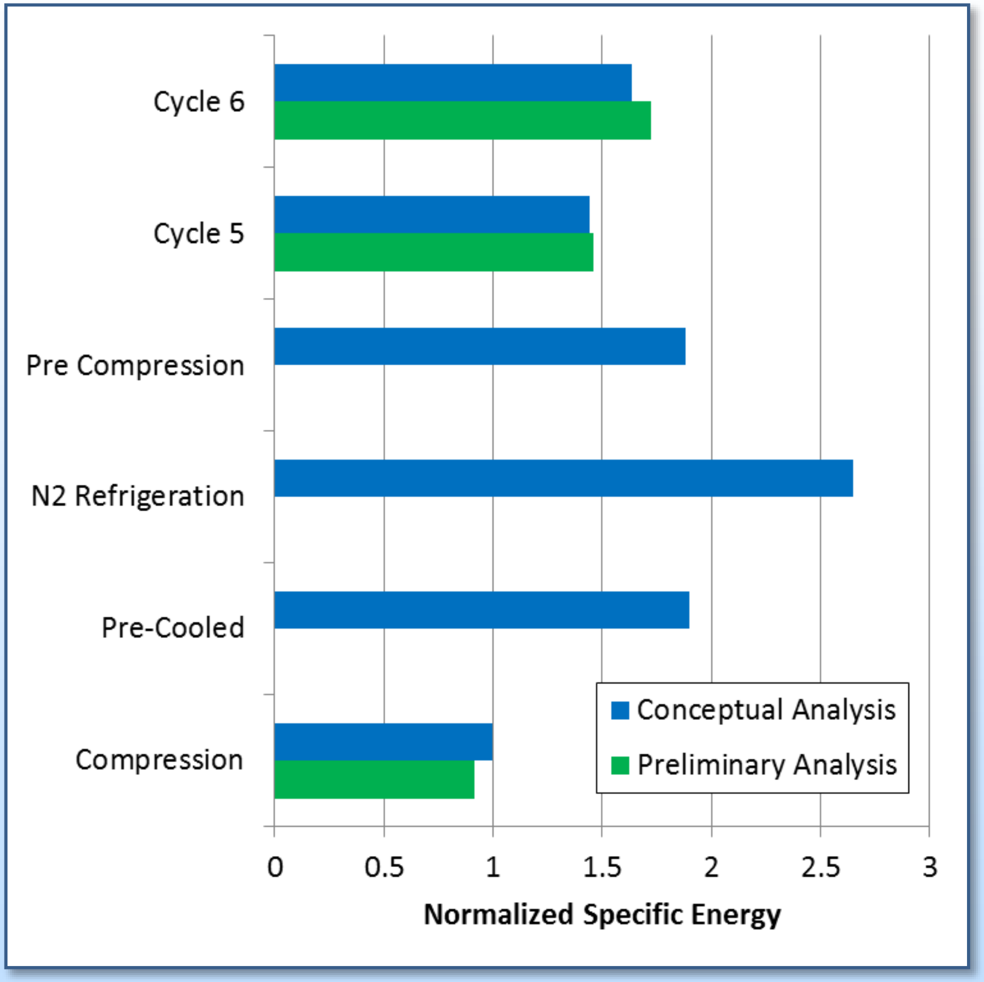
- *HYSYS models were updated with specific equipment performance values: η, ΔP, ΔT*
- *Cycles were optimized to achieve lowest cycle specific energy*



- *Process footprint estimates were generated*
- *System costs were estimated using vendor quotations*



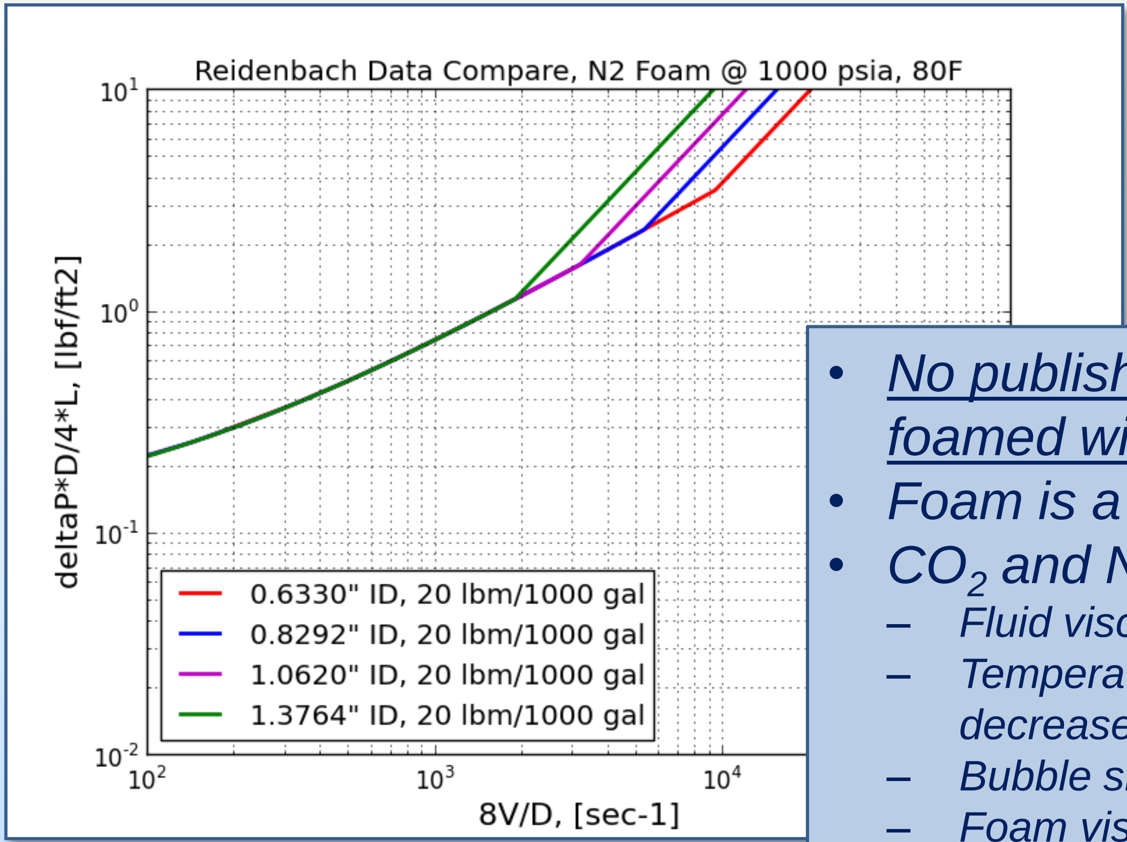
Models were updated with quoted performance specifications and optimized



all values normalized to direct compression specific energy from conceptual analysis

- *Direct compression cycle:*
  - *Included the fewest number of components*
  - *Had the lowest equipment cost*
- *The cycle was selected for continued development into project years 2 & 3*

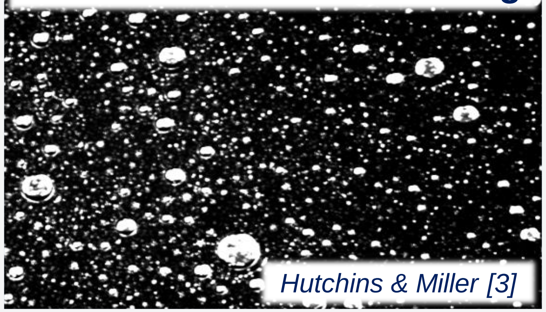
A literature survey was conducted to identify rheological properties of NG foam



- <u>*No published rheology data on fluids foamed with methane/NG*</u>
- *Foam is a non-Newtonian fluid*
- *CO_2 and N_2 foam trends:*
  - *Fluid viscosity changes with foam quality*
  - *Temperature impacts viscosity (increasing T decreases μ)*
  - *Bubble size has minimal impact on foam μ*
  - *Foam viscosity is dominated by foam quality and base fluid viscosity*
  - *Pressure has a small effect on viscosity*

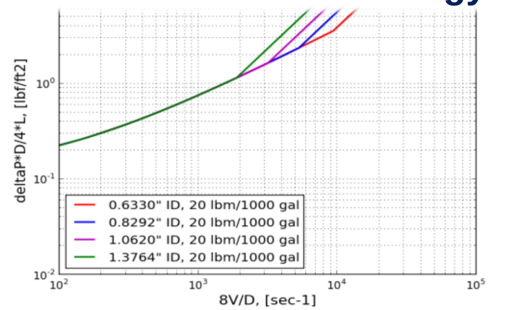
A lab-scale test concept was generated and test goals were identified

Goal: Evaluate Foam Mixing


Hutchins & Miller [3]

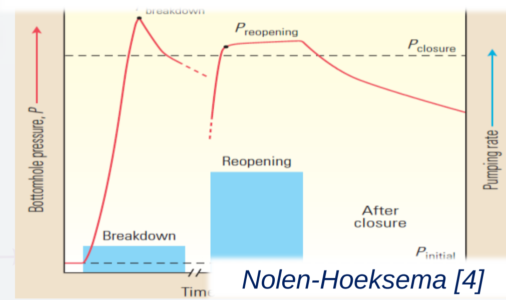
- NG should be dispersed uniformly in base fluid
- Foam mixing will be evaluated

Goal: NG Foam Rheology



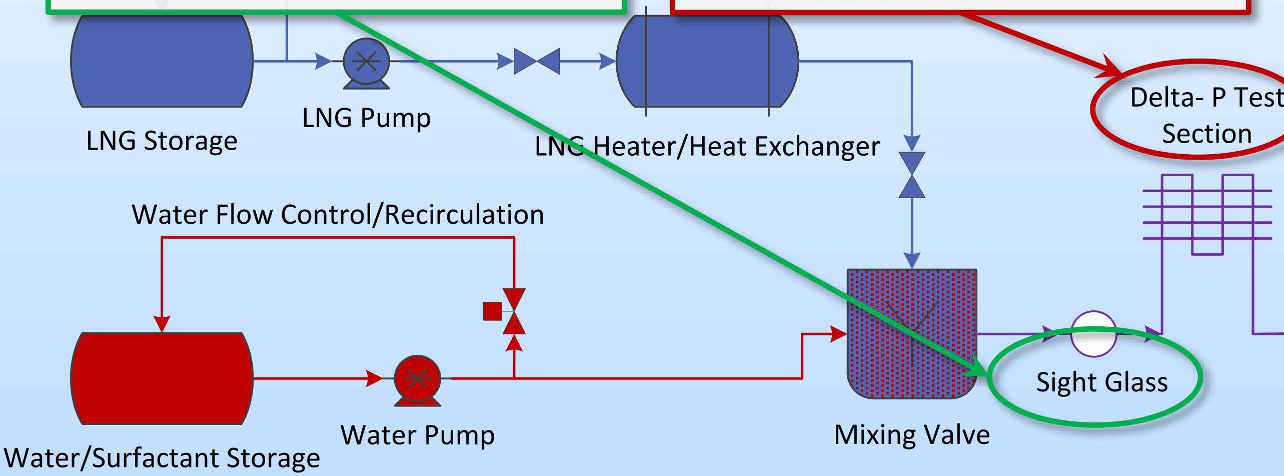
- Generate rheology data
- Critical for reservoir simulations, system simulations, and others

Goal: Pressure Transient



Nolen-Hoeksema [4]

- Pressure transients can impact upstream compression equipment
- Measured transients will be compared to models



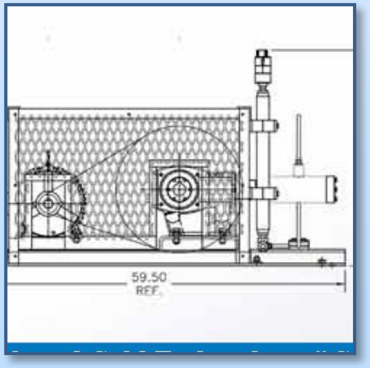
Year 2 project work has focused on the detailed design and construction of the lab-scale test stand

Year 2 Lab-Scale Test Parameters

Parameter	Parameter Range
Pressure (psia)	2500, 5000, and 7500
Flow Rate (gpm)	0.3 to 7
Shear Rate (s^{-1})	660 to 140,570
Natural Gas Fraction (Quality, %)	60, 70, and 80
Guar and Surfactant Concentration	Guar: 30 lbm/1,000 gal Surfactant: 5 gal/1000 gal
Delta-P Test Section Diameter (in)	0.125 to 0.270
Temperature (°F)	90, 125, and 160
Fracture Pressure (psi)	300 or 500

- *Test matrix and test parameter ranges are defined*
  - *Limits account for equipment operating limits*
  - *Test conducted at conditions that match field conditions*
- *17 test points*

- *Significant effort to identify equipment suitable for the rigorous test conditions*



CS&P Pump and J.M. Canty Sight-Glass [5-6]

Several accomplishments have been made and additional tasks are planned for the future

Year 1 – System Design and Optimization	
Brainstorm different paths for processing natural gas	Complete
Identify top process (based on thermodynamics and cost/availability)	Complete
Design lab scale test set-up	Complete
Investigate the rheological properties of natural gas foams	Complete
Year 2 – Lab Scale Testing	
Procure equipment for test system	In progress
Construct test system	Aug./Sept. 2016
Commission test system	October 2016
Complete Testing and analysis of data	November 2016
Evaluate lab scale testing and identify successes and areas for improvement	December 2016
Year 3 – Field Testing	
Evaluate available test sites	In progress
Set-up equipment at field location	2017
Run system in field and analyze data	2017
Estimate cost of industrial size system	In progress

There are opportunities for collaboration between projects

Foam/Fracture Fluid Test Stand

- Lab-scale test stand can be used to investigate a variety of foams and other fracturing fluids **at field** conditions.
- Current and future investigations can utilize the facility at SwRI

Enhanced Oil Recovery (EOR)

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

Foam Fluid Data

- NG foam rheology data not published
- Foam rheology results from current work can used in multiple simulation codes

The alternative fracturing process using NG as the primary fluid appears promising

Key Findings from Year 1

- *Fracturing with NG foam could decrease water consumption by as much as 80% (by volume)*
- *The optimal process to produce high pressure NG is through direct compression*
- *Equipment needed to compress gas is commercially available*
- *Additional benefits include:*
  - *Possible recovery and use of fracturing fluid*
  - *Enhanced production*

Future Work

- *Perform fracture treatment at field location using NG foam*
- *Estimate cost for a full-scale system*

Focus of Year 2 Efforts

- *Rheology data for NG foams is not published in literature*
- *The lab-scale test stand will provide key data at/near actual field conditions:*
  - *NG foam rheology data*
  - *Evaluation of foam stability/mixing*
  - *Simulate fracture initiation to observe pressure transients in foam*

Questions?

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Appendix

Project Organization

SwRI

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Engineering Support
Craig Nolen & Charles Krouse

Contracts
Mary Lepel

Schlumberger

PI
Dr. Sandeep Verma (SDR)

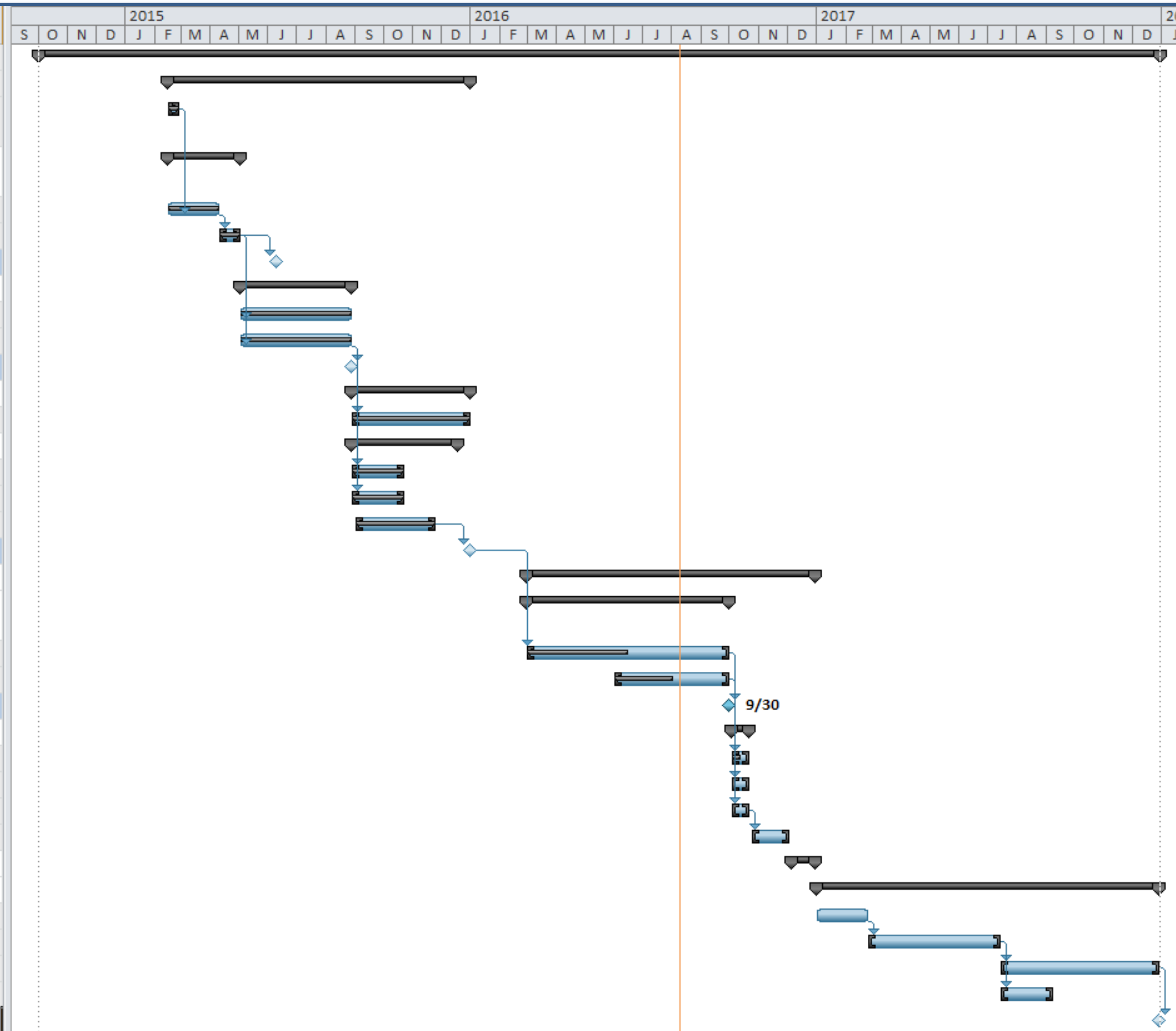
PM
Garud Sridhar

Engineering Support
Alhad Phatak, Terrence Goettsch, & Carina Pechiney

Engineering Consultation
Dr. John Brisson (MIT)

Project Schedule

Task No.	Task Name
1.0	**Project Management and Planning**
2.0	**BP1 - Optimization and Design**
2.1	Identification and evaluation of potential thermodynamic processes
2.2	**Optimization of thermodyamic paths and equipment availability**
2.2.1	Initial concept investigation
2.2.2	Concept selection
	Milestone A - Top 2 or 3 Ranked Processes
2.3	**Techno-economic evaluation**
2.3.1	Thermodynamic modeling
2.3.2	Cost and availability analysis
	Milestone B - Top Ranked Process Identified
	Detailed design
2.4.1	Major component selection
2.4.2	**Piping simulation**
2.4.3	Development of test matrix
2.4.4	Safety considerations
2.5	LNG rheology literature review
	Milestone C - Finalized Detailed Design
3.0	**BP2 - Reduced scale system construction and testing**
3.1	**Reduced scale system equipment procurement, construction, and calibration**
3.1.1	General
3.1.2	Safety
	Milestone D - Compressor/Pump Train Set-up Complete
3.2	**Commissioning**
3.2.1	Operation procedure development
3.2.1a	Start-up testing
3.2.1b	Process tuning
3.3	Testing
3.4	**Data analysis**
4.0	**BP3 - Field evaluation**
4.1	Evaluation of available sites
4.2	Set-up of equipment at field location
4.3	Testing and data analysis
4.4	Industrial scale cost study
	Milestone F - Field Test Data Acquired and Analyzed



Bibliography

- At the time of presentation, no publications have resulted from this project work

References

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2. *Cyrostar, 2016, retrieved from www.cryostar.com/pdf/data-sheet/en/hpp.pdf*
3. *Hutchins, R. D., and Miller, M. J., 2003, "A Circulating Foam Loop for Evaluating Foam at Conditions of Use," Society of Petroleum Engineers, Houston, TX, p. 10. SPE-80242.*
4. *Nolen-Hoeksema, R., 2013, "Elements of Hydraulic Fracturing," Oilfield Rev., 25(2), pp. 51–52.*
5. *CS&P, 2016, retrieved from www.csphouston.com/industrial_cryogenic/ICP45-01202010.pdf*
6. *J.M. Canty, 2016, "TA7461-1 F700 Series Flanged Sight Flows", retrieved from http://www.jmcanty.com/product/f700-series-flanged-sight-flows/*