REX2024
PRCI Research Exchange

PRCI-REX2024-004: Change Management For Introducing Hydrogen At Compressor Stations

A GMRC/PRCI, Project Phase 2

Sarah Simons

San Diego, California

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PRCI LEADING PIPELINE RESEARCH

Pipeline Research Council International

Topics Covered

1. Gas Property Changes
2. Building Considerations
3. Compressors and Drivers
    1. Limitations
    2. Materials
    3. Combustion
4. Piping and Equipment:
    a) Integrity and Repairs
    b) Safety and Leakages
    c) Pulsations
    d) Valves, Blowdown
    e) Coolers and Scrubbers
    f) Gas Analysis and Metering
5. Where to Start When Evaluating a Station

Blending Up To 20% H2-- Volumetric Concentration

Hydrogen vs. Natural Gas Properties

- Different design in piping & compression systems
  - Small molecules
    - Embrittlement
    - Leakage concerns
- Decrease in mixture density, up to 20% decrease for 20% H2
  a) Lower density = higher sound speed
  b) Lower density = higher gas flow velocity
  c) Pulsation control design change
- Lowering of the J-T coefficient, increase in specific heat and compressibility
- High energy density by mass, but decrease in volumetric calorific value
  - Need more volume or pressure to transport same amount of energy

	Natural Gas	Pure Hydrogen	Natural Gas/10% Hydrogen	Natural Gas/20% Hydrogen
Mol. Wt.	16.8	2.0	15.3	13.8
Density (lbm/ft^3)	3.4	0.34	3.0	2.6
Sound Speed (ft/s)	1375	4480	1472	1577
J-T Coeff. (°F/psi)	0.05	-0.004	0.04	0.03
Dynamic Viscosity (lbm/ft-s)	8.5x10-6	6.0x10-6	8.4x10-6	8.3x10-6
LHV (Btu/lbm)	21,013	51,598	21,417	21,906
Volumetric Energy Density (Btu/ft3)	71,444	17,543	64,251	56,956

Data from NIST REFPROP at 70 °F, 1000 psi with “Gulf Coast Gas” mixture

Building Considerations

- **Electrical Area Classification Group**
  - Does not change for H_2<20%, current PRCI-Sandia Study
- **Fire/Gas Detection Systems**
  - Need to be recalibrated or replaced if Semi-conductor (10%) or FID/Thermal Conductivity (5%)
  - Infrared is not accurate without filters, false alarms
  - MIR (multispectrum infrared) and UVIR (ultraviolet infrared) are top choices (see INGAA report)
  - Use a secondary detector specifically for H_2
- **Fire, Ignition, Venting**
  - Auto-ignition risk is low for <10% H_2, unknown above that
  - CO_2 extinguisher/dry powder retardant work for H_2 blends
  - Building should have good ventilation, typical of natural gas, but particularly located at top of building
  - Fire suppression systems can still use water for H2, may change droplet size and volume
- **Leakage and Leak Detection**
  - Perform baseline leakage survey at 100% NG
  - If H_2>10%, survey equipment and piping sealing points and areas with high dynamic stress
  - External leak detectors (LIDAR, Diff absorption)—consult OEM on accuracy above 5% H2

Major Equipment--Compressors

Due to differences in heat capacity ratios and specific heat of the gas at constant pressure, isentropic compression work for hydrogen can be more than 5x greater than that of natural gas per unit mass at same T and pressure ratio.

$$\Delta h_s = c_p T_1 \left[\left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - 1 \right]$$

	Hydrogen	Methane
Specific heat at constant pressure (kJ/kg K)	**14.3**	**2.3**
Ratio of heat capacities (**g**)	**1.4**	**1.3**

Discharge temperatures also increase due to heat capacity ratio increase! $\frac{T2}{T1} = \frac{P2}{P1}^{(1-\frac{1}{\gamma})}$

Compression Work Increases or Energy Transport Decreases

Pipeline Operation Approach 1

	Hydrogen	100% NG
Std Flow Rate (MMscfd)	1178	1178
Mass flow rate (lbm/s)	72	592
Heating Potential (Actual MMBtu/hr)	16,285	46,850
Isentropic Compression Power Req'd (Hp)	16,900	15,269

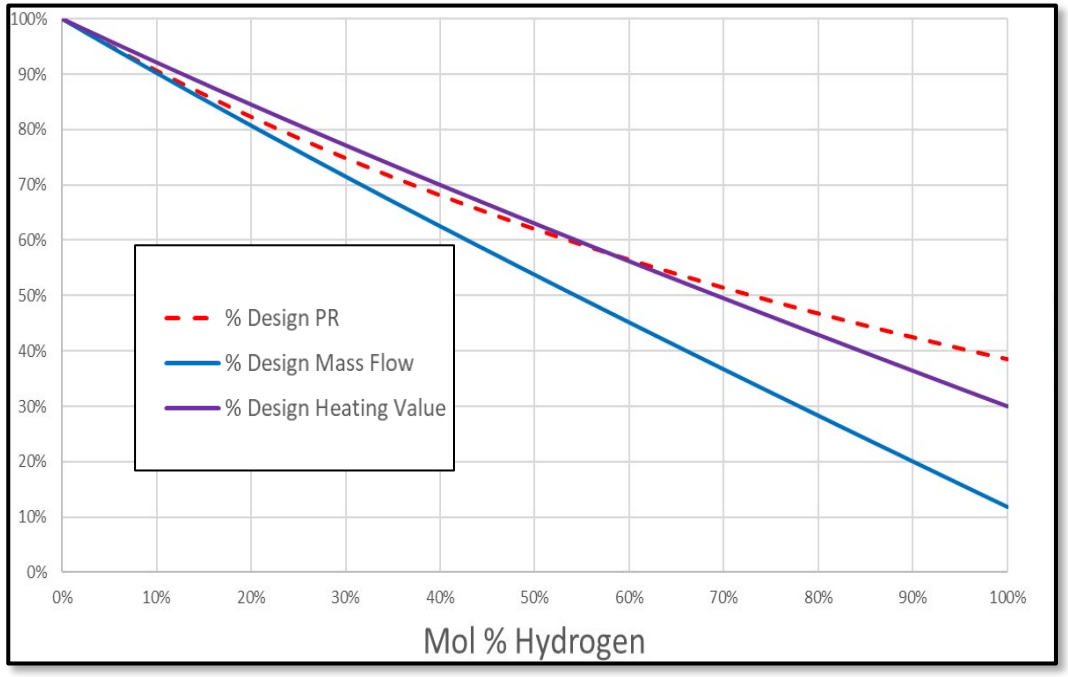
Pipeline Operation Approach 2

	Hydrogen	100% NG
Std Flow Rate (MMscfd)	3389	1178
Mass flow rate (lbm/s)	208	592
Heating Potential (Actual MMBtu/hr)	46,850	46,850
Isentropic Compression Power Req'd (Hp)	48,823	15,269

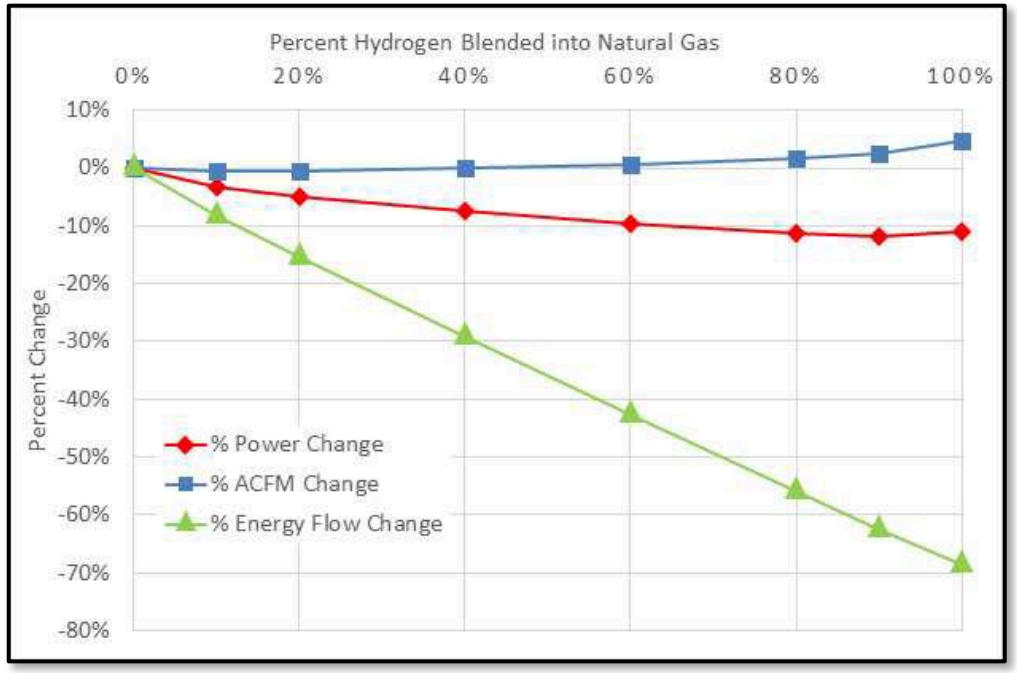
At Constant Suction Conditions of 596 psi and 78 deg F with pressure ratio of 1.34

Compressor Performance Trends

Centrifugal: Fixed Speed, Suction, Volume Flow Conditions



Reciprocating: Fixed Speed, Suction, and Pressure Ratio



- To maintain volumetric energy capacity or mass flow
  - Compressor speed and power must increase
  - Total increase in emissions due to more HP required for pipeline energy capacity

Allison, T., et al, "Hydrogen Compressor Requirements and Technology for Blended Pipelines" GMC,2021.

Centrifugal Compressor Seals and Materials

- Dry gas seals typically compatible with up to 20% hydrogen NG blends—should be verified by OEM
- O-rings typically are made of hydrogen compatible materials such as FKM (eg Viton®)
- Shaft seals made of PEEK or PTFE which are usually compatible with hydrogen
- All of this is conditional on temperatures below ~392°F—cut-off for high temperature hydrogen attack

The material requirements for rotating machinery defined by API 617,Paragraph 4.5.1.11

"Materials that have a yield strength in excess of 827 MPa (120 ksi) …are prohibited for use in hydrogen gas service where the partial pressure of hydrogen exceeds 689 kPa (100 psi gauge)"

- **Primarily affects the impeller and shaft since casing and stationary components are usually made of low yield strength carbon steel [1]**
- May not be a concern at low hydrogen concentrations (less than 5%) or at low pressures

1. Bauer, Derrick, "Materials for High Pressure Hydrogen Compression and Transportation," GMC, 2021

Reciprocating Compressor Valves, Seals, Materials

- **Acceptable for Hydrogen Concentrations Less than 20% and Below HTHA Limit**
  - Most o-rings are made of Aflas® or Viton®
  - Shaft seals made of PEEK or PTFE compatible with hydrogen
  - Reciprocating Compressor Valve Performance and Materials Acceptable
- **For lubricated compressors, materials are acceptable if temperatures below HTHA and MW greater than 12 per API 618**
  - For non-lubricated machines, OEM evaluation over 10% H2
  - Lubrication rate may need adjusting above 15-20% hydrogen

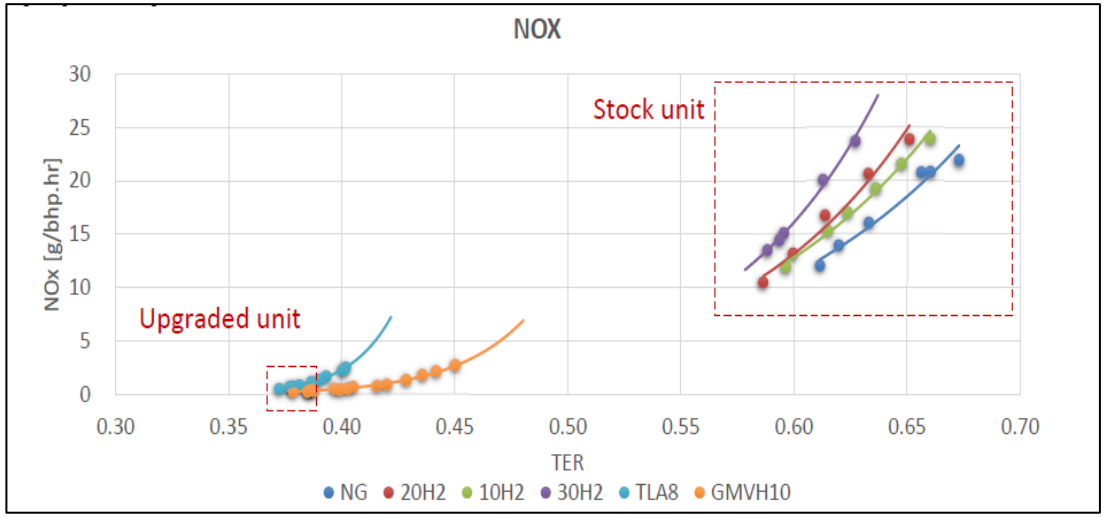
Discharge Pressure	Hydrogen Gas (H_2) Percentage in Gas Being Compressed	Trimming Level Requirement Recommended
At all pressures	Less than 20%	No special trim requirements.
1200 psig and greater	Greater than 20% - Less than 70% (Most Syngas applications would fall in this range)	Level I
Less than 1200 psig	All H_2 gas percentages	No special trim requirements
For 1200 to 3000 psig	Greater than 70%	Level I
Greater than 3000 psig	Greater than 70%	Level II

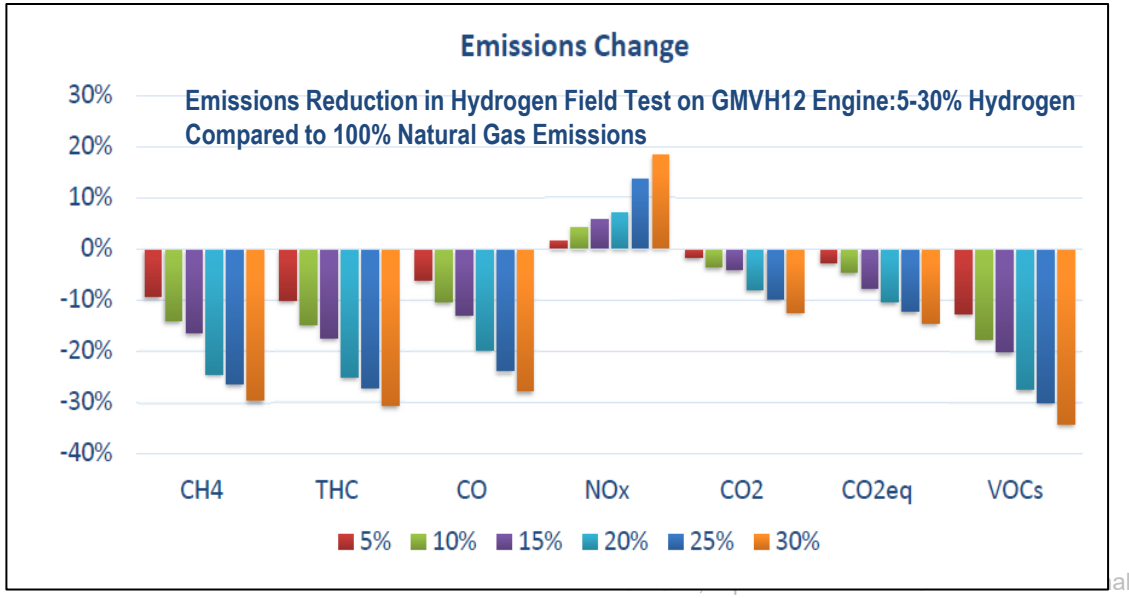
ACI Services General Guidelines for Compressor Valves When Blending Hydrogen

Drivers—Gas Engines

- **Most manufacturers state that 5-10% hydrogen blends are acceptable with no or minor mods**
- **At 20% H2, ignition timing and fuel flow need adjusting**
- **Operation with fluctuating gas compositions:** difficult to adapt an engine for varying H2, lose power and optimization
- **General Comments**
  - Lube oil will need optimizing for H2 blending
  - H2 sensor required
  - Emissions: NOx can be reduced with controls system
  - Most advancements are being made in engines for power gen, less demand for drivers

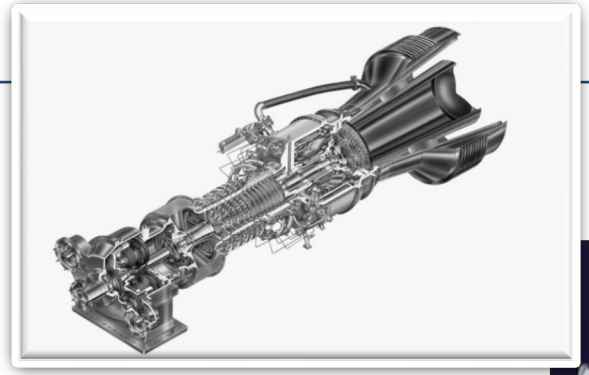
Measured NOx Emissions on Engine Designed for 100% NG Fuel vs Modified Engine for NOx Reduction with H2 Blended Fuel

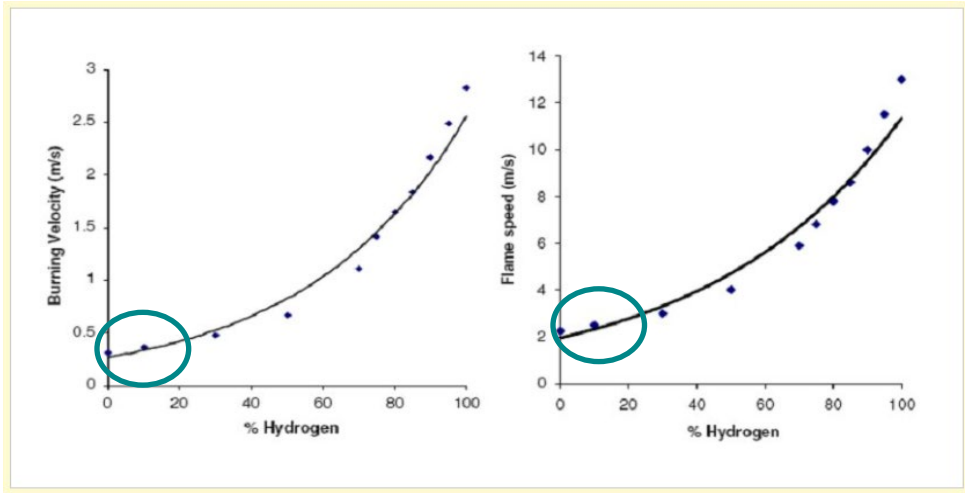




Drivers—Gas Turbines

- **Most manufacturers say 5-10% hydrogen blends are acceptable with no or minor changes, depending on technology used for combustion**
  - Older DLE systems have a higher risk of flashback
  - Conventional combustors can handle higher H2 with fewer modifications
- **Transient conditions—start-up/shut down, operation with fluctuating gas compositions**
- **Overall Trends**
  - Increased fuel volume consumption at higher H2%
  - Increase in NOx
- **Overall Package Reviewed for H2 compatibility**





Ceper, "Use of Hydrogen-Methane Blends in Internal Combustion Engines," 2012, DOI: 10.5772/50597

Piping-Pulsations and Instrumentation

- **Pulsations**
  - **Vortex-Shedding**
    - If changes in flow velocity are greater than 3%, should be re-evaluated
  - **Pulsation Filter Bottles**
    - If SOS change is greater than 5%, should be re-evaluated
  - **Orifice Plates—Bore Sizing**
    - If SOS or flow velocity will change by more than 5%, should be re-evaluated
- **Instrumentation**
  - Commonly installed pressure transmitters and thermowells are compatible
    - PTC 10 calcs should be reviewed for flow velocity changes above 5%
  - Lubricants/sealants listed as compatible with sour gas in the data sheet are compatible with H_2 less than 20%

Piping -Blowdown, Valves, Sealing Elements

- **Blowdown**
  - If flow velocity in blowdown flow-path will increase by 3% or more, re-evaluate structural integrity and noise rating of choke point(s) (diffusers in silencers or control valve)
  - Orifice plates re-evaluated when flow velocity increases by 5%, mass flow decreases at choke
- **Valves**
  - Control valves with internal trim may have structural or performance problems
  - Testing is needed to determine leakage rate vs % H_2 across closed valves and soft goods
  - Most non-pressure reducing valves are compatible with up to 10% H_2
  - Gas hydraulic actuators need to be replaced at 5% or higher H_2
- **Sealing Elements**
  - Polymers such as Nitrile, Viton®, Buna S/N, and Neoprene are compatible as long as temperatures are less than 300 deg F
  - Spiral wound 304 or 316 SS gaskets with graphite filler are compatible
  - Natural and silicone rubber are not compatible

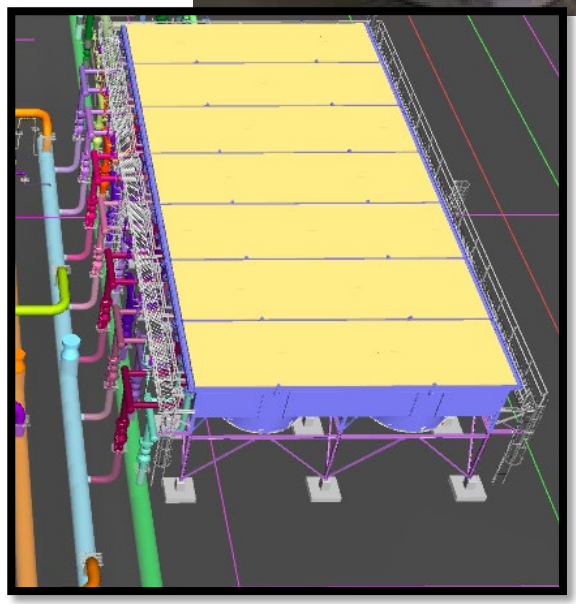
Major Equipment—Pressure Vessels, Coolers, Boilers

Coolers

- Cooler efficiency needs to be re-evaluated if operating above 2% H_2 with higher flow velocities

Pressure Vessels

- Typically no changes required below 20% hydrogen to maintain efficiency and performance
  - Changes do start at 20%.
- Welds are typically not pre-heat treated on most pressure vessels designed for natural gas, unclear if this is a problem when blending in hydrogen



Boilers

- Most standard burners are acceptable to operate with up to 10% H_2, if Wobbe Index of resultant gas mixture is within boiler limits
  - Some boilers/burners can operate with up to 30%--consult OEM
  - Low-NOx modifications may not be compatible with hydrogen

Gas Analysis

Three Gas Chromatographs Measure up to 20% H2 in NG Blends:

1. Emerson Rosemount 770XA
2. MECI MGC16
3. ABB PGC 1000

- Have a second module using Argon or Helium as a carrier gas
- Limitations on O2 and heavy component mol% measurements, may need more/alternate modules
- Process time can be up to 6 minutes

A Typical Rosemount 770XA Gas Chromatograph Configured for a Natural Gas Processing Application.

Recommended Initial Steps for Evaluation

Recommended steps for evaluation when converting a natural gas compressor station to incorporate hydrogen concentrations of less than 20% :

- **Define The Boundaries Of The Pipeline Exposed To Hydrogen**
  - Injection and extraction points of hydrogen
  - Requirements for the pipeline: pressures, energy transport capacity, volumetric flow rate
  - Identify areas of piping for internal contamination or lacking external protection
- **Safety Hazard Review:**
  - Gas and leak detector re-calibration, addition, or replacement
  - Fire extinguishers, ventilation, personnel gas detector review
- **Pipeline Analysis To Evaluate System And Compressor/Driver Limitations**
- **Gas Component Analysis And Flow Measurement Given Process Constraints**
- **Gas Turbines and Engines: fuel systems, additional safety and controls requirements**
- **Re-Evaluate Pulsation Amplitudes:**
  - Reciprocating Compressor pulsation bottles and orifices
  - Vortex-shedding excitation
- **Piping and Components:**
  - Integrity, Welding And Repair Processes
  - Valves, Including Blowdown Process
  - Evaluate cooler/scrubber efficiencies

Additional Areas of Research/Next Steps

- **The following components/topics have little information available and more research/testing is recommended:**
  - Fatigue crack growth rates in piping and gas metering when exposed to high differential pressure cycles such as line packing stresses or pressure reducing dynamic stresses
  - Updated welding processes such as “hot-tapping” when operating with hydrogen—PRCI is currently studying this with DNV
  - Updated defect criticality limits for hydrogen concentrations <20% in materials with yield strengths above API 5L X52 (~52,000 psi) based on hydrogen partial pressure—HyBlend research.
  - Leak rate multiplier for hydrogen natural gas blends—DOE HYBLEND and SwRI/GMRC/DOE H2 Blending Research
  - Levels of “acceptable” allowable contaminants, such as free sulfur, when mixing with hydrogen
  - Leak rate vs. H_2% across normally closed non-pressure reducing valves (gate valves, check valves, etc) and through the soft goods into atmosphere
  - Cooler materials and welds

SwRI

Next Step: Full Scale Natural Gas Compressor Loop Testing with Blended Hydrogen

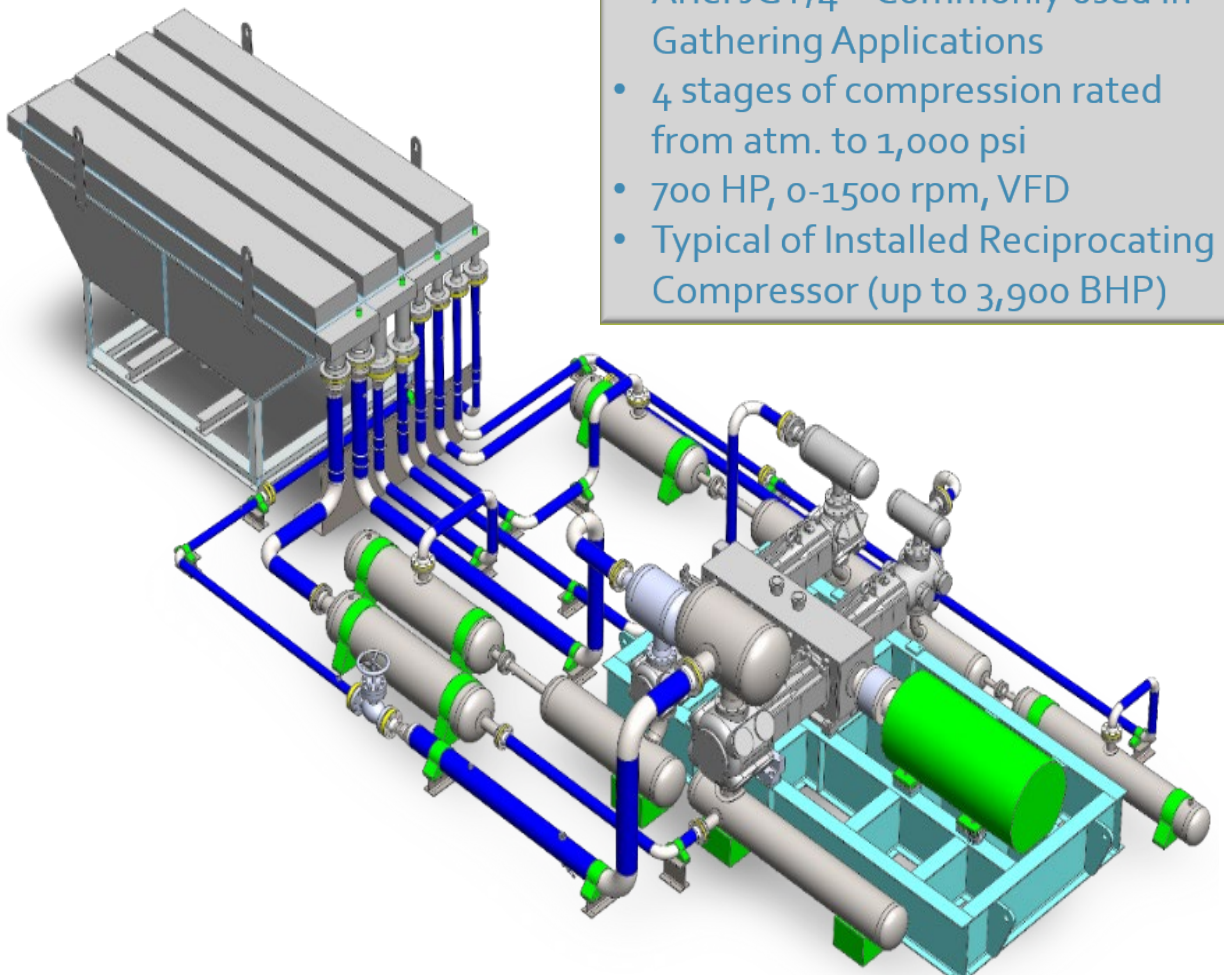
Principal Investigator: Sarah Simons

Prime Recipient: Southwest Research Institute

Team Members: Gas Machinery Research Council; a Consortium of Pipeline Operators and Compressor OEMS

Project Goals: 2 Year Project

- Design and Modify an Existing SwRI Compressor Loop for Hydrogen/Natural Gas Blending:
  - Design a H2/NG blending skid and modify loop for 20% hydrogen compatibility
  - Perform modeling predictions: performance, pulsation, leakage, blowdown
  - Test loop characteristics at varying H2% (0-20%) and compare
  - Perform leakage testing
  - Separation testing
- Write best practice guideline document
- Identify key technology gaps in converting natural gas compressor systems for hydrogen compatibility



- Ariel JGT/4 – Commonly used in Gathering Applications
- 4 stages of compression rated from atm. to 1,000 psi
- 700 HP, 0-1500 rpm, VFD
- Typical of Installed Reciprocating Compressor (up to 3,900 BHP)

thank you

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Sarah Simons
Southwest Research Institute

210-522-2418

sarah.simons@swri.org