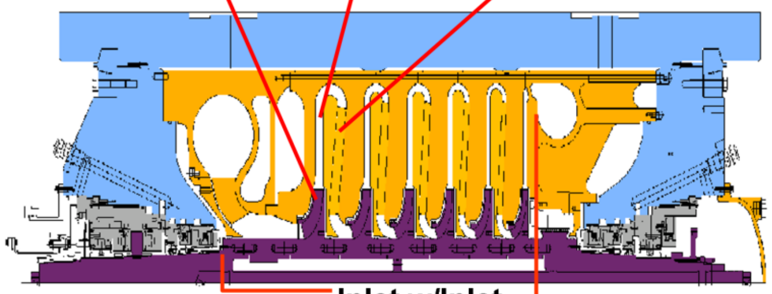
Impacts of Hydrogen Transport in Pipelines

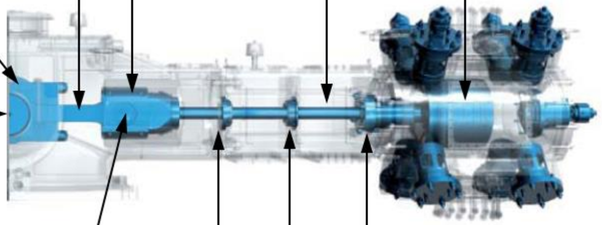


Timothy C. Allison, Ph.D.

Sarah Simons

Eugene "Buddy" Broerman

Southwest Research Institute

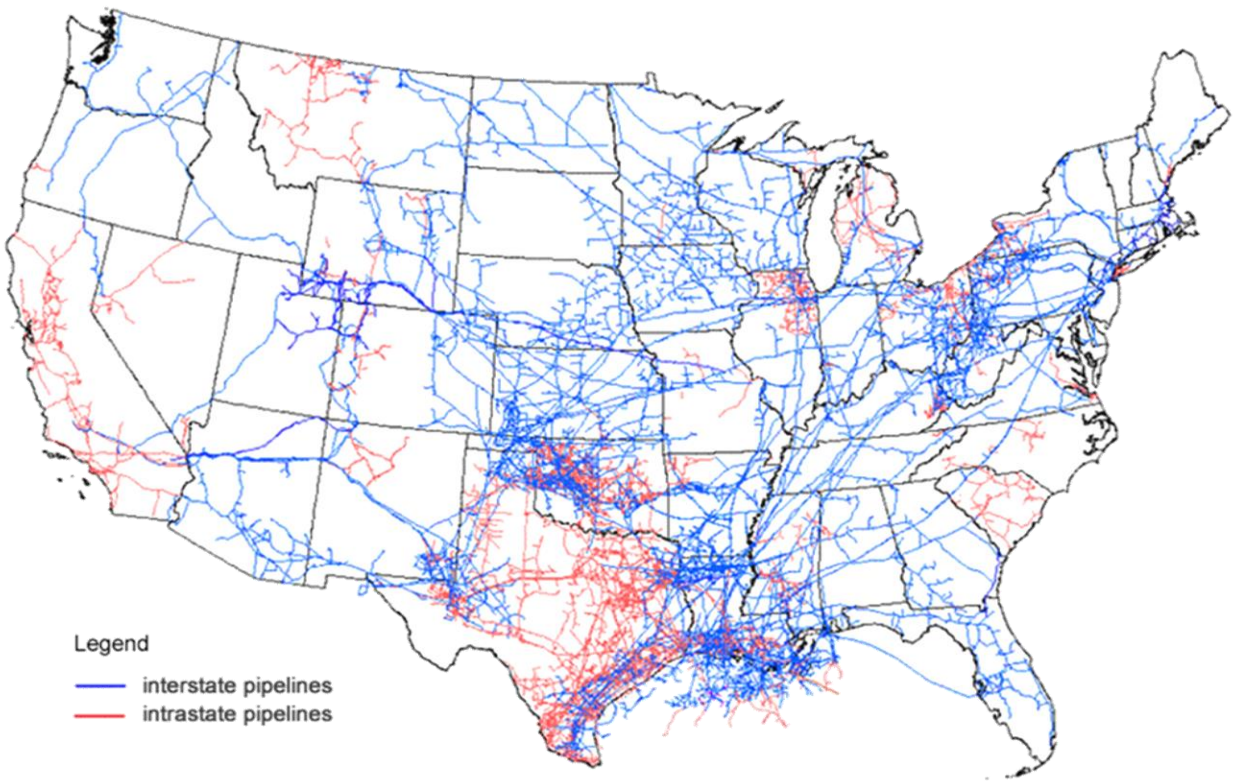


October 11, 2022

Hydrogen Blending

- Why hydrogen?
  - Effective form of thermochemical energy storage
  - Green hydrogen to decarbonize industry
- Why pipelines?
  - Leverage existing infrastructure
  - Efficient way to transport energy vs. power lines
  - Hydrogen can be phased into traditional natural gas pipelines allowing for a gradual transition
- Infrastructure Considerations
  - Once Hydrogen is introduced into the network, it will get EVERYWHERE
  - Hydrogen content may fluctuate, particularly green generation
  - Equipment will need to operate for the entire range of hydrogen content

Map of U.S. interstate and intrastate natural gas pipelines



Source: U.S. Energy Information Administration, *About U.S. Natural Gas Pipelines*

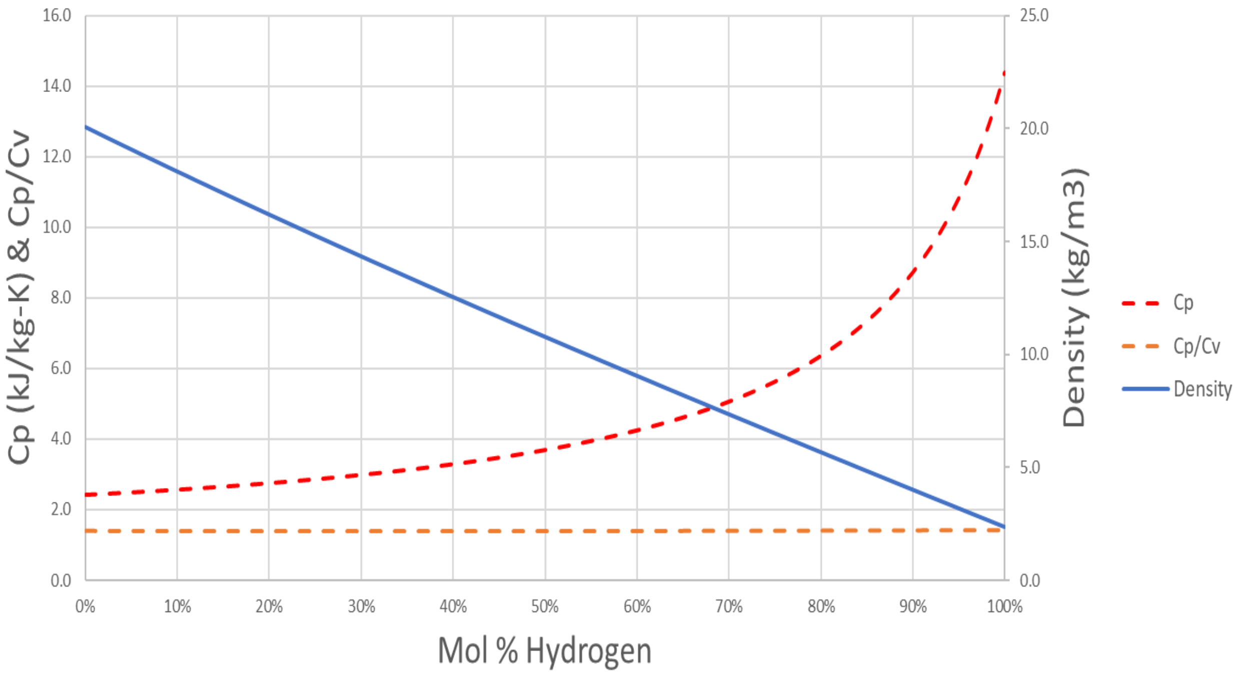
Hydrogen Pipeline Experience in Continental U.S.

- Hydrogen pipeline network supporting petrochemical industry exists along gulf coast, but at relatively small scale
- Salt dome cavern storage exists (Spindletop)
- Pressures from 250-1400 psi
- Piping diameters from 8-14”
- Primarily reciprocating compressors
- For blended pipelines:
  - Prior studies address material, safety, metering, combustion drivers
  - This paper focuses on effect of hydrogen blending on compressor aerodynamic and mechanical performance

Images Courtesy Air Liquide

Centrifugal Compressor Thermodynamics

$$\frac{P_2}{P_1} = \left(1 + \frac{\eta}{c_p T_1} \Delta h\right)^{\frac{\gamma}{\gamma-1}}$$	P_2 & P_1 = Discharge and Suction Pressure η = isentropic Efficiency Δh = Head Rise (Enthalpy Change) c_p = Specific Heat at Constant Pressure T_1 = Suction Temperature γ = Ratio of Specific Heats
$$P = \dot{m} \cdot \Delta h = \dot{m} \cdot \left(u_2 c_{u2} - u_1 c_{u1}\right)$$	P is compression power $\dot{m}$ is the mass flow u is the velocity of the impeller c_u is the velocity component in circumferential direction Subscripts 1 and 2 refer to the impeller inlet and outlet

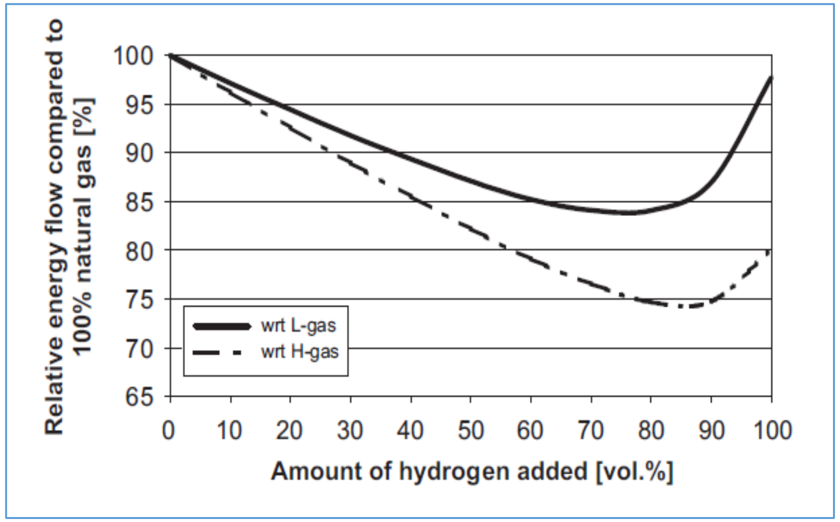


- As specific heat increases and head rise is maintained, pressure ratio decreases
  - More head rise and power will be required to maintain pressure ratio (centrifugal and reciprocating compressors)
  - Higher compressor speeds will produce more head rise (centrifugal compressors)
- As density decreases and mass flow is maintained, volume flow increases

Pipeline Capacity Constraints

- **Need to select evaluation approach**:
  - Keep volumetric or standard flow constant
    - Mass flow and energy density decrease
  - Keep volumetric energy capacity or mass flow constant
    - Volumetric flow (flow velocities) will increase
    - Must transport 3x the volume of hydrogen as of natural gas.
    - Hydrogen requires more power to transport the same amount of energy as Natural Gas
- **Include All Pipeline Limitations:** available power and compressor speed, temperature, economics, delivery pressure, flow velocities (increased noise, cooling, erosional/structural limits)

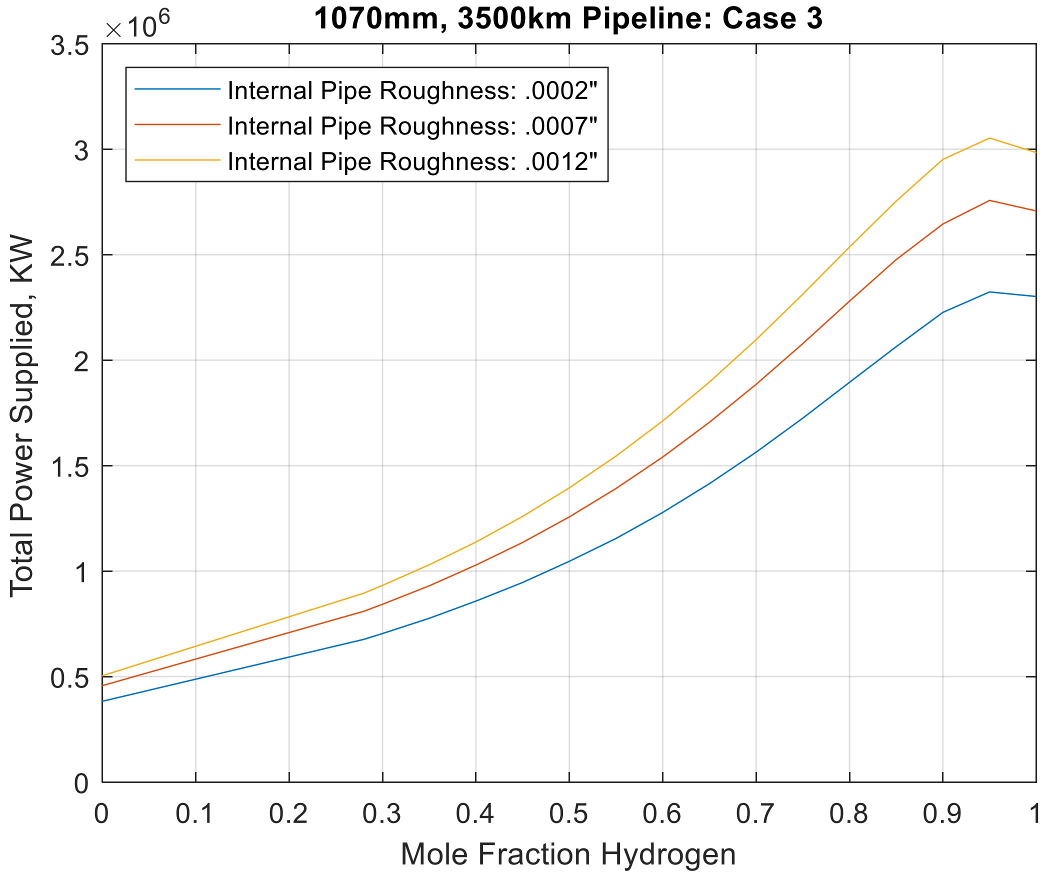
L-low calorific gas, H-high calorific gas



Tabkhi, F., Azzaro-Pantel, C., Pibouleau, L., Domenech, S., "A Mathematical Framework for Modelling and Evaluating Natural Gas Pipeline Networks Under Hydrogen Injection," (2008) Journal of Hydrogen Energy, 3(21). 6222-6231

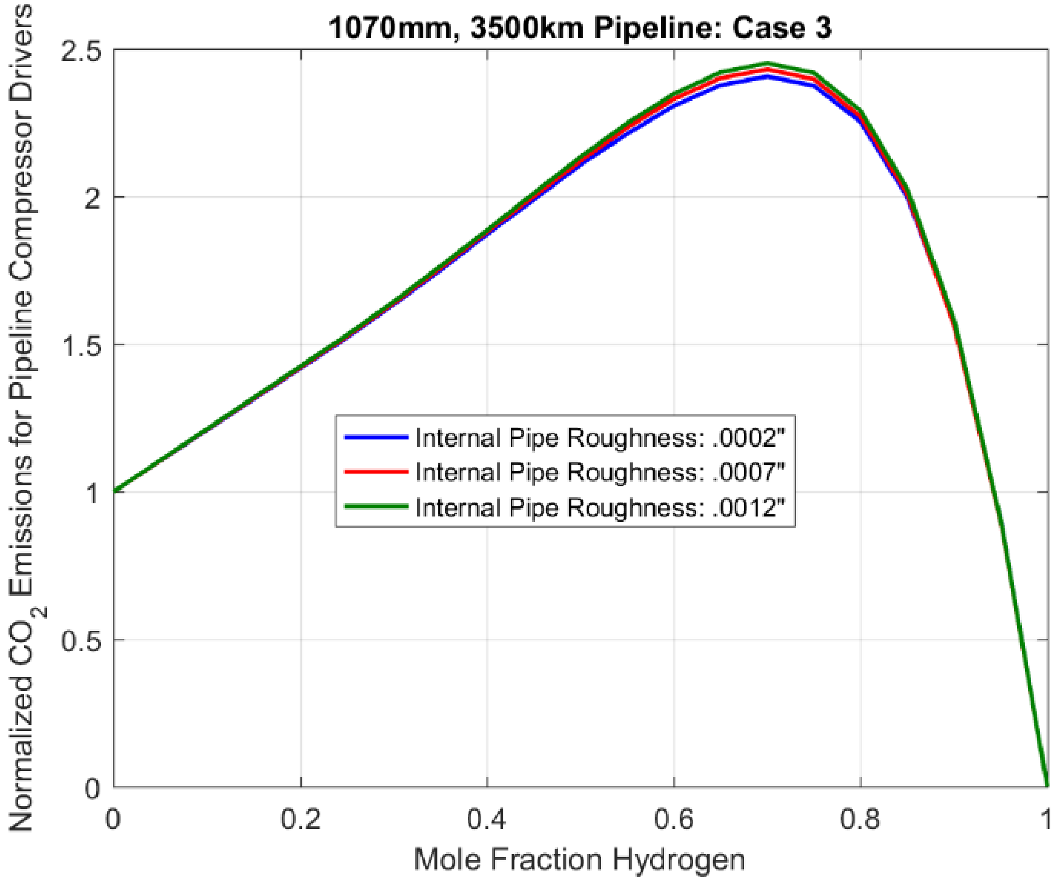
Hydrogen Blending Mostly Increases Compression Work

- What is maintained?
  - Energy Flow? Volumetric / Mass Flow?
- Compression work is increased by
  - Higher pressure drop between stations
  - Lower molecular weight of H2
- At 100% H2, increase in compression head rises by ~1x order of magnitude
- Power increase is less due to lower mass flow, still a ~5x increase



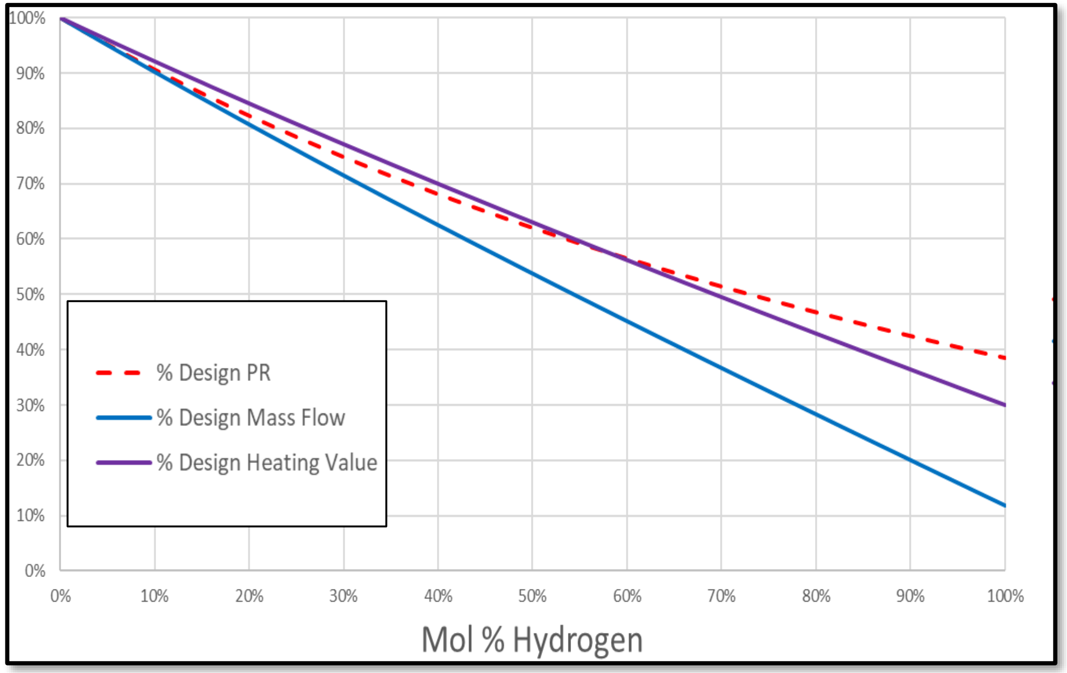
Hydrogen Blending Initially Increases Transport CO_2 Emissions

- Increased compression power vs. decreased carbon in fuel
  - Assuming gas turbine drivers
  - Motor drivers require improved electrical infrastructure, consider generation emissions, danger of black start failure
- Significant increase in transport emissions
  - Need compressor station CCS?
- Does not include end-use CO_2 emission reduction

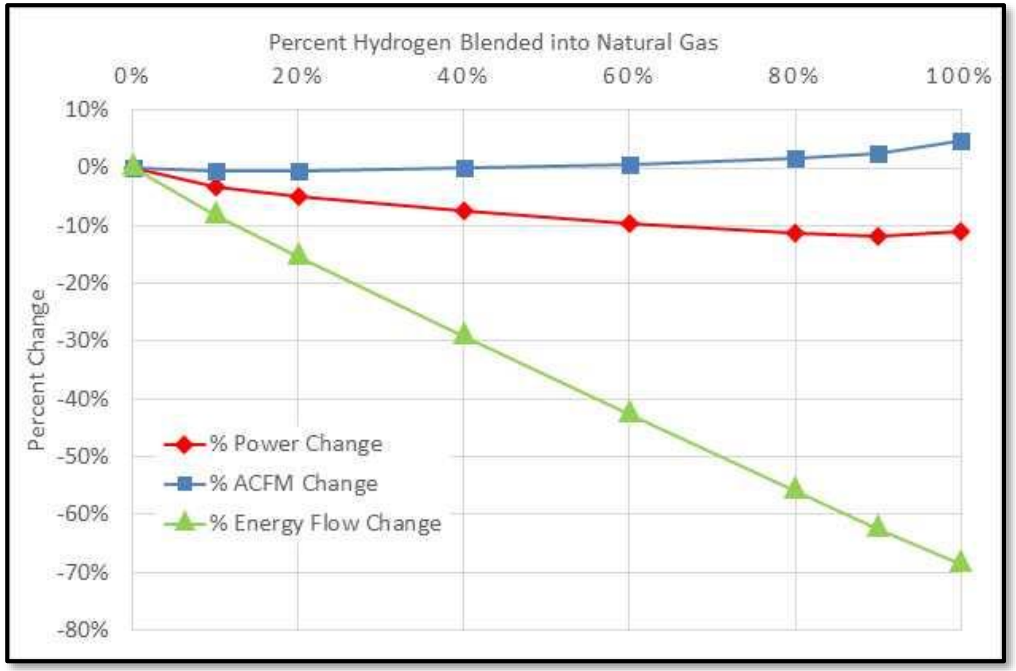


Compressor Performance Trends

Centrifugal: Fixed speed, suction, volume flow conditions

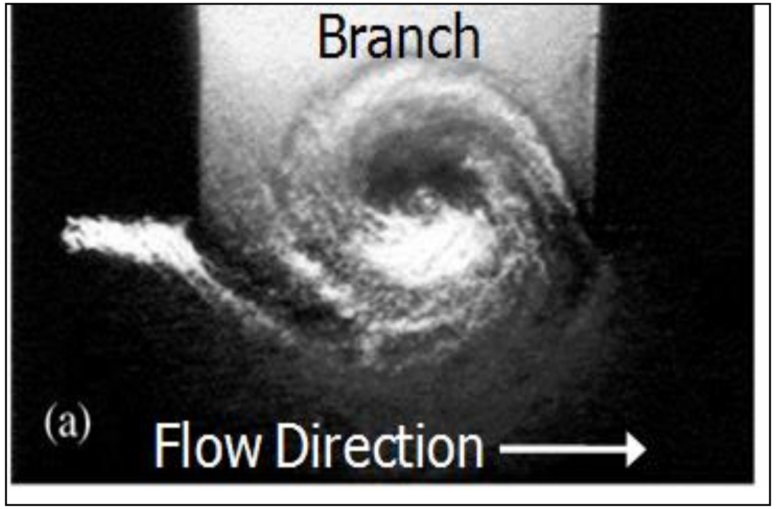


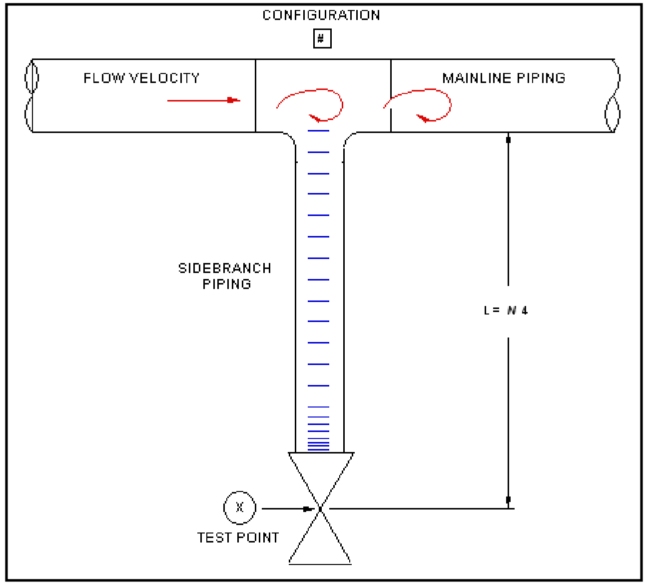
Recip: Fixed speed, suction, and pressure ratio

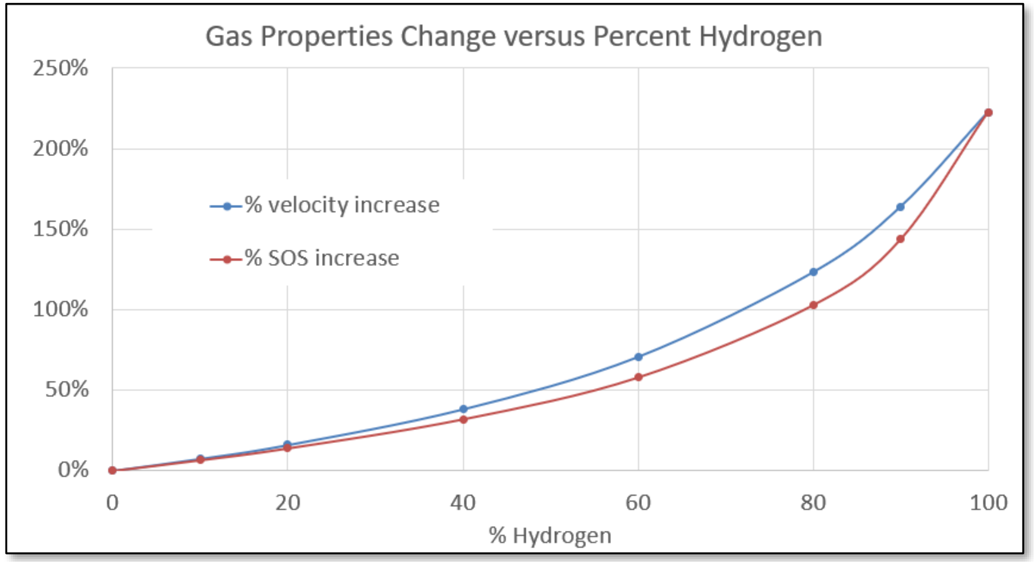


- To maintain volumetric energy capacity or mass flow
  - Compressor speed and power must increase
  - Total increase in emissions due to more HP required for pipeline energy capacity
  - Increase in compressor discharge temperature due to increase in "k"

Vortex-Shedding Excitation





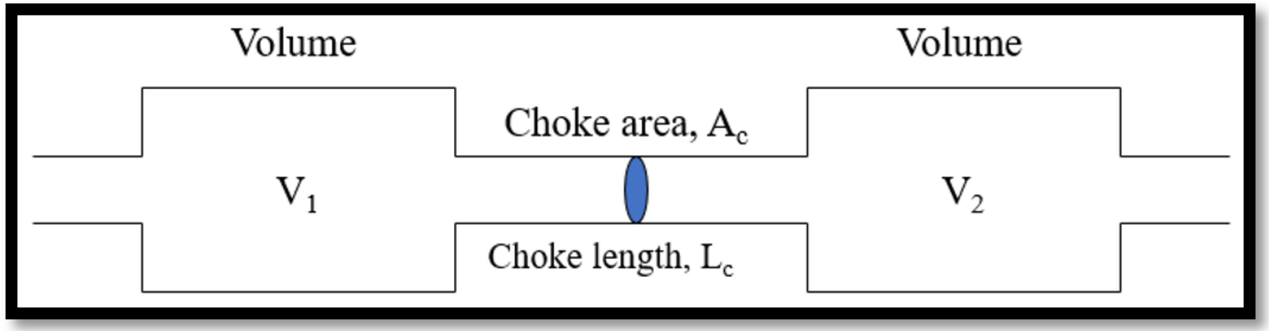


% H2	velocity (ft/s)	% velocity increase	SOS (ft/s)	% SOS increase
0	61	0.0%	1370	0.0%
10	65	7.4%	1461	6.6%
20	70	16.0%	1562	14.0%
40	84	38.1%	1809	32.0%
60	104	70.7%	2164	57.9%
80	136	123.2%	2779	102.8%
90	160	163.9%	3339	143.6%
100	196	222.7%	4423	222.8%

Pulsation Control for Reciprocating Compressors

$$f_n = \frac{c}{2\pi}\sqrt{\frac{\mu}{V_1} + \frac{\mu}{V_2}}$$

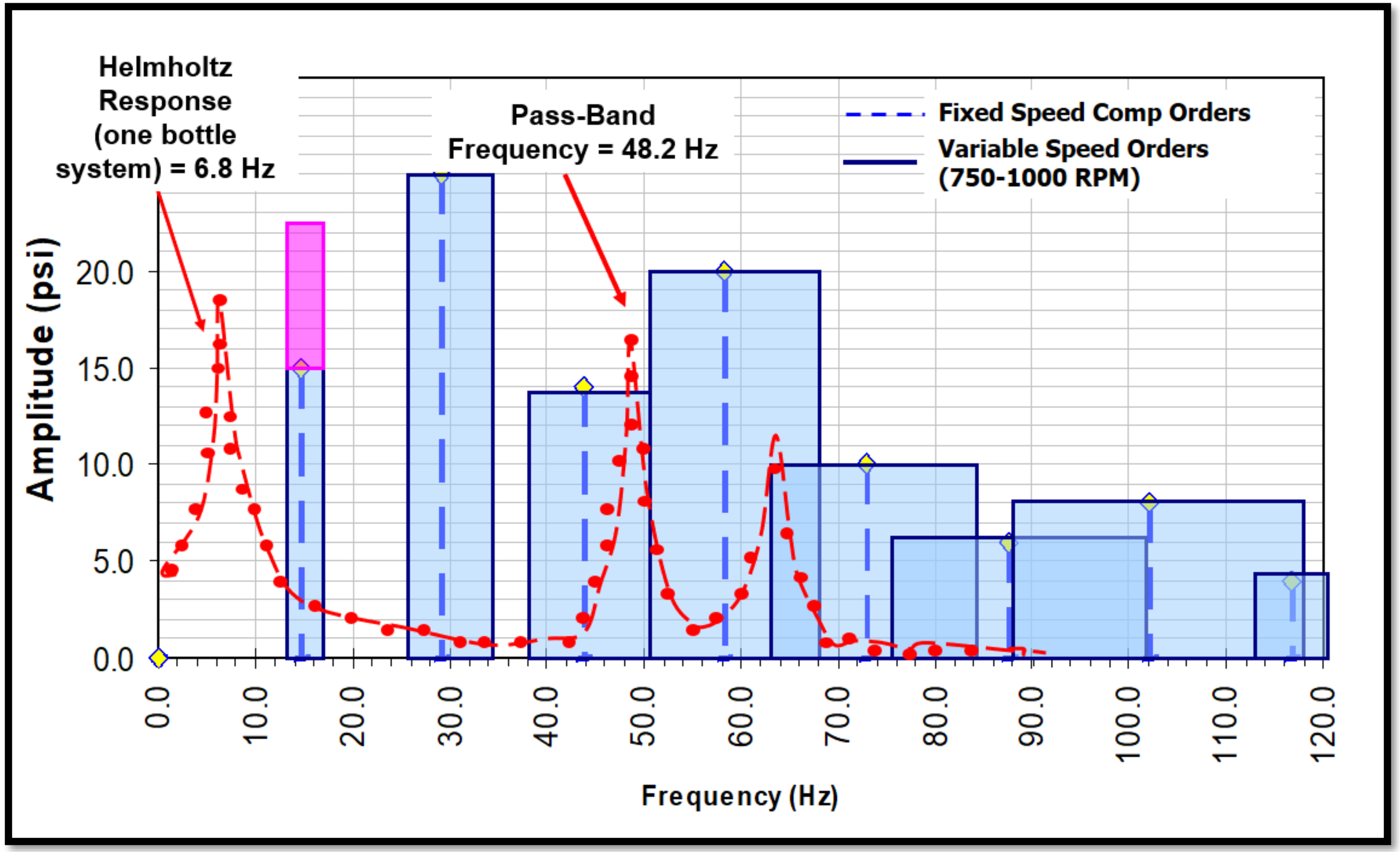
$$\mu = \frac{A_c}{L_c}$$



f_n = Helmholtz natural frequency
c = velocity/SOS
V_1&V_2 = volume one & volume 2

- As speed of sound increases, pulsation bottle volume must also increase to maintain Helmholtz / filter frequency
- For existing designs, filter frequency will increase while excitation orders remain the same.
  - For high-speed units with filter frequency below 1X will approach 1X -> May need redesign to place between 1X and 2X
  - Low-speed units with filter frequency between 1X and 2X will approach 2X -> May need to switch to empty vessels and orifices

Pulsation Control for Reciprocating Compressors



Low-speed lockout may be an interim measure to separate Helmholtz response from excitation orders when hydrogen blending

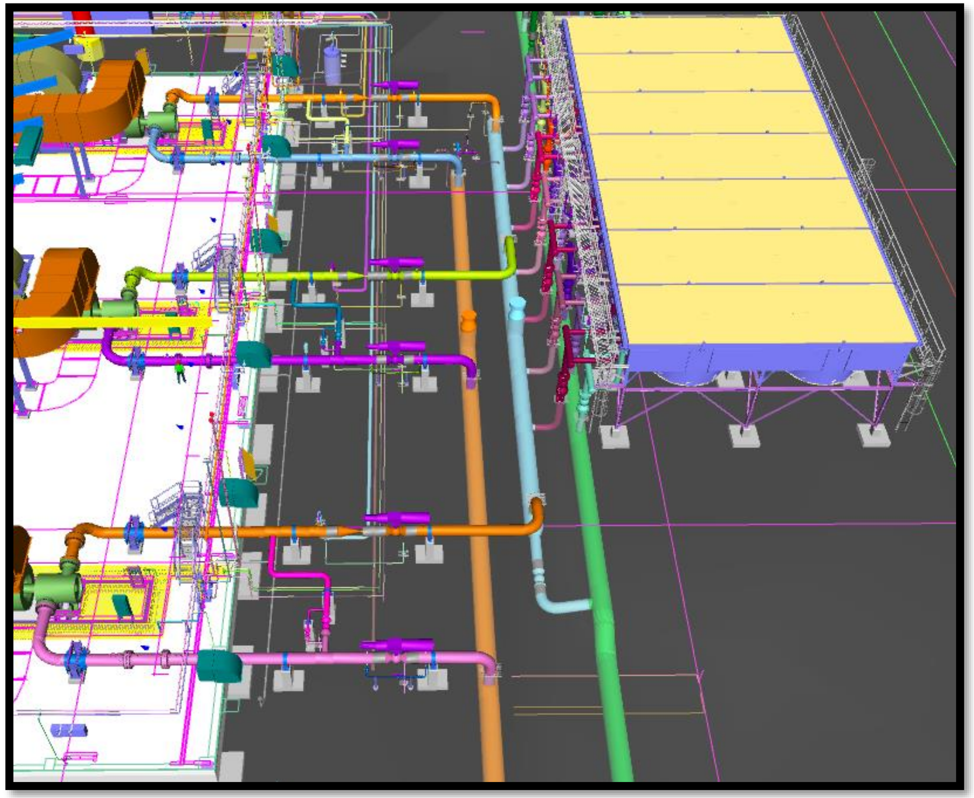
Gas Scrubbers and Coolers

Coolers

- Cooler efficiency needs to be re-evaluated if operating with higher flow velocities
- Coolers may not meet required pipeline temperatures depending on expected flow velocities and ambient conditions
- Coolers may be required on recycle lines due to lower J-T cooling on valves

Scrubbers

- If flow velocities will increase, efficiency and performance may decrease, depending on the type of unit
- 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
  - May decrease the life of the unit



Questions?

Tim Allison, Ph.D.
Southwest Research Institute
(210) 522-3561
tim.allison@swri.org