Impacts of Hydrogen Blending in Natural Gas Networks

PI: Hodge, Bri-Mathias

Lab performers: Guerra, Omar; Sergi, Brian

National Renewable Energy Laboratory (NREL)

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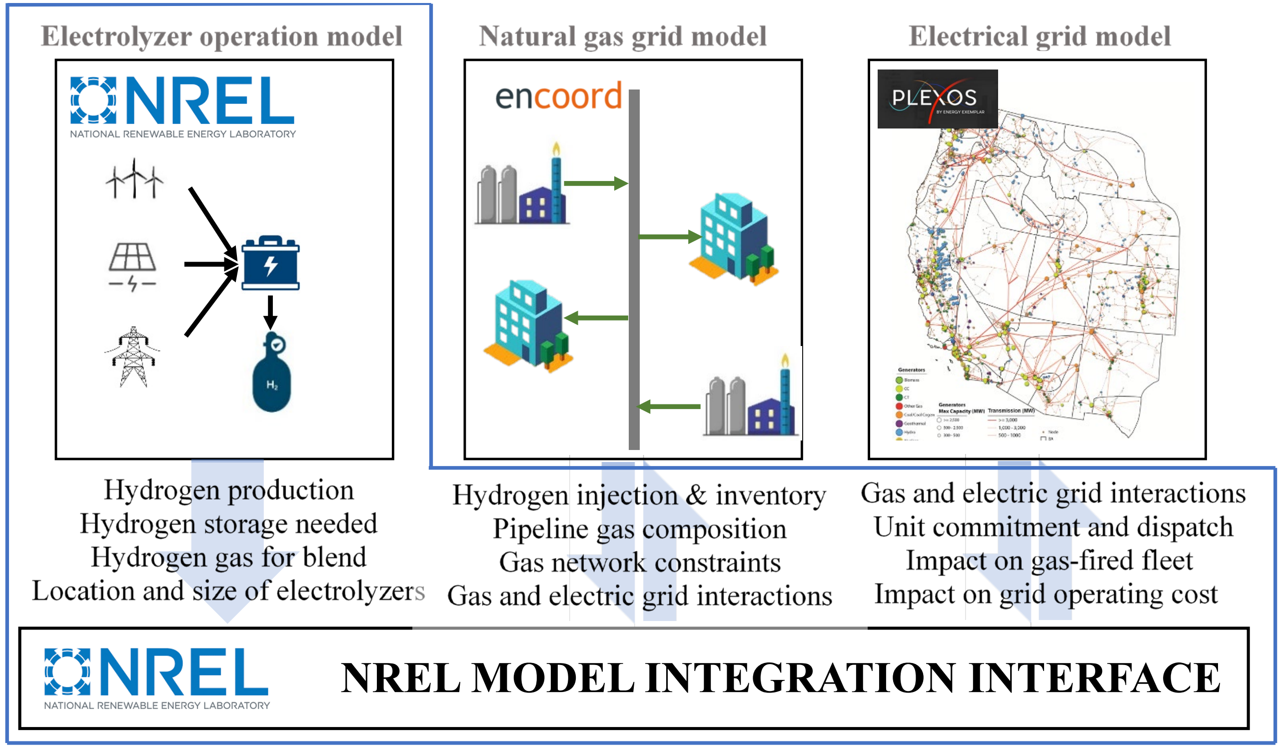
DOE Hydrogen Program

2021 Annual Merit Review and Peer Evaluation Meeting

AMR Project ID #

Project Goals

- Create a framework for the integrated modeling of hydrogen production, blending into the natural system, and use as fuel for power generators
- Establish metrics for system operation including gas composition throughout the gas network
- Establish metrics for determining the lifetime impacts of hydrogen blending on the gas network equipment
- Evaluate the impacts of fuel composition on gas generators on the electric grid



Items in the blue box will be developed under the TCF

Project Outcome

An integrated modeling framework to assess operational limits of hydrogen blending in natural gas networks

Overview

Timeline

- ❑ Project Start Date: 10/1/2020
- ❑ Project End Date: 9/30/2021
- ❑ Percent Complete: 50 %

Barriers

Barriers addressed

- Lack of real system data
- Interface challenges within different commercial software

Budget

- ❑ Total project budget: $375,000
- ❑ Total federal share: $175,000
- ❑ Total funds spent: $29,412 (March Update – Subcontracts not yet in place)

Partners

- ❑ NREL
- ❑ University of Colorado (Encoord
- ❑ SoCalGas
- ❑ I-GIT @ Stony Brook University

Relevance/Potential Impact

Objectives:

- Perform R&D to provide science and engineering basis for the hydrogen blending and transportation in natural gas networks.
- Develop models and tools to facilitate the assessment of the impacts of the hydrogen injection into gas system (including transmission and distribution) and enable use of that information for develop metrics.

Barriers addressed

- Lack of understanding around the natural gas and power system challenges associated with hydrogen blending in gas networks
- Addresses both operational and planning barriers

DOE goal

- Hydrogen blending has the potential to provide a near-term use case for carbon-free hydrogen to help develop the market
- Can potentially reduce greenhouse gas emissions using existing infrastructure, without the need for large capital investments

Approach

- Develop a model interface framework that enables integration of hydrogen production, natural gas system and electricity system models and verify operation.
- Develop a test network to correctly show case the capabilities of the integrated model.
- Use the developed model interface framework to capture important metrics related to hydrogen blending on the natural gas system (e.g., up-stream composition, end-use composition, longitudinal inventory of hydrogen throughput across the system).

Milestone Name/Description	End Date	Type
Develop overall model structure: This involves ensuring that each sub-model is running as expected and creating the software environment that enables integration of each model.	12/31/2020	Quarterly Progress Measure (Regular)
Complete development of a test system: Use available information to develop and refine a test system that will be used to demonstrate hydrogen blending. This system must be large enough and have sufficient detail to capture key features of hydrogen blending into the gas system.	3/31/2021	Quarterly Progress Measure (Regular)
Complete model integration platform: Complete the platform that allows for connection of the hydrogen production model, gas system model and electricity system model. This includes features to capture inputs and outputs from each model, exchange that information and perform analyses to understand instantaneous hydrogen concentration throughout the gas system as well as maintain a longitudinal inventory of hydrogen movement through the system.	6/30/2021	Quarterly Progress Measure (Regular)
Verify operation of the integration platform: This will be done through discussions with stakeholders, and comparison against existing data and additional information available in the literature regarding gas system operation.	9/30/2021	Annual Milestone (Regular)

Review Paper: Regulatory Requirements

- ❑ Nearing completion of a review paper summarizing research, policies, and projects related to hydrogen blending
- ❑ Have developed an initial set of metrics from which to evaluate changes to gas quality
- ❑ Currently testing the gas quality tracking capabilities in the SAInt gas model

Review Paper: Regulatory Requirements

- Intended to summarize current state of knowledge related to pipeline blending of hydrogen and natural gas

- Discussion of technical limitations (both known and unknown), regulatory requirements, ongoing projects, and potential role as a decarbonization strategy)

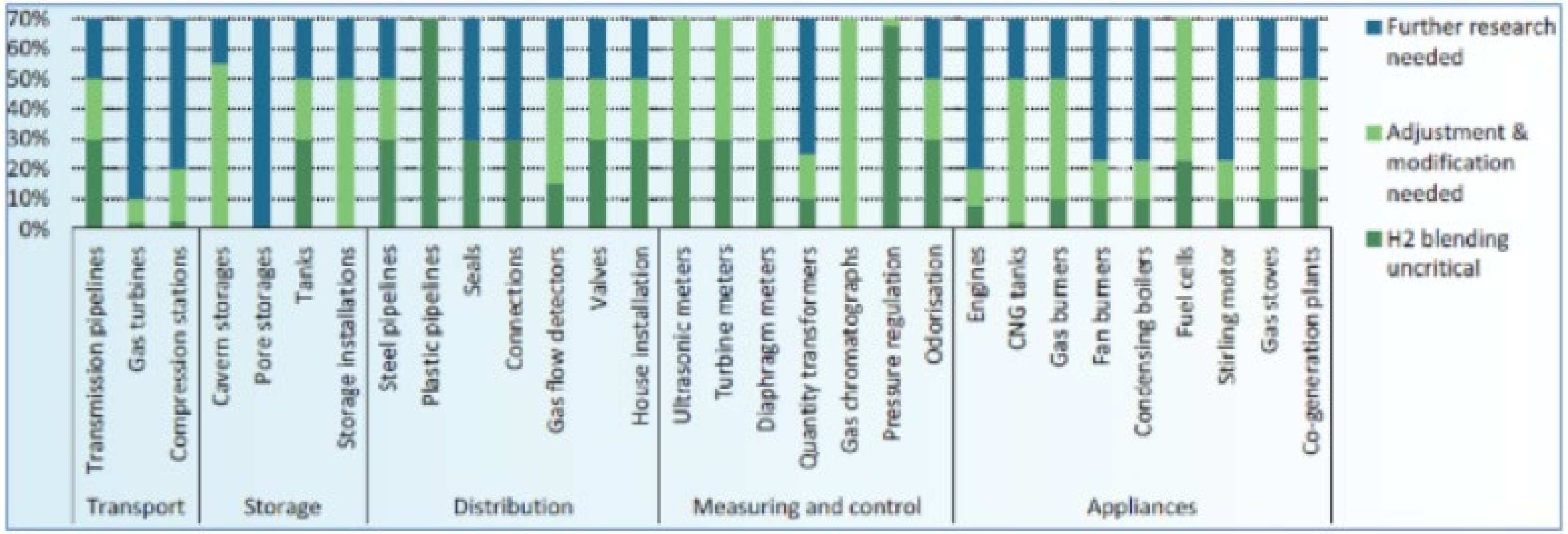


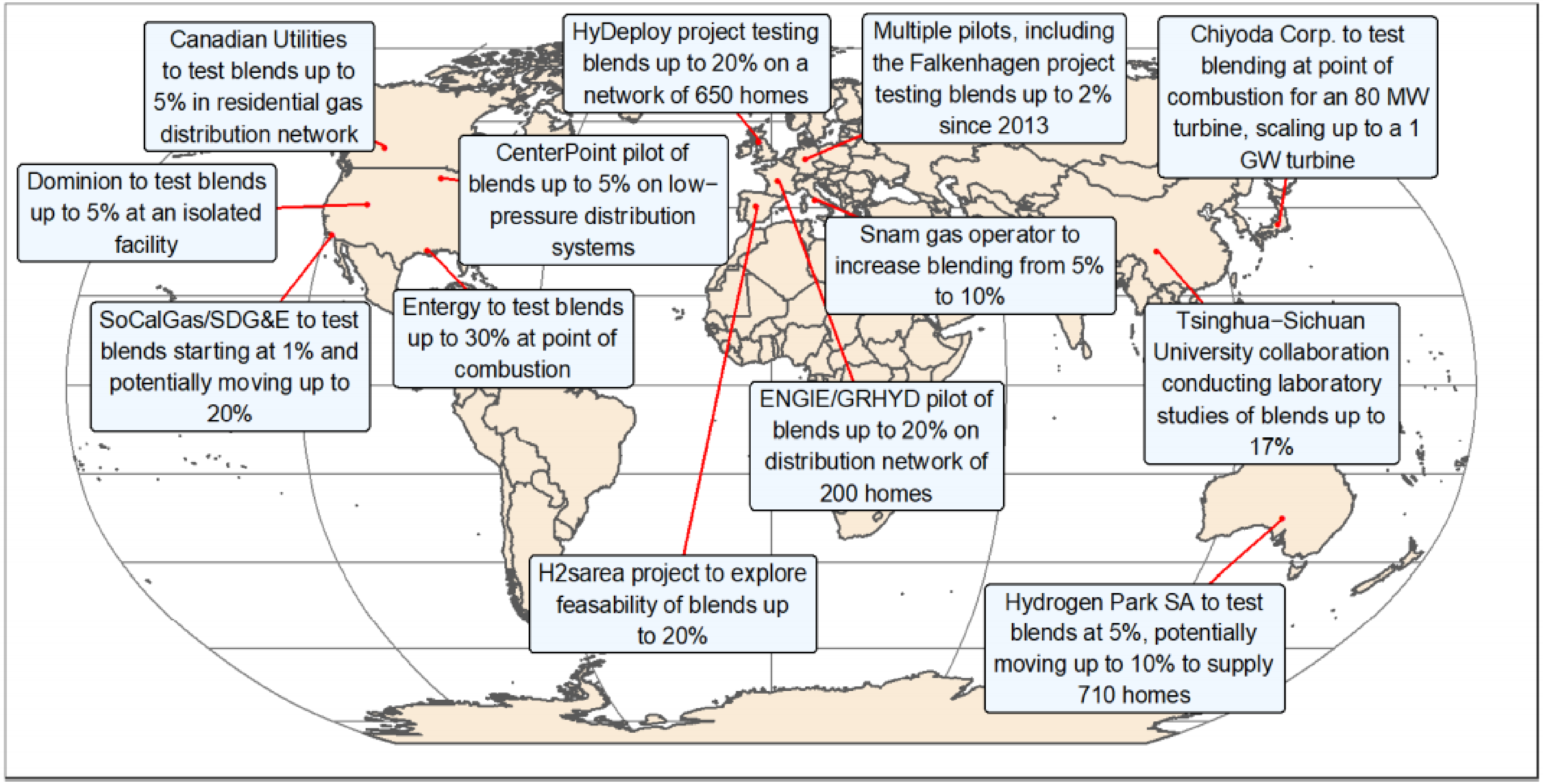
Figure 5 Limitations on the blend share of hydrogen by application – the most important applications to the blend share are gas turbines, compressing stations and CNG tanks. (PG&E R&D and Innovation, 2018)

Source: https://www.pge.com/pge_global/common/pdfs/for-our-business-partners/interconnection-renewables/interconnections-renewables/Whitepaper_PipelineHydrogen.pdf

Review Paper: Regulatory Requirements

Country	Limit	Notes
Germany	10%	Networks with compressed natural gas filling stations limited to <2%
France	6%	
Spain	5%	
Austria	5%	
Belgium	2%	No official limit, but 2% treated as a practical limit by operators
Lithuania	2%	Blending only permitted if pipeline pressure >16 bar
Switzerland	2%	
Canada	2%	De facto limit above which additional restrictions might apply;Alberta gas operator has energy content restrictions that implicitly limit blend levels to 5%
Finland	1%	
Italy	0.5%	Direct hydrogen injection not explicitly regulated
Czech Republic	0.5%	
Netherlands	0.5%	No official limit at the distribution level, but delivered gas must be <0.5% when received by the customer. Gas transmission entry pointsmust be <0.02%
Latvia	0.1%	
UnitedKingdom	0.1%	
Sweden	0.1%	Blends must be classified as natural gas to be in the transmission system; allowing levels up to 2% hydrogen has been discussed
New Zealand	0.1%	
Japan	0.1%	
California (U.S.)	0.1%	No official limit, but blends above 0.1% trigger additional compliance and monitoring requirements

Review Paper: Regulatory Requirements



Proposed metrics for evaluating gas quality

- Blend fraction/level: percent of gas that is hydrogen by volume

- Calorific value: energy content of a gas, usually given in units of MJ/m^3 (expressed in either HHV or LHV)

- Wobbe Index: defined using the calorific value and the relative density to air.
  - Useful for determining the interchangeability of gas
  - Increasing the hydrogen blend fraction lowers both the calorific value and the density of the gas

$$Wobbe = \frac{C_v}{\sqrt{p_{gas,STP}/p_{air,STP}}}$$

Proposed metrics for evaluating gas quality

- Gas flow rates: percent of gas that is hydrogen by volume
  - Volumetric flow rate: rate of flow of a volume of gas throughout the pipeline system
  - Energy flow rate: product of volumetric flow rate and the gas' energy content
  - Higher levels of hydrogen ⇨ lower energy content and density ⇨ faster volumetric flow

- Pressures: gas-fired generators typically have minimum delivery pressures that may be violated with decreasing density of gas

Initial test system analysis

- Currently testing tracking hydrogen injection and gas quality with a test system in the SAInt model

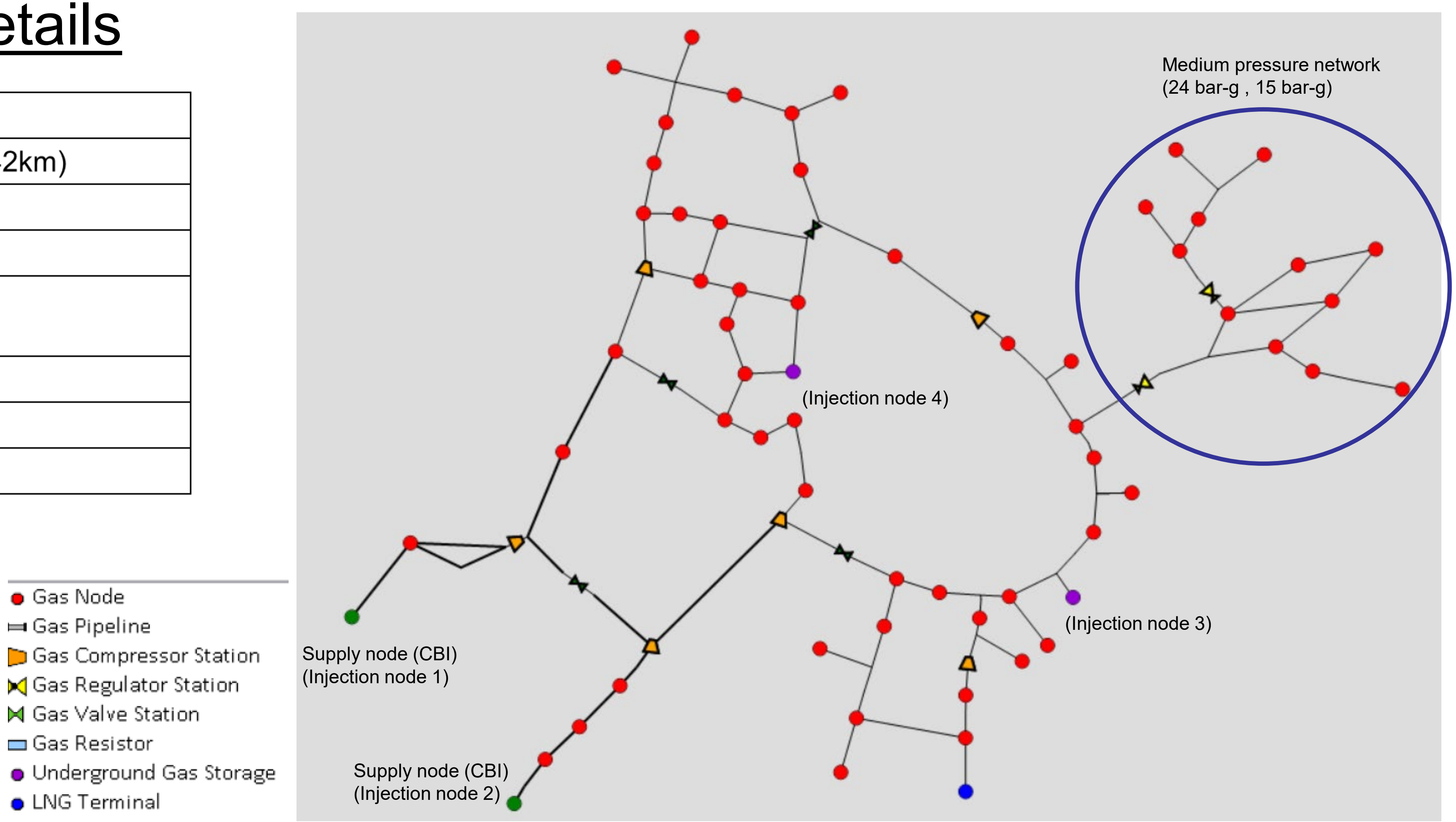
- Model includes three pressure domains:
  - **High-pressure level (60 bar-g):** provides gas to the city gates, distribution regulators and gas-fired-power plants (GFPP). Includes facilities such as compressor stations, underground storages and LNG facilities.
  - **Medium-pressure level (24 bar-g and 15 bar-g):** distributes gas to industrial users, gas fired power plants and a cluster of end users.

- Minimum delivery pressure for gas-fired power plants in 60 bar-g network is assumed to be 30 bar-g

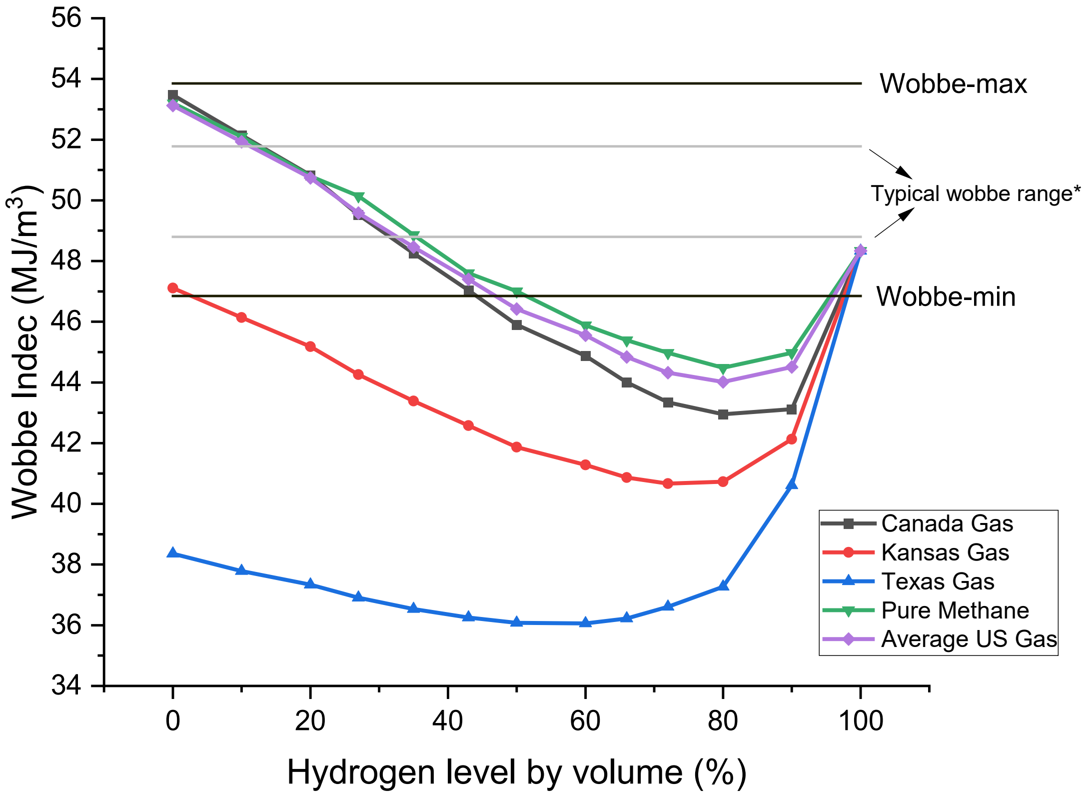
- Import stations, the LNG terminal, and UGS facilities are pressure controlled

Test system details

Network object	Count
Pipe segments	106 (3742km)
Compressor stations	6
Nodes	106
Links to local distribution	24
Industrial consumers	4
Underground storages	2
Gas fired power plants	28



Initial system results

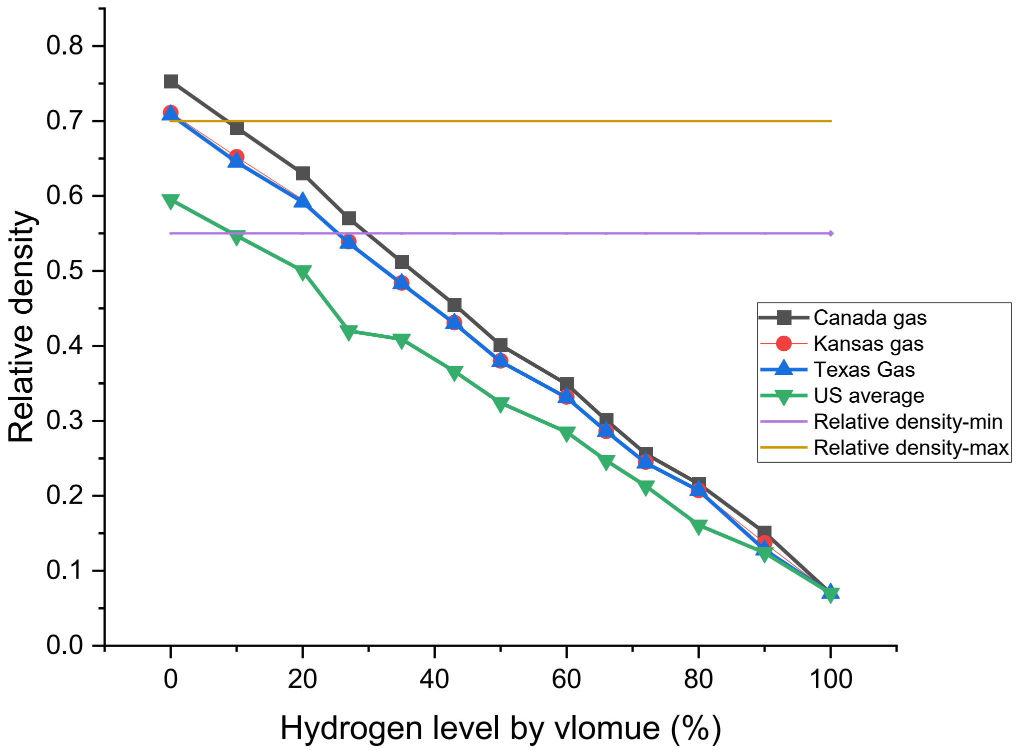


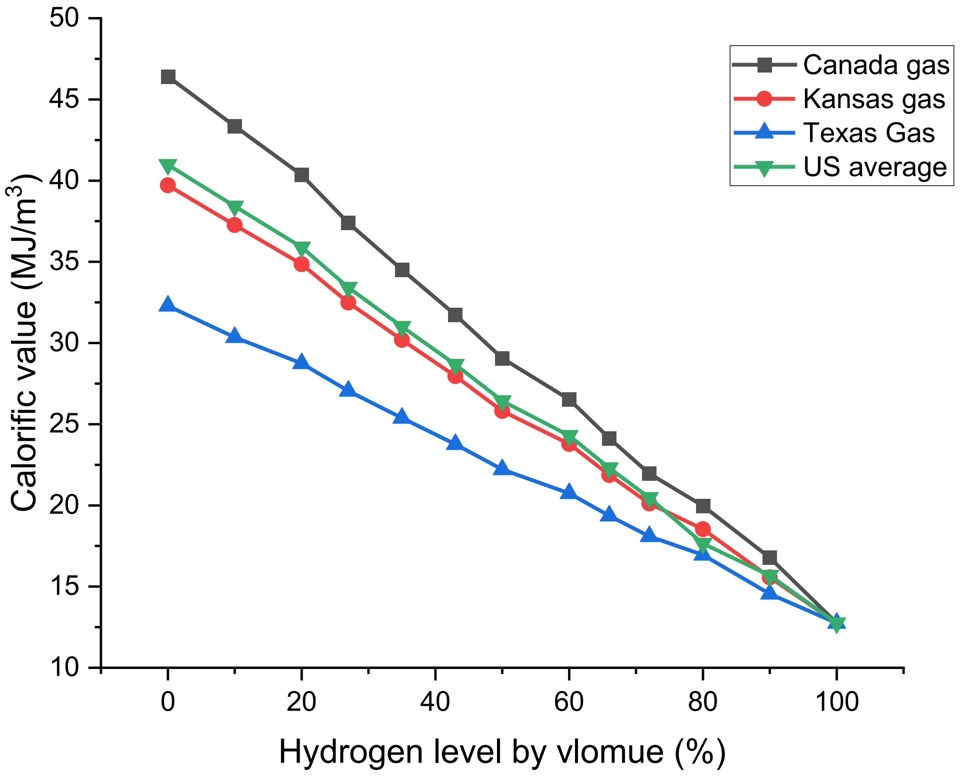
- The highest Wobbe gases (Canada gas, average US, pure methane can accept the most hydrogen (~44-50%) before reaching the lower limit
- Kansas gas is already at the lower limit of the band and can admit no hydrogen
- These limits can be different in each state.

Gas Compositions (%)				
	Canada	Kansas	Texas	Average US
Methane	77.1	73	65.8	92.3
Ethane	6.6	6.3	3.8	3.6
Propane	3.1	3.7	1.7	0.8
Nitrogen	3.2	14.7	25.6	1.8
Others	10	2.3	3.1	1.5

*Typical wobbe ranges in US, source: Gas Technology Institute
Wobbe max and Wobbe min values are calculated +/- 4 % based on Wobbe range limits, source : CRE Interchangeability Shell .PDF

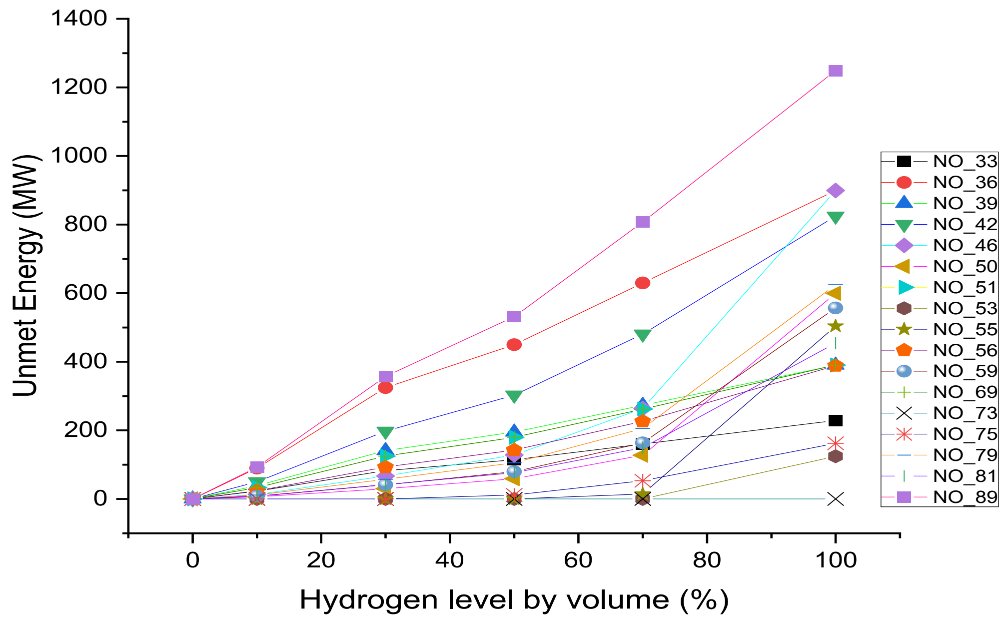
Initial system results

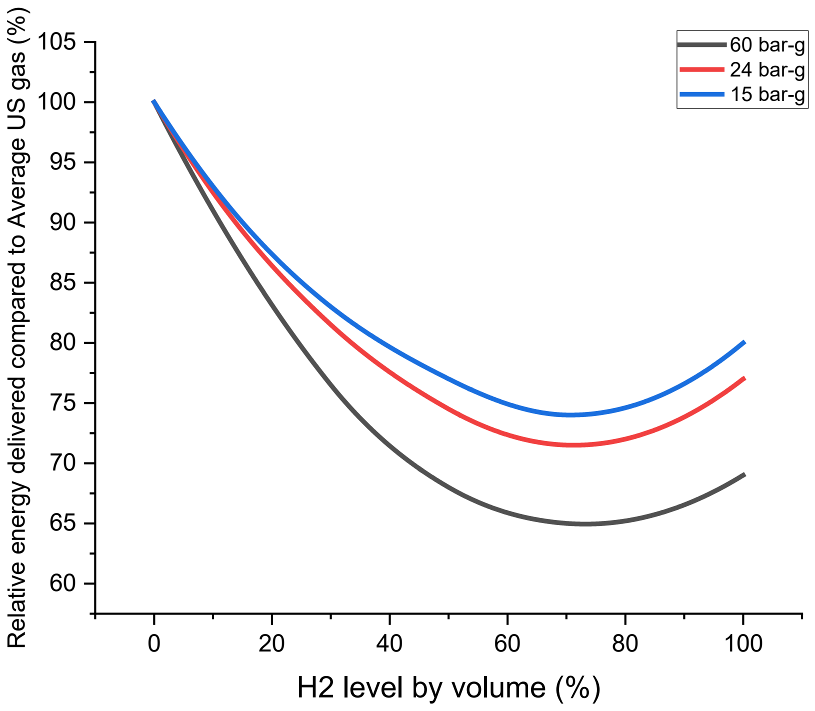




* Min and max values for relative density is obtained from e EASEE-gas Specification

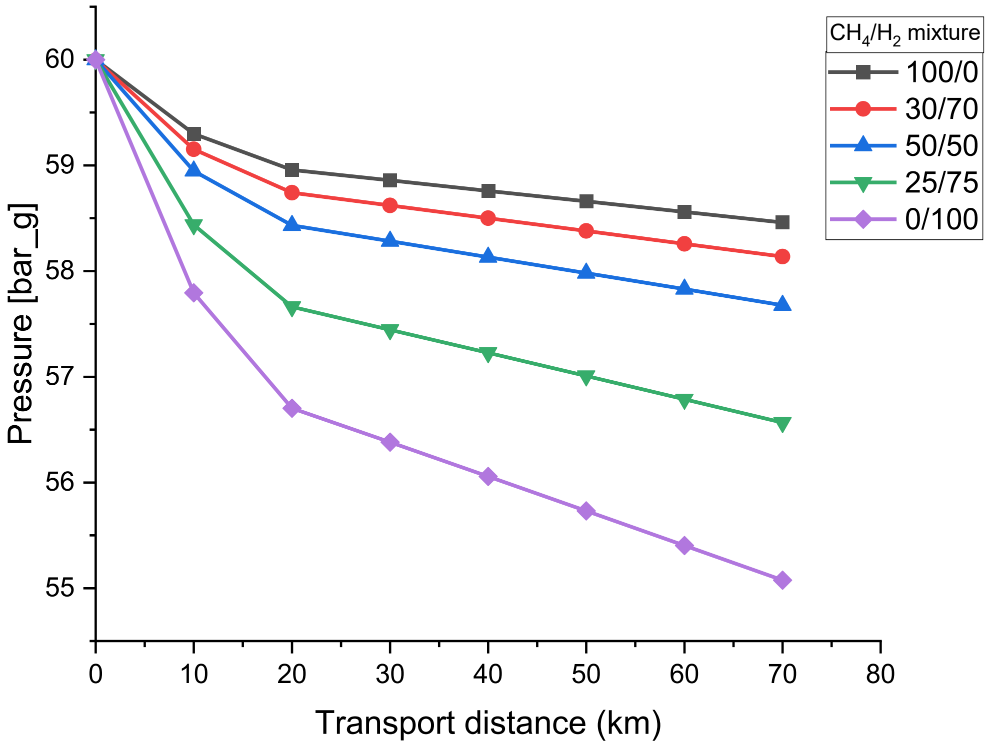
Initial system results





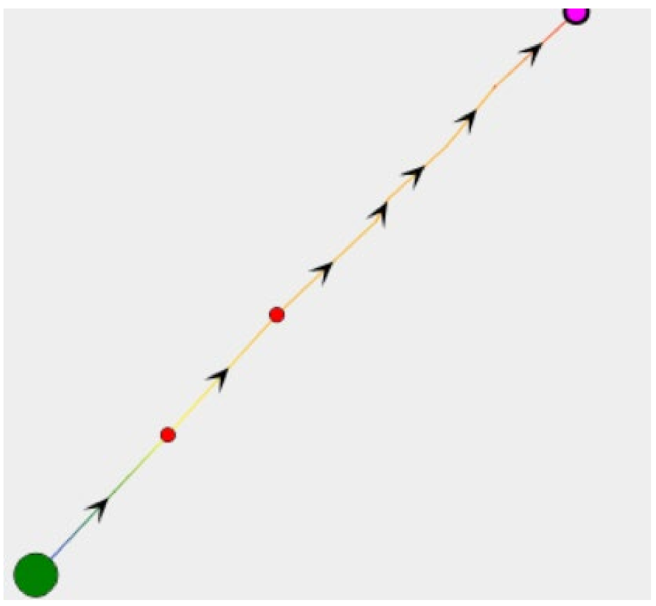
- ❑ Figure (left) shows unmet energy requirements with increased hydrogen blends when volumetric flows at offtake nodes are fixed (for 60 bar-g network)
- ❑ Maintaining constant flow requirements with higher hydrogen blends results in unmet energy requirements
- ❑ Falling energy content / Wobbe index of higher blend levels would thus require higher volumetric flow levels to ensure energy requirements are met
- ❑ The relative energy satisfied delivered for transmission and distribution pressure levels are shown in the figure (right)

Initial system results



Diameter: 600 mm, Inner wall roughness: 0.012 mm

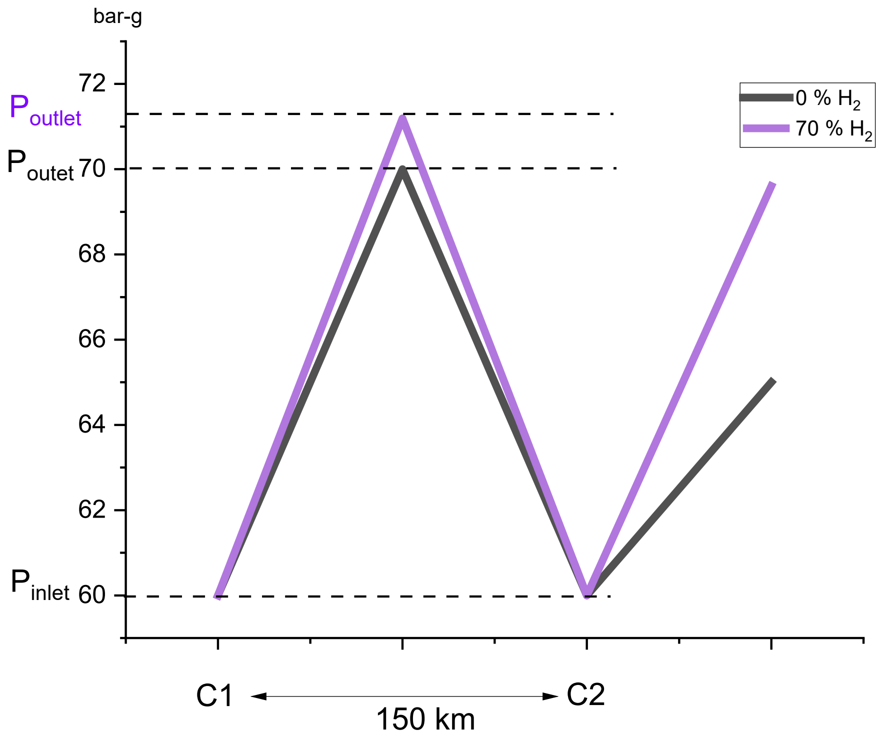
Injection node



Part of pipeline analyzed

- ❑ Allowing flow to follow energy requirements can result in pressure issues if more gas is not injected into the system to compensate
- ❑ As gas travel longer distances, pressure drop increases (*compressor stations are kept in bypass mode)

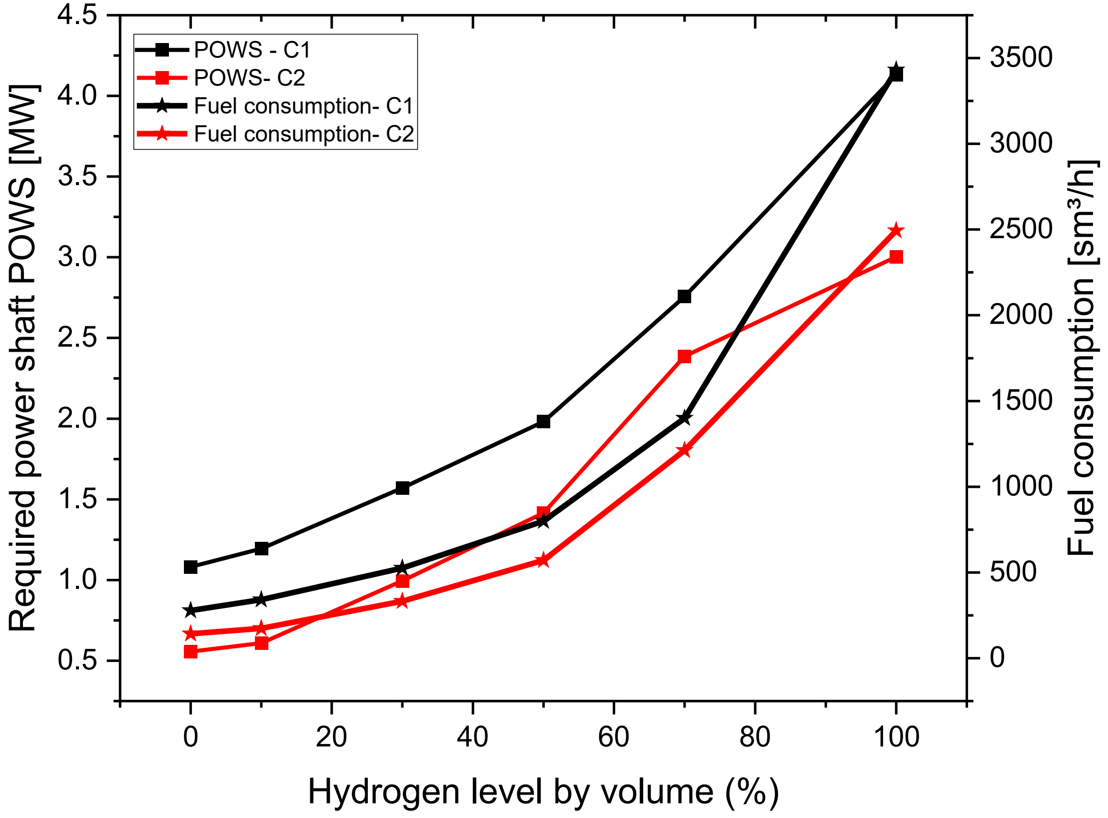
Initial system results



Part of pipeline analyzed

- Compressor stations can maintain the pressure profile of the system.
- Figure represents the schematic representation of the pressure between two compressors.
- The distance between two compressor stations is set 150 km.
- By setting the inlet pressures for each compressor to 60 bar-g, the outlet pressure of compressor 1 can be calculated to provide compressor 2 with 60 bar-g again. The pressure loss is bigger for 70% hydrogen admixture.

Initial system results



- ❑ Figure represents the increase in required power shaft and fuel consumption of compressor 1 and compressor 2 with increasing level of hydrogen injection, while satisfying total energy requirements and keeping the pressure level of the system constant.
- ❑ No additional gas is injected into the grid.

- This project has not been previously reviewed at an AMR

Collaboration and Coordination

Partner	Project role
NREL	Development of the electrolyzer model, co-simulation platform that links SAInt and the electricity system model (i.e., PLEXOS), preparing and conducting overall system analysis, project coordination and updates with partners.
Encoord	Verify that the SAInt model appropriately represents mixtures of natural gas and hydrogen on the gas network.
SoCalGas	Bring knowledge of gas system planning and operations and their progressive thinking with respect to the evolution of the natural gas system.
I-GIT	Bring expertise in infrastructure integrity, supply diversification and safety and environmental impacts along with their collaborations (domestic and international) with related projects and partners. P Provide connections and data with other groups currently pursuing hydrogen methanation and blending in projects around the world.

Remaining Challenges and Barriers

Challenges

Uncertainties in hydrogen blending simulations

- <u>Which hydrogen</u>
  Green, blue, grey etc.
- <u>Production level</u>
  Low, high, varying
- <u>Injection point</u>
  Transmission, distribution, both
- <u>Gas grid properties</u>
  Seasonal variations
  Demand variations
  (Increasing, flat, declining)
- <u>Injection characteristics</u>
  Flat ,dynamic
  One node, distributed
- <u>Technological considerations</u>
  Separation (deblending)
  Reverse flows
- <u>Storage availability</u>
  Limited, high

Remaining Challenges and Barriers

Barriers

- Software capabilities
- Interface Limitations
- Real parameter and data requirements

❑ The modelling framework should correctly capture the uncertainties in order to develop adequate metrics

Proposed Future Work

- ❑ Complete model integration platform:
- ❑ Verify operation of the integration platform
- ❑ Creation of scenarios for simulation.
- ❑ Provide post-processing results for understanding the resulting gas composition across the network, impacts on the thermal generators from a different composition, and the metrics necessary to determine lifetime impacts to the gas network equipment.

Summary

- Modeling framework is proposed to accurately evaluate hydrogen blending and transportation in gas grid.
- The model comprises of;
  - an electrolyzer operation model
  - a gas simulation model to perform steady state and transient simulations for gas quality tracking
  - an electric system model (PLEXOS)
- A test network is developed to represent the real system behavior.
- Gas model is tested to confirm the capability of simulations in case of hydrogen mixed natural gas is supplied.
- High concentrations of hydrogen in gas would results decrease of total energy delivered because of its lower density.
- Satisfying flow requirements would create pressure problems and compressor stations will require more shaft power and fuel in order to maintain the pressure.

Technology Transfer Activities

- Will be including the work through the HyBlend project

Progress toward DOE Targets or Milestones

Milestone	Methodology
Develop an integrated framework to correctly analyze hydrogen transportation through existing gas grid	Data exchange between the electrolyzer model, SAInt gas simulation software, PLEXOS electricity software
Create a test network large enough and have sufficient detail to capture key features of hydrogen blending into the gas system	The test system has three pressure levels, a 60 bar-g high pressure level and a 24bar-g and 15bar-g medium level pressure level. Underground storages, compressor stations, LNG facilities and different type of end users (GFPPs, Industrial users, domestic users) are also included.
Test of the simulators separately	Electrolyzer model and SAInt model is tested and their capabilities are verified.

Publications and Presentations

- A review of technical and regulatory limits for hydrogen blending in natural gas pipelines (to be submitted)