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July 9, 2020

VIA EMAIL and RESS

Ms. Christine Long
Board Secretary
Ontario Energy Board
2300 Yonge Street, 27th Floor
Toronto, ON M4P 1E4

Dear Ms. Long:

Re: Enbridge Gas Inc. (Enbridge Gas)
Ontario Energy Board (OEB) File: EB-2019-0294
Low Carbon Energy Project – Updated Interrogatory Response

Further to the submission made by Enbridge Gas on June 15, 2020, enclosed please find the following updated interrogatory response.

- Exhibit I.H2GO.1, plus Attachment

Please contact the undersigned if you have any questions.

Yours truly,

(Original Digitally Signed)

Stephanie Allman
Regulatory Coordinator

ENBRIDGE GAS INC.
Answer to Interrogatory from
H2GO Canada (H2GO)

INTERROGATORY

Reference:

Exhibit B, Tab 1, Schedule 1, Attachment 1, paras 1, 10-13, 18, 20-21
Exhibit B, Tab 1, Schedule 1, para 4

Preamble:

EGI states that it has conducted a detailed review of the feasibility and recommendations for blending hydrogen into natural gas supply for distribution using existing infrastructure (para 1).

EGI further states that it engaged several consultants in order to complete the analysis and investigation work for hydrogen blending, including a consultant experienced with town-gas applications and a global consulting firm specializing in risk management (para 18).

EGI has concluded that blending hydrogen in a concentration of up to 2% hydrogen is safe and reliable for the LCEP. To define the appropriate hydrogen blending concentration (2%), EGI followed an assessment methodology that included a research and development (R&D) work stream (i.e., literature review) to leverage existing industry knowledge and recommendations from the Canadian Gas Association (**CGA**) / American Gas Association (**AGA**) Task Force on Hydrogen Blending, the HYREADY Consortium, the multi-year European-led NATURALHY technical study and other technical literature (paras 20-21).

EGI's assessment methodology also included a work stream focused on gas distribution network hydrogen tolerance. EGI's investigation into the Blended Gas Closed Loops concluded that 5% hydrogen by volume can be injected (para 24).

Question**:**

Please file copies of any reports, working papers, presentations, datasets, or other materials related to the work performed by the consultant experienced with town-gas applications.

Please file copies of any reports, working papers, presentations, datasets, or other materials related to the work performed by the global consulting firm specializing in risk management.

Please file copies of any reports, working papers, presentations, datasets, or other materials that EGI reviewed in connection with its literature review, including any such materials related to the CGA/AGA Task Force on Hydrogen Blending, the HYREADY Consortium, and the multi-year European-led NATURALHY technical study.

Given that EGI's investigation concluded that up to 5% hydrogen by volume can be injected (para 24), please provide an outline of the reasons why EGI limited both the study and the LCEP to injection of 2% hydrogen by volume. Please file copies of all related reports, working papers, presentations, datasets, or other materials.

Please file a copy of the 2-year engineering assessment recommending 2% hydrogen by volume (Exhibit F, Tab 1, Schedule 1, Attachment 5, p. 3).

Please provide (preferably in table format) EGI's assessments of the potential greenhouse gas (**GHG**) emissions reductions, additional power and gas efficiencies, and costs that may result under each of the following scenarios:

(i) 4% hydrogen by volume and:
   a. 15% enhanced used of natural gas blend as a transportation fuel; and
   b. status quo usage of natural gas and 15% enhanced use of electricity as a transportation fuel.

(ii) 2% hydrogen by volume and:
   a. 15% enhanced used of natural gas blend as a transportation fuel; and
   b. status quo usage of natural gas and 15% enhanced use of electricity as a transportation fuel.

<u>Response:</u>

a) to c) Attachment 1 to this response sets out a literature review report developed by the CGA/AGA. The report contains a summary of findings of a literature review conducted by the CGA/AGA related to hydrogen blending. The CGA has confirmed that this document can be publicly produced.

Enbridge Gas has summarized the findings of its technical review and reports from consultants in Exhibit B, Tab 1, Schedule 1, Attachment 1.

Enbridge Gas has responded to other interrogatories seeking specific additional information about technical aspects of the Project.

Enbridge Gas believes that there is sufficient information on the record related to the safety and technical aspects of the Project.

Other than the CGA/AGA study, Enbridge Gas is not prepared to provide copies of the requested documents (engineering assessment, consultant report, working papers and datasets) for several reasons, including the following.

- The detailed review undertaken by Enbridge Gas (including work by consultants) includes technical information that will be valuable to third parties, including other parties seeking to commercialize hydrogen and/or use hydrogen in gas distribution systems. It is not in the interests of Enbridge Gas and its ratepayers to file such material so that it will be available to these other parties at no cost. That deprives Enbridge Gas and its ratepayers of potential future financial benefit of this material.

- Some of the material requested comes from third party consultants and organizations who have provided the material to Enbridge Gas on a paid basis, and on the understanding that it will not be shared publicly. Those third parties will suffer harm if their work product is provided to the public at no charge.

- The information requested is technical in nature and some of it relates specifically to the portions of the Enbridge Gas distribution system being considered for the Project. The Company is concerned that other parties who access the detailed technical information being requested could mis-interpret of mis-use the information, causing potential safety concerns and potential future exposure to Enbridge Gas.

d) Enbridge Gas's engineering assessment concluded that 2% hydrogen blending is the acceptable limit for the selected injection area. The 5% by volume limit referred to in the question was based on review of the different components in the subject distribution network – when other parts of the review were also taken into account, the conclusion was that 2% blending was the appropriate limit (see

Exhibit B, Tab 1, Schedule 1, Attachment 1, para. 33).

e) Refer to H2GO 1 a) to c).

f) i) to ii)
Set out below are the GHG emission impacts of using hydrogen blending of 2%. Enbridge Gas is not requesting a 4% blending approach. As explained at Exhibit I.STAFF.2, Enbridge Gas has arranged to receive hydrogen for 2% blending at no additional cost versus conventional natural gas. There is no such agreement for the volume of hydrogen required for 4% blending. Enbridge Gas estimates the emission reduction from its LCEP pilot to be in the range of 97 to 120 tCO2e/yr.

No responses are provided for the request to consider the implications of the enhanced use of natural gas and electricity as a transportation fuel, since these are outside the scope of this application.

Blending of Hydrogen into Natural Gas Delivery Systems

American Gas Association

Canadian Gas Association
Association Canadienne du Gaz

Information Summary Report

May 2019

LEGAL NOTICE

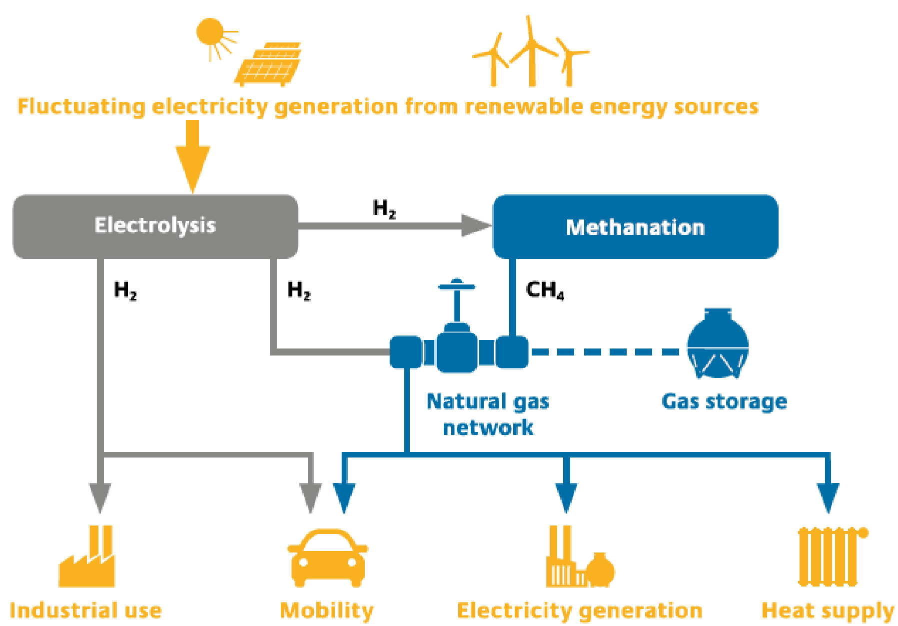
Suggested changes must include: contact information, including name, address and any corporate affiliation; full name of the document; suggested revisions to the text of the document; the rationale for the suggested revisions; and permission to use the suggested revisions in an amended publication of the document.

SUMMARY

A successful transition towards a cleaner and more sustainable energy system in the next decades will require large scale implementation of sustainable and renewable energy sources. Renewable power sources, like wind and solar energy, can mainly be distinguished from conventional fossil-based power sources by their low life cycle carbon emissions and their intermittent character. By introducing intermittent energy sources, the need for overall flexibility in our energy system increases strongly. Multiple solutions exist for providing the required flexibility; one of them is Power-to-Gas (PtG).

Power-to-Gas is the common description of the conversion of electrical energy into chemical energy in the form of hydrogen or methane. The process typically uses water electrolysis, powered from renewable energy sources, to 'split' water molecules (H_2O) to produce hydrogen (H_2) and oxygen (O). Hydrogen can be directly fed into the existing natural gas infrastructure and blended with natural gas. To convert and feed in a greater volume of renewable electricity, methane (synthetic natural gas, SNG) can be produced in a second step using this hydrogen with the addition of carbon dioxide.

This alternative energy concept is currently being piloted in Europe and has the potential to deliver a number of overall societal benefits to North America (Appendix A). These include development of an additional renewable energy supply and reduction in the greenhouse gas emissions profile of natural gas, development of a mechanism to help balance the power system using surplus electricity in off-peak periods and provision of a storage vessel for surplus electricity. Existing gas infrastructure may be leveraged (pipes and gas-powered electricity generating plants) to reduce the need for building additional electrical generation or transmission facilities. It could also help enable the growth of the use of hydrogen powered vehicles.



As part of the United States and Canada's commitment to increase the use of renewable and alternate energy in North America, the AGA's Operations Section Managing Committee and the CGA's Standing Committee on Operations and Safety formed a Task Group to conduct an open-source literature search around the introduction of hydrogen into existing natural gas delivery systems.

General Note

In reading this **Blending of Hydrogen into Natural Gas Delivery Systems, Information Summary Report**, it must be understood that the agree-to scope for the Task Group's work was for 0% to 5% blending of hydrogen into natural gas.

This specific scope limitation was in no way meant to imply that blending rates greater than (>) 5% are not possible or feasible. The CGA & AGA believe that hydrogen blending at >5% is an important consideration for a number of reasons, that will require further, separate study that both organizations will take forward as a possible next step in their combined work around understanding potential sustainable and renewable energy sources.

Summary of Findings from the Literature Search

The body of information found via the literature search was substantial. A key finding was that, due to the complexity of natural gas delivery systems, and the wide variety of the components, materials and equipment, <u>it is not possible to specify a limiting hydrogen value which would be valid for all parts of North American natural gas delivery infrastructure</u>.

And as with every ongoing research subject and initiative, there are gaps in the knowledge, and studies do not always come to the same conclusions. Nonetheless, the information summarized from the literature search suggests that the natural gas delivery system may be able to accommodate blending of hydrogen from 0% to 5% with little effect on the systems being utilized for delivery or the end user.

However, it must be understood that a system-specific analysis will be required for each location where the introduction of hydrogen is being considered, to determine specific hydrogen concentrations that do not pose an unacceptable level of risk to the affected areas of the natural gas system or end-users. In particular, the non-typical end-use equipment within any given natural gas delivery system must be identified and considered individually through a detailed engineering assessment, e.g., dispensing to CNG vehicles, natural gas use as a feedstock, etc.

Each system, code and regulatory framework is different and proposed solutions must be customized accordingly even if an engineering assessment is carried out.

Recommendations

<u>Based on the results of this literature search, the acceptability of hydrogen blending into natural gas streams from 0% to 5% will depend on critical pipeline system components, end-user equipment tolerances and operating considerations.</u> These items, among others, would need to be addressed and documented in an engineering assessment that would examine the safety, integrity and reliability of company-owned and customer-owned assets. The corresponding company would also need to ensure that the blended gas meets its tariff requirements. However, it is in no way a general value, and each organization must consider a number of factors which must be applied on a system-by-system basis, i.e., each specific system must be looked at in the context of the materials it is made up of and the end-users that it serves. It should be noted that there is no one international standard for the percentage blending rate of hydrogen into natural gas delivery systems. Upgrading of components can be considered by the distribution company where it is feasible and practical to do so.

General Considerations

Natural gas infrastructure is rather complex: from the production sites to storage, transmission and distribution pipelines to a wide variety of end-users, there are many types of materials, components and appliances to consider. Blending hydrogen into natural gas requires attention to safety, integrity, reliability and interchangeability, as hydrogen has different properties than methane.

Each organization considering blending hydrogen into natural gas streams should review and understand their own system details. The information gathered may assist each organization in their decision-making processes within their own tolerance parameters concerning hydrogen blending into natural gas streams.

Comparison of Hydrogen & Methane Properties

The basic properties of hydrogen (H_2) are different than those of methane (CH_4), the primary component of natural gas (92% - 96%), as shown in the table below.

Hydrogen is a colourless, odourless[1], tasteless, non-toxic, and non-poisonous gas. It's also non-corrosive, but it can lead to embrittlement in some metals, especially steel alloys. Compared to methane, hydrogen is a very small and light molecule with low viscosity, and thus prone to leakage through porous materials, fittings, and seals. Hydrogen has the lowest density of all gases: it is 8 times less dense than methane.

Due to its low density, hydrogen has a volumetric energy content 3 times lower than methane at standard conditions for temperature and pressure. This means more hydrogen is needed to provide the same energy as methane (by volume). Since hydrogen does not have the same density and volumetric energy content as methane, its Wobbe Number is different. Being that it is an indicator of the interchangeability of fuel gases, it means that a burner rated for natural gas may not function correctly with the addition of hydrogen.

Hydrogen has a broader flammability range than methane, and under the optimal combustion conditions (e.g., stoichiometric conditions: a 29% hydrogen-to-air or a 9% methane-to-air volume ratio), the energy required to initiate hydrogen combustion is much lower (e.g., a small spark will ignite it). The flame speed of hydrogen is also far greater than that of methane (8 times), meaning the flame propagation in a hydrogen-air mixture is much quicker. For these reasons, hydrogen is a much more flammable gas than methane. However, it should be noted that the auto-ignition temperatures[3] of hydrogen and methane are very similar.

[1] Methane is also odourless, but industry adds a sulfur-containing odorant to natural gas for safety reasons, so that people can detect it by smell.

Comparison between the properties of hydrogen and methane as the principal constituent of natural gas

Item	Methane	Hydrogen
Chemical Formula	CH_4	H_2
Molecular Size[1]	416 pm (isotropic molecule)	340 pm / 304 pm (anisotropic molecule)
Molar Mass[2]	16.043 g/mol	2.016 g/mol
Specific Gravity[2]	0.5548	0.0695
Density[2]	0.6787 kg/m³ 0.0424 lb/ft³	0.0851 kg/m³ 0.0053 lb/ft³
Higher Calorific Value (HHV)[2]	37.7 MJ/m³ 1,013 BTU/ft³	12.1 MJ/m³ 325 BTU/ft³
Wobbe Number (WN)[2]	50.6 MJ/m³ 1,359 BTU/ft³	45.9 MJ/m³ 1,231 BTU/ft³
Lower Explosive Limit (LEL)	5 %	4 %
Upper Explosive Limit (UEL)	15 %	75 %
Minimum Ignition Energy (MIE) at Stoichiometric Ratio	0.300 mJ 0.284 µBTU	0.017 mJ 0.002 µBTU
Auto-ignition Temperature	600 °C 1,112 °F	560 °C 1,040 °F
Flame Speed	0.43 m/s 1.41 ft/s	3.46 m/s 11.35 ft/s
Boiling Point	-161.5 °C -258.7 °F	-252.8 °C -423.2 °F
Products of Combustion	Carbon Dioxide (CO_2) Water Vapour (H_2O)	Water Vapour (H_2O)

All properties given at standard conditions for temperature and pressure (15.6°C and 101.4 kPa or 60°F and 14.7 psia)

1 Molecular size based on the Van der Walls radius of the molecule.

2 Value of properties calculated in accordance to standard ISO 6976 with NGTC's Interchangeability Calculator.

General Energy Delivery System Considerations

- Safety & Integrity;
- Load-balancing;
- Transmission & Distribution;
- End-Users:
  - Interchangeability;
  - Residential & Commercial;
  - Industrial (equipment and feedstock);
  - Transportation.

Higher Heating Value (HHV) & Wobbe Number

The HHV seems the most obvious property to consider when looking at the interchangeability of gases, however, it only provides a crude indication; the Wobbe Number was defined to give more accurate information. The definition of the Wobbe Number is based on the HVV and specific gravity of a gas and it is related to the thermal input to a burner (BTU per hour). The usefulness of the Wobbe Number is that for any given orifice, all gas mixtures that have the same Wobbe Number will deliver the same amount of heat.

Given that hydrogen's HVV and Wobbe Number are lower than methane's, the addition of hydrogen to natural gas produces a blend with a reduced HHV and Wobbe Number; in other terms, the energy content decreases with higher percentages of hydrogen. However, the decrease is much more significant for the HHV than the Wobbe Number, which suggests that this property would become limiting first (see table below).

Impact of blending hydrogen into methane on the Higher Heating Value and the Wobbe Number

Blend	Higher Heating Value (HHV)		Wobbe Number	
100 % Methane	37.7 MJ/m^3 1,013 BTU/ft^3	-	50.6 MJ/m^3 1,359 BTU/ft^3	-
99 % Methane / 1 % Hydrogen	37.5 MJ/m^3 1,006 BTU/ft^3	- 0.7 %	50.5 MJ/m^3 1,356 BTU/ft^3	- 0.2 %
98 % Methane / 2 % Hydrogen	37.2 MJ/m^3 999 BTU/ft^3	- 1.4 %	50.4 MJ/m^3 1,353 BTU/ft^3	- 0.4 %
95 % Methane / 5 % Hydrogen	36.4 MJ/m^3 978 BTU/ft^3	- 3.5 %	50.0 MJ/m^3 1,343 BTU/ft^3	- 1.2 %

All properties given at standard conditions for temperature and pressure (15.6°C and 101.4 kPa or 60°F and 14.7 psia).
Value of properties calculated in accordance to standard ISO 6976 with NGTC's Interchangeability Calculator

It should be noted that while Wobbe is an effective, easy to use screening tool for interchangeability, the industry historically recognizes that the Wobbe Number alone is also not sufficient to completely predict gas interchangeability because it does not adequately predict all combustion phenomena. The same thing can be said about the HHV.

Specific Blending Rate Admissibility Considerations

The specific blending rates and the accompanying information in this Information Summary Report are intended for use by each organization in their decision-making processes within their own risk tolerance parameters concerning hydrogen introduction into natural gas streams. Given the complexity of natural gas delivery systems, this Information Summary Report is an overview focusing on larger issues and is not intended to be an exhaustive investigation.

There are any number of suggestions about what percentage of hydrogen in natural gas streams should be considered. The GERG study states that it is not currently possible to specify a limiting hydrogen value which would generally be valid for all parts of the European gas infrastructure, and a case-by-case analysis is therefore recommended.

For this Information Summary Report, the PtG TG did decide to limit the consideration of blending hydrogen into natural gas streams to 0% to 5 %. This was chosen for three reasons:

- There is a greater body of research and analysis work, primarily European, for blending rates of under 5% leaving less uncertainty and fewer potential operating concerns.
- Under 5% hydrogen, the literature reviewed seems to indicate there is little impact on the Wobbe Number, thereby having little impact on end-use.
- Typical natural gas tariff specifications on the higher heating value support a hydrogen content of 5%.

The specific percentage blending information obtained from the literature search has been summarized into specific groupings in the tables below:

- General Knowledge Points;
- Areas where no H_2 Blending into NG streams have been addressed;
- H_2 Blending into NG streams at less than or equal to (≤) 1%;
- H_2 Blending into NG streams at less than or equal to (≤) 2%;
- H_2 Blending into NG streams at less than or equal to (≤) 5%.

Each percentage level of hydrogen blending into natural gas streams identifies potential risks/areas of concern and what actions could be considered.

Blending of H_2 in NG, General Knowledge

Specifics	Areas of Focus	Potential Impacts	Comments
Blending of H_2 in NG **General Knowledge Points**	Safety – Fire and Explosion Risks	Hydrogen has a broader range of conditions under which it will ignite.	Results indicate that mixtures of 0% to 5% hydrogen in natural gas unlikely to present a significantly greater issue in practical situations.
	Integrity – Hydrogen Embrittlement and Durability of Metal Pipes	The durability of high-strength metal pipes can degrade when exposed to hydrogen over long periods, particularly with hydrogen in high concentrations and at high pressures.	Existing studies have concluded that concentrations of hydrogen at 0% to 5% do no cause any issues for metal pipes.
	Integrity – Permeability of Hydrogen Through Metal and Plastic Pipes	The hydrogen permeation coefficient in plastic piping is 4-7 times higher than that of methane.	Leakage rates from permeation are insignificant from a safety point of view. Existing studies have concluded that concentrations of hydrogen at 0% to 5% do not cause any issues.
	Integrity – Leakage	Leakage rates through joints in steel pipes for hydrogen are about three times higher than that for natural gas.	At o% to 5% of hydrogen, leakage is negligible in gas distribution pipework systems.
	Gas Meters	Volumetric gas meters will record quantities of either methane or methane/hydrogen mixtures with almost equal accuracy. Mass flow meters are not affected.	Calibration and approval from Federal Authorities (e.g. Measurement Canada) may be needed.
	Pressure Reduction Stations	Pressure reduction stations are not affected by the addition of hydrogen, as it pertains to temperature effects.	Temperature increases with hydrogen as it expands and this increase will depend upon percentage of hydrogen.

Blending of H_2 in NG, General Knowledge

Specifics	Areas of Focus	Potential Impacts	Comments
Blending of H_2 in NG General Knowledge Points	Odorization	There seems to be no chemical incompatibility issues of notes between hydrogen and the odorizing compounds commonly used in natural gas. However, the literature reviewed does not state clearly why odorants are non-reactive with hydrogen.	Most odorants contain sulphur, and hydrogen is often used in chemical processes which would be adversely affected by the presence of sulphur compounds. If the natural gas-hydrogen blend is to be used as a hydrogen feedstock, sulphur-containing odorants will need to be removed prior to use.
	Interchangeability: Impacts on Higher Heating Value and Wobbe Number	A mixture of hydrogen with natural gas will decrease the higher heating value and the Wobbe Number.	Based on sample tariffs, 5% hydrogen could be added while still respecting the specifications for the HHV, and Wobbe Number.
	Interchangeability: Other Impacts	The addition of hydrogen also increases flashback and lifting, reduces yellow tipping and creates a more complete combustion.	
	Impact on End-use Systems	Effects of hydrogen addition on end-use systems are variable due to the wide range of existing equipment. Some might tolerate high hydrogen blends while for others, no hydrogen blends would be acceptable. How well the equipment is adjusted will also have an impact on the hydrogen content it could tolerate.	A case-by-case approach is preferable.

Blending of H_2 in NG, Points Not Addressed

Specifics	Areas of Focus	Potential Impacts	Comments
Blending of H_2 in NG **Points not addressed**	Underground Gas Storage (UGS)	Hydrogen addition could have an impact on the tightness of the cap rock, both for porous reservoirs and salt caverns. In porous reservoirs, there is also the potential for bacterial growth. Hydrogen is a good substrate for sulfate-reducing and sulphur reducing bacteria. The associated issues are principally loss of gas volume and disappearance of injected hydrogen, as well as potential damage to the cavity itself, and production of H_2S (poisonous, corrosive, and flammable).	The geology, operating pressure and temperature will differ according to reservoir and therefore the degree to which hydrogen addition may be problematic will also differ. The suitability of UGS should be carefully assessed on an individual basis. It is worth noting that hydrogen storage within caverns or porous reservoirs is exercised in specific locations within Europe and the US, but there is a lack of information on the subject.
	Natural Gas Liquefaction Plants	Hydrogen is a non-condensable gas and will therefore pass through an LNG liquefaction system, adding a non-productive load on the compressors and ultimately degassing in the LNG tanks.	No publicly available information concerning the impact of hydrogen addition on LNG facilities was found in the literature review. Further research is needed.
	Gas Metering	The addition of hydrogen changes the properties of the gas. Thus, it has an effect on volume measurement, gas composition analysis, metering and measurement of calorific value.	Federal Government approval might be required.
	Compressor Stations – Equipment Other Than Compressors	In addition to compressors, compressor stations include other equipment such as gas cooling systems.	No information was found about potential issues with the addition of hydrogen for this equipment.

Blending of H_2 in NG at ≤ 1%

Specifics	Areas of Focus	Potential Impacts	Comments
Blending of H_2 in NG at ≤ 1%	Gas Chromatographs	Chromatographs are unable to detect hydrogen.	Only low levels of hydrogen are acceptable for now, but chromatographs could be retrofitted to measure hydrogen.
	End-users – Industrial Combustion Equipment	The consequences of mixing hydrogen with natural gas for industrial combustion applications should be considered case by case. Compared to domestic or commercial equipment, industrial equipment usually has stricter fuel specifications, and therefore narrower tolerances for fuel composition variations.	
	End-users – Gas Turbines	Most of the currently installed gas turbines are specified for a 1 % blend of hydrogen in natural gas. Even very low fractions of hydrogen to natural gas could cause issues due to low tolerances to gas composition variation, including increasing NOx emissions.	Up to 5% may be attainable with tuning or modification measures. Current fuel specifications for many gas turbines place a limit on the hydrogen content in natural gas below 5 %.
	End-users – Feedstock	Effects of hydrogen addition are dependent on the process involved.	Action is needed in order to identify sensitive processes and mitigation measures.

Blending of H_2 in NG at ≤ 2%

Specifics	Areas of Focus	Potential Impacts	Comments
Blending of H_2 in NG at ≤ 2%	End-users – Stationary Reciprocating Gas Engines	Addition of hydrogen reduces the Methane Number of the fuel and increases knocking in engines. It can also increase NOx emissions.	Existing studies have concluded that 2-5 % hydrogen addition could be acceptable for engines. Pending further study, caution suggests setting the limit at the lower end of the study's results, i.e., 2 %.
	Transportation – Steel Tanks in CNG Vehicles	A maximum limit of 2 % hydrogen in CNG as a fuel is set for tank cylinders that are manufactured from steel with an ultimate tensile strength exceeding 950 MPa (137,800 psi), which is usually the case of type 1 and 2 tanks.	Type 3 or 4 tanks for on-board storage are technologically mature and used in fuel cell hydrogen electric vehicles, as well as in some models of CNG vehicles.

Blending of H_2 in NG at ≤ 5%

Specifics	Areas of Focus	Potential Impacts	Comments
Blending of H_2 in NG at ≤ 5%	Safety – Leak Detection	FID & DIAL devices are not sensitive to hydrogen and will give an inaccurate response due to the diluting effect of addition of H_2.	In terms of accuracy, use of FID and DIAL devices could be acceptable in situations with hydrogen blends up to 5 %, but it needs further investigation.
	Compressors	Centrifugal compressors are affected by hydrogen's higher volumetric flow rate: either the rotational velocity would have to be increased or a higher number of compression stages would be required.	At 0% to 5% of hydrogen, the effects are expected to be minor, but further investigations should be performed.
	End-users – Residential & Commercial	Available studies show that the current appliances can handle the addition of 5 % to 28 % hydrogen if they are properly serviced and adjusted.	Due to the wide range of hydrogen limits recommended in the studies, and the wide variety of existing appliances, caution suggests setting the limit, pending further study, at the lower end of the studies' results, i.e., 0% to 5%.
	Transportation – Engines in CNG Vehicles	The impact of hydrogen mixture for natural gas vehicle engines is similar to stationary engines, but vehicle engines do not suffer the same knock problems since they are not tuned to optimum efficiency and can therefore tolerate higher hydrogen blends. However, due to hydrogen's lower energy content, the vehicle range will be reduced.	Since the literature on the subject is limited, caution suggests setting the limit lower, ≤5%.
	Transportation – Refuelling Stations	CNG dispensers rely on mass-based flow meters for proper fill level (temperature compensation) and retail sale.	Need for "smart" dispenser controls and/or communications.

APPENDIX A. POTENTIAL BENEFITS OF BLENDING H_2 IN NATURAL GAS STREAMS

The Rational for Power-to-Gas

- Grid-scale storage is needed to support rapidly expanding intermittent renewable power sources such as solar and wind energy, i.e., balancing of the electric grid and making use of excess power in off-peak periods.
- Existing natural gas grid infrastructure can be leveraged to support renewable power development and to stabilize the power grid, by using natural gas piping systems as energy storage vessels for (renewable) electricity both short-term and seasonal.

General Societal Benefits

- Expanded use of natural gas piping systems as delivery vessels for renewable energy, e.g., biomethane, hydrogen, syngas, solar fuels, etc.
- Decarbonizing heat/reducing greenhouse gas (GHG) emissions.
- Enabling the growth of hydrogen powered transportation adoptions.
- Production of gas or chemicals from renewable sources as feedstock for industry and mobility.
- Paving the way for methanation, the production of synthetic methane from hydrogen and carbon dioxide.

Benefits for the Gas Industry

- Ongoing knowledge development for the future optimization of the gas network.
- Regulatory Compliance, e.g., potential regulation around renewable energy content and emissions.
- Environmental stewardship; assisting the natural gas delivery industry in pursuit of its aspirational goals for renewable energy content within natural gas streams.