

# Blending of Hydrogen into Natural Gas Delivery Systems



## Information Summary Report

May 2019

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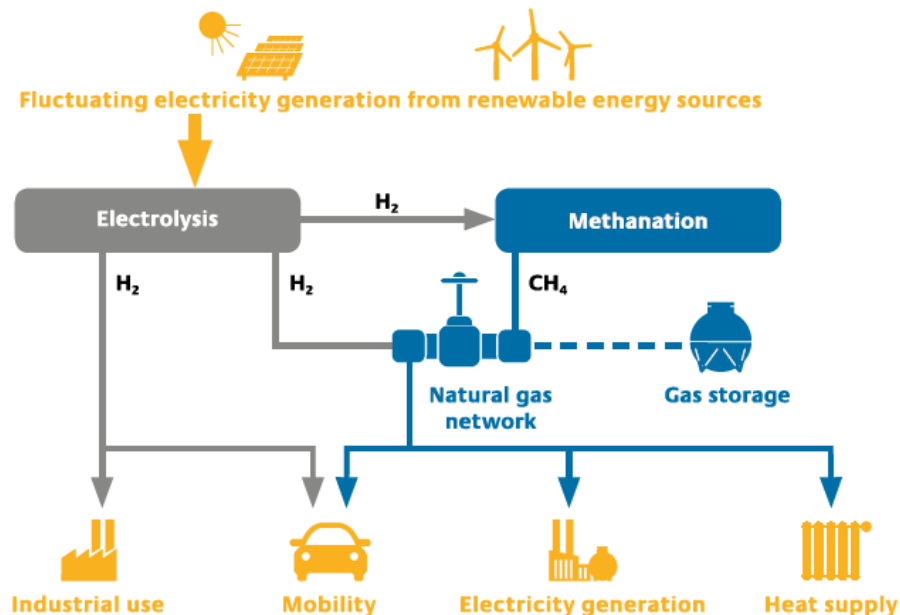
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## SUMMARY

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, it is not possible to specify a limiting hydrogen value which would be valid for all parts of North American natural gas delivery infrastructure.

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

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. 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<sup>1</sup>, 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<sup>3</sup> of hydrogen and methane are very similar.

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<sup>1</sup> 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 <sub>4</sub>	H <sub>2</sub>
Molecular Size <sup>1</sup>	416 pm (isotropic molecule)	340 pm / 304 pm (anisotropic molecule)
Molar Mass <sup>2</sup>	16.043 g/mol	2.016 g/mol
Specific Gravity <sup>2</sup>	0.5548	0.0695
Density <sup>2</sup>	0.6787 kg/m <sup>3</sup> 0.0424 lb/ft <sup>3</sup>	0.0851 kg/m <sup>3</sup> 0.0053 lb/ft <sup>3</sup>
Higher Calorific Value (HHV) <sup>2</sup>	37.7 MJ/m <sup>3</sup> 1,013 BTU/ft <sup>3</sup>	12.1 MJ/m <sup>3</sup> 325 BTU/ft <sup>3</sup>
Wobbe Number (WN) <sup>2</sup>	50.6 MJ/m <sup>3</sup> 1,359 BTU/ft <sup>3</sup>	45.9 MJ/m <sup>3</sup> 1,231 BTU/ft <sup>3</sup>
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 <sub>2</sub> ) Water Vapour (H <sub>2</sub> O)	Water Vapour (H <sub>2</sub> O)

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 Waals 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 HHV 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 HHV 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	
	MJ/m <sup>3</sup>	BTU/ft <sup>3</sup>	MJ/m <sup>3</sup>	BTU/ft <sup>3</sup>
100 % Methane	37.7 MJ/m <sup>3</sup>	1,013 BTU/ft <sup>3</sup>	50.6 MJ/m <sup>3</sup>	1,359 BTU/ft <sup>3</sup>
99 % Methane / 1 % Hydrogen	37.5 MJ/m <sup>3</sup>	1,006 BTU/ft <sup>3</sup>	50.5 MJ/m <sup>3</sup>	1,356 BTU/ft <sup>3</sup>
98 % Methane / 2 % Hydrogen	37.2 MJ/m <sup>3</sup>	999 BTU/ft <sup>3</sup>	50.4 MJ/m <sup>3</sup>	1,353 BTU/ft <sup>3</sup>
95 % Methane / 5 % Hydrogen	36.4 MJ/m <sup>3</sup>	978 BTU/ft <sup>3</sup>	50.0 MJ/m <sup>3</sup>	1,343 BTU/ft <sup>3</sup>

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<sub>2</sub> Blending into NG streams have been addressed;
- H<sub>2</sub> Blending into NG streams at less than or equal to ( $\leq$ ) 1%;
- H<sub>2</sub> Blending into NG streams at less than or equal to ( $\leq$ ) 2%;
- H<sub>2</sub> Blending into NG streams at less than or equal to ( $\leq$ ) 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<sub>2</sub> in NG, General Knowledge

Specifics	Areas of Focus	Potential Impacts	Comments
<b>Blending of H<sub>2</sub> in NG</b>  <b>General Knowledge Points</b>	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 not 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 0% 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<sub>2</sub> in NG, General Knowledge

Specifics	Areas of Focus	Potential Impacts	Comments
<b>Blending of H<sub>2</sub> in NG</b>  <b>General Knowledge Points</b>	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<sub>2</sub> in NG, Points Not Addressed

Specifics	Areas of Focus	Potential Impacts	Comments
<b>Blending of H<sub>2</sub> in NG</b>  <b>Points not addressed</b>	Underground Gas Storage (UGS)	<p>Hydrogen addition could have an impact on the tightness of the cap rock, both for porous reservoirs and salt caverns.</p> <p>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<sub>2</sub>S (poisonous, corrosive, and flammable).</p>	<p>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.</p> <p>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.</p>
	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<sub>2</sub> in NG at ≤ 1%**

Specifics	Areas of Focus	Potential Impacts	Comments
<b>Blending of H<sub>2</sub> in NG at ≤ 1%</b>	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<sub>2</sub> in NG at ≤ 2%**

Specifics	Areas of Focus	Potential Impacts	Comments
<b>Blending of H<sub>2</sub> in NG at ≤ 2%</b>	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<sub>2</sub> in NG at ≤ 5%**

Specifics	Areas of Focus	Potential Impacts	Comments
<b>Blending of H<sub>2</sub> in NG at ≤ 5%</b>	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 <sub>2</sub> .	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<sub>2</sub> 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.