LOW CARBON ENERGY PROJECT – HYDROGEN BLENDING

Introduction

1. In preparation and support for the Low Carbon Energy Project (LCEP or the Project), Enbridge Gas Inc. (Enbridge Gas or the Company) has conducted a detailed review of feasibility and recommendations for blending hydrogen into natural gas supply for distribution using existing infrastructure. This evidence summarizes the work that has been completed, and the recommendations made.

2. As described, Power-to-Gas (PtG) uses electricity from the grid to electrolyze water and produce hydrogen (H_2 gas). The hydrogen produced by PtG can then be blended with natural gas and used as a source of energy. The addition of hydrogen to natural gas will lower the total carbon content of natural gas delivered to end-users, thereby reducing greenhouse gas (GHG) emissions.

3. Initial feasibility discussions on blending hydrogen into existing natural gas infrastructure identified several technical constraints and unknowns. These constraints and unknowns mainly focused on the impact to existing gas distribution infrastructure and customer-owned appliances and systems.

4. This evidence provides details on Enbridge Gas's analysis and investigation findings related to hydrogen blending. The main purpose of the analysis and investigation work was to determine a suitable level of hydrogen that may be injected into natural gas and where, in an existing Enbridge Gas network, that injection could occur.

5. Enbridge Gas has concluded that a closed loop within its distribution network is suitable for hydrogen blending. The analyses leading to these conclusions were

based on literature reviews, analytical modeling, risk assessments, field surveys, industry consultation (e.g., external consultants, internal subject matter experts, manufacturers, etc.), integrity considerations and engineering judgement. Any recommendations resulting from this work were based on validation against existing operational and design practices to identify and track potential gaps and/or incompatibilities in order to facilitate the effective implementation into Enbridge Gas's Operations.

6. As described herein, Enbridge Gas's conclusion is to recommend hydrogen blending at a concentration of up to 2.0% by volume in the identified closed loop system in Markham, Ontario (starting with the area identified in Exhibit B, Tab 1, Schedule 1 as the "Blended Gas Area" or BGA).

Background

7. The key benefit from hydrogen blending is emissions reductions. Where hydrogen blending is used, carbon emissions are expected to be reduced by the net change in the carbon content of the fuel. However, due to the lower energy content contained by pure hydrogen on a volumetric basis, for the same amount of gas, more volume must be used overall. This partially offsets the emissions reduction caused by the addition of hydrogen.

8. European research institutions and utilities have been looking at hydrogen as an alternative to traditional fossil fuels for about 20 years. NATURALHY, for example, is a research consortium that completed work over a time span of 5 years. The objective of the NATURALHY study was "Preparing for the hydrogen economy by identifying and removing the potential barriers regarding the introduction of hydrogen into society, using the existing natural gas system as a catalyst".

Worldwide Hydrogen Blending Projects

9. Hydrogen blending has been employed in other locations, namely Europe, but no utility scale projects have been completed in North America. The list of projects in Table 1, although not exhaustive, highlights some of the main projects identified by Enbridge Gas along with a short description for each. Other projects exist or are in the planning stages. Any blend fractions referenced in Table 1 are all percentages by volume.

Table 1: International Hydrogen Blending Projects

Name	Description	Source
The GRHYD demonstration project (France)	Natural Gas Vehicle (NGV) Bus Fueling Station, 50 buses to run with a natural gas-hydrogen mixture, starting at 6%-20% by volume hydrogen New residential neighbourhood of around 200 homes at 6%-20% by volume hydrogen	(ENGIE, 2019)
Mainz (Germany)	DVGW[1] standards allow up to 10% by volume hydrogen in natural gas networks in Germany	(Energiepark Mainz, 2019)
HyDeploy (UK)	Keele University trial, up to 20% by volume hydrogen injected on campus (130 customers)	(HyDeploy, 2019)
University of California Irvine (US)	Customer piping, privately-owned, sponsored by SoCalGas	(University of California Irvine (UCI), 2016)
H21 – Leeds + Northern Gas Networks (UK)	Hydrogen produced from methane using Steam Methane Reformation (SMR) and Carbon Capture and Sequestration (CCS) Proposal is that appliance replacement and network modifications are all at cost of customers	(Northern Gas Networks, 2019)

[1] The Deutscher Verein des Gas- und Wasserfaches (DVGW) is a German association for gas and water standards similar to the CSA in Canada.

Basis of Evaluation

10. Enbridge Gas conducted literature reviews, field surveys, and record searches in order to establish an appropriate level of knowledge on the topic of hydrogen blending. The key research items are summarized below.

Canadian Gas Association (CGA)/ American Gas Association (AGA) Task Force

11. Enbridge Gas is part of a CGA/AGA Hydrogen Blending Task Force. The CGA/AGA task force undertook a literature search of publicly available data that aimed at understanding the impacts of adding hydrogen to natural gas. This work did not endeavour to specify limiting a hydrogen injection value which would be valid for all parts of the natural gas infrastructure. The Task Force concluded that each individual component or system must be assessed in order to evaluate its compatibility with hydrogen.

HYREADY Project

12. The HYREADY Project is a collaborative industry effort to provide engineering guidelines for the assessment of existing natural gas systems and their suitability for mixtures of hydrogen and natural gas. It includes organizations involved in the CGA/AGA task force as well as European utilities. The HYREADY Project's objective is to issue a comprehensive set of engineering guidance documents and guidelines on how to determine an appropriate level of hydrogen blending based on existing infrastructure. Legacy EGD contributed to the HYDREADY engineering guidelines and Enbridge Gas is following these guidelines for this Project.

Literature Review

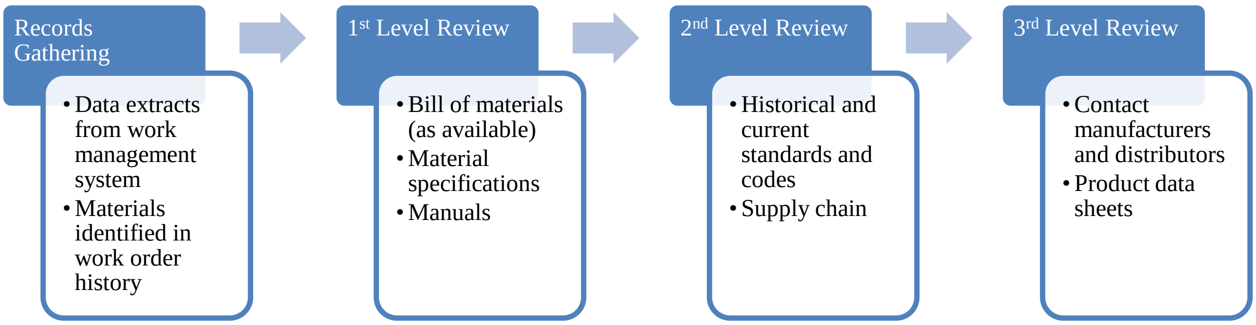
13. NATURALHY and other technical literature were utilized to further support and supplement findings. To supplement the work completed as part of the above initiatives, technical papers, periodicals and articles were reviewed by Enbridge Gas to build and improve its technical understanding of hydrogen blending. The results of the review allowed for the identification of a preliminary percentage by volume hydrogen that could be supplied to the distribution network. This conclusion served as an initial baseline for the development of subsequent research.

Company Records

14. As described below, Enbridge Gas conducted an evaluation process to identify potential networks in its distribution system that are suitable for hydrogen blending.

15. Once the most suitable candidate (closed loop) was identified, company records were gathered in order to gain an understanding of the components in the specific area of study. Figure 1 shows the approach used to obtain the necessary information; each subsequent level resulted in increased records completeness and reliability.

Figure 1: Records Investigation Approach



16. The following activities were undertaken as part of the records investigation.

Records Gathering

- List of assets and customers in selected areas
- Data extract of the mains, services and stations within these loops. This included: main valves, regulators and meters for customers, as well as materials attached to the work orders (WO) completed in these loops

1st Level Review

- A list of currently approved distribution components was created

2nd Level Review

- Company manuals, dating back to the earliest installation dates for the assets within these loops, were reviewed to create a list of all available materials that may have been installed in the distribution system; this provided a conservative approach since all possible combinations were assessed for compatibility

- Listed all known manufacturers and distributors for the distribution components to facilitate the collection of additional information about the products; the approved materials list did not specify the manufacturer for most components

3rd Level Review

- The manufacturers and distributors were contacted for feedback about their products' suitability with hydrogen
- The product data sheets were reviewed to create a list of materials of construction which were compared with available literature to determine their compatibility with hydrogen

Field Survey of Customers

17. In order to get an accurate sample of the appliances that appear in the selected loops, onsite surveys of customer equipment were performed. Information on 341 commercial appliances and 1,305 residential appliances were gathered and assessed individually. Surveys captured a representative sample of the overall population, the combined confidence interval achieved was 90% with a 5% error. A census was completed for the commercial customers in loop S1. This was found to be acceptable considering the consistent data gathered from these surveys.

Consultant Reports

18. In order to complete the analysis and investigation work for hydrogen blending several consultants were engaged. The major items reviewed and addressed by them are as follows:
    - Consultant experienced with town-gas applications (i.e., high hydrogen content manufactured gas), hydrogen blending and PtG, who completed:

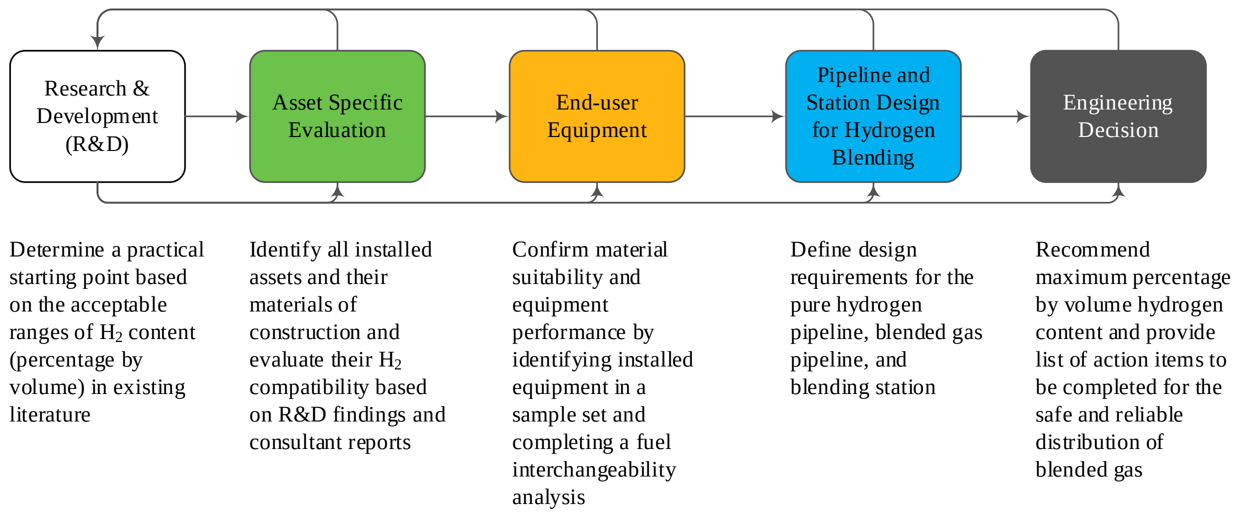
i. Line by line review of available distribution system components to evaluate the hydrogen compatibility of existing pipes, meters, stations and other components in the selected closed loops
ii. Line by line review of surveyed appliances and customer piping components
iii. Comparison of Codes and Standards
iv. Dispersion Modelling and Safety Review

- Global consulting firm specializing in risk management who completed:
  i. An interchangeability analysis in order to keep the blended gas within the range of acceptable, established parameters of natural gas combustion
  ii. Quantitative Risk Assessment (QRA) of gas-fired equipment and appliances into the changes in risk associated with blending hydrogen into natural gas

Assessment Methodology

19. In order to define the appropriate hydrogen blending concentration, Enbridge Gas followed the assessment methodology presented in Figure 3.

Figure 2: Methodology for Determining Hydrogen Blending Suitability



20. This methodology conducted an extensive evaluation under the following interdependent work streams:

- *Research & Development (R&D),* which comprised an internal literature review, the HYREADY Project and the Canadian Gas Association/American Gas Association (CGA/AGA) Hydrogen Blending Task Force;
- *Gas Distribution Network Hydrogen Tolerance*, specifically for Company-owned assets in the distribution system;
- *End-user Equipment*, for customer-owned appliances and piping systems;
- *Pipeline and Blending Station Preliminary Design and Guidelines*; and
- *Qualitative and Quantitative Risk Assessment* work.

Details of each work stream are set out below.

A. Research & Development (R&D)

21. As already described, the objective of the R&D stream was to leverage existing industry knowledge and recommendations from the CGA/AGA Task Force on Hydrogen Blending, the HYREADY Consortium, the multi-year European-led NATURALHY technical study and other technical literature. This information was gathered in order to inform subsequent work streams on which levels of hydrogen blending should be considered and served as information to orient the further investigation required. Among other things it served to provide a baseline range of hydrogen blending values that may be technically feasible. It also identified the key issues and challenges that must be addressed at a network specific level.

B. Gas Distribution Network Hydrogen Tolerance

22. Building on the knowledge from the R&D Stream, the objective of the Gas Distribution Network Hydrogen Tolerance stream was to select the location of blending within the Enbridge Gas distribution network and define the corresponding hydrogen concentration tolerance. Enbridge Gas identified closed loop candidates that needed to be capable of being easily isolated and modified for the purpose of blending. This study yielded eight macro loop systems requiring further evaluation.

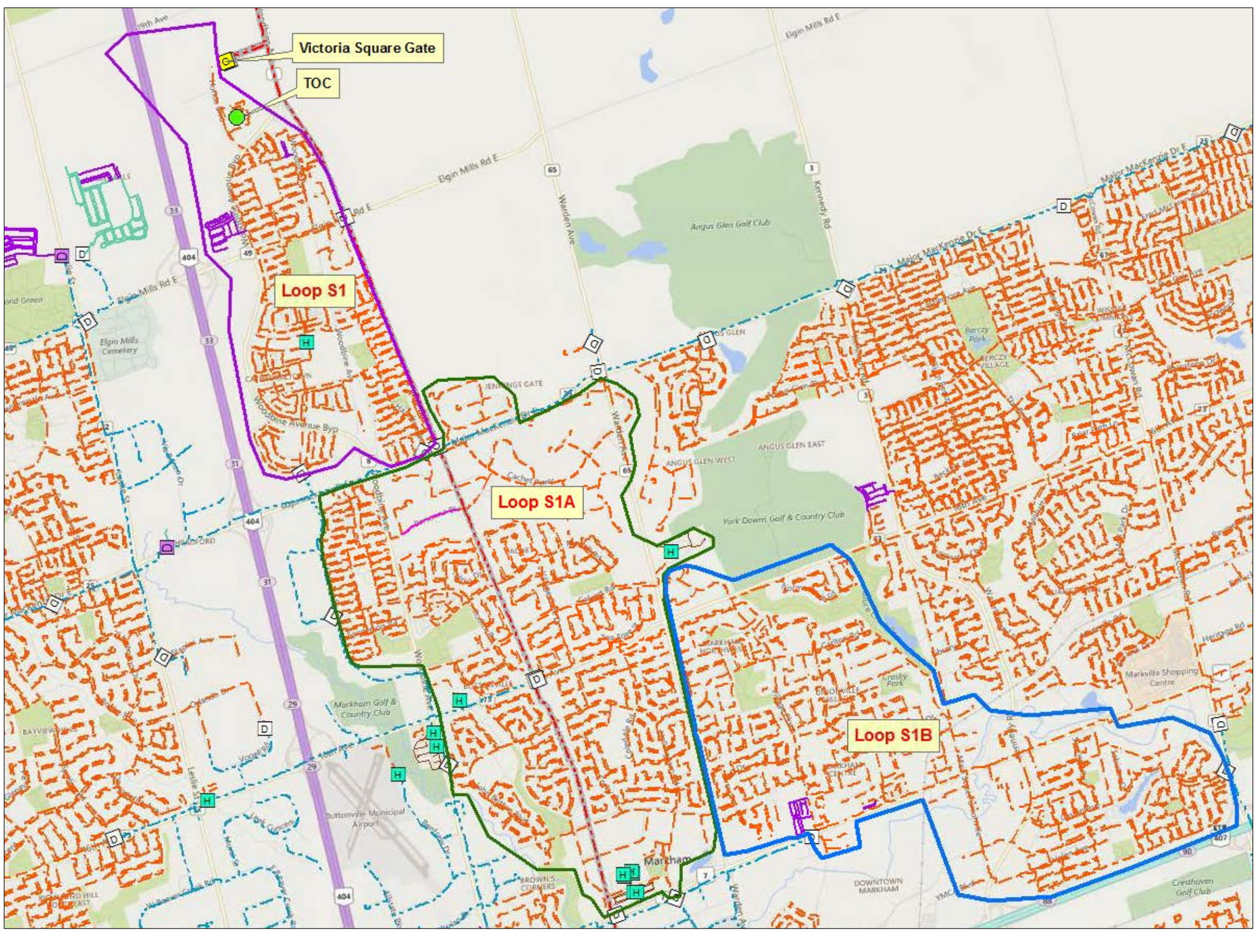
23. An evaluation matrix consisting of the criteria in Table 2 was used to rank their suitability for hydrogen blending. From this investigation, it was determined that Loop 1, the macro loop immediately adjacent to the Technology and Operations Centre (TOC) production facility, was the most suitable candidate based on the information collected. The existing gas distribution network that will be modified into a closed loop system and supplied with blended gas is shown in Figure 4. Distribution components that were evaluated in this work stream include all gas-containing assets downstream of the gate station up to the customer meter set.

Table 2: Initial Criteria for Selection of Closed Loop Systems

Name	Reasoning/Methodology
Number of Customers	Selection of a reasonable number of customers and a distribution network that could be assessed in a timely fashion.
Number of Industrial Customers	Industrial customers are much more sensitive to variations in their fuel, and therefore would not be suitable for the first phase of hydrogen blending.
Number of District Stations	Initially envisioned separate blending stations at various district stations. More district stations would have required many blending stations. As the project evolved and more knowledge became available to the project team (technical and regulatory), this criterion was discarded. This option also required pure hydrogen pipelines in the public right-of-way (ROW).
Natural Gas Consumption	The target is to have enough natural gas flow to allow for the greatest flexibility to utilize hydrogen effectively.
Distance to TOC	This is an estimated length of required new infrastructure to introduce blended gas to the targeted closed loop system. It involves building a pure hydrogen pipeline, among other infrastructure.
Real Estate Availability	Land to accommodate new infrastructure.
Highway or River Crossing	Major crossings negatively affect the feasibility in terms of cost of the project and permitting process.
Pipeline Age	Newer networks have higher record availability and would be easier to evaluate than older networks.
Pipeline Pressure	Hydrogen could lead to potential integrity effects on steel pipelines under certain material and operational parameters, such as higher pressures, temperatures and large, frequent cycling.

Pipeline Material	Some carbon steel pipes and welds might be affected by the presence of hydrogen, under certain conditions. Available reports in the early stages of this work indicated that plastic could exhibit fewer issues with regards to hydrogen interaction compared to other pipe materials like certain carbon steels.
Sensitive End-use Equipment	Industrial customers are much more sensitive to variations in their fuel, and therefore would not be suitable for the first phase of hydrogen blending. In addition, during initial investigation, it was known that turbines, CNG tanks and some other sensitive equipment were not compatible with low levels of introduced hydrogen.

Figure 3: Map of the Blended Gas Closed Loops in Markham, ON



24. The investigation into the Blended Gas Closed Loops shown in Figure 4 involved the following:
    - Full distribution record investigation
    - List of assets and materials of construction were evaluated against the engineering guidelines using the HYREADY Project and other relevant research in order to better understand their compatibility with hydrogen
    - Comparison of all the different components of the distribution network yielding the conclusion that up to 5% hydrogen by volume can be injected into the selected Blended Gas Closed Loop

25. At the time that this review was completed, Enbridge Gas had not yet decided to proceed with only Loop S1 (the “Blended Gas Area” or BGA that is the subject of this Application). Therefore, the review covered all parts of Loop 1 (Loops S1, S1A and S1B).

C. End-user Equipment

26. The objective of this stream was to identify the recommended injection concentration of hydrogen without resulting in a material change to the safety, operability or reliability of customer gas appliances.

27. The consultants’ work (described above at paragraph 18) was used to form the conclusion on the maximum blending levels. The information from the first consultant was used to establish an upper limit and bolster the confidence of the second’s interchangeability analysis. This was based on a field survey completed on the selected loops. The second consultant performed an interchangeability analysis which is more conservative placing further limits on the amount of hydrogen that can be blended.

28. Heating and cooking appliances are the major focus of the investigation into Loops S1, S1A and S1B as they are the predominant appliance type. A premixed combustion where the combustion air is mixed prior to combustion is commonly used. This follows a similar combustion process to the “Bunsen burner”. In heating and cooking appliances, the major concerns are flashback and burner overheating. Flashback occurs when the flame retreats back into the tip of the combustion nozzle. Burner overheating can result in failure in extreme cases, but over time can cause issues with the integrity of burners that were not designed for higher temperatures or built with substandard materials. Enbridge Gas’ conclusions regarding the amount of hydrogen to be blended will ensure that burner temperatures will remain within historical ranges.

29. With respect to gas engines, the appliance survey yielded a few engines that will be receiving blended gas, mainly backup generators at larger facilities (or residential generators) such as Enbridge Gas’ TOC facility and Honda’s facility located on Honda Boulevard in Markham, Ontario. These engines are capable of operating with higher percentages based on the interchangeability study of hydrogen and were therefore not identified as an area of concern.

30. In addition, there is a Natural Gas Vehicle (NGV) station at the TOC facility. The vehicle engine itself is not the limiting factor for NGVs, but rather the high pressure and cycling that occurs in the tanks that hold the compressed natural gas (CNG). As such, the NGV fueling station will have a dedicated natural gas feed and will not be exposed to hydrogen content.

31. Based on the review for the closed loop system, no turbines were identified in any of the areas proposed for blending.

32. As noted above in Table 2, Enbridge Gas determined that it would not consider closed loop systems with industrial customers for the initial hydrogen blending project. Accordingly, there are no industrial customers or facilities to be considered at this time.

33. Based on the analysis described above, in conjunction with the Gas Distribution Network Hydrogen Tolerance work stream, it was determined that a hydrogen blend up to 2% by volume is appropriate for the selected Blended Gas Closed Loop. This conclusion, which is supported by the consultant report on gas interchangeability, is based on the gas supply to the Blended Gas Closed Loop and the mix of appliances contained therein.

D. Pipeline and Blending Station Preliminary Design and Guidelines

34. The objective of these design streams was to present preliminary designs and guidelines for hydrogen and blended pipelines, and for hydrogen blending and injection stations. Several design iterations were carried out in 2018 and early 2019, to balance system safety and reliability, technical risks, regulatory requirements, municipal requirements, operational practicality and costs. Design guidelines were also proposed based on several international codes, including Canadian, American and European standards. A thorough comparison with existing related Legacy EGD manuals was carried out to identify any necessary modifications to design and construction practices.

35. Enbridge Gas consulted with the Technical Standards and Safety Authority (TSSA) to introduce and provide information on the Project. The TSSA indicated that they

will act as a technical reviewer on behalf of the Ontario Energy Board for the LTC application if requested.

36. Fuels Safety falls under the purview of the TSSA, and hydrogen and blended gas pipelines are under the jurisdiction of the TSSA. The following Ontario Regulations are applicable to the project:
    - Ontario Regulation (O. Reg) 210/01 Oil and Gas Pipeline Systems
    - FS 238-18 Oil and Gas Pipeline systems code adoption document, Dated: 15th February 2018

37. In addition, the scope section of the CSA Z662 Oil and Gas Pipeline Systems states that it is applicable for pipeline systems that convey gas, such as Manufactured Gas (MG) and Synthetic Natural Gas (SNG), which have high hydrogen contents. These gases contain a mixture of hydrogen and carbon monoxide, with potential presence of methane and carbon dioxide.

38. SNG/MG covers a wide range of compositions that generally fall within the following limits:
    - 10 to 90% by volume hydrogen
    - 200 ppm to 90% by volume carbon monoxide
    - Balance – inert gasses, carbon dioxide, methane

39. Although the CSA Z662 definition of “gas” does not explicitly cover blended gas, the design requirements for a SNG pipeline (which is covered by CSA Z662) would need to be more stringent than those for the blended gas service at a 2% hydrogen by volume level due to the higher concentration of hydrogen in the gas. Enbridge Gas

does not expect modifications to CSA Z662 will be required to cover blended gas pipeline design.

40. Preliminary designs of the hydrogen blending station, pipelines and associated facilities or instruments have been carried out. Design work is expected to be finalized in 2020 as LTC approval is obtained. The relevant codes, standards and resources have been identified in order to perform this work. The following conclusions can be made from the design stream:
    - Pipeline, pressure-regulating facility and associated metering equipment will be designed in accordance with CSA Z662.
    - Hydrogen portions of the blending station will be designed and installed as per ASME B31.12, CAN-BNQ 1784, CSA B51 and MIS-PRD-R01.

E. Risk Assessment

41. The purpose of the risk assessment was to understand through quantitative assessment, the operational risk of introducing 2% by volume hydrogen blended natural gas to a select area within the natural gas distribution network and how it compares to operation with natural gas. The outcome of the risk study was used to help inform the Company's decision to deliver hydrogen blended natural gas to customers.

42. Risk assessment activities occurred both internally for the distribution system and externally for quantification of customer-owned piping and equipment. In order to evaluate risk, Enbridge Gas first identified the hazards associated within the following scope:
    - General Hydrogen Effects and Hazards

- Customer Premises (including the Enbridge Gas Meter Station and Customer owned equipment and piping)
- Hydrogen Blending Station
- District Stations
- Distribution Network Mains and Services
- Materials of Construction and Integrity thereof
- Worker Safety and Human Factors

43. A Quantitative Risk Assessment (QRA) was developed for the identified hazards to determine the overall effect on the risk level for the specific network. The QRA methodology included consequence analysis, likelihood analysis, risk estimation, risk evaluation and analysis of proposed risk reduction. The risks associated with customer owned domestic gas equipment and piping were quantified.

44. The key findings from the risk assessment identified that the risk with introducing hydrogen blending was deemed to be as low as reasonably practicable. The baseline risk associated with natural gas distribution in scope was deemed to be broadly tolerable.

Conclusions

45. The conclusions from each of the work streams are as follows:

A. *Research & Development (R&D)*: This work stream served to provide an orientating value for the upper limit of hydrogen blending that should be considered.

B. *Gas Distribution Network Hydrogen Tolerance*: Loop S1 and subsequently Loops S1A and S1B were found to be appropriate networks for hydrogen blending. In the specific area of study, an upper limit of 5% by volume hydrogen for the Gas Distribution Network was applicable.

C. *End-user Equipment*: In the specific area of study, based on the local gas composition, heating equipment and appliances, the upper limit for hydrogen was found to be 2% by volume.

D. *Pipeline and Blending Station Preliminary Design and Guidelines*: Pipeline, pressure-regulating facility and associated metering equipment will be designed in accordance with CSA Z662, and all hydrogen portions as per ASME B31.12, CAN-BNQ 1784, CSA B51 and MIS-PRD-R01.

E. *Risk Assessment (Hazard Identification and Quantitative Risk Assessment* work): Completed and the results were accepted.

46. Increased monitoring of the gas distribution network in Markham will take place in the initial period of the Project in order to confirm the findings of Enbridge Gas.

47. The overall investigation and analysis approach described above by Enbridge Gas will allow the same evaluation process to be applied to other areas of the system with a high degree of confidence.