

STANDARDS RESEARCH

Codes and Standards for Renewable Gas Pathways

Current Status and Future Directions

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Executive Summary

Renewable gas is produced from a renewable resource that can be replenished. It is often produced from a range of agricultural products and by-products (such as crops, livestock manure, and biowaste). Green hydrogen (electrolytic hydrogen produced using a renewable power source like solar or wind) is also a renewable gas. Non-renewable gas is produced from sources that will deplete or cannot be replenished, such as fossil fuels like coal or natural gas.

The renewable gas production potential for Canada, the United States, and the world is significant, with current production being underutilized, especially in Canada. To meet its Paris Accord requirements, Canada must reduce greenhouse gas emissions dramatically and displacing natural gas with renewable gas will contribute to these reduction efforts.

This research report reviewed existing renewable gas standards landscape to identify needs and gaps by completing a comprehensive literature review, consulting experts, and analyzing information provided by key industry stakeholders via questionnaires.

An integral part of this research was defining renewable gas pathways, providing process descriptions for their production, and creating simplified block flow diagrams for each pathway. This was done to provide context for identifying current codes and standards (along with any gaps) used in Canada, the United States, and Europe.

Existing codes and standards in Canada and the United States that support the oil and gas industry are also used for designing and constructing renewable gas system components. Some standards and guidance documents have been specifically developed for renewable gas.

A common comment from questionnaire respondents was the lack of standards and codes for approved renewable gas production pathways that provide guidance relative to feedstocks, production, and renewable gas quality. Designers of these facilities must determine which codes and standards to apply; they often rely on international ones, without understanding the basis or the methodology behind them. An overall guide on applicable codes and standards for each pathway (a roadmap) would be useful for designers.

Renewable gas production pathways considered established and mature involve first generation technologies like anaerobic digestion of organic waste and splitting water molecules using electrolysis to produce green hydrogen. One of the many challenges of renewable gas in gaining initial market access is that the natural gas supply infrastructure is typically not near these production plants. Emerging second generation technologies involve converting biomass via gasification and steam reforming or methanation into renewable hydrogen or renewable natural gas. These technologies are not yet financially viable but stand to produce renewable gas in significant volumes by deploying central production.

The gaps identified for codes and standards are summarized as follows:

Standard/code topic	Identified gaps
Feedstock	Codes and standards for feedstocks of renewable gas pathways are scarce. The variation of feedstocks and their variability in composition, especially for biomass, are technical challenges addressed during system design (i.e., selection of appropriate technologies and the arrangement of the processes) but do not constitute an area that necessarily needs to be heavily standardized. A code or standard defining acceptable feedstocks (nature and types of contaminants) would prove useful. Adopting international codes for testing various feedstocks (tests for contaminants and biogas potential) would also help designers.
Production and Storage	For biogas and renewable gas, research is required to determine whether additional design features need to be incorporated into the construction materials for the equipment and processes used (specifically anaerobic digesters and biogas storage). For electrolytic hydrogen, additional research and development are required; this work concerns linear power/generation for hydrogen production, storage methods and materials, reactor design, and system performance and efficiency (i.e., operation and maintenance, electrolyte conductivity, and material stability and durability).
Product Quality	No widely-adopted standardized specifications or guidelines were found specifically for renewable natural gas. A lack of consistent standards for the RNG specifications were noted by questionnaire respondents as hampering their design and implementation efforts. Potential feedstock contaminants that could end up in the renewable hydrogen gas can affect the willingness of utility companies and end-users to use that hydrogen or affect its allowable quantity. The unknown presence of feedstock contaminants requires research for determining contaminant types and their potential impact on hydrogen production. Existing specifications for hydrogen fuel cells could be referenced for renewable hydrogen testing procedures and quality standards.
Transmission Applications and End-Use	The acceptable levels of contaminants in renewable gas originating from digestion of different feedstocks and their long-term impact on the production equipment, transmission system, instrumentation, pipelines, and the end-use equipment is unknown. The integrity of the existing natural gas distribution network with long term exposure to elevated levels of hydrogen at high pressures seen in the transmission systems is unknown. The achievable amount of hydrogen to be injected into Canada's and North America's existing transmission system needs to be studied and identified to account for different gas end users and for different construction materials in the pipeline systems. For new pipeline construction, a new code or standard could be applied but may have to be addressed on a case-by-case basis for existing transmission systems.
Safety/Risk	Research and development are required to fully understand the physical mechanisms of renewable gas diffusion as they relate to gas build-up and combustion in enclosed spaces, flammable cloud formation, ignition, deflagration-detonation transition, and renewable gas flashing, pooling, and vaporization. Components and systems need to be tested under operational and environmental conditions that replicate real-world use to confirm the safe and effective operation of renewable gas technologies. The contaminant potential of some components (like arsenic and mercury) in renewable gas needs to be understood.
Overall Guide	An overall guide on the applicable codes and standards for each pathway (a roadmap) would be useful for designers. This report can be a supporting document for the initiative to develop the necessary regulations.



"The renewable gas production potential in the world is significant, with current production being underutilized, especially in North America."

1 Introduction

Renewable gas is usually produced from a range of agricultural products and by-products, including but not limited to crops; livestock manure and slurry; and various types of biowaste, such as municipal solid waste, industrial waste, and sewage sludge [1]. Green hydrogen—electrolytic hydrogen produced using a renewable power source like solar or wind—is also a renewable gas. Non-renewable gas is produced from sources that will deplete or cannot be replenished, such as fossil fuels like coal or natural gas [2].

The renewable gas production potential in the world is significant, with current production being underutilized, especially in North America. The goal of increased renewable gas production is to displace conventional natural gas and therefore help reduce greenhouse gas emissions. Canada must reduce its greenhouse gas emissions by 30% below 2005 levels by 2030 to meet its Paris Agreement target and displacing natural gas with renewable gas will contribute to these reduction efforts.

This research report reviews the existing renewable gas standards landscape to identify needs and gaps through a comprehensive literature review, consultations with experts, and information provided by key industry stakeholders via questionnaires.

1.1 Definitions

Biomass – material of biological origin excluding that embedded in geological formations and/or transformed to fossilized material. Biomass is plant-based or animal-based organic material. It includes but is not limited to dedicated energy crops; agricultural crops and trees; food, feed, and fibre crop residues; aquatic plants, algae; forestry and wood residues; organic agricultural, animal, and processing by-products; agricultural, municipal, and industrial organic waste; residues in landfills, sludge, wastewater; and other non-fossil organic matter [ISO 20675, See Table 6].

Biogas – gas produced by anaerobic digestion of organic matter; biomass gasification or power-to-gas from biomass sources; and without further upgrading or purification [ISO 20675, See Table 6]. Biogas comprises mainly methane and carbon dioxide, with small amounts of hydrogen, carbon monoxide or heavier hydrocarbons with two to six carbon atoms, or a combination of them.

Raw biogas – biogas obtained directly from the digester, which is not conditioned and therefore not yet dried and cleaned [ISO 20675, See Table 6]. For the purposes of this report, raw biogas also includes gas obtained directly from a landfill.

> **Digester gas –** gas produced in a digester from organic sludge originating at a municipal wastewater treatment plant. It is generally composed of approximately one-half to two-thirds methane and one-third carbon dioxide produced from the decomposition of organic residues, with a heating value averaging approximately 22 to 26 MJ/m^3 (590 – 700 Btu/ft^2). Given the biological process nature under anaerobic conditions, its production and constituents are considered flammable, corrosive,

wet, and potentially hazardous. Digester gas can contain traces of water, hydrogen sulphide gas, and dissolved ammonium and bicarbonate ions [CSA/ANSI B149.6, See Table 6].

Note: Given its high inert content, digester gas has a slow flame propagation rate compared to natural gas and propane.

Landfill gas – gas consisting primarily of methane, carbon dioxide, water, and traces of hydrogen sulphide gas from organic waste material decomposition at a landfill [CSA/ANSI B149.6, See Table 6].

Bio-syngas (Bio-synthetic gas) – a type of biogas comprised principally of carbon monoxide and hydrogen, obtained from biomass gasification (also contains traces of methane and carbon dioxide) [ISO 20675, See Table 6].

Renewable natural gas (Biomethane per ISO 20675 and EN 16726) – methane-rich gas with properties similar to natural gas. Produced by upgrading biogas obtained by anaerobic digestion or gasification, or power to gas (gas generated from electrical power from biomass) [ISO 20675, See Table 6]. Cleaned and refined biogas having more than 95% methane can be injected into the gas network [BNQ 3672-100, See Table 7].

Renewable gas – gas produced from any of the following:

a. Biogas; digester gas; landfill gas derived from biomass feedstock, including agricultural, commercial, municipal, and waste-water sources,

b. bio-syngas (bio-synthetic gas),

c. renewable natural gas (RNG),

d. renewable hydrogen gas derived from (a), (b) or (c),

e. renewable hydrogen gas derived from water electrolysis and renewable primary energy input,

f. hydrogen gas derived from industrial byproduct waste of a biological origin that would otherwise be vented,

g. synthetic natural gas derived from (d), (e) or (f) and biogenic or atmospheric carbon dioxide, and

h. a mixture or dilution of any of the above.

Green hydrogen – electrolytic hydrogen obtained via separation of water into hydrogen and oxygen, using power supplied from renewable energy, such as wind, hydropower, and solar energy. The electrolytic hydrogen production process is also termed power-to-gas (P2G) technology. Green hydrogen is currently the most expensive method of producing hydrogen but creates zero emissions [3]. Note that there is also a definition of yellow hydrogen, used for hydrogen derived via electrolysis using solar power, or from renewable gas. Also, the term pink (or nuclear) hydrogen is used for hydrogen derived via electrolysis using nuclear energy [4]. In this report, these types of hydrogen (yellow and pink) will be considered as part of green hydrogen.

Grey hydrogen – hydrogen derived from natural gas through steam methane reforming or auto thermal reforming, with carbon dioxide emissions vented. Grey hydrogen is not a renewable gas.

Blue hydrogen – similar to grey hydrogen, blue hydrogen is derived from natural gas through steam methane reforming or auto thermal reforming, but with the carbon dioxide emissions captured and stored underground using carbon capture, utilization, and storage (CCUS) technology [3]. Blue hydrogen is not a renewable gas.

Brown and black hydrogen – hydrogen produced from the transformation of coal into gas, subsequently separated from the other produced elements. Brown hydrogen is produced from lignite coal and black hydrogen is produced from bituminous coal. This is a highly polluting hydrogen generation process, as the carbon dioxide and carbon monoxide produced are not reused [4]. Brown and black hydrogen are not renewable gases.

2 Study Methodology

Information on standards and documents pertinent to renewable gas producers and users was collected via literature review, consultations with experts, and information provided by key industry stakeholders in the questionnaire outlined in Appendix A. Table 1 summarizes respondents who answered questionnaires on the current codes and standards landscape in renewable gas.

Table 1: Questionnaire Respondents by Category

Category (Area of work)	**Received**
Engineering and Fabrication	seven (7) (accounts for different divisions in case of two (2) companies)
Government and Research	six (6)
Regulatory and Commission	four (4)
Renewable Gas Suppliers	five (5)
Utility Companies	six (6)
Standards Development Organizations (SDOs) and Committee Members	three (3)

The questionnaires provided insight into the industry's current activities regarding renewable gas as well as the role standards and codes play in these activities. Industry stakeholders were able to raise concerns and identify gaps they believe hinder progress on renewable gas related activities.

Interviews with subject matter experts were conducted to reconcile information gathered through literature research, reviews of codes and standards, and reviews of publications and journals. This research formed the basis for the background information on renewable gas technology, considerations for their use, and available relevant codes and standards. The interviews were used as the foundation for the gap analysis, providing industry input on codes and standards needed to improve renewable gas production efforts.

3 Renewable Gas Pathways and Production

3.1 What are Renewable Gases?

As defined in Section 1.1, renewable gas is a broad term that refers to biogas, bio-syngas, renewable natural gas (also known as biomethane), and hydrogen produced from renewable sources. Renewable gas is easy to store and is more reliable than other renewable energy sources, such as wind or solar, since it can be produced in different quantities and at various times of the day or year [5]. Wind and solar energy sources are also non-dispatchable, meaning output cannot be moderated or switched on/off according to demand.

The renewable gas pathways currently known in use worldwide will be discussed in this report, including production of:

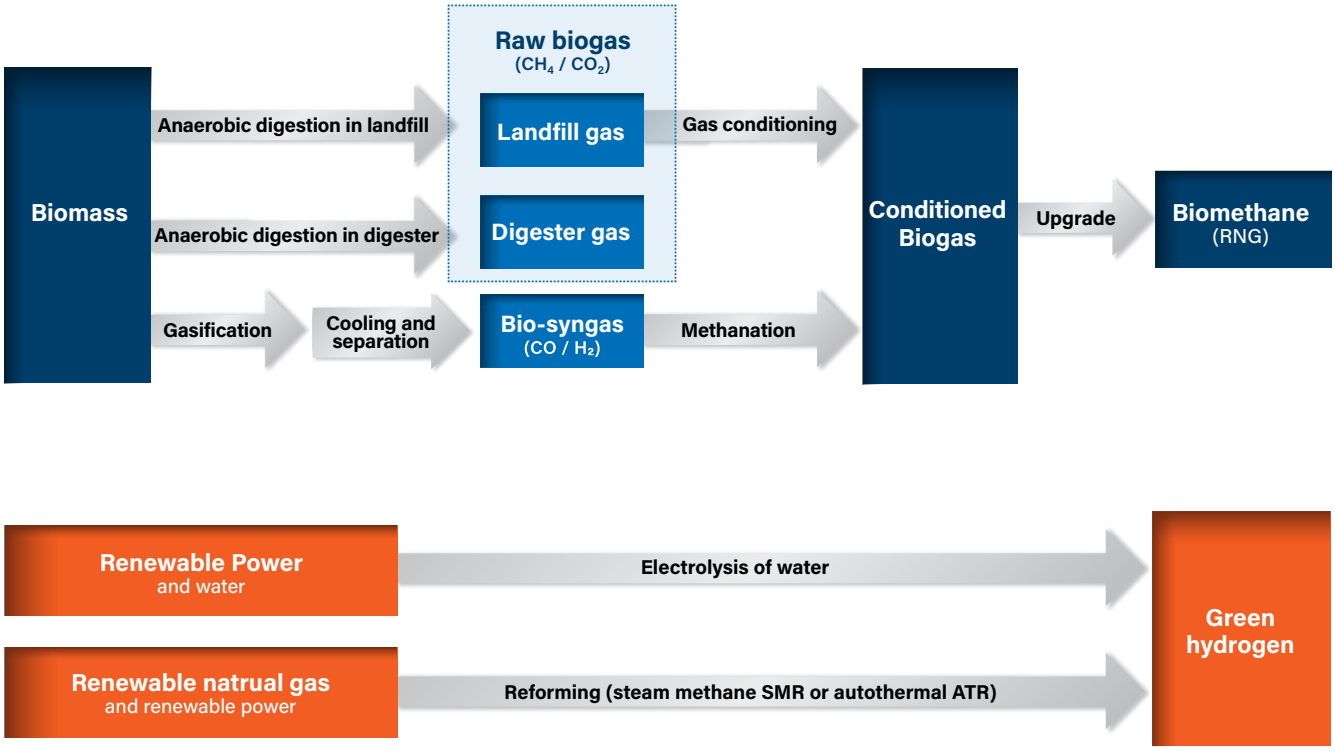
- Biogas,
- Bio-synthetic gas (bio-syngas),
- Renewable natural gas (RNG),
- Hydrogen generated via renewable gas pathways as follows:
  - Electrolytic hydrogen – green hydrogen produced via water electrolysis using renewable (clean) primary energy,
  - Hydrogen produced via reformation of renewable natural gas.

A schematic diagram of the renewable gas pathways is given in Figure 1 [6].

A diagram for non-renewable hydrogen production pathways is presented in Figure 2. Blue hydrogen production will be an important step before transitioning to only green hydrogen use, as all fossil fuel resources (natural gas, crude oil, and bitumen) can be converted to low-carbon, blue hydrogen.

Gas produced from coal is not renewable [7] and thus not discussed here. Also note that renewable liquid biofuels (such as biodiesel and ethanol for gasoline blending) will not be discussed in detail.

Figure 1: Schematic Diagram of Renewable Gas Pathways



3.2 Process Description of Renewable Gas Pathways

3.2.1 Biogas produced via anaerobic digestion

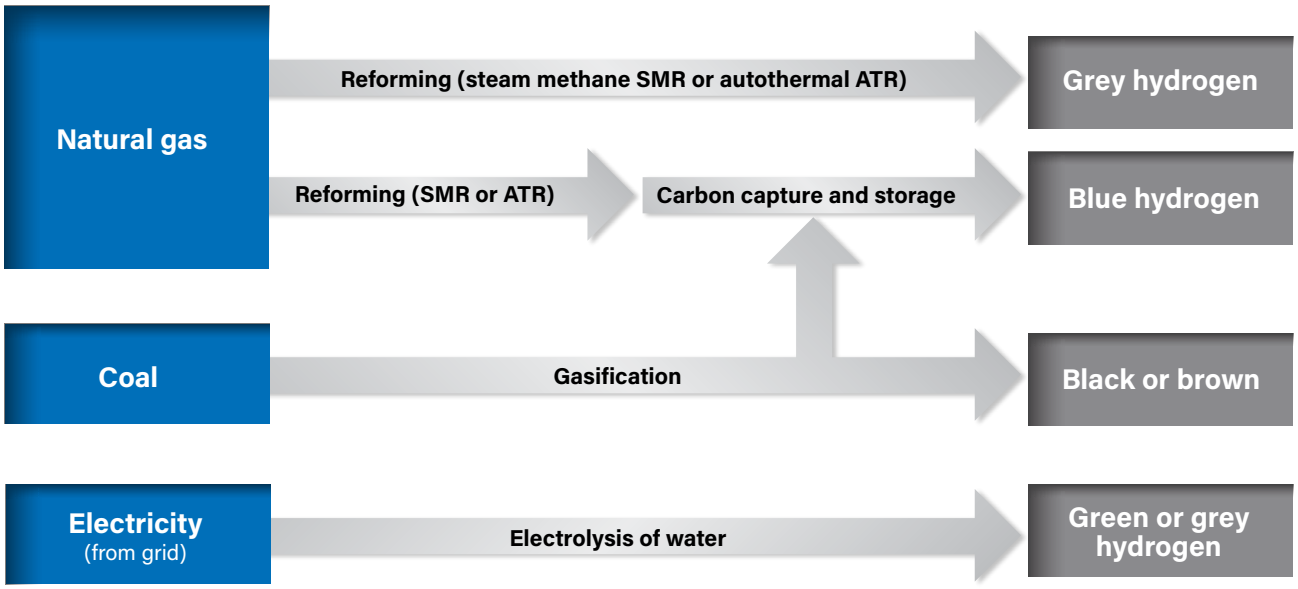
Raw biogas used to produce renewable heat, electricity and/or renewable natural gas is derived from the feed waste material sorted into its organic and inorganic fractions. Non-organics are collected and recycled. Recovered organics are directed into anaerobic digestion. Depending on the type of organic waste, it can undergo additional pre-treatment that can include particle size reduction, fermentation, thermal hydrolysis, and/or chemical treatment. Following pre-treatment, organic waste is blended with other organics to undergo co-digestion. Anaerobic digestion is a process in which bacteria break down organic matter in the absence of oxygen to produce biogas and digestate. Raw biogas contains by volume roughly 55 to 70% methane and 30 to 45% carbon dioxide, and trace amounts of other gases. Digestate is a wet mixture that can be separated into a solid and a liquid fraction. It is rich in nutrients and can be applied either as a liquid or solid organic fertilizer. The recovered raw biogas undergoes gas conditioning that includes moisture removal, desulphurization, drying, heating, and absorption to produce treated biogas. Following gas conditioning, biogas is compressed and either transferred into temporary storage or directly upgraded into renewable natural gas.

See Appendix B.1 for a detailed process description and block flow diagram.

3.2.2 Bio-syngas

Two thermo-chemical gasification methods are currently used to produce bio-syngas from biomass. These are high temperature gasification (using temperatures of 1200°C to 1400°C) producing

Figure 2: Schematic of Non-Renewable Hydrogen Production Pathways



carbon monoxide and hydrogen, or low temperature gasification (using temperatures of 800°C to 1000°C) producing a product gas that is then treated by a downstream catalytic reformer. The processes for bio-syngas production begin with biomass pre-treatment that involves particle size reduction through crushing and screening. Following pre-treatment, the biomass undergoes drying to reduce the moisture content. After drying, the biomass is fed into a gasification unit for the major conversion step of the solids into a product gas, raw bio-syngas. The raw bio-syngas composition will vary depending on the gasification temperature and gasification agent (air, oxygen, or steam blown). Several types of thermal gasification technologies are used and include fixed bed gasification, fluidized bed gasification, and entrained flow gasification. Raw bio-syngas will then undergo gas cleaning to remove tars, particulates, sulphur, nitrogen compounds, alkali metals, and higher molecular weight hydrocarbons. The resultant bio-syngas will contain mainly carbon monoxide, hydrogen, and carbon dioxide (with high amounts of nitrogen if air is used as the oxygen supply). If used for processing into renewable natural gas, bio-syngas is further catalytically converted into methane via methanation.

See Appendix B.2 for a detailed process description and block flow diagram.

Raw bio-syngas can also be converted to liquid fuels though the Fischer-Tropsch process. See Appendix B.2 for a process description and block flow diagram.

3.2.3 Renewable Natural Gas

Renewable natural gas (RNG, also known as biomethane) is produced from biogas obtained via anaerobic digestion or gasification. Biogas is a mixture of mainly methane, carbon dioxide, and water with trace amounts of nitrogen, hydrogen, and carbon monoxide. Before the biogas can be injected into a natural gas grid, it must be further upgraded to purify the methane using pressure swing adsorption or membrane separation technology. The produced renewable natural gas can undergo post treatment for deoxygenation prior to sales – injected into the pipeline for distribution, further processed into liquid natural gas for transportation use, or placed into underground storage for later use.

See Appendix B.3 for a detailed process description and block flow diagram.

3.2.4 Electrolytic Hydrogen (Power-to-Gas Hydrogen Production via Electrolysis)

Power-to-gas producing electrolytic hydrogen is a technology that uses electricity to produce hydrogen via water electrolysis— a process that splits water into hydrogen and oxygen using electricity. The reaction takes place in an electrolyzer, which comprises anodes and cathodes separated by an electrolyte. Hydrogen molecules are derived from the anode, and oxygen molecules from the cathode. Water or wastewater used as the water source must first undergo advanced water treatment to produce a treated water quality acceptable for electrolysis. The water conditioning process typically consists of two steps, ultrafiltration with post ultraviolet disinfection, followed by membrane distillation. Electricity can be obtained from various sources that include photovoltaic panels and aerogenerators complete with batteries or directly from the electrical grid operating on a blend of renewable and fossil fuels. Products of the electrolyzer are streams of hydrogen gas/water and oxygen gas/water. The hydrogen gas/water stream from the electrolyzer will undergo additional gas conditioning to dry and remove the moisture from the hydrogen. Similarly, the oxygen gas/water stream undergoes additional gas conditioning to remove the moisture from the oxygen, allowing the recovered oxygen to be recycled and used as a utility stream in a plant process or converted into a value-add product. Recovered hydrogen gas is compressed from where it can be transferred to temporary storage or used directly in power-to-gas applications.

See Appendix B.4 for a block flow diagram.

3.2.5 Hydrogen Production via Steam-Methane Reformation

Methane can be used to produce hydrogen via steam methane reformation and partial oxidation. Potential methane feedstocks include raw biogas, bio-syngas, and renewable natural gas. The process of steam methane reforming involves the use of high-temperature steam (700°C to 1000°C) whereby methane within the feed gas reacts with the steam at a pressure under 25 bar in the presence of a catalyst. The reaction produces hydrogen, carbon monoxide, and a small amount of carbon dioxide. Products of the steam methane reforming process are then treated using water-gas shift reaction, where carbon monoxide and steam react in presence of a catalyst to produce carbon dioxide and more hydrogen. In a final process step, the hydrogen is purified using pressure swing adsorption or membrane separation, thus removing carbon dioxide and other impurities, leaving essentially pure hydrogen. Carbon dioxide recovered from the process can be purified and converted into liquid carbon dioxide for use as a value-added product. Following gas purification, the hydrogen gas is compressed and transferred to temporary storage or used in power-to-gas applications.

See Appendix B.5 for a detailed process description and block flow diagram.

3.2.6 Autothermal Reforming for Hydrogen Production

Autothermal reforming is a low-cost hydrogen production technology that recovers heat at maximum energy (highest quality). Process efficiency benefits are achieved by coupling a gas heated reformer (GHR) with an autothermal reformer (ATR). This technology differs from steam-methane reforming; the energy driving reaction is provided by introducing oxygen into the autothermal reformer, instead of burning natural gas in a steam-methane reformer. Feed gas is pre-heated and reformed in the GHR before entering the ATR. In the GHR, 30% of the total hydrocarbon is reformed by reaction with the added steam to form syngas. In the ATR, oxygen is added, which combusts some of the partially reformed gas to raise the process gas temperature. The resultant gas is then passed through a catalyst bed inside the same ATR vessel for further reforming, converting the remaining hydrocarbon to the desired levels (some liquid fuel products could be produced if desired). The hot gas then exits the ATR, flowing back into the GHR and providing heat to drive the reforming reaction. The reformed gas leaves the GHR where it is subjected to water-gas shift reactions for the conversion of carbon monoxide and steam into hydrogen and carbon dioxide. These reactions lead to a significant increase in hydrogen concentration in the syngas. It also produces substantial amounts of carbon dioxide that can be recovered, purified, and converted into liquid carbon dioxide for use as a value-added product. Following isothermal temperature shift, the syngas undergoes hydrogen separation and purification to produce hydrogen. Suitable technologies used for hydrogen separation and purification are



"Biogas and renewable natural gas production are more prevalent in Europe than in Canada and the United States."

pressure swing adsorption and membrane separation. Following separation, the hydrogen gas is compressed from where it can be transferred to temporary storage or used in power-to-gas applications.

See Appendix B.6 for a block flow diagram.

3.2.7 Summary

Table 2 is a summary of the feedstocks, major processes, and uses of the renewable gas pathways described in detail in Sections 3.2.1 to 3.2.7.

3.3 Renewable Gas Production around the World

In this section, some of the existing facilities and future potential of renewable gas are discussed. Although behind Europe, the renewable gas market potential in North America is significant, with motivation created by the need to reduce greenhouse gas emissions, the need to process organic waste, and the potential profit available by the sale of renewable gas.

3.3.1 Biogas, and Renewable Natural Gas

Biogas and renewable natural gas production are more prevalent in Europe than in Canada and the United States. Germany, the United Kingdom, France, Belgium, Sweden, and Spain are a few of the many European countries that have several biogas facilities. In 2015, there were more than 17,400 biogas plants in Europe, most of them producing electricity (more than 10,000 MW) with a small part of the biogas being used in boilers for heating purposes on farms or for steam generation in industrial applications. A shift is currently underway in Europe from electricity production to renewable natural gas production that can be used to displace natural gas in existing pipelines or used in natural gas-powered vehicles [8].

3.3.1.1 Canada

Canada has lagged the United States and Europe in renewable gas production, but more facilities are starting to appear. There does not appear to be one complete listing of on-line and planned renewable gas facilities in Canada. Four listings of biogas or renewable natural gas production projects were found:

- The most extensive listing of mostly North American biogas projects is provided on Biogas World's website [9]. Of the 2,691 entries on this listing, there are 159 Canadian projects listed (148 are running). Other renewable natural gas databases that may list the same or additional projects are:
- RNG Coalition's website [10] lists 11 projects in operation in Canada, with 1 project in construction and 11 more in substantial development [11].
- Canadian Gas Association RNG Registry (draft March 2021) lists 9 Canadian projects currently on-line and states 12 in development (includes the provinces of BC, ON, and QC only).
- The Canadian Biogas Association provides an industry snapshot on some biogas and renewable gas projects in Canada, either in operation or in planning phase [12]. This database lists 11 projects under substantial development or in construction in Canada.

Table 2: Renewable Gas Feedstocks, Major Processes, and Uses

Renewable Gas product	Feedstocks	Major Processes	Uses
Raw Biogas and Conditioned Biogas	▪ Organic Waste ▪ Biomass	▪ Pre-treatment and blending. ▪ Anaerobic digestion to produce raw biogas and digestate (used for fertilizer). ▪ Conditioning (drying, desulphurization, and contaminant removal).	▪ Farm or neighbour use – building heat, greenhouse, food storage, combined heat, and power at source. ▪ Adjacent commercial/industrial uses. ▪ Upgrade to renewable natural gas.
Bio-syngas and Conditioned Biogas	Biomass	▪ Pre-treatment ▪ Gasification ▪ Conditioning ▪ Methanation	▪ Compressed and liquified natural gas for vehicle use. ▪ Distribution via pipeline for heat and industrial uses. ▪ Upgrade to renewable natural gas.
Renewable Natural Gas	Conditioned biogas (derived from raw biogas and bio-syngas)	▪ Carbon dioxide removal (typically by membrane separation or pressure swing adsorption). ▪ Post treatment	▪ Pipeline to users for heat or power (can mix with natural gas network or on its own). ▪ Electricity generation. ▪ Convert into compressed or liquefied gas for transportation use.
Electrolytic Hydrogen (from Power-to-Gas)	Water and power	▪ Water treatment ▪ Electrolysis ▪ Separation and drying	Hydrogen for pipelining to users (mixed with natural gas), or transportation (e.g., fuel cells).
Hydrogen from Steam Reforming	Feed biogas	▪ Steam reforming ▪ Water-gas shift	Same as for electrolytic hydrogen

Some Current Operating Plants in Canada

The provinces of Ontario, Québec, Alberta, and British Columbia are home to the most on-line biogas facilities [13] [9]. These provinces also have the greatest biogas production potential, as they are the largest generators of biomass [14].

The first operating Canadian biogas project was the Berthierville project, which produced RNG from landfill gas and injected it into a natural gas pipeline in Québec in 2003 [15]. In 2010, farm waste processing started at Fraser Valley Biogas in Abbotsford, BC. Since 2011, excess biogas generated from the Woodward Avenue Wastewater Treatment Plant in Hamilton, ON is injected into Union Gas's nearby distribution system [15]. Since 2013, biogas collected from the landfill at Salmon Arm, BC is upgraded and injected into the local distribution system. FortisBC monitors the produced gas quality and connects the renewable natural gas produced by Fraser Valley Biogas to FortisBC customers [15]. There are also operating facilities in Lethbridge (AB) and in Surrey, Delta, and Kelowna (BC).

Green energy provider Bullfrog Power offers renewable natural gas to consumers across Canada, sourcing its supply from landfills and wastewater treatment plants [15].

Future Potential in Canada

There are over 480,000 kilometres of natural gas pipelines currently in Canada [15]. The infrastructure exists to allow renewable gas producing facilities to get their products to consumers via this extensive infrastructure.

An estimate stated in 2013 showed that Canada's renewable gas production could equal 40,770 thousand tonnes per year [16] (1,200 billion cubic feet per year), which equates to over a third of the natural gas

consumption in Canada in 2017. Natural gas utility companies in Canada have set their own aspirational target to have 5% of renewable natural gas blended with conventional natural gas by 2025 and 10% by 2030 [17].

Canadian biogas development could result in 1,800 construction projects; 16,700 jobs for one year; and 2,650 long term jobs for operating these projects [18]. These numbers exclude spin-off jobs for equipment suppliers, designers, fabricators, mechanical contractors, electrical contractors, etc. Biogas development and production also provides opportunities for diversification and new revenue streams for farms, municipalities, businesses, etc. Some examples include:

- Excess electricity generated on a farm using biogas can be sold back to the grid.
- Digestate can be used to enhance soil quality while reducing the need and cost for synthetic fertilizers. However, in certain areas the soil may already be over fertilized and therefore 'exporting' the digestate to other regions may be required. An example of this is the Fraser River Valley, where the soil currently contains too much nitrogen, phosphorous, and potassium.
- Carbon offsets.
- Anaerobic digestion of source separated organics has a reduced spacing requirement, as compared to composting facilities [18].

3.3.1.2 United States

The first landfill biogas project in the United States was commissioned in 1975, in California. The renewable gas produced was injected into a nearby pipeline for ten years [19]. Since then, the number of renewable gas projects has grown substantially. Biogas World's website [9] lists 2,407 biogas projects in the United States in various stages of operation or design. The facilities include livestock operations, landfills, wastewater treatment facilities and various other facilities. As of February 2020, 34 states have more than 100 operating renewable gas projects [19].

Projects in the United States are producing renewable natural gas for use as transportation fuel (either locally on site or transported via pipeline) or for electricity generation [19]. Anaerobic digesters in the United States are used to treat wastewater flow (48% of the total flow) and livestock manure (dairy being the majority, followed by swine, and a small portion from a mix of poultry and beef cattle). Most anaerobic digesters for livestock manure generate electricity; some recover waste heat in combined heat and power projects, and others produce renewable natural gas for electricity, vehicle fuel, or as pipeline gas [19]. There is tremendous growth potential for the biogas industry in the United States. As of April 2018, 15,000 new sites were ready for development. These sites include dairy; poultry and swine farms; wastewater recovery facilities, and landfills [20]. Wastewater treatment plants are the most plentiful; landfills produce the highest volume of biogas; and biogas from farms are the most underdeveloped [21].

3.3.1.3 Europe

Biogas World's website lists some of the European biogas projects, in various stages of operation and design. The facilities include livestock operations, landfills, organic food waste, and various other facilities [9]. European Biogas Association prepared a brochure summarizing some biogas success stories in Europe. There are 19,000 biogas plants and 726 renewable natural gas plants currently operating in Europe and over the past decade the number of renewable natural gas plants has been doubling every four years [22].

An example of Europe's advancement of renewable natural gas is their existing policies that provide incentives for increased biogas injection into European natural gas pipelines via tariffs and government subsidies [23].

The countries discussed below are some of the renewable gas production leaders in Europe.

Germany had more than 50% of the biogas plants and production in Europe as of 2015 and has plans to cut greenhouse gas emissions by up to 95% by 2050 [23] [24].

Natural gas used for space and water heating in homes is currently half of the final energy consumed in the United Kingdom, with 85% of homes heated by natural gas. The United Kingdom has an extensive natural gas grid system it prefers to use by blending with lower carbon gas in the aim to convert entirely to hydrogen eventually [23].

The United Kingdom's biogas industry increased 3.6-fold between 2010 and 2016, with 987 plants in operation in 2016 [24].

France plans to use its existing natural gas grid system, injecting 10% renewable natural gas by 2030, with conversion to all low carbon gas (including hydrogen) by 2050 [25]. France's biogas industry increased by 38% between 2010 and 2016, with 687 plants in operation in 2016 [24].

Sweden is a moderate producer of biogas, with 279 plants in operation in 2016 [24].

As per the cooperative efforts, TenneT Netherlands, TenneT Germany, Energinet, Gasunie, and Port of Rotterdam joined to build a hub (artificial) island in the North Sea planned to be used until 2050. The focus is to develop the North Sea as a source and distribution center for Europe's energy transition [26].

3.3.1.4 Other

Several noteworthy major projects and experiences were noted in other parts of the world. Information on current and planned projects is most readily available for Australia, China, and Japan, including a few projects in other countries.

Australia has a biogas potential comparable with Germany's 2019 biogas production. As of 2017, Australia had 242 biogas plants, half of which were based on landfill gas [24].

As of 2014, China had 100,000 modern biogas plants and 43 million residential scale digesters. China's target was 80 million household biogas plants by 2020 [24].

The Japanese government plans to double biogas generation by 2030 [27].

In 2018, Anaergia Inc announced construction of a facility in Yabu City, Japan that converts farm and food waste into renewable energy [28]. In 2019, a biogas power plant project was contracted for Ishigaki Island off the south-west coast of Japan; this project will power around 1,300 homes using organic waste, including manure and grass [29]. A 2021 completion date is expected for a project in Handa, Aichi in Japan that will use organic biomass in the form of agricultural and animal waste to generate energy for a biogas power generation facility [27].

Nepal had 300,000 domestic biogas units installed over the last couple of decades, with an average installation of 1,040 biogas units per month [24].

Between 2003 and 2014, Vietnam constructed 183,000 commercial biogas plants [24].

As of 2016, South Korea had 110 biogas plants and 10 biogas upgrading plants. South Korea's biogas plants include landfill, biowaste, and wastewater treatment. South Korea's biogas upgrading plants supplied biomethane as vehicle fuel to 0.2% of the country's buses [24].

3.3.2 Hydrogen

Hydrogen is the most abundant chemical element in the universe and although it does occur naturally on Earth, it does not exist in large enough quantities in elemental form to be produced cost effectively. Therefore, it must be separated from its source compound (e.g., water, renewable natural gas, natural gas, wood). Hydrogen produced worldwide is mostly from fossil fuels (and in some cases biomass), using gasification or steam-methane reforming (most common with 95% of the production), with some production via water electrolysis [30] [31]. In 2020, the world hydrogen production reached a total of 71 million tonnes and is expected to reach 168 million tonnes by 2030 [32] [33]. Currently, hydrogen is most often used in industrial processes (e.g., within oil refineries and petrochemical facilities) but renewable hydrogen production is critical for meeting greenhouse gas reduction targets worldwide.

Blue hydrogen is produced from fossil fuels with carbon emissions, which are emitted during conversion, captured, and stored. Blue hydrogen production is seen by many as a necessary part of decarbonization, at least short term. The large natural gas production in Canada, coupled with the extensive infrastructure in both Canada and the United States, will allow blue hydrogen production to be developed quickly. Green hydrogen production can then be increased over time (and when its economics improve), displacing blue hydrogen production over time.

Current and planned global blue hydrogen capacity in many leading nations is summarized in Table 3 [34].

Note that the numbers in Table 3 include all types of blue hydrogen production and uses. A current updated excel database that can be organized by production method or end-use is maintained by the International Energy Agency (IEA) [35].

Green hydrogen is produced from renewable non-fossil fuel sources. Less than one percent (1%) of the current annual hydrogen production is green hydrogen [36]. However, the following countries are among those pursuing the development of green hydrogen production: Canada, United States, Australia, United Kingdom, France, Germany, Norway, China, Japan, and South Korea [37].

Operational and planned (announced) green hydrogen capacity for Canada, the United States, and the remainder of the world is summarized in Table 4. Planned green hydrogen capacity is calculated from a few large projects, like that for blue hydrogen capacity [38].

Notes:

1. One of the world's largest green hydrogen plants was announced in January 2021 for Varennes, Québec. The new facility is expected to be commissioned at the end of 2023 and will produce 11.1 thousand tonnes of green hydrogen yearly [39].
2. 3 thousand tonnes (425,000 GJ) of green hydrogen will be produced yearly by water electrolysis in a production plant in Québec's Outaouais region [40].

Table 3: Current and Planned Blue Hydrogen Capacity

Country	**Operational** (thousand tonnes per year)	**Planned** (will not necessarily be completed) (thousand tonnes per year)
Canada	188.6	22
United States	267.3	4,667
Australia	unknown	3,590
Chile	unknown	204
China	9.8	119
France	10.3	unknown
Germany	8.6	218
Italy	unknown	335
Japan	1.7	unknown
Netherlands	40.1	2,001
Norway	4.8	271
Oman	unknown	43
Paraguay	unknown	53
Portugal	unknown	1,059
Saudi Arabia	unknown	239
U.K.	unknown	3,413

Table 4: Current and Planned Green Hydrogen Capacity

Country	**Operational** (thousand tonnes per year)	**Planned** (will not necessarily be completed) (thousand tonnes per year)
Canada	No information found	14 (Notes 1, 2, 3)
United States (Note 4) [38]	4	151
Remainder of World (Note 4) [38]	15 (Note 5)	358 (Note 6)

3. Significantly more hydrogen will need to be produced to meet Canada's projected hydrogen demand of 20 million tonnes (20,000 thousand) per year by 2050 [41].
4. The operational green hydrogen capacity is as of 2018.
5. China is the world's largest hydrogen producer, yielding one-third of the world's total. However, as of August 2020, only 3% of China's hydrogen is green [42].
6. By the year 2030, the European Union is planning to produce as much as 10 million (10,000 thousand) tonnes of green hydrogen [39].

3.3.2.1 Canada

Some examples of future Canadian developments include:

- A pilot project in Markham, Ontario developed by Enbridge is potentially the first renewable hydrogen blending project in North America. The power-to-gas facility will blend a portion of the hydrogen gas into the existing natural gas pipeline network [43].
- Toronto, Ontario has proposed a renewable natural gas facility, with plans for three more facilities. The intent is to blend the renewable natural gas with natural gas consumed by the city [44].
- Utility subsidiaries of Atco Ltd. Plan to inject hydrogen into the natural gas streams entering home furnaces and water heaters in Fort Saskatchewan, Alberta [45].
- There are studies underway in Québec to determine how much hydrogen certain gas systems could accept, supplying the basis for increased hydrogen production and then injection into the existing network.
- Renewable Hydrogen Canada recently announced the renewable Sundance Hydrogen project in British Columbia [46], which is stated to be 'world-class scale' though its capacity details remain unknown.
- Canada recently launched the Hydrogen Strategy for Canada. This strategy aims to grow the domestic opportunity for hydrogen and modernize Canada's energy system. The current hydrogen production in Canada is 3 million tonnes per year while the projected hydrogen demand is 20 million tonnes per year. The expectation is that the hydrogen industry could create 350,000 jobs and help Canada reach net-zero emissions by 2050 [41]. Noted in this strategy is that $5 to $7 billion is needed to aid the hydrogen industry.

3.3.2.2 United States

Hydrogen produced in the United States, currently in amount of 9 million tonnes per year [47], is mostly produced via steam-methane reforming of natural gas. Depending on whether the CO2 is vented or captured and stored during production, hydrogen is termed grey or blue, respectively. Significant quantities of hydrogen are produced and used within refineries [48]. Excess hydrogen production and hydrogen production from biomass and other renewables is planned.

There are 2,600 kilometres of hydrogen pipelines currently operating in the United States, with a network of hydrogen pipelines around the US Gulf Coast that transport hydrogen from production plants to users [49].

National Renewable Energy Laboratory (NREL) recently announced the HyBlend Project, an R&D effort (multi-industry, multi-lab) to address the technical barriers of blending hydrogen into natural gas pipelines [50]. This two-year project aims to address technical barriers; the indefinite long-term impact of hydrogen on the pipeline/equipment materials; the costs and environmental impacts of hydrogen injection; and impact of hydrogen blends on appliances and other equipment in homes and buildings.

3.3.2.3 Europe

The number of biogas installations in Europe nearly tripled between 2009 and 2015. However, growth has been stable since 2015 [24]. As of 2020, to reach the EU's climate neutrality objective for 2050, bioenergy production must increase over ten-fold. Electrolytic hydrogen is of primary interest [25]. To cut carbon dioxide emissions by moving away from natural gas while keeping grids in use, Europe is planning several renewable power-to-gas projects in the next five years [51].

Some future German projects to cut emissions include several 100 MW power-to-gas facilities planned for operation starting in 2022 and 2023, plus additional plants coming online later [26] [52].

UK HyNet North West will save over one million tonnes of carbon dioxide emissions per year upon the start of production (2023-2026), with the potential to expand to 25 million tonnes by 2035. HyNet will produce blue hydrogen from natural gas, incorporating the United Kingdom's first carbon capture and sequestration system. The first phase of the project is intended to allow for easy expansion to provide a repeatable program across the United Kingdom. Plans are to supply 100% hydrogen to several large industrial users and introduce as much as 20% hydrogen (by volume) into the existing pipeline network. This project is now in Phase 1 (technical and cost evidence build) and should deliver hydrogen in 2026 [53].

HyDeploy is a pioneering hydrogen energy project in the United Kingdom. It aims to prove that blending up to 20% volume of hydrogen in the existing natural gas infrastructure is safe, thus supplying a greener alternative than natural gas alone [54]. The project has started supplying a hydrogen blend (up to 20%) to customers on Keele University campus in England, with a second, larger demonstration planned to start in 2021.

In the UK, SGN is developing a world-first hydrogen heating network (the H100 Fife project) on the east coast of Scotland that will bring 100% renewable hydrogen into homes in 2022. The first phase will supply about 300 local homes with hydrogen produced by a dedicated electrolysis plant powered by a nearby offshore wind turbine. Phase 2 plans to supply 1,000 homes with renewable hydrogen [55].

3.3.2.4 Other

An Australian power-to-gas demonstration project converts renewable electricity to hydrogen using electrolysis. Most hydrogen is injected into the existing natural gas network, with a portion for generating return-to-grid electricity via a generator; the rest is stored underground in a hydrogen refuelling station for future use [56].

The following will use the existing natural gas network to deliver blended renewable gas to customers:

A renewable hydrogen project, Hydrogen Park South Australia (HyP SA) begun its operation in 2021. It uses renewable electricity (wind and solar) and water that produces hydrogen (using a 1,250-kW proton exchange membrane electrolyzer) to blend up to 5% hydrogen content with natural gas in the current network [57].

Another renewable hydrogen project, Hydrogen Park Gladstone (HyP Gladstone) uses water and renewable electricity from the local grid, which produces hydrogen (with a 175-kW proton exchange membrane electrolyzer) to blend up to 10% hydrogen content with natural gas in the current network [57].

In 2019, the Dubai Electricity and Water Authority (DEWA) began constructing a 1 GW hydrogen from a solar-driven electrolysis facility in the United Arab Emirates [52] [58].

4 Standards Landscape for Renewable Gases

4.1 General Considerations

A distinction must be made between mandatory and voluntary documents used to establish safety and quality specifications of products and services. This report follows the Standards Council of Canada definitions of codes and standards [59] as follows:

- **Code –** broad in scope, it could include references to standards, and is intended to carry the force of law when adopted by a provincial, territorial, or municipal authority.
- **Standard –** document that provides a set of agreed-upon rules, guidelines or characteristics for activities or their results. Standards establish accepted practices, technical requirements, and terminologies for diverse fields.

Table 5: Standards, Codes, and Relevant Documents for Renewable Gas – Feedstocks

Designation	Title	Publication date
ASTM D6866	Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis	2021
Clean Fuel Standard	Government of Canada – Clean Fuel Regulations	2020 Draft
ISO 13641-1	Water quality – Determination of inhibition of gas production of anaerobic bacteria – Part 1: General test	2003
ISO 13641-2	Water quality – Determination of inhibition of gas production of anaerobic bacteria – Part 2: Test for low biomass concentrations	2003
Municipal Waste Guideline	Alberta Government – Municipal Waste Guideline for Renewable Energy Feedstock Version 1.2	2018
SBP Standard 1	Feedstock Compliance Standard	2015

Table 6: Standards, Codes, and Relevant Documents for Renewable Gas – Production and Storage

Designation	Title	Publication date
API 620	Design and construction of large, welded, low-pressure storage tanks	2013
API 650	Welded tanks for oil storage	2020
ASME B31.12	Hydrogen piping and pipelines	2019
ASME BPVC Series	Boiler and pressure vessel code	2019
AWWA B110	Membrane systems	2009
AWWA B112	Microfiltration and ultrafiltration membrane systems	2019
AWWA B130	Membrane bioreactor systems	2018
AWWA D100	Welded carbon steel tanks for water storage	2020
AWWA D103	Factory-Coated Bolted Carbon Steel Tanks for Water Storage	2019
AWWA D108	Aluminum dome roofs for water storage	2019
CAN/BNQ 1784-000	Canadian hydrogen installation code	2007
CEN/TC 234 Document in preliminary stage	Gas infrastructure – Plants for the injection of renewable gases into natural gas networks	In progress
CEN/TC 234 Document number unknown	General requirements for the design, manufacture, construction, testing, commissioning, and operation of plants for the injection of renewable gases into natural gas networks	In progress
CEN/TS 15439	Biomass gasification – Tar and particles in product gases – Sampling and analysis	2006
CSA A23.1/CSA A23.2	Concrete materials and methods of concrete construction / Test methods and standard practices for concrete	2019
CSA A23.3	Design of concrete structures	2019
CSA A23.4	Precast concrete – materials and construction	2021
CSA A23.5	Supplementary cementing materials	1992
CSA B51	Boiler, pressure vessel, and pressure piping code	2019

Designation	Title	Publication date
CSA/ANSI B149.6	Code for Digester Gas, Landfill Gas, And Biogas Generation and Utilization	2020
ISO 11734	Water Quality – Evaluation of the "ultimate" anaerobic biodegradability of organic compounds in digested sludge – Method by measurement of the biogas production	1995
ISO 14593	Water quality – Evaluation of ultimate aerobic biodegradability of organic compounds in aqueous medium – Method by analysis of inorganic carbon in sealed vessels (CO_2 headspace test)	1999
ISO 14855-1	Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions – Method by analysis of evolved carbon dioxide – Part 1: General method	2012
ISO 14855-2	Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions – Method by analysis of evolved carbon dioxide – Part 2: Gravimetric measurement of carbon dioxide evolved in a laboratory-scale test	2018
ISO 16110-1	Hydrogen generators using fuel processing technologies – Part 1: Safety	2007
ISO 16110-2	Hydrogen generators using fuel processing technologies – Part 2: Test methods for performance	2010
ISO 16111	Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride	2018
ISO 16929	Plastics – Determination of the degree of disintegration of plastic materials under defined composting conditions in a pilot-scale test	2021
ISO 17556	Plastics – Determination of the ultimate aerobic biodegradability of plastic materials in soil by measuring the oxygen demand in a respirometer or the amount of carbon dioxide evolved	2019
ISO 20675	Biogas production, conditioning, upgrading and utilization – Terms, definitions, and classification scheme	2018
ISO 22580	Flares for combustion of biogas	2020
ISO 22734	Hydrogen generators using water electrolysis – industrial, commercial, and residential applications	2019
ISO 23590	Household biogas system requirements: design, installation, operation, maintenance, and safety	2020
ISO/AWI 19884	Gaseous hydrogen – cylinders and tubes for stationary storage	In progress
ISO/AWI 23898	Gasification systems for bio-syngas and biomethane production	In progress
ISO/AWI TR 23585	Safety and Environment Guidelines for Biogas	In progress
ISO/FDIS 24252	Biogas systems – Non-household and non-gasification	2020
ISO/TR 15916	Basic considerations for the safety of hydrogen systems	2015
ISO/TS 19883	Safety of pressure swing adsorption systems for hydrogen separation and purification	2017
NFPA 2	Hydrogen Technologies Code	2020
NFPA 59A	Standard for the Production, Storage and Handling of Liquefied Natural Gas (LNG)	2019

Table 7: Standards, Codes, and Relevant Documents for Renewable Gas – Product Quality

Designation	Title	Publication date
ASTM D8080	Specification for Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG) Used as a Motor Vehicle Fuel	2021
BNQ 3672-100	Biomethane – quality specifications for injection into natural gas distribution and transmission systems	2012
Canadian Gas Association Guideline	Guideline for the introduction of biomethane into existing natural gas distribution and transmission systems	2018
CEN/TR 17238	Proposed limit values for contaminants in biomethane based on health assessment criteria	2018
CGA G-5.3	Commodity specification for hydrogen	2017
ECE Regulation 110	Compressed and Liquefied Natural Gas System Components - Uniform provisions concerning the approval of: I. Specific components of motor vehicles using compressed natural gas (CNG) and/or liquefied natural gas (LNG) in their propulsion system II. Vehicles with regard to the installation of specific components of an approved type for the use of compressed natural gas (CNG) and/or liquefied natural gas (LNG) in their propulsion system.	2014
EN 16723-1	Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network – Part 1: Specifications for biomethane for injection in the natural gas network	2017
EN 16723-2	Natural gas and biomethane for use in transport and biomethane for injection in the natural gas network – Part 2: Automotive fuels specification	2017
ISO 14687	Hydrogen fuel quality – Product specification	2019
ISO 21087	Gas analysis – analytical methods for hydrogen fuel – proton exchange membrane (PEM) fuel cell applications for road vehicles	2019

Table 8: Standards, Codes, and Relevant Documents for Renewable Gas – Transmission

Designation	Title	Publication date
ASME B31.12	Hydrogen piping and pipelines	2019
ASME B31.8	Gas transmission and distribution piping systems	2020
ASME BPVC	Boiler and pressure vessel code	2019
CAN/BNQ 1784-000	Code for Digester Gas, Landfill Gas, and Biogas Generation and Utilization	2007
CSA B51	Boiler, pressure vessel, and pressure piping code	2007
CSA Z662	Oil and gas pipeline systems	2019
NFPA 2	Hydrogen technologies code	2019
NFPA 55	Compressed gases and cryogenic fluids code	2020
R.S.C., 1985, c. O-7	Canada Oil and Gas Operations Act	2020
S.C. 2019, c. 28, s. 10	Canadian Energy Regulator Act	1985
TDG SOR/2001-286	Transportation of Dangerous Goods regulations	2019
US DOT 49 CFR Part 192	Transportation of natural and other gas by pipeline: minimum federal safety standards	2020

Table 9: Standards, Codes, and Relevant Documents for Renewable Gas – Applications/End use

Designation	Title	Publication date
CGA G-5.4	Standard for hydrogen piping systems at user locations	2019
CGA G-5.5	Hydrogen vent systems	2014
CGA G-5.8	High pressure hydrogen piping systems at consumer locations	2007
CSA B149.1	Natural gas and propane installation code	2020
CSA B149.2	Propane storage and handling code	2020
CSA B149.3	Code for the field approval of fuel-burning appliances and equipment	2020
CSA HGV series	Compressed and gaseous hydrogen fuel system components, containers, and stations	various
CSA NGV 1	Compressed natural gas vehicle (NGV) fueling connection devices	2017
CSA NGV 2	Compressed natural gas vehicle fuel containers	2019
CSA Z21 and Z83 series	Series of standards covering gas-fueled appliances and their accessories, components, and equipment	various
ISO 19880 series	Gaseous hydrogen – Fueling stations	2018-2020
ISO 19881	Gaseous hydrogen – Land vehicle fuel containers	2018
ISO/AWI 19885	Gaseous hydrogen – Fueling protocols for hydrogen-fueled vehicles	In progress
ISO/AWI 19887	Gaseous hydrogen – Fuel system components for hydrogen fueled vehicles	In progress
NFPA 37	Standard for the installation and use of stationary combustion engines and gas turbines	2018
NFPA 52	Vehicular natural gas fuel systems code	2019
NFPA 54/ANSI Z223.1	National fuel gas code	2021
NFPA 55	Compressed Gases and Cryogenic Fluids Code	2020
NFPA 58	Liquefied petroleum gas safety	2020
SAE J2406	Recommended practices for CNG powered medium and heavy-duty trucks	2002
SAE J2601	Fueling protocols for light duty gaseous hydrogen surface vehicles	2020

Other relevant documents referenced in this report, such as policies, guidelines, specifications, and technical reports are usually produced as interim or internal documents in the absence of standards and codes.

Existing codes and standards used to support the conventional oil and gas industry within Canada and the United States. These codes and standards are also often reported to be used for designing and constructing the renewable gas system components, although they may require updates to target specific needs of the renewable gas industry. Canadian requirements usually align with American and international ones, though some Canadian national standards and other documents have been developed. Codes and standards applicable in renewable gas pathways are discussed in Sections 4.2 to 4.6. They are summarized in Tables 5 to 9 in the following sections: feedstock, production and storage, product quality, transportation, and applications/end use.

Besides standards development organizations, regulators also play a crucial role in establishing standards and codes. Also, there are several industry associations within Canada, the United States, and Europe that collaborate on renewable gas issues and advocate for sustainable development, deployment, and renewable gas use, such as Canadian Gas

Association, the Coalition for Renewable Natural Gas (RNG Coalition), and Canadian Biogas Association (CBA). These organizations provide information, training, and other resources to guide energy and climate policies, boost renewable gas production, and promote research and development on current issues and innovative or alternative technologies. Appendix C gives some information on the standard organizations and other agencies/associations.

4.2 Feedstocks

Codes and standards specific for feedstocks of renewable gas pathways seem scarce. One is SBP Standard 1, developed in 2015 by European utilities under the Sustainable Biomass Partnership (SBP). This standard contains sustainable sourcing requirements for a woody feedstock to be used in biomass production.

However, there are a few documents that could be used for renewable gas feedstocks acceptable quality criteria. ISO has published two standards for testing toxicity of components in environmental samples that could feed anaerobic digesters, ISO 13641-1 and ISO 13641-2. These standards outline tests for the presence of contaminants and their effect on biodegradation; therefore, they could be used to determine the suitability of certain feedstocks or the amount that could be used in anaerobic digestion. It is plausible that ISO test standards for some other contaminants and components could prove useful in renewable gas (especially biogas) production, but a comprehensive review of their applicability was beyond the scope of this research.

Without precise and standardized acceptable contaminant levels, a policy guideline for bioenergy feedstock originating from municipal waste was generated by the Alberta Government [60]. This policy guideline outlines limitations of minimum 50% biogenic carbon content as determined by ASTM D6866 and allows only trace amounts of dangerous compounds in the bioenergy feedstock obtained by sorting and preprocessing the solid waste feedstock.

Although most current Canadian and US policies and regulations for different renewable feedstocks focus on liquid fuels not directly relevant to this research, these policies could be expanded to benefit the renewable gas industry. For instance, this could be done by requiring a certain level of renewable gas to be mixed into the natural gas network, and by dictating acceptable feedstock content for that renewable gas. The Government of Canada's proposed regulation, Clean Fuel Standard [61], is an example of a policy that will promote clean technology, including the use of biofuel and hydrogen as acceptable fuel sources.

4.3 Production and Storage

The equipment and processes used to produce and store renewable gas (such as blowers, compressors, pressure vessels, exchangers, filters, tanks, pumps, desulphurization systems, drying) are common in the natural gas industry. Therefore, many existing natural gas codes, standards and relevant documents were reported by the questionnaire respondents of this study to be used for the biogas, renewable natural gas, and hydrogen gas production (see Appendix C). Among these codes are CSA B51 and ASME BPVC, which set requirements for boilers, pressure vessels, and pressure piping. Standards specifically developed or adjusted for renewable gas production and storage include CSA/ANSI B149.6, which outlines biogas systems installation requirements; CAN/BNQ 1784-000, which sets installation requirements for hydrogen systems; ISO 20675, which defines terms and describes classifications related to biogas production; and ASME B31.12, which provides requirements for design, construction, operation, and liquid and gaseous hydrogen pipelines maintenance. NFPA 59A provides minimum fire protection requirements for liquefied natural gas plants.

ISO 22580 gives specifications for design, productions, and operation of flares for biogas combustion. In addition, technical specification CEN/TS 15439 outlines sampling and analysis methods for tars and particles in product gases of biomass gasification.

Current gaps in renewable gas production standardization are partially addressed by CEN technical committee 234 (CEN/TC 234), Gas Infrastructure, in a working program designed to provide requirements for the plants to inject renewable gases into natural gas networks. Part 1 covers general requirements for design, manufacture, construction, testing, commissioning and operation; part 2 presents specific requirements for biogas; part 3 gives specific requirements for hydrogen; and part 4 will cover plants for preparing combustible gas mixtures.



"Household biogas systems (HBS) that process organic waste into biogas that can be used for cooking, and digestate convertible to fertilizer are covered by ISO 23590."

4.3.1 Biogas and Bio-Syngas

In Canada, CSA/ANSI B149.6 Code is applicable to the installation of systems for production, handling, storage, and use of digester gas in wastewater treatment plants. Many questionnaire respondents answered that they still consider CAN/CGA-B105-M93 to be applicable for these installations although this code was superseded by CSA/ANSI B149.6 in 2011, which highlights some of the confusion or misunderstanding in the industry regarding which codes and standards to apply in the renewable gas pathways.

Anaerobic digesters used in the production of biogas are constructed of either concrete or steel. Steel tanks used for digestion or storage of biogas are either bolted or welded water tanks designed and constructed according to AWWA D103 and AWWA D100, respectively. Design, fabrication, and erection criteria for dome roofs covering these tanks are given in AWWA D108. Oil storage tanks built of steel according to API 650 and API 620 can also be used as anaerobic digesters.

Concrete tanks used as digesters and for storage can be designed to CSA A23 series of standards that specify criteria for materials and methods of concrete constructions, design of concrete structures, and materials and construction for precast concrete.

Household biogas systems (HBS) that process organic waste into biogas that can be used for cooking, and digestate convertible to fertilizer are covered by ISO 23590. This standard provides design, installation, operation, maintenance, and safety requirements for these HBS systems including the production devices (biomass inlet, digestate, biogas storage, etc.) and pipelines. Any equipment or appliances connected to a HBS or using the energy are not part of this standard.

Biodegradation test standards are mainly developed by ISO. An anaerobic biodegradation test that evaluates the ultimate anaerobic biodegradability of organic compounds with a known carbon content in digested sludge is described in ISO 11734. Aerobic biodegradability of organic compounds in water is tested by ISO 14593, and biodegradability of plastic material under controlled composting conditions by ISO 14855 series and ISO 16929, while ISO 17556 describes test for assessing biodegradability of plastic materials in soil.

ISO/TC 255 is currently preparing three documents: ISO/AWI TR 23585 will provide safety and environmental guidelines for biogas; ISO/AWI 23898 will provide guidance on bio-syngas and biomethane gasification systems; and ISO/FDIS 24252 will provide guidance on non-household and non-gasification biogas systems from design to maintenance phases.

4.3.2 Renewable Natural Gas

For production of renewable natural gas, most notable has been the development of efficient, state-of-art membrane material with high gas selectivity for methane purification (primarily carbon dioxide removal) in the biogas mix. A few AWWA standards applicable for filtration in water and reclaimed water systems have been used for the minimum design, use, and installation requirements of several types of membrane

separation technologies in the renewable natural gas pathway, where possible. AWWA B110 standard is applied for membrane filtration systems, AWWA B112 for ultra and micro membrane filtration systems, and AWWA B130 for membrane bioreactor systems. AWWA B112 does not cover membranes used in biological wastewater treatment, so its applicability is limited.

4.3.3 Hydrogen

ISO/TR 15916 outlines basic safety considerations for hydrogen systems. Hydrogen generators that use electrochemical reactions to electrolyze water to produce hydrogen are built following ISO 22734; and ISO 16110-1 and ISO 16110-2 are applicable to hydrogen generators using fuel processing technologies that convert fuels such as natural gas and hydrogen. Chapter 13 of NFPA 2 sets requirements for hydrogen generation systems, namely the fundamental safety provisions for hydrogen generation, installation, storage, piping, use, and handling in compressed gas form or cryogenic liquid form. ISO 16111 addresses construction and testing requirements for transportable gas storage devices, so called metal hydride assemblies. ISO/TS 19883 specifically deals with design and safety of pressure swing adsorption systems for hydrogen separation. ASME B31.12 applies to the design of hydrogen piping systems, in addition to ASME B31.3 giving requirement for all piping systems.

ISO/TC 197 is currently developing ISO/AWI 19884 standard to provide guidance on hydrogen stationary storage, specifically cylinders and tubes.

4.4 Product Quality

The following sections discuss documents that establish quality specifications for renewable natural gas and hydrogen. Documents for raw biogas, bio-syngas quality, and conditioned biogas, as well as for their transmission, are not discussed in this report. The reason for this omission is that these gases are used as intermediate products on site, and their specifications, if required, may be addressed specifically by the company handling them.

4.4.1 Renewable Natural Gas

Since renewable natural gas is blended with natural gas and transmitted through natural gas networks, it must meet the specifications applicable for the natural gas network. These specifications are similar within Canada and the United States, but slight differences do exist [62]. Table 10 provides a comparison of the renewable natural gas requirements of BNQ 3672-100 to the natural gas specification of several gas distributors/utilities. The data confirm that although common parameters of renewable and natural gas (such as hydrogen sulphide, oxygen, and heating value) are in alignment, there is no consensus for scarce components in renewable natural gas.

In addition to Table 10 specifications, other utility companies also created renewable gas specifications, such as:

- Vermont Gas (VGS) – Renewable Natural Gas Program Manual [66].
- Pacific Gas and Electric Company (PG&E) – Gas Rule 21 [67].
- DTE Energy – Operating statement [68].
- NWNatural – Northern Natural Gas Operating Guidelines Biomethane Receipts [69].
- Northeast Gas Association; Interconnect Guide for RNG in New York State [70].

Canada

There are two pan-Canadian documents on biomethane quality. BNQ 3672-100 standard applies to biomethane produced from biogas resulting from anaerobic decomposition and details the requirements renewable natural gas must meet prior to injection into existing natural gas pipelines. Although specifications of major components are detailed, minor constituents like nitrogen and siloxanes are deemed acceptable if non-detectable by current test methods.

Biomethane Quality Guideline of Canadian Gas Association is based on existing Canadian natural gas quality specifications, recommended component limits from European and American standards, and practices recommended by the Canadian Gas Association Biomethane Task Force. The guideline is not prescriptive and states that the final decision for renewable natural gas introduction should be considered by gas utility [71].

Table 10: Comparison of Common Parameters of Renewable Natural Gas as specified in BNQ 3672-100 standard to Natural Gas specified by utilities companies or distributors

Component	BNQ 3672-100	TC Can. Mainline [62]	Alliance Canada (USA) [62]	Enbridge [62]	SoCalGas [63]	Kinder Morgan [64]
Max Hydrogen Sulphide (mg/m^3)	6-23	23	23	6	6	6 (Note 1)
Max Carbon Dioxide (vol %)	2	2	2	2	3	2 – 3 (Note 1)
Max Oxygen (vol %)	0.4	0.4	0.4	0.4	0.2	0.001 – 0.2 (Note 1)
Carbon Monoxide (Note 4)	Not stated	Not stated	Not stated	Not stated	Not stated	Not stated
Heating Value HHV (MJ/m^3)	36 – 41.3	36 – 41.34	36 – 60 (35.8 min)	36 – 41.3	36.9 – 42.8	35 – 46 (Note 2)
Siloxanes (ppmv)	1	Not stated	Not stated	0.001	1	1
Max Arsenic (mg/m^3)	Not stated	Not stated	Not stated	Not stated	0.019	0.19
Biologicals	Free using a 0.3 – micron filter (not stated)	Not stated	Not stated	Technically free of live bacteria	Commercially free of bacteria >0.2 microns)	Free from dusts and gums or solid particles; (Note 3)

Table 10 Notes:

1. Content limits for hydrogen sulphide, total sulphur, carbon dioxide, nitrogen, oxygen, and other inert compounds are included in Kinder Morgan tariffs or gas quality contract clauses for specific pipelines. These limits apply to biomethane supplies [65].
2. Individual pipeline tariffs and contractual gas quality requirements for heating value requirements must be followed [65].
3. Refer to the individual Kinder Morgan pipeline's tariff or gas quality contract clause for specific limitations [65].
4. Carbon monoxide is not mentioned in any of the pipeline specifications listed in this table. Carbon monoxide can cause stress corrosion cracking in carbon and low alloy steels, therefore acceptable carbon monoxide levels need to be defined [65].

United States

Likewise, American Biogas Council published its renewable natural gas quality recommendations, based on data provided by companies injecting renewable natural gas into the natural gas grid [72].

Certain regions, like Southern California, defined limits of contaminants allowable in biomethane typically found in low levels in the current fossil-fuel based pipelines [73]. Southern California Gas (SoCalGas) company's biomethane quality specifications, Rule No. 30, established limitations on the following [63]:

- Arsenic
- p-Dichlorobenzenes
- Ethylbenzene
- n-Nitroso-di-n-propylamine
- Vinyl Chloride
- Antimony
- Copper
- Hydrogen Sulphide
- Lead
- Methacrolein
- Toluene
- Alkyl Thiols (mercaptans)
- Siloxanes
- Ammonia
- Hydrogen
- Mercury
- Biologicals (Bacteria)

As per specific applications, a recently published ASTM D8080 specifies requirements for compressed and liquified natural gas, including biogas, used as a motor vehicle fuel.

Europe

Technical committee CEN/TC 408 was established in 2011 with a mandate to develop standards for biomethane for use in transport and injection in natural gas pipelines. The committee so far published three documents relevant for this topic. Standards EN 16723-1 and EN 16732-2 provide specifications for biomethane for injection in the natural gas network and for use in transport, respectively, and define limits for silicon, carbon monoxide, and ammonia but do not encompass all possible contaminants in renewable natural gas. Technical report CEN/TR 17238 provides an approach for assessing limit values for contaminants that may be found in biomethane based on health assessment criteria.

Economic Commission for Europe (ECE) Regulation 110 sets limits on various contaminants, including hydrogen sulphide, oxygen, hydrogen, and siloxanes/silicon [74] specific to vehicles using compressed natural gas (CNG) and/or liquefied natural gas (LNG). These limits need to be considered when designing and operating facilities that obtain natural gas from the pipeline where RNG is injected.

Members of the European Association of Internal Combustion Engine Manufacturers (EUROMOT) [75] agreed on several specifications for natural gas containing hydrogen used by gas engines and turbines, some of which include:

- Wobbe Index, an empirical parameter often used as a specification for gas interchangeability, not exceeding 53 MJ/m^3;
- a variability in Wobbe Index limited to 3 MJ/m^3 for gas applications in a given region;
- early notification of changes in the average Wobbe Index;
- siloxane free gas composition;
- a total sulphur content not exceeding 10 mg/m^3; and
- a maximum calorific value of 2 MJ/m^3.

4.4.2 Hydrogen

There are several international specifications available for hydrogen fuel, but most are applicable specifically for hydrogen fuel powering fuel cells, as opposed to hydrogen quality. Some specifications that cover a broader range of items and could set quality standards for renewable hydrogen, include [76]:

- CGA G-5.3 – describes requirements for commercially available hydrogen, both liquid and gas; includes quality verification and testing procedures.
- ISO 14687 – specifies quality requirements for hydrogen used in vehicles and stationary equipment, and analytical techniques for laboratory, production, and in-field operations.
- ISO 21087 – specifies suitable laboratory analyzing techniques for determining hydrogen impurities specified for D-grade hydrogen per ISO 14687.

4.5 Transmission

The renewable gas industry currently relies on the oil and gas industry's codes and standards for the design, fabrication, and construction of transmission systems, as the equipment and processes used in transmission are common in the natural gas industry.

North American industry complies with the requirements of these major documents:

- Renewable natural gas is transported through pipeline systems constructed and operated to CSA Z662 and ASME B31.8.
- Hydrogen specific piping and pipelines requirements are described in ASME B31.12 and CAN/BNQ 1784-000.
- Boilers and pressure vessels are certified to CSA B51 in Canada and ASME Boiler and Pressure Vessel Code (BPVC) in the U.S.A.

4.5.1 Renewable Natural Gas

Renewable natural gas, once conditioned to meet pipeline quality specifications, is suitable for pipeline transmission to customers, the major natural gas transmission route.

Renewable natural gas transportation is regulated by the Canadian Energy Regulator Act, the Canada Oil and Gas Operations Act of the National Energy Board, the laws of provinces in Canada, and by Codes of Federal Regulations (CFRs) established by Department of Transportation's Office of Pipeline Safety, as well as US state laws, the most notable being 49 CFR Part 192.

4.5.2 Hydrogen

Hydrogen can be transported by tanker truck, rail transport, and pipelines. In Canada, hydrogen transportation is controlled by Transportation of Dangerous Goods (TDG) regulations, which govern transport by air, highway, rail, or water [77]. Hydrogen transportation regulations in the US are summarized in detail in Sandia National Laboratories report [78]. NFPA 2 also contains requirements pertinent to hydrogen transmission, and NFPA 55 outlines requirements for portable cylinders, tanks, and containers for compressed gases.

Regarding hydrogen pipelines, questionnaire respondents noted that portions of a hydrogen blending station are currently designed and installed by ASME B31.12, CAN/BNQ 1784-000, and CSA B51.

Hydrogen injection concerns still include safety, refuelling standards, and permitting for refuelling stations [79]. Hydrogen embrittlement of existing steel pipelines designed for natural gas is a material longevity *and* safety concern, especially at higher pressures in existing pipeline networks (hydrogen adsorption into the steel increases with higher pressures). Increased hydrogen content in piping networks impacts the pipeline hydraulics and compression operation (hydrogen occupies more space than natural gas). Higher hydrogen content increases flame velocity and temperature, causes different autoignition behaviours, and leads to a wider flammability range. Therefore, the maximum allowable hydrogen content is being investigated.

Current allowable pipeline hydrogen levels range from less than 0.5% volume (Lithuania, Netherlands, Japan, United Kingdom, and Belgium) to 1.0% volume (Finland), 2.0% volume (Germany and Switzerland), and 6.0% volume (Austria). Under certain circumstances, hydrogen levels in higher amounts are allowed by certain countries (e.g., 8.0% in specific locations in Germany where no compressed natural gas filling stations are connected to the network) [80]. In Canada, Enbridge gas utility will be injecting, by fall 2021, up to 2% hydrogen in the natural gas pipeline of Markham, ON [81] [82].

4.6 Applications / End-Use

Appliances producers currently rely on existing codes and standards to design and build guidelines for products to be used with renewable gas. Gas-fueled appliances, and their accessories, components, and equipment are designed and fabricated, according to numerous standards, among them CSA Z21 and CSA Z83 standard series. Appliances installation is performed mainly according to CSA B149.1, CSA B149.2, and CSA B149.3 in Canada, and ICC International Fuel Gas Code and NFPA 54/ANSI Z223.1, NFPA 58, and NFPA 37, in the United States.

The CSA research report on hydrogen use in space-heating appliances determined that hydrogen gas blends with up to 15% hydrogen content did not pose any operational or safety issues, despite the reduced hydrogen density in comparison to natural gas, and a wider range of flammability [83].

In the automotive industry, NFPA 52 covers design and operation of CNG engine fuel systems on vehicles and fueling systems and facilities, with fuel-specific standards produced by CSA Group (such as NGV and HGV series) and SAE (e.g., J2406 and J2601). In Europe, ISO 19880 series cover fueling stations and ISO 19881 covers land vehicle fuel containers. ISO/TC 197 is preparing ISO/AWI 19885 series for fuelling protocols for hydrogen-fuelled vehicles, and ISO/AWI 19887 fuel system components for hydrogen fuelled vehicles.

NFPA 55 contains requirements for gaseous hydrogen systems at consumer sites, and CGA G-5.4, CGA G-5.5, and CGA G-5.8 specify hydrogen piping and vent systems at consumer locations, respectively.



"The literature review shows a persistent lack of consensus among technical experts regarding the long-term impact of contaminants on renewable gas and of blends on pipeline components and end-use devices."

5 Critical Needs and Potential Gaps in Codes and Standards

Literature review and industry stakeholders' surveys and expert consultations, identified needs for consensus and standardization documents in the following areas:

- Technical (design, material durability, and integrity management) requirements, and safety and risk mitigation, and
- Economy and policy.

While the latter theme is not directly related to this research on standards and codes, it is important for increasing renewable gas production.

5.1 Technical Requirements, and Safety and Risk Mitigation

Technical barriers for renewable gas and hydrogen development and implementation vary depending on the type of renewable gas and its production pathway. There are also terminology differences across the industry for various renewable gas products and pathways.

The literature review shows a persistent lack of consensus among technical experts regarding the long-term impact of contaminants on renewable gas and of blends on pipeline components and end-use devices. Studies completed to date suggest renewable gas blend ratios of 20% hydrogen by volume or less are viable for existing infrastructure where little or no modifications would be needed [84]. This said, other experts have said any amount of renewable gas blend, regardless of concentration, particularly hydrogen, poses a long-term risk with respect to material durability. Opinion discrepancy can only be addressed by developing a national based agenda to support research and activities that will allow standard and code development. Without technical consensus, any standard and code will be rigid and overly conservative [85].

Critical to codes and standards development for renewable gas technology is research and development that will examine gas behaviour and effects of unintended renewable gas release. Although industry knowledge has been improving, much research and development is still needed to fully understand the physical mechanisms of renewable gas dispersions as they relate to gas build-up and combustion in enclosed spaces, flammable cloud formation, ignition, deflagration-detonation transition, and renewable gas flashing, pooling, and vaporization. Components and systems need to be tested under operational and environmental conditions that replicate real-world use to confirm the safe and effective operation of renewable gas technologies.

5.1.1 Feedstock

Survey participants did not report compliance with any specific document for selecting or processing feedstocks for renewable gas. Also, no standards prescriptive of the feedstock chemical composition

were found in the literature. There are several existing codes and standards developed for testing certain contaminants by organizations like ISO (some stated in section 5.3.1) currently used by Canadian companies that should be adopted in Canada.

Feedstock variation challenges, especially biomass composition variability, can be overcome by designing the feedstock processing system (i.e., select appropriate technologies and arrange processes steps). Therefore, standardizing the feedstock makeup may be unnecessary. However, regulating acceptable feedstock contaminant levels is important from a health and environmental perspective, and Table 5 lists a few existing standardization documents. Further advancement of renewable gas industry is expected to increase the number of this type of regulatory and consensus documents.

5.1.2 Production and Storage

Most equipment and processes in renewable gas production are well known to the oil and gas industry. However, industry respondents noted that material durability associated with long term exposure to contaminants in renewable gas and high hydrogen content blends presents a possible concern. A few equipment items unique for renewable gas production were identified to pose challenges in both the surveys and literature.

5.1.2.1 Biogas, Bio-Syngas, and Renewable Natural Gas Pathways

A need for research and standards development was identified for the internal tank mixing systems and internal protective coatings for anaerobic digesters and biogas storage. These coatings should be able to withstand harsh process conditions. Therefore, requirements for materials resilient to cold climates, stability and durability criteria, fabrication and defect management, and coatings application devices should be determined.

Although the equipment used for renewable gas production is made of concrete or steel, just like for the conventional gas industry, consideration should be given for additional design features supporting the resistance to the process. Construction materials to withstand potential contaminants in renewable gas production, especially concerning anaerobic digesters and biogas holders, need further research and development for both wall and roof material, including roof-to-shell joint and flexible inflatable membranes or bladder.

Since renewable natural gas composition is comparable to that of natural gas, uncontrolled release poses similar combustion risk, but the contaminant potential and impacts of some components (like arsenic and mercury for instance) needs to be understood.

5.1.2.2 Hydrogen

Since electrolysis is an emerging and promising technology for hydrogen production from renewable resources, standardization documents are anticipated for design prescription and construction of hydrogen linear power/generation systems; storage methods and materials (particularly metal hydrides, nano-structured materials, and chemical hydrides); reactor design, system construction, and material selection; system performance and maintenance; as well as electrolysis energy (i.e., electrolyte conductivity).

In addition, hydrogen produced via any pathway will require greater storage facilities than typical for the oil and gas industry, as more hydrogen will be required for the same energy outputs. Designing these large storage facilities is a technical and commercial challenge. Storing large quantities of hydrogen will require either geologic formations (e.g., salt caverns) or cryogenic liquid storage systems. Key issues with geologic storage include locating a suitable geologic formation close to production, hydrogen leakage through the geologic openings, hydrogen reactivity, and material degradation and failure [86]. It is, therefore, expected that cryogenic liquid storage systems will be more prevalent. As NFPA 2 sets an upper maximum of 283,907 litres (75,000 gallons) for stationary liquid hydrogen storage systems, codes and standards for larger hydrogen storage will need to be developed.

The integrity of the existing natural gas distribution network with long term exposure to elevated levels of hydrogen at high pressures is unknown. As stated earlier, there are globally several ongoing pilot projects injecting 10% hydrogen into existing transmission systems. Injections of 20% hydrogen are achieved

in one, and planned for another pilot project. The achievable amount of hydrogen to be injected into Canada's and North America's existing transmission system needs to be identified due to the different users of gas from the system (e.g., several compressor stations use the transmitted gas to power compressors via gas turbines) and different materials used for pipeline systems.

Hydrogen has a broader range of conditions under which it will ignite and is lighter than natural gas. Therefore, high hydrogen blends and pure hydrogen will have a greater risk of ignition and resulting damage [84].

5.1.3 Product Quality

5.1.3.1 Renewable Natural Gas

Typically, renewable natural gas can be transportation fuel when liquefied gas or injected into existing natural gas distribution systems. As stated in Section 5.4.2, a few utility companies-created specifications pointed to a lack of a consistent set of requirements for the renewable gas products as hampering their implementation. Specifically, contaminant levels allowed in renewable gas were not completely standardized (specifications available for natural gas are typically silent on possible contaminants in renewable gas, especially originating from biomass).

5.1.3.2 Hydrogen

Contaminants potentially found in feedstock can be transferred to the hydrogen product and deter its use by utility companies and end-users. The nature and types of contaminants possibly present in the hydrogen product and their potential impacts are unknown and warrant further research.

5.1.4 Transmission and End-Use

5.1.4.1 Renewable Natural Gas

Like standardization of product quality, transmission and application of renewable natural gas is expected to follow the natural gas standardization documents.

CSA/ANSI B149.6 Code is well developed and covers the design of the low-pressure applications/end-use of these products.

5.1.4.2 Hydrogen

The integrity of the existing natural gas distribution network with long term exposure to elevated levels of hydrogen at high pressures is unknown. The maximum amount of hydrogen to be injected into existing transmission system needs to be studied and identified to account for different gas end users and for different construction materials making up the pipeline systems. It is expected that the blending cap for existing infrastructure will be 20% hydrogen, based on the existing combustion equipment. Beyond that level of hydrogen, it would be necessary to significantly modify or replace equipment. For new pipeline construction, maximum hydrogen amount might be higher.

Beyond the CSA Group research report on space heating appliances under controlled conditions [83] and a few similar studies on hydrogen blends effect on appliances (e.g. [87]), the full impact on end-use devices of hydrogen will require substantial research and development. Gas build-up in a confined space leading to fire and explosion is a risk specific to high hydrogen blend use that needs to be investigated for domestic use.

5.2 Economy and Policy

Renewable gas pathways, particularly renewable natural gas, and hydrogen from renewable sources, are currently more expensive than fossil fuel pathways [88] [89]. This is typical for new technologies and small scale or not widely used production. To lower costs, government support for developing infrastructure for renewable gas production, distribution, and dispensing is essential. Government regulations or initiatives could include:

- Prioritize large-scale hydrogen infrastructure development based on blue (low carbon) and renewable (green) hydrogen.
- Develop policies specifying carbon intensity of renewable gas versus natural gas.
- Establish short and long-term tiered thresholds for renewable gas content in natural gas networks.
- Adopt policies and regulatory framework that will allow additional renewable gas infrastructure to be completed economically for the developer.

- Support renewable gas technologies research, development, and deployment to create competitive advantages.
- Establish a strategic investment fund to support all the above policy developments.

Jurisdictions that have developed renewable gas standards did so to provide quality, price, and supply certainty to aid renewable gas technology deployment [90] [91]. Regulatory and policy content considered in the development of a renewable gas standard have included greenhouse gas (GHG) emissions cap-and-trade program, low-carbon fuel standard program, renewable portfolio standard program, self-generation incentive program, and renewable fuel standards.

5.3 Summary

Questionnaire respondents noted the lack of adopted standards and codes that provide guidance for allowable feedstocks, production, and renewable gas quality. Designers of renewable gas production facilities must determine alone which codes and standards to apply, and often rely on international standards and codes, without understanding the basis or the methodology used to develop those standards. An overall guide on applicable codes and standards for each pathway (a roadmap) would be useful for designers.

Research and development will support the discussed gaps focused on promoting standardization with respect to feedstock quality, renewable gas quality, production pathway, and safety.

Table 11: Gaps in Codes and Standards – Technical and Safety / Risk Gaps in Codes and Standards

Standard/ code topic	Identified gaps
Feedstock	Codes and standards for feedstocks of renewable gas pathways are scarce. Variation of feedstocks and their composition variability, especially for biomass, are technical challenges addressed during system design (i.e., select appropriate technologies and arrange processes) but do not necessarily need heavy standardization. A code or standard defining acceptable feedstocks (nature and types of contaminants) would prove useful. Adopting international codes for testing various feedstocks (tests for contaminants and biogas potential), would assist designers.
Production and Storage	For biogas and renewable gas, research is required to determine whether additional design features need to be incorporated into construction materials for the equipment and processes used (specifically anaerobic digesters and biogas storage). For electrolytic hydrogen, additional research and development are required for linear power/generation for hydrogen production, storage methods and materials, reactor design, and system performance and efficiency (i.e., operation and maintenance, electrolyte conductivity, and material stability and durability).
Product Quality	No widely-adopted standardized set of specifications or guidelines was found specifically for renewable natural gas. A lack of consistent standards for RNG specifications were noted by questionnaire respondents as hampering their design and implementation efforts. The contaminants potentially found in the feedstock that could end up in the renewable hydrogen gas can affect the willingness of utility companies and end-users to use that hydrogen or affect its allowable quantity. Feedstock contaminants presence is an unknown requiring research to determine types of contaminants and their potential impacts on hydrogen production. Existing specifications for hydrogen fuel cells could be referenced for renewable hydrogen testing procedures and quality standards.
Transmission Applications and End-Use	Acceptable levels of contaminants in renewable gas originating from digestion of different feedstocks and their long-term impact on production equipment, transmission system, instrumentation, pipelines, and end-use equipment is unknown. Integrity of existing natural gas distribution network with long term exposure to elevated levels of hydrogen at high pressures seen in transmission systems is unknown. The achievable amount of hydrogen to be injected into Canada's and North America's existing transmission system needs to be studied and identified to account for different gas end users and different construction materials making up the pipeline systems. For new pipeline construction, a new code or standard could be applied but may have to be addressed on a case-by-case basis for existing transmission systems.

Safety/Risk	Research and development are required in order to fully understand the physical mechanisms of renewable gas diffusion as it relates to gas build-up and combustion in enclosed spaces; flammable cloud formation; ignition; deflagration-detonation transition; and renewable gas flashing, pooling, and vaporization. Components and systems need to be tested under operational and environmental conditions replicating real-world use to confirm the safe and effective operation of renewable gas technologies. The contaminant potential of some components (e.g., arsenic and mercury) in renewable gas needs to be understood.
Overall Guide	An overall guide on applicable codes and standards for each pathway (a roadmap) would be useful for designers. This report can be a supporting document for the initiative to develop the necessary regulations.

6 Identification of Promising Pathways in the Canadian and USA Markets

Increased renewable gas production is vital for meeting Canada's 2050 net zero emissions goal. Low carbon fuels are expected to supply up to 60% of Canada's energy needs in a net zero future [41]. USA goals and targets have been changing but increased renewable gas production is critical for them to decrease carbon emissions.

The Canadian potential for renewable gas (including hydrogen) production from biomass is estimated at 44,168 thousand tonnes per year (Mt/y) [16] or 1,300 billion cubic feet per year (Bcf/y), which is over half the country's current annual natural gas consumption of 84,938 Mt/y (2,500 Bcf/y) [16]. There is also motivation created by the need to process organic waste since landfilling options are decreasing and the potential profit available by the sale of renewable natural gas. Renewable natural gas can emit up to 85% less greenhouse gas emissions than traditional fossil fuels [14].

Hydrogen is the lowest carbon fuel, so it is essential to decarbonize most energy intensive end-use applications. Canada has all the ingredients necessary to develop a competitive and sustainable hydrogen market, given its large quantity of natural resources and the extensive gas distribution network already in place. Hydrogen is emissions-free but the process of producing hydrogen itself is often not clean. The large natural gas production can also help fuel hydrogen production since hydrogen can be produced from natural gas. Combined with carbon capture and storage, blue-hydrogen can initially reduce the carbon footprint until renewable hydrogen production is increased significantly [92].

In summary, the promising renewable gas production pathways for the Canadian and USA markets are:

- Biogas pathway – typically used as the source for power and heat purposes
  - Canada's and USA's potential are high given their large biomass production.
  - The pathway is well-known and established world-wide, with proven technology and equipment designs.
- Renewable natural gas production through the upgrade of biogas
  - Canada's and USA's potential are high given their large biomass production. There will be competition for biogas use.
  - The pathway is well-known and established world-wide. Innovative technologies or improvements are becoming commercial with lower heat input and/or constructed for lower capital costs and/or requiring lower operating costs.
- Renewable (green) hydrogen production pathways, including electrolytic hydrogen production and energy storage and hydrogen production from renewable gas using renewable energy sources
  - Canada and the USA are rich in feedstocks to produce hydrogen.

- Canada and the USA are among the lowest carbon intensity electricity supplies in the world given their hydroelectric and nuclear generation capacity.
- Canada and the USA have world class CO_2 storage geology.
- Canada is recognized as a global leader in hydrogen and fuel cell, with extensive technical expertise, intellectual property, and leading products and services.
- Hydrogen consumption via hydrogen fuel cells, for use in the heavy-duty transport and rail industry, is expected to increase to help decarbonize this industry.

7 Summary and Conclusion

Renewable gas development and implementation will change the fuel and energy industry and assist communities to transition to a low-carbon economy. Blending renewable natural gas or hydrogen and natural gas, with ratios increasing over time, has the potential to accelerate energy transition to net zero emissions.

Pathways for renewable gas production considered established and mature involve first generation technologies like anaerobic digestion of organic waste and splitting water molecules using electrolysis to produce green hydrogen. One of many challenges renewable gas faces in gaining initial market access is that the natural gas supply infrastructure is typically not near gas production plants. Second generation technologies involve the pathways of converting biomass via gasification and methanation or steam reforming into either renewable natural gas or renewable hydrogen. These technologies are not yet financially viable, but once commercialized, they stand to produce renewable gas in significant volumes by deploying central production plants that will have a greater impact than first generation technologies operating on a small-scale basis.

A common response from questionnaire respondents was the lack of standards and codes for approved renewable gas production pathways that provide guidance with respect to feedstocks, production, and renewable gas quality. Currently, designers of these facilities must determine on their own which codes and standards to apply, and often rely on international standards and codes, without understanding the basis or methodology used to develop those standards. An overall guide on applicable codes and standards for each pathway (a roadmap) would be useful for designers.

To our knowledge, this research report is a first step in developing an understanding of the existing standards landscape on renewable gas pathways. A comprehensive literature review, expert consultation, and information from key industry stakeholders was compiled to show existing standards and gap areas requiring development. The report supplies initial information for developing Canadian codes and a standards roadmap for renewable gas and maximizing standards harmonization domestically and internationally.

The findings of this report informed some renewable gas research, policy, and standards development efforts. These efforts need to continue and harmonize to further renewable gas deployment while leveraging its benefits of reducing greenhouse gas emissions to meet global reduction targets. A focus on international cooperation and standards harmonization will allow technology and consistent safety regulations promotion interoperability.

Renewable gas production is a major, proven industry in many parts of the world. Biogas production has an especially significant footprint in Europe (19,000 facilities), China (100,000 facilities), Nepal (300,000 facilities), and Vietnam (183,000 facilities), to name a few. Renewable gas production is becoming a focal point for many countries to further displace fossil fuel use and reduce net greenhouse gas emissions. Hydrogen production, for blending into existing natural gas networks or direct use in industrial and major fuel users, is emerging as a critical focal point in many countries as an added means to displace fossil fuel use and is a critical part of many countries' decarbonization plan.

Extensive renewable gas deployment in Canada is required to meet its 2030 (30% reduction) and 2050 (net-zero) decarbonization goals and emission reduction commitments [93]. Direct electrification and supply of renewable sources (e.g., wind and

solar) alone will not displace enough fossil fuel-based energy to meet reduction requirements and transition to low carbon economy. Achieving these goals is only possible by deploying renewable gas together with other renewable energies (e.g., wind and solar).

Canada is relatively new to renewable gas production. There are a few hundreds operating renewable gas production facilities, with more facilities planned to be built. All renewable gas forms including hydrogen production need to be maximized to help Canada meet the net-zero emission target by 2050. The recent launch of Canada's hydrogen strategy is part of Canada's strategy to decarbonize domestically.

Canada is well positioned to play a significant role in the relevant efforts moving forward, due to our significant natural resources and extensive natural gas distribution system. Key areas where Canada can contribute and/or take a leading role include standards harmonization efforts; the development of a renewable gas code; and frameworks for research, development, and testing renewable gas technologies. Active cooperation and efforts alignment with the United States will help ensure interoperability and shared knowledge, critical considering the shared natural gas infrastructure.

Renewable gas is a rapidly evolving industry in Canada and the United States. Although many efforts have started for displacing natural gas with renewable gas, a lot of work still remains. It is important that necessary codes and standards be in place to guide the industry, promote safety, and foster renewable gas innovation and growth.

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Appendix A – Questionnaire

CSA Codes and Standards Roadmap – Questionnaire

WSP has been retained by the CSA Group to assist with research on the development of a Codes and Standards Roadmap for Renewable Gas Pathways. This research project will lay the foundation and provide guidance for future Codes and Standards development.

As part of this process, WSP is interested in engaging with key industry agencies and organizations to learn more about their current and planned activities, particularly as they relate to Codes and Standards, and hear their perspectives on relevant needs, trends, and gaps/issues.

Note renewable gases include biogas, bio-syngas, renewable natural gas, synthetic natural gas, and hydrogen (via power-to-gas or other renewable pathways).

Agency/Organization Name: _____

Contact Information: _____

Questionnaire

Question 1: Please provide a general description of your organization.

Question 2: What are your main activities with regards to renewable gases (production, feedstocks, products, storage and transmission, monitoring, regulating, etc.)? What specific renewable gas pathway(s) is your organization involved with?

Question 3: Please provide insight to the technical, commercial, and infrastructure challenges or barriers that limit the growth of the renewable gas industry.

Question 4: Where does your organization go to look for Standards, Codes or Regulations that are relevant for your work?

Question 5: What are your main activities with regards to codes and standards development efforts (e.g., follow, actively monitor, participate)? What are your organization's priorities in this space? Is there focus on specific standards or areas?

Question 6: ***[For Public Sector]*** Are there Renewable Gas relevant specific codes, standards and/or regulations that are currently being used by your organization for procurement and planning activities? If so, what are they and how are they used by your organization?

[For Private Sector] Are there Renewable Gas relevant specific codes, standards and/or regulations that are currently being used by your organization? If so, what are they and how are they used by your organization? Is your company developing any product or technology that could benefit from standardization (domestic and/or international)?

Question 7: Are you aware of any other ongoing work or projects related to the development of codes, standards and regulations for Renewable Gas production?

Question 8: Please provide insight into known gaps (or concerns) relating to codes, standards and/or regulations for Renewable Gases?

Question 9: What would your organizations priorities be to resolve the gaps in codes, standards and/or regulations identified in Question 8 above? When is this needed by? Describe the importance to your organization and the industry as a whole.

Appendix B – Detailed Process Description of Renewable Gas Pathways

Provided in this section is a detailed process descriptions and simplified block flow diagrams of the renewable gas pathways as discussed in this report.

B.1 Biogas production via anaerobic digestion

Biogas derived from the anaerobic digestion encompasses production and conditioning of digestion and landfill gas. Biogas can be used at the source for renewable heat or electricity, or can also be purified to produce renewable natural gas.

Organic wastes can include a multitude of different feedstocks including biological sludge, municipal solid waste, agricultural residues, animal farm waste, animal by-products and manures, food waste, and biomass [94] [95] [96]. Other feedstocks for biogas production include organic waste from industrial, institutional, and commercial entities (such as food manufacturers and wholesalers, supermarkets, restaurants, hospitals, and educational facilities). Biogas can also be produced from lignocellulosic material (such as crop residues, woody biomass, and dedicated energy crops) via thermochemical conversions (combustion and gasification), co-digestion, and dry fermentation. These technologies are underway in Europe, with limited applications in Canada and the United States [97].

A block flow diagram showing the major processes or steps in biogas production from organic wastes via anaerobic digestion is given in Figure 3. The producing biogas process from landfill is similar – in the diagram the landfill gas would be equivalent to raw biogas.

Upon receipt, the feedstock first undergoes pre-treatment. Pre-treatment process differs depending on feedstock type and may include screening; particle size reduction and slurring; thermal hydrolysis; fermentation; and/or chemical (alkyl-acid) treatment. As an example, animal by-products will require particle size reduction followed by thermal hydrolysis. Following pre-treatment, the conditioned waste can be temporarily stored in tanks or blended with other feedstock materials in a mix tank to produce a feedstock with an optimum carbon to nitrogen ratio prior to anaerobic digestion.

Anaerobic digestion occurs in the absence of oxygen and involves organic matter breakdown into methane and carbon dioxide. Anaerobic digestion occurs in nature – in bogs, lake sediments, landfills, and digestive tracts [98]. In commercial biogas production, the biomass feedstock can be heated externally prior to injection into the digester or alternatively via recycle of a slip stream from the digester using, for example, spiral heat exchangers. The digester contents can also be heated directly using internal heating coils within the digester. Anaerobic digestion can be of the wet or dry type. Wet anaerobic digestion can be designed to operate at mesophilic or thermophilic temperatures, depending on the desired digestion. A mesophilic digester operates between 20 °C and 40 °C (typically around 37 °C), whereas thermophilic digesters operate above 50 °C. Mesophilic digesters require a retention time between 20 to 30 days to breakdown and convert the organic matter into biogas, whereas thermophilic digesters require a retention time about 10 to 12 days. Mesophilic digestion is the most common. The main stages of anaerobic digestion are hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Hydrolysis breaks down large polymers, namely proteins, fats, and carbohydrates. These compounds are further broken

down via acidogenesis and acetogenesis. Acidogenesis produces an acidic environment within the digester while creating shorter chain volatile fatty acids, in addition to alcohols, hydrogen, and carbon dioxide. These compounds, while still too large, are further broken down by the process of acetogenesis by bacteria that catabolize many products created in acidogenesis to yield mainly acetic acid, in addition carbon dioxide and hydrogen. Methanogenesis is the anaerobic digestion stage where methanogens create methane from the final acetogenesis by-products.

Anaerobic digestion produces two by-products comprising of raw biogas and liquid digestate (about equal amounts in terms of mass). Raw biogas contains by volume 55 to 70% methane, and 30 to 45% carbon dioxide, between 100 ppm to 10,000 ppm of hydrogen sulphide (H_2S) and trace amounts of other gases. Digestate is rich in nutrients and can be used as a liquid or solid organic soil conditioner or fertilizer. Alternatively, the solids can be used in a composting operation.

Raw biogas, before it can be used, must undergo gas conditioning. Raw biogas conditioning from organic waste is like landfill gas conditioning.

Depending on its end use, biogas conditioning can involve moisture removal, desulphurization, drying, heating, and/or siloxane removal by adsorption [99] [100]. Arranging these process steps will vary depending on selected technologies. Technologies for desulphurization can consist of wet desulphurization, dry desulphurization, or bio-desulphurization [101]. Gas drying would be performed downstream of biological desulphurization, whereas gas drying would be performed upstream of desulphurization when using wet or dry desulphurization [102].

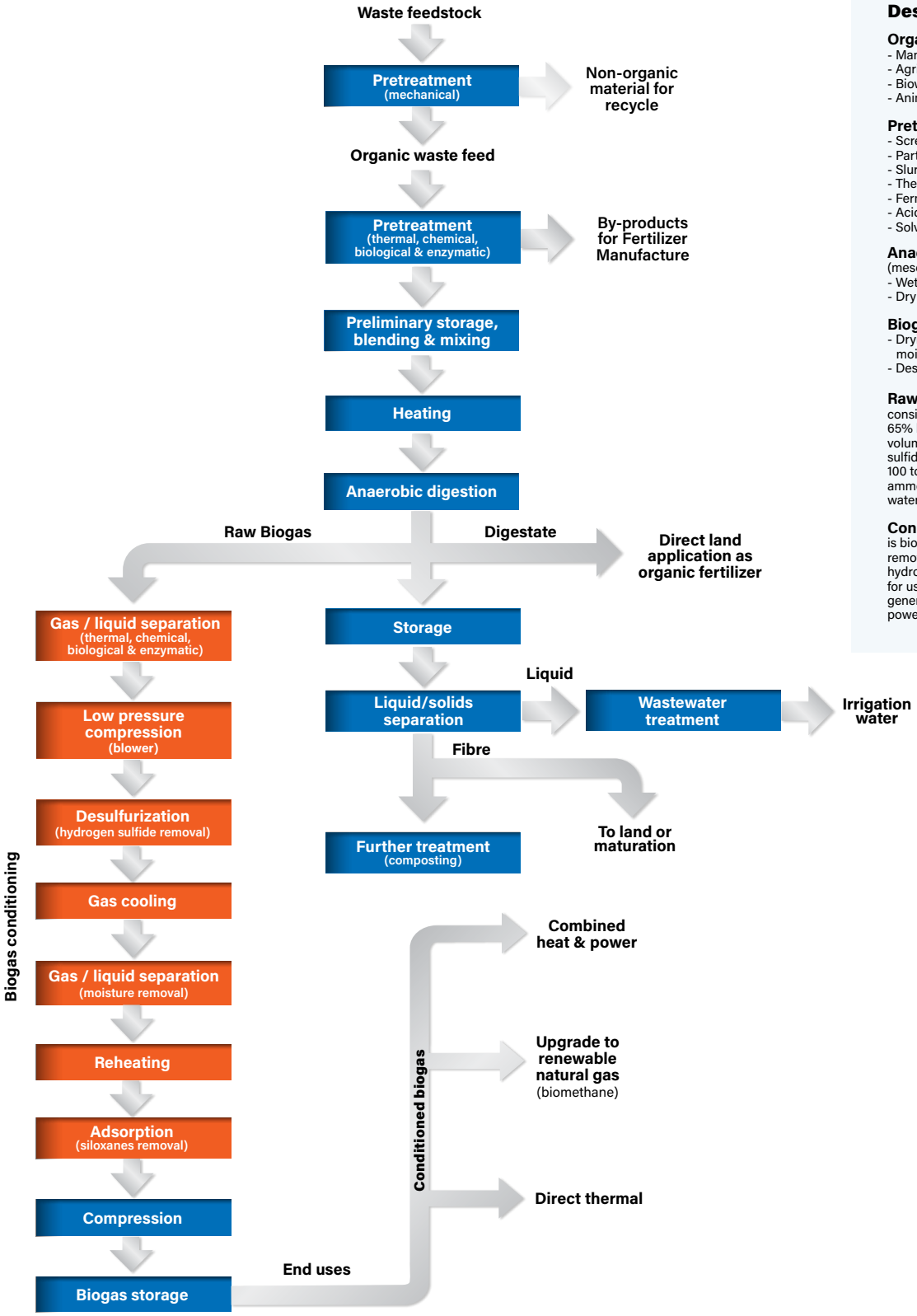
Raw biogas initially collected from the anaerobic digester will undergo gas/liquid separation to remove any entrained moisture droplets before being compressed using a low-pressure blower. From the blower, the gas will undergo particulate prefiltration followed by desulphurization. Wet desulphurization involves the removal of hydrogen sulphide using a solvent within a gas/liquid scrubber. Examples are chemical absorption, physical absorption, and wet oxidation. Dry desulphurization involves removal of hydrogen sulphide using a powder or particle desulphurization agent. Examples are membrane separation, molecular sieve, fixed bed adsorption, and Claus oxidation. Biological desulphurization is a biological process where bacteria help oxidize hydrogen sulphide into its elemental compounds.

Oxygen, in low amounts, can also be injected into the headspace of the anaerobic digester to reduce the amount of hydrogen sulphide produced during anaerobic digestion. Following desulphurization, the gas is cooled, separated from liquid, and reheated. Gas to be upgraded into renewable natural gas may undergo further treatment by adsorption to remove siloxanes [103] [104]. Adsorption by activated carbon is widely used for siloxanes removal. Following gas conditioning, the conditioned biogas is compressed and transferred into temporary storage, directly used for heating within the plant, or directly upgraded into renewable natural gas.

Biogas can be stored for later use in external biogas tanks, the simplest being low-pressure, flexible, and inflatable membrane gas tanks. Conditioned biogas can be used as a fuel to generate electricity and heat using combined heat and power technology.

Some dairy farms and livestock operations use anaerobic digesters to produce biogas from manure and used bedding material. Some livestock farmers cover manure holding ponds (also called manure lagoons) to capture biogas that forms in the lagoons. Methane in biogas can be burned to produce heat and used as fuel in diesel-engine generators to generate electricity for the farm. The U.S. Energy Information Administration (EIA) estimates that in 2019, 25 large dairies and livestock operations in the United States produced a total of about 224 million kWh (or 0.2 billion kWh) of electricity from biogas [105].

Figure 3: Block Flow Diagram – Biogas Generated via Anaerobic Digestion of Waste



Descriptions

Organic Waste Feedstock
- Manure
- Agricultural Crops
- Biowaste
- Animal By-products

Pretreatment
- Screening
- Particle Size Reduction
- Slurring
- Thermal Hydrolysis
- Fermentation
- Acid – or alkali pretreatment
- Solvent treatment

Anaerobic Digestion
(mesophilic/thermophilic)
- Wet Digestion
- Dry Digestion

Biogas Conditioning
- Drying (cooling & reheating for moisture removal)
- Desulfurization

Raw Biogas
consists of a gas that contains 55 to 65% by vol methane, 35 to 45% by volume carbon dioxide hydrogen sulfide between the concentration 100 to 10,000 ppm, trace amounts of ammonia and is fully saturate with water

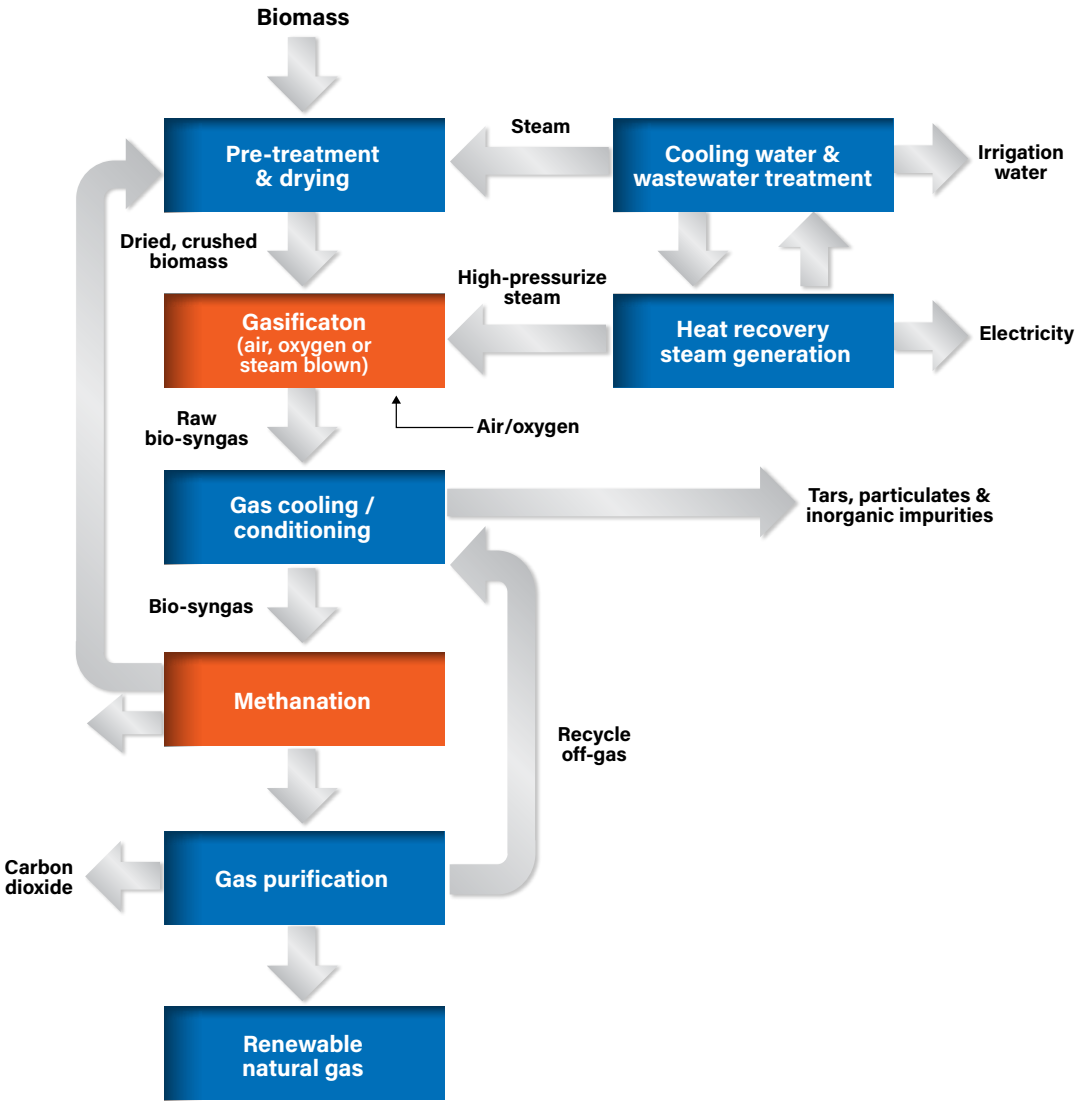
Conditioned biogas
is biogas that has been treated to remove siloxanes, moisture, and hydrogen sulfide making it suitable for use boilers and electrical generators to produce heat and power

B.2 Bio-syngas

Bio-syngas production is achieved in two major steps: (1) biomass gasification to produce a raw bio-syngas followed by (2) methanation for converting carbon monoxide and carbon dioxide into methane [106]. Gasification of woody biomass is depicted in Figure 4.

Biomass gasification process begins with biomass feedstock preparation. To produce proper feedstock, biomass must undergo pre-treatment to make the feed more homogeneous with respect to size, density, and moisture content. This involves particle size reduction by crushing and screening, as well as removing non-organic materials like plastics and metals.

Figure 4: Block Flow Diagram – Bio-syngas Production



Following pre-treatment, the biomass is dried (e.g., via direct rotary dryers) to reduce moisture content below 30%. Heat for drying can be recovered from the gasifier flue gas. Following pre-treatment and drying, biomass undergoes gasification by reaction with oxygen or air at around 1000 °C. Gasification results in incomplete biomass combustion, i.e. formation of raw bio-syngas that consists of carbon monoxide, hydrogen, and trace amounts of methane. Also present in the bio-syngas is carbon dioxide, nitrogen, undesirable tar, and dust. Tar is a typical contaminant in bio-syngas post gasification. Tar removal systems are divided into elevated (high) and low temperature methods. Elevated temperature technologies involve thermal cracking or catalytic reforming of tars. Low temperature technologies involve physical removal systems. The recovered syngas from tar reforming is cooled and then subjected to gas/liquid separation. The syngas, as part of gas clean-up, may also undergo desulphurization to remove hydrogen sulphide. Following gas clean-up and conditioning, the syngas undergoes compression, and additional cooling and gas/liquid separation before methanation.

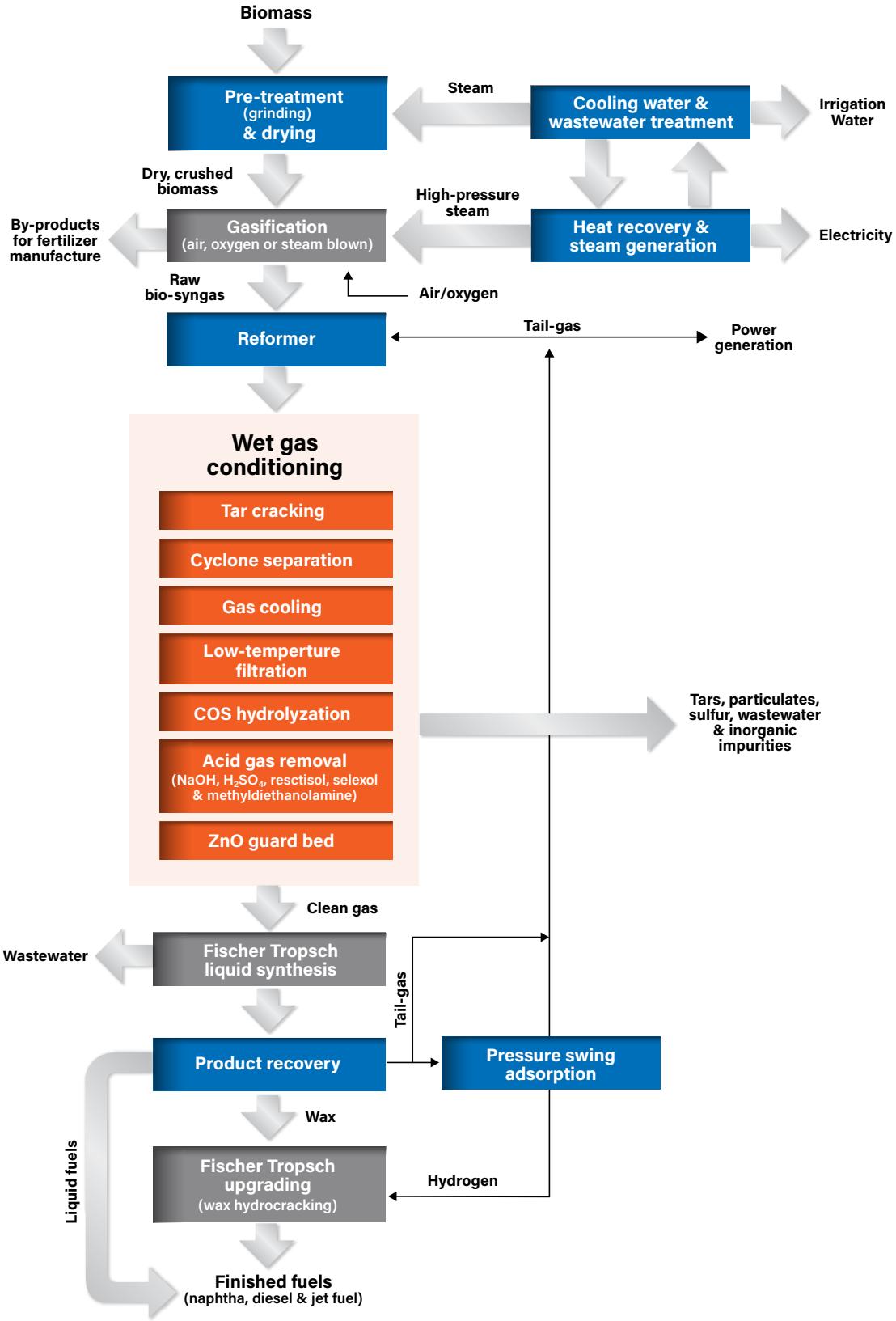
Fischer Tropsch Synthesis

Fischer Tropsch Synthesis (FTS) is a heterogeneous catalytic process for converting biomass-derived syngas (mixture of carbon monoxide and hydrogen) into synthetic liquid fuels and valuable chemicals. FTS has received renewed interest in recent years due to the necessity to decrease global dependency on fossil fuels. It is a promising technology to produce a clean, carbon neutral, and sustainable energy source.

To produce biomass-derived syngas involves coupling biomass gasification with FTS. Biomass gasification is performed in the presence of a gasifying agent. The gasifying agent can be air, oxygen, or steam. Syngas production from biomass can be produced using high or low temperature gasification followed by a downstream catalytic reformer. Upon receipt, the biomass undergoes pre-treatment that includes particle size reduction, screening, and drying. Following pre-treatment, dry, crushed biomass is gasified. Raw bio-syngas produced from gasification may undergo additional reforming, where the tail-gas from the FTS process can be (i) split and recycled for blending with the product gas entering the reformer, (ii) used for power generation, (iii) sent to a hydrogen recovery unit for hydrogen recovery for use in wax hydrocracking, or any combination of these. Product gas leaving the reformer will then undergo gas cleaning. Producing synthetic hydrocarbons via FTS reactions is strongly affected by feedstock type. The type of gas cleaning will depend on feedstock characteristics. FTS demands a higher level of gas cleaning when producing synthetic hydrocarbons from biomass than other bio-syngas conversion technologies (methanation). Gas cleaning for FTS will typically consist of wet gas conditioning, which involves tar cracking, cyclone separation, gas cooling, low-temperature filtration, carbonyl sulphide hydrolyzation/acid gas removal and treatment using a zinc oxide bed. Following gas conditioning, clean gas is then transferred to the FTS process.

FTS is not a singular technology with only one product state. FTS technology has evolved to include many different combinations of catalysts, operating conditions, and reactor designs. FTS will produce only two basic types of products. The first product types are from high-temperature FTS (HTFTS) employing iron-based catalysts operating at 320 °C and higher. The product property with respect to carbon number range for HTFTS will range from C_1 to C_{30}. The second product types are from low-temperature FTS (LTFTS) employing iron and cobalt based catalysts operating between 170 °C to 279 °C. The product property with respect to carbon number range for LTFTS will range from C_1 to $C_{120.}$ FTS is a catalytic (iron, cobalt, nickel, and ruthenium) chemical reaction by which a syngas comprising of carbon monoxide and hydrogen is converted into wax, hydrocarbon condensate, tail gas, and reaction water. The hydrocarbon condensate is recovered and distilled within the product recovery step, producing the liquid fuels naphtha, diesel, and jet fuel. The wax is sent onto the upgrading unit for hydrocracking to chemically split the wax into smaller molecular weight compounds.

Figure 5: Block Flow Diagram – Biomass to Hydrocarbons using Fischer-Tropsch Synthesis



B.3 Renewable Natural Gas

Renewable natural gas (RNG, also known as biomethane) is produced by upgrading biogas derived through anaerobic digestion and organic waste conditioning or bio-syngas methanation.

Conditioned biogas, consisting primarily of methane and carbon dioxide is initially subjected carbon dioxide removal, as CO_2 lowers gas heating value. Currently, there are four mainstream competing technologies in use for carbon dioxide removal [107] [108] [109]. These technologies are membrane separation, extraction by solvent, pressure swing adsorption system, and water adsorption. The two most common technologies used to upgrade conditioned biogas are membrane separation and pressure swing adsorption technology.

Membrane separation systems used to remove carbon dioxide can be a two-step or three-step process, the latter resulting in a higher methane yield. Figure 6 is a block flow diagram of a typical membrane system for carbon dioxide removal.

In a membrane separation system, conditioned biogas is first compressed to high pressures. This process is followed by heat recovery, and gas cooling and filtration for moisture and particulate removal. Membrane separation for carbon dioxide removal works on the principle of selective permeation. Smaller molecules such as carbon dioxide and oxygen pass through the membrane, while larger molecules like methane and nitrogen do not. In stage 1 membrane separation, conditioned biogas is separated into methane and carbon dioxide. In stage 2, methane is further purified while producing a carbon dioxide exhaust stream. In stage 3, the carbon dioxide exhaust stream is further purified to recover any residual methane prior to discharge. Methane recovery yields by membrane separation can be as high as 99.5%.

Pressure swing adsorption technology can also be used instead of membrane separation (see Figure 7 for block flow diagram). In pressure swing adsorption, conditioned gas is compressed to high pressures, followed by gas cooling and filtration for moisture and particulate removal prior to heating. Pressure swing adsorption for carbon dioxide separation is achieved through cyclic repetition of adsorption/production, depressurization, recycle, regeneration/desorption, and lastly, pressurization. Methane recovery yields obtained by pressure swing adsorption can be as high as 98%.

Following carbon dioxide removal by membrane separation or pressure swing adsorption, renewable natural gas can undergo post treatment for deoxygenation if required [110] [107].

The renewable natural gas product can be injected into the pipeline for distribution, further processed into liquid natural gas for transportation, or placed into underground storage for later.

Figure 6: Block Flow Diagram – Renewable Natural Gas Production – CO_2 Removal via Membrane Separation

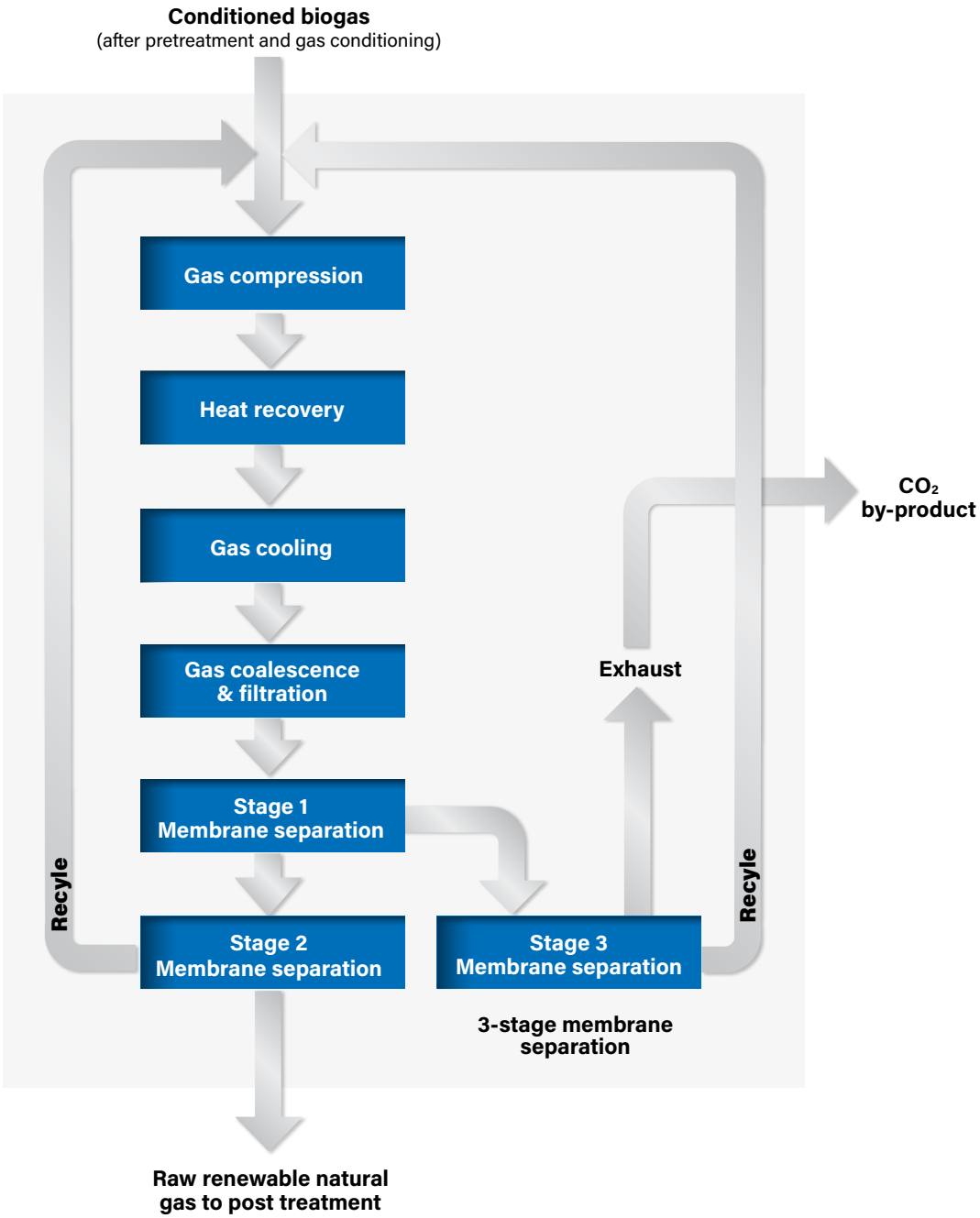
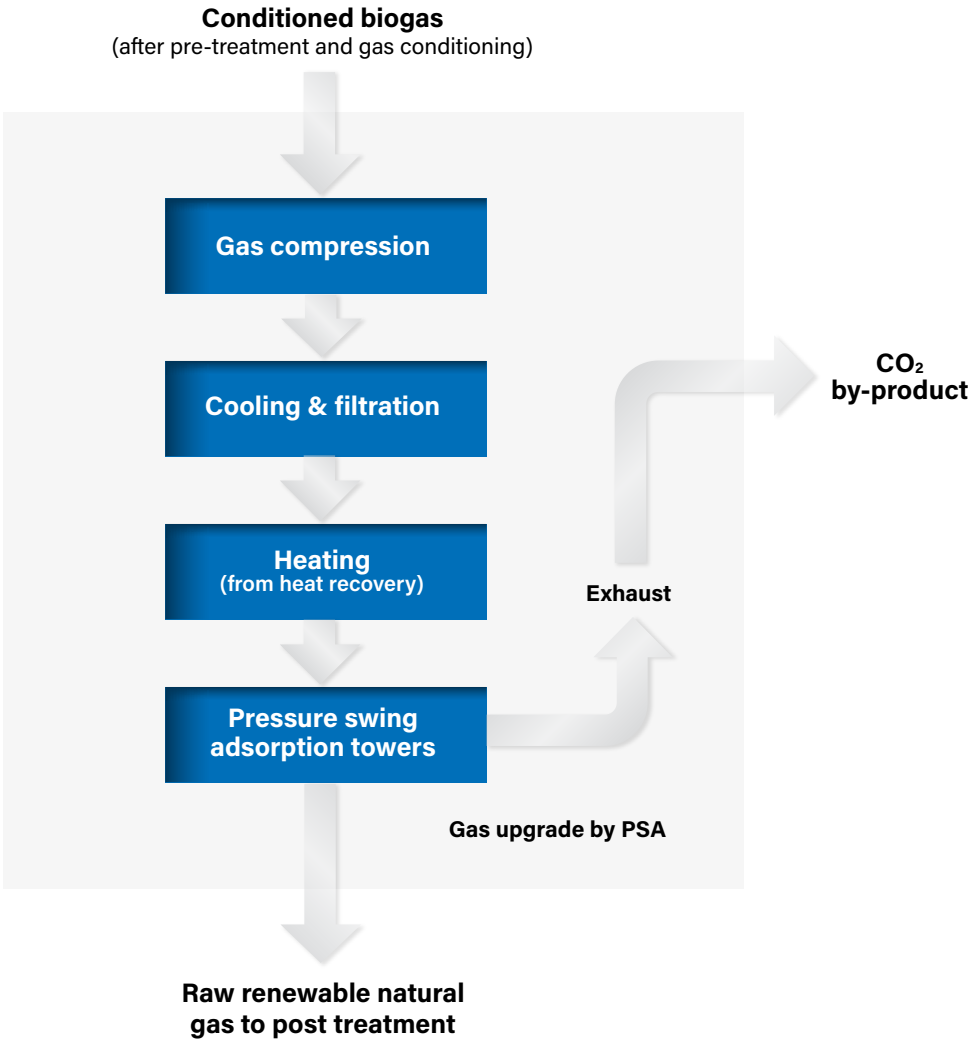
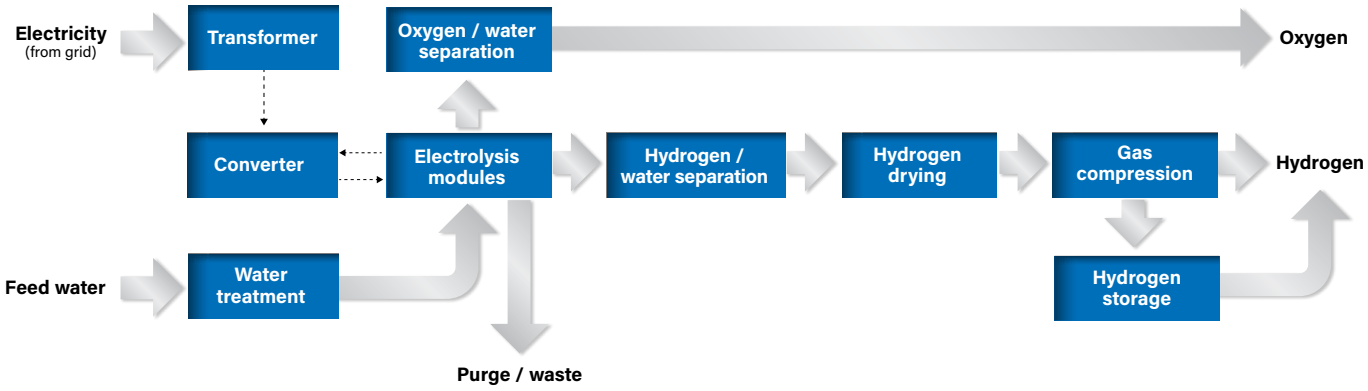


Figure 7: Block Flow Diagram – Renewable Natural Gas Production – CO_2 Removal via Pressure Swing Adsorption (PSA)



B.4 Electrolytic Hydrogen Production (Power-to-Gas Hydrogen)

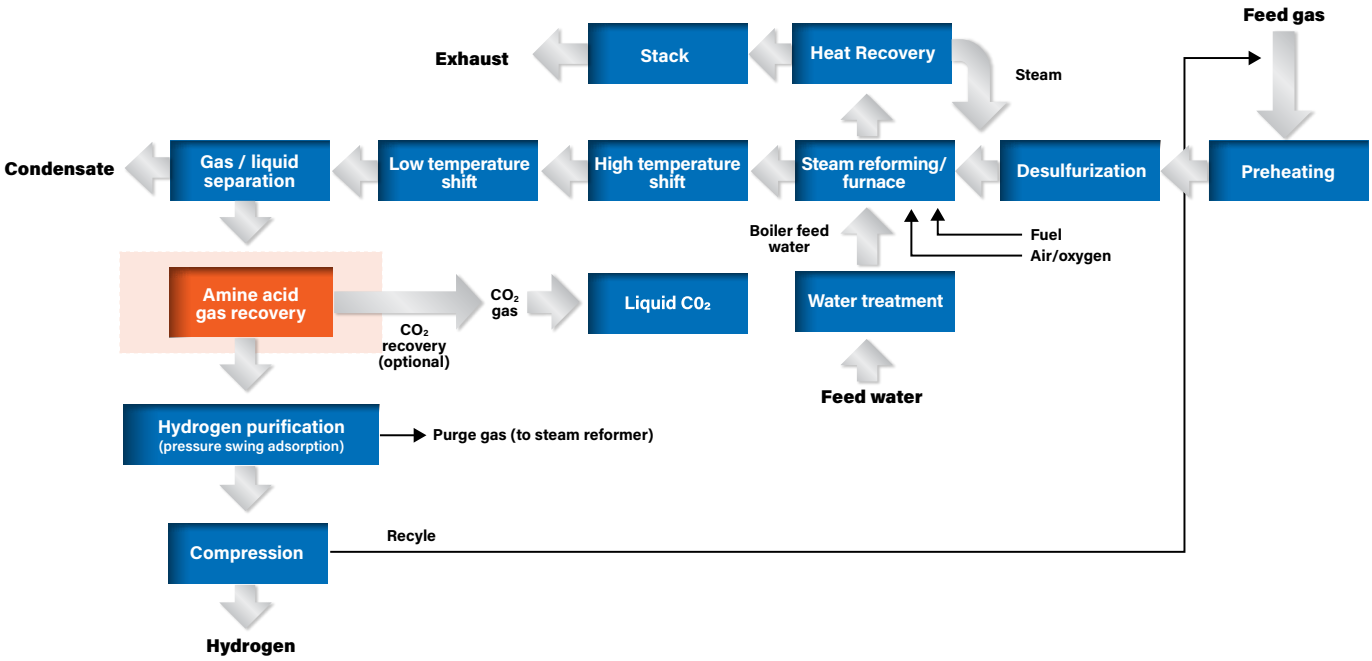
Figure 8: Block Flow Diagram – Electrolytic Hydrogen Production (via Water Electrolysis)



B.5 Hydrogen Production via Steam Reformation

Hydrogen production from biomass involves gasification, steam reforming, and water-gas shift reaction of the renewable gas source (includes raw biogas, bio-syngas, or renewable natural gas) produced from biomass gasification [111] [112]. Feed gas processing can be divided into two major steps: 1) steam reforming for methane conversion into hydrogen and carbon monoxide; 2) water-gas shift reaction for carbon monoxide conversion into hydrogen and carbon dioxide [113] [114].

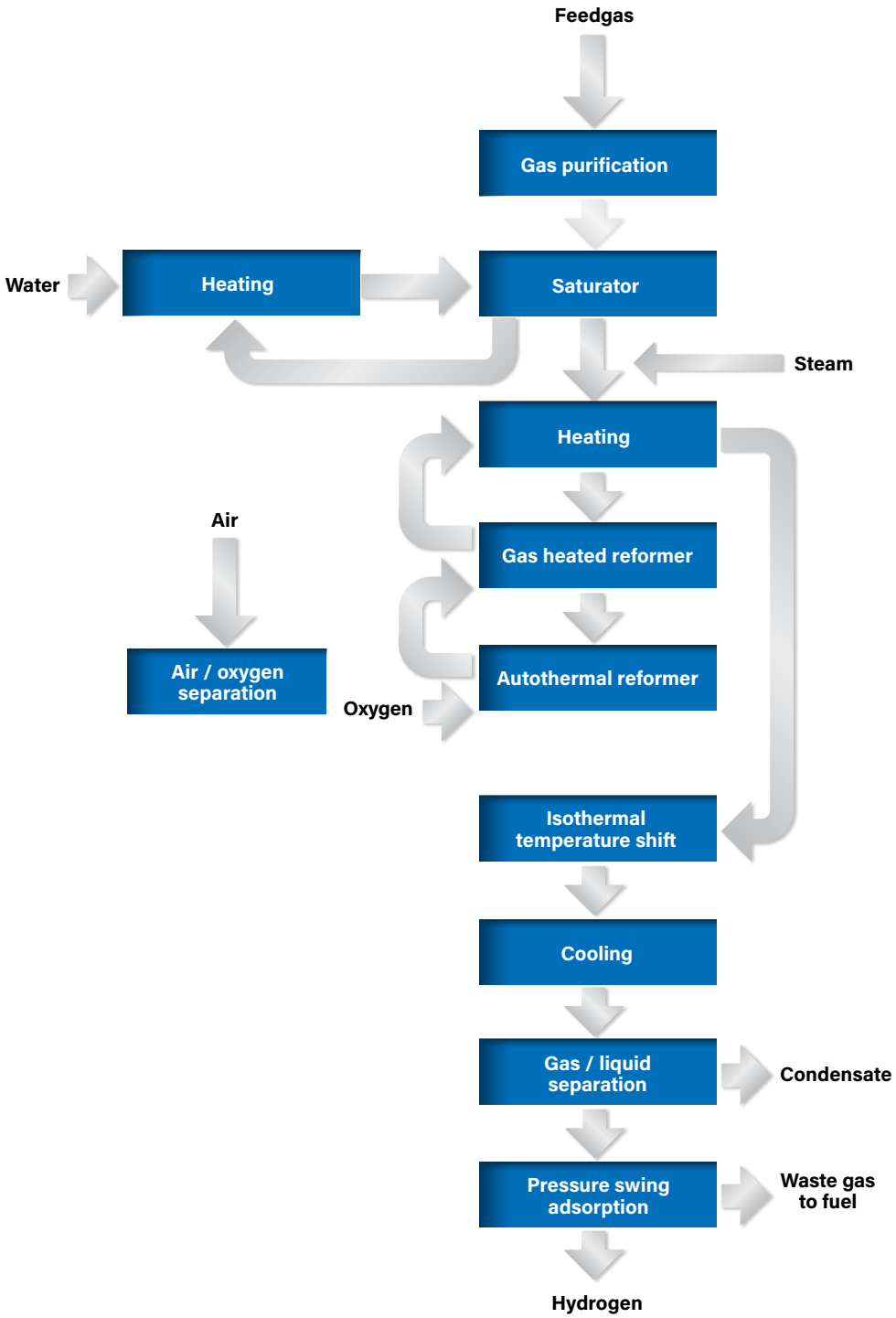
Figure 9: Block Flow Diagram – Hydrogen Production via Steam Reforming



Renewable feed gas is converted into hydrogen by steam reforming and water-gas shift processes [38]. Prior to steam reforming, biogas undergoes preheating followed by desulphurization. Steam reforming is used to convert methane into hydrogen and carbon monoxide (syngas) by reacting methane with steam in presence of a catalyst between 500 °C and 900 °C. The reaction is strongly endothermic. To produce hydrogen, the syngas exiting the reformer is further subjected to water-gas shift reactions at high and low temperatures with the aid of catalysts for the conversion of carbon monoxide and steam into hydrogen and carbon dioxide [115]. These reactions lead to a significant increase in hydrogen concentration in syngas. Also produced are substantial amounts of carbon dioxide that can be recovered, purified, and converted into liquid carbon dioxide for use as a value-added product, permanently sequestered, or vented to atmosphere. Following steam reforming, the gas undergoes hydrogen separation and purification. Suitable hydrogen separation and purification technologies are pressure swing adsorption and membrane separation. Following purification, hydrogen gas is compressed and transferred to temporary storage or used in power-to-gas applications. Renewable hydrogen gas can be injected into a pipeline designed to carry pure hydrogen or alternatively blended with natural gas for greenhouse gas emission reduction. Renewable hydrogen gas can also be used in industrial and chemical processes, power production, and transportation [116].

B.6 Autothermal Reforming for Hydrogen Production

Figure 10: Block Flow Diagram – Hydrogen Production via Autothermal Reforming



Appendix C – Standards Development Organizations and Renewable Gas Industry Agencies and Associations

As introduced in Section 5, key leading global and national standards development organizations (SDOs) and some of associations and agencies relevant to natural gas and renewable gas production, distribution, and application include:

- **American National Standards Institute (ANSI)** is a private, non-profit organization founded in 1918 that administers and coordinates the United States voluntary standards and conformity assessment system. ANSI works in close collaboration with stakeholders from industry and government on development of standards and conformance solutions of national and global priorities.
- **American Petroleum Institute (API)** was formed in 1919 and represents all segments of America's oil and natural gas industry. API develops petroleum, natural gas and petrochemical equipment, and operating standards. API maintains more than 700 standards and recommended practices. Many have been incorporated into the United States' state and federal regulations, and are also widely cited by the international regulatory community.
- **American Society of Mechanical Engineers (ASME)** is a non-profit professional organization founded in 1880 that enables collaboration, knowledge sharing, and skill development across all engineering disciplines. ASME develops and promotes codes and standards, publications, conferences, continuing education, and professional development programs to supply a foundation for advancing technical knowledge and a safer world.
- **American Water Works Association (AWWA)** is an international, non-profit society founded in 1881 dedicated to supplying water solutions. AWWA includes membership of over 4,300 utilities and 51,000 total members representing the full water community: public water and wastewater, environmental advocates, scientists, academics, and others. AWWA trains water professionals, advocates for safe and sustainable water, and collects and shares knowledge through standards and specifications.
- **Bureau de normalisation du Québec (BNQ)** is mandated by the Québec government to oversee standardization in Québec. BNQ designs and applies solutions based on standards, sources of innovation, and trust in industry. BNQ is organized in four business sectors: standards development, certification, laboratory assessment, and verification of greenhouse gas emission statements.
- **Canadian Biogas Association (CBA)** is the collective voice of the biogas industry in Canada with over 100 members including: farmers, municipalities, technology developers, consultants, finance and insurance firms, and other representatives. They focus on building the biogas sector in Canada.
- **Canadian Gas Association** is the voice of Canada's natural gas delivery industry. Its members include distribution companies, transmission companies, equipment manufacturers, and other service providers. Canadian Gas Association works to build the understanding of gas (via educational information and training/workshops/seminars/conferences); advance efficiency and innovation; drive for improved regulatory engagement; ensure continuous safety and integrity improvements; and pursue partnerships to better deliver energy services.

- **Canadian Standards Association (CSA Group)** is a global organization dedicated to safety, social good, and sustainability. Comprising of Standards Development and Testing, Inspection and Certification organizations, CSA Group is active around the world, including Canada, the U.S., Europe, and Asia.

  CSA Group's Standard Development organization works to enhance the lives of Canadians by advancing standards in the public and private sectors via standards research, development, education, and advocacy. The technical and management standards developed with 10,000 members improve safety, health, the environment, and economic efficiency in Canada and beyond.

  CSA Group's global commercial subsidiaries generate funding for continued standards research and development to support the company's mission. Commercial subsidiaries provide expert testing, inspection, and certification services that enable manufacturers to demonstrate their products comply with applicable safety, environmental, and operating performance standards for global markets. CSA Group offers deep expertise and industry-leading service delivery across a wide range of current and emerging technologies.

- **Clean Energy Ministerial (CEM)** is a high-level global forum to promote policies and programs that advance clean energy technology; share lessons learned and best practices; and encourage the transition to a global clean energy economy. Initiatives are based on areas of common interest among participating governments and other stakeholders. CEM is a high-level global forum to promote policies and programs that advance clean energy technology deployment.

- **Coalition for Renewable Natural Gas (RNG Coalition)** aims to serve as the public policy advocate and education platform for the renewable natural gas industry in North America. They are a member-led non-profit organization formed to provide an education platform and advocacy voice for the protection, preservation, and promotion of the renewable natural gas industry in North America and have about 200 members from Fortune 500 companies or small business and non-profit organizations. One of RNG Coalition's initiatives (SMART) is to capture and control methane produced from the 43,000 aggregated waste sites in North America by 2050.

- **Compressed Gas Association (CGA)** was founded more than 100 years ago, and currently has more than 130 member companies, representing all facets of the industry: manufactures, distributors, suppliers, and transporters of gases, cryogenic liquids, and related products. CGA is dedicated to the development and promotion of safety standards and safe practices in the compressed gas industry, and develops technical specifications, safety standards, along with training and educational materials.

- **European Biogas Association (EBA)** works with European institutions, industry, agricultural partners, non-government organizations and academia to develop policies which enable the large-scale deployment of renewable gases throughout Europe

- **European Committee for Standardization (CEN)** is an association that brings together the National Standardization Bodies of 34 European countries and supports standardization activities in relation to a wide range of fields and sectors including: air and space, chemicals, construction, consumer products, defence and security, energy, the environment, food and feed, health and safety, healthcare, ICT, machinery, materials, pressure equipment, services, smart living, transport, and packaging.

- **European Renewable Gas Registry (ERGaR)** is a European association that has a mission to set up an independent, transparent, and trustworthy documentation scheme for mass balancing of biomethane and other renewable gases distributed along the European gas network. ERGaR has 27 members consisting of renewable gas registries, renewable gas industry associations, gas DSOs/TSOs and natural gas industry partners.

- **Global Bioenergy Partnership (GBEP)** founded in 2006, includes 37 partners (23 national governments and organizations) and 39 observers (28 national governments and 11 organizations), including Canada and the United States. GBEP provides a mechanism for partners to organize, coordinate and implement targeted international research, development, demonstration, and commercial activities related to production, delivery, conversion and use of biomass for energy, with a focus on developing countries. Global Bioenergy Partnership also provides a forum to develop effective policy frameworks to: (1) suggest rules and tools to promote sustainable biomass and bioenergy development; (2) facilitate investments in bioenergy; (3) promote project development and implementation and (4) foster R&D and commercial bioenergy activities.
- **International Energy Agency (IEA)** is at the heart of global dialogue on energy, supplying authoritative analysis, data, policy recommendations, and real-world solutions to help countries supply secure and sustainable energy for all. The IEA is made up of 30 member countries and 8 association countries. The IEA's Policies and Measures Database supplies access to information on past, existing or planned government policies and measures to reduce greenhouse gas emissions, improve energy efficiency, and support the development and deployment of renewables and other clean energy technologies.
- **International Gas Union (IGU)** was founded in 1931, with the mission to advocate gas as an integral part of a sustainable global energy system. IGU has 162 members in 5 continents, including Canada and the United States. While their focus is on natural gas, this union is looking at ways to reduce emissions and enable renewable power generation.
- **International Organization for Standardization (ISO)** is an independent, non-governmental international organization with a membership of 164 national standards bodies, and through its members, it brings together experts to share knowledge and develop voluntary, consensus-based, market relevant international standards that support innovation and supply solutions to global challenges.
- **International Renewable Energy Agency (IRENA)** is an intergovernmental organization that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international cooperation, a center of excellence, and a repository of policy, technology, resource, and financial knowledge on renewable energy. IRENA, with more than 180 countries engaged, promotes renewable resources and technologies as the key to a sustainable future and helps countries achieve their renewable energy potential. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar, and wind energy in the pursuit of sustainable development, energy access, energy security, and low-carbon economic growth and prosperity.
- **Natural Resources Canada (NRCan) – Government of Canada** develops policies and programs that enhance the contribution of the natural resource sector to the economy and represent Canada at the international level to meet Canada's global commitments related to the sustainable development of natural resources. NRCan's Office of Energy Research and Development collaborate with stakeholders, including industry, academia, adopters, and regulators. They own federal labs and work with international organizations to find gaps in codes and standards that would benefit from research, development, and demonstration programs. As programs are funded, they solicit projects that can help to address these identified gaps. NRCan works with international partners such as the Clean Energy Ministerial (CEM) to advance codes and standards related to hydrogen.
- **Standards Council of Canada (SCC)** is Canada's voice on the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). SCC provides Canadians with a gateway to international standards development and conformity assessment. SCC facilitates and drives collaboration among their stakeholders such as Standard Development Organizations, provincial and territorial governments, regulators, Canadian experts, and others.

CSA Group Research

In order to encourage the use of consensus-based standards solutions to promote safety and encourage innovation, CSA Group supports and conducts research in areas that address new or emerging industries, as well as topics and issues that impact a broad base of current and potential stakeholders. The output of our research programs will support the development of future standards solutions, provide interim guidance to industries on the development and adoption of new technologies, and help to demonstrate our on-going commitment to building a better, safer, more sustainable world.

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