Discussion Paper

Skills and Safety Considerations for Low-Carbon Fuels Use in Newfoundland and Labrador

July 2026

econext

Advancing Newfoundland & Labrador's **Green Economy**

Contents

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1. Executive Summary

The objective of this paper is to generate discussion and encourage further exploration of the education and skills required to support the safe and effective use of low-carbon fuels in NL.

Based on research undertaken by econext exploring the potential for low-carbon fuels adoption in within various sectors of NL's economy – and the possible valorization of provincial organic waste streams for low-carbon fuels production – some conclusions can be drawn that can inform education and skills initiatives:

- Conventional fuels like diesel and gasoline are expected to be in use in NL for a long time to come. This means that efforts to decarbonize these fuels will be meaningful in the short, medium, and long terms.
- Diesel is used in almost all sectors of NL's economy. This presents opportunities for introducing the use of biodiesel (as a blend) and renewable diesel (either as a blend or as a replacement) economy wide.
- Passenger vehicles account for a significant share of NL's GHGs. This presents opportunities for the use of ethanol (as a blend).
- Natural gas (and Liquefied Natural Gas - LNG) has promise for adoption within electricity and marine transportation sectors – presenting opportunities for renewable natural gas and green hydrogen (or low-carbon hydrogen) blending.
- Global trends in the marine transportation sector suggest that green methanol is going to be a low-carbon fuel of choice in the long term. Green methanol production requires green hydrogen and C02 as inputs. In addition, other low-carbon hydrogen and ethanol can be blended with methanol.

Therefore, it is reasonable to focus on education, awareness, and skills development that relate to the following areas:

- Biomass valorization (biofuel production using locally available organic materials)
- De-risking the adoption of fuels 'new' to NL (i.e., transportation, storage, fueling, use etc.) including natural gas / LNG, hydrogen, CO2, and methanol through testing
- Fuel blending concepts and processes

The adoption of low-carbon fuels represents a social and cultural shift, not just a technological one. NL can advance the adoption of low-carbon fuels by ensuring its people have the education and skills required. At present, this means: (1) defining the technology/equipment that can support research, development, and deployment; conducting deeper analysis of low-carbon fuels safety / skills requirements; and developing and implement and education and awareness program.

2. Background and Context

2.1 Introduction

In 2025 econext completed a study with KPMG titled '*Opportunities for Domestic Clean Fuels Use in Newfoundland and Labrador*[1]'. This research explored potential low-carbon fuel use according to various economic sectors within the province.

The outlook for the future adoption of low-carbon fuels is based on many different variables and is difficult to predict – particularly within a localized geography. However, the research did help to advance discussions and outline some of the opportunities and challenges for low-carbon fuels adoption within specific sectors in Newfoundland and Labrador (NL).

With deeper investigation that followed in specific sectors (marine transportation, surface transportation, electricity, biomass), it has become clear that low-carbon fuels adoption is more likely than not to accelerate through NL's economy in the years ahead.

While not necessarily new to the world, many of these fuels are 'new' to NL. The particular characteristics of each of these fuels and their production can impact their handling, storage, and transportation – in addition to how they are ultimately used.

With relative inexperience with these low-carbon fuels and the fact that fuels are not currently blended within the province, in areas where adoption is most likely it is important for workers in NL to have the awareness and skills required to safety and effectively work with these fuels.

Discussion Paper Objective

The objective of this paper is to generate discussion and encourage further exploration of the education and skills required to support the safe and effective use of low-carbon fuels in NL. This paper does not arrive at definitive recommendations on specific training and professional development needs but provides insight into the areas where future development should be focused.

While every effort has been made to provide sources for information provided, this discussion paper is not an academic publication and is not intended to be. This is a

[1] https://econext.ca/discussion-paper-opportunities-for-domestic-clean-fuels-use-in-newfoundland-and-labrador/

document produced internally by econext staff informed by secondary research and information known to be available in the public domain.

econext welcomes all feedback that can help improve the quality and usefulness of this discussion paper. Feedback can be sent to info@econext.ca.

2.2 About *econext*

econext is a not-for-profit industry association dedicated to advancing environmentally sustainable economic growth in Newfoundland and Labrador. With a network of approximately 200 member businesses, research institutions, governments, and organizations, econext serves as a leading voice for the province's green economy.

econext has four key areas of focus:

Member Opportunities
We connect our members with opportunities to grow their businesses in the green economy.

Public Policy & Advocacy
We identify, analyze, and champion policy frameworks that support sustainable economic growth in NL.

Capacity Building
We equip NL's businesses, communities, and workforce with skills, experience, and knowledge needed to contribute to green economic growth.

Innovation
We identify emerging trends and provide insights that inform policy, investment, and innovation that advance clean growth in NL.

Together, we strengthen NL's green economy by supporting our members and help drive sustainable growth and innovation across the province. Learn more at econext.ca.

3. About Low-Carbon Fuels

Clean fuels, or 'low-carbon' fuels, are fuels that produce lower GHGs than traditional (or conventional fossil) fuels on a life-cycle basis[2]. Their increased production and use are viewed as being vital in the world's fight against climate change and the pursuit of net zero.

3.1 Benefits of Low-Carbon Fuels

This discussion paper assumes that there will be an increased adoption of low-carbon fuels in NL over time. There are a number of benefits to the adoption of low-carbon fuels which helps to explain why this assumption has been made.

Decreased GHGs: The use of low-carbon fuels allows for lifecycle GHG reductions. These reductions will either be associated with the direct use of the fuel (e.g., a clean fuel will produce far fewer GHGs) and/or the displacement of conventional fossil fuels. The amount of GHGs replaced will depend on the low-carbon fuel used, how it is produced, and what it is displacing.

Reduced air pollutants: The use of low-carbon fuels is often associated with the reduction of other air pollutants such as particulates (tiny particles of solid matter that lodge in the lungs and deposit on buildings), carbon monoxide, sulfur dioxide, hydrocarbon, and other air toxins[3]. Each low-carbon fuel and the process used in their deployment will result in unique reductions. The amount of air pollutants reduced will depend on the low-carbon fuel used, how it is produced, and what it is displacing.

Energy security: Many low-carbon fuels can be produced using local renewable resources (i.e., biomass, electricity, etc.) Even when locally produced fuels are blended with conventional fuels, this: (1) displaces the volume of fuel that must be imported; (2) protects against supply and supply chain disruptions caused by geopolitical events; (3) protects against price volatility of globally traded commodities; and (4) provides for domestic fuel production and supply capabilities that can be called on when needed in an emergency. For example, a diesel fuel blended with 30% locally produced biodiesel and renewable diesel displaces 30% of the required diesel to be imported and the geopolitical impacts on that import which are out of the user's control.

Valorization of wasted resources: Oftentimes organic waste material (e.g., household organic waste, forestry residues, fishing and aquaculture discards, agricultural waste) are

[2] https://natural-resources.canada.ca/energy-sources/clean-fuels/clean-fuels-fueling-future
[3] https://advancedbiofuels.ca/net-zero

sent to landfill. This 'waste' is actually a resource which has value and can be considered as feedstock for low-carbon fuels production. Moreover, the diversion of these waste streams away from landfills reduces the harmful GHGs that are caused by the decomposition of biomass.

Economic development and growth: The production and distribution of low-carbon fuels (including the diversion of biomass from landfills) creates jobs, wealth, and improved environmental outcomes for communities. Many low-carbon fuels have value and opportunity domestically, while also are tradeable commodities on a regional, national, and global scale. As various biomass-derived fuels are interoperable with their e-fuel counterparts, there are opportunities for the scaling of production utilizing electricity as an additional feedstock.

3.2 Categorizing Low-Carbon Fuels

There are many types of low-carbon fuels. Before identifying specific low-carbon fuels that have the potential for use in NL, it is beneficial to understand the relevant types of fuels and how they are generally produced and used.

Low-carbon fuels can be produced from a variety of feedstocks, such as agricultural and forest biomass, waste materials, electricity, and fossil fuels with carbon capture and storage[4].

Some low-carbon fuels can be used to supplement conventional fuels; some can be used as a direct replacement for conventional fuels within existing equipment and infrastructure; while others are replacements that require new equipment and infrastructure.

It is helpful to categorize low-carbon fuels into three categories that acknowledge these important differences: (1) biofuels; (2) renewable biofuels; and (3) e-fuels.

Biofuels

Biofuels are fuels made from recently living organic matter (biomass) like plants, agricultural waste, or animal fats, offering alternatives to fossil fuels. There are a wide variety of biofuels depending on the type of biomass used and the processes used in their creation. Biomass can be converted to fuels through different processes including direct combustion, thermochemical and chemical conversion, and biological conversion. A

[4] https://natural-resources.canada.ca/energy-sources/clean-fuels/clean-fuels-fueling-future

biofuel can be produced with much lower GHGs than their fossil fuel-based counterparts, and when 'burned' can also be less harmful. However, as they are not chemically identical to their conventional fuel counterpart (i.e., biodiesel vs. diesel), most often biofuels cannot directly replace fuels at a 1:1 ratio without affecting equipment. To achieve environmental benefits, biofuels are most often blended with petroleum-based products to reduce the GHG intensity of their use. 'First generation' biofuels are those made from sugar, starch, or vegetable oil. Their feedstocks are those that might have an impact on food supply if used in large quantities. 'Second generation' biofuels are those made from sustainable feedstocks as defined by the feedstock's availability, its impact from a GHG perspective, and land use [5].

Renewable Biofuels

Produced through a different method ('catalytic pyrolysis') than biofuels but with similar feedstocks, 'renewable' biofuels are chemically identical to their petroleum-based counterparts (i.e., diesel and renewable diesel).

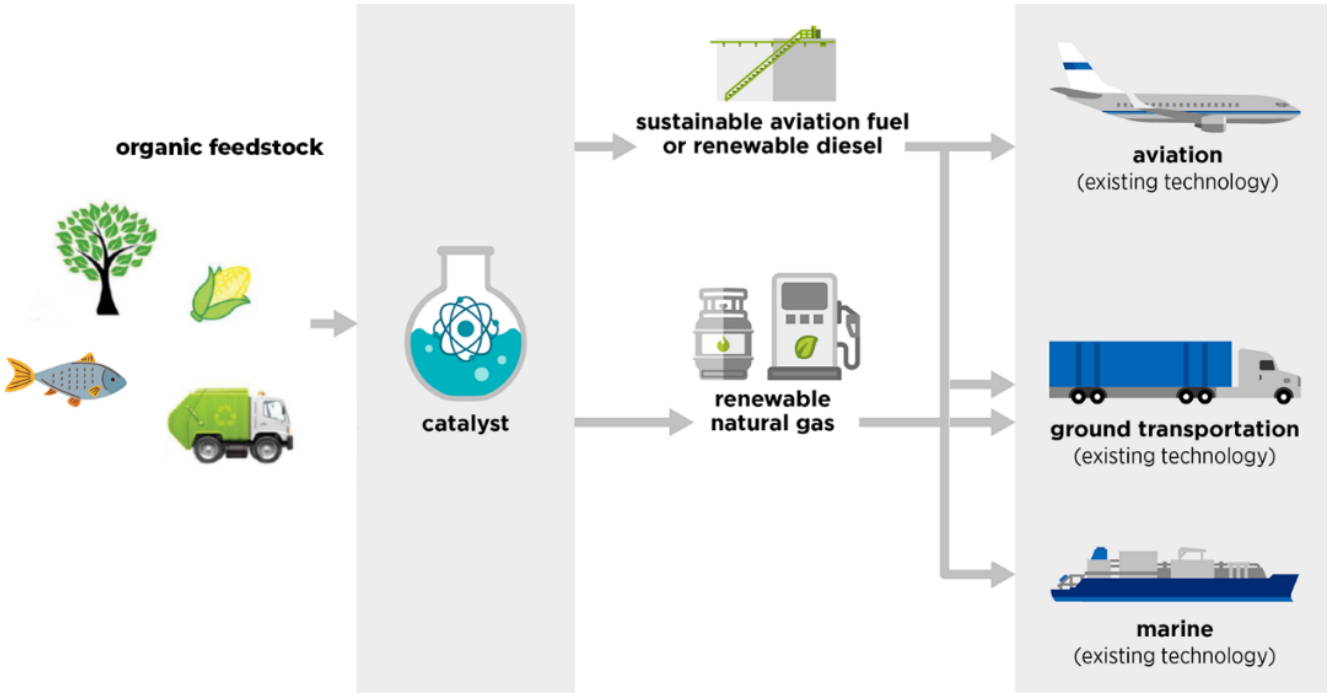

Figure 1: Examples of renewable biofuel pathways

This means that renewable biofuels can potentially be used as a direct replacement (i.e., as a 'drop-in') for conventional fuels in existing technology (i.e., combustion turbines, car/truck/ship engines, other heavy equipment) if not a heavy additive in blending. The concept of blending is defined and explored in detail further in the report. This also means

[5] https://econext.ca/wp-content/uploads/2025/06/Biomass-Energy-Potential-NL-Version-1.0-2025-06-11.pdf

that existing transportation, storage, and refueling infrastructure can be used for these fuels – simplifying the logistics of decarbonization.

E-Fuels

E-fuels (electro-fuels) are synthetic fuels produced through electrolysis, which splits water molecules into hydrogen and oxygen using renewable electricity[6]. The most commonly discussed e-fuel is hydrogen, but the category includes fuels that have hydrogen as one of the key components. E-fuels are viewed as being instrumental in the fight against climate change and the global pursuit of net zero as they generally emit significantly less GHGs than fossil fuel alternatives, and their main component – hydrogen – can be produced using clean energy sources.

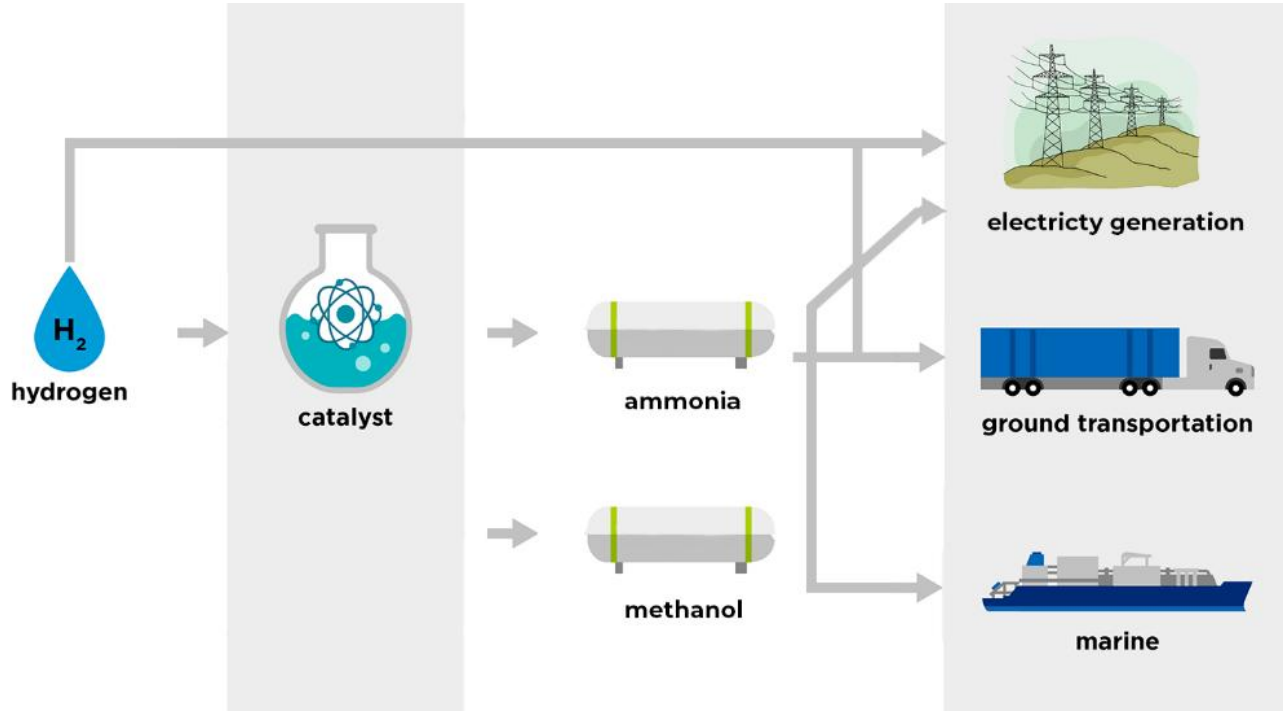

Figure 2: Examples of e-fuel pathways

There are a number of different terms that are being used to describe fuels with a lower carbon intensity than conventional fuels, often used interchangeably and sometimes incorrectly. However, in econext's experience, using these three terms (biofuels, renewable biofuels, and e-fuels) has proven to be the most effective approach to categorizing and communicating these fuels.

'Low-carbon fuels' is a catch-all term describing any fuel with a lower carbon intensity than the status quo fuel.

[6] https://spectra.mhi.com/energy-transition/what-are-e-fuels-and-can-they-help-decarbonization

3.3 Blending Fuels

Fuel types do not necessarily need to be homogeneous or used exclusively. As alluded to above, fuels can often be blended. In the context of safety and skills development, understanding the concept of fuel blending is important as it can be complex and require specialized equipment, processes, and safety measures.

Purpose of Blending

Blending allows for the realization – even if in part – of the benefits to low-carbon fuel use as described above. While the blending of fuels does not provide the environmental benefits that the wholesale adoption of low-carbon fuels might, given the prevalence of internal combustion engine technologies in vehicles and the reality that they will exist for many years to come, blending presents an immediate opportunity to achieve GHG emissions reductions.

Fuel blending is likely to become more important over time as (a) pressures continue to mount worldwide to lower the carbon intensity of fuels produced and consumed, while (b) the availability of low-carbon fuels to meet this demand is likely to be in short supply.

Blending of Different Fuels

In some cases, the degree to which fuels can be blended is limited or there is an optimal blending ratio.

For example, ethanol is commonly blended with gasoline but there are limits. The Government of Canada currently requires that gasoline at the pump contains an average of five per cent ethanol, with some provinces requiring more[7]. Higher ethanol blends can result in corrosion and performance problems[8], with the emerging E15 (or 15% ethanol blend) only for use in vehicles manufactured after 2001.

[7] https://www.canadianfuels.ca/industry-facts/low-carbon-fuels/ethanol/
[8] https://natural-resources.canada.ca/energy-efficiency/transportation-energy-efficiency/ethanol

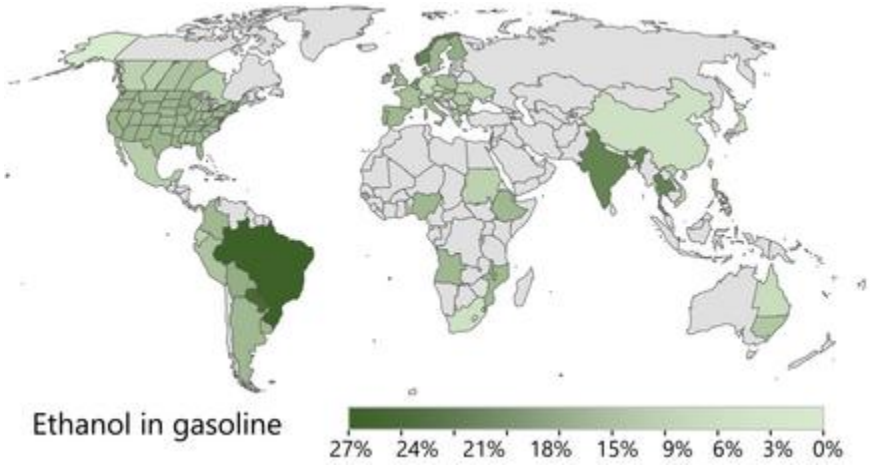

Figure 3: Global Ethanol Blending Mandates[9]

Biodiesel is another example. As biodiesel is not chemically identical to conventional diesel, it is most often an additive in a blend with conventional diesel. A blend classified as B2, for example, is 98% petroleum diesel and 2% biodiesel. B20 is a blend of 80% petroleum diesel and 20% biodiesel. Blending of biodiesel with diesel has become commonplace; the majority of North American engine manufacturers now endorse up to a B5 biodiesel blend[10]. Generally, B20 and lower-level blends can be used in current engines without modifications. In fact, many diesel engine manufacturers approve the use of B20[11].

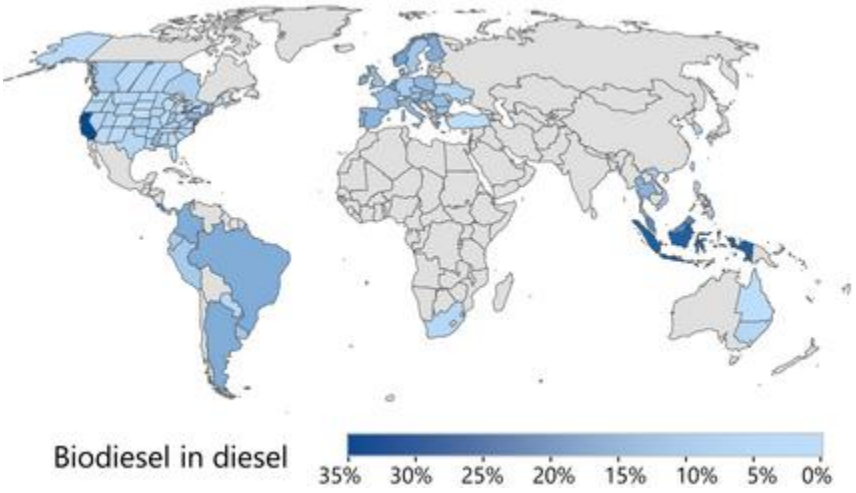

Figure 4: Global Biodiesel Blending Mandates[30]

[9] Biofuel Technologies: Lessons Learned and Pathways to Decarbonization - https://onlinelibrary.wiley.com/doi/10.1111/gcbb.13091
[10] https://natural-resources.canada.ca/energy-efficiency/transportation-energy-efficiency/biodiesel
[11] https://afdc.energy.gov/fuels/biodiesel-blends

Another similar case is the potential to blend low-carbon methane with natural gas. While a significant amount of low-carbon methane can be blended due to having the same chemical makeup as the methane component of natural gas, methane totals 90% of the makeup of natural gas so 100% replacement is not possible. Similarly, there is the potential to blend low-carbon hydrogen with natural gas. Hydrogen can be blended with natural gas and delivered through its existing infrastructure for end-use appliances such as stoves, water heaters, generators, etc.[12] Existing natural gas equipment can typically handle a blend of up to 15% hydrogen without compromising performance or safety[13]. Blending natural gas with other fuels is less common than other blends for end-use in surface transportation purposes because natural gas vehicles are not as prevalent as other technologies.

Blending of Same Fuels

In other cases, the low-carbon fuel is chemically identical to its fossil fuel counterpart and can be blended at any ratio at it will not change the composition or characteristics of the original or resulting fuel. This is the case with diesel and renewable diesel.

Multi-Fuel Blends

Blending does not necessarily need to be limited to two fuels. For example, the Canadian Coast Guard is testing fuel blends composed of 10% biodiesel, 40% renewable diesel, and 50% conventional diesel in its ships[14],[15]. It is anticipated that multi-fuel diesel blends will become more common for surface transportation over time.

4. Low-Carbon Fuels with Potential for Use in NL

Through a series of discussions papers focused on marine transportation, surface transportation, electricity generation, and biomass, econext has identified low-carbon fuels which have the potential for application within NL. Below is a summary of this list, beginning with conventional fossil fuels that are lower-carbon, moves into biomass derived fuels, and then e-fuels produced via electricity.

[12] https://www.cga.ca/natural-gas-101/hydrogen-a-lower-emitting-and-versatile-fuel
[13] https://www.csagroup.org/article/research/appliance-and-equipment-performance-with-hydrogen-enriched-natural-gases
[14] https://www.ccg-gcc.gc.ca/corporation-information-organisation/greening-initiatives-ecologisation-eng.html
[15] https://www.canada.ca/en/canadian-coast-guard/corporate/about-us/greening-initiatives.html

Natural Gas

Conventional natural gas is found in subsurface rock formations and is extracted through a well drilled into that formation. Once extracted, the gas is separated from free liquids, such as crude oil, hydrocarbon condensate, water, and entrained solids – and then processed[16]. While still a fossil fuel, the use of natural gas offers several benefits compared to gasoline or diesel. The primary component (70-95%) of natural gas is methane (one part carbon, four parts hydrogen) with the remainder being a mix of a variety of elements. Burning natural gas for energy results in fewer emissions of nearly all types of air pollutants and carbon dioxide (CO_2) emissions than petroleum products to produce an equal amount of energy[17]. In NL there are possible applications for natural gas within the electricity sector and, to a lesser extent, the surface transportation sector.

Liquified Natural Gas (LNG)

LNG is natural gas in its liquid form. LNG is produced by purifying natural gas and super-cooling it to -260°F to turn it into a liquid[18]. LNG is more expensive than natural gas due to higher production and storage costs but are valuable in transportation applications that require longer ranges due to its higher density[19]. LNG is being embraced in the marine transportation sector as a potential transitional fuel as the industry looks towards a carbon-neutral future that includes non-fossil fuels[20].

Biomethane / Renewable Natural Gas (RNG, Bio-LNG)

Biogas is a renewable source of methane gas produced when organic matter breaks down without oxygen[21]. Biogas can come from a variety of sources, including municipal solid waste landfills, anaerobic digester plants at water resource recovery facilities (wastewater treatment plants), livestock farms, food production facilities, and organic waste management operations[22] for use in place of (or in tandem with) fossil natural gas.

[16] https://afdc.energy.gov/fuels/natural-gas-conventional
[17] https://www.eia.gov/energyexplained/natural-gas/natural-gas-and-the-environment.php
[18] https://afdc.energy.gov/fuels/natural-gas-basics
[19] https://afdc.energy.gov/fuels/natural-gas-basics
[20] https://www.lr.org/en/knowledge/research/fuel-for-thought/lng/
[21] https://biogasassociation.ca/biogas_101/
[22] https://afdc.energy.gov/fuels/natural-gas-renewable

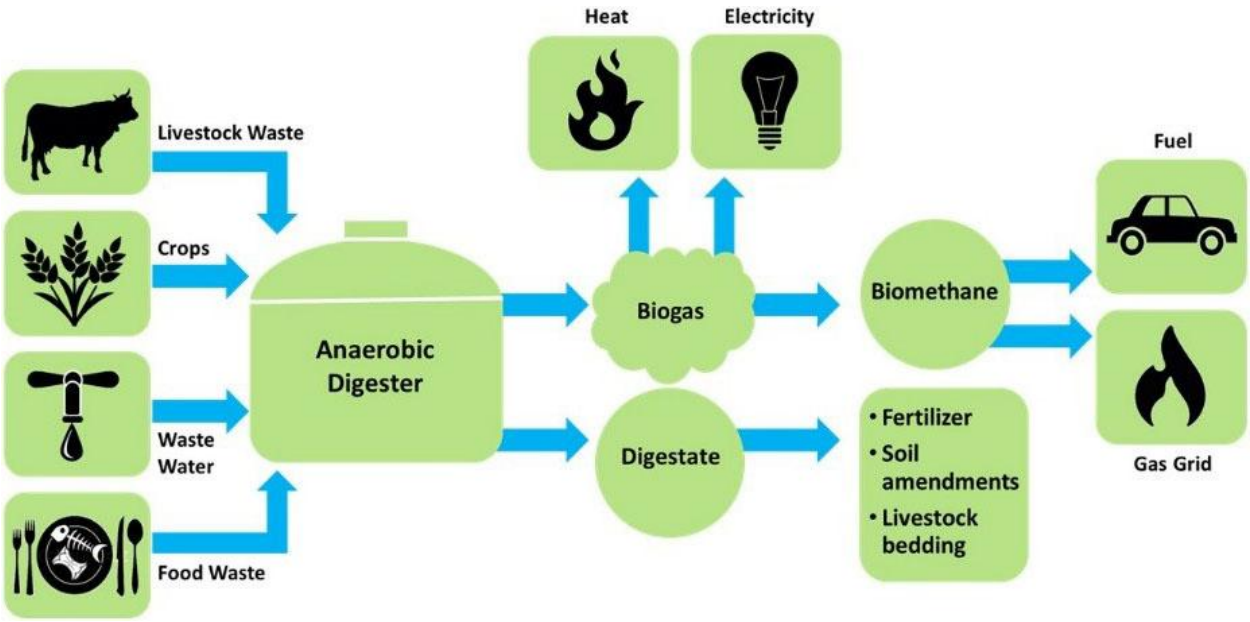

Figure 5: Examples of biomethane pathways[23]

The biological matter that's used to produce biogas will naturally decay anyway, so capturing the gases produced by this decay, and using them as an energy source, causes less harm to the environment than allowing them to escape into the atmosphere[24]. Biomethane – or 'Renewable Natural Gas (RNG)' – refers to biogas that has also been cleaned and conditioned to remove or reduce non-methane elements allowing it to be used as a replacement for (or supplement to) traditional natural gas or LNG[25]. Because of this, RNG has the same potential applications in NL as natural gas or LNG: marine transportation, electricity generation, and (to a lesser extent) surface transportation.

Biohydrogen

Biohydrogen refers to hydrogen obtained from biogenic sources (for example, biogases and biomass) using a variety of technologies including biological, thermochemical, and bioelectrochemical processes[26]. For example, the vast majority of hydrogen used today is produced via natural gas through a process called 'steam methane reforming' (SMR). Consider that RNG is chemically identical to natural gas; a low-carbon hydrogen can be produced with biomass as the original feedstock via SMR using RNG. While biohydrogen itself is not expected to be used in large quantities in NL, it is mentioned here because of the potential uses of green hydrogen and the potential for biohydrogen as a supplement.

[23] https://www.eesi.org/papers/view/fact-sheet-biogasconverting-waste-to-energy
[24] https://www.nationalgrid.com/stories/energy-explained/what-is-biogas
[25] https://afdc.energy.gov/fuels/natural-gas-renewable
[26] https://www.europeanbiogas.eu/wp-content/uploads/2025/06/Decarbonising-Europes-hydrogen-production-with-biohydrogen.pdf

Bio-methanol

Biogas can also be refined to produce bio-methanol. Whereas RNG is gaseous, the compound can be further refined into a liquid alcohol (bio-methanol)[27]. Methanol is a light, versatile, colourless and flammable alcohol. Methanol is used as a solvent for lacquers, paints, varnishes, cements, inks, dyes, plastics and various industrial coatings. It is also used in the production of pharmaceuticals, formaldehyde and other chemical products. Methanol appears as an ingredient in many products, from industrial solvents to windshield-washer fluid and nail-polish remover. It can also be used as a fuel and is a viable option for various applications with increasing interest in its use in power generation and adoption within the marine transportation sector. In an internal combustion engine, methanol reacts with the oxygen in the air to create energy with carbon dioxide and water as the residuals.

Ethanol

Ethanol is a renewable, alcohol-based fuel made primarily from the fermentation of plant materials like corn, sugarcane, wheat, wood fibres, or other biomass feedstocks – potentially even wood waste from the construction and demolition industry. Ethanol is commonly blended with gasoline and blending is required in most jurisdictions in North America. With a higher-octane value than gasoline, ethanol improves the effectiveness of the fuel by preventing engine knocking. Typically, gasoline contains E10 (10% ethanol, 90% gasoline), which reduces air pollution[28]. Quebec has recently introduced legislation which will require a 12% ethanol blend by 2026 and 15% by 2030[29], with other provinces already having made these commitments. NL has a permanent exemption from requirements in Canada for ethanol blending, but its use on a voluntary basis presents opportunity for the decarbonization of the surface transportation sector.[30]

Biodiesel

Biodiesel is a diesel fuel substitute made from renewable materials such as: plant oils (canola, soy, flax, etc.), waste cooking oil (yellow or tap grease), other oils (tall, fish, and algae), animal fats (beef or sheep tallow, pork lard, or poultry fat); and potentially from cellulosic feedstock consisting of agriculture and forest biomass. The process to create biodiesel is called 'transesterification.' Made from renewable resources biodiesel has

[27] https://methanol.org/wp-content/uploads/2020/04/IRENA_Innovation_Renewable_Methanol_2021.pdf
[28] https://afdc.energy.gov/fuels/ethanol-fuel-basics
[29] https://www.ctvnews.ca/montreal/article/quebec-rolling-out-higher-ethanol-blend-in-gasoline-starting-this-week/
[30] Biofuel Technologies: Lessons Learned and Pathways to Decarbonization - https://onlinelibrary.wiley.com/doi/10.1111/gcbb.13091

the potential to reduce GHG emissions by over 80% on a lifecycle basis.[31] Biodiesel is most often used blended with conventional diesel (see 'Blending Fuels' above). As such, biodiesel has applications in NL that mirror those of conventional diesel – including use in the marine transportation sector, surface transportation sector, and electricity generation.

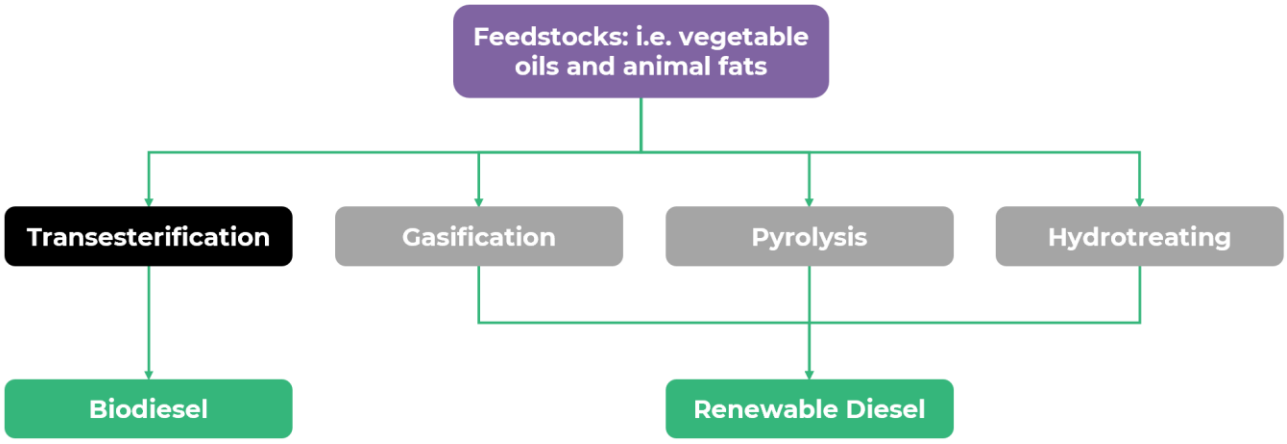

Figure 6: Example of Biodiesel and Renewable Diesel production pathways

Renewable Diesel

Similar to biodiesel in terms of feedstock, renewable diesel is a fuel made from fats and oils, such as soybean oil or canola oil – however the process utilized in fuel production is different. Produced most often by hydrotreating, and also via gasification, pyrolysis, and other biochemical and thermochemical technologies, the resulting fuel is chemically identical to conventional diesel[32] but has a much lower lifecycle carbon footprint. This means that renewable diesel can be used as a direct replacement for conventional diesel (i.e., as a 'drop-in'), if not a heavy additive in blending. While renewable diesel has a similar chemical structure to diesel, it has been shown to produce equal or lower levels of NOx and PM emissions when burned. In addition, traditional diesel contains aromatic compounds present in distillates that contribute to toxicity, whereas renewable diesel does not contain such compounds and as a result, has a decreased environmental toxicity and a higher degradation rate. As such, in the case of a spill, renewable diesel has less short and long-term environmental effects compared to conventional fossil fuels[33]. Renewable diesel is produced in NL; Braya Renewable Fuels has converted the Come by Chance refinery to produce up to 18,000 barrels per day of renewable diesel[34]. Renewable diesel has applications in NL that mirror those of conventional diesel – including use in the marine transportation sector, surface transportation sector, and electricity generation.

[31] https://natural-resources.canada.ca/energy-efficiency/transportation-energy-efficiency/biodiesel
[32] https://afdc.energy.gov/fuels/renewable-diesel
[33] https://econext.ca/discussion-paper-opportunities-for-domestic-clean-fuels-use-in-newfoundland-and-labrador/
[34] https://brayafuels.com/

Green Hydrogen

Hydrogen is the most abundant element in the universe. When burned, hydrogen produces only water vapour, resulting in zero GHG emissions which makes it an attractive fuel source. Hydrogen has been a widely used input in a variety of industries for many years and can be produced through a variety of methods[35]. Most of hydrogen used today is produced via natural gas through a process called 'steam methane reforming' ('grey hydrogen'). This process can be paired with carbon capture and storage (CCS) to produce hydrogen with much fewer resulting GHGs ('blue hydrogen').

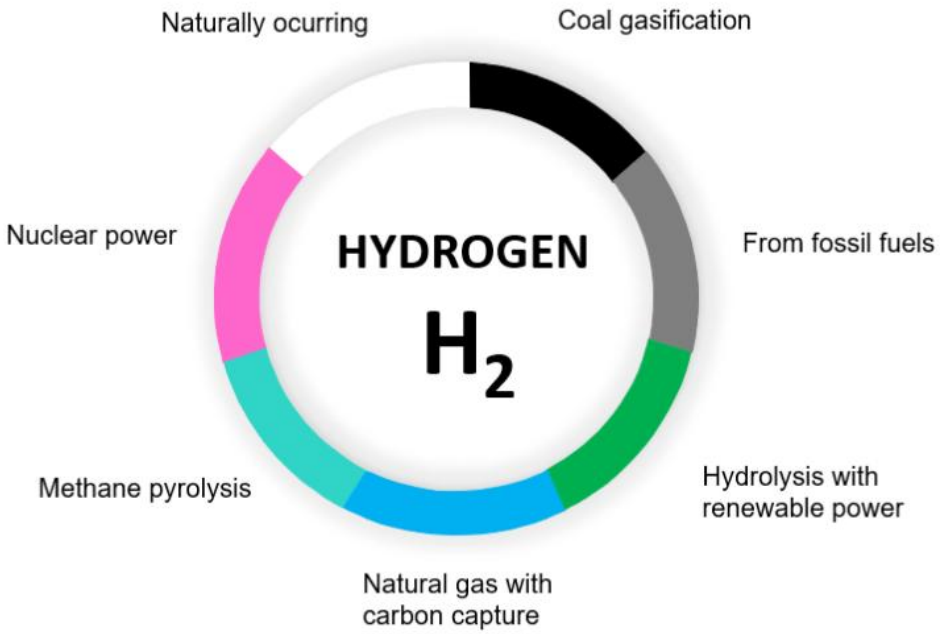

Figure 7: Hydrogen production pathways and colour associations[36]

'Green hydrogen' is when hydrogen is produced through a process called 'electrolysis' utilizing renewable energy. Green hydrogen can be produced with zero GHGs and be 'burned' resulting in zero GHGs – positioning it strongly as an important contributor in the fight against climate change. Green hydrogen is expected to be produced in NL in the early 2030s with a focus on export markets. Domestically, there are potential uses for green hydrogen in the surface transportation and electricity generation sectors. Also important to consider is hydrogen's relationship with other fuels such as methane and natural gas (see below). Hydrogen is also required in the production of renewable diesel, and thus the use of green hydrogen in these processes further decarbonizes that fuel. Moreover, green hydrogen is the key fuel in the production of other e-fuels like green methanol and green ammonia (see below).

[35] https://www.siemens-energy.com/global/en/home/products-services/solutions-usecase/sustainable-fuels.html#Hydrogen-tab-0
[36] https://jpt.spe.org/twa/the-color-palette-of-the-colorless-hydrogen

Liquid Organic Hydrogen Carrier (LOHC)

Hydrogen is light gas with low energy density, making storage and transportation costly. For this reason, several different fuels which feature hydrogen as one of the primary elements are being considered as 'hydrogen carriers' as they have more favourable characteristics for transport and storage. LOHC is one of these 'hydrogen derivative' fuels and allows hydrogen to be chemically bonded to a liquid carrier making it safer and more efficient to handle. LOHCs can be transported easily using existing diesel infrastructure, with the organic compound removed near the point where hydrogen is to be used. These organic compounds are capable of reversible hydrogenation – binding and releasing hydrogen through chemical reactions[37]. Much of the organic compound can be 'recycled' and bonded with hydrogen again many times. Given the potential LOHC has as a hydrogen carrier and the fact it may be produced within NL by the early 2030s[38], it presents expanded opportunities for hydrogen use within the province that are not practical if transporting and storing hydrogen in its pure state.

Green Methane

Methane has been used as a fuel and, later, a chemical feedstock since it was discovered and isolated in the 18th century. It is four parts hydrogen and one part carbon. Methane is a key component of natural gas (90%) and historically has been taken either directly from natural gas fields or as a by-product of other fossil fuel extraction[39]. However, methane can be synthetically created through the combination of hydrogen and carbon dioxide. When green hydrogen is used in this process (along with sustainably sourced carbon dioxide), the resulting fuel is green methane (or 'e-methane'). Similar to biomethane, green methane is chemically identical to conventional methane and thus can be used as a heavy blend (or replacement for) natural gas. Green methane production has been commercialized at a relatively small scale, with most projects tied to existing biogas/biomethane plants; supplying green hydrogen in addition to anaerobic digestion can reportedly increase methane output by 60% compared to typical biogas upgrading[40]. As natural gas is primarily methane, and methane is primarily hydrogen, green hydrogen can be used in the decarbonization of natural gas / LNG / RNG and their applications (marine transportation, electricity generation, and to a lesser extent surface transportation).

[37] https://www.deassociation.ca/newsfeed/what-is-lohc-liquid-organic-hydrogen-carrier
[38] https://www.greenenergyhub.ca/
[39] https://enapter.com/en/blog/the-promise-of-green-methane/
[40] https://www.idtechex.com/en/research-article/e-fuels-explained-methanol-methane-diesel-and-saf/34444

Green Methanol

Methanol is one part carbon, three parts hydrogen, one part oxygen, and one part methyl group (CH_3OH). Methanol as a fuel has several potential benefits, including low emissions, low cost, and excellent energy density. Methanol is water-soluble and readily biodegradable. With hydrogen being a primary component, the use of green hydrogen in methanol production results in 'green methanol' or 'e-methanol'. Liquid methanol has a higher energy density than gaseous hydrogen, making it practical for transport and storage. Low-carbon methanol (including bio-methanol and green methanol) is increasingly being viewed as a fuel of choice within the international marine transportation sector.

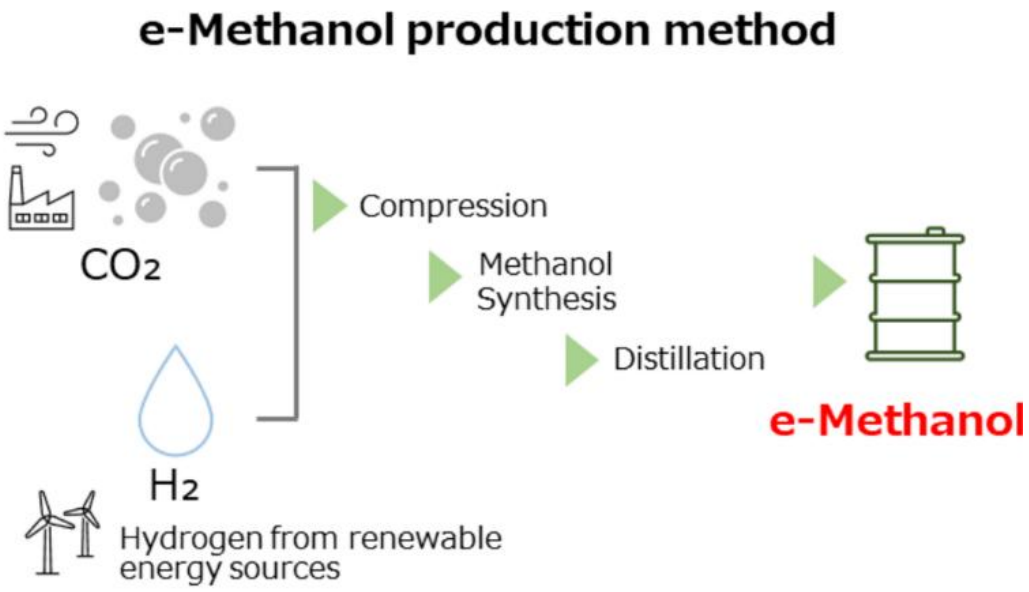

Figure 8: e-methanol production method[41]

Green Ammonia

Ammonia is one part nitrogen and three parts hydrogen (NH_3). Similar to green methanol, ammonia can be produced using green hydrogen resulting in a clean fuel that is commonly referred to as 'green ammonia' or 'e-ammonia'. Ammonia can be used in a variety of applications with an international focus on chemical processing, fertilizer production, marine transportation, and some early work in electricity generation. Its high energy density and low viscosity make it a suitable option as a 'hydrogen carrier' or as a method to transport hydrogen long distances. While significant domestic use of green ammonia is not predicted for NL, a final investment decision is expected to be made on a

[41] https://www.idemitsu.com/en/business/oil/lowcarbon/e-methanol_future.html

large green ammonia production in NL before 2030[42] with production being export-focused for international markets.

5. Safety and Skills Considerations for Low-Carbon Fuels Use in NL

The fuels covered in this discussion paper have been safely and efficiently handled globally at scale for many years, however there is limited experience working with them within the NL context.

While renewable fuels are in production in NL, it is currently not used domestically within the province[43]. There is some capacity in biofuel production and testing in academic circles within the province, however there is very little in terms of hands-on industry experience. The use of e-fuels will be entirely new to NL.

Best practices in the production, transportation, handling, storage, and use of these fuels will be relatively new concepts for the workforce in NL. Meanwhile, as NL is exempt from Canadian renewable fuels requirements the gasoline and diesel used domestically does not contain any ethanol or biodiesel blends. Thus, the concept of fuel blending is foreign within the province.

Given this relative inexperience locally, it is reasonable to consider the characteristics of low-carbon fuels and the technologies and equipment associated with them that may require safety and skills upgrades within NL's workforce.

5.1 Low-Carbon Fuel Characteristics

Below is a summary of low-carbon fuels and their characteristics (with information from,[44],[45],[46], [47],[48]) including potential use cases within NL. Observations on safety and skills requirements specific to each fuel and its associated processes are made. These considerations are high-level and are provided to assist in informing a future more thorough analysis and should not be considered exhaustive.

[42] https://evrec.ca/project/
[43] https://vocm.com/2026/06/15/301618/
[44] https://afdc.energy.gov/fuels
[45] https://www.siemens-energy.com/global/en/home/products-services/solutions-usecase/sustainable-fuels.html
[46] https://www.lr.org/en/knowledge/research/fuel-for-thought/methanol/
[47] https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/h2_safety_fsheet.pdf
[48] https://www.europeanbiogas.eu/wp-content/uploads/2025/06/Decarbonising-Europes-hydrogen-production-with-biohydrogen.pdf

Natural Gas

Characteristics

- Natural gas is an odorless and colorless gas.
- It is also highly flammable.
- This means that leak detection is important in handling, transportation, and use.
- It is typically infused with chemicals (odorants) to create a distinctive pungent smell as a method of leak detection and morning.
- In enclosed spaces, carbon monoxide presents danger in the event of a leak.
- Natural gas is stored at very high pressures.

Potential NL Use Cases

- Natural gas has the potential to be used within NL's electricity sector as its combustion turbine(s) have dual-fuel capability (in addition to diesel).
- Activities would include transportation, storage, fueling, and use within the context of these assets.
- Natural gas has (to a much lesser extent) potential applicability within the surface transportation sector. Use would include transportation, storage, and refueling within the context of vehicles.

Skills Considerations

- Flammability, pressure, and combustion characteristics
- Leak detection
- Corrosion control
- Pipeline inspection and maintenance
- Overpressure protection
- Flow rates, pressure requirements, and fuel consumption
- Fluid mechanics
- Thermodynamics
- Structural mechanics
- Emissions control
- Regulatory compliance
- Emergency preparedness
- Storage, transport, and handling
- … and more

Liquified Natural Gas (LNG)

Characteristics

- LNG is a cryogenic liquid stored at around -162°C.
- It is odorless and does not contain an odorant, with leaks difficult to detect.
- LNG is stored and transported inside double-walled or double-hulled containers to keep it cold and to reduce the risk of a leak.

Potential NL Use Cases

- LNG has the potential to be used within NL's marine transportation sector as newer ships (and those on the order book) increasingly feature LNG as a potential fuel.
- Activities would include transportation, storage, fueling, and use within the context of shipping.

▪ When stored, LNG is not flammable or explosive because there is no air to create a mixture that could ignite. LNG needs a much higher ignition source temperate to ignite. ▪ In the unlikely event of a leak, LNG would warm, turn back into natural gas, rise and dissipate without leaving any residue on land or water. ▪ Being stored at very cold temperatures creates a danger for freeze burns that can occur from coming into contact with LNG or its vapor.	
Skills Considerations ▪ Liquefaction processes ▪ Regasification processes ▪ Temperatures, pressures, and flow rates ▪ Cryogenic piping ▪ Cryogenic hazard awareness ▪ Compressors	▪ Refrigeration and heat exchange ▪ Inerting and cooling ▪ Regulatory compliance ▪ Emergency preparedness ▪ Storage, transport, and handling ▪ … and more

Biomethane / Renewable Natural Gas (RNG, Bio-LNG)

Characteristics ▪ As RNG is chemically identical to its natural gas and LNG counterparts, the same characteristics and considerations apply. ▪ There are safety considerations related to RNG production processes, i.e.: methane capture; purification and upgrading; CO2 removal; and the technologies used such as anaerobic digesters, etc.	**Potential NL Use Cases** ▪ RNG or Bio-LNG have the same potential for adoption as do their fossil fuel-based equivalents, i.e., the electricity sector, marine transportation sector, and to a much lesser extent the surface transportation sector. ▪ Activities would include transportation, storage, fueling, and use within these contexts in addition to its local production and blending with other fuels.
Skills Considerations ▪ All factors relating to natural gas and LNG, in addition to…	▪ Gas compression and injection ▪ Waste and water management ▪ Pressure relief and flares

- Organic waste streams and their characteristics
- Capture and cleaning of biogas
- Removal of contaminants and upgrading of biogas
- Pumps, compressors, blowers, and treatment
- Regulatory compliance
- Emergency preparedness
- Storage, transport, and handling
- … and more

Green Methane

Characteristics

- As green methane is chemically identical to methane and natural gas is mostly methane, the same characteristics and considerations apply.
- There are safety considerations related to green methane production processes, i.e. methanation which combines hydrogen and CO2.
- Methanation processes require extreme temperatures and pressures; equipment failures or leaks can rapidly release volatile, highly reactive gas clouds.

Potential NL Use Cases

- Similar to biomethane, green methane has the same potential for adoption as do its fossil fuel-based equivalents, i.e., the electricity sector, marine transportation sector, and to a much lesser extent the surface transportation sector.
- Use would include transportation, storage, fueling, and use within these contexts in addition to its local production (using hydrogen and CO2) and blending with other fuels.

Skills Considerations

- All factors relating to natural gas, LNG, biomethane (see above)
- All factors relating to hydrogen production and handling (see below)
- CO2 capture, purification, and compression
- Carbon accounting and lifecycle assessment
- Catalytic methanation reactions
- Reactor operation and monitoring
- Heat and mass transfer principles
- Compressors, pumps, valves, and reactors
- Prevention of asphyxiation and frostbite
- Pressure optimization
- Regulatory compliance
- Emergency preparedness
- Storage, transport, and handling
- … and more

Ethanol

Characteristics

- Ethanol is a clear, colorless liquid.
- It is poisonous and flammable.
- In general, the same safety measures that apply to gasoline apply to ethanol blended fuels.
- There are safety considerations related to ethanol production processes, i.e.: liquefaction, fermentation, distilling, and dehydration.

Potential NL Use Cases

- Ethanol has the potential to be used within the surface transportation sector as a blend within gasoline – as is commonly done in many other jurisdictions.
- Activities would include transportation, storage, and refueling within the context of vehicles, in addition to local production and blending.

Skills Considerations

- Feedstock quality assessment
- Drying operations
- Steam explosion processing
- Acid or alkaline pretreatment
- Reactor optimization
- Biochemistry and microbiology
- Enzymatic liquefaction
- Fermentation
- Saccharification
- Distillation
- Denaturation
- Regulatory compliance
- Emergency preparedness
- Storage, transport, and handling
- … and more

Biodiesel

Characteristics

- Biodiesel is safer than petroleum diesel because it is less combustible; the flashpoint for biodiesel is higher than 130°C, compared with about 52°C for petroleum diesel.
- Biodiesel causes far less damage than petroleum diesel if spilled or released to the environment.
- In general, the same safety measures that apply to diesel apply to biodiesel blended fuels.

Potential NL Use Cases

- Biodiesel has the potential for broad adoption (wherever diesel is used) within the electricity, marine transportation, and surface transportation sectors – as is commonly done in many other jurisdictions.
- Activities would include transportation, storage, and refueling within the context of each application, in addition to local production and blending.

▪ There are safety considerations related to production processes (transesterification, separation, and purification)	
Skills Considerations ▪ Feedstock characteristics ▪ Feedstock pre-processing ▪ Transesterification ▪ Titration ▪ Catalyst and methoxide preparation ▪ Separation, washing, and purification ▪ Viscosity monitoring	▪ Handling concentrated lye and alcohol vapours ▪ Byproduct management ▪ Regulatory compliance ▪ Emergency preparedness ▪ Storage, transport, and handling ▪ … and more

Renewable Diesel

Characteristics ▪ As renewable diesel is chemically identical to its petroleum-based counterpart, the same characteristics and considerations apply. ▪ There are safety considerations related to renewable diesel production processes, of which there are several methods: hydrotreating; sugar upgrading; catalytic conversion; gasification; pyrolysis; and/or hydrothermal processing. ▪ Hydrogen is used in the production of renewable diesel.	**Potential NL Use Cases** ▪ Renewable diesel has the potential for broad adoption (wherever diesel is used) within the electricity, marine transportation, and surface transportation sectors. ▪ Activities would include transportation, storage, and refueling within the context of each application, in addition to local production and blending.
Skills Considerations ▪ Quality assessment of oils and fats ▪ Feedstock pretreatment ▪ Catalytic hydrotreating ▪ Hydroprocessing and hydrogenation ▪ Hydrocracking and isomerization ▪ Managing corrosion and byproducts ▪ Distillation	▪ Catalytic reaction management ▪ Cold weather fuel management ▪ All factors relating to hydrogen production and handling (see below) ▪ Regulatory compliance ▪ Emergency preparedness ▪ Storage, transport, and handling

▪ Catalytic reaction management	▪ … and more

Green Hydrogen

Characteristics ▪ Hydrogen is odorless, colorless and tasteless. ▪ It is lighter than air and diffuses rapidly; when released, it dilutes quickly into a non-flammable concentration. ▪ Leak detection can be challenge, but it is non-toxic. ▪ Hydrogen is flammable, igniting easier than other fuels and burns with an invisible/ near invisible flame. ▪ Its low energy density means that the gas is typically stored at very high pressures, low-temperatures, or chemical processes. ▪ When burned, hydrogen produces only water vapor, resulting in zero carbon emissions. ▪ There are safety considerations related to green hydrogen production processes related to electrolyzer technology.	**Potential NL Use Cases** ▪ Green hydrogen has potential for adoption within NL's electricity sector either as a blend with natural gas or as a stand-alone view (requiring modification of combustion turbine assets). ▪ Activities would include transportation, storage, fueling, and use within the context of electricity generation assets, in addition to local production (via clean energy) and blending. ▪ Green hydrogen has potential for adoption within NL's surface transportation sector. ▪ Activities would include transportation, storage, and refueling within the context of vehicles, in addition to local production and blending.
Skills Considerations ▪ Ventilation ▪ Leak detection ▪ High-pressure fittings ▪ Water purification ▪ Electrolysis systems ▪ High-voltage electrical systems ▪ Embrittlement prevention ▪ Fuel cells systems and components	▪ Fuel cells systems and components ▪ Pressure and flow control ▪ Hazards and emergency response ▪ Regulatory compliance ▪ Emergency preparedness ▪ Storage, transport, and handling ▪ … and more

Liquid Organic Hydrogen Carrier (LOHC)

Characteristics

- LOHCs are stable and handled like conventional gasoline, making them safe and practical.
- There are safety considerations related to LOHC processes related to the hydrogenation and dehydrogenation processes where the organic compounds are bound and unbound from the hydrogen.
- Various organic compounds can be used for binding with hydrogen; NL projects focus on the use of toluene which is a flammable liquid and toxin

Potential NL Use Cases

- LOHCs have the same potential for adoption within NL as hydrogen – i.e., within its electricity and surface transportation sectors. While transportable as LOHC, the product must be dehydrogenated to separate the hydrogen for use.
- Activities would include transportation and storage within the context of each sector, in addition to local production and the hydrogenation / dehydrogenation processes.

Skills Considerations

- Hydrogenation reactor control
- Catalyst loading and management
- Dehydrogenation processes
- Previous metals
- Methylcyclohexane storage and transfer
- Pressure swing adsorption
- Ventilation
- Gas chromatography
- Chemical processes
- Static electricity controls
- … and more

Biohydrogen

Characteristics

- As renewable biohydrogen is chemically identical to hydrogen (and green hydrogen), the same characteristics / considerations apply.
- There are safety considerations related to biohydrogen production processes which can vary considerably. Production pathways include biological processes, thermochemical processes, and bio-electrochemical processes.

Potential NL Use Cases

- Biohydrogen has the same potential for adoption within NL as hydrogen – i.e., within its electricity and surface transportation sectors.
- Activities would include transportation, storage, refueling, and use within the context of each sector, in addition to local production and the hydrogenation / dehydrogenation processes.

Skills Considerations

- Dark fermentation
- Biophotolysis
- Photofermentation
- Gasification, pyrolysis, raw biogas and biomethane steam reforming
- Microbial electrolysis
- Regulatory compliance
- Emergency preparedness
- Storage, transport, and handling
- … and more

Green Methanol

Characteristics

- Methanol is a liquid at ambient temperatures.
- It has a higher energy density than gaseous hydrogen, making it practical for transport and storage.
- Methanol It is biodegradable and miscible in water, with fewer and shorted environmental impacts in the event of a spill.
- Methanol is highly flammable with vapors dangerous in confined areas.
- It has corrosive characteristics which requires specific storage and handling arrangements.
- There are safety considerations related to green methane production processes, i.e. the combination of hydrogen and CO2.

Potential NL Use Cases

- Green methanol has potential for adoption within NL's marine transportation sector as procurement trends within the shipping industry point towards likely adoption in the medium to long term.
- Activities would include transportation, storage, and fueling within the context of shipping.

Skills Considerations

- All factors relating to hydrogen production and handling (see above)
- CO2 capture, purification, and compression
- Carbon accounting and lifecycle assessment
- Heat and mass transfer
- Compression and heating
- Distillation
- Distillation
- Vapour monitoring
- Dermal and respiratory protection
- Ignition control
- Static dissipation
- Regulatory compliance
- Emergency preparedness
- Storage, transport, and handling
- … and more

Bio-methanol

Characteristics ▪ As bio-methanol is chemically identical to methanol (or green methanol), the same characteristics and considerations apply. ▪ There are safety considerations related to bio-methanol production processes, i.e. thermochemical gasification or biogas reforming.	**Potential NL Use Cases** ▪ Bio-methanol has the same potential for adoption as green methanol (i.e., within NL's marine transportation sector). ▪ Activities would include transportation, storage, and fueling within the context of shipping – in addition to local production.
Skills Considerations ▪ All factors relating to methanol handling (see above) ▪ Moisture content control ▪ Gasifier operation ▪ Syngas cleanup and conditioning ▪ Sulfur and contaminant removal ▪ Water separation and purification	▪ Water separation and purification ▪ Thermochemical gasification ▪ Regulatory compliance ▪ Emergency preparedness ▪ Storage, transport, and handling ▪ … and more

Green Ammonia

Characteristics ▪ Ammonia is typically liquified for transport and storage at a temperature of -33°C. ▪ Liquid ammonia has a higher energy density than gaseous hydrogen, making it practical for storage and transport. ▪ Ammonia is less flammable than other fuels. ▪ However, it is a toxic, poisonous, and corrosive gas that can have significant environmental impacts and health hazards in the event of a spill or leak.	**Potential NL Use Cases** ▪ Ammonia is viewed primarily as an export from NL. ▪ Ammonia is used in a number of circumstances beyond energy in NL, including as a refrigerant for cold storage and ice rinks and in water treatment – meaning that initiatives aimed at safety and skills have application beyond low-carbon fuels.

▪ Being stored at very cold temperatures creates a danger for freeze burns that can occur from coming into contact with ammonia. ▪ There are safety considerations related to green ammonia production processes, i.e. the Haber-Bosch process.	
Skills Considerations ▪ All factors relating to hydrogen production and handling (see above) ▪ Haber-Bosch process ▪ Pressurization and refrigeration ▪ Cryogenic distillation ▪ Membrane nitrogen production ▪ Catalytic process management	▪ Leak detection ▪ Hazards and emergency response ▪ Regulatory compliance ▪ Emergency preparedness ▪ Storage, transport, and handling ▪ … and more

5.2 Technology and Equipment Considerations

Below is a non-exhaustive list of technology and equipment applicable to the testing and blending of a variety of low-carbon fuels.

Blending

It has become clear that fuel blending will play a key role in NL's low-carbon fuels future. Therefore, in considering the different safety and skills that will be necessary to support these activities – it is important to understand the various processes and equipment that will be in play.

The general process of creating fuel blends involves measuring fuel components, mixing, and sampling. There are many blending methods available, and they can be categorized as in-line blending or batch blending.

In-line blending methods meter fuels into a single pipe, allowing mixing within the pipe prior to injection into a container.

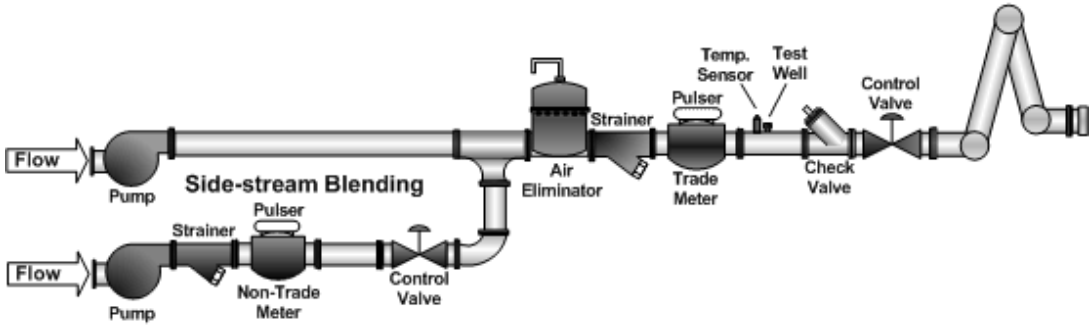

Figure 9: Diagram of in-line blending method (side stream)[49]

There are a number of different types of in-line blending methods which are based on the point at which the components are combined. Configurations include side stream, ratio, sequential, and hybrid blending.

- Side stream strains and meters a secondary fuel component into a primary stream, after which the mixture is strained and re-metered (see figure above)
- Ratio blending simultaneously and individually meters the fuel components and combines the streams at the end of the process (see figure below). Two separate streams undergo straining and metering, after which they are combined into one stream.

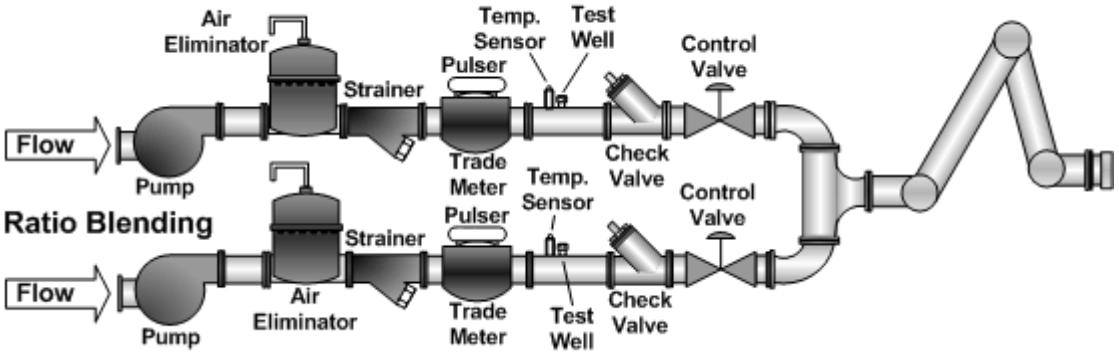

Figure 10: Diagram of in-line blending method (ratio blending)[49]

- Sequential blending uses the same straining and metering equipment for each fuel component, which must be alternately passed through the pipe (see figure below). In sequential blending, little mixing occurs between components in the pipe; mixing primarily occurs in its storage or transportation vessel.

[49] Blend Systems - https://ised-isde.canada.ca/site/measurement-canada/en/laws-and-requirements/v-28-blend-systems

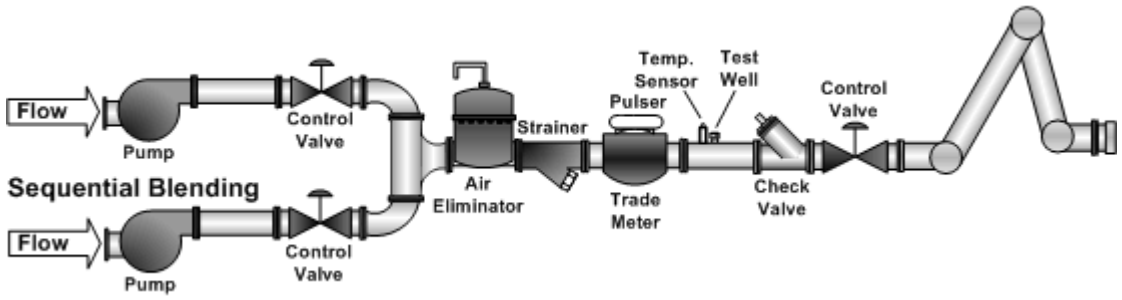

Diagram of in-line blending method (sequential blending)[49]

Batch blending may be used, whereby mixing occurs solely within the storage or transportation vessel. Two primary versions are in-tank and splash blending.

- In-tank blending, or pre-blending, is a simple blending method where the component fuels are separately pumped into a container and are mixed using either the incoming turbulence or additional static mixing. This blending method is typically done at the refinery.
- Splash blending is a form of in-tank blending that is specifically used during transportation of the fuel mixture. The constituent fuels are separately pumped into the transportation vessel and mixing is achieved through the 'splashing' of the fuels during transportation.

While blending fuels at the fuel pump is not common, it is possible and is referred to as rack blending[50]. This allows users to directly add constituent fuels at the pump and can allow for more customizable blend ratios.

There are many nuances with blending fuels depending on the fuels being used, the blend ratios desired, and the end use application of the product. The blending of fuels is a highly technical activity requiring various areas of expertise ranging from chemistry to mechanical engineering. The summary of blending processes above is not meant to be all-inclusive; rather it is meant to demonstrate the complexity of the activities and the need for appropriate skills and training.

[50] Biodiesel Blending - https://www.targray.com/biofuels/biodiesel/blending

Laboratories and Testing

Beyond industrial-scale activities, research, development, and education related to low-carbon fuels production, use, and blending is supported by technology and equipment in laboratory and testing environments.

The below list of technologies is drawn from a catalogue of relevant test facility assets at National Research Council centres and universities across Canada. This list is meant to advance discussion around the technology and equipment involved in laboratories, testing, and blending of low-carbon fuels. This is not a targeted or definitive list of what is used or what may be required. More work is required for NL to identify the specific technologies and equipment that would support the advancement of low-carbon fuels use within the province.

- Gas Chromatography – Electron Capture Detector (GC-ECD)
- Gas Chromatography – Flame Ionization Detector (GC-FID)
- Temperature Programmed Reduction, Desorption, and Oxidation (TPR/TPD/TPO)
- Gas Chromatography with Mass Spectrometer (GC-MS)
- Photochemical Reactor
- Capillary Electrophoresis (CE)
- High Performance Liquid Chromatograph (HPLC)
- Scanning Electron Microscope with Energy Dispersive Spectrometer (SEM-EDS)
- X-Ray Diffractometer (XRD)
- Nuclear Magnetic Resonance (NMR)
- Fourier Transform Infrared (FTIR) Spectroscopy with Diffuse Reflectance (DRIFTS)
- Thermogravimetric Analyzer with Differential Scanning Calorimeter (TGA)
- 3Flex Surface and Catalyst Characterization Instrument
- Dryers, Evaporators, and Muffle Furnaces
- Fixed-bed, Batch and Gas flow Reactors
- Hydraulic Press
- Microviscometer
- Viscometer
- Density Meter
- Shaking Incubator
- ICP-OES Spectrometer
- XRD (X-ray Diffraction)
- Gas Chromatography-Mass Spectrometry and Purge and Trap
- TOC-L Total Organic Carbon Analyzer
- 2,000 L continuously stirred tank reactor (CSTR) digester and a 500 L upflow anaerobic sludge blanket (UASB) digester
- 4,000 L refrigerated feed tank for continuous operation and a 1,000 L pre-treatment reactor (chemical or enzymatic)

- Mechanical pre-treatment equipment (macerator, shredder, screw press)
- 1500 L reception tank
- Grinder to homogenize heterogeneous substrate
- 2 CSTR-type digesters
- Permanent gas analyzer
- Tar sampling train
- Fourier transform infrared (FTIR) gas analyser
- Thermogravimetric analyzer (TGA)
- Carbon, hydrogen, nitrogen, sulfur analyzers (CHNS)
- High-performance liquid chromatography (HPLC)
- Calorimeter
- Ignition quality tester (IQT)
- Parr 6200 isoperibol calorimeter
- High-frequency reciprocating rig (HFRR) for lubricity testing
- Liquid chromatography–mass spectrometry (LC-MS)
- Viscometer (SVM 3000 Stabinger-Anton PAAR)
- Homogenous charge compression ignition (HCCI) engine test cell
- Fuel-flexible compression ignition heavy-duty engine test cell
- Fuel-flexible compression ignition power-generation engine test cell
- Gas analyzers (CO2, CO, HC, CH4, NOx)
- Continuous Fourier-transform infrared spectroscopy (FTIR)
- MultiGas analyzer (MKS 2030)
- 3DATX portable emission-measurement system
- Nova Model 975PA transportable syngas analyzer
- Portable natural gas analyzer
- Laser-induced incandescence (LII) black-carbon measurement instrument
- BG-2 particulate partial flow sampling system
- IndiCom real-time combustion analysis system
- Greenlight G60 and G100 PEM fuel cell test station (800W, 1300W)
- Arbin FCTS fuel cell test stations (500W)
- Scribner 850C, 850E, and 890E compact fuel cell test systems (100W) for screening PEM fuel cell components
- Greenlight E60 PEM electrolyser test station 2 kW (max 200A/10V) for cell development
- Electrolyser test stations for PEM electrolyser component screening
- Hydrothermal dual-reactor gasifier
- Batch autoclaves and tubular reactors
- High shear homogenizer/wet mill
- High-Pressure Spray Facility (HPSF)
- Optically Accessible Single Injector System (OASIS) Facility
- Low-pressure Optically-Accessible Combustion Rig (LOACR)
- Optically Accessible Combustion Rig (OACR)
- Planar Laser Induced Fluorescence (PLIF)
- Particle Image Velocimetry (PIV) for planar 2D and 3D velocity measurements
- Laser Sheet Dropsizing (LSD) for planar droplet visualization and sizing
- Phase Doppler Particle Analyzer
- Malvern Laser Diffraction Particle Analyzer

- Thermal desorption units
- Combustion chambers

Training may be necessary for some of these systems if they will be used locally in NL for the purposes of supporting and enabling low-carbon fuels adoption.

5.3 Cultural Considerations

The adoption of low-carbon fuels represents a social and cultural shift, not just a technological one. Acceptance and use of 'new' ideas and products is influenced by societal values, trust, and habits.

In its research and activities related to low-carbon fuels adoption within NL, the importance of considering culture has become clear. econext has heard first-hand from early adopters the challenges that have been faced related to the acceptance of low-carbon fuel use on the front-line – even in cases where there are no material changes in how the fuel is transported, stored, or deployed as compared to the status quo.

If the benefits of low-carbon fuels use are to be realized, there will be a need for continuous education, awareness, and engagement amongst the general public and knowledge and skills development within the workforce.

Access to low-carbon fuel blending and testing facilities and the demonstration of these technologies in action will allow for key audiences to see fuel usage and outcomes which will help to de-risk adoption from a cultural and skills perspective.

5.4 Observations Based on Likelihood of Adoption

In considering the development and advancement of low-carbon fuels training and professional development programming that contributes to safety and skills development, stakeholders cannot plan for all possibilities. In the midst of the energy transition, there are many unknowns and uncertainty about what specific fuels will be adopted – and when.

However, it is possible to make some judgments on the likelihood of production and/or adoption pf low-carbon fuels within the NL context. Recently published discussion papers by econext exploring low-carbon fuel adoption opportunities in the marine transportation, surface transportation, and electricity sectors allow for some high-level assumptions to be made.

Based on the findings of these discussion papers, the table below summarizes the probability of domestic production and domestic use of various low-carbon fuels in NL. The results shown are not based on techno-economic analysis but on an examination of global trends, the current state of GHG emissions and energy use in key sectors, and an understanding of available resources.

Fuel	Probability of Domestic Production	Probability of Domestic Use		
		Marine Transportation Sector	Surface Transportation Sector	Electricity Sector
Natural Gas				
LNG				
RNG				
Biohydrogen				
Bio-methanol				
Ethanol				
Biodiesel				
Renewable Diesel				
Green Hydrogen				
LOHC				
Green Methane				
Green Methanol				
Green Ammonia				

Likely	
High Potential	

Medium Potential	
Some Potential	
Not likely	

Some forward-looking assumptions can be made based on this information:

- Conventional fuels like diesel and gasoline are expected to be in use in NL for a long time to come. This means that efforts to decarbonize these fuels will be meaningful in the short, medium, and long terms.
- Diesel is used in almost all sectors of NL's economy. This presents opportunities for introducing the use of **biodiesel** (as a blend) and **renewable diesel** (either as a blend or as a replacement) economy wide.

- Passenger vehicles account for a significant share of NL's GHGs. This presents opportunities for the use of **ethanol** (as a blend).
- **Natural gas** (and Liquefied Natural Gas - LNG) has promise for adoption within electricity and marine transportation sectors – presenting opportunities for **renewable natural gas** and **green hydrogen** (or low-carbon hydrogen) blending.
- Global trends in the marine transportation sector suggest that **green methanol** is going to be a low-carbon fuel of choice in the long term. Green methanol production requires **green hydrogen** and **C02** as inputs. In addition, other low-carbon hydrogen and **ethanol** can be blended with methanol.

Therefore, it is reasonable to focus on education, awareness, and skills development that relate to the following areas:

- Biomass valorization (biofuel production using locally available organic materials)
- De-risking the adoption of fuels 'new' to NL (i.e., transportation, storage, fueling, use etc.) including natural gas / LNG, hydrogen, CO2, and methanol through testing
- Fuel blending concepts and processes

6. Recommendations

The analysis undertaken in this discussion paper points to three next steps that should be taken to advance the adoption of low-carbon fuels within NL through skills development.

6.1 Define technology/equipment that can support research, development, and deployment

To advance the adoption of low-carbon fuels in NL, the province must build more capacity in the areas described above: biomass valorization; de-risking the use of testing of 'new' fuels through testing, and fuel blending. In order to achieve this, easy access to equipment at laboratory and industrial scales will be necessary. Required technology must be identified and prioritized. The results of this exercise can inform the establishment of a 'low-carbon fuels centre of excellence' for the province.

6.2 Conduct deeper analysis of low-carbon fuels safety / skills requirements

Workforce training and professional development is required to accelerate the adoption of low-carbon fuels in NL. This discussion paper describes safety and skills considerations at a high-level, but more work is required to inform and prioritize the specific training and professional development interventions that should be taken and when. A training strategy must be developed which focuses on the right low-carbon fuels and considers how they will be used within the NL context (i.e., production, transportation, storage, fueling) and within what sector (i.e., electricity, marine transportation, surface transportation, etc.)

6.3 Develop and implement and education and awareness program

As NL is exempt from ethanol and renewable fuel requirements in its gasoline and diesel products, the concept of 'fuel blending' is unknown to the public in its most basic application. While it is unnecessary and unwieldly to attempt to educate the public on the peculiarities of each low-carbon fuel and their potential application in NL, given the cultural 'resistance' that can be expected with the adoption of new fuels and processes – helping the public to understand the 'why' is important.

7. Conclusion

The objective of this paper is to generate discussion and encourage further exploration of the education and skills required to support the safe and effective use of low-carbon fuels in NL. We hope that the content has provided useful insights into the areas where future training and professional development activity should be focused – with the overarching goal to advance the adoption of low-carbon fuels within the province.