Hydrogen Feasibility Study in High Emissions Components of Ontario Agriculture

Prepared For:
Innovation Farmers Association of Ontario

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ABSTRACT

Fossil fuel usage in high emissions components of Ontario agriculture is generating substantial greenhouse gas emissions, and is costing farmers large sums of money due to the rising carbon tax and increasing fossil fuel price volatility across the globe. This feasibility study is focused on two high emisison operations; grain drying and poultry barn heating. The report includes an assessment of baseline and emerging alternative technologies, opportunities for hydrogen and its derivatives (e.g. ammonia), and a financial comparison of fuel costs and conversion costs for hydrogen end-use technologies. Beyond just fuel use on farms, the feasibility study investigates the production, transport and storage of hydrogen and its derivatives. While there are promising opportunities for hydrogen and its derivatives as low-carbon fuels in the agriculture industry, today the lack of existing technologies and high fuel prices compared to natural gas and propane present a significant barrier to adoption. A second accompanying report titled, *Gap Assesment of Hydrogen Application in High Emissions Components of Ontario Agriculture*, lays out a number of gaps and some strategies to bridge them. It is recommended that further study be undertaken to produce a similar report for alternative low-emission technologies such as biomass and electricity. Following this more detailed comparison, one or more of the technologies should be demonstrated at scale under real world conditions. A large scale demonstration such as a grain drying co-op that uses hydrogen or ammonia as fuel, will provide learning opportunities for technology developpers, farmers, and government, and derisk future on farm technology conversions.

1.INTRODUCTION

1.1. Project Background

The Innovation Farmers Association of Ontario ("IFAO") has commissioned Zen Clean Energy Solutions ("Zen") to conduct a Feasibility Study on the use of hydrogen as a fuel in high emissions components of Ontario grain drying and poultry farming operations. The Feasibility Study scope includes an assessment of baseline and emerging technologies, opportunities for hydrogen, and a financial comparison of fuel costs and conversion costs for hydrogen end-use technologies. Additionally, a Gap Assessment (see second report) was conducted to identify the major limiting factors to the adoption of hydrogen use on Ontario farms. The regional scope included in this study is limited to farms in Huron, Perth, Bruce, and Grey Counties, as well as the Simcoe region (See Figure 1).

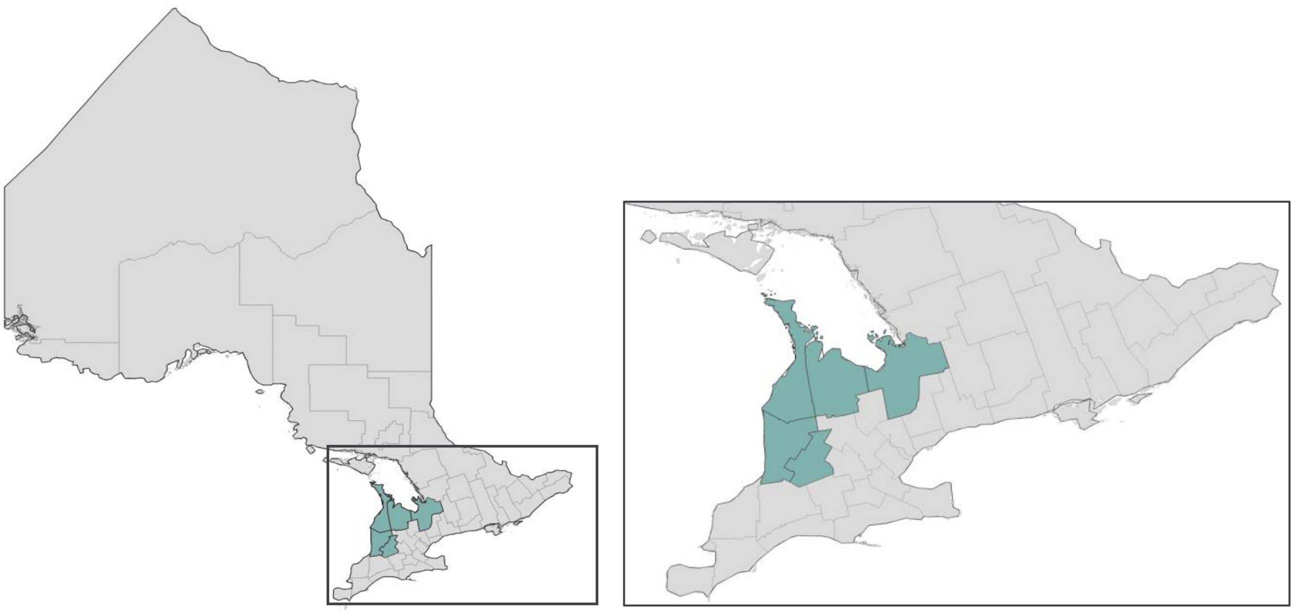

Figure 1: Regions included in study

As articulated in Ontario's recently released *Low-Carbon Hydrogen Strategy: a Path Forward,* hydrogen can play an important decarbonization role in sectors where traditional electrification cannot provide the energy required.[1] This Feasibility Study focuses on the role for hydrogen as a fuel used in grain dryers and poultry barn heaters. Hydrogen could play a role in other on-farm activities such as fuel for tractors and other mobile equipment. Although these activities are not the focus of this report, they will be addressed as synergies between multiple on-farm hydrogen end-uses could lower costs.

As hydrogen production, infrastructure, and end-use technologies are being scaled up across the country, the concept of hydrogen hubs has been identified as a critical component. Hydrogen hubs are locations where hydrogen production is matched with hydrogen demand, and existing or new infrastructure.

[1] https://www.ontario.ca/files/2022-04/energy-ontarios-low-carbon-hydrogen-strategy-en-2022-04-11.pdf

Hydrogen hubs help to minimize costs of distribution and to increase utilization in the near-term, while also building knowledge and jobs related to the hydrogen sector. The following hydrogen hubs in southern Ontario have been identified by government and industry and will be discussed further in this report; Sarnia-Lambton, Hamilton, and Bruce County.

1.2. Baseline Operations

To define the agriculture operations that are analyzed in this report, the following summary table outlines the baseline operations for grain drying farms, grain drying elevators, and poultry barns. The information was provided by experts, and where there was missing data assumptions were made.

	Grain Drying - Farms	Grain Drying - Elevator	Poultry Barn
General description	Field crop farms in Ontario that dry their own grain.	Large-scale grain drying operations with onsite grain storage.	Farms that raise poultry in barns.
Production Capacity	400-800 bu[2]/hr Up to 100,000 bu/yr	800-4000 bu/hr Up to 5,000,000 bu/yr	8-10 weeks/flock* 6 flocks/year*
Source of emissions for study	Grain dryer	Grain dryer	Heater
Fuel used	Propane	Natural gas	Natural gas (propane)
Frequency of use	1-3 weeks/yr	3-5 weeks/yr	30-50 weeks/yr with fluctuating fuel usage throughout
Fuel delivery	Propane produced in Sarnia delivered by rail to central depots, trucks deliver to farms	Connected to natural gas grid	Connected to natural gas grid otherwise same propane delivery as grain drying farms
Fuel Storage	24-48 hours	24-48 hours	1-2 months average

*for broiler chicken only, other poultry will have different lifespans

[2] Bu = Bushel of grain

1.3. Baseline Energy Use

To better compare the agriculture operations and the opportunity for alternative fuels, the following summary table outlines the baseline energy use for grain drying farms, grain drying elevators, and poultry barns. The fuel use per year is based on the baseline operations outlined above, and energy constants.

	Grain Drying - Farms	Grain Drying - Elevator	Poultry Barn
Incumbent Fuel Source	Propane	Natural Gas	Natural gas (propane)
Energy Required	5-10 MMBTU/hr	10-50 MMBTU/hr	0.5-1 MMBTU/hr
Efficiency	2250 BTU/lb	2250 BTU/lb	75-85%
Fuel use per year[3]	36,197 – 217,183 L/yr	140,600-1,171,663 m3/yr	107,739-269,348 m3/yr (166,423-416,059 L/yr)

1.4. Baseline Emissions and Fuel Costs

In Canada, agriculture emissions are reported in three categories, stationary combustion emissions, transportation emissions, and the remainder of agriculture emissions largely from processes and livestock or crops (see figure to the right). Combining the three emissions sources listed above, the agriculture industry in Ontario produced 12 MtCO2e or 7.5% of Ontario's total emissions in 2019, however this does include some transportation and stationary combustion emissions from forestry.[4] Fertilizer production from fossil fuels is another source of upstream emissions from the agriculture industry, however due to the reporting categories in the *National Inventory Report* for Canada, the emissions from fertilizer production were not able to be separated from other chemical production emissions.

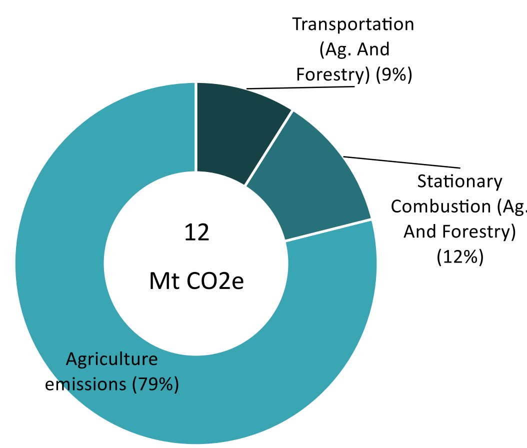

Figure 2: Agriculture Emissions in Ontario 2019

In 2019, the agriculture and forestry stationary combustion emissions totaled 1.5 Mt CO2e. The stationary combustion emissions are largely produced by the consumption of fossil fuels in grain dryers, greenhouses, and space heating (e.g. in poultry barns). As grain drying and poultry barn operations are the focus of the report, hydrogen and other low- emission technologies will be considered and compared throughout the report.

Apart from the emissions, fossil fuel usage in grain drying contributes a significant amount to the cost and energy usage of grain produced in Ontario. According to OMAFRA, 17% of the cost of growing corn comes from drying.[5] A study by the University of Minnesota found that ~42% of the fossil energy use in

[3] Fuel use calculated from baseline operations assumptions and energy content of fuels
[4] https://www.canada.ca/en/environment-climate-change/services/climate-change/greenhouse-gas-emissions/inventory.html
[5] OMAFRA Publication 60: http://omafra.gov.on.ca/english/busdev/facts/pub60.pdf

conventional corn production comes from fuel used for drying (Figure 3, below).[6] A crop drying calculator produced by Manitoba Agriculture calculates on average that for propane powered continuous flow grain dryers, propane fuel contributes ~55% of the grain drying cost (Figure 4, below). [7] As carbon tax in Canada rises from 50$/tonne-CO2e in 2022 to 170$/tonne-CO2e in 2030, the fuel costs of propane and natural gas will increase as well. The emissions, fuel costs, and rising fuel costs due to the emissions associated with propane and natural gas are the reasons why the agriculture industry in Ontario is looking towards alternative fuels for high emission components such as grain drying and heating for poultry barns.

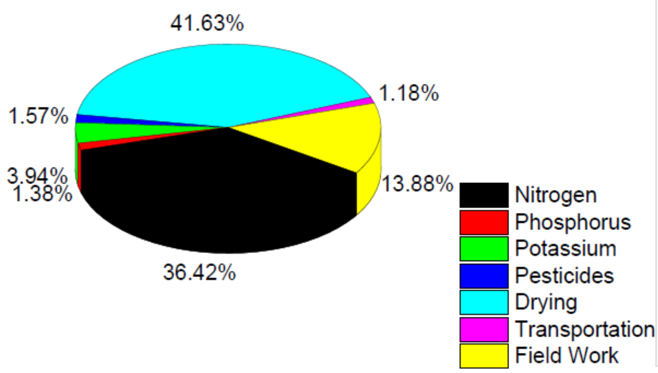

Figure 3: Conventional corn production energy usage (MJ)

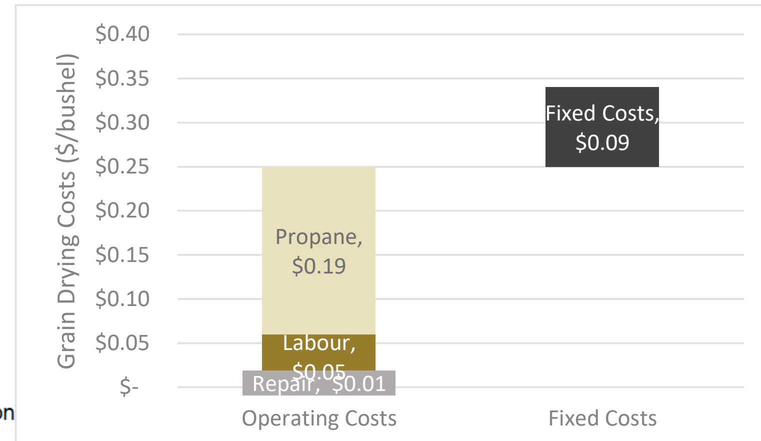

Figure 4: Example of crop drying costs breakdown

[6] Transforming Future Energy Systems for Crop and Livestock Production, 2019
[7] https://mbdiversificationcentres.ca/grain-drying-cost-calculation-tool/

2. TECHNOLOGY COMPARISON

2.1. Hydrogen Production

As hydrogen emerges as a key ingredient to any net zero pathway, the global hydrogen market is scaling up rapidly. A recent study by Goldman Sachs shows the potential for global hydrogen demand to reach from 220-539 Mt-H2/year for 2.0-1.5°C global warming scenarios, respectively, leading to the decarbonization of ~15% of global GHG emissions.[8] In the *Hydrogen Strategy for Canada*, released in 2020, the demand for hydrogen in Canada, as modeled under a bold policy scenario, is projected to reach up to 4 Mt by 2030 and 20 Mt by 2050, providing up to 26% of Canada's GHG emission reductions by 2050. Ontario released its *Low-Carbon Hydrogen Strategy* in 2022, outlining the vision and pathway to leverage the province's strengths to develop a self-sustaining low-carbon hydrogen sector. Ontario is well-positioned to become a leader in the low-carbon hydrogen sector in Canada due to the advantages of a skilled manufacturing and industrial workforce, clean and reliable electricity, existing storage and pipeline infrastructure, and clean biofuel resources.

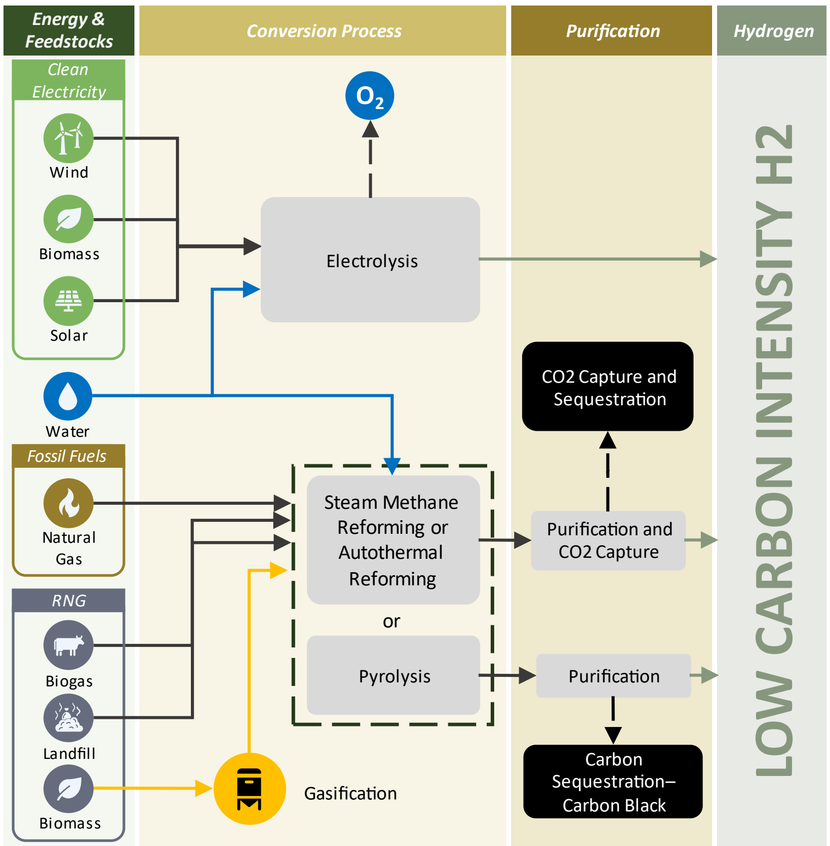

Figure 5: Hydrogen production pathways

2.1.1. Production Pathways Overview

Today, most hydrogen generated around the world is made through steam methane reforming (SMR), in which natural gas and high-temperature steam react to produce hydrogen and CO2. This pathway is not considered low-carbon because of the by-product CO2 produced; however, if carbon capture utilization and storage (CCUS) is employed, the emissions can be reduced by up to 90%, resulting in low-carbon hydrogen.

Pyrolysis is an alternative hydrogen production pathway that also uses natural gas as a feedstock. In this

[8] https://www.goldmansachs.com/insights/pages/gs-research/carbonomics-the-clean-hydrogen-revolution/carbonomics-the-clean-hydrogen-revolution.pdf

case, hydrogen is produced by decomposing natural gas in an environment without oxygen into its two constituents: hydrogen, which is output as a gas, and carbon black, which is output as a solid. Since CO2 is not produced in the reaction, the emissions from this pathway are limited to the upstream emissions of the feedstock natural gas, and the hydrogen produced is considered low carbon.

The emissions related to SMR and pyrolysis can be further reduced if renewable natural gas (RNG) is used as a feedstock instead of fossil-based natural gas. The RNG could be produced from biomass feedstocks such as landfills, municipal waste, wastewater treatment, manure, or wood waste. Using biomass as a feedstock can also lead to low-carbon hydrogen if gasification is used rather than SMR or pyrolysis. Biomass gasification produces hydrogen as well as other by-products, and if the CO2 emissions are captured and stored, a low-carbon hydrogen is produced.

A final pathway that is rapidly growing around the world is electrolysis, in which electricity is used to split water into hydrogen and oxygen. The hydrogen produced can be low carbon, but the resulting emissions are heavily dependent on the carbon intensity (CI) of the electricity. If renewable sources, such as wind and solar, are used, the CI of the hydrogen will be zero. However, if the electricity is generated by high-emitting sources like coal, the CI of the hydrogen can be relatively high.

2.1.2. Production Cost and Carbon Intensity

Within each pathway, the cost and carbon intensity are dependent on several key assumptions. Figure 6 and Figure 7 show the estimated production cost and carbon intensity for the key pathways. The lowest cost production pathway is SMR from natural gas with CCUS. The carbon intensity varies significantly depending on both the technology and feedstock. When using RNG, particularly when derived from organic waste, the estimated carbon intensity is negative, because of the avoided methane emissions. Beyond the cost of production, the different production pathways have varying production scales, capacity factors, and feedstock availabilities.

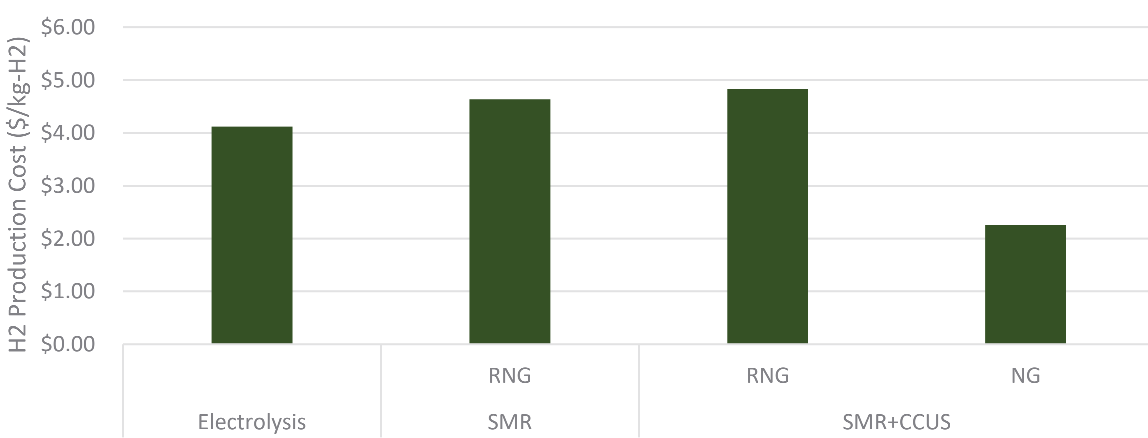

Figure 6: Estimated Hydrogen Production Cost by Pathway[9]

[9] Estimated assuming electricity cost of $70/MWh, natural gas cost of $6/GJ, and renewable natural gas cost of $20/GJ. Equipment capital cost and operating parameters consistent with IEA G20 Hydrogen Report Assumptions Annex (https://iea.blob.core.windows.net/assets/a02a0c80-77b2-462e-a9d5-1099e0e572ce/IEA-The-Future-of-Hydrogen-Assumptions-Annex.pdf)

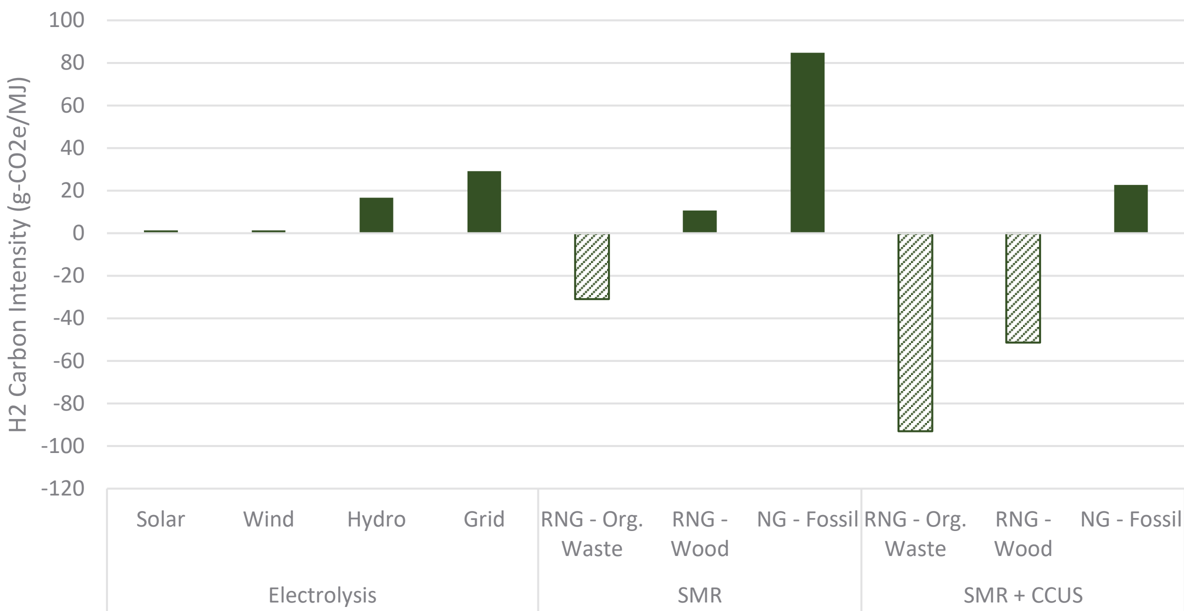

Figure 7: Estimated Hydrogen Production Carbon Intensity by Pathway and Feedstock[10]

2.2. Hydrogen Transportation and Storage

2.2.1. Storage

Hydrogen is typically stored as a compressed gas in cylinders or liquid in storage tanks. As a compressed gas the cost of storage increases with pressure as the strength of the storage vessel materials need to increase. However, the lower the pressure the larger the volume required to store a fixed amount of hydrogen. Low-pressure storage is typically around 50-250 bar (~725-3,600 PSI). On a heavy-duty hydrogen fuel cell electric vehicle, hydrogen is typically stored at 350 bar (~5,000 PSI) and on a light-duty vehicle, it is typically at 700 bar (~10,000PSI).

At a commercial scale, hydrogen storage as a gas or liquid is commonly employed. Depending on the scale of hydrogen production and the storage capacity requirements, a compressed hydrogen storage system is less capital-intensive than a liquefaction plant. Storage of hydrogen as a liquid requires cryogenic temperatures of -252.8°C due to the boiling point of hydrogen at one atmosphere. It is energy-intensive and can require as much as 30% of the energy content of the hydrogen in the process. When liquefied, it is typically stored in large highly insulated vessels without active cooling. As the vessel gradually warms, some hydrogen will evaporate and may be lost to boil off as it must be exited from the tank, so the pressure does not build up. Some systems are designed to recover the boil-off hydrogen while others will safely vent it to the atmosphere. In all existing applications, hydrogen is reconverted back to gas before consumption in its end-use application.

[10] Feedstock carbon intensities extracted from GHGenius version 5.01g: solar electricity = 3.9 g-CO2e/kWh, wind electricity = 4.1 g-CO2e/kWh, conventional hydro = 48.8 g-CO2e/kWh, ON electric grid = 85.1 g-CO2e/kWh, natural gas combustion = 50.5 g-CO2e/MJ, fossil natural gas = 61.56 g-CO2e/MJ, renewable natural gas from organic waste = -23.14 g-CO2e/MJ, renewable natural gas from wood pellets = 7.33 g-CO2e/MJ.

There are five main types of tanks that are used for compressed gaseous hydrogen storage, utilizing different materials and linings, with different maximum pressure ratings based on the application. The table below outlines the 5 main types, including materials and maximum rated pressures. For onsite ground storage on farms or elevators, Type IV polymer vessels would be recommended at 450 bar.

Table 1: Compressed Hydrogen Storage Tank Types

H2 Tank Type	Material	Maximum Rated Pressure
Type I	Steel / aluminum	Aluminum – 175 bar Steel – 200 bar
Type II	Aluminum with filament windings around the metal cylinder	263 bar – 299 bar
Type III	Composite material, fiberglass or carbon fiber	305 bar – 700 bar
Type IV	Composite, carbon fiber with a polymer liner	700 bar
Type V	All composite, linerless	1,000 bar

If hydrogen is stored as liquid, commercial tanks are available in sizes that would hold ~4,000kg of liquid hydrogen. Liquid could be delivered by tanker truck, however the farmer would also need to have a liquid pump and vaporizer onsite to convert the liquid hydrogen to gaseous hydrogen before dispensing it into the farming application. The table to the right gives an indication of the amount of storage required for 24 hours for the different farming applications being studied.

Table 2: 24 hour hydrogen storage requirements

		Hydrogen Storage for 24 hours (kgs)
Farm	**Low**	934
	High	1,867
Elevator	**Low**	1,867
	High	9,336
Poultry Barn	**Low**	89
	High	179

For grain drying farms or poultry barns where there is ~90-2000 kg hydrogen storage required per day, Type I, II, or III gaseous storage tanks would suffice as the these applications would not require high pressure hydrogen. An example of a ground storage design would be an array of horizontal cylindrical vessels similar to the array shown in Figure 8. The ground storage array example shown would hold 500 kg of hydrogen with 12 cylinders, or an array stack of 3 cylinders wide and 4 cylinders high. The resulting storage area would be 1.5 m in width, 12 m in length, with a footprint of 18 m². For poultry barn operations, fewer cylinders may be required and for a grain drying farm, likely two of these arrays would be sufficient.

Figure 8: Ground Storage Array example

For a grain drying elevator, onsite liquid hydrogen storage of ~4,000kg or ~8,000kg (2 tanks) would be feasible, however it is recommended that the farmer enter into a lease agreement for a liquid tank on a skid that could be replaced by the liquid hydrogen delivery truck. Companies such as Air Products would offer this type of lease service, however, the lease agreements are often based on a regular delivery schedule throughout the year, so it is unclear if they would offer the service for only a few weeks per year.

Alternatively for grain drying elevators that are connected to the natural gas grid, it is recommended that hydrogen be blended into the natural gas system upstream of the farm by the natural gas utility. See section 2.2.4 for further details on hydrogen blending in natural gas systems.

2.2.2. Transport

Over land, hydrogen will be transported by road or pipeline. Each method has its advantages and disadvantages and is best suited for certain situations. Via road, hydrogen can either be transported as a gas or liquid. Hydrogen tube trailers transport gaseous hydrogen at pressures typically between 250-500 bar and can carry between approximately 300 kg-H2 and 1,200 kg-H2 per trailer depending on pressure and size. Liquid hydrogen trailers can carry much more hydrogen per vehicle, approximately 4,000 kg; however, liquefying hydrogen requires much more energy than compressing it for transportation, so there is an increased cost associated with liquefaction. Typically, it will be more cost-effective to transport hydrogen as a liquid over long distances and at large scales and as a gas over short distances at smaller scales.

Pipelines are an effective way to move large quantities of hydrogen and function similarly to the existing natural gas network. Hydrogen's chemical properties require pipeline equipment to be manufactured of specific materials to ensure there are no leaks or embrittlement, but it is possible to leverage existing natural gas pipes to transport hydrogen. At blends of approximately 5-20% hydrogen by volume, natural gas pipeline networks are generally able to function with only minor upgrades or no changes at all. At higher blends or in a 100% hydrogen pipeline, deeper retrofits would be required. A 2020 European report estimated the cost of retrofitting an existing natural gas pipeline to transport 100% hydrogen would be only 10-35% of the cost of constructing a new hydrogen pipeline.

Figure 9 shows the estimated cost of transporting hydrogen via different methods over varying distances. It includes the cost of purchasing the necessary equipment, including compression and/or liquefaction, as well as operating costs, such as driver labour and truck fuel. The liquid trailer option is largely insensitive to distance because the major expense is associated with purchasing and operating the liquefaction equipment and so much more hydrogen can be transported in each delivery compared to the gaseous trailers. Pipelines are the least expensive approach, but the majority of costs are in upfront capital, so a large investment is required. The cost of pipeline distribution is also highly dependent on the scale of the system since the cost of installing the pipeline is not highly sensitive to the diameter of the pipe which is determined by flow rate.

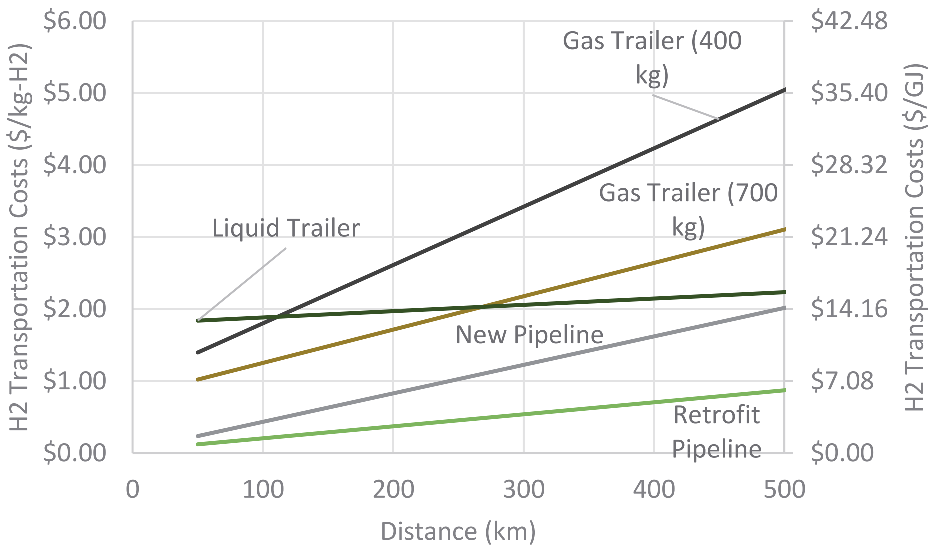

Figure 9: Estimated Cost of Hydrogen Transportation

Hydrogen could also be transported over land via rail. This is not currently done for gaseous or liquid hydrogen but is being investigated by key stakeholders. The hydrogen would be transported as a liquid or a hydrogen carrier. It would likely be more cost-effective than trucking but would require sufficient scale to justify the investment. Likely, rail would be most suitable for large-scale production and distribution to a port for export or to another major distribution hub.

2.2.3. Hydrogen Carriers

In addition to handling pure gaseous or liquid hydrogen, several alternative hydrogen carriers can be advantageous for distribution. The leading technologies are ammonia (NH3) and methylcyclohexane (MCH). The distribution of hydrogen as ammonia has several advantages. First, the volumetric density of ammonia is approximately 1.5 times that of liquid hydrogen, so 50% more hydrogen can be transported in a fixed volume as ammonia than as pure hydrogen. Second, liquid ammonia has a much higher evaporation point than hydrogen (-33°C compared to -253°C), so storage vessels do not need to be as well insulated, and less boil-off will occur. Third, there is already a large global ammonia market experienced in safely transporting large volumes. For decades, ammonia has been widely used and transported via truck, rail, ships, and pipelines. Today that market primarily uses ammonia derived from fossil fuels, but the same technology for distribution will be applicable for ammonia derived from low carbon hydrogen.

MCH is a liquid at room temperature and does not need to be insulated to protect from boil-off. Essentially, hydrogen is attached and removed from a toluene molecule through a reversible reaction enabling the hydrogen to be transported. The MCH can be handled by chemical tankers so it can be efficiently moved over long distances.

For both ammonia and MCH, hydrogen can be recovered in its pure form from the carrier. The process of converting hydrogen to its carrier and reconverting back to hydrogen requires energy and equipment so there is a cost associated with it. For this cost to be less than liquefying the hydrogen, distribution will typically need to be at a large scale and over a long distance. As such, these technologies are particularly well suited to international shipping of hydrogen.

2.2.4. *Hydrogen Blending with Natural Gas*

Another method to utilize hydrogen and benefit from some of the decarbonization opportunities without the added infrastructure and logistics, is blending a percentage of hydrogen into the natural gas grid. Many jurisdictions around the world are testing hydrogen blending in natural gas to study the effects on pipeline materials, gas properties, safety systems, metering equipment, and end-use equipment and appliances. To date, hydrogen blending in natural gas burners has been proven up to 5% by volume without the need for any equipment modifications however increasing the blending percentage to 15% by volume and beyond will require equipment modifications and eventually equipment replacement. 100% hydrogen boiler technology is being developed primarily in the UK but is not yet commercially deployed (Worcester Bosch in the UK, BDR Termea in the Netherlands). Figure 10 below shows an overview of available test results and regulatory limits for hydrogen admission into natural gas end-use equipment up to 100%.[11]

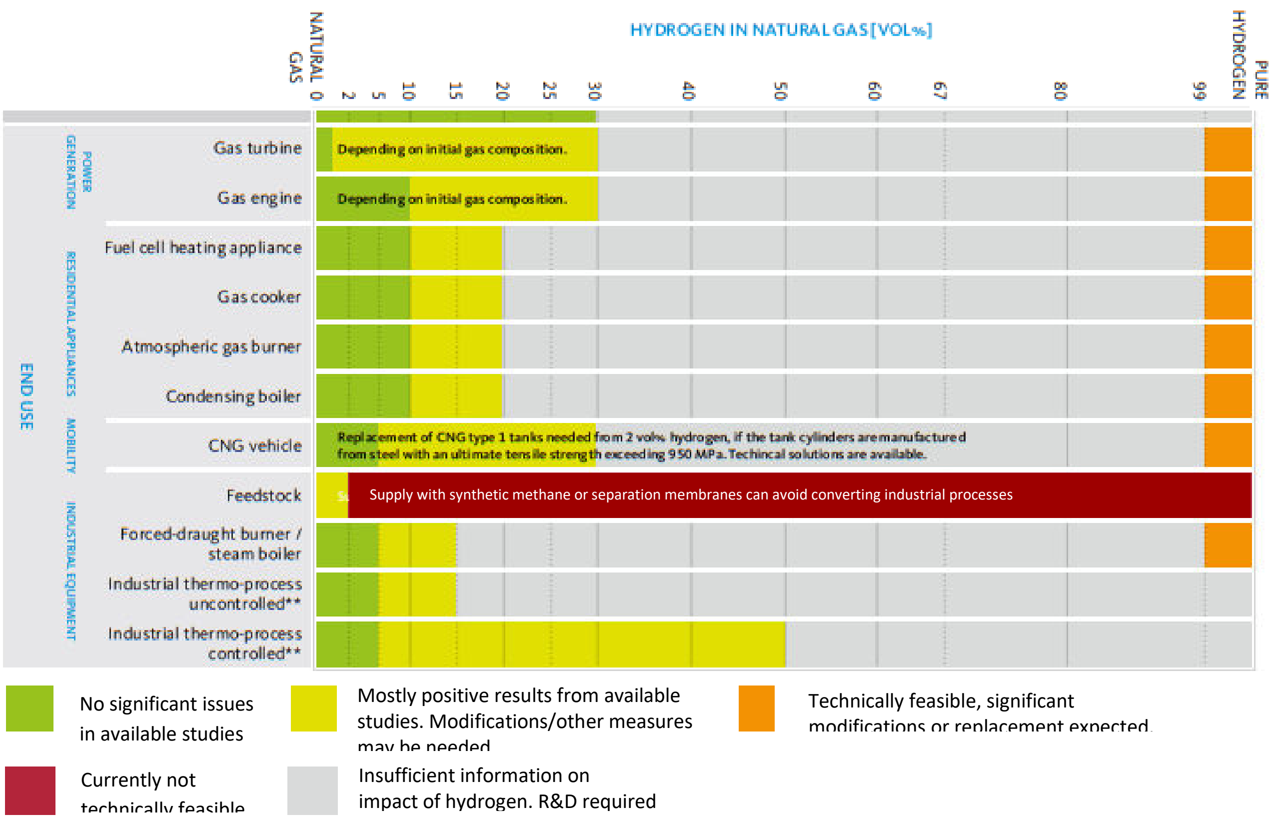

Figure 10: Available test results of hydrogen blending in various end-uses at different percentages

This year in Ontario, Enbridge and Cummins started piloting hydrogen gas blending and are currently supplying a natural gas blend with up to 2% hydrogen by volume to ~3,600 residential customers in Markham. The Enbridge facility uses electrolysis to produce hydrogen, and the project is expected to

[11] https://entsog.eu/sites/default/files/2021-05/ENTSOG_GIE_HydrogenEurope_QandA_hydrogen_transport_and_storage_FINAL_0.pdf

abate up to 117 tons of CO_2 from the atmosphere every year.[12]

The grain drying operations and poultry barns that are already connected to the gas grid could decarbonize their operations by using a blended hydrogen and natural gas fuel, if offered by the natural gas provider, however it is unlikely that in the near-term the fuel costs would be any lower than the current natural gas prices. However, over time as all natural gas systems are required to decarbonize to meet Canada's GHG Emissions reductions targets, this could provide an opportunity for those farms attached to the grid. For the farming operations that rely on propane because they are not connected to the natural gas grid, hydrogen blending will not be feasible.

2.3. Hydrogen for End-Use Heat

2.3.1. Grain-Drying

The grain drying process uses heat and aeration to remove moisture from grain and is a necessary step following the harvest to prevent spoilage during storage. There are several methods used including batch and continuous flow processes. Although grain can be dried naturally in certain applications, the focus of this study will be on fuel- and electric-powered processes. Both batch and continuous processes involve a stream of hot air which is forced through the grain using an aeration fan. The hot air stream consists of dry outside air which normally passes under a natural gas or propane burner. Propane is often used in small scale, on-farm applications whereas natural gas is preferred for larger scale operations such as grain elevators.

Hydrogen could have the potential to replace propane and natural gas in grain drying. Since hydrogen burners are a relatively new technology there is still research that needs to be done regarding their efficiency and other performance metrics. Hydrogen has a wide flammability range, being able to burn in gas-to-air ratios of 4-75%. A hydrogen flame is easy to maintain when compared to the limits for alternatives natural gas (5-15%) and propane (2-10%), however this also means it must be handled and stored more carefully than other fuels.[13] Hydrogen flames have other unique characteristics that would need to be considered in the design of a hydrogen grain dryer. When carbon fuels like natural gas and propane burn, they produce soot particles which increase radiation and heat transfer. Because pure hydrogen fuel does not contain any carbon, it does not produce soot particles when burning. The resulting lack of radiation could impose some challenges in a hydrogen heating system. Because the air temperature required is in the range of 180-230 °F, a significant amount of fuel needs to be burned.[14] Hydrogen burners have been used successfully in the shipping industry, being implemented in the world's first liquid hydrogen tanker. The burner was a key component in the GCU (Gas Combustion Unit) that burns the excess boil-off gas coming from the tanks.[15]

In theory, it would be possible to retrofit a current grain dryer, replacing the heat/fan unit with hydrogen technology. Since the heater and fan are often combined, as seen in Figure 11 below, it is likely that the

[12] https://www.enbridge.com/stories/2022/january/hydrogen-blending-project-enbridge-gas-cummins-operational-markham-ontario
[13] https://h2tools.org/bestpractices/hydrogen-compared-other-fuels
[14] https://fyi.extension.wisc.edu/energy/files/2016/09/Grain-drying-Systems-GEAPS-2002-secured.pdf
[15] https://www.saacke.com/fileadmin/saacke/pdf/hydrogen-burners-industrial-decarbonization-whitepaper.pdf

entire unit would need to be replaced.[16] Luckily, the fan/heater unit is located externally to the dryer and would likely be simple to remove and replace. There are a small number of hydrogen burners commercially available, from companies such as Saacke, Flamatec, and Selas. They are mainly used for industrial chemicals production. Their design focuses on maximizing flame temperature while minimizing NOx emissions and it is unclear whether they would be applicable in a grain drying system.

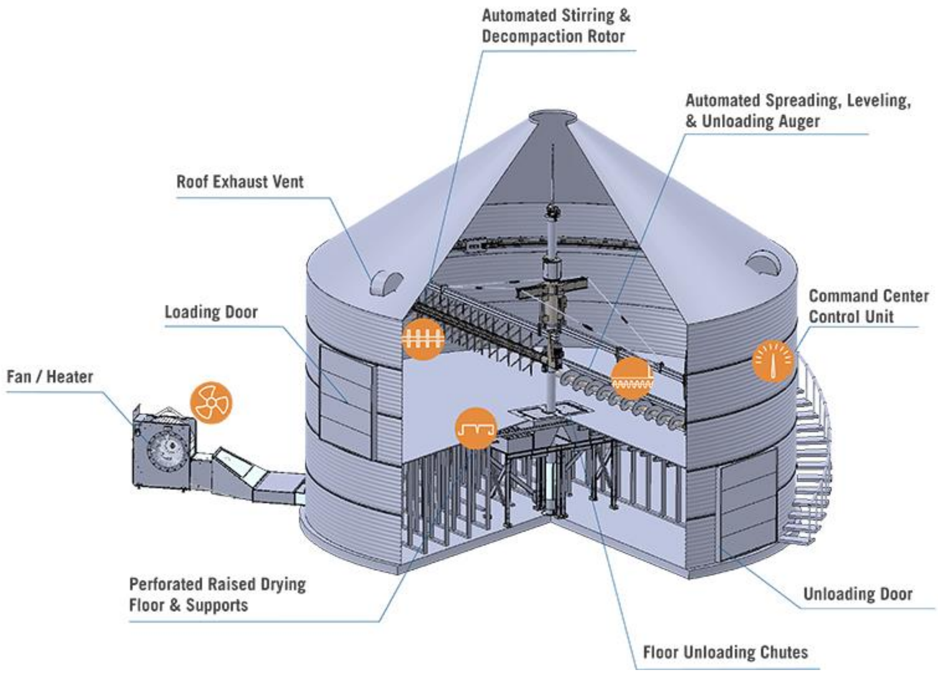

Figure 11 : A batch grain drying system

[16] https://www.shivvers.com/hemp/system-components.aspx

2.3.2. Poultry

Poultry barns can vary greatly in size and heating requirements, so there are many different heating methods that are available. Poultry barns are heated in the winter months and at night to keep the animals at a regulated and comfortable temperature. Poultry barns are also heated throughout the year when chicks are newly placed during the first few weeks of age. As birds get older, temperatures are turned down and heating is no longer required. The heating methods can be classified into two groups: air heating and boilers. For air heating, the burner is either located in the barn and heating the air directly (radiant tube heaters, box heaters (Figure 13), open flame brooders), or is located externally with the warm air being forced into the barn.[17] If products of hydrogen combustion; water vapour and NOx emissions, are discharged into barn space, the ventilation rate for the room will need to be increased to maintain living conditions. If the heating system uses a hot water boiler (Figure 12), the boiler is located outside of bird housing area. The warm/hot water is piped to in-floor distribution pipes to warm the floor slab or to hot water radiators in the bird housing area. An external hot water storage tank is sometimes used to store water for peak demand times.

Figure 13: Box heater in a poultry barn

Figure 12: Hot water manifold for in-floor heating

Compared to a grain dryer, the heating demands of a poultry barn are relatively small, as only room-temperature heat is required (target 22-32C depending on age of the birds). However, heat is required for a much larger portion of the year, which is something to take into consideration in the design. If using hydrogen as a fuel for in-barn heating, it will be important to ensure proper ventilation of the resulting NOx emissions. Although no CO2 will be produced, these NOx emissions can still have harmful effects on the poultry. The flame characteristics mentioned in the previous section could also cause problems/inefficiencies for an indoor burner system. Additionally, hydrogen has a flame speed that is 4x faster than natural gas and propane, meaning potential fire hazards for an indoor application.

[17] Interview with experts, May 27, 2022

To retrofit an indoor-heating system in a poultry barn with hydrogen technology, the burners would have to be replaced and potentially the fuel piping system as well. Pure hydrogen burners require a different design than conventional burners to operate properly. As with grain drying, hydrogen burner technology has not been fully developed. Replacing a hot water system would likely be simpler, as the piping could remain the same. Hydrogen-powered boilers are under development but are not yet commercially available. Hydrogen Technologies Inc. has created an innovative hydrogen boiler design with reduced emissions and greater efficiency. The combustion chamber is under vacuum and contains only hydrogen and oxygen, meaning all CO2 and NOx emissions are eliminated. They also claim a 20% increase in efficiency over conventional boilers.

2.4. Alternative low-emission heating technologies

Aside from hydrogen utilization, there are other low-emission alternatives available. In grain drying, electric heat can be used, virtually eliminating carbon emissions. Depending on the price of electricity, this method can sometimes be competitive due to its high efficiency. Electric heat is not popular due to high capital costs including the heating equipment and electrical upgrades to the site, as well as the high cost of electric demand charges compared to propane or natural gas (up to 5-7 times the cost per unit of energy). In recent years very high electricity demand for a short period of the year, has shown to significantly increases farmers' utility bill. Additionally, high output heaters run on three-phase power which is often not available, requiring additional costs for installation.[18]

Biomass is a renewable energy that is often readily available on farms, which is another option that can be used to generate the hot air for the dryer. However, the variability of on farm feedstocks (straw, stover, etc..) can introduce significant variability in the combustion process, and depending on the source of biomass additional processing may be required onsite (e.g. grinding, pelletizing, etc…). Biomass flames require specific flows for all the gasses, which means a biomass dryer cannot heat the intake air directly like in a propane or natural gas burner. Instead, biomass is used with a heat exchanger. The burner is used to heat up water or air which flows next to the intake air, transferring the heat indirectly. The heat transfer process can be seen in Figure 14 below. One advantage of the heat exchanger is that the air entering the dryer is completely dry. In direct-flame propane heaters, the flue gas generated from combustion will enter the dryer, increasing the moisture content in the air and decreasing its efficiency. Biomass grain dryers are commercially available in Canada.[19]

[18] https://pami.ca/wp-content/uploads/2021/05/Carbon_Reduced_Grain_Drying_Final_Mar-17-21.pdf
[19] https://www.saatotuli.ca/wp-content/uploads/2021/02/Biomass-heating-for-farms-and-greenhouses.pdf

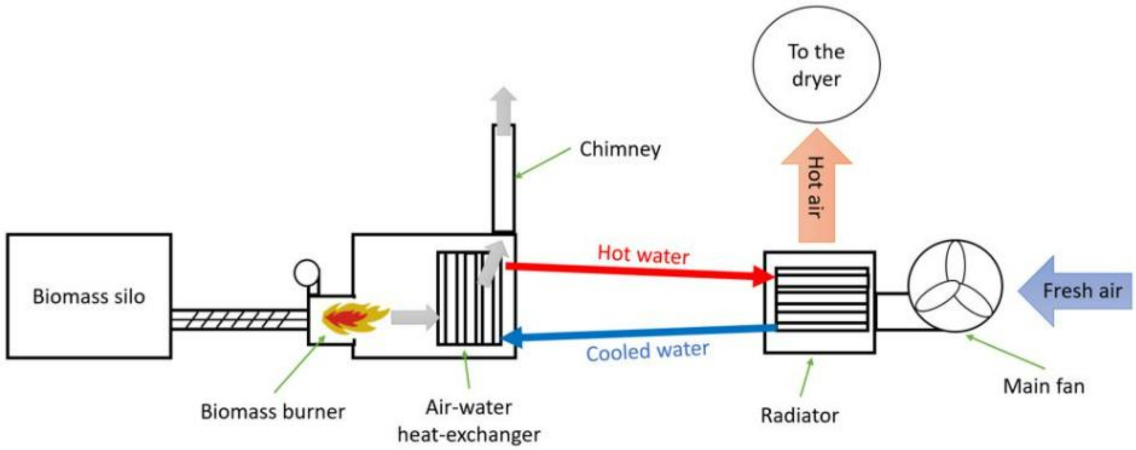

Figure 14 : Process flow in a biomass grain dryer

Heat pumps are another alternative technology. These devices use electricity and refrigerants to pump heat from the ambient air into the drying bin. A study from the University of Guelph found that low-temperature, heat pump grain drying could reduce GHG emissions as much as 90% at a similar cost to natural gas or propane dryers.[20] Another study by the Bloom Centre for Sustainability found that due to the small scale of on-farm grain drying heat pumps, emissions reductions were canceled out by the global warming potential (GWP) of the refrigerant, however at commercial scale there would be significant emission reduction opportunities.[21] Additionally, heat pump technology in grain drying needs to be demonstrated further to prove it can perform at high-speed, high-temperature drying, as demonstrations have not yet shown viability in this use case.

There are several other emerging grain-drying technologies that are under development. Radio wave dryers operate under the same principle as conventional household microwaves and have a very high degree of efficiency. Benefits of this technology include safety (less explosion and fire risk) and emissions reduction (fully electric). Dry Max Solutions is developing a radio wave system that operates on 3-phase electricity, which has automated control that analyzes moisture content and optimizes efficiency.[22]

2.5. Comparison of Hydrogen vs Incumbent Fuels and Alternatives

The following tables summarize and compare hydrogen to the incumbent fuels propane and natural gas as well as alternative technologies, electric heat pumps and biomass. Table 3 compares the grain drying technologies while Table 4 compares the poultry barn heating options.

Table 3: Grain Drying Technology Comparison

[20] https://atrium.lib.uoguelph.ca/xmlui/handle/10214/17638
[21] Bloom Centre for Sustainability, CASE STUDY Demonstrating the Performance of an On-Farm Heat Pump Grain Drying System, 2018
[22] https://drymaxsolutions.com/

	Propane (farm)	Natural Gas (elevator)	Hydrogen[23]	Electric (heat pump)[24] [20]	Biomass[25]
Fuel/Energy Consumption	36,197-217,183 L/yr	140,600-1,171,663 m3/yr	6-40 tonne/yr (farm) 40-330 (elevator)	60-350 MWh/yr (farm) 350-2,900 MWh/yr (elevator)	47-275 tonne/yr (farm) 330-2,720 tonne/yr (elevator)
Technology Readiness Level (TRL)	9	9	5	7	9
GHG Emissions[26] (gCO2e/MJ)	59.64	50.60	0.02	N/A	2.3
Infrastructure Considerations	Onsite storage with deliveries every 24-48 hours	Connected to natural gas grid	Onsite gas or liquid H2 storage (4000kg) with deliveries every 24 hours. Or connected to natural gas grid.	Electrical upgrades – 3 phase power	Biomass silo, boiler & heating system, deliveries

Table 4: Poultry Barn Heating Technology Comparison

	Propane	Natural Gas	Hydrogen [23]	Electric (heat pump) [24] [20]	Biomass [25]
Fuel/Energy Consumption	166,423-416,059 L	107,739-269,348 m3/yr	30-75 tonnes/yr	1,182-2,954 MWh/yr	210-530 tonnes/yr
Technology Readiness Level (TRL)	9	9	5	9	9

[23] Based on higher heating value for hydrogen
[24] https://www.researchgate.net/publication/281668963_Energy_efficiency_of_a_new_heat_pump_system_for_drying_grain
[25] https://farm-energy.extension.org/introduction-to-biomass-combustion/
[26] GHGenius 501g, combustion emissions only

GHG Emissions[27] (gCO2e/MJ)	59.64	50.60	0.02	N/A	2.3
Infrastructure Considerations	Onsite storage with storage for 30-50 days	Connected to natural gas grid	Onsite gaseous storage with deliveries every 24-48 hours in peak	Electrical upgrades – 3 phase power	Biomass silo, boiler & heating system, deliveries

[27] GHGenius 501g combustion emissions only

3. ECONOMIC COMPARISON

3.1. Capital Costs of Retrofits and Infrastructure

3.1.1. Hydrogen powered technologies

As described in section 2.3 hydrogen can be used as a fuel to provide heat for grain dryers and poultry barn heaters. Although technically hydrogen can produce enough heat required for drying grain and heating poultry barns, commercially available burners and end-use technologies powered by hydrogen do not yet exist. However, it is expected that retrofitting an existing grain dryer or poultry barn heater that runs on propane or natural gas is feasible.

To simplify the discussion, all grain dryers have a burner, a fan and a drying chamber with an inlet and outlet for the grain. To retrofit an existing grain dryer the burner will likely need to be retrofitted or replaced. Depending on how the burner is integrated with the fan, it may be easiest to replace the fan as well. Since there are no hydrogen powered grain dryers or retrofit packages that are commercially available today it is not known whether any of the other components would need to be retrofitted or replaced. For air heating poultry barn heaters, the same retrofits as grain dryers would apply. However, for boilers used for poultry barn heating, it is likely that the entire boiler system would need to be replaced, which would be more capital intensive than a burner retrofit.

Another consideration for retrofitting existing technology is the timeline. Grain dryers have a useful lifetime of 20-30 years, and often have limited upgrades or retrofits during that time.[28] Grain dryer replacements often only happen because farms or elevators are expanding operations. Therefore, retrofits and replacements for hydrogen powered grain dryers should be given more consideration when operations are expanding or there are new farms or elevators being developed. Poultry barn heaters are usually smaller and have a shorter lifetime, so there may be more opportunities to retrofit the burners or replace the boilers.

Additional infrastructure would be required onsite to use hydrogen as a combustion fuel including storage and compression. The capital costs of the additional infrastructure required to utilize hydrogen fuel on farms is summarized in the table below.[29]

Table 5: Hydrogen infrastructure costs

	Grain Drying Farm	Grain Drying elevator	Poultry Barn
Onsite Storage Tank	Gaseous storage array (~500kg) =CAD $1.9 million for total of 12 cylinders	Liquid tank (4,650kgs) = ~CAD $1 million Vaporizer + liquid pump = CAD $ 500,000 N/A if using hydrogen	Gaseous storage array (~500kg) =CAD $1.9 million for total of 12 cylinders

[28] Interview with experts May 27, 2022
[29] All costs are indicative costs provided to Zen by various vendors

		blended in natural gas system	
Additional considerations	Balance of plant costs including pumps, concrete pad, etc…	Costs of blending hydrogen into grid would be taken on by the utility which may impact the natural gas price the elevator pays	Balance of plant costs including pumps, concrete pad, etc…

3.1.2. Alternative technologies

For grain drying, the use of electric heat pumps has been shown to be efficient and comparable to alternative fuels in terms of operational expenses. Since this technology is not yet commercially available, its capital costs are unknown, as is if it would be possible to retrofit an existing grain dryer. Using traditional electric radiators in grain drying is not practiced because the cost of electricity is very high, as is the cost of the required electrical upgrades to the site. For poultry barn heating, significantly less heat is required at one time, meaning a smaller scale electric radiator could be more feasible. This technology is readily available for various space heating applications and would be feasible to install indoors, in the place of existing heaters.

Biomass is a low-carbon alternative that has already been implemented in farms across Canada. It has been shown to greatly reduce operating costs, especially in large-scale applications. A baseline dryer with capacity of 7.5-10 MMBTU/hr costs $140,000 - $160,000 from Manitoba company Triple Green Products. Costs increase with dryer size and options, with the maximum capacity dryer supplying 30 MMBTU. [30] If the location has a propane or natural gas dryer in place, it can be retrofitted with biomass technology for a lower cost. Multiple units can be combined to meet the needs of large grain elevator operations. Biomass boilers can also be used as a heating source for poultry barns with in-floor or radiator heating, replacing the conventional propane boilers. Biomass boilers often cost more than double a propane boiler of similar size, but can still be worth it in the long run with reduced fuel costs and clean energy incentives.[31]

3.2. Fuel and Operating Costs

One of the major costs for both grain drying and poultry barn operators is the fuel cost. With the increasing carbon tax from 50$/tonne-CO2e in 2022 to 170$/tonne-CO2e in 2030, farmers are going to have to pay higher costs for fossil fuels such as natural gas and propane. Figure 15 below shows the equivalent fuel price for propane, natural gas, hydrogen, electricity, and biomass, on a $/GJ energy unit in 2022 and 2030. The base fuel price assumptions are shown on the figure for each fuel. As described above, electric heat pumps are more energy efficient than combustion and therefore a coefficient of performance of 4 was included to adjust the price to compare to the other fuels.[32] As shown the fuel cost of hydrogen in 2022

[30] https://www.grainews.ca/machinery/manitoba-company-offers-biomass-grain-drying-system/
[31] https://www.canr.msu.edu/wood_energy/uploads/files/woopelletcost%20-%20MILLER%20edits%20(002).pdf
[32] https://www.researchgate.net/publication/281668963_Energy_efficiency_of_a_new_heat_pump_system_for_drying_grain

is well above the alternatives. However in 2030, when the carbon tax ($170/tonne-CO2e) significantly increases the price of natural gas and propane, hydrogen could become competitive with propane.

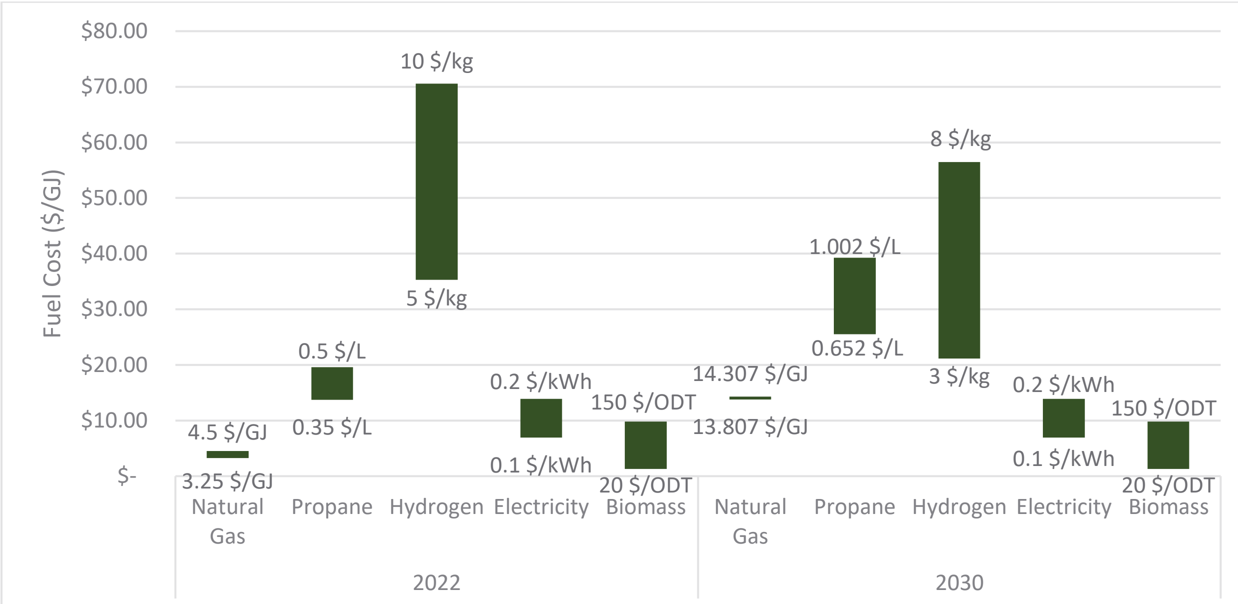

Figure 15: Fuel Cost Comparison

The natural gas and propane costs for 2030 are based on todays fuel prices plus the increased carbon tax, which will amount to $170/tonne-CO2e. Not shown in this cost comparison is the large variability in fossil fuel prices that have farmers have seen over the past few years. Figure 16 below shows an example of propane commodity spot prices over the last ten years. Although these numbers will differ from the retail price of propane for farmers, it shows that propane prices are quite variable, even monthly. For example farmers have reported paying 1$/L in the past, even though with today's average prices and carbon tax that is the upper limit of the price projected for 2030. Although this cannot be shown in the fuel cost figure above, it is important to understand that alternative fuels such as hydrogen, electricity or biomass, may be more attractive to farmers if they are slightly more expensive then propane/natural gas but are under a fixed price contract. The fuel cost comparison figure above does not show a holistic comparison between fuels, it only shows a snapshot of the potential fuel costs at a point in time. Beyond these fuel costs, there are other important factors to consider including price variability, fuel supply security, additional fossil fuel taxes or low-carbon fuel incentives, other operating costs, fuel delivery logistics/costs, and fuel/operational safety. Some of these considerations are discussed in this report, however farmers' and experts' opinions will be required to ultimately decide which fossil fuel or alternative makes the most sense on a case by case basis.

Figure 16: Propane commodity pricing variability over the last ten years[33]

Today there is limited hydrogen produced in Canada and sold for combustion so there is no historical data to inform the hydrogen prices. In BC today, hydrogen is sold as a transportation fuel at a price of 12.50$/kg-H2. Various entities have calculated the cost of producing hydrogen via different pathways. From *The Hydrogen Strategy for Canada*, the cost to produce hydrogen (not including delivery) ranges from $1-$9 between 2020, 2030, and 2050 (see Figure 17 below).[34] Therefore a large range for the sale price of hydrogen was shown as $5-10/kg-H2 in 2022 and $3-8/kg-H2 in 2030.

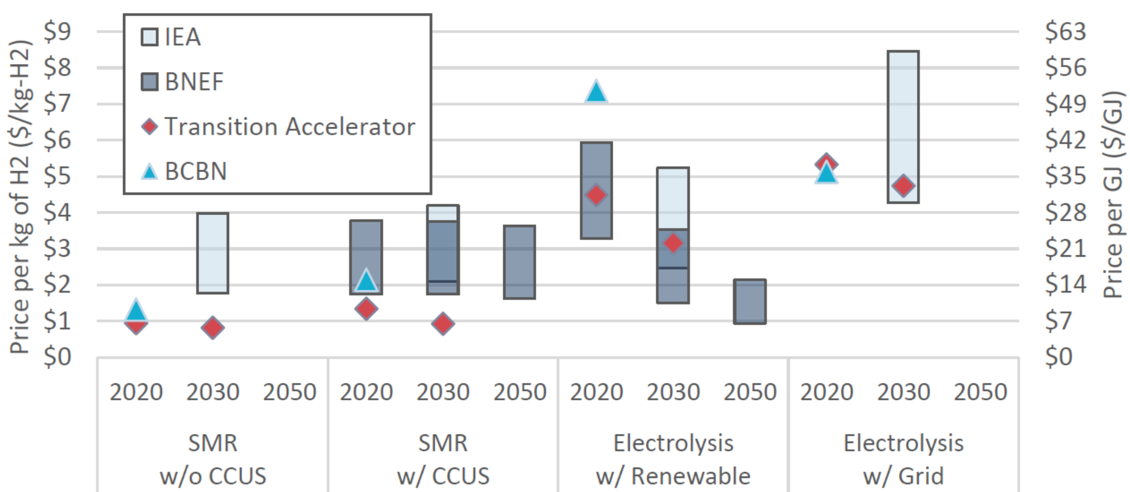

Figure 17: Comparison of Hydrogen Production Pathway Costs in 2020, 2030, 2050

Additionally, a large range for the price of biomass was shown as there are many different types of biomass which have varying levels of value. Depending on the type of biomass that would work in the grain dryer, the farm could already have a source of biomass that could be utilized for little or no cost.

Other operating costs such as maintenance, electricity costs, and labour are beyond the scope of this study. It is expected that most of the combustion and alternative operations would have similar operating costs, except for biomass. A large-scale biomass grain drying operation would require someone to move

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[33] https://www.indexmundi.com/commodities/?commodity=propane&months=120&currency=cad
[34] https://www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

and load large amounts of biomass, resulting in higher labour costs.

3.3. Taxes and Incentives

It is clear that the capital costs of retrofitting existing technology and adding infrastructure on top of the higher fuel costs for lower carbon fuels, will make shifting to alternative technologies difficult for most farmers. To counteract the prohibitive cost of decarbonizing on farm fuel use, there are a few capital cost funding opportunities and credits available to lower the cost of the fuel.

The funding sources that could potentially provide grant funding or other capital investment reductions include the Federation of Canadian Municipalities, Canadian Infrastructure Bank, Sustainable Development Technology Canada, Strategic Innovation Fund, and the Agricultural Clean Technology Program: Research and Innovation Stream. These funds are likely to be awarded to larger projects that impact many stakeholders, so a larger project such as a grain drying co-op powered by clean fuels such as hydrogen or its derivatives would be applicable.

The federal Clean Fuel Regulation (CFR) announced in June will come into affect in July 2023. The CFR will require liquid fuel producers to lower the carbon intensity of their fuels at an increasing rate every year until 2030 when the carbon intensity limit will then remain the same. To meet the standard requirements, liquid fuel producers can either lower the carbon intensity of their fuel, or purchase credits from the market. One credit is equivalent to 1 tonne of CO2e emissions abated. Low-carbon fuels that are delivered to the transportation market can produce credits that can be sold on the market. Additionally, the liquid fuel producers can meet up to 10% of their annual reduction amount by purchasing credits from low-carbon fuels in gaseous applications such as replacing natural gas and propane. Although the credit market would not directly impact the farmers, it might incentivize low-carbon fuel producers to sell to the gaseous market, and could potentially reduce the cost to consumers.

3.4. Economic Comparison of Hydrogen and Incumbent Fuels and Alternatives

While some of the infrastructure and retrofit costs were difficult to quantify, the estimated fuel costs are compared across the hydrogen, incumbent fuels and alternative technologies. Alongside the fuel costs, the other costs such as retrofits, infrastructure, operating costs, as well as funding opportunities and incentives are compared qualitatively across the options. For the qualitative comparison a ranking of 1-5 was used where 1 indicates low cost and 5 indicated high cost.

Table 6: Economic comparison of hydrogen and incumbent fuels and alternatives

	Natural Gas	Propane	Hydrogen	Electricity (heat pump)	Biomass
Capital Cost for Retrofits	N/A	N/A	Low	Med	Med

Capital Cost for Infrastructure	N/A	N/A	High	Med-high depending on power availability	Med
Fuel Cost in 2030 ($/GJ)	$13-14	$26-40	$21-56	$7-14	$1-10
Other Operating Costs	Low	Low	Low	Low	Med
Capital cost funding opportunity	Low	Low	High	High	High
Other incentives (tax reduction, credits)	Low	Low	High	High	High

4. HYDROGEN HUB CONCEPT

4.1. Hydrogen Hub

As hydrogen production, infrastructure, and end-use technologies are getting scaled up across the country, the concept of hydrogen hubs are emerging. Hydrogen hubs are locations where hydrogen production is matched with hydrogen demand, and existing or new infrastructure. Hydrogen hubs help to minimize costs of distribution and to increase utilization in the near-term, while also building knowledge and jobs related to the hydrogen sector. A hydrogen hub is defined as a central location where there is supply and demand (see Figure 18 below).

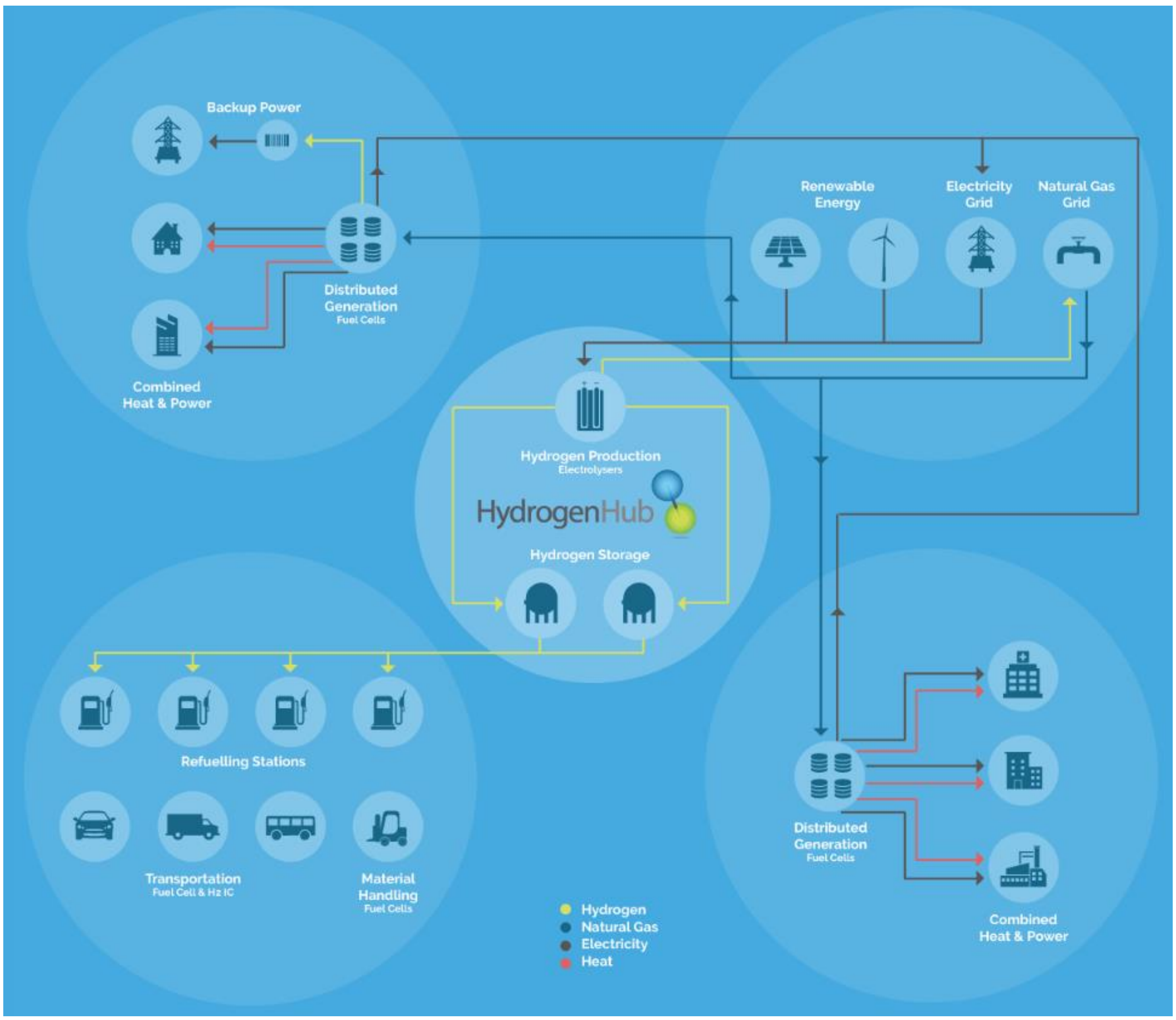

Figure 18: Hydrogen hub schematic

For this study the hydrogen hubs identified by government and industry; Bruce County, Sarnia-Lambton, and Hamilton will be considered as the centre of a hub with a delivery radius defining the reaches of each hub. Hydrogen could be delivered outside of this radius on a case-by-case basis, however for simplicity a road-based delivery radius of 500 km for gaseous hydrogen is assumed based on industry knowledge. Due to the higher density of liquid hydrogen, liquid hydrogen could be delivered up to 1000km, however liquid hydrogen will not be considered for agriculture applications as the benefits are more applicable to transportation options such as heavy-duty fueling stations.

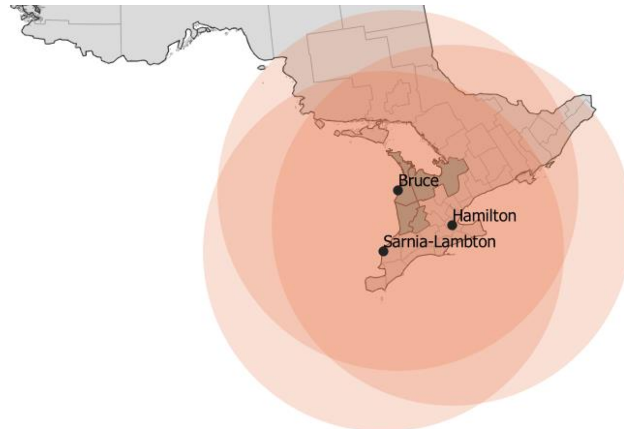

Figure 19: Hydrogen Hubs and radii of delivery for gaseous hydrogen

Assuming a 500 km radius of road delivery for gaseous hydrogen, hydrogen produced at the Bruce County, Sarnia-Lambton, and Hamilton hubs will be able to serve all of southern Ontario. As shown in the figure to the right, gaseous hydrogen from these three hydrogen hubs could serve all the farms in the regions of interest for this feasibility study.

4.2. Grain Drying Co-Op

Regardless of the fuel used for grain drying, grain drying condos run by co-ops are emerging as an alternative to grain drying elevators for farmers. Storing grain in elevators becomes expensive for farmers and does not allow them to benefit from changes in the market, which is why many farmers choose to store and dry their grain onsite. The benefits of a grain drying condo where farmers have to invest in a co-operative grain drying and storage structure allows farmers to have lower operating costs and more control over when the grain is sold onto the market.

Locating a grain drying co-op central to the farms located in the regions of interest in the study, within the delivery distance from any of the hydrogen hubs mentioned above, would provide a real-world demonstration and testing site for decarbonizing the agriculture industry across Ontario and Canada. With centralized services, knowledge, and demonstration, a grain drying condo in southern Ontario could benefit from government funding and would de-risk the fuel conversion for many farmers and elevators in the region. A grain drying condo in southern Ontario should consider a number of alternative fuels including hydrogen, hydrogen carriers such as ammonia, hydrogen blended with natural gas, and electricity. If possible, the condo could act as a demonstration facility and test a number of alternative fuels.

Although increasing fuel costs will impact the grain drying condo operation as well as farmers, the condo structure allows the farmers to benefit from economies of scale for both fuel storage and deliveries. When considering hydrogen or hydrogen derivatives as a potential fuel for grain drying, the transportation and storage has a large impact on the fuel costs often adding up to 2$/kg-H2. If there were a central grain drying location for the farms in the regions of interest of this study, there could be fewer deliveries and fewer but larger storage cylinders onsite.

Additionally for each hydrogen fueled grain dryer and storage system, significant safety training would be required. The economies of scale of a grain drying condo could allow for one or two operators to be trained and become experts on running the hydrogen fueled grain dryer, which would allow the farmers to focus on farming. The time and cost inputs of training multiple farmers in hydrogen safety and operation is expected to be a large barrier in hydrogen adoption in the grain drying industry.

Additionally having a central grain condo within a 500km radius of fuel production would increase the fuel reliability and security. Truck deliveries going to a central location minimizes the risks of rail interruptions that have prohibited propane deliveries in the past.

4.3. Other Considerations

Beyond the grain drying co-op, a farm could benefit from economies of scale by converting other farm equipment to run on hydrogen or hydrogen derivatives. For example, the University of Minnesota is piloting the use of ammonia in tractors, as well as for fertilizer. To date, hydrogen has seen more interest from transportation applications including heavy-duty applications such as class 9 trucks, marine vessels, and mining haul trucks. When hydrogen is used in a fuel cell to produce electricity to power vehicles there are no GHGs emitted, and there is a higher efficiency compared to when it is combusted. As described in section 3.1 above, hydrogen storage tanks have high capital costs, and in the grain drying example where they would only be used a few weeks per year, providing another offtake for the storage infrastructure would reduce costs. Switching to hydrogen as a combustion fuel on grain drying or poultry farms would only be feasible if there were other applications using the hydrogen such as tractors and other mobile equipment.

5. KEY FINDINGS

- Due to the large amount of fuel required for a short number of weeks per year, the infrastructure costs for hydrogen as a fuel for grain drying may be prohibitive.
- On farm hydrogen use will likely only be feasible where economies of scale can be utilized such as grain drying co-ops or farms where mobile equipment is also converted to run on hydrogen.
- The frequency of fuel use in poultry barns makes more sense for hydrogen, however there are other alternative technologies that might use less fuel and have lower operating costs such as electric systems (heat pumps or resistive heating). Further study to compare hydrogen and electric systems is required for poultry barn heating.
- In the near-term blending hydrogen in the natural gas system up to 10% or 15% by volume could provide decarbonization opportunities to farms that are connected to the grid.
- There is no technology available on the market today to retrofit grain dryers or poultry barns to run on hydrogen, so further study of the equipment available for ammonia, or a blend of hydrogen/ammonia and natural gas is recommended.