Ontario's Hydrogen Hub in Sarnia-Lambton

Strategic Plan

Sarnia-Lambton Economic Partnership

Final Report, Rev. 1 – December 22, 2022

→ **The Power of Commitment**

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Acknowledgement of Territory

We acknowledge that the lands on which we gather, work, and live in the Sarnia-Lambton region are the traditional territories and ancestral lands of the Chippewa, Odawa, Aamjiwnaang, and Potawatomi peoples, referred to collectively as the Anishinabek Nation. We recognise their strength, diversity, resilience and deep connections to these lands. It is through the connection of the Anishinabek with the spirit of the land, water and air that we recognize their unique cultures, traditions, and values. Together as treaty people, we have a shared responsibility to act with respect for the environment that sustains all life, protecting the future for those generations to come.

Abstract

This report presents the Strategic Plan for Ontario's Hydrogen Hub in Sarnia-Lambton that was prepared by GHD Limited (GHD) for the Sarnia-Lambton Economic Partnership (SLEP). The Strategic Plan presents the outcomes of stakeholder engagement, learnings from other hydrogen hubs globally, and modelling of forecasted hydrogen demand and cost competitiveness for the Sarnia-Lambton region to become one of the largest low-carbon H_2ubs in Canada.

Stakeholder engagement completed through the course of the Strategic Plan development included 2 group workshops with the Sarnia-Lambton H_2ub Working Group, a series of one-on-one interviews and discussions with major stakeholders, and reviews and responses to draft modelling and report. Over 20 stakeholders across industry, academia, and research and development organizations were consulted during the development of the Strategic Plan.

SLEP is the lead economic development agency for the Sarnia-Lambton area and has focused efforts over the last 18 months on development and growth of the low-carbon hydrogen economy in the region. In January 2021, the area was branded as Ontario's Hydrogen Hub to reflect the fact that the Sarnia-Lambton area is Ontario's largest cluster of current and potential hydrogen producers and users, with unique competitive advantages positioning the region to become Ontario's leading producer, user, and exporter of low-carbon hydrogen and hydrogen technologies and services. Given that the Sarnia-Lambton region already acts as a large-scale, multi-industry H_2ub, producing and using over 150,000 tonnes of hydrogen annually, the goals of the Strategic Plan presented herein are to transition to low-carbon hydrogen production, enable implementation of transformational technologies that utilize hydrogen for deep decarbonization to grow demand, and to attract foreign direct investment to benefit the local economy and communities.

The Strategic Plan presented in this report consists of four components:

Part 1: **Foundation Report:** Organizes and evaluates the basis for the regional low-carbon H_2ub by assessing current industry, communities, and infrastructure, key stakeholders along the value chain and existing assets to support the growth of a low-carbon hydrogen economy, low-carbon hydrogen demand and production potentials, and the competitive advantages and disadvantages of the regional H_2ub. The Foundation Report concludes by identifying the main barriers to attracting investment into the low-carbon H_2ub.

Part 2: **Roadmap:** The Roadmap visualizes the potential future growth, infrastructure needs, and key opportunities along the hydrogen value chain for the Sarnia-Lambton low-carbon H_2ub and discusses alignment with the federal and provincial published hydrogen strategies.

Part 3: **Economic Analysis:** The economic analysis evaluates at a high-level the cost competitiveness of the potential H_2ub and compares against other regions in Canada.

Part 4: **Investment Attraction Action Plan:** Building on the other components, the Investment Attraction Action Plan provides specific and targeted near-term action items to tackle key barriers for enabling the opportunities of the H_2ub and includes a Call to Action for key stakeholders to engage in the Action Plan.

Executive Summary

Ontario's Hydrogen Hub (H_2ub) in the Sarnia-Lambton region in Southern Ontario is home to Ontario's largest cluster of current and potential hydrogen producers and users, comprised of major industrial facilities across the petrochemical and refining, hybrid chemistry, advanced manufacturing, and value-added agriculture sectors. Over 150,000 tonnes of hydrogen are produced and utilized within Sarnia-Lambton each year as feedstock for refining, chemicals, and fertilizer production. While the current hydrogen produced, traded, and used in the region is almost entirely sourced from steam methane reforming of natural gas, also known as grey hydrogen, the region has ambitions to build on its existing industry, hydrogen supply chain, and strategic advantages to become the largest low-carbon H_2ub in Ontario.

The consultations and investigations completed through the development of this Strategic Plan support the clear advantages and opportunities for a low-carbon H_2ub in Sarnia-Lambton as one of the leading potential hydrogen hubs in Canada. The region has extensive advantages through existing industry and connecting infrastructure (notably including an existing 30-km pure hydrogen pipeline network), highly-skilled workforce, established research and development leadership, export routes and infrastructure via road, rail, water, and pipeline, and opportunities for key enabling infrastructure to support a large-scale sustainable hydrogen economy including salt caverns for underground hydrogen storage as well as reservoirs and oil fields for carbon capture and storage (CCS) and enhanced oil recovery (EOR). Liquid hydrogen and ammonia are currently being produced in the region and exported across Canada and the US from Air Products' Sarnia Liquefaction Plant and CF Industries' facilities.

Sania-Lambton is a major energy-consuming area of the province, largely supplied by natural gas. There is significant potential to reduce greenhouse gas emissions (GHGs) for the large industrial emitters in the region by displacing natural gas with low carbon hydrogen. The demand forecasting detailed within the Foundation Report indicates incredible opportunity for scaling-up the local low-carbon H_2ub in Sarnia-Lambton through replacing existing hydrogen demand with low-carbon hydrogen, blending hydrogen into the region's 4 natural gas power plants to reduce peak carbon intensity of the Ontario electric grid, blending hydrogen into industrial natural gas heating systems to tackle large-scale industrial emissions reductions, and blending hydrogen into the local low-pressure gas distribution network feeding residential, commercial, and light-industrial customers (separate network than that which feeds the large industrial facilities in the region):

- By 2030, demand for low-carbon hydrogen could range from 25,000 tonnes per year to over 60,000 tonnes per year.
- By 2050, demand could range from nearly 500,000 tonnes per year to over 1 million tonnes per year in the region alone. Assuming the Transformational scenario in Canada's Hydrogen Strategy, which estimates a national market size of 20 million tonnes hydrogen per year by 2050, Sarnia-Lambton's demand could comprise between 2.5 and 5% of low-carbon hydrogen demand across the country.

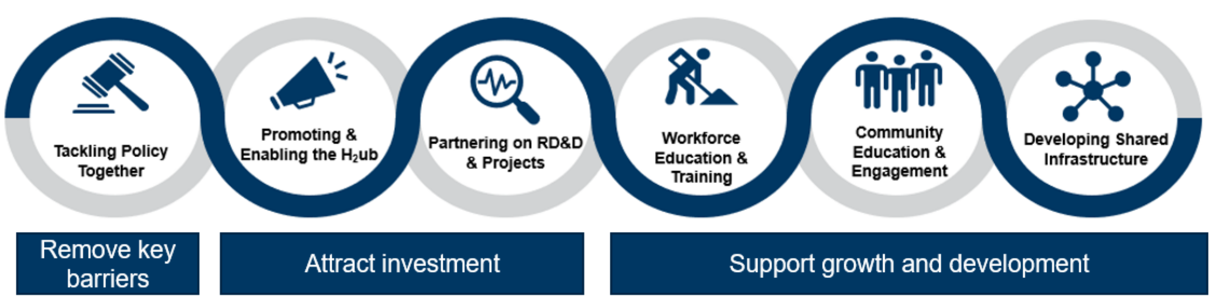
Furthermore, Sarnia-Lambton is strategically positioned to take advantage of potential sources of demand and export markets that are difficult to predict today and not included in the presented forecasts. Converting shipping through the Great Lakes to low-carbon ammonia or hydrogen fuel, supplying hydrogen to the large steel plants near Hamilton and future fueling stations along Hwy 401 (Montreal-to-Detroit corridor), exporting hydrogen and ammonia to merchant markets across North America, conversion of mobile heavy-duty equipment to hydrogen (tractors, etc.), potential hydrogen utilization at airports to offset fossil fuels, blending hydrogen into the natural gas transmission network from the central Dawn Hub, and more are not included in the current forecasts and can result in much higher-than-forecasted demand.

On the production side of the equation, Sarnia-Lambton sees several strategic advantages for low-carbon hydrogen production demonstrations and at-scale facilities. The region is well-positioned to be Ontario's largest centralized source of blue hydrogen provided that existing barriers and regulatory restrictions to CCS can be overcome, built on the existing grey hydrogen facilities and expertise. Atura Power is investigating opportunities for a landmark electrolysis facility at the former Lambton Generating Station powered by grid electricity, which could provide the region's first source of low-carbon hydrogen and has significant potential for scale-up utilizing existing infrastructure. The abundant salt cavern resources in Sarnia-Lambton additionally makes the region an ideal location for grid-scale energy storage through hydrogen production during periods of excessive low-carbon power on the grid, which can then be converted back to electricity during periods of high-demand to support lowering the carbon intensity of the provincial electric grid. On the research and development side, Sarnia-Lambton has excellent potential for becoming a leader in the development and demonstration of bio-hydrogen (from biomass waste) and pyrolytic hydrogen (from natural gas with solid carbon co-products), given the regions strong research and development expertise and supporting organizations, abundant biomass waste feedstock potential from the agricultural industry, and existing market access for solid carbon products. Additionally, Sarnia-Lambton already has sources of by-product hydrogen from chemical industries that can be captured and utilized. All of these production pathways can attract significant investment into the region to benefit local communities and economy. Cost competitiveness analysis presented within Part 3 of the Strategic Plan concluded that the region has the potential to be cost competitive with other hydrogen hubs across Canada.

Through the information and analysis presented in the Strategic Plan, it is clear that the Sarnia-Lambton region has abundant strategic advantages for hosting the launching point of a large-scale, multi-faceted low-carbon hydrogen economy in Ontario. Built on the strengths of the existing industries, infrastructure, skilled workforce, and abundant resources, the region is well-positioned to be one of the largest low-carbon H_2ubs in Canada and a leader in industrial decarbonization as well as research and development of emerging low-carbon hydrogen solutions. However, there are notable barriers and challenges that inhibit the opportunities identified for low-carbon hydrogen demand and production today. Many existing businesses and potential investors in low-carbon hydrogen have operations across North America and are evaluating where to prioritize their investments – the barriers identified need to be addressed to attract investment to the region and enable the rich opportunities of the potential low-carbon H_2ub. These barriers are discussed in detail in the Foundation Report, with the major themes summarized as follows:

- Policy & Incentives: In general, the key barriers to investment and particularly to siting low-carbon hydrogen projects in the Sarnia-Lambton region relate to provincial and federal policies and incentives. Electricity pricing and CCS restrictions were consistently raised by stakeholders as major barriers for low-carbon hydrogen production, both of which the provincial government have stated intentions to address. These will be critical as the region needs to be able to produce low-carbon hydrogen economically. The region is competing for foreign direct investment (FDI) against jurisdictions across Canada and the US, and governmental incentives can be a key deciding factor in the early stages of where companies choose to invest.
- Lack of Awareness & Education: An important first step of attracting investment is ensuring that private and public investors are aware of the many opportunities in the region. Promoting the potential H_2ub and spreading awareness of the significant opportunities including demand market and shared infrastructure will be critical in the near-term.

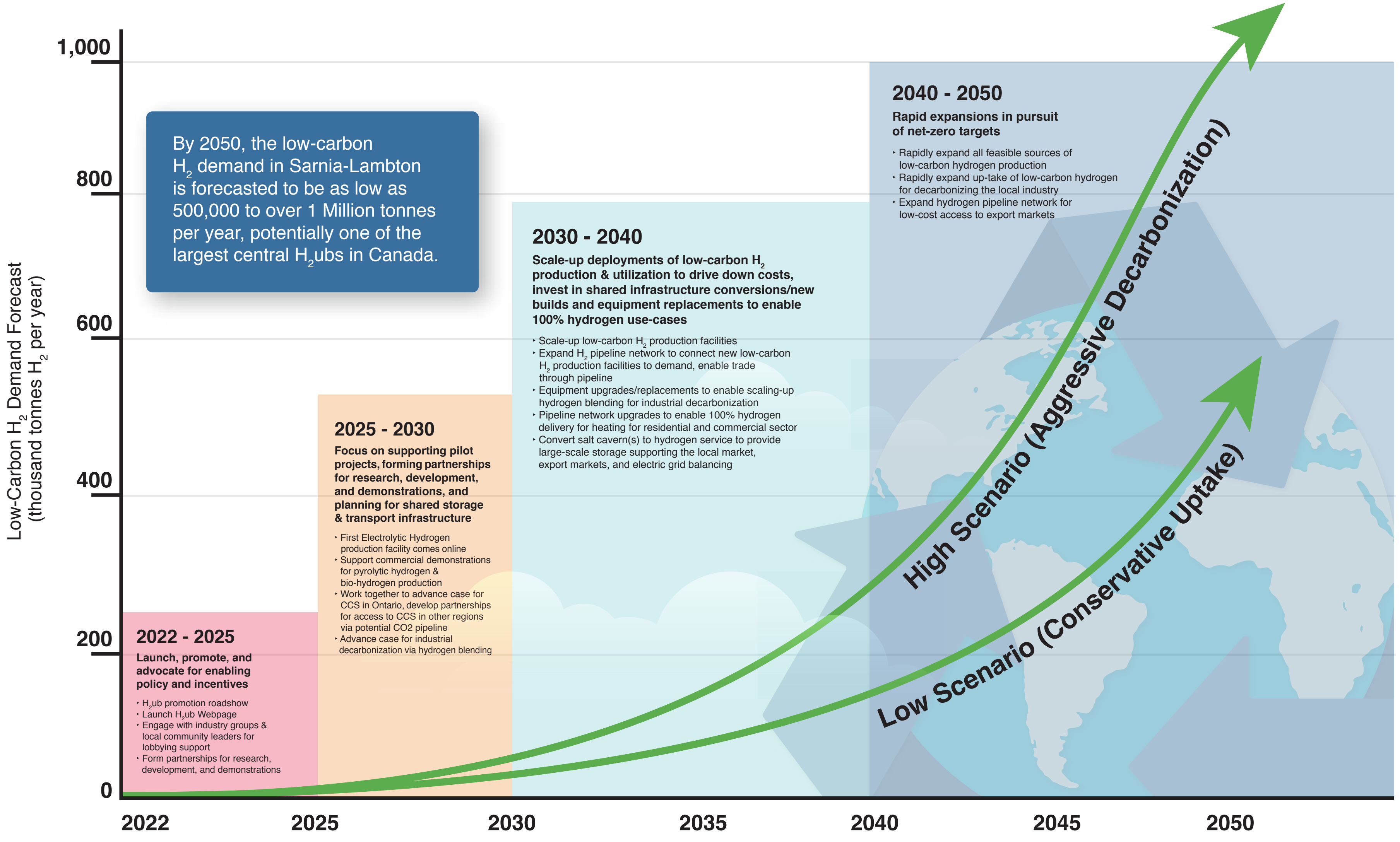
The Investment Attraction Action Plan presented in Part 4 of the Strategic Plan was developed to provide specific recommendations on actions to address the key barriers and enable the abundant opportunities of the H_2ub, with the goal of attracting public and foreign direct investment into the region. The Action Plan is built on 6 key pillars with specific actions, key performance indicators, and stakeholder roles detailed in Part 4:



Finally, tying together the Strategic Plan is the Roadmap to 2050 for Ontario's Hydrogen Hub in Sarnia-Lambton, presented on the next page.

Ontario's H_2ub in Sarnia-Lambton

Roadmap to 2050



Near-Term Action Plan
To enable the potential low-carbon H_2 economy and capture opportunities for local growth and export, the H_2ub needs to collaborate to address a number of key challenges and barriers limiting low-carbon hydrogen production and adoption. These are divided into 6 Pillars of the Investment Attraction Action Plan:

Tackling Policy Together
Collaborate on advocating for local & provincial policy changes and incentives to enable the H_2ub, with a focus on CCS framework, electricity price incentives, and clear approval pathways for projects.

Broadcasting the H_2ub
Promote & advertise the advantages of the region to attract external investment, government attention on key needs, and public support. Create an online H_2ub platform and promote at conferences/events.

Partnering on RD&D
Industry-College collaboration to attract investment for RD&D, with focus on advancing low-cost H_2 production pathways and key potential use-cases such as industrial hydrogen blending.

Community Engagement & Education
Engage with local communities, First Nations, and community interest groups on H_2ub opportunities and concerns; get ahead of public perception challenges with targeted education and awareness.

Workforce Training & Education
Form a Program Advisory Committee at Lambton College with H_2ub industry stakeholders to advise on the introduction of hydrogen micro-credentials and upskilling. Engage with unions on opportunities.

Developing Shared Infrastructure
Work together to assess, coordinate, and plan cost-effective shared infrastructure opportunities, such as H_2 pipeline network expansion, underground H_2 storage, export infrastructure, and CCS.

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Introduction & Purpose of Report

GHD Limited (GHD) is pleased to present this Draft Strategic Plan to the Sarnia-Lambton Economic Partnership (SLEP) for Ontario's Hydrogen Hub (H_2ub) based in the Sarnia-Lambton area of Ontario, Canada. The Strategic Plan presents the outcomes of stakeholder engagement, learnings from other hydrogen hubs globally, and modelling of forecasted hydrogen demand and cost competitiveness for the Sarnia-Lambton region to become one of the largest low-carbon H_2ubs in Canada. The Strategic Plan consists of four components:

Part 1: **Foundation Report:** Organizes and evaluates the basis for the regional low-carbon H_2ub by assessing current industry, communities, and infrastructure, key stakeholders along the value chain and existing assets to support the growth of a low-carbon hydrogen economy, low-carbon hydrogen demand and production potentials, and the competitive advantages and disadvantages of the regional H_2ub. The Foundation Report concludes by identifying the main barriers to attracting investment into the low-carbon H_2ub.

Part 2: **Roadmap:** The Roadmap visualizes the potential future growth, infrastructure needs, and key opportunities along the hydrogen value chain for the Sarnia-Lambton low-carbon H_2ub and discusses alignment with the federal and provincial published hydrogen strategies.

Part 3: **Economic Analysis:** The economic analysis evaluates at a high-level the cost competitiveness of the potential H_2ub and compares against other regions in Canada.

Part 4: **Investment Attraction Action Plan:** Building on the other components, the Investment Attraction Action Plan provides specific and targeted near-term action items to tackle key barriers for enabling the opportunities of the H_2ub and includes a Call to Action for key stakeholders to engage in the Action Plan.

Scope and limitations

This report: has been prepared by GHD for Sarnia-Lambton Economic Partnership and may only be used and relied on by Sarnia-Lambton Economic Partnership for the purpose agreed between GHD and Sarnia-Lambton Economic Partnership as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Sarnia-Lambton Economic Partnership arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

Accessibility of documents

If this report is required to be accessible in any other format, this can be provided by GHD upon request and at an additional cost if necessary.

GHD has prepared this report on the basis of information provided by Sarnia-Lambton Economic Partnership and various stakeholders who provided information to GHD (including private and public organizations)], which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

Part 1: Foundation Report

1. Introduction

The unique advantage of the Sarnia-Lambton region in becoming the largest low-carbon H_2ub in Ontario is the foundation on which the H_2ub stands. Today, the region is already a large H_2ub, with infrastructure, operations, and extensive knowledge across the hydrogen value chain. The Foundation Report assesses the following:

- H_2ub Background – Ontario's H_2ub developments to date, hydrogen hubs in context with Canada's and Ontario's hydrogen strategies, hydrogen hub developments elsewhere in Canada.
- Sarnia-Lambton Economic Region – summary profiles of the industries, communities, and existing enabling infrastructure and resources that comprise the Sarnia-Lambton region and form the basis for building out the low-carbon H_2ub.
- Stakeholder Perspectives for Ontario's H_2ub – potential roles of key stakeholders at the heart of Ontario's H_2ub and perspectives from stakeholder engagement on the challenges and opportunities for the region.
- Low-Carbon Hydrogen Demand – discussion and forecasting of potential low-carbon hydrogen demand in the region for current and emerging end-uses.
- Low-Carbon Hydrogen Production – methods for low-carbon hydrogen production and the strategic advantages or disadvantages for each in the Sarnia-Lambton region, with identification of barriers that need to be overcome for enabling supply to meet forecasted demand.
- Strategic Advantages – identification and discussion of the key strategic advantages for attracting investment into the low-carbon H_2ub.
- Key Barriers & Needs – discussion of the barriers that need addressing to enable the low-carbon H_2ub.

2. H_2ub Background

2.1 Ontario's Hydrogen Hub

The SLEP is the lead economic development agency for the Sarnia-Lambton area. SLEP has focused efforts over the last 18 months on development and growth of the low-carbon hydrogen economy in the Sarnia-Lambton area. In January 2021, the area was branded as Ontario's Hydrogen Hub to reflect the fact that the Sarnia-Lambton area is Ontario's largest cluster of current and potential hydrogen producers and users, with unique competitive advantages positioning the region to become Ontario's leading producer, user, and exporter of low-carbon hydrogen and hydrogen technologies and services. The current hydrogen industry in Sarnia-Lambton produces and uses over 150,000 tonnes of hydrogen per year for petrochemical and hybrid chemistry facilities, production of ammonia and other fertilizer products, and liquefaction for export to a myriad of customers across Canada. This hydrogen is largely produced from steam methane reforming of natural gas (commonly known as grey hydrogen) either by the end-use facility itself or by a central hydrogen provider (Air Products being the largest in the region). Air Products operates a dedicated hydrogen pipeline network in the Sarnia-area to deliver hydrogen to refineries and other customers, which could act as a starting backbone for the low-carbon H_2ub.

Given that the Sarnia-Lambton region already acts as a large-scale, multi-industry H_2ub, the goals of the strategy are to transition to low-carbon hydrogen production, enable implementation of transformational technologies that utilize hydrogen for deep decarbonization to grow demand, and attract foreign direct investment to benefit the local economy and communities.

In January 2021, SLEP developed a response letter to the Ontario Low-Carbon Hydrogen Strategy – Discussion Paper (November 2020). In developing the submission, SLEP consulted with more than 40 experts across the hydrogen value chain including leaders from ten private sector industrial operations, and 6 stakeholders from academia and research, government, and industrial support organizations. Stakeholders highlighted that the Sarnia-Lambton area is the best place for the focused development of the low-carbon economy to create opportunity for all of Ontario. The continued development of the low-carbon economy in the Sarnia-Lambton area creates environmental and economic opportunity, including investment attraction, job creation and competitiveness, large-scale decarbonization, and alignment with the Ontario Low-Carbon Hydrogen Strategy.

The Ontario Hydrogen Hub Working Group was created in early 2021 with SLEP as the lead organization of a 22-member stakeholder group representing local interests in the hydrogen economy. The group's vision and mission are as follows:

- Ontario Hydrogen Hub Working Group Vision: **"to leverage the strong local hydrogen infrastructure as the catalyst to remove barriers and position Sarnia-Lambton to become the home to the low-carbon hydrogen sector for Ontario and beyond"**.
- Ontario Hydrogen Hub Working Group Mission: "**to create a strategy and implement an action plan to meet Ontario's foreseen demand for low carbon hydrogen through the following goals: identify competitive advantages and opportunities, develop a business case, collaborate on joint projects, build relationships, influence policy and promote the existing strength of the Sarnia-Lambton area as a leader in the hydrogen sector as a natural extension to current opportunities."**

2.2 What is a Hydrogen Hub?

A hydrogen hub can be defined as a network or interconnection of low-carbon hydrogen producers, connective infrastructure, and hydrogen end-users in a close proximity. Hydrogen hubs have been earmarked as key launching points for the energy transition to a clean hydrogen economy, where early adopters and producers of hydrogen can come together to overcome the classic chicken-and-egg dilemma of deploying new supply and demand infrastructure.

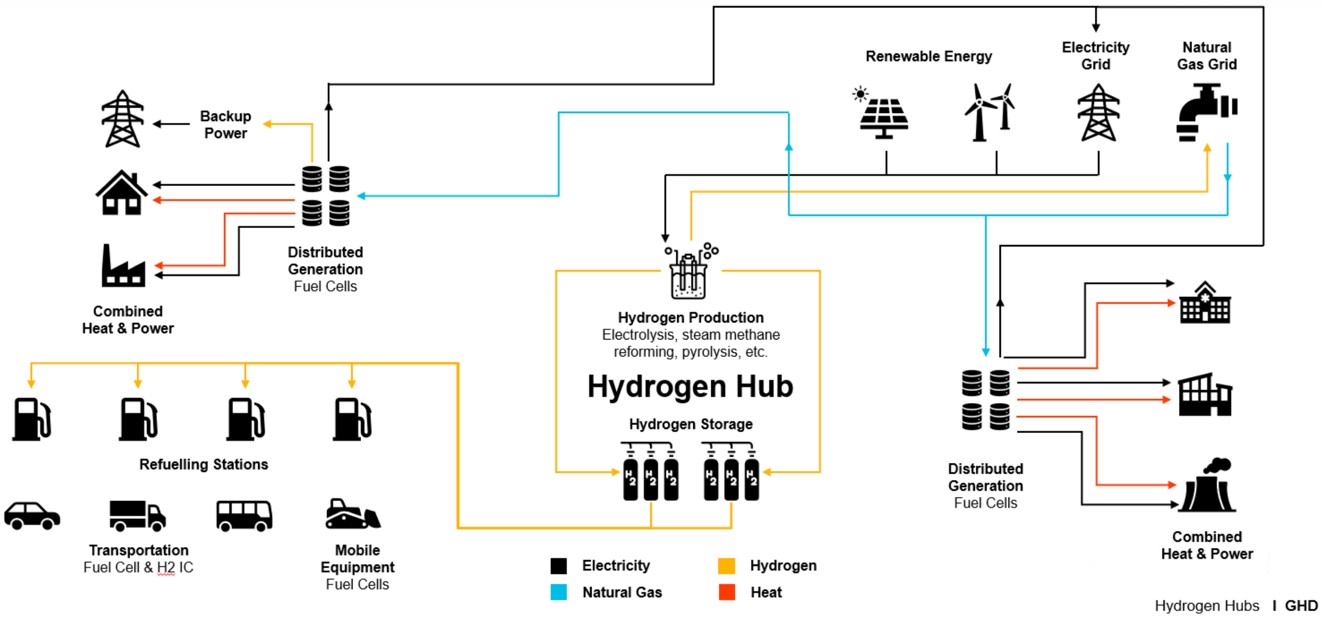

Figure 1 Example Visualization of a Connected Hydrogen Hub

Continuing with the analogy, a hydrogen "hub" necessarily involves several "spokes" to create the hub. A single project delivering low-carbon hydrogen to an end-user does not constitute a hub but can be one of several components that comprise a hub.

With hydrogen hubs emerging across North America, companies and investors are evaluating where to focus their investments to optimize the return. Hydrogen hubs are competing to attract this investment. There are several key attributes of strong hydrogen hubs that help to de-risk investment decisions and enable the market, which can be categorized as "Essential", "Core", and "Sustaining":

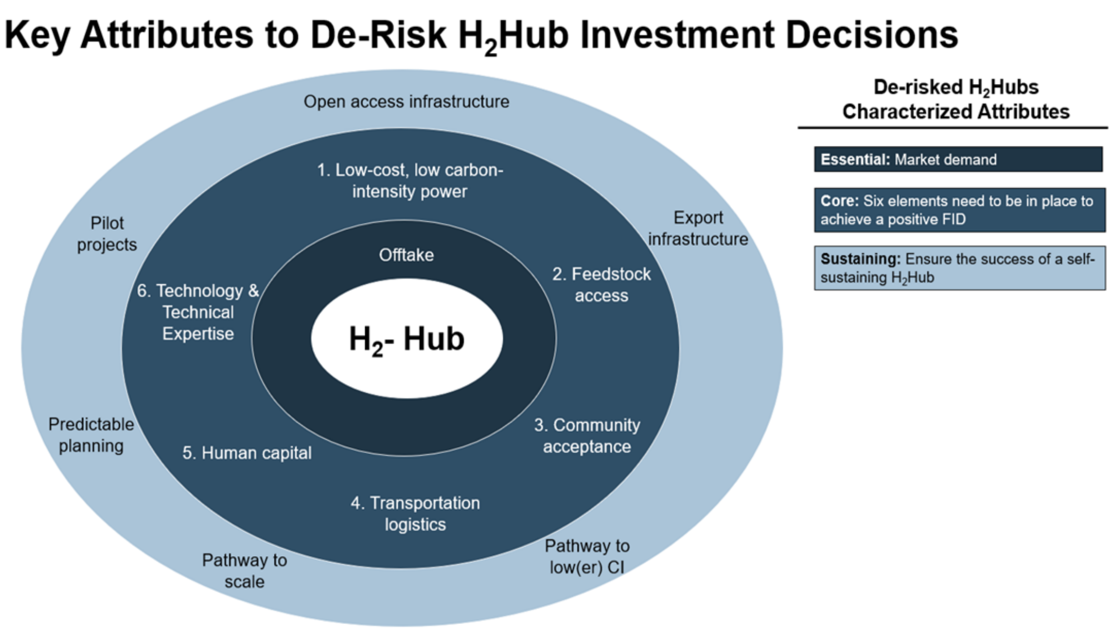

Figure 2 Key Attributes to De-Risk H_2Hub Investments

The essential attribute of any hydrogen hub is the local demand and off-take market. Without potential demand for hydrogen in the region, there can be no hydrogen hub, only singular projects that export hydrogen to off-takers. Multiple off-take opportunities are important to building a sustainable and reliable hydrogen demand, which supports de-risking the commercial business case for investment into low-carbon hydrogen production. There are many potential sources of demand within the Sarnia-Lambton region, which are evaluated in detail in this Foundation Report:

- Decarbonizing current hydrogen feedstock demand for petrochemical refining, hybrid chemistry, and ammonia manufacturing within the region.
- Decarbonizing industrial process heating by blending hydrogen into natural gas and eventual full conversion of natural gas combustion systems to low-carbon hydrogen.
- Decarbonizing natural gas power production (5 gas power plants in Sarnia-Lambton) by blending hydrogen or low-carbon ammonia (produced from low-carbon hydrogen) into natural gas and potentially full eventual conversion to hydrogen or ammonia power.
- Hydrogen for fuel cell electric vehicle (FCEVs) refueling, for local fleet conversions, heavy-duty truck traffic along the Highway 402, and potentially mobile industrial and farming equipment.
- Decarbonizing residential and commercial heating by blending hydrogen into the local low-pressure natural gas distribution system.

In addition to the in-region demand, there is significant potential for Sarnia-Lambton to take advantage of export markets for both low-carbon hydrogen and ammonia, such as:

- Supplying hydrogen to emerging or future demand markets in Ontario such as steel plants near Hamilton and fueling stations along Highway 401,
- Blending hydrogen into the natural gas transmission network out of the Dawn Hub, which Enbridge estimates may be technically feasible by 2050 and could create a massive demand for low-carbon hydrogen,
- Exporting hydrogen and ammonia across Canada via road and rail (as is already done today with liquefied hydrogen and ammonia exports from Air Products and CF Industries), and
- Exporting hydrogen and ammonia to Michigan or elsewhere in the U.S (as is already done today with liquefied hydrogen and ammonia exports from Air Products and CF Industries).

Core elements of a successful hydrogen hub include the following:

- Low-cost, low-carbon intensity power: critical for electrolytic hydrogen production, low-carbon intensity power presents a core opportunity for diversified hydrogen hubs. While the Ontario provincial electric grid is fairly low-carbon, with hydro and nuclear power comprising the largest shares of generation, there is concern over increasing carbon intensity as more natural gas peaking power is needed to manage peak demand in a world of increasing electrification. “Low-cost” is presently a challenge for the region due to grid price and Ontario’s Global Adjustment (GA) system, however with smart control and fast-response electrolyzers peak periods may be avoidable resulting in lower-cost electricity.
- Feedstock access: Feedstocks critical for a diverse hydrogen hub primarily include water (for electrolysis) and natural gas (for blue and turquoise hydrogen production, which are defined in the next section). The Sarnia-Lambton region has excellent access to low carbon feedstocks for both of these pathways, with abundant fresh water resources, as well as plentiful access to biomass or agricultural and animal raising waste feedstocks which can also be used to produce low-carbon hydrogen (bio-hydrogen).
- Community acceptance: Community understanding, engagement, and acceptance are core attributes for de-risking investment into a regional hydrogen hub. To this day, the word “hydrogen” may evoke references to atomic bombs and the *Hindenburg* disaster among the public. Community education research conducted by GHD in Australia found that only 3% of public respondents have a positive view of hydrogen, while the vast

majority (81%) have a neutral response, in need of further information, and 13% have a negative view of hydrogen referencing bombs and explosion concerns [1]. Education and awareness around the safety of hydrogen, the need for decarbonization, and the opportunities presented by a low-carbon hydrogen economy is needed to mitigate the risk of community rejection of landmark hydrogen projects. Due to the existing hydrogen value chain and skilled workforce in Sarnia-Lambton, the local community is expected to be relatively receptive to low-carbon hydrogen opportunities.

- Transportation and logistics: The ability to connect production to demand is core to a hydrogen hub. Shared infrastructure for hydrogen transport and storage in the form of an interconnected pipeline network supported by growing hydrogen storage capacity as the market expands can provide reduced cost for hydrogen producers to access the market. Port and rail access for exports provide value-added opportunities. With extensive active and decommissioned pipeline networks, CN and CSX rail lines, port facilities, highway connections, and active salt caverns, Sarnia-Lambton has a strong starting point for a low-carbon H_2ub.
- Human capital: Access to skilled workforce for delivering and operating low-carbon hydrogen projects is a key aspect of hydrogen hubs. The Sarnia-Lambton region has a highly skilled and experienced workforce as a starting point, which supports the large petrochemical and refining, hybrid chemistry, and advanced manufacturing sectors in the region. Lambton College is well-positioned to introduce hydrogen curriculum into existing programs that feed the local industries.
- Technology & technical expertise: Decarbonizing existing energy systems and industries presents major technical challenges and will require an “all hands on deck” approach. Commercializing emerging technologies, reducing costs for low-carbon hydrogen production, implementing shared infrastructure, and advancing decarbonization solutions all require significant technical expertise and benefit from industry-academia collaboration.

Finally, beneficial aspects that support sustainable long-term growth of hydrogen hubs include open access to shared infrastructure, access to export infrastructure to reach distant markets, clear pathways for lower carbon intensity hydrogen production to expand over time, clear pathways to scale-up hydrogen production and utilization across the hub, predictable policies and incentives for project and investment planning, and landmark pilot projects to drive the early-implementation and expansion of the hub.

2.3 Hydrogen Colours and Carbon Intensities

Throughout this report, hydrogen production pathways are frequently referred to by colours: grey, green, blue, pink, turquoise and dark green, although further colours have been claimed for an even wider range of potential production pathways. There are no universally accepted definitions of the colours of hydrogen and there are more production pathways than colours claimed, however using the colours does provide a convenient shorthand. The definitions below for colours and associated production pathways are used throughout this report.

While the colours provide a convenient shorthand for the various production technologies and feedstocks, the *lifecycle carbon intensity* of produced hydrogen is much more valuable to understand than the colour alone. Lifecycle carbon intensity quantifies the greenhouse gas (GHG) emissions emitted over the lifecycle of producing and delivering hydrogen, typically measured in kilograms (kg) of carbon dioxide equivalent (CO_2e) per kg of hydrogen (kgCO_2e/kgH_2) or grams of CO_2e per mega-joule (MJ) of hydrogen (gCO_2e/MJ). The latter allows for comparing against other fuels and energy forms, for example Canadian pipeline natural gas has a default carbon intensity of 62 gCO_2e/MJ (~3.5 kgCO_2e/kgNG) according to Environment and Climate Change Canada (ECCC) [2].

In short, the colours of hydrogen as used in this report are defined as follows:

- Grey H_2: Produced from steam methane reforming (SMR), auto-thermal reforming (ATR), or similar technology, of natural gas, with the produced CO_2 emitted to atmosphere. Carbon intensity of approximately 100 gCO_2e/MJ (~14.2 kgCO_2e/kgH_2) according to ECCC (process dependent).
- Blue H_2: SMR/ATR of natural gas where the produced CO_2 is captured and permanently utilized or sequestered. The carbon intensity of blue hydrogen can vary greatly depending on the efficiency of CO_2

capture and sequestration, from as low as 11 gCO_2e/MJ (1.56 $kgCO_2e/kgH_2$) to over 50 gCO_2e/MJ (7.1 $kgCO_2e/kgH_2$) according to the Pembina Institute [3].

- Green H_2: Produced via electrolysis by splitting water with renewable electricity (wind, solar, hydropower, geothermal). Lifecycle carbon intensity is generally near-zero for green hydrogen, with the exception of electricity from human-made reservoir hydropower, as many carbon intensity methodologies recognize the lifecycle emissions from anaerobic biomass decomposition caused by flooding land to build reservoirs. Hydrogen specifically produced via solar power has been referred to as yellow hydrogen, although confusingly others have used yellow hydrogen to describe a mix of electricity sources. Throughout this report, green refers to electrolytic hydrogen via renewable electricity sources, while the general term “electrolytic hydrogen” refers to hydrogen from a mix of potential sources (for example, powered by the provincial electric grid). Carbon intensity of electrolytic hydrogen depends on the carbon intensity of the input electricity mix. For example, if using the average grid intensities published by Environment and Climate Change Canada (ECCC) for the Fuel LCA Model [4], electrolytic hydrogen produced in Ontario (grid intensity of 50.4 gCO_2e/kWh) could have a carbon intensity of about 18 gCO_2e/MJ while in Quebec (grid intensity of 18 gCO_2e/kWh) electrolytic hydrogen could have a carbon intensity of about 7 gCO_2e/MJ (depending on actual electrolyzer efficiency).
- Pink H_2: Electrolytic hydrogen with nuclear power as the electricity source, with near-zero carbon intensity. Hydrogen from nuclear power has also been referred to as red or purple hydrogen, with pink appearing to be most commonly used.
- Turquoise H_2: Produced via pyrolysis of natural gas, producing hydrogen and solid carbon products such as carbon black and graphite. Pyrolytic hydrogen has significant potential to be a major competitor to blue and electrolytic hydrogen in the future, requiring significantly less water and electricity than electrolytic hydrogen, not emitting CO_2 compared to blue hydrogen, and producing a value-added solid carbon product with a broad range of market applications. However, it is not yet commercially proven at scale and requires further development and investment. Carbon intensity of turquoise hydrogen can be near-zero in theory but will be highly process-dependent.
- Dark Green H_2: Refers to hydrogen produced from the advanced thermal treatment of biomass feedstocks, such as pyrolysis or gasification of wood or agricultural wastes or SMR/ATR of biogas or renewable natural gas (RNG). Similar to turquoise H_2, this pathway has significant potential advantages compared to blue and electrolytic hydrogen, but remains a pre-commercial technology today requiring further research, development and demonstration (RD&D). Carbon intensity of dark green hydrogen can be near-zero in theory, or even negative depending on the feedstock and if CCS is applied.

Electrolytic hydrogen can be produced via grid electricity, which in Ontario is a combination of renewables (largely hydro with some wind and solar), nuclear, and gas generation. Depending on levels of gas generation, hydrogen produced using the Ontario electric grid can be low-carbon, as described above.

What is “low-carbon” hydrogen? There is no universally-accepted defined threshold for low-carbon hydrogen as of yet. The European Union’s (EU) CertifHy program, which aims to establish a harmonized Europe-wide guarantee of origin scheme for hydrogen production, is currently using the threshold of 36.4 gCO_2e/MJ (4.36 $kgCO_2e/kgH2$) for low-carbon hydrogen. The Canada Clean Fuels Fund (CFF) in 2021 used a threshold of 36 gCO2e/MJ for funding applications, while the Canada *Clean Fuel Regulations*, SOR/2022-140, offers potential carbon credits for hydrogen at less than the reference carbon intensity of 67.8 gCO_2e/MJ. Throughout this report, “low-carbon hydrogen” can be considered to be inclusive of all production pathways that can achieve <36 gCO2e/MJ. However, this is debatable.

By-product hydrogen refers to hydrogen produced as a waste or by-product from primary industrial processes. There is no agreed upon colour for by-product hydrogen, which is probably appropriate since the processes and feedstocks may vary greatly from source to source.

The figure below visualizes the hydrogen colours as used in this report and approximate carbon intensity ranges.

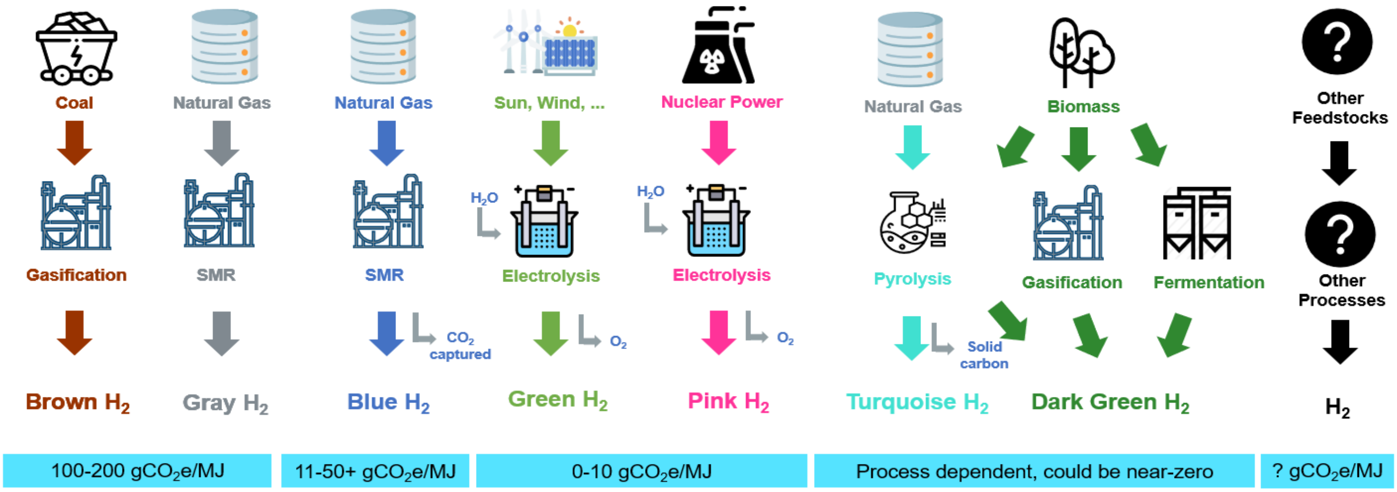

Figure 3 Hydrogen Colours – Production Pathways and Carbon Intensities

2.4 Hydrogen Hubs in the Context of Canada’s & Ontario’s Hydrogen Strategies

In December of 2020, the Government of Canada published the *Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen, A Call to Action* [5]. The *Hydrogen Strategy for Canada* aims to utilize hydrogen as a central component of achieving Canada's goal of net-zero emissions by 2050 while positioning Canada as a global industrial leader in clean low-carbon fuels, creating jobs, and growing the economy. The federal strategy divides the pathway to achieving 2050 goals into 3 essential phases:

- 2020-2025 (Near-Term): Lay the foundation of the low-carbon hydrogen economy by encouraging early development of hydrogen hubs that build on mature applications and demonstrate emerging applications of low-carbon hydrogen, and deploying regulation and policy to enable and support the growth of the low-carbon hydrogen economy.
- 2025-2030 (Medium-Term): Growth and diversification of the low-carbon hydrogen value chain by building on the foundation, expanding demonstrations, and scaling-up emerging technologies.
- 2030-2050 (Long-Term): Rapid expansion of at-scale deployments of low-carbon hydrogen technologies and infrastructure along the value chain, to achieve emissions reductions targets with hydrogen playing an integral role of delivering up to 30% of Canada’s end-use energy by 2050.

Canada currently produces approximately 3 million tonnes of hydrogen per year, almost entirely produced from natural gas as grey hydrogen. By 2050, the strategy predicts that Canada could grow production by a factor of seven to meet domestic demand, producing more than 20 million tonnes of low-carbon hydrogen per year, with potential for significant expansion to meet export markets demand.

In implementing the near-term targets of the national strategy, the importance of hydrogen hubs is clear. Regional hydrogen hubs within each province provide a central point for building out low-carbon hydrogen production alongside existing and emerging demand, enabling scaling of production and utilization of shared infrastructure to drive down costs. There are many industrial hubs in Canada currently that are already established producers and users of hydrogen for refining, ammonia, and methanol applications, which provide central opportunities for developing low-carbon hydrogen production at scale. The strategy identifies several high-potential areas for building out hubs in Canada:

- The Alberta Industrial Heartland, which has many of the same advantages of the Sarnia-Lambton region (large-scale petrochemical refining and ammonia production representing existing hydrogen demand and expertise, existing pure hydrogen pipeline network and expertise, abundant natural gas resources) with the added advantage of enabled and operating CCS facilities that can be the cornerstone of large-scale blue hydrogen production.

- Coastal ports of BC, Ontario, Quebec, Manitoba, and Atlantic Canada, where ports can act as central exit points for low-carbon hydrogen while also providing significant potential demand for low-carbon hydrogen.
- Transportation corridor between Montreal & Detroit, which passes East of Sarnia-Lambton down Highway 401 and connects demand for transportation with industrial and manufacturing sectors in Montreal and Detroit.
- Ethanol and renewable natural gas (RNG) plants in provinces with access to hydroelectricity, where green hydrogen can be produced and combined with carbon via methanation to increase RNG and methanol/ethanol production (note that Sarnia-Lambton is home to ethanol production facilities owned by Suncor and Woodland Biofuels).

Notably, the federal strategy misses out on identifying the Sarnia-Lambton region, which emphasizes the need for promotion of the Sarnia-Lambton H_2ub. The strategic advantages of Sarnia-Lambton are many and align with the target areas described above.

In April of 2022, the Ontario Government published *Ontario's Low-Carbon Hydrogen Strategy: A Path Forward,* which sets out a foundation and vision for the low-carbon hydrogen economy within the province [6].

The provincial strategy is grounded on immediate actions that should be taken to enable low-carbon hydrogen, including supporting the launch of Atura Power's Niagara Falls hydrogen production project, identifying and evaluating Ontario's H_2ub communities, assessing feasibility of low-carbon hydrogen production opportunities from Bruce Power's nuclear generating station, developing an interruptible electricity rate to enable lower-cost electrolytic hydrogen production, supporting pilot projects for hydrogen storage and grid integration, supporting industry to utilize low-carbon hydrogen for decarbonization, enabling CCS in Ontario through policy changes and consultations, and supporting hydrogen research and development.

The actions identified address several of the key barriers to a large-scale low-carbon hydrogen economy in Ontario, perhaps most notably the high cost of electricity due to the GA price that limits electrolytic hydrogen production and the fact that CCS is currently not permissible nor recognized in Ontario policy and regulations, in effect making blue hydrogen production impossible. Overcoming these barriers will be critical for the Ontario hydrogen economy and in turn the Sarnia-Lambton H_2ub. As of the date of publication of this report, Sept. 2022, the Ontario Government is in the process of assessing these barriers and developing a plan to overcome them to enable the provincial hydrogen strategy.

The Ontario strategy acknowledges the Sarnia-Lambton region as a potential focal hydrogen hub, recognizing the strategic advantages of the existing chemical and refining industries, fertilizer and ammonia production, natural resources for salt cavern hydrogen storage and CCS, skilled workforce, and existing infrastructure and assets. Atura Power has identified four strategic locations across the province where low-carbon hydrogen demand can be matched by electrolytic hydrogen that leverages existing electricity infrastructure and Ontario's clean electricity grid, one of which is the potential Lambton Hydrogen Centre at the site of the decommissioned Ontario Power Generation (OPG) Lambton Generating Station. Atura Power is investigating the opportunity to produce large-scale low-carbon hydrogen at this site and serve heavy industry in the Sarnia-Lambton area in support of a local H_2ub.

2.5 Hydrogen Hub Developments in Canada

At the current time, there have been 2 major H_2ub announcements in Canada: the Edmonton Region H_2ub (in the Alberta Industrial Heartland) and the Southeast Alberta H_2ub (centred around the City of Medicine Hat). Both of these H2ubs have been (and continue to be) heavily supported by the activities of the Transition Accelerator, a not-for-profit organization focused on advancing the energy transition with significant presence in Alberta, as well as the local municipalities and provincial government.

Edmonton Region Hydrogen Hub

Officially announced in 2021, the Edmonton Region H_2ub is branded as Canada's First H_2ub, launched with the support of over $2 million in funding ($1.2 million in funding from Western Economic Diversification Canada, $600,000 from Alberta's Industrial Heartland Association, and $450,000 from the Province of Alberta through Emissions Reduction Alberta).

The foundational report of the Edmonton Region H_2ub was published in November of 2020 by the Transition Accelerator [7]. The H_2ub is grounded in strategic advantages from the large-scale industrial and petrochemical sector in Alberta's Industrial Heartland, including large-scale hydrogen production and utilization, an existing pure-hydrogen pipeline network operated by Air Products, existing carbon capture and pipeline transport (Alberta Carbon Trunkline) to operating CCS facilities, suitable geology for further expansion of CCS, and a skilled workforce from the existing industry. The H_2ub plans to start with low-carbon hydrogen demand sectors closest to economic viability to establish and grow demand, with a near-term focus on transportation, followed by combined heat and power, blending hydrogen into natural gas systems, heating, and finally electricity generation.

Since the initial publication and announcements, the Edmonton Region H_2ub has engaged with over 100 companies through stakeholder engagement and market sounding across 4 action areas: municipal fleets, commercial fleets, heat & power, and low-carbon hydrogen supply [8]. The H_2ub has plans for further reports and webinars to continue developing and disseminating information on the region and connecting with industry to help drive investment and projects in the region. Thanks to the webinars, publications, and presence at conferences and events, awareness around the Edmonton Region H_2ub is high.

The Edmonton Region H_2ub has a dedicated website (**www.erh2.ca**) that provides information on the hub through publications, blogs, and webinars, links to news and events regarding the hub, and contact information for interested parties to connect into the hub. According to the website landing page, over 25 projects related to the low-carbon hydrogen value chain are currently in development. This includes several heavy-duty trucking and transportation fleet conversion/demonstration projects, the ATCO Fort Saskatchewan hydrogen blending in natural gas pilot project, CO_2 pipeline expansions, microgeneration projects utilizing hydrogen, and more.

Southeast Alberta Hydrogen Hub

The Southeast Alberta H_2ub is supported and spearheaded by the Southeast Alberta Hydrogen Task Force, comprised of municipalities, economic development agencies, the provincial government, and private industry. In July of 2022, the region published its foundational report through the Transition Accelerator: "*Towards Hydrogen" A Hydrogen HUB Feasibility Study for Southeast Alberta*" [9]. The report identifies and discusses the strategic advantages and opportunities specific to the Southeast Alberta region, including high regional demand and its potential to be among the lowest-cost producers of low-carbon intensity hydrogen in North America (largely grounded in blue hydrogen production given the vast natural gas and CCS resources, and challenges of high-carbon intensity electric grid for electrolytic hydrogen production). The vision of this hub is to replace the economic impact of the oil and gas sector that once was the region's primary economic driver, utilizing similar infrastructure and workforce skillsets to advance hydrogen as the path toward a sustainable energy future.

The foundation report further defines intentions to develop a formal H_2ub governance structure, comprised of a steering committee and integrating secretariate, several action teams for targeted collaborative efforts as part of the larger hub ecosystem, and a coalition of economic development and philanthropic entities to support the hub.

The Southeast Alberta H_2ub is currently focused on four strategic areas of action:

- Moving forward with CCUS developments as quickly as possible to establish low-cost blue hydrogen and attract industry decarbonization investment,
- Initiating discussion with regulatory and renewable power proponents to include green hydrogen as part of long-term electric generation strategy in Alberta,
- Establish regional hydrogen demand by focusing on fueling stations and return-to-base operations along the Trans-Canada corridor, as well as supporting supply and demand partnerships along the value chain, and

- Build external demand from nearby domestic and United States (US) regions for which the hub can produce and export low-carbon hydrogen utilizing existing road and rail infrastructure while positioning for larger long-term export infrastructure (pipelines).

The Southeast Alberta Hydrogen Task Force plans to actively engage with public and private stakeholders and funding providers to work towards establishing a formal H_2ub in Southeast Alberta, providing education and awareness campaigns about hydrogen and initiating hydrogen pilots and projects.

In-Development Hydrogen Hubs

There are several other regional H_2ubs in pre-foundation report or early planning stages in Canada. Many are based around partnerships for individual landmark projects/facilities, and therefore are in early stages of working to pull together collaborations and the various aspects needed for a H_2ub. A few have developed partnerships or consortiums across industry and government with publicly announced intentions to investigate launching H_2ubs. These include:

- Regina-Moose Jaw region, SK, where the Government of Saskatchewan's Ministry of Energy and Resources, Whitecap Resources, and Federated Cooperatives Limited are jointly supporting a foundation report study to be developed by the Transition Accelerator and the Saskatchewan Research Council [10].
- Metro Vancouver, BC, where the BC Centre for Innovation and Clean Energy is partnering with industry and government to establish the "BC Hydrogen Changemakers Consortium" with the intent of launching a H_2ub in Metro Vancouver [11]. Members to date include Ballard, FortisBC, HTEC, Powertech Labs, TransLink, Hydra Energy, Parkland Refining, the Climate Action Secretariat, Ministry of Environment and climate Change Strategy, Fort Capital, Capilano Maritime Design, and the Innovative Clean Energy Fund.

3. The Sarnia-Lambton Economic Region

3.1 Overview

Sarnia-Lambton is home to nearly 130,000 people across several municipalities and First Nations communities. Located in Southwestern Ontario at the southern end of Lake Huron and the St. Clair River, Sarnia-Lambton is connected to the US via the Bluewater Bridge with about 200,000 monthly crossings. The region has a highly integrated labour market and broad mix of industries including petrochemical and refining, hybrid chemistry, value-added agriculture, advanced manufacturing, power generation, information technology and tourism. The largest concentration of residents and the largest share of employment in health care, arts and entertainment, and personal services is in the City of Sarnia, which is also home to Canada's second largest petrochemical and refining cluster. The Sarnia-Lambton region is known for its strong petrochemical and biochemical/hybrid chemistry clusters, which contribute significantly to the regional, provincial, and national economies and require substantial energy inputs.

The region is strategically located on the Canada/US border in the Great Lakes Basin, providing access to major rail, road, pipeline, air, and water corridors. There is direct access to the Ontario 400-series highway system via Highway 402 and to the U.S Interstates I-69 and I-94 via the Blue Water Bridge. The region is also located within a one-day drive to 65% of the Ontario, Quebec, and US markets. Regional rail infrastructure is supported by mainline Class I railroad service from Canadian National (CN) and CSX Transportation, and the St. Clair Tunnel allows for movement to the US Midwest, Gulf Coast, and eastern US ports. The area has over 1,500 kilometres of pipeline service that supplies gas and liquid utilities and hydrocarbon raw materials. The Detroit Metropolitan Wayne County Airport, London International Airport, Sarnia Chris Hadfield Airport, and Flint Bishop International Airport are all within 130 km of Sarnia-Lambton. The St. Lawrence Seaway system provides ships with access to the Atlantic Ocean. There is also access to several 700+ foot liquid loading docks and the Sarnia Harbour that can accommodate the movements of over-sized process modules.

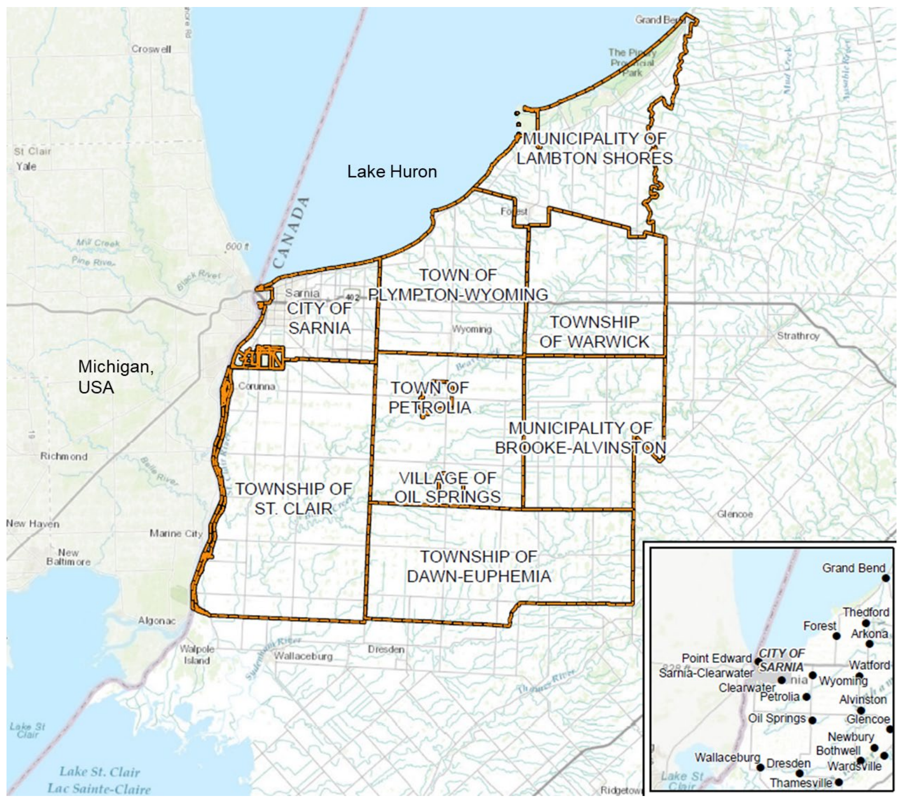

Figure 4 Sarnia-Lambton Borders

3.2 Workforce & Education

Sarnia-Lambton offers a dependable and abundant supply of skilled labour, with a total labour force of 64,500 and over 21,700 people employed in manufacturing and service industries in Lambton County. The total labour force within a 100km radius is almost 250,000 [12]. The region's skill pool is exceptionally strong in the areas of science, engineering, process operations, instrumentation, metal fabrication and managerial ability. The existing workforce and training programs are a strategic advantage for Sarnia-Lambton for the envisioned low-carbon H_2ub as the availability of qualified talent for the hydrogen economy is an important factor in attracting investment.

Lambton College is the primary post-secondary institution in the region, offering over 70 technology and trades programs and apprenticeships that support the diverse local industries. Lambton College's Sarnia campus has approximately 5,000 students, with about 350 students each year supporting paid research projects, often in partnership with industry. Industry research projects have been supported by Lambton College for over 15 years across 6 core areas of research: energy, materials, manufacturing, IT, water, and biotechnology. Applied research at Lambton College has built a strong network of research partners and high-quality labs, facilities and an exceptional research team that suit a multitude of research projects. Through collaboration, the applied research department works with partners to connect them with the appropriate resources, expertise, and funding opportunities. Previously around the 2008 hydrogen hype, the College hosted an electrolysis and fuel cell research facility in collaboration with industry. The Sustainable House research program integrated renewable energy and hydrogen for a home energy system. Although the project ended, Lambton College's Hydrogen Lab continues to provide a test-bed for hydrogen technologies and the College has significant capability, experience, and expertise to support future research, development and demonstration (RD&D) in partnership with industry.

Lambton College is already considering options for introducing hydrogen-related curriculum in preparation for the low-carbon hydrogen industry. Current programs in gas handling, chemical engineering, fire response, safety, and risk could be supplemented with hydrogen courses or "micro-credentials". Current workers could undergo re-training or upskilling for hydrogen handling and safety.

3.3 Industries

The existing industrial activity and infrastructure in Sarnia-Lambton provide a substantial strategic advantage for the region to become one of Canada's largest low-carbon H_2ubs. Detailed profiles of the key industries in the region are provided on the Sarnia-Lambton Economic Partnership's website resources page[1]. Overviews of key industries and discussion in relation to the potential low-carbon H_2ub are provided in this section.

Petrochemical & Refining

Sarnia-Lambton is known as the birthplace of Canada's petrochemical industry, as it is the site of North America's first commercial oil well in 1857. The Sarnia-Lambton Petrochemical and Refining Complex is now Canada's second largest cluster of petrochemical and refining sectors, and the largest industrial sector locally. The complex includes three large refineries and over 35 chemical facilities with processes across the full hydrocarbon value chain. It is home to many companies including Air Products, CF Industries, ARLANXEO, Cabot, Imperial Oil, NOVA Chemicals, Plains Midstream, Pembina, Praxair, Royal Dutch Shell, INEOS Styrolution, Suncor, Diamond Petrochemicals, and more. Air Products' Corunna Hydrogen Facility supplies 80 million standard cubic ft (scf) per day of (currently) grey hydrogen to the local refineries as well as Air Products' hydrogen liquefaction plan through a dedicated hydrogen pipeline network. Several facilities produce and utilize their own hydrogen, such as CF Industries which produces ammonia products for the agricultural sector and exporting and NOVA Chemicals. Proximity to the Dawn Hub and Enbridge Gas infrastructure network provides companies within the Sarnia-Lambton Petrochemical Refining Complex with some of the lowest cost natural gas feedstocks in North America. The infrastructure, experience, and expertise of the petrochemical and refining sector provides significant strength for the low-carbon H_2ub.

Deep-well storage salt caverns are used in the region to store gaseous and liquid hydrocarbon products, forming a critical component of the existing petrochemical and refining industry. 73 active storage caverns operate in the Sarnia-Lambton region, utilizing 124 wells with a total storage capacity of 3.5 million cubic metres. These provide an opportunity for cost-effective development of large-scale underground hydrogen storage as demand and applications with seasonality grow; the cost of converting an existing cavern for hydrogen storage is significantly lower than the cost to develop new caverns.

[1] **https://www.sarnialambton.on.ca/resources**

Hybrid Chemistry

The Hybrid Chemistry industrial cluster in Sarnia-Lambton represents a diverse array of over 35 inter-related chemical facilities with processes ranging across the hybrid chemistry value chain, integrating traditional petrochemical processes with the industrial bio-economy for the production of high-value products. Hybrid chemistry represents the industry producing clean, green, and sustainable bio-fuels, bio-materials, and bio-chemicals from biomass or waste feedstocks. Major facilities in the cluster include Suncor's ethanol facility that produces over 400 million litres of fuel-grade ethanol annually using corn grown in Ontario, Woodland Biofuels' waste biomass-to-cellulosic ethanol demonstration plant in the Western Sarnia-Lambton Research Park, LCY Biosciences' 30,000 tonne per year bio-succinic acid, nutraceuticals, and other biochemicals plant, and Origin Materials' facilities for production of bio-PET, terephthalic acid, and other advanced products. Biomass feedstocks come from Lambton's and Southwestern Ontario's large agriculture sector. The region is a one-day drive to 1.6 billion bushels of corn and 621 million bushels of soybeans, with Southwestern Ontario representing 3.8 million acres of farmland.

The hybrid chemistry cluster presents opportunities for both the production and utilization of low-carbon hydrogen. Hydrogen can be produced from biomass materials ("dark green" hydrogen) and can be used as a feedstock for the production of methanol, ethanol, and other products.

Advanced Manufacturing

The advanced manufacturing sector in Sarnia-Lambton has grown to become a significant cluster of innovative and high-tech manufacturing industries and contributor to the local economy. A diverse range of industry-leading products are produced in the region, including industrial equipment, automotive and transportation parts, military and police supplies, plastics and rubbers, air filters, construction and custom metal products, and glass and ceramics.

Sarnia-Lambton is home to one of Canada's largest clusters of companies in the plastic and rubber manufacturing sector, supported by the Sarnia-Lambton Petrochemical & Refining Complex and Hybrid Chemistry Cluster. It is home to many well-known multinational companies, including ARLANXEO, Cabot Canada, Dow Canada, NOVA Chemicals, INEOS Styrolution, Imperial Oil, Origin Materials, and ReVital Polymers, who produce the raw materials the industry relies on. The advanced manufacturing of finished products is highlighted by companies like sofSURFACES and Waterville TG Inc who distribute plastic and rubber products worldwide. Hydrogen can be utilized for decarbonized process heating in advanced manufacturing, and pyrolytic hydrogen production could produce low-emission solid carbon products for feedstock to the industry. Carbon black is already produced at large scale in the region by Cabot Canada, which also produces hydrogen as a by-product that is utilized for fuel at Cabot's facility. Given these significant existing advantages, the Sarnia-Lambton region would be well-positioned to host commercial demonstrations and scale-up efforts of pyrolytic or turquoise hydrogen, where both the hydrogen and solid carbon products already have large markets.

Value-Added Agriculture

Agri-business is the second largest industry in Sarnia-Lambton following chemical manufacturing. With over 2,000 farms across 500,000 acres of cultivated land, Lambton County is a leading Ontario producer of soybeans, winter wheat, corn, sugar beets, cattle, pigs, and poultry, as well as related agricultural by-products and wastes. The local industry consists of some of Ontario's largest volumes of crops and animal production and has grown to include thriving value-added agriculture businesses such as soy and oilseed crushing, sweeteners, cellulosic sugar producers, beverages and food processing. There is interest from stakeholders in the region in exploring biomass-to-hydrogen applications to support the low-carbon H_2ub.

Electricity Generation

In addition to the industries above, it is worth noting the electricity generation capacity in the region. Sarnia-Lambton is home to 4 large natural gas power generation facilities, 3 solar power facilities, and 6 wind farms:

- TransAlta Sarnia Cogeneration facility: located in the Bluewater Energy Park generating power and steam from natural gas with rated capacity of 506 MW.
- St. Clair Energy Centre: Gas power generation facility with 577 MW rated capacity.

- Greenfield Electron Power Plant: Gas power generation facility with 300 MW rated capacity.
- Greenfield Energy Centre: Combined cycle gas turbine power plant with rated capacity of 1,005 MW, making it the second largest natural gas power plant in Canada.
- Enbridge's First Solar facility in Sarnia with 80 MW capacity.
- NextEra's Moore Solar Energy Centre in St. Clair with 20 MW capacity.
- NextEra's Sombra Solar Energy Centre in St. Clair with 20 MW capacity.
- Sky Generation's Ravenswood Wind Farm in Lambton Shores with 9 MW capacity.
- Northland Power's Grand Bend Wind Farm in Lambton Shores with 100 MW capacity.
- NextEra & Suncor's Cedar Point II Wind Farm in Lambton County with 100 MW capacity.
- NextEra's Jericho Wind Energy Centre in Lambton County with 150 MW capacity.
- Zephyr Wind Farm in Brooke-Alvinston with 10 MW capacity.
- Churchill Wind Farm with 70 MW capacity.

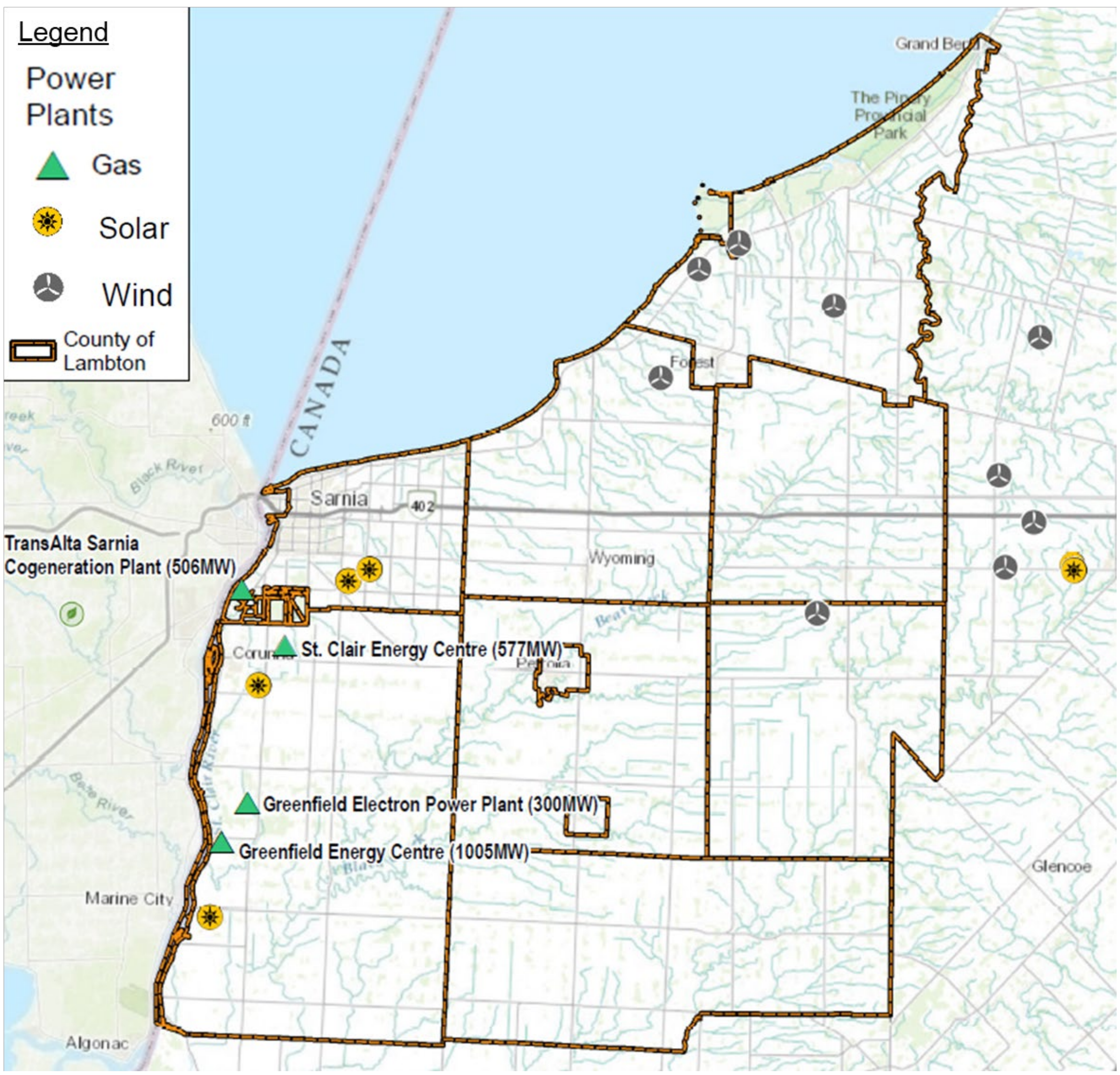

Figure 5 ***Power Generation Facilities in Sarnia-Lambton***

3.4 Advantages of Existing Industrial Clusters & Parks

The existing industrial parks, clusters, and support services in Sarnia-Lambton present many opportunities and advantages for new investments along the hydrogen value chain. Sarnia-Lambton has the industrial support businesses and skilled workforce to support industry from site selection to operation. This is accommodated by the 1,200 industrial related companies in the sectors of manufacturing, construction, utilities and communications, engineering, industrial services and warehousing and transportation. The Sarnia-Lambton Industrial Alliance is a coalition of 35 companies specializing in design, engineering, environmental permitting, manufacturing of machinery and equipment modules, construction, installation, and plant commissioning[2].

There are several competitive advantages with water and wastewater for local industry as well. The St. Clair River provides an abundant supply of cooling and process water for industrial users in the petrochemical and refining complex, and several brownfield and greenfield industrial siting opportunities exist on land that are serviced by existing cooling and process water infrastructure and capacity. For many of these industrial lands a permit to take water (PTTW) is already in place. Many current chemical facilities operate their own wastewater treatment facilities. To accommodate new developments, there are opportunities for process wastewater to be treated at the existing ARLANXEO biological wastewater treatment plant. The facility is a Ministry of the Environment, Conservation and Parks approved industrial wastewater facility, with a capacity of 24,000 m3/day.

The Bluewater Energy Park and Bio-Industrial Park Sarnia are fully serviced industrial parks ideal for pilot, demonstration, and full-scale facilities, with direct connections to extensive shared infrastructure:

- The Bio-Industrial Park in Sarnia is a fully serviced, 408-acre site located along the St. Clair River that is owned and operated by ARLANXEO Canada Inc. It offers 42-acres of brownfield development opportunity and potential savings of up to 20% on capital costs through shared infrastructure. The park offers many amenities and services including:
  - Medical services, security services, human resources and accounting, maintenance scheduling, employee lockers, and shunt services
  - CSX rail service with interswitch to CN Rail
  - 219 metre marine terminal for ocean and lake freighter service
  - Steam and electrical power from neighbouring TransAlta Sarnia Regional Cogeneration Plant and behind-the-fence energy pricing. Steam at 450, 165, 15 psi and 13.8 KV electrical distribution are available.
  - Direct access to US Midwest and seaport of Halifax, Nova Scotia, via the St. Clair River runnel
  - Process or cooling water distribution services and wastewater treatment capacity of 24,000 m3 per day
  - Access to petrochemical pipeline chemicals and industrial gases, with the Air Products hydrogen pipeline bisecting the industrial park
  - Access to high-pressure natural gas supply from the nearby Enbridge Gas pipeline and storage network for energy or feedstock
- The Bluewater Energy Park is a fully serviced, 268-acre site located along the St. Clair River in Sarnia that is owned and operated by TransAlta. It offers up to 170-acres of brownfield land for new manufacturing development. The park is ideal for heavy energy users and offers many amenities and services including:
  - Steam and electrical power from TransAlta's Sarnia Regional Cogeneration Plant and potential for behind-the-fence energy pricing. Steam at 470,185, 45 psi and 15kV electrical distribution are available.

[2] **http://sarnialambtonindustrialalliance.com/**

- CSX rail service with interswitch to CN Rail
- Marine terminal for ocean and lake freighter service
- 110,000 sq.ft. of office and laboratory space at the Bluewater River Centre.
- Service water, fire water and city water lines
- Hydrogen, nitrogen and compressed air at the fence line
- Access to high-pressure natural gas supply from the nearby Enbridge Gas pipeline and storage network for energy or feedstock
- 760-foot liquid transfer river docking facility

Other industrial parks with beneficial access to power, natural gas, water, sewer, and transportation, although not zones for heavy industrial use, include the Chippewas of Sarnia Industrial Park in Sarnia, the Forest Industrial Park in Lambton Shores, the St. Clair Industrial Park in St. Clair Township, and the Warwick Industrial Park in Warwick Township. The Hwy 40 Industrial Park is zoned for heavy industrial use and would be appropriate for hydrogen facilities development.

3.5 Connecting & Enabling Infrastructure & Resources

The Sarnia-Lambton region has rich existing enabling infrastructure connecting the existing industries and export markets, which can provide strategic advantages for the potential low-carbon H_2ub. These include:

- Transportation: roads, railways, liquid loading docks at the Bluewater Energy Park and Bio-Industrial Park Sarnia, the Sarnia Harbour, airports
- Gas distribution and transmission: Air Products' hydrogen pipeline, Enbridge Dawn Hub and associated pipelines for natural gas distribution and transmission
- Gas and liquids storage: reservoirs for CCS and salt caverns that can be utilized for large-scale hydrogen storage

3.5.1 Transportation

Roads

Sarnia-Lambton is served by an excellent network of highways that connect the region to the Great Lakes industrial corridor and the US. Highway 402 passes through Sarnia connecting industries in the region to London, Ontario, and Highway 401 to the East, and the Blue Water Bridge border crossing that connects Sarnia to Michigan and the US interstates I-69 and I-94 over the St. Clair River. The Blue Water Bridge is Canada's second-busiest crossing for commercial traffic, seeing over 1.5 million trucks and $42 billion in road trade annually, and permits transport of hazardous materials.

The region is located within a one-day drive to 65% of the US market, and major Ontario and Quebec markets. Through the United States-Mexico-Canada Agreement (USMCA), companies in Sarnia-Lambton have direct highway access to a market of nearly 400 million people. Liquid hydrogen is currently being trucked and transported long distances from Air Products' Sarnia Liquefaction Plant across Canada and into the US.

Railways

The Sarnia-Lambton region is serviced by CN and the CSX Transportation operating mainlines for Class I railroad service. This includes the CN St. Clair Rail Tunnel connecting Sarnia-Lambton to Michigan which carries more freight than any other US-Canada border rail crossing, allowing for wide distribution into US markets.

CN operates five rail yards in the region including the Sarnia Rail Yard which is the largest flat switching yard in the Great Lakes District, with about 30 trains per day. On a normal working day, it has a capacity of 1,100 cars but a true capacity of 1,600 cars. The yard has a 1,100-car customer industrial spur capacity, with normal car totals on hand of approximately 1,000. Major customers include NOVA Chemicals, Pembina, CF Industries, Cabot Canada, ARLANXEO Canada Inc, and Suncor Energy Products.

CSX provides service to companies including Imperial Oil, Shell, Air Liquide, and ARLANXEO Canada Inc, while offering shunting services through spur lines located throughout the industrial complex.

Rail cars can also be transported from Sarnia to the Port of Montreal (east) or Port of Vancouver (west) for transloading to ocean freighter. Companies such as VIP Rail, Procor Limited, ARI Fleet Services of Canada Inc, and OWS Rail Car provide railcar switching, transloading, storage, and cleaning services.

The Sarnia Harbour and Liquid Loading Docks at Bluewater Energy Park and Bio-Industrial Park Sarnia

The Sarnia Harbour is located at the centre of the Great Lakes, on the St. Lawrence Seaway System. At the south end of Lake Huron on the eastern shore of the St. Clair River, it is one of the busiest inland waterways in the world with access to the Atlantic Ocean. While the Sarnia Harbour itself is not suitable for import/export of hydrogen, ammonia, or related products, the Bluewater Energy Park and Bio-Industrial Park Sarnia both have liquid loading docks suitable for import/export along the St. Clair river. The berthage of vessels at the docks and wharfs in the harbour is already a principal business for the region, with many vessels being operated by a number of different large Canadian shipping companies as well as international vessels. The oversized load corridor accommodates movement of massive vessels that could potentially be required for a future hydrogen facility. Through the Harbour, industries in Sarnia-Lambton have direct access to several 700+ foot liquid loading docks for incoming or outgoing shipments. Navigating through the St. Lawrence Seaway System, ships can travel from Sarnia-Lambton to the Atlantic Ocean in March through December.

Airports

Sarnia-Lambton is serviced by several regional and international airports that are capable of delivering goods and people anywhere in the world. The Sarnia Chris Hadfield Airport is the regional airport owned and operated by the City of Sarnia located on Highway 402. It is also a designated port of entry with custom services. International airports nearby, in addition to Toronto Pearson, include the Detroit Metropolitan Wayne County Airport, the London International Airport, and the Flint Bishop International Airport.

Figure 6 ***Transportation Infrastructure in Sarnia-Lambton: Roads, Rails, Airports, and Port Facilities***

3.5.2 Gas Distribution & Transmission

Natural Gas

Enbridge Gas Inc. owns and operates the natural gas storage, transmission, and distribution systems in Sarnia-Lambton. With a working capacity of 274 billion cubic feet, the Enbridge Dawn Hub is one of the largest natural gas trading hubs in North America, providing direct access to major supply basins and providing abundant and affordable natural gas supplies. The Dawn Hub currently provides the majority of Ontario with its natural gas needs, with over 100 companies actively trading at the Dawn Hub every day. The Hub interconnects directly with 8 major North American supply pipelines, is connected to most of North America's supply basins, and has takeaway capacity of approximately 7.9 peta-Joules (PJ) that is expected to grow to meet market demand [13]. Enbridge additionally operates the local natural gas distribution networks in Sarnia Lambton, with a lower-pressure network connecting residential, commercial, and light industrial customers and a higher-pressure network supplying the large industrial facilities. Sarnia-Lambton has rich access to low-cost and abundant natural gas resources.

Figure 7 Enbridge's Dawn Hub in Southern Ontario [13]

Air Products' Dedicated Hydrogen Pipeline

Given that the Sarnia-Lambton already operates as a large-scale H_2ub, although not low-carbon, a major infrastructure advantage of the region is the existing pure hydrogen pipeline network and expertise. Air Products' pipeline network connects all the refineries in the Sarnia-Lambton region, supporting Suncor, Shell, and Imperial Oil, connects to Air Products' Sarnia Liquefaction Plant, and is approximately 30 km in total length with the potential to increase capacity. The Air Products Sarnia Liquefaction Facility produces liquid hydrogen that meets fuel cell specifications and can help enable the transition of the transportation sector to a zero-emission fuel. There is potential that this pipeline could enable wider connections between low-carbon hydrogen producers and users, increasing the network and distribution area. Additionally, Air Products has the knowledge and skills to develop future pipelines or convert existing pipelines to hydrogen service.

Other Pipelines

In addition to the dedicated hydrogen pipeline network and the gas distribution network connecting to the Dawn Hub, there are several pipelines that have been built, used, and some decommissioned over time. Plains Midstream owns a dedicated underground hydrogen pipeline that ceased operations years ago but is not decommissioned. It runs through Enbridge's tank farm and all the way south to Air Products on highway 40. The figure below shows the extent of known pipelines in the region. These are pulled from GHD's Geo-Intelligence database.

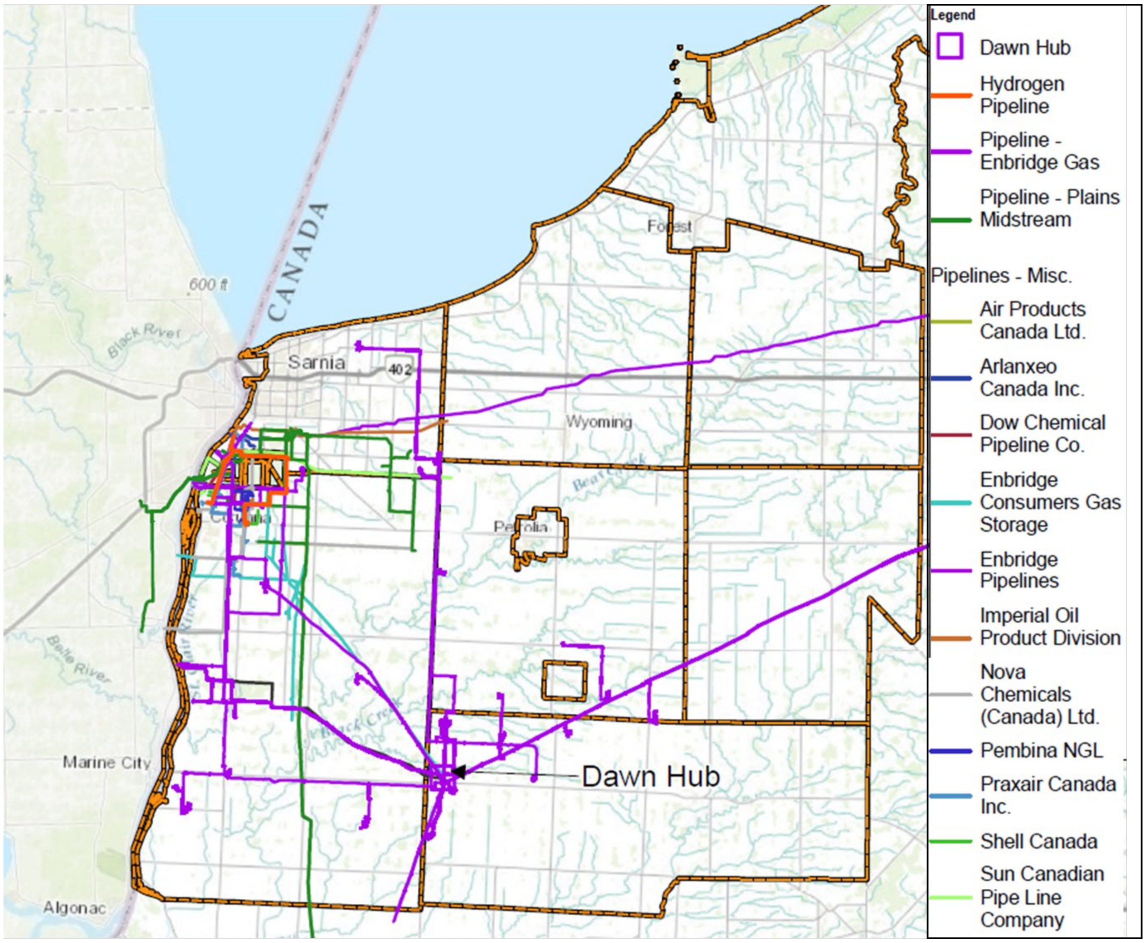

Figure 8 Known Existing Pipelines in Sarnia-Lambton

3.5.3 Gas & Liquids Storage

Salt Caverns

As hydrogen production and demand increases over time, geologic storage, such as salt caverns, will be required to achieve the storage volumes necessary to decouple generation from demand and provide seasonal energy storage. Large merchant hydrogen producers will need high-capacity bulk volume storage for day-to-day operations and shipping/marketing, and above-ground bulk hydrogen storage can be prohibitively expensive even for large scale manufacturing daily needs. Storage caverns will be needed to support large low carbon producers on an operational basis as well as for future seasonal storage as the hydrogen hub grows.

Salt caverns are ideal for underground hydrogen storage due to low permeability of gas, favourable rheological properties for self-sealing of fractures and capacity to redistribution stress peaks, and lack of biological activity. The Sarnia-Lambton region is well positioned in this regard being located on Canada's largest salt deposit, with various local chemical and energy industries currently utilizing large volumes of storage, mostly for gaseous and liquid hydrocarbons storage, through 73 active salt caverns. The caverns, which have an extensive history of compliance with environmental regulations, have total working capacity of approximately 3.5 million cubic meters. Economies of scale for geologic hydrogen storage can result in the costs for underground storage being roughly 3-5 times less than above ground storage options. The proximity of the Ontario salt deposits to nuclear and hydropower energy systems makes the use of salt caverns for underground hydrogen storage an attractive possibility that could enable large-scale energy storage to support grid resiliency [14].

Carbon Sequestration

The Sarnia-Lambton region is home to 17 of the top 50 emitters in Ontario, with an estimated 10 million tonnes of CO_2 emitted per year [15]. While CCS has not been historically permissible in Ontario by regulatory restrictions, the region has geologic potential for some CCS and the Ontario provincial government has recently announced proposed legislative changes that will potentially remove one of the major hurdles to CCS in Ontario[3]. Previous assessments of CCS in Ontario suggest that permanent geological sequestration would be best accomplished through storage in deep saline aquifers in the Mount Simon formation, which encompasses Sarnia-Lambton and other regions of Southern Ontario [16], [17]. A 2004 evaluation of this formation estimated that approximately 725 million tonnes of CO_2 could be stored in the Mount Simon aquifer [17]. There is higher capacity for CCS in Michigan that could potentially be accessible through CO_2 pipeline transport, which would require significant capital investment to develop the pipeline and connections. CanmetENERGY-Ottawa is investigating this option of a CO2 pipeline in Southern Ontario connecting to CCS reservoirs in Michigan, Ontario, and further in Eastern Canada for enabling H_2ubs and large-scale decarbonization.

There are prevalent challenges with underground CO_2 sequestration in Southern Ontario. Beyond the regulatory and permitting barriers that make the path forward with CCS uncertain today, technical challenges include limited pore space, limited depth, and fractures and abandoned wells that could result in gas losses. Additionally, some of the eligible pore space in Southern Ontario is located under the Great Lakes, which will complicate access and approvals for sequestration projects and require jurisdictional coordination. CanmetENERGY-Ottawa is actively engaging in extensive research and development for CCS in Ontario, investigating the storage capacity and permanence and developing solutions to increase capacity and de-risk CCS [18].

In addition to permanent CCS in depleted reservoirs or aquifers, there is the potential for enhanced oil recovery (EOR) to support early CCS projects in Southern Ontario. Lagasco's oil fields are well suited for EOR for example, and Lagasco reports that the pinnacle reefs in Lambton County are at depths that could allow for pressures that meet the supercritical pressure requirement for CCS. Under the Federal Clean Fuel Standard, EOR is recognized as an avenue for low-carbon fuel production with a dedicated quantification methodology describing the requirements that must be met.

3.6 Municipalities & First Nations

Aamjiwnaang First Nation

Aamjiwnaang First Nation (formerly known as Chippewas of Sarnia) is a First Nations community located on the shores of the St. Clair River, three miles south of the southern tip of Lake Huron in the city limits of Sarnia. The community is comprised of about 2,500 peoples, 900 of whom live on the Aamjiwnaang First Nation Reserve. The community's traditional language is Ojibwa. The community is home to a business park, Chippewa Industrial Development Corporation, Maawn Doosh Guimig Community and Youth Centre, and is dedicated to saving culture and the environment for future generations.

Bkejwanong First Nation

Bkejwanong First Nation is located in the south of Lambton County on five islands: St. Anne's, Squirrel, Bassett, Seaway, and Walpole Island. The community has a population of approximately 5,000 with 2,300 on Reserve. Farming is a major activity in the community, with 12,000 acres of agricultural area on three of the islands. The community is home to an arena and community centre, children's centre, library, youth centre, and the Walpole-Algonac Ferry crossing.

Kettle & Stony Point First Nation

Kettle and Stony Point First Nation is located 35 kilometres north of Sarnia, along the shores of Lake Huron between Forest and Grand Bend. Kettle Point, also known as Wiiwkwedong, is part of the Anishinabek Nation. Stony Point is also known as Aazhoodena. There are 1,000 band members who live on the Reserve and 900 who live off-reserve.

[3] Consultation and comment on these proposed changes is open until January 9, 2023. See: **https://ero.ontario.ca/index.php/notice/019-6296**

The community is home to sandy beaches, the Indian Hills Golf Course, and Points Plaza. The community's vision statement focusses on wellness, development and financial stability and sustainability, accountability and transparency, and wealth creation.

City of Sarnia

The City of Sarnia is located at the southern tip of Lake Huron and has the largest concentration of Lambton County residents with a population of 71,600 people. The population declined by 1.1% between 2011 and 2016. The population is aging; the average age in Sarnia in 2016, 43.9, was much greater than both the province and country. Lambton County as a whole also faces challenges with a lack of inward migration. In the most recent five-year period, the number of immigrants to the County decreased by 15% compared to the previous five-year period and by 39% compared to the previous decade.

Sarnia has strong roots in the chemical and petrochemical industries, and a large share of metal product manufacturers. Sarnia is home to the Western Sarnia-Lambton Research Park, ranked as one of the top 10 university business incubators, Bioindustrial Innovation Canada, and two city-owned business parks (not for industrial use), Sarnia 402 Business Park, and Sarnia Research and Business Park. It is also home to a strong and growing entrepreneurial sector, with many small business start-ups. As of December 2016, Sarnia had over 5,000 business establishments, over 2,000 of which had employees. Compared to the province, Sarnia has fewer establishments, but the average establishment size is larger. Sarnia has 84 engineering services firms, 60% more and greater than double than the provincial average. There is also a high concentration of health care, arts and entertainment, and personal services in Sarnia.

Village of Point Edward

The Village of Point Edward is located along the shores of the St. Clair River and has a population of 2,000 people. Point Edward has a population density per square kilometre of 620 and is the most population dense municipality in Lambton County. The population has remained the same between 2011 and 2016 but is aging. The average age is 47.7, putting Point Edward in the top quartile of municipalities in the province. As of December 2016, Point Edward had 294 business establishments, 129 of which had employees. The economy is primarily service based, with 87% of establishments in the services sectors. There are 8 manufacturing firms, 17 retail firms, 14 transportation and warehousing firms, and 12 firms in NAICS 5416 – Management, scientific and technical consulting services. Point Edward has a large health care cluster for its size, with three times as many as the provincial average. Point Edward also has a large tourism sector with 16 arts, entertainment, recreation, accommodation, and food services establishments.

Township of St. Clair

The Township of St. Clair is located south of Sarnia, along the eastern shores of the St. Clair River and is comprised of the communities of Brigden, Corunna, Courtright, Mooretown, Port Lambton, Sombra, and Wilksport. It has a population of 15,000 people. St. Clair has a thriving industrial park and several industrial clusters. St. Clair has an above average income of $120,894 with 21.7% of the labour force being in trades, transport, and equipment sectors. As of December 2016, St. Clair had 1,259 business establishments, 303 of which had employees. The community's economy has a high concentration of agricultural firms. The largest sub-sector is soybean farming. The community also has a higher concentration of heavy and engineering construction firms, and relatively large manufacturing sector. Relative to its size, the community has a small services sector and a small accommodation and food services sector compared to the province. The St. Clair River is one of the busiest inland waterways and a 20-minute drive to the US border, providing the area with a competitive advantage for businesses.

Township of Plympton-Wyoming

The Township of Plympton-Wyoming has a population of 7,800 and the second highest growth rate among Lambton County municipalities. As of December 2016, Plympton-Wyoming had 910 business establishments, of which 211 had employees. The community has a high concentration of establishments in the agricultural sector. Crop or animal farming makes up 34% of all establishments, with soybean farming being the largest sub-sector. Compared to the province, the community has twice as many establishments in NAICS 237 - Heavy and civil engineering construction and 20% more in NAICS 238 - Specialty trade contractors. The community's professional services, health care, and tourism sectors are smaller than the provincial average.

Township of Enniskillen

The Township of Enniskillen has a population of 3,200. The population decreased by 4.6% between 2011 and 2016, and by 10% over the last decade. Enniskillen is approximately 340 square kilometres of productive farmland. Agriculture, including soybean, wheat, and corn crops, as well as livestock operations and a new greenhouse industry, is the township's largest industry. Manufacturing is also an important sector, with five large manufacturers in the township. There are a greater number of manufacturing firms and a larger average firm size compared to the province. The township also has a high concentration of health care firms and a broad mix of financial and professional services firms relative to its size. Additionally, North America's first commercial oil field was established in Enniskillen in 1858 and the township is currently home to 16 oil and gas firms.

Town of Petrolia

The Town of Petrolia has a population of 5,700. It is the fastest growing municipality in Lambton County, having increased by 3.9% between 2011 and 2016. Petrolia has a population density per square kilometre of 453 and is the second most population dense municipality in Lambton County after the Village of Point Edward. Petrolia has a large retail trade sector with 48 firms and 242 workers. The town has 14 manufacturing firms, 13 restaurants, six firms in NAICS 54121 - Accounting, tax preparation, bookkeeping and payroll services, three firms in NAICS 54151, and four firms in freight trucking, and health care is the town's second largest sector.

Village of Oil Springs

The Village of Oil Springs is located in central Lambton and has a population of less than 650 people. The largest economic sector in Oil Springs is agriculture. The village has 99 farms with soybean farming being the largest sub-sector. The community is home to North America's first oil well and the name was changed from "Black Creek" to Oil Springs after the discovery of oil in 1858. There are 10 oil and gas-related firms in the community currently. Adjusted for population size, there are twice as many construction firms in Oil Springs as in the province. There are three small manufacturing firms, and small trade and finance and professional services sectors in the community.

Municipality of Lambton Shores

The Municipality of Lambton Shores has a population of 10,681, and includes the communities of Grand Bend, Ipperwash and Port Franks as well as Forest, Thedford and Arkona. As of December 2016, Lambton Shores had 1,605 businesses. There is a heavy concentration of businesses in the agricultural sector, with soybean farming being the largest sub-sector, followed by wheat, corn, potto, beef and dairy, and hog/pig farming. Manufacturing is another important sector in the Municipality's economy. There is also a heavy concentration of firms in electric power generation, retail, trucking, and accounting and general consulting services. Lambton Shores is home to the famous Grand Bend and Pinery Provincial Park, making it a major tourist destination. It is also home to the Forest Industrial Park.

Township of Warwick

The Township of Warwick has a population of 3,800 and is home to the communities of Warwick and Watford. It is bisected by Highway 402 and CN Rail lines, and is located close to London, Sarnia, and the US border. As of December 2016, Warwick had 539 businesses. A large portion of the labour force is employed in agriculture, the circular economy, value added manufacturing, and the construction industry. Almost half of all the community's businesses are involved in crop or animal farming, with soybean farming being the largest subsector. There is a heavy concentration of construction firms, but few professional services, health care, and tourism-related firms. Local Council has adopted a Community and Economic Development strategy that emphasizes welcoming potential new businesses and new residents. Warwick offers the lowest property taxes in Lambton County and no development charges to support its businesses and residents. The Township also offers entrepreneurs the Business Boost Bundle Contest, which provides free office space for one year, a $5,000 grant toward lease hold improvements, and a $2,500 grant toward new office signage. Warwick is also home to the fully serviced Warwick Industrial Park.

Municipality of Brooke-Alvinston

The Municipality of Brooke-Alvinston is located in eastern Lambton County and has a population of 3,000. As of December 2016, there were 362 businesses in Brooke-Alvinston. The economy is agriculturally based. There are 182 farms in crop and animal production, and the largest sub-sector is soybean farming. Adjusted for population size, there are a similar number of construction firms compared to the national economy. There are also an above average number of firms in truck transportation and wholesale trade. There are very few firms in manufacturing, retail, professional services, and tourism. Brooke-Alvinston is also home to Ontario’s only meadery.

Township of Dawn-Euphemia

The Township of Dawn-Euphemia is located in the southeast of Lambton Country and includes the communities of Florence, Shetland, Oakdale, Edys Mills, Rutherford, Cairo, and Bentpath. Dawn-Euphemia is primarily an agriculture-based economy, with 48 farms in crop and animal production. Soybean farming is the largest sub-sector. Some of the community’s agriculture-based businesses include Cargill, Southwest Ag and Haggerty Creek. There are three construction firms, one chemical manufacturing firm, four truck transportation firms, and very few services in the community. Dawn-Euphemia is home to the largest integrated natural gas storage facility in Canada and one of the largest in North America, Enbridge’s Dawn Hub. The Hub provides shippers with direct access to North America's major supply basins and is an important link in the movement of natural gas to markets in central Canada and the northeast US.

4. Key Stakeholders & Perspectives for the Current & Future Hydrogen Hub

In 2021, SLEP formed the Sarnia-Lambton H_2ub Working Group, which has been meeting regularly to discuss and define the opportunities for the regional low-carbon H_2ub. Throughout the development of this Strategic Plan, GHD met twice with the Working Group for group workshops and activities to evaluate and gather perspectives on the regional H_2ub opportunities and challenges, as well as several individual targeted meetings with stakeholders to discuss opportunities and barriers in depth. The information presented in this section was gathered through these engagements.

4.1 Stakeholders and Potential Roles

The founding framework of Ontario's H_2ub is comprised of the many stakeholders that produce, use, transport, store, enable, and support the existing and future low-carbon hydrogen economy. The table below provides an introduction to the key stakeholders and their potential roles in the Low-Carbon H_2ub.

Please note – several stakeholders have multiple potential roles along the hydrogen value chain, for example Enbridge is currently producing, using, and distributing low-carbon hydrogen in Ontario. In the table below, stakeholders are described once in the first category in which they appear and named in the black left column for every potential role along the value chain (production, end-use, storage and distribution) they may play in Ontario's H_2ub in Sarnia-Lambton.

Table 1 Key Stakeholders & Roles in the Low-Carbon H2ub

Potential Low-Carbon Hydrogen Producers • Air Liquide • Air Products • Atura Power, OPG • Cabot Canada • CF Industries • Enbridge • Linde Canada • NOVA Chemicals • Woodland Biofuels	• Air Liquide: Air Liquide has two facilities in the Sarnia-Lambton region distributing welding supplies and gases (industrial, lab, and bulk), with on-site nitrogen production, for advanced manufacturing and other industries. • Air Products: Currently the largest hydrogen provider in the region, Air Products owns the Corunna Hydrogen Plant which produces and provides approximately 70,000 tonnes of hydrogen per year to local refineries and to Air Products' Sarnia Liquefaction Plant through Air Products' dedicated 30-km hydrogen pipeline network in the region. Air Products exports liquefied hydrogen via truck from the region to merchant markets across North America. Air Products is therefore a potential producer, user, and distributor of hydrogen for the H_2ub. • Atura Power / Ontario Power Generation (OPG): Atura Power, a subsidiary of OPG, is investigating the opportunity to produce large-scale low-carbon hydrogen at the decommissioned OPG coal-fired power generation site in Lambton County. Atura has been investing in hydrogen production via electrolysis in Ontario, including the Niagara Hydrogen Project, where hydrogen will be produced from hydropower for blending into Atura's gas turbine facilities or future hydrogen transportation off-take, and the Halton Hills Energy Centre, where low-carbon hydrogen is planned to be blended into the gas generation facility to reduce carbon intensity of produced electricity. • Cabot Canada: Cabot, the largest manufacturer of carbon black in the world, operates three manufacturing units in Sarnia that produce carbon black for use in production of tires, rubbers, plastics, inks, toners, etc. The facility plays a part in the circular economy by using waste products as feedstocks. A by-product of the carbon black production process is hydrogen, which Cabot currently uses internally for fuel. • CF Industries: CF Industries is a leading global producer of ammonia and hydrogen products. In Sarnia-Lambton, CF owns and operates the Courtright Nitrogen Complex, with capacity to produce a million tonnes of nitrogen products per year, including ammonia and urea for the agricultural sector. CF Industries is interested in producing low-carbon hydrogen and ammonia to replace existing grey hydrogen and ammonia production and is exploring opportunities for exporting low-carbon

	ammonia. CF Industries is also an active participant in the Southeast Alberta Hydrogen Hub (Medicine Hat). • Enbridge: Enbridge Gas is the owner and operator of the natural gas transmission, storage, and distribution systems in most of Ontario, including Sarnia-Lambton. This system uses large natural gas fired compressors to move the natural gas to markets. As a large emitter, Enbridge Gas is looking to reduce and manage GHG emissions, targeting a 35% reduction by 2030 and net zero emissions by 2050. Gas-fired compressor plants can utilize low-carbon hydrogen via blending to reduce the carbon intensity of operations. Enbridge's Dawn Hub is the largest integrated underground natural gas storage facility in Canada and one of the largest in North America. The Hub provides shippers with direct access to North America's major supply basins and is an important link in the movement of natural gas to markets in central Canada and the northeast US. The Dawn Hub has interconnections to eight major supply pipelines and has multiple supply routes from western Canada, mid-continent, the Rockies, and the Gulf of Mexico. Enbridge operates the local gas distribution networks in the Sarnia-Lambton area, consisting of a low-pressure system connecting residential, commercial, and light-industrial customers as well as a higher-pressure system supplying the major industrial facilities – as hydrogen blending advances, Enbridge may become a major hydrogen user in Sarnia-Lambton for blending into the local gas network. Furthermore, Enbridge is currently producing hydrogen in Markham, Ontario, with a 2.5 MW utility-scale hydrogen production and blending facility in partnership with Cummins, and expects to pursue further large-scale hydrogen production and blending projects elsewhere in Ontario, including Sarnia-Lambton. • Linde Canada: In the Sarnia-Lambton area, Linde owns and operates two nitrogen producing facilities along with an oxygen and nitrogen producing plant. They also operate two pipeline distribution networks, supplying the major chemical plants in the region's Petrochemical and Refining Complex. • NOVA Chemicals: NOVA is a leading producer of plastics and chemicals. NOVA has a significant presence in Sarnia-Lambton, with 3 manufacturing facilities and 1 corporate office collectively employing over 1,000 employees. NOVA's Corunna Site produces 1.8 billion pounds of ethylene and 700 million pounds of co-products per year, feeding NOVA's Moore and St. Clair River Sites that convert ethylene into polyethylene resins. NOVA exports products via rail and truck. For production, NOVA produces and uses its own hydrogen, making them a potential producer and user of low-carbon hydrogen. • Woodlands Biofuels: Woodlands Biofuels makes carbon negative, renewable fuel at the lowest cost on the planet. Their technology uses waste biomass to generate low cost, carbon negative hydrogen, RNG methanol or ethanol. They currently have an integrated end-to-end biomass-to-biofuel demonstration plant in Sarnia producing ethanol, and are exploring opportunities for production of other low-carbon fuels such as hydrogen.
Potential Low-Carbon Hydrogen End-Users • Air Products • ARLANXEO • CF Industries • Diamond Petrochemicals • Eastern Power • Enbridge • Imperial Oil • Lagasco Inc. • NOVA Chemicals • Plains Midstream • Shell Canada • Suncor Energy	• ARLANXEO: One of the world's largest producers of synthetic rubber, ARLANXEO operates a major synthetic rubber production facility producing butyl rubber in Sarnia. The site also manufactures olefines. ARLANXEO also operates the Bio-industrial Park, suppling utilities and services to small to mid-sized green technology companies. • Diamond Petrochemicals Canada (DPCC): DPCC operates a manufacturing facility located in Sarnia. The 1,3-Butadiene extraction unit uses 1,3-butadiene as a raw material to create synthetic rubber which is used in tires and other industrial and consumer goods. As a large industrial operation, DPCC can potentially utilize low-carbon hydrogen to offset natural gas consumption for process heating. • Eastern Power: Eastern Power is a power producer in Ontario currently considering building a natural gas power plant in Sarnia-Lambton that will be hydrogen-ready with the capacity to blend low-carbon hydrogen up to 65% by volume. • Imperial Oil: Located in Sarnia, Imperial operates both a refinery and a chemical plant in the Sarnia area. The refinery processes up to 121,000 barrels of crude oil to produce a range of petroleum products including gasoline and home heating fuel. The chemical plant uses a variety of feedstocks to produce a range of products such as solvents, aromatics and polyethylene. Imperial utilizes hydrogen for refining

• TransAlta	feedstock and natural gas for process heating, which can be decarbonized with low-carbon hydrogen. • Lagasco Inc.: Lagasco is a family-owned oil and gas company in Ontario that owns a large share of Ontario's oil and gas production, including off-shore and on-shore operations. Lagasco's assets may be suitable for CCS, although evaluation is required. Lagasco may investigate utilizing low-carbon hydrogen for decarbonization. • Plains Midstream Canada: Plains Midstream Canada (Plains) is one of the largest salt cavern storage operators in Canada and, together with Plains LPG Services, L.P., manages 72 caverns and 118 wells in North America, some of which are located within the Sarnia-Lambton region. These assets and Plains' existing infrastructure could allow for potential future hydrogen storage and service. Plains also owns and operates a large natural gas liquids fractionation plant in Sarnia, with a capacity of 90,000 barrels a day, where ethane, propane, isobutane, normal butane and condensate are processed and then delivered to customers by pipeline, road and rail. As a large industrial operation, Plains can utilize low-carbon hydrogen to decarbonize process heating for fractionation and has signed an MOU with a third-party producer to explore converting existing storage assets to hydrogen storage. • Shell Canada: Shell operates the Sarnia Manufacturing Centre (SMC) located between Froomfield and Corunna. The refinery can process up to 85,000 barrels of crude oil a day, converting and refining it to gasoline, diesel and jet fuel, using hydrogen supplied by Air Products. Located at the SMC, an isopropyl alcohol plant provides key materials for chemical and propane producers in the Sarnia area and to support Shell's own chemical plant adjacent to the refinery. Shell is additionally involved in hydrogen fueling station ownership and operation elsewhere in North America. • Suncor: Suncor operates a refinery as well as a biomass-to-ethanol plant in Sarnia-Lambton. Due to numerous major upgrades at their Sarnia Refinery, Suncor can produce gasoline, diesel, kerosene, diesel fuels, benzene, toluene, and xylene with a capacity of 80,000 barrels a day. Suncor consumes hydrogen for refinery operations, currently provided by Air Products. In 2006, Suncor opened their St. Clair Ethanol plant, the largest ethanol plant in Canada, which produces 200 million litres of ethanol from 40 million bushels of corn each year, supplying Suncor's Petro-Canada gas stations across Canada. Suncor's existing expertise is distributing oil and gas products may see them transition to distribution low-carbon hydrogen in a future hydrogen economy as well. • TransAlta: TransAlta's Sarnia Regional Cogeneration Plan was commissioned in 2003. The plant provides power using gas turbines, condensing steam turbines and back pressure turbines, with a generating capacity of 506 MW. The Plant has long term contracts to supply electricity to ARLANXEO, NOVA Chemicals and Suncor Energy. The plant is located at Bluewater Energy Park, for which TransAlta is the owner. Gas generation power plants can utilize low-carbon hydrogen via blending to reduce the carbon intensity of produced power.
Hydrogen Storage & Distribution • Air Products • CSX Rail • CN Rail • Enbridge • Pembina Pipeline Corp. • Plains Midstream Canada • Suncor Energy • VIP Rail	• CSX Rail: CSX Transportation operates mainlines Class I railroad service, providing essential services to Imperial Oil, Shell, Air liquid, and ARLANXEO Canada Inc. which also offers shunting services. • CN Rail: CN maintains five rail yards in the Sarnia-Lambton region and has a daily working capacity of approximately 1,100 cars. Additionally, the CN Rail Tunnel carriers more freight than any other US-Canada border rail crossing and allows for distribution to US. markets. • Pembina Pipeline Corporation: Pembina provides extensive NGLs storage and terminaling capacity at their Corunna Facility utilizing salt caverns. Commissioned in 1970, the facility services 6 million barrels of underground cavern storage, rail and truck terminaling and connectivity to major pipelines and other facilities. Pembina could provide large-scale underground hydrogen storage in support of the future low-carbon H2ub. • VIP Rail: VIP Rail is the leading rail logistics company servicing the local chemical valley in Sarnia-Lambton, and is an active member of H_2ub Working Group.
Workforce Training & Education	• Lambton College: Lambton College is a community college operating for over 55 years, originally providing the workforce for the large petrochemical industry and

	growing overtime to serve the large and varied industries in the region. Lambton College's main campus is located in Sarnia with approximately 5,000 students, with satellite campuses in Toronto and Mississauga. The College continues to work collaboratively with the industries in the region to demonstrate innovation, strengthen the local community, and help meet industry demand for skilled workers for the future. Lambton College has been supporting industry research projects for over 15 years. Staff researchers lead projects in collaboration with industry, and students are employed for periods to support the projects and gain experience. There are 6 core areas of research at Lambton – energy, materials, manufacturing, IT, water, and biotechnology. Around 2008, Lambton College build an electrolysis and fuel cell facility for research and demonstration of low-carbon hydrogen opportunities, and maintains a Hydrogen Lab to this day. Lambton College is currently investigating options for a hydrogen-related program to prepare and train workforce for emerging low-carbon hydrogen applications. There are many existing programs at the College that would be well-suited for introducing hydrogen curriculum and microcredentials, including gas handling, fire school, safety training, engineering technicians, and more.
Industrial Support Services	Sarnia-Lambton has extensive industrial support services providers and organizations to help industry in the region, accommodated by approximately 1,200 industrial-related companies that provide services across manufacturing, construction, engineering, utilities and communications, industrial services, warehousing, and transportation. • Sarnia-Lambton Industrial Alliance (SLIA): SLIA is a coalition of over 35 companies that specialize in all aspects of metal fabrication, engineering, environmental, and support services. SLIA companies have the skills and trained workforce to take projects from concept through design, engineering, environmental permitting, manufacturing of machinery and equipment, construction, installation, and commissioning. Sarnia-Lambton Environmental Association (SLEA): SLEA has over 20 member companies that provide excellence in environmental monitoring and management, promoting a healthy environment consistent with sustainable development for the local industries. • Bluewater Association for Safety, Environment, and Sustainability (BASES): Launched in 2021 through collaboration between the Community Awareness Emergency Response (CAER), the Industrial Educational Cooperative (IEC) and the SLEA, BASES provides interactive information exchanged in Sarnia-Lambton related to the protection of workers, the public and the environment.

Non-Governmental Organizations (NGOs)	• Bio-industrial Innovation Canada (BIC): Founded in 2008, BIC provides strategic investment, advice and services to aid in the development of clean, green and sustainable technologies. BIC may be engaged to help secure and identify the required funding for the H_2ub and transition towards a sustainable, net-zero carbon economy.
	• Bowman Centre for Sustainable Energy: An established sustainable energy think-tank comprised of associates who volunteer and contribute their ideas, expertise, and experience towards driving Canada's energy strategy to generate wealth and jobs which are both economically and environmentally sustainable. The Bowman Centre publishes thought leadership, advocates for sustainable solutions, and sponsors a series of research projects through connections with universities, much of which has focused on low-carbon hydrogen and opportunities for the Sarnia-Lambton H_2ub.
	• CanmetENERGY: CanmetENERGY is a Canadian leader in clean energy research and development, with over 100 years of research and collaboration with industry, academic, and other governments. CanmetENERGY-Ottawa is currently conducting significant research and development in Ontario focused on advancing low-carbon hydrogen production and end-use technologies, CCS, and underground hydrogen storage, including ongoing work in the following areas:
	  o SMR/ATR with CCS
	  o Biomass-to-hydrogen
	  o Pyrolytic hydrogen production
	  o Blending hydrogen into residential natural gas equipment
	  o Hydrogen codes & standards for residential and commercial hydrogen-natural gas blends

	○ Direct reduced iron (DRI) ○ Hydrogen utilization for catalytic hydrotreating of bio-intermediates to produce transportation fuels such as sustainable aviation fuel (SAF) ○ Techno-economic analysis and life-cycle assessments ○ National CCUS Assessment Framework ○ Open-source tools and data to support subsurface projects (CCS and underground hydrogen storage) • Canadian Hydrogen and Fuel Cell Association (CHFCA): A national non-profit association comprised of industry, academia, research agencies and other stakeholders with a focus on advancing clean hydrogen use and fuel cell technology. • H2GO Canada: A non-profit corporation with a focus on accelerating the development of the hydrogen market as an alternative fuel and energy source. The leadership team coordinates the roll-out of hydrogen systems to support society's needs for low-carbon alternatives. H2GO is currently leading an evaluation of hydrogen and CCUS hubs in Ontario, funded by NRCan and supported by CanmetENERGY-Ottawa. • Hydrogen Business Council of Canada (HBC): HBC is comprised of like-minded members dedicated to bringing knowledge and opportunities to those who can apply and recognize the benefits of hydrogen technology. HBC has frequent stakeholder engagements focused on evaluating and developing the economic case for hydrogen in Ontario, and is currently progressing an evaluation of hydrogen for transportation along Highway 401. • Sarnia-Lambton Economic Partnership (SLEP): At the heart of this Strategic Plan and the H_2ub Working Group, SLEP has been facilitating cross-industry connections and planning for the H_2ub. SLEP works to enable companies and people to access the resources they need to successfully do business in Sarnia-Lambton. SLEP is well-positioned to play an integrating and connecting role in the H2ub.
Governmental Organizations	• Ministry of Economic Development: The Ministry of Economic Development, Job Creation and Trade offers a wide variety of support as it relates to providing a strong, innovate economy that creates jobs, opportunities, and prosperity for all Ontarians. • Ministry of Energy Ontario: the Ministry oversees regulatory framework and develops policy for electricity pricing in Ontario in addition to supporting energy efficiency, conservation, promoting clean technology and innovation within the electricity sector. • Natural Resources Canada (NRCan): NRCan develops policies and programs to enhance the contribution of natural resources to the economy to improve quality of life for Canadians as well as conducts innovative science to generate ideas and transfer technologies. NRCan will be engaged throughout the development of the H_2ub as needed. • Min. of Natural Resources and Forestry (MNRF): The MNRF oversees and administers the Oil, Gas and Salt Resources Act. This Act requires amending to better support and enable CCS in Ontario, so that it can support blue hydrogen production and industrial decarbonization. • Ministry of Environment, Climate and Parks (MECP): The MECP oversees and administers the Emission Performance Standards Act and regulations. Changes are needed here to fully recognize the role of CCS in reducing reportable emissions for large or covered emitters, but also smaller emitters and implementing an offset protocol. This change is needed to support blue hydrogen production and utilization. • Canada's Department of Finance: The Finance department has announced their intentions to support the low carbon energy transition through the Canada Growth Fund. Low-carbon hydrogen production will require off-take agreements and Canada backed contracts for carbon pricing differences will support and enable needed investment decisions. • Canada's Ministry of the Environment: Oversees the Ontario Greenhouse Gas Pollution Pricing Act (GGPPA). The GGPPA stipulates that natural gas producers must charge the carbon charge on all gas distributed, with a special exemption for RNG but none yet for hydrogen. Currently, if low-carbon hydrogen is blended into the natural gas system, Enbridge still has to charge 100% of the carbon charge despite the emissions reductions. Recent amendments to the regulations for GGPPA have

	been proposed that would extend the carbon charge to low carbon hydrogen, but it has not yet been implemented.

4.2 Stakeholder Perspectives – Hydrogen Hub Workshop

A virtual workshop was hosted for key stakeholders and participants in the Sarnia-Lambton H_2ub on July 6, 2022. The workshop was hosted via MS Teams and used the virtual whiteboard app “Mural” to record input and insight from attendees. A survey was additionally distributed to give opportunity for comments on the Workshop activities for those who could not attend. The ideas generated and perspectives of the stakeholders in attendance are captured in this section.

4.2.1 Defining a Low-Carbon Hydrogen Hub

The H_2ub Working Group stakeholders were asked to comment on the following questions when thinking about a H_2ub:

- What is a H_2ub, how would you describe it?
- What are some of the key elements and attributes of an effective H_2ub?
- Who / what / how should the H_2ub be managed?

Stakeholder comments on these questions are captured in the following table.

Table 2 Stakeholder Perspectives – Defining a Hydrogen Hub

What is a hydrogen hub?	• Development centre for commercial scale low-carbon hydrogen manufacture, storage, use and distribution • A likeminded industry group working towards integrating hydrogen as a low-carbon energy source • A central location where clusters of working professionals and industry leaders assemble to conduct research, produce, distribute, and store low carbon hydrogen, establish market requirements, answer inquires as they relate to the hydrogen space and drive policies for proliferation of hydrogen across Canada and the world • A H_2ub allows for a shift away from fossil fuels and grey hydrogen, producing blue and green hydrogen (or other forms of low-carbon hydrogen) • Sarnia-Lambton already is a hydrogen hub, the challenge is to make a *low-carbon* hydrogen hub
What are the key elements and attributes of an effective hydrogen hub?	• Ability to utilize existing infrastructure to aid in the development of hydrogen production, delivery and future off-take • Multiple suppliers, multiple consumers, shared/central storage and transport • All colours of low-carbon hydrogen production with agreed-upon certification program for tracking carbon intensity with transactions • Hubs need many buyers and sellers, an active open and liquid market, infrastructure to link supply and demand with balancing services; producers of low-carbon hydrogen and investors should be drawn to the hub • Established geographical resources such as water, availability for hydrogen storage, access to various markets and experienced personnel in the hydrogen field • Public-private partnerships • Self-sustaining; getting to economies of scale for competitive costs • Knowledge sharing to support projects locally • Value chain, governance, and a dedicated workforce and research and development

	• Similar to the Enbridge Dawn Hub, the H_2ub will require an active market with both buyers and sellers, linking supply and demand • Establishing a long-term vision and goal to work towards, while simultaneously reaching short term goals • A good understanding of requirements as it relates to exports vs. domestic use • Facilitating the integration of a suite of projects to make them collectively more economically viable • Investment and trade • Opportunities for synergies/collaborations between industry, with assistance from government and community organizations • Governments must have a role; private companies are looking for opportunities to invest in hydrogen, governmental support in the form of policies and incentives are need to attract those opportunities to Ontario
How should a hydrogen hub be managed?	• Management could be in the form of a partnership between private and public groups • No direct management of the hub, rather more of a collaboration between private and public entities that have a vested interest in the local hydrogen economy • SLEP is in an ideal position to manage the hydrogen hub as they have representation from the industry, government, Lambton College, and community • There should be a central "one-stop shop" group to contact or join for any hydrogen-related questions/services/potential projects, providing a jump-off point for hydrogen market enquiries and to connect potential producers, users, and supporting services • Minimize third-party involvement to allow for a streamlined agenda/goal • Government involvement to integrate industry involvement and opportunity, support lobbying for enabling policies and incentives • Limited direct management with a focus on collaboration between entities that have a vested interest, investments and knowledge of the hydrogen market

4.2.2 Challenges and Opportunities for the Low-Carbon Hydrogen Hub

For each of the categories in the table below, stakeholders were asked to comment on the challenges / disadvantages and opportunities / advantages specifically for the development of the low-carbon H_2ub in Sarnia-Lambton.

Table 3 Stakeholder Perspectives – Challenges & Opportunities for the Low-Carbon Hydrogen Hub in Sarnia-Lambton

	Challenges / Disadvantages	Opportunities / Advantages
Access to Low-Carbon Electricity	• High electricity costs, particularly considering the Global Adjustment (GA) fee; trying to optimize GA with time-of-use methods are not practical • A desire for 100% green hydrogen would require behind-the-meter renewables generation; grid electricity is low-carbon but not "green" • May be difficult to offer low-carbon hydrogen at a low cost given current electricity pricing; cost-competitiveness is a challenge at present • Lack of incentives / policies supporting utility-scale renewable power	• Established solar and wind potential in the Saria-Lambton area; wind and solar are more mature with low costs • Temporary subsidies/incentives can eliminate cost issues such as the global adjustment fee • Ontario electric grid is relatively low-carbon currently, with large nuclear and hydropower resources. Lower-carbon than several other provinces.

	Challenges / Disadvantages	Opportunities / Advantages
	• With Pickering Nuclear Generation Station planned to be decommissioned, carbon intensity of grid electricity is expected to increase in the near term	
Access to Water for Hydrogen Production	• Public perception regarding freshwater consumption for industrial use • Ensuring water reserves are free of contamination for hydrogen production • Will require consultation with surrounding First Nations/jurisdictions	• Potential to form a partnerships with local First Nations for lasting community benefits through the H_2ub • Use of existing water treatment facilities to aid in water quality • Water resources and accessibility are generally good in the region
Enabling Infrastructure & Resources	• Determining what infrastructure is required, how much investment is required and when is a challenge	• Various infrastructure required is already in place, such as salt caverns, dedicated hydrogen pipelines, NG distribution networks, and access to rail and roadways • Established transport corridors • Extensive pipeline network, some of which is decommissioned, which could be upgraded for hydrogen service at reduced cost compared to new builds • Potential opportunities to work with the current industry and provincial and federal government to determine infrastructure needs • Strong existing RD&D expertise and capacity to evaluate and expand shared infrastructure
Carbon Capture, Utilization, & Sequestration (CCUS)	• Currently, CCS is not permissible in Ontario, and there are no existing CO2 pipelines to export CO2 to other CCS markets. Significant policy/regulatory change is needed, and a CO2 pipeline network would require large investment. The Ontario government has recently signalled their intention to facilitate CCS in Ontario, but details are few and a framework for commercial scale CCS is still being developed. • Legality surrounding total pore space available relative to other jurisdictions; some of the eligible pore space in Ontario is under the Great Lakes which will complicate access and approvals given jurisdictional coordination • OGSRA (Oil, Gas and Salt Resources Act) and Mining Act only refers to hydrocarbon pipelines and	• Sarnia-Lambton region has the required geological features for CCUS (salt caverns and oil and gas reservoirs) as well as for CCS through EOR in oil fields • Opportunity to survey the land to determine available pore space, collaborate with research institutions • Ontario government appears supportive of making needed amendments to legislation and linked regulations to enable CCS • Lagasco has oil and gas pools onshore and offshore that may be suitable for CCS/EOR • Enbridge has significant experience storing natural gas temporarily underground and that expertise can be leveraged for hydrogen storage and carbon sequestration.

	Challenges / Disadvantages	Opportunities / Advantages
	will require amending to support and enable the hydrogen hub • Will require public support • Additional guidance is required from the government and regulating bodies	
Legislation, Policy, Regulations	• The feasibility of green hydrogen will largely depend on the carbon tax program and incentives for emissions reductions • Natural gas blending policies are not well established • Lack of policies/regulation surrounding the hydrogen market • CCS impermissible in Ontario (currently in process of being potentially changed, framework is needed and no changes in place yet) • Legislation tends to change with changes in government, this creates risk for companies, especially for large investments in decarbonization. Certainty is needed	• Implementing legislation, policies and regulations will support all future low-carbon facilities; with change, the opportunities are great for a low-carbon hydrogen economy in Ontario • Need to tell the story of the H2ub to build momentum
Planning & Approvals	• Current system for permitting, approvals, etc. can be complicated and time consuming • Required knowledge may not be available through City staff • Pore space and saline aquifers jurisdiction is under both Michigan and Ontario, which could result in legal battles over who owns the pore space (Government of Ontario owns the production rights to the subsurface formations under Lake Erie, however) • Determining the electrical capacity required and competing with broad electrification	• Opportunities to involve and educate city builders • Ability to leverage environmental benefits associated with hydrogen infrastructure approvals
Commercial & Economic	• Costs related to project execution including hub, hydrogen network, new infrastructure, storage, etc. • Economic incentive for energy consumers to switch to low-carbon hydrogen is lacking; policy and incentives needed to encourage decarbonization • Competing with jurisdictions who have already started to implement low carbon hydrogen options	• Provincial mandates to blend natural gas and hydrogen by the Ontario Energy Board would create an advantage, as would investment tax credits similar to those seen in the US • Creates additional opportunities for new commercial users and producers • More participants in a hub brings overall costs down and minimizes duplication of infrastructure and research investments

	Challenges / Disadvantages	Opportunities / Advantages
		• Provides further opportunities to develop new hydrogen application technologies • Canada's proposed Carbon Contracts for Differences may help reduce risk of carbon policy change
Community & Social	• Lack of public knowledge surrounding the hydrogen market • Potential for efforts to be viewed as 'Green Washing' without the actual hydrogen hub in place; an example is CCS using enhanced oil recovery (EOR), which may not be viewed well by the public	• Existing hydrogen networks within the Sarnia-Lambton region will help address safety fears surrounding hydrogen implementation • Need a coordinated narrative around the H2ub • Community benefits with the H2ub can be great; expanded industry, workforce training, future-ready job opportunities
Workforce Training, Education, Health & Safety	• Perceived demand vs. actual demand for trained / education workforce; people want to know they will have career opportunities when investing in their education • Timing of development of any new programs is important, demand for workforce needs to be there • Public education	• Sarnia-Lambton already works with hydrogen, existing expertise, training, and health and safety protocols in place in current industries • Lambton College has the availability to establish short- and long-term training programs, has relevant existing programs that supply the existing diverse and advanced industries and strong relationships with First Nation communities • Opportunities to work with the current industries within the Lambton-Sarnia region to understand the current and future demand of hydrogen
Land for New Projects	• Need more heavy industry land that is serviced and preferably owned by the municipality available within a proximity to the existing industrial area • Limited space in short distance to the existing industry • Chosen land needs to account for future expansion as well as community expansion	• Potential land purchase and subsequent hub development will aid in community growth • Streamlines permitting within Sarnia-Lambton and provincial environmental assessments • Opportunities to repurpose brownfields which are currently idle within the industrial region

5. Low-Carbon Hydrogen Demand Forecasting

At the cornerstone of any H_2ub is the demand for low-carbon hydrogen. The Transition Accelerator emphasizes the need for establishing and growing demand as a fundamental component of any emerging H_2ub. The Sarnia-Lambton region has an advantageous starting point in this regard, as there already exists a strong value chain for hydrogen in the region with hydrogen used as a feedstock by the petrochemical & refining, hybrid chemistry, and value-added agriculture sectors. Decarbonizing this hydrogen for feedstock and growing the low-carbon hydrogen demand for emerging applications are core opportunities of the Sarnia-Lambton H_2ub.

5.1 Low-Carbon Hydrogen Demand Categories

To understand the potential opportunities for the Sarnia-Lambton Low-Carbon H_2ub, GHD has developed forecasts for several demand categories of significance for the region, grounded in data collected on current energy and hydrogen demand. The forecasts have been refined and vetted through engagement with stakeholders, including one-on-one discussions with several potential low-carbon hydrogen producers and users, a data collection form sent to large industrial companies, as well as group workshops to gather feedback from the H_2ub Working Group.

The key categories for low-carbon hydrogen demand within the Sarnia-Lambton region include decarbonizing the current hydrogen feedstock demand, fuel switching natural gas consumption for power generation and industrial heating to hydrogen, hydrogen for fuelling stations within the region, and hydrogen for blending into the natural gas networks.

Decarbonizing Existing Hydrogen Demand	Supplying Emerging Hydrogen Demand
• Hydrogen feedstock for petrochemical and refining facilities • Hydrogen feedstock for hybrid chemistry sector, including fertilizer and chemical products	• Industrial fuel switching natural gas to hydrogen for process heating • Industrial fuel switching natural gas to hydrogen for power generation • Hydrogen for transportation • Blending hydrogen into the local low-pressure natural gas network feeding residential, commercial, and light industry

The opportunities and challenges are discussed for each demand category in the following sub-sections.

5.1.1 Decarbonizing the Existing Hydrogen Feedstock Demand

Decarbonizing the existing hydrogen demand in the region for petrochemical and hybrid chemistry may initially seem to be low-hanging fruit. However, there are a number of challenges that need to be overcome for decarbonizing this hydrogen demand to become reality.

It is estimated that over 150,000 tonnes of hydrogen per year is produced and used in Sarnia-Lambton for oil and gas refining and ammonia manufacturing. Several companies produce and use their own hydrogen on site from low-cost natural gas, while others are supplied by Air Products, Air Liquide, or Linde. Air Products' hydrogen production plant is connected to all the refineries in the region by a pipeline network, providing a large-scale, low-cost grey hydrogen supply. The industries that utilize this hydrogen operate in highly competitive global markets with feedstock cost comprising an important factor in market competitiveness. The increased cost of low-carbon hydrogen is therefore a key barrier for decarbonizing this demand. Policies and incentives are needed to encourage uptake and enable competitiveness while decarbonizing, and scale for low-carbon hydrogen production needs to be achieved to drive down costs. Tracking carbon intensity of hydrogen feedstock and being able to monetize the resulting emissions reductions for the industrial users will help to enable the business case for low-carbon hydrogen utilization.

5.1.2 Industrial Fuel Switching Natural Gas Combustion to Hydrogen

Converting natural gas combustion systems to hydrogen is a feasible avenue for lowering the emissions intensity of industry. Hydrogen can be blended into existing and vintage industrial natural gas boilers, turbines, and engines at low levels as a near-term transitionary step to support value chain growth (<5% hydrogen by volume), with higher blending levels achievable for newer equipment or with equipment retrofits or replacements [19]. The effects of added hydrogen in methane on combustion properties are well understood, and many original equipment manufacturers (OEM's) already have considerable experience with other hydrogen rich fuels, such as manufactured town gas. Several OEM's, including Siemens, GE, Wartsila, Jenbacher, and others, have commercially available industrial equipment that can handle 30-60%+ hydrogen blending and are developing equipment that can handle up to 100% hydrogen. This provides a technically feasible immediate avenue for decarbonizing industrial process heating, steam generation, and natural gas power generation.

The demand forecasts for this category are divided into 2 applications: (1) blending hydrogen into industrial natural gas process heating systems for emissions-intensive industries, and (2) blending hydrogen into the natural gas power plants in the region, which provide peak power supply in Ontario and comprise the highest-carbon component of the current electric grid.

There are several demonstrations and projects under development globally for hydrogen blending into natural gas power plants. Eastern Power is proposing a 600 MW hydrogen-ready natural gas power plant in Sarnia-Lambton, capable of blending up to 65% low-carbon hydrogen with natural gas to meet growing peak demand in Ontario. Atura Power is assessing the potential to produce and use low-carbon hydrogen via blending in the Halton Hills Energy Centre near Toronto. Capital Power's Genesee Generating Station near Edmonton, Alberta, is undergoing upgrades to become hydrogen-ready. Several more projects have been announced in the US, including at the Intermountain Power Plant in Utah where Mitsubishi is providing a turbine capable of blending up to 30% hydrogen, Florida Power & Light's 1.75 GW Okeechobee combined cycle gas generation plant which will be supplied by an on-site renewable power to electrolysis system, and Ohio's Long Ridge Energy Terminal which is converting a 485 MW combined cycle gas power plant to handle up to 100% low-carbon hydrogen. Given the industry activity in this area and technical feasibility, hydrogen blending into the natural gas power plants in Sarnia-Lambton is potentially a key immediate opportunity that can drive demand for the local H_2ub while lowering the carbon intensity of Ontario's electric grid. However, this opportunity requires buy-in from power plant owners and operators – existing power plants should consult with the OEMs for their equipment and may need to replace older equipment with units capable of handling hydrogen blending.

Blending hydrogen into natural gas process heating systems across emissions-intensive industries also presents a significant opportunity, although with less action to date for demonstrations and projects. Technical challenges are more significant for these systems due to increased facility complexities with multiple equipment and processes compared to natural gas power plants. The lower energy content of hydrogen needs to be accounted for, and systems may need to be redesigned or upgraded for higher gas flow rates as hydrogen blending increases. In general, 5% hydrogen blending in existing and vintage industrial equipment is expected to be acceptable without changes to control systems or restaging [19]. This is due to allowable fuel purity ranges that the equipment was originally tested and designed for. Depending on the equipment, blends from 5% to 30% by volume may be manageable with minor modifications or upgrades to manage increased nitrous oxide (NO_x) emissions, increased flow rate to deliver the same energy, and flashback/knock and related durability issues. For higher blending levels up to 100% hydrogen, industrial facilities will need to replace existing equipment with new equipment specially designed for hydrogen service.

There are 2 key challenges for industrial fuel switching of natural gas to hydrogen. First and foremost is cost. Natural gas is relatively inexpensive and abundant, and there are currently insufficient incentives for replacing this natural gas with high-cost low-carbon hydrogen. Reducing costs for low-carbon hydrogen production and an increasing price on carbon emissions are needed to enable the commercial case for converting industrial natural gas systems to hydrogen. Second is technical. Hydrogen is a vastly different molecule than natural gas, and while there have been extensive laboratory and small-scale, controlled investigations of hydrogen blending into industrial equipment, there is generally a lack of demonstrations and available data that operators need to de-risk hydrogen blending. Hydrogen burns fast, has a wide flammable region, high diffusivity, and lower ignition energy when compared to natural gas [20], [21]. Technical challenges include managing changes to combustion and flame properties (burner re-design, control systems), managing NO_x emissions, changes to operations and maintenance procedures, equipment integrity, integrity management of piping and controls systems, among others. Collaboration for RD&D and knowledge sharing is critical to advance the case for industrial fuel switching natural gas to hydrogen.

5.1.3 Hydrogen for Transportation

A fast-emerging use-case for hydrogen is for FCEVs or dual-fuel vehicles, particularly for fleets and the heavy-duty trucking sector where hydrogen may provide certain advantages over battery electric vehicles (BEVs). In Ontario, the main corridor envisioned for early hydrogen adoption is along the Hwy 401 connecting Montreal to Detroit and several major municipalities and industrial areas in between. The Hydrogen Business Council of Canada (HBC) is undertaking a collaborative study with industry to evaluate the 401 hydrogen corridor opportunities. Sarnia-Lambton could potentially be producing and supply hydrogen for fueling stations along the 401, although the industry would need to act fast to scale-up low-carbon hydrogen production to capture this market. Given the uncertainty and competition for this potential export market, the opportunity for supplying hydrogen fueling stations outside of Sarnia-Lambton is not built into the local hydrogen demand forecasts presented in this report and should be re-evaluated as the market develops.

Within Sarnia-Lambton, the main opportunities for hydrogen transportation are along the 402 and upgrading local industrial or public fleets to FCEVs. The 402 sees approximately 200,000 crossings per month connecting the industrial powerhouse of Sarnia with export markets across Eastern Canada and the US. It is feasible that a handful of hydrogen fuelling stations could be located in Sarnia-Lambton to meet future transportation demand. However, the demand on the 402 through the region is unlikely to be high enough to justify more than 1 station by 2030, considering potential plans to develop hydrogen fuelling stations in London and Windsor along the 401 which are each only about 100 km from Sarnia. Local fleets provide perhaps an even smaller opportunity, as the population of Sarnia-Lambton is not nearly as significant as seen in other hydrogen hubs. The City of Sarnia operates 29 busses, for which upgrading to hydrogen would be expensive and difficult to justify in the short-term.

A potential opportunity may be with converting mobile farm equipment such as tractors and combines from fossil fuel to hydrogen. Given the heavy-duty nature of these equipment, hydrogen may offer a more advantaged decarbonization pathway for mobile agricultural equipment than electrification. While there has been limited development on this front to date, recent news that Kubota, a Japanese agricultural technology manufacturer, is planning a hydrogen-ready tractor to be on the market in 2025 shows promise[4]. Sarnia-Lambton would also be well-positioned to support RD&D for hydrogen applications in agriculture and food processing industries.

While GHD has included a small number of hydrogen fueling stations in Sarnia-Lambton in the hydrogen demand forecasts, the potential demand is nearly negligible when compared to hydrogen feedstock decarbonization and industrial fuel switching of natural gas to hydrogen.

5.1.4 Blending Hydrogen into the Natural Gas Networks

Hydrogen blending is not a distant dream; it is here and happening now. It presents a key element of the near-term energy transition: low-carbon hydrogen blended with natural gas can deliver cleaner energy for industry, commercial, and household uses as an intermediary step on the path to net zero. There are currently more than 100 projects throughout the world trialling, demonstrating and starting implementation of hydrogen injection and blending components, including research, laboratory experimentation, pilot, demonstration-scale and commercial projects [19]. There has been a significant acceleration in the number of projects in recent years, largely focused in Europe, followed by North America and Australia. In Canada, Enbridge is actively blending hydrogen into the Markham area

[4] https://www.farms.com/ag-industry-news/kubota-developing-hydrogen-tractors-by-2025-940.aspx

feeding approximately 3,600 homes and businesses with 2% hydrogen by volume, ATCO is planning to blend 5% hydrogen by volume into the Fort Saskatchewan network in Alberta feeding approximately 5,000 customers starting in 2022, and FortisBC is evaluating several potential blending pilot projects in BC.

At the present time, there is generally the understanding from research and demonstrations globally that existing low-pressure natural gas distribution networks can handle up to about 20% hydrogen by volume without requiring significant upgrades or equipment replacements. The HyDeploy project in the UK, GRHYD project in France, and Ameland project in the Netherlands have successfully demonstrated 20% blending by volume for residential and commercial customers. Highlights from research, development, and demonstration projects globally include the following:

- HyDeploy Keele Pilot, United Kingdom – successfully demonstrated blends of up to 20% hydrogen by volume at the Keele University campus, supplying 100 residential homes and 30 faculty buildings containing typical natural gas appliances. Phase 2 of HyDeploy will replicate this demonstration into a gas supply network in Northeast UK, feeding approximately 670 customers.
- Hawaii Gas Town Gas, US – Hawaii Gas has been delivering a town gas blend comprising approximately 12% hydrogen by volume to customers on the island of Oahu since the 1970’s [22].
- GRHYD, France – Led by ENGIE and involving a consortium of members, this is a power-to-hydrogen demonstration project in a small, isolated, low pressure gas distribution grid in France which successfully demonstrated blending for about 100 customers from 2018 to March 2021 when the pilot ended. Blending was successfully demonstrated for up to 20% hydrogen by volume with no issues with end-use equipment.
- Power-to-Gas Ameland, Netherlands – Successful demonstration of up to 20% hydrogen blending in the Ameland islanded natural gas distribution network with a variety of customers. Prior to the demonstration, laboratory testing of residential and commercial end-use equipment up to 30% hydrogen was completed with no issues identified.
- ATCO residential appliance testing – ATCO has tested typical and vintage residential home appliances in Alberta, Canada, for up to 40% hydrogen by volume successfully. ATCO has a YouTube video presenting the experiments and results, where fireplaces, stovetops, and furnaces were tested with increasing hydrogen blend [23]. Figure 9 shows a screencap from that video, showing the flame on a gas stove with 100% natural gas and 80% natural gas with a 20% hydrogen blend, indicating a slight but noticeable reduction in flame visibility.

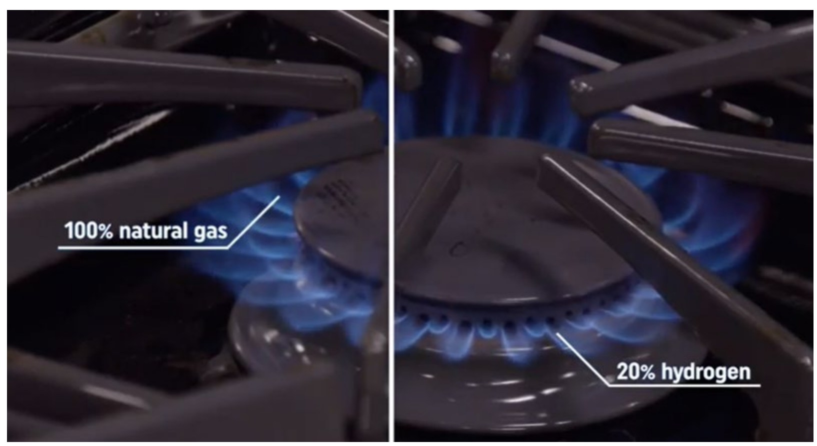

Figure 9 Flame Visibility Comparison from ATCO, 2020 [23]

- SoCalGas has been successfully blending and testing up to 20% hydrogen by volume in natural gas to fuel a closed-loop household system with appliances at its Engineering Analysis Center and Centralized Training Facility in California. Technicians are measuring the performance of typical household gas appliances such as stoves, wall heaters, and forced-air furnaces, with an emphasis on safety and training. The blending began in the summer of 2021 and preliminary findings have shown that the gas appliances tested are compatible with a 20% hydrogen blend. The facility also allows for testing of pipeline leaks and other key aspects of distribution system operation with hydrogen admixing. In addition, SoCalGas has broken ground on its award-winning Hydrogen Home project, which will demonstrate how hydrogen can be used in our households of the future, integrated with solar panels, battery storage, and in-home electrolyzer.

Performance and operational safety of natural gas residential appliances were tested according to North American CSA/ANSI Z21 series of standards by the CSA Group, as communicated through a 2021 publication [24]. The study looked at pure methane as a proxy for natural gas and evaluated equipment per CSA/ANSI Z21 series standards for a 5% and 15% hydrogen blend in methane by volume. Generally, for all residential equipment tested (furnaces, boilers, water heaters, and space heaters), the testing concluded that hydrogen blending up to 15% by volume does not represent operability challenges and no critical issues were identified. The study did not test higher than 15%.

Beyond 20% blending by volume, upgrades and replacements will likely be needed both for end-use equipment and for the pipeline network that manages and distributes the gas. While these are expected to be costly, there is increasing recognition that our natural gas home heating systems can feasibly be replaced completely by low-carbon hydrogen networks in a net-zero future. The "H100" series of projects in the United Kingdom (UK) are leading the charge in this regard. SGN, one of the UK's main gas distribution network providers, has announced plans for a pioneering project in Fife, Scotland, to demonstrate 100% green hydrogen home heating (the "H100 Fife" project)[5]. In the project's first phase, the network will heat around 300 local homes using clean gas produced by a dedicated electrolysis plant, powered by a nearby offshore wind turbine. Northern Gas Networks (NGN), another main gas distribution network provider in the UK, has evaluated the grid for 100% hydrogen and determined the conversion to be feasible with minimal disruptions to customers[6]. By converting the gas grid to carry 100% hydrogen UK-wide, NGN says heating emissions would be reduced by at least 73%.

There is a clear opportunity for hydrogen blending in the Sarnia-Lambton region. Enbridge operates the local gas networks, with a low-pressure distribution network feeding residential and commercial (and some light industry) customers while a separate higher-pressure distribution network connects the large industrial gas customers. The opportunity to blend hydrogen into large industrial facilities was discussed above under industrial fuel switching, and, in general, stakeholder engagement has provided insight that these large industrial sites would prefer to control hydrogen blending on-site rather than receiving blended gas through the network. The opportunity and forecasts for blending into the local gas network thus focuses on the low-pressure distribution network that feeds residential and commercial customers in the region. Enbridge has provided average energy delivery for this network, which was used by GHD to generate the potential hydrogen demand forecasts from blending.

5.2 Forecasted Low-Carbon Hydrogen Demand in Region

Low-carbon hydrogen demand forecasts in the Sarnia-Lambton region have been developed based on each category described in the previous section for both a High Scenario representing aggressive decarbonization and a Low Scenario representing conservative uptake of low-carbon hydrogen.

5.2.1 Note on Hydrogen Blending

Throughout this report, hydrogen blending in natural gas is discussed as percent by volume blending unless otherwise noted. This is the most commonly used terminology when discussing hydrogen blending. However, hydrogen has significantly lower energy content by volume than natural gas (approximately one-third), meaning that blended gas has a lower energy content by volume than baseline natural gas and a higher volume of blended gas is needed to meet the same energy demand as hydrogen blend by volume increases (in a non-linear relationship). To accommodate this, demand forecast modelling for hydrogen blending is based around delivering the same total energy demand as in the baseline. In other words, while percent volume blending is discussed, percent energy blending is used in the calculations. For the readers reference, the approximate relation between percent volume of hydrogen and percent energy content of hydrogen in the blended gas is provided below.

Table 4 Relation between Hydrogen Blending by Volume and by Energy for Delivering the Same Energy Demand

% Volume H2	1%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
% Energy H2	0.34%	1.7%	3.6%	7.6%	13%	18%	25%	34%	44%	57%	75%	100%

[5] https://ifrf.net/ifrf-blog/world-first-100-hydrogen-to-homes-heating-network-gets-go-ahead/
[6] https://networks.online/gas/100-hydrogen-gas-grid-feasible-says-ngn/

5.2.2 High Scenario (Aggressive Decarbonization)

The High Scenario targets achieving net-zero goals by employing aggressive uptake of low-carbon hydrogen across the demand categories. The High Scenario generally agrees with Canada's Net-Zero Strategy, with the period of 2025-2030 focused on growth and diversification following by rapid expansion and scale-up from 2030-2050. While the High Scenario is technically feasible, significant infrastructure and equipment upgrades will be needed as well as changes to existing policy and regulatory programs to remove barriers and enable disruptive solutions. The following assumptions were used to evaluate the High Scenario:

- Decarbonizing existing hydrogen feedstock demand: Minimal uptake by 2025 considering current cost and regulatory barriers, with accelerating uptake thereafter assuming those barriers are progressively overcome. As there are no equipment replacements needed for current hydrogen users to convert to using low-carbon hydrogen, the assumed % replacement is moderately more aggressive than the blending cases. The High Scenario assumes 2% feedstock replacement by low-carbon hydrogen in 2025, 20% by 2030, accelerating to 100% replacement by low-carbon hydrogen in 2045 and thereafter. The existing hydrogen feedstock demand is based on information gathered through stakeholder engagement for the large refineries and ammonia manufacturing companies. Information was not fully available across the diverse industries in the region, and therefore the numbers presented likely represent an underestimation.
- Industrial fuel switching natural gas to hydrogen: The High Scenario assumes initially modest uptake of low-carbon hydrogen of 2% blending by volume in 2025 to 10% by 2030, with equipment replacements in the 2030's enabling accelerating uptake thereafter to achieve 100% replacement of natural gas process heating systems and power generation by hydrogen in 2050. Uptake is assumed slightly more aggressive for the gas power plants than industrial process heating due to less technical and cost barriers. The natural gas heating demand at the core of the model calculations was collected from large emitter GHG data and supplemented with data provided by a handful of large industrial facilities through stakeholder engagement, representing an underestimate of total natural gas process heating demand in the region since small-to-medium facilities are not captured. The natural gas energy demand for the large gas power plants in the region is based on GHG reporting information for the 4 large emitter plants.
- Hydrogen for transportation: Current fueling stations have a typical capacity nearing 200 kg hydrogen throughput per day, while data from the fueling station market in California from 2019 shows average fueling station throughput of approximately 100 kg per day [25]. GHD has assumed a single 100 kg per day fueling station in 2025 in the High Scenario, which could be for fleet conversion or to support increasing FCEV traffic along the 402 (or both), increasing ten-fold by 2050 to 1,000 kg per day delivered across multiple stations. Given that existing hydrogen feedstock demand in the region today is over 400,000 kg per day, the estimated hydrogen demand for transportation is virtually negligible in comparison to the other demand categories.
- Blending hydrogen into the local low-pressure gas distribution network: The High Scenario assumes 1% hydrogen blending into Enbridge's low-pressure gas distribution network feeding local residential and commercial customers in Sarnia-Lambton in 2025, 5% in 2030, up to 20% by 2040. Network and end-use equipment upgrades in the late 2030's are assumed to enable increasing the hydrogen content rapidly in the 2040's in pursuit of net-zero targets, achieving 100% replacement in 2050. This is generally consistent with Enbridge's *Pathways to Net-Zero Emissions for Ontario* report, published by Guidehouse [26].

Table 5 ***Summary of Hydrogen Demand Forecast High Scenario Assumptions***

		"High" Scenario - Aggressive Decarbonization					
		2025	2030	2035	2040	2045	2050
Fuel Switching NG to H_2 – Industrial Process Heating	%v Blending	2%	10%	20%	40%	60%	100%
Fuel Switching NG to H_2 – Natural Gas Power Plants	%v Blending	2%	10%	30%	60%	90%	100%
Replacing Hydrogen Feedstock Demand with Low-Carbon H_2	% tonnes replaced	2%	20%	50%	80%	100%	100%
Hydrogen For Transportation	x100 kg/day	1	2	4	6	8	10
Blending Hydrogen into Local Distribution Network	%v Blending	1%	5%	10%	20%	60%	100%

5.2.3 Low Scenario (Conservative Uptake)

The Low Scenario represents a much more conservative forecast, whereby decarbonization via low-carbon hydrogen is slower on the initial uptake and acceleration. It is important to understand that the Low Scenario modelled does not support achieving net-zero targets by 2050, unless there is disruptive uptake of alternative decarbonization solutions for industry and heating. The following assumptions were used to evaluate the Low Scenario:

- Decarbonizing existing hydrogen feedstock demand: In the Low Scenario, 2% replacement of hydrogen feedstock demand with low-carbon hydrogen is assumed by 2025, 10% by 2030, increasing 20% every 5 years thereafter to reach 80% decarbonization by 2050.
- Industrial fuel switching natural gas to hydrogen: Hydrogen blending into industrial natural gas systems is assumed to have a slower uptake in the Low Scenario, with 0% blending in 2025. By 2030, it is assumed that natural gas power plants achieve 5% blending while industrial process heating systems achieve 2% blending, accelerating thereafter to reach 80% and 60% net blending by 2050, respectively.
- Hydrogen for transportation: In the Low Scenario, the hydrogen demand for refuelling is halved compared to the High Scenario. This demand is virtually negligible compared to the other categories.
- Blending hydrogen into the local low-pressure gas distribution network: The Low Scenario assumes 0% hydrogen blending in 2025, with 2% blending achieved by 2030, 10% by 2040, and 20% by 2045. In the Low Scenario, hydrogen blending remains at 20% by volume into 2050.

Table 6 ***Summary of Hydrogen Demand Forecast Low Scenario Assumptions***

		"Low" Scenario - Aggressive Decarbonization					
		2025	2030	2035	2040	2045	2050
Fuel Switching NG to H_2 – Industrial Process Heating	%v Blending	0%	2%	10%	20%	40%	60%
Fuel Switching NG to H_2 – Natural Gas Power Plants	%v Blending	0%	5%	20%	40%	60%	80%
Replacing Hydrogen Feedstock Demand with Low-Carbon H_2	% tonnes replaced	2%	10%	20%	40%	60%	80%
Hydrogen For Transportation	x100 kg/day	0	1	2	3	4	5
Blending Hydrogen into Local Distribution Network	%v Blending	0%	2%	5%	10%	20%	20%

5.2.4 Forecast Results & Discussion

Results of the low-carbon hydrogen demand forecasting are presented in the figures below. Note that while hydrogen for transportation is modelled and included in the total numbers, the category does not register on the figures below as the resulting demand forecast is insignificant compared to the other demand categories.

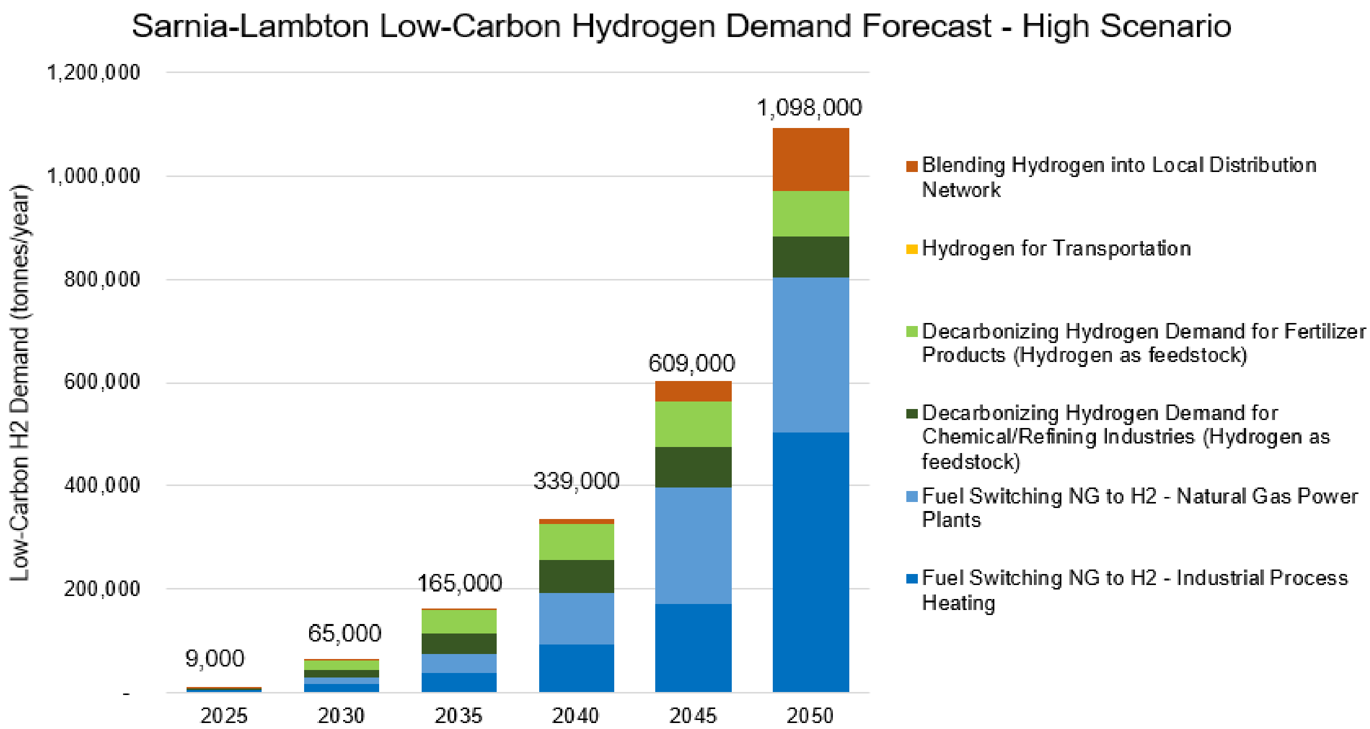

Figure 10 ***Low-Carbon Hydrogen Demand Forecast – High Scenario***

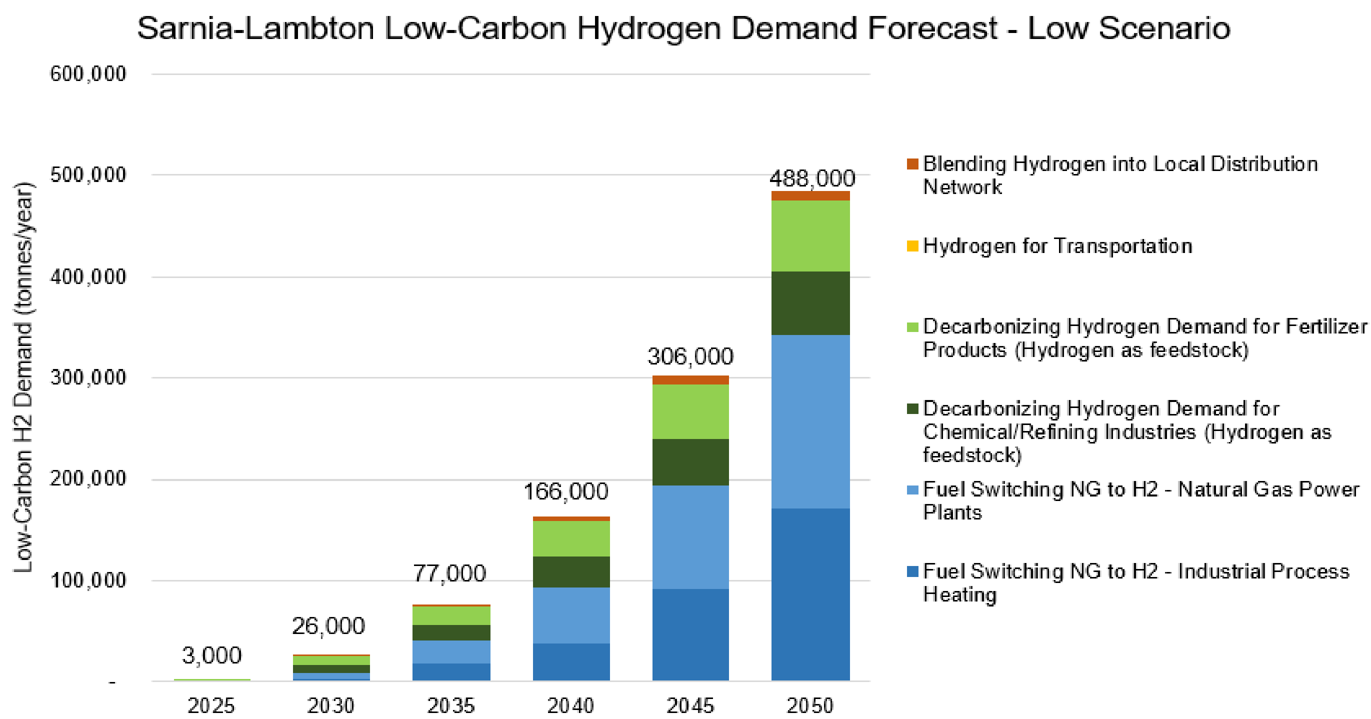

Figure 11 ***Low-Carbon Hydrogen Demand Forecast – Low Scenario***

The demand forecasting indicates incredible opportunity for scaling-up a local low-carbon H_2ub. By 2030, demand for low-carbon hydrogen could range from 25,000 tonnes per year to over 60,000 tonnes per year. By 2050, demand could range from nearly 500,000 tonnes per year to over 1 million tonnes per year in the region alone. Assuming the Transformational scenario in Canada's Hydrogen Strategy, which estimates a national market size of 20 million tonnes hydrogen per year by 2050, Sarnia-Lambton's demand could comprise between 2.5 and 5% of low-carbon hydrogen demand across the country.

Furthermore, the forecasts above are focused on existing industries in the region and exclude several potential sources of demand that are difficult to predict today. Converting shipping through the Great Lakes to low-carbon ammonia or hydrogen fuel, exporting hydrogen and ammonia to merchant markets across North America, conversion of mobile heavy-duty equipment to hydrogen (tractors, etc.), potential hydrogen utilization at airports to offset fossil fuels, blending hydrogen into the natural gas transmission network, and more are not included in the current forecasts and can result in higher-than-forecasted demand.

5.2.5 Limitations

Across all scenarios and demand categories, the model is based on existing industries, available data on current energy demand, and known technologies for supporting low-carbon hydrogen uptake. Energy demand is not assumed to increase or decrease in the model, due to lack of achievable certainty for such estimates for the purposes of this study. Disruptive innovations, policy, or events are not attempted to be predicted. It is therefore recommended that the market demand forecasts and correlating H_2ub Roadmap be reviewed, revised and updated at least every 5 years going forward in order to remain relevant.

There are several potential accelerators or decelerators that could result in actual demand for low-carbon hydrogen being much higher or lower than the forecasted scenarios. Some may be anticipated such as changes to governmental policy and incentives for decarbonization and technological advancement of emerging use-cases, but others could be "unknown unknowns" that are not predictable today. Regular engagement among the H_2ub working group and stakeholders to monitor, identify, and plan for accelerators or decelerators can enable the H_2ub to capitalize on emerging opportunities and stay ahead of threats.

5.3 Export Markets

There are several accessible markets for exporting low-carbon hydrogen or ammonia produced within the Sarnia-Lambton region. These markets will be competitive; challenges and barriers with scaling up low-cost low-carbon hydrogen production in the region pose a risk for capturing export market share.

Sarnia-Lambton is already a major export region with established export corridors, infrastructure, and trade. The petrochemical, hybrid chemistry, advanced manufacturing and value-added agriculture industries all produce and export goods via road, rail, air, water, and pipelines. There are existing power lines, hydrocarbon pipelines, and natural gas pipelines that connect Sarnia to Michigan providing access to US markets. Ethanol is produced at large-scale by Suncor and Woodland Biofuels and subsequently exported across the country.

Even more notably, Sarnia-Lambton already exports both hydrogen and ammonia to markets across North America. Air Products has been liquefying and exporting hydrogen from their Sarnia Liquefaction Plant for over 25 years via road. CF Industries produces and exports ammonia and related products. The connecting infrastructure, market relationships, skilled workforce, and technical expertise for exporting low-carbon hydrogen and ammonia are already in place, which reduces investment required and risk for potential producers.

5.3.1 Hydrogen for Steel Manufacturing in Ontario

Approximately 200 km East of Sarnia via Highways 402 and 403, the Hamilton-area is home to leading manufacturing giants and large-scale steel and advanced manufacturing facilities. Canada is the 19th largest steel producer in the world with over 30 facilities across 5 provinces, with the largest concentration being near Hamilton, Ontario. The Canadian Steel Producers Association has announced plans to achieve net-zero steel manufacturing by 2050. The most promising route for steelmaking decarbonization is through low-carbon hydrogen in combination with low-carbon electricity for direct reduced iron (DRI) and electric arc furnaces (EAF), which will require significant investment into process changes [27].

In 2021, the Governments of Canada and Ontario announced major commitments to supporting green steel transformation in Hamilton's steel making industry including $500 million and $400 million (respectively) contributions to ArcelorMittal Dofasco's $1.8 billion investment into decarbonizing their steel manufacturing. The transformation will replace carbon-intensive coke ovens and blast furnaces with hydrogen-ready EAFs by 2028, enabling DRI/EAF for low-carbon steel making. Similar transformations of steel making are occurring around the world. The DRI/EAF approach will provide significant demand for low-carbon hydrogen to support decarbonization. Hydrogen produced in Sarnia-Lambton could be exported to Hamilton-area steel plants via established road routes or potentially via a direct hydrogen pipeline if demand were to become significant enough to justify the investment in the future.

5.3.2 Blending Hydrogen into the Dawn Hub

Hydrogen blending into high-pressure natural gas transmission systems could present a disruptively large demand for low-carbon hydrogen. Enbridge's Dawn Hub generally fills during the summer and withdraws during the winter to meet seasonal heating energy demand, with average of 0.84 peta-Joules (PJ) daily summer injections and average 1.1 PJ daily winter withdrawals [13].

However, blending hydrogen into the Dawn Hub high-pressure gas transmission network will require further studies to determine the maximum allowable blend possible. Technical challenges of pipeline and components are exacerbated under high-pressure conditions compared to low-pressure systems, due to the increased partial pressure of hydrogen and incompatibility with high-strength steels, however research and demonstration globally indicates that repurposing gas transmission assets for hydrogen blending service is feasible. Integrity and materials challenges may require upgrades to the network which would have to be assessed and quantified. The piping system in the various systems are different and must be assessed on their own merits.

In Italy, the gas transmission network operator Snam has successfully been blending 10% hydrogen by volume into a portion of the country's 33,000-km high-pressure gas network since 2021, which has been enabled due to hydrogen-ready piping materials. Similar achievements could be possible in North America following the requisite pipeline network upgrades. On the commercial side, downstream utilities and networks would need to agree to accept a hydrogen blend, which could take time to achieve.

Provided the technical challenges and any customer reluctance can be overcome, hydrogen blending at the Dawn Hub at any volume would represent a material demand for low-carbon hydrogen to move the hydrogen economy forward.

5.3.3 Exporting to Wider Ontario

Exporting low-carbon hydrogen produced in Sarnia-Lambton to wider Ontario markets could present a significant off-take opportunity for supporting large-scale locally produced low-carbon hydrogen. Fueling stations along Highway 401 and markets in industrial sectors in London, Windsor, Toronto, or even Quebec could be accessed via road and rail.

H2GO Canada, a not-for-profit organization working to advance the case for a low-carbon hydrogen economy in Canada, is currently working on developing an Ontario Hydrogen Foundation Study which will include modelling and estimates for the potential hydrogen market across the province [28]. The results of this ongoing study will be of interest for the Sarnia-Lambton region to help understand the potential for export across Ontario.

5.3.4 Exporting to the US

Industries in Sarnia-Lambton export a variety of products to the US via road, rail, ship, and pipelines. The export potential for low-carbon hydrogen could be significant depending on achievable levelized cost for delivered hydrogen.

The US Northeast region's high cost of electricity, concerns over regional air quality, available state and federal tax incentives for renewable power, and legislative policy for climate control contribute to an environment that could be very receptive to hydrogen adoption across a number of applications. The region has cold winters and uses large amounts of natural gas for building heating. This has led to some blending studies to understand possibilities for hydrogen in the gas utility infrastructure. There are numerous ports and oil refining infrastructure in the region that could be hydrogen demand centres for industrial feedstocks and marine transportation refuelling. New York, New Jersey, Massachusetts, Virginia, and Washington D.C. all have adopted decarbonization commitments that will perhaps make the region ready to move on hydrogen sooner than other regions.

As part of the US Department of Energy (DOE) Hydrogen Hubs development and funding process, multiple Northeast US states (including New York, Massachusetts, Connecticut, New Jersey, New Hampshire, and Maine) have formed a multi-state coalition led by New York to apply for DOE Hub funding. As we are seeing in other North American hubs, there is a concerted effort for H_2ubs to look at providing import or export of hydrogen/ammonia/CO_2 from/to Hubs with adjacent or nearby provinces, states and countries. Export of hydrogen/ammonia to the US Northeast from Sarnia-Lambton by pipeline, railroad, highway and/or marine transport are existing and potential opportunities. This is a key region to continue to monitor activities of and identify and develop existing trade relationships to determine where hydrogen development opportunities can be actively developed.

An organizational meeting of 80 stakeholders for a DOE H_2ub including Michigan and adjacent states (OH/IN/IL) was held in June 2022. The attendees ranged from academic, government, utilities, manufacturing, nuclear, associations and an initial strategy development followed. During organization activities the Michigan H_2ub has specifically highlighted the Sarnia Lambton area as a key potential partner for Hub development due to its existing hydrogen infrastructure and significant cross-border and marine transport of industrial and fossil fuel products. Based on existing long standing import-export activities with Sarnia/Michigan and neighbouring states, this is a good Hub to continue to monitor activities of and identify and develop existing trade relationships to determine where hydrogen development opportunities can be actively developed. SLEP or the H_2ub Working Group should formally connect with the MI Hub to identify areas which can be jointly worked on to mutually support ongoing development of both Hubs.

6. Hydrogen Production

Current hydrogen production in Sarnia-Lambton is generally accomplished via SMR or ATR of natural gas without CCUS (grey hydrogen). Several hydrogen users produce and use their own hydrogen, for example CF Industries for ammonia production manufacturing and NOVA Chemicals for chemical processes. The large refineries generally receive hydrogen from Air Products' Corunna Hydrogen Plant, which is co-located with the Shell refinery and connected via pipeline to Suncor and Imperial Oil. Linde and Air Liquide additionally have operations in the region.

To meet the forecasted low-carbon demand, Sarnia-Lambton will need to see initial low-carbon hydrogen production projects take root over the next 5-8 years, with landmark production projects demonstrating scale in place by 2030, followed up by rapid expansions at scale thereafter. Meeting the forecasted demand will require advancements to reduce costs and increase scale of hydrogen production, which is seen as an "all-hands on deck" challenge. While blue and green hydrogen are generally recognized as being the main pathways for low-carbon hydrogen production at scale today, advancing emerging production pathways such as pyrolytic and biomass-derived hydrogen will be important for diversifying the feedstocks to produce hydrogen and reducing costs through competition.

The opportunities and challenges associated with several potential pathways for low-carbon hydrogen production in the region are discussed in this section, including hydrogen from reforming natural gas, from electrolysis, from pyrolysis of natural gas, from biomass feedstocks, and capturing by-product hydrogen.

6.1 Blue Hydrogen

Blue hydrogen refers to utilizing existing technology in the form of steam methane reformation or autothermal reformation (SMR or ATR) in conjunction with carbon capture for utilization or permanent storage. There is a general consensus that blue hydrogen with CCUS will need to be an essential part of any plans to significantly scale hydrogen adoption in North America. Blue hydrogen market share depends on a number of factors including hydrogen demand, supportive government policies, improvements to hydrogen generation and CCUS technologies, development of storage and transmission infrastructure, and decreases in the overall unit cost of blue hydrogen.

Converting the existing grey hydrogen production to blue hydrogen by applying CCS may appear to be an obvious near-term opportunity for Sarnia-Lambton. However, current policy and regulations in Ontario do not support and enable CCS and there are no existing pipelines or agreements for exporting CO_2 to potential storage sites (such as in Michigan). As a core priority for the potential hydrogen economy in Ontario, this major barrier needs to be overcome. Beyond simply removing the ban on CCS in Ontario (as proposed by the MNRF), a clear-cut regulatory framework that works to enable fast decarbonization through CCS needs to be developed, and the emissions reductions from CCS need to be formally recognized in the provincial GHG compliance program (Emission Performance Standard, EPS – note that draft regulations are proposing to recognize this, but they have yet to be implemented).

More supportive government policies through higher carbon prices, tax incentives, carbon contracts for differences, and support for individual projects could provide a pathway for the development of credible near-term investments in blue hydrogen from industries with concentrated CO_2 emissions, such as the ammonia production, petrochemical, hybrid chemistry, and advanced manufacturing industries in Sarnia-Lambton. Use of CCUS in these applications could also create a virtuous cycle by accelerating the development of technology that would decrease blue hydrogen unit costs and thereby open the technology to additional higher abatement cost applications.

Presently, on a unit cost basis, blue hydrogen is seen as more expensive than grey but lower cost than green. Blue hydrogen facilities will however require greater scale than green hydrogen production to be cost efficient, so there will be greater capital expenditures and commercial risks associated with early involvement in blue hydrogen projects. The expense of transporting CO_2 and developing utilization or storage opportunities can vary widely from one region to the next, with the expense of any of these factors potentially ruling out the commercial viability of a blue hydrogen project.

Blue hydrogen producers should ensure that they can leverage a network of underground storage facilities, gas infrastructure and petrochemical expertise, and are able to offtake enough volume of hydrogen for CCUS projects to be successful. Owning or having access to these assets and capabilities will allow for faster scaling and mitigation of some associated technical and commercial risks. Hubs or geographically concentrated portions of the CCUS supply chain like geological storage, existing pipeline infrastructure, a high concentration of CO_2 emitters, and areas of enhanced oil recovery can improve the economics of blue hydrogen investments and connecting blue hydrogen value chain partners to coordinate production, transmission, storage, and off-takers can decrease individual risks and speed growth and adoption of blue hydrogen.

6.2 Electrolytic Hydrogen

Electrolytic hydrogen refers generally to hydrogen produced via water electrolysis, a process that consumes water and electricity to produce hydrogen and oxygen. The carbon intensity of electrolytic hydrogen mostly depends on the carbon intensity of the electricity supply. The Ontario electric grid is comprised largely of renewables (mainly hydropower with some wind and solar) and nuclear power with several gas power plants contributing to meet peak demand. According to the federal Clean Fuel Standard's Fuel LCA Model, the Ontario grid has a default/average carbon intensity of 14 gCO_2e/MJ, which translates to hydrogen generation via electrolysis at a carbon intensity of approximately 18 gCO_2e/MJ (assuming efficiency of 50 MWh consumed per tonne hydrogen produced).

If peaking periods can be avoided, the carbon intensity of hydrogen produced would be expected to be much lower. This hydrogen would not have a carbon intensity nearly as low as green hydrogen produced solely from renewables such as wind and solar power (which generally have near-zero lifecycle carbon intensity) but has the significant commercial advantage of not requiring behind-the-meter renewable power facilities. In the long-term, the carbon intensity of the electric grid in Ontario may be anticipated to decrease in support of pursuing net-zero targets, which would result in lower-carbon hydrogen produced via grid electrolysis in the future. However, in the short term from now to 2030, it is possible that the carbon intensity of the Ontario grid will increase modestly, due to the anticipated closure of the Pickering Nuclear Generating Station in 2026 and current lack of supportive policies and incentives for utility-scale renewable power projects.

Grid electrolysis can also capitalize on periods where variable power generation exceeds grid demand, during which renewables are often curtailed today. In 2021, Ontario curtailed a total of 1,289 GWh of wind and, to a lesser extent, solar power, which is down from 2,621 GWh in 2020 [29]. Grid-tied electrolysis facilities that can ramp up and down efficiently could offer a significant opportunity to mitigate renewables curtailment and provided large-scale seasonal energy storage through hydrogen and salt caverns. Sarnia-Lambton would be well-positioned to host such seasonal energy storage with the salt caverns in the region. Converting an existing salt cavern operated by Pembina or Plains is expected to be lower cost than development of new salt caverns, although development of new caverns is also certainly possible.

The Bowman Centre for Sustainability has been evaluating and promoting this opportunity to produce low-carbon hydrogen during off-peak times (and at off-peak prices), store it at large-scale in salt caverns in Sarnia-Lambton, and provide both seasonal energy storage as a hydrogen battery and a low-carbon hydrogen supply for the local industries. In collaboration with Queen's University, they completed a "Techno-Economic Analysis of Hydrogen Storage in Salt Caverns" that found the proposed project could reduce between 200,000 and 400,000 tonnes of GHG's per year [30]. As a grid-scale energy storage system, with the hydrogen routed through fuel cells for zero-carbon electricity generation during periods of high-demand, the system is estimated to cost less than $200 per kWh compared to $400 per kWh for state-of-art grid-scale chemical batteries. The proposed project would improve utilization of variable renewable energy power and support grid resiliency through large-scale, low-cost storage and balancing.

Atura Power plans to play a leading role in becoming a large-scale low-carbon electrolytic hydrogen producer in Ontario. Atura has preliminary plans currently to explore hydrogen production at the decommissioned OPG Lambton Generation Station, which was previously the last coal-fired generating station in Ontario and was demolished in early 2022. This facility could be the first commercial-scale electrolytic hydrogen source in the H_2ub, providing a launching point for enabling low-carbon hydrogen demand to grow.

With large-scale electrolytic hydrogen production also comes large-scale oxygen production. Oxygen may have many use-cases synergistic with the hydrogen economy. For example, oxygen injection is a potential solution for improving efficiency and mitigating NO_x emissions from hydrogen blending in industrial natural gas heating systems and gas power generation [19], oxygen is consumed for ATR of natural gas to produce hydrogen, and oxygen has a number of uses for greenhouses, the medical sector, and even gasification [31].

There are three primary types of electrolysis technologies for generating hydrogen – alkaline, polymer electrolyte membrane (PEM), and solid oxide (SO). The different technologies each utilize different materials, configurations, and operating temperatures to produce hydrogen. Alkaline electrolysis has been in use the longest and is the cheapest to manufacture at approx. $200/kWh, however it is slow to switch on and off which makes it less applicable for use with intermittent renewable energy sources. SO electrolyzers are the newest of the three technologies and rely on very high operating temperatures of 550 – 1,000 ºC, which can see synergies with high-temperature industries and nuclear power plants. Development of SO electrolysis is still relatively new, so research into specific use cases and long-term viability for hydrogen production is undetermined at present. PEM electrolysis is viewed as the longer-term preferred production process for green hydrogen generation at present, because it requires a smaller operational footprint, has a low operating temperature at 80 ºC, can operate using variable electricity loads, and can switch on and off to match intermittent renewable energy generation.

The levelized cost of electrolytic hydrogen depends primarily on the cost of renewable electricity, electrolyzers, and electrolyzer utilization. Historically, electrolysis has been more expensive than SMR due to the electrolyzer capital cost and cost of power required for production. Since 2010, the cost of electrolysis has fallen by 60% from $10 – $15/kg hydrogen to as low as $4 – $6/kg today. The cost of renewable energy is expected to continue decreasing over the coming decades as more production comes online, manufacturing costs decrease, renewable generation technologies improve, and operational efficiencies increase. Should the cost of electricity reach $20 - $30/MWh at the point of consumption (inclusive of transmission and distribution costs if using grid electricity, and any additional fees such as the Global Adjustment program in Ontario), green hydrogen can become competitive with large-scale SMR-produced hydrogen with CCUS. An electricity cost of $10 - $15/MWh would be required for green hydrogen to be cost competitive with SMR-produced hydrogen without CCUS (assuming electrolyzer capex assumptions for $400/kW system).

PEM electrolyzers also have significant opportunities to reduce costs. These electrolyzers are just recently getting to megawatt scale, and manufacturing costs are expected to drop 65-75% over the next decade. The US DOE estimates that 70 GWh of electrolyzers deployed will be the break-even threshold for green hydrogen to draw even with grey hydrogen in regions of the US with cheap renewable electricity. DOE targets for cost competitive PEM electrolyzers are $400/kW by 2030. As electrolyzer capex cost decreases, electrolyzers are expected to see efficiency improve from 60 – 80% by 2030 and utilization to increase as well. If an electrolyzer is connected to the power grid, utilization could be up to 95%. If using wind power alone, utilization could be only 40%. A combination of wind and solar power could get utilization over 60%.

Additional economic factors that could decrease costs include continued renewable energy friendly government policy and sustainability-focused customer demand pushing greater renewable energy production and lower costs of generation between now and 2030.

6.3 Turquoise Hydrogen

Turquoise hydrogen refers to hydrogen produced via pyrolysis of natural gas. Methane pyrolysis is the thermal decomposition of methane in the absence of oxygen into two products: hydrogen and solid carbon, the latter of which can take a variety of forms such as carbon black, graphite, and more. This is an emerging technology for low-carbon hydrogen production that has notable potential advantages over blue or green hydrogen production.

Unlike natural gas reforming, no CO_2 is formed in the process, and therefore there is no need for CCUS. Pyrolysis can therefore be scaled up in regions without accessible CO_2 sequestration. The CO_2 footprint of methane pyrolysis corresponds to the emissions from the electricity source and any emissions generated in the extraction and delivery of the natural gas feedstock. Additionally, methane pyrolysis is a one-step process, unlike SMR in which the water-gas shift reaction is needed following reforming to produce additional hydrogen from the reaction of carbon monoxide (CO) in the syngas and water. Methane pyrolysis to hydrogen is a less-efficient energy conversion process than methane reforming when CCS is not considered, but more-efficient when the energy consumption for CCS is considered [32]. Compared to electrolytic hydrogen production, methane pyrolysis requires significantly less electricity and water inputs.

The solid carbon products that can be produced through methane pyrolysis provide potential for advanced manufacturing markets. The characteristics of the produced carbon depend on the catalyst used and reaction conditions, which can be adjusted to respond to various carbon markets. Carbon black already has a market in Sarnia-Lambton, with Cabot Canada manufacturing carbon black for rubber, plastics, inks, toners, and elastomer reinforcement customers across North America. Synthetic graphite from methane pyrolysis could be the basis for developing value-added manufacturing opportunities in the areas of battery materials, electrode and refractory products, or novel composite materials. Other markets may include soil amendment and environmental remediation, carbon fibres, construction materials, and, further in the future, nanomaterials.

Despite these advantages, the production of pyrolytic hydrogen has a long way to go to become cost competitive with blue and electrolytic hydrogen. The technology is generally considered pre-commercial at the current time, and de-risking investments will require commercial demonstrations and scale-ups. However, there are increasing announcements of commercial demonstrations and technology deployments regarding pyrolysis supporting the advancement of this promising technology. For example, Suncor Energy and FortisBC recently announced a planned commercial demonstration project in BC that will utilize Hazer pyrolysis technology to produce nearly 3,000 tonnes of low-carbon hydrogen per year.

For Sarnia-Lambton, pyrolytic hydrogen may have the potential to become a significant competitor to blue and green hydrogen production while attracting investment for RD&D. Sarnia-Lambton would be an ideal location for research and development and commercial demonstrations of methane pyrolysis, with existing market and expertise for evaluating and developing solid carbon market applications. Lambton College could support research and development into this alternative pathway, and partnerships for demonstrations could attract private and public investment into the region.

6.4 Hydrogen from Biomass

Hydrogen can be produced from biomass or biogas using similar processes as hydrogen from fossil fuels: reforming, gasification, and pyrolysis. This pathway has been described in industry variably as green hydrogen, dark green hydrogen, and bio-hydrogen. While reforming and gasification produce CO_2 emissions, since the feedstock is biomass, these emissions are considered biogenic (part of the natural carbon cycle). The carbon intensity of bio-hydrogen can therefore be near-zero, with transport of the biomass feedstock, electricity source, and any fossil fuels for heating being the main factors contributing to lifecycle emissions. Coupled with CCS, bio-hydrogen can result in net-negative CO_2 emissions, making this the lowest-carbon intensity pathway possible. If emissions offsets are allowed for the biomass feedstock used, for example offsets for diversion of organic waste from landfill or cattle manure methane emissions reductions, the carbon intensity can be even lower.

Biomass feedstocks may include:

- Forestry waste and wood residues such as chips, pellets, sawdust
- Agricultural energy crops, wastes, and residues, such as corn stalk, rice hulls and stalks, wheat straw, nutshells, soybeans, straws of various pulses and cereals
- Organic municipal solid waste such as food waste, paper, cotton, wood waste from construction
- Animal manure

For hydrogen production pathways, feedstocks can be considered in two categories: low-moisture biomass and high-moisture biomass. Low-moisture biomass can be used in gasification, pyrolysis, and other thermochemical conversion processes while high-moisture biomass can be converted via biochemical processes such as anaerobic digestion and fermentation to biogas. The biogas produced from these processes is then upgraded and purified to produce the product hydrogen stream, using a variety of established processes such as water gas shift reaction, pressure or temperature swing adsorption, or membrane separation.

With the expertise and experience of the local hybrid chemistry and value-added agriculture sector combined with the vast farming and animal raising land to provide ample feedstock, Sarnia-Lambton is well-positioned to be a launching point for RD&D and commercialization of bio-hydrogen production in North America. The region is already home to several bio-fuels companies and facilities, producing ethanol and other products, such as Woodland Biofuels' Sarnia Biochemical Plant that converts wood waste to ethanol and Suncor's St. Clair Ethanol Plant that provides ethanol for Petro-Canada retail stations across the country. The expertise and capabilities of Lambton College could support RD&D efforts and offer a strong industry-academia partnership for seeking public funding support.

6.5 By-Product Hydrogen

Hydrogen is produced as a by-product through a number of industrial processes. It is estimated that total by-product hydrogen production in the US is 3.4 million tonnes per year [33], making by-product hydrogen a potential significant production source. There are a number of processes that result in by-product hydrogen. One of the significant potential sources is through the chlor-alkali process which is used to produce chlorine, sodium hydroxide, and other chemicals. An example of existing by-product hydrogen in Sarnia-Lambton is Cabot Canada's carbon black production facility, which produces hydrogen as a by-product that is subsequently used as fuel in Cabot's facility.

Depending on the specific industrial process (and carbon intensity quantification methodology employed), by-product hydrogen may have a low carbon intensity competitive with green hydrogen.

6.6 Summary

The table below provides a summary of the opportunities and challenges for the various hydrogen production pathways for the Sarnia-Lambton H_2ub.

Table 7 Opportunities & Challenges for Low-Carbon Hydrogen Production in Sarnia-Lambton

Hydrogen Production Pathway	Opportunities & Strategic Advantages for Sarnia-Lambton	Challenges & Barriers to Deployment and Scale-Up
Blue Hydrogen (from fossil fuels with CCUS)	• Expected to be low-cost at large-scale • Clear path to decarbonize existing grey hydrogen production in Sarnia-Lambton if CCS can be enabled in policy • Strong existing experience and expertise with the processes/equipment • CanmetENERGY-Ottawa evaluating CCS and CO_2 pipeline options for Ontario, and offering research support for wells to evaluate subsurface resources • Research capabilities to support newer capture and off-take opportunities such as use of CO_2 in construction products	• Not currently possible in Ontario as CCS is not supported or enables and there are no existing CO_2 pipelines that could transport CO_2 to sites where CCS projects do exist • High capital cost • Public perception as "not green"
Electrolytic Hydrogen (from water electrolysis with low-carbon electricity)	• Site identified for first deployment of utility-scale electrolytic hydrogen at the Lambton Generation Station, with Atura Power exploring the opportunity • Ontario's electric grid is fairly low-carbon already, one of the lowest-carbon grids in Canada	• Cost of electricity in Ontario is high (particularly with Global Adjustment); cost of hydrogen produced would not be competitive with existing grey hydrogen (however if low-price, off-peak periods can be utilized, this challenge may be easily overcome)

Hydrogen Production Pathway	Opportunities & Strategic Advantages for Sarnia-Lambton	Challenges & Barriers to Deployment and Scale-Up
	• Curtailed renewables may be able to be stored as hydrogen in the region's salt caverns, providing seasonal energy storage. Existing caverns in operation for gaseous or liquid fossil fuels can be converted to hydrogen service at lower cost than a new cavern development.	• Policy change and/or incentives are needed to support deployment of grid-powered electrolysis to lower costs and provide demand management • Strictly green hydrogen (from 100% renewables) would require behind-the-meter generation; lack of incentives for renewables in Ontario makes business case unattractive for investors
Turquoise Hydrogen (from methane pyrolysis where carbon is captured as a solid co-product)	• Existing market for certain solid carbon products in advanced manufacturing sector (carbon black) • Sarnia-Lambton well-positioned to be a leader in RD&D for methane pyrolysis; research projects in partnership between industry and academia could attract significant investment to the region • Vast natural gas resources for feedstock, with no need for CCS • Reduced water and electricity consumption compared to electrolytic hydrogen • Variety of processes/catalysts can produce different solid carbon products, able to support growing advanced manufacturing industries	• Not currently commercially demonstrated, therefore higher-risk for investors. Variety of technology providers have successful lab and pilot-scale demonstrations that require investment for raising technology readiness level. • Further RD&D needed to improve efficiency, reduce costs, develop markets for solid carbon co-products
Dark Green Hydrogen (derived from biomass feedstocks)	• Vast biomass resources for feedstock from farm and animal raising industry • Sarnia-Lambton well-positioned to be a leader in RD&D for bio-hydrogen, particularly given strength of hybrid chemistry sector and history of bio-chemistry research and development; research projects in partnership between industry and academia could attract significant investment to the region	• Not currently commercially demonstrated, therefore higher-risk for investors • Further RD&D needed to improve efficiency, reduce costs, demonstrate scale-up
By-Product Hydrogen (existing hydrogen production as by-product of industrial processes, often vented today)	• Existing source of hydrogen in the region, can be captured for use as a potential "low-hanging fruit"	• Carbon intensity uncertain under Canada's Clean Fuel Standard • Limited scale-up potential, dependent on industries/facilities that produce • Available quantities uncertain

7. Strategic Advantages of Sarnia-Lambton as Ontario's Hydrogen Hub

The Sarnia-Lambton region has abundant strategic advantages for hosting the launching point of a large-scale, multi-faceted low-carbon hydrogen economy in Ontario. Promoting these advantages and tackling barriers to deployment and scale-up can attract significant investment into the region, supporting the growth of the H_2ub with the potential for the region to become one of Canada's largest clean industrial hubs.

Table 8 Strategic Advantages & Opportunities for Sarnia-Lambton as Ontario's Hydrogen Hub

Category	Strategic Advantages & Opportunities
Hydrogen Demand in Region	• Existing large-scale hydrogen demand for petrochemical and refining, chemical facilities, and ammonia production; over 150,000 tonnes of hydrogen produced and used each year in Sarnia-Lambton • As a major industrial region with over 10 millions tonnes of CO_2e emissions annually, potential low-carbon hydrogen demand to support industrial decarbonization by offsetting fossil fuels is substantial; forecasted to be between 330,000 and 780,000 tonnes of hydrogen per year by 2050 • Local low-pressure natural gas distribution network feeding residential and commercial customers may be a good candidate for hydrogen blending in natural gas and potential full conversion to hydrogen • Current hydrogen production and pipeline transport is fuel cell-grade, as the purity requirements for the connected Air Products Liquefaction Plant are the same as for fuel cells. The infrastructure and expertise to deliver high-purity hydrogen is in place, which can be attractive for fleet conversions to fuel cell vehicles.
Hydrogen for Export	• Hydrogen is already produced and exported from the region, liquefied for road transport at Air Products' Liquefaction Plant – existing value chain, infrastructure, and expertise for export • Ammonia is already produced and exported from the region by CF Industries • Established export corridors along road, rail, and from the liquid loading docks at the Bluewater Energy Park and Bio-Industrial Park Sarnia • Established access and trade with the US market
Hydrogen Production	• Opportunities for shared infrastructure in the region can reduce costs for low-carbon hydrogen production and delivery • Existing grey hydrogen production and trade, could be decarbonized by applying CCUS (although major challenge of no currently accessible subsurface sequestration resources) • Ample feedstocks for diversified low-carbon hydrogen production: water, low-carbon intensity electric grid, natural gas, biomass and agricultural waste • Atura Power is already assessing potential electrolytic hydrogen production at the former OPG Lambton Generating Station, with existing process water and utilities connections making the site an attractive project location • With the strengths of the local hybrid chemistry and value-added agriculture sectors combined with the vast farming and animal raising land to provide feedstock,

Category	Strategic Advantages & Opportunities
	Sarnia-Lambton could be an excellent a launching point for RD&D and commercialization of bio-hydrogen production • Low-cost natural gas for feedstock and existing market for solid carbon products in advanced manufacturing sector provides good opportunity for demonstrations and scale-up of turquoise (methane pyrolysis) hydrogen production
Connecting Infrastructure	• Existing and active high-purity hydrogen pipeline network operated by Air Products connecting the major petrochemical and chemical facilities, about 30 km in total network length • Existing decommissioned pipelines connecting industry that may provide opportunities for converting to hydrogen service at lower cost than new builds • Highway 402 through Sarnia connecting the industrial region to the US to the West and to London and Highway 401 to the East • CN and CSX rail lines and interconnects • Active salt caverns in the region currently used for NGLs storage, providing an opportunity for converting to hydrogen service at significantly lower cost than new cavern development • Local natural gas networks operated by Enbridge with a lower-pressure network supplying residential, commercial, and light industrial customers and a higher-pressure distribution network supplying the heavy industries. Tied in with Enbridge's Dawn Hub that connects natural gas supply and demand with large-scale subsurface storage. • Geologic conditions are favorable for CCS in Southern Ontario (pending regulatory changes), and existing oil and gas fields in Lambton County may be well-suited to CCS through EOR • CanmetENERGY-Ottawa is evaluating possibility of a CO_2 pipeline connecting heavy industry in Ontario to CCS sites in Michigan or Eastern Canada, with a potential pipeline running through Sarnia's industrial region. This shared infrastructure would enable blue hydrogen production. • Cost savings at the local industrial parks: Bluewater Energy Park & the Bio-Industrial Park Sarnia offer electricity savings of up to 35-40% offered by TransAlta; although this is offered through direct connection to TransAlta's natural gas fired Cogeneration Plant, which is higher carbon intensity than the Ontario electric grid, and therefore would not be a good opportunity for electrolysis.
Research & Development	• Excellent history of RD&D with strong partnerships between industry and Lambton College, major innovation and research parks that are attractive for RD&D investments and start-ups • Lambton College has been supporting industry research for decades with previous hydrogen technologies experience, has capacity for RD&D spaces and equipment and can support cross-industry research while educating students that support staff • Lambton College has strong existing relationships with the local First Nations providing an avenue for connecting in First Nations communities to RD&D opportunities to support projects that can provide lasting benefits for these communities • Promoting the RD&D advantages of the H2ub can attract public and foreign direct investment into the region, benefitting communities and industry • Ongoing research and evaluation of CCS and underground hydrogen storage in Ontario CanmetENERGY-Ottawa, good opportunity to partner with them to assess resources in region and potential CO_2 pipeline

Category	Strategic Advantages & Opportunities
Workforce & Training	• Highly skilled and experienced workforce serving the petrochemical and refining, hybrid chemistry, advanced manufacturing, and value-added agricultural industries; largely trained by the extensive practical programs offered at Lambton College • Existing programs at Lambton College can be supplemented with upgrading/re-skilling courses or microcredentials for emerging hydrogen technologies and use-cases. Programs such as the fire school, which trains local community firefighters as well as fire safety professionals for industry, engineering technicians, gas handling, and others would be well-suited for hydrogen curriculum. • Opportunities to engage and work with local workers unions
Community	• Local community is familiar with and largely employed by the diverse industries in the region; hydrogen is not new in the community with existing large-scale production, pipeline transport, use as feedstock, liquefaction and export. • Opportunities to collaborate with First Nations communities on projects and RD&D through Lambton College

8. Competitive Disadvantages & Key Barriers to Tackle

While the opportunities are significant, there are several inhibiting barriers and competitive disadvantages for the deployment and expansion of a low-carbon H_2ub in Sarnia-Lambton. To enable the forecasted demand and production to meet that demand, the H2ub will need to work together to tackle these barriers over the next few years.

Table 9 Competitive Disadvantages & Key Barriers for the H_2ub

Category	Key Barriers and Disadvantages
Hydrogen Demand in Region	• Lack of policies and incentives to drive uptake of low-carbon hydrogen for decarbonization: the Ontario EPS program does not currently recognize hydrogen blending for emissions reductions, there are no regulatory/policy drivers for decarbonizing grey hydrogen used as feedstock, and the large industry in the region is not sufficiently incentivized to purchase higher-cost low-carbon hydrogen to offset emissions. • Cost of low-carbon hydrogen in the near-term with limited projects will be high, difficult to compete with existing low-cost grey hydrogen production • A program for certifying and tracking carbon intensity of molecules for transactions will be needed to enable purchasers of low-carbon hydrogen to claim associated emissions reductions • Equipment conversions to enable industrial hydrogen blending in process heating systems requires an unclear pathway through TSSA (Technical Standards and Safety Authority) approval, not as simple as process changes in other regions such as Alberta
Hydrogen for Export	• Competition for market share of export markets will be high; ability to produce low-carbon hydrogen will be key
Hydrogen Production	• CCS is currently impermissible in Ontario, and with no current CO_2 pipeline in place to connect producers to CCS sites elsewhere, blue hydrogen production is currently not possible • High cost of electricity with the Global Adjustment fee is prohibitive to potential electrolytic hydrogen producers • Turquoise and dark green hydrogen production pathways are not currently commercially-ready, requiring further investment into RD&D before these pathways can provide hydrogen at scale and low-cost • Lack of awareness of the competitive advantages of the Sarnia-Lambton region for attracting low-carbon hydrogen production investment
Connecting Infrastructure	• Hydrogen pipeline network would need expansion or a new network built to connect in other potential producers. The Air Products network is restricted for very high-purity hydrogen as it feeds the Air Products Liquefaction plant. • Developing a CO_2 pipeline to enable CCS through external regions will be high-cost, and permitting new pipelines is very challenging
Research & Development	• No barriers identified; the region is well-positioned for attracting RD&D investment
Workforce & Training	• Currently there are few hydrogen ticket holders in the workforce compared to the natural gas G1, G2 and G3 system that exists for natural gas handling (information provided by Enbridge). A robust training system will be needed to ensure adequate workforce is ready to support the growing low-carbon hydrogen economy.

Category	Key Barriers and Disadvantages
Community	• Community engagement and education around hydrogen and the opportunities for decarbonization of heavy industry and other sectors through low-carbon hydrogen is non-existent to-date and needed

An Investment Attraction Action Plan has been developed to organize and prioritize actions that can be taken by the H_2ub Working Group to tackle these barriers. The draft Action Plan is provided in Part 4.

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Part 2: Roadmap

1. Introduction

By 2050, Ontario's Hydrogen Hub in Sarnia-Lambton could have a hydrogen market producing, trading and utilizing over 1 million tonnes of low-carbon hydrogen per year, supporting large-scale industrial decarbonization and net-zero targets while benefitting the local economy and communities.

The Roadmap presented in this section describes alignment with Canada and Ontario's published hydrogen strategies, key opportunities and technologies of focus along the low-carbon hydrogen value chain, and the envisioned Roadmap to 2050 for Ontario's Hydrogen Hub. Roles of SLEP and key stakeholders in growing and expanding the local hydrogen economy are discussed in Part 4: Investment Attraction Action Plan.

2. Alignment with Canada and Ontario's Hydrogen Strategies

Aligning Ontario's Hydrogen Hub in Sarnia-Lambton with Canada's Hydrogen Strategy and Ontario's Low-Carbon Hydrogen Strategy will be valuable for gaining federal and provincial support for the investment and policy changes needed to enable emerging opportunities.

The federal Strategy divides Canada's Hydrogen Roadmap to 2050 into three phases, which are in alignment with the forecasts and opportunities recognized for Sarnia-Lambton as follows:

- 2020-2025 (Near-Term): The federal Strategy focuses near-term efforts on identifying and supporting hydrogen hubs that can build on mature applications while demonstrating and advancing emerging applications of low-carbon hydrogen production and utilization. Sarnia-Lambton is an ideal location for such a hub, as identified and discussed throughout the Foundation Report. With an existing hydrogen market, pipeline network, applications in refining, chemicals, and fertilizer production, and export capabilities, Sarnia-Lambton is extremely well-positioned to be one of the core launching hubs for the low-carbon hydrogen economy in Canada. Currently, there is a lack of awareness of the opportunities of the region especially at the federal level and therefore promoting the local hydrogen hub will need to be a key focus of the action plan to attract federal support and investment. Major near-term opportunities for Ontario's H_2ub include Atura Power's planned investigation into an electrolysis facility at the prior Lambton Generating Station, which could provide the first at-scale source of low-carbon hydrogen for decarbonizing the local industry.
- 2025-2030 (Medium-Term): The federal Strategy focuses medium-term efforts on expanding the foundation of mature technologies, exploring diversification through demonstrations and pilot projects, and scaling-up emerging solutions and applications. On top of Sarnia-Lambton's strong base of mature technologies and applications for hydrogen production, transport, storage and end-use as a feedstock in refining, chemical, and fertilizer applications, are opportunities for expanding the market through emerging solutions and use-cases including:
    - Large-scale electrolytic hydrogen produced using the Ontario electric grid with smart control to optimize carbon intensity and electricity pricing
    - Bio-hydrogen production from agricultural and animal farming waste
    - Pyrolytic hydrogen production with an existing market for carbon black and potentially other solid carbon co-products
    - Hydrogen blending in natural gas to decarbonize heating in the local heavy industries
    - Hydrogen blending in natural gas power plants to support lowering the carbon intensity of the Ontario electric grid particularly during peaking periods

- Hydrogen blending into the local low-pressure natural gas distribution network to support decarbonizing residential and commercial heating

Demonstrations and pilot projects in these key opportunity areas for Sarnia-Lambton should be pursued in the years leading up to 2030 to support diversifying the hydrogen value chain while attracting public and private investment and expanding local knowledge and expertise. Sarnia-Lambton is well-positioned to provide a launching point for RD&D into the above production pathways and use-cases, with Lambton College potentially playing a key role in tying together industry-supported research and development with workforce and community education.

- 2030-2050 (Long-Term): From 2030 on, the federal Strategy focuses on rapid expansions and scale-ups of low-carbon hydrogen production and utilization as well as infrastructure for storage and transport. In Sarnia-Lambton, this will mean investment into expanding or developing additional pure-hydrogen pipeline networks to connect distributed supply with demand, developing salt caverns for large-scale hydrogen storage to balance, and supporting at-scale deployments of diversified low-carbon hydrogen production pathways. To enable blue hydrogen production at scale, CCS projects will need to be initiated in Southern Ontario or a dedicated CO_2 pipeline will need to be deployed to connect Sarnia-Lambton to CCS projects in Michigan or elsewhere in Eastern Canada.

Ontario's provincial Hydrogen Strategy recognizes the potential opportunities of Sarnia-Lambton as an early hydrogen hub, built on the strategic advantages of the existing chemical, refining, and fertilizer/ammonia industries and exports. The Ontario Strategy additionally identifies several key barriers emphasized by stakeholders in Sarnia-Lambton limiting the growth of the local hydrogen economy, including electricity pricing and enabling CCS, and more recently the Ontario Government has announced intentions to assess and tackle these barriers. Sarnia-Lambton has the potential to play a major role in the growth, diversification, and scale-up of the low-carbon economy in Ontario, and representatives or stakeholders from the region should engage with policy makers to promote and advocate for the region's opportunities and needs.

3. Key Opportunities Along the Low-Carbon Hydrogen Value Chain

The key opportunities, technologies, and sub-sectors of focus for the Sarnia-Lambton region along the low-carbon hydrogen value chain are identified in the table below in alignment with the Near-Term, Medium-Term, and Long-Term phases of the federal Hydrogen Strategy.

Table 10 Key Opportunities Along the Low-Carbon Hydrogen Value Chain in Near-, Medium-, and Long-Term

	Near-Term (2022-2025)	Medium-Term (2025-2030)	Long-Term (2030-2050)
Low-Carbon Hydrogen Production	• Atura Power's planned investigation into developing an electrolysis facility at the demolished Lambton Generating Station to produce electrolytic hydrogen from grid power offers a key landmark project for Ontario's H_2ub • Initiating collaborations, defining projects, and seeking funding for RD&D for bio-hydrogen and pyrolytic hydrogen	• Scaling up hydrogen production via electrolysis • Demonstrations and pilot projects for bio-hydrogen and pyrolytic hydrogen • Dependant on CCS policy changes, pursue a blue hydrogen demonstration by pairing CCS or CO_2 export to a CCS location with existing hydrogen production from natural gas to demonstrate the case for blue hydrogen production	• Scale-up deployments of all hydrogen production pathways, encouraging market competition to drive innovation and cost reductions • Once optimal at-scale deployments are demonstrated, rapidly deploy further large-scape hydrogen production plants to meet expanding demand and capture export opportunities

	Near-Term (2022-2025)	Medium-Term (2025-2030)	Long-Term (2030-2050)
Hydrogen Storage and Transport	• Explore and assess options for expanding the existing hydrogen pipeline network – can the Air Products network be built-out further, and/or develop a secondary network for applications that do not require fuel cell-grade purity (such as hydrogen blending into natural gas applications) • Explore and assess export options to deliver low-carbon hydrogen to anticipated markets in Ontario (i.e. Hamilton, Hwy 401) and Michigan	• Initial low-carbon hydrogen production and end-use projects are anticipated to be effective with above-ground storage solutions developed as project needs demand • Begin assessments and engineering and design for underground hydrogen storage in salt caverns – assess conversions vs. new developments • Expand the hydrogen pipeline network within Sarnia as determined through near-term assessments • Evaluate port, rail, road, and pipeline options for low-cost access to export markets for hydrogen, ammonia, and related low-carbon fuel projects	• Construct and commission salt caverns for large-scale hydrogen storage, grid balancing, and seasonal storage as the market grows • Develop export infrastructure as determined through medium-term assessments to enable low-cost, large-scale delivery of low-carbon hydrogen to export markets
Hydrogen End-Use	• Initiate collaborations, define scope of work, and seek funding for RD&D into hydrogen blending into natural gas to decarbonize industrial operations and natural gas power generation in Sarnia-Lambton • Engage with Enbridge and local municipalities to assess the low-pressure distribution network in Sarnia-Lambton for the next hydrogen blending pilot project in Ontario	• As costs fall for low-carbon hydrogen production, begin decarbonizing the existing hydrogen end-use market in refining, chemical, and fertilizer industries • Initiate demonstrations at selected facilities for hydrogen blending to reduce industrial heating emissions • Initiate low-blend levels of hydrogen blending into the natural gas distribution network feeding residential, commercial, and light-industrial end-users • Evaluate and potentially construct the first hydrogen fueling station in Sarnia to support traffic along Hwy 402	• Rapid scale-up of end-use applications as low-carbon hydrogen costs become increasingly cost-competitive • Equipment replacements and upgrades to enable up to 100% hydrogen at natural gas power plants and industrial heating applications (boilers, turbines, engines) • Equipment and pipeline network replacements to enable up to 100% hydrogen delivery for residential, commercial, and light-industrial heating

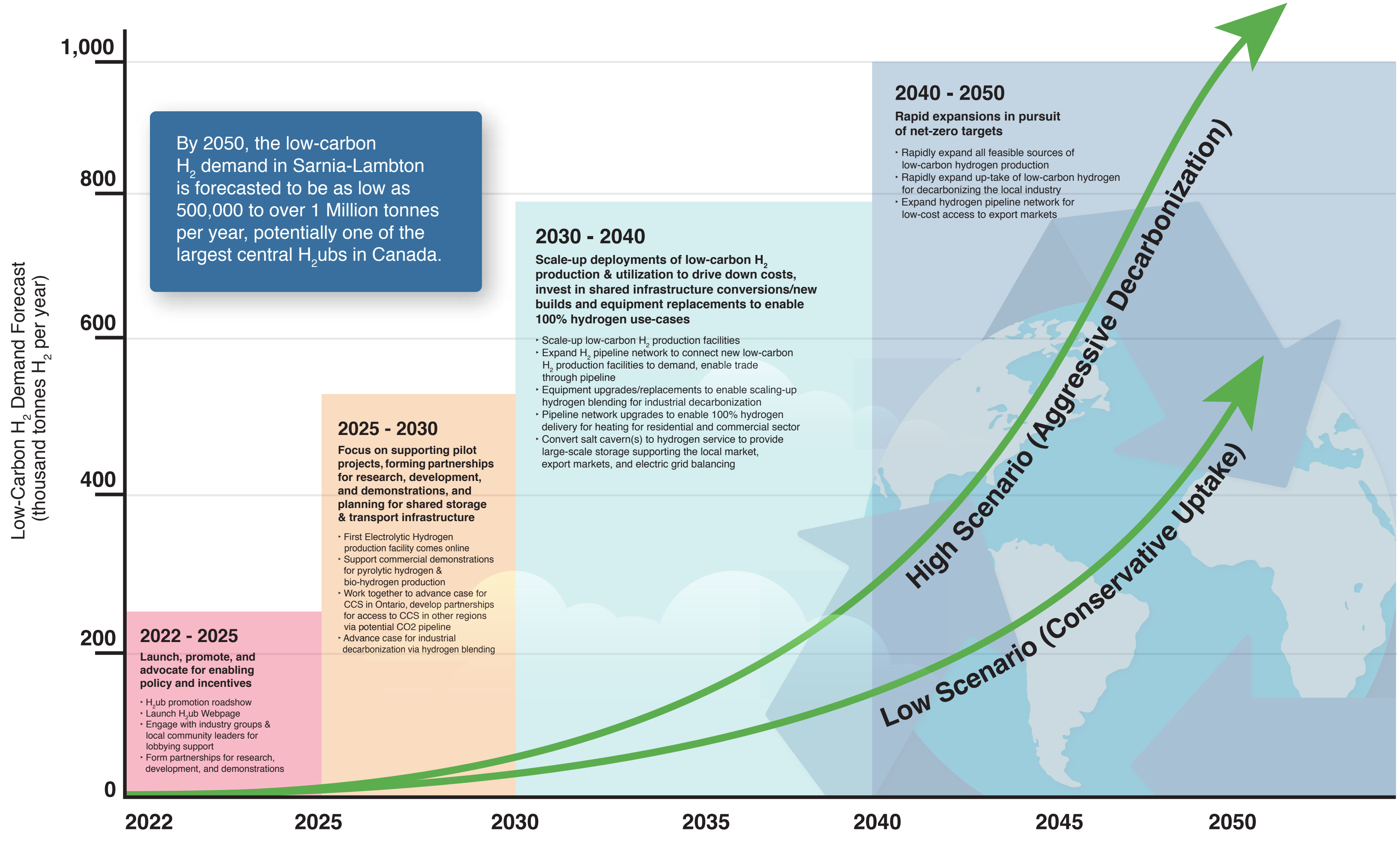
4. Roadmap to 2050

The Roadmap to 2050 for Sarnia-Lambton as Ontario's Hydrogen Hub ties together the forecasts for low-carbon hydrogen demand, the key opportunities identified, and the investment attraction action plan detailed in Part 4 of this report. The Roadmap is presented on the following page.

To enable and realize the key opportunities identified along the Roadmap, GHD has developed an Investment Attraction Action Plan presented in Part 4 of this report. The Investment Attraction Action Plan includes description on the recommended roles of key stakeholders in enabling the H_2ub Roadmap.

Ontario's H_2ub in Sarnia-Lambton

Roadmap to 2050



Near-Term Action Plan
To enable the potential low-carbon H_2 economy and capture opportunities for local growth and export, the H_2ub needs to collaborate to address a number of key challenges and barriers limiting low-carbon hydrogen production and adoption. These are divided into 6 Pillars of the Investment Attraction Action Plan:

Tackling Policy Together
Collaborate on advocating for local & provincial policy changes and incentives to enable the H_2ub, with a focus on CCS framework, electricity price incentives, and clear approval pathways for projects.

Broadcasting the H_2ub
Promote & advertise the advantages of the region to attract external investment, government attention on key needs, and public support. Create an online H_2ub platform and promote at conferences/events.

Partnering on RD&D
Industry-College collaboration to attract investment for RD&D, with focus on advancing low-cost H_2 production pathways and key potential use-cases such as industrial hydrogen blending.

Community Engagement & Education
Engage with local communities, First Nations, and community interest groups on H_2ub opportunities and concerns; get ahead of public perception challenges with targeted education and awareness.

Workforce Training & Education
Form a Program Advisory Committee at Lambton College with H_2ub industry stakeholders to advise on the introduction of hydrogen micro-credentials and upskilling. Engage with unions on opportunities.

Developing Shared Infrastructure
Work together to assess, coordinate, and plan cost-effective shared infrastructure opportunities, such as H_2 pipeline network expansion, underground H_2 storage, export infrastructure, and CCS.

Part 3: Economic Analysis

1. Introduction

The purpose of the Economic Analysis is to understand the costs associated with developing the Sarnia-Lambton H_2ub. To understand these costs and the competitive nature of developing a low-carbon hydrogen value chain, GHD has built a financial model to map out the Levelized Cost of Hydrogen (LCOH) for the proposed hub. LCOH represents all the capital and operating costs of producing hydrogen, and therefore enables comparing different production pathways, feedstock sources, etc. on a similar basis. The input costs have been estimated using an AACE Class 5 estimate. After the LCOH was developed, GHD has compared these values against known LCOH values of other hydrogen projects to evaluate cost competitiveness.

2. Scope limits

The following scope limits apply to the model:

- Due to limits of available input information, hydrogen production scope limits are strictly for electrolytic hydrogen production and blue hydrogen production facilities (costs associated with pyrolytic and biomass-derived hydrogen are too uncertain to estimate at this time)
- Blue hydrogen production assumptions include CCUS facilities with the scope limits being from sequestration to underground storage
- Shared Infrastructure scope limits include pipelines from production facility to injection into larger hydrogen pipeline network

3. Key Assumptions

To account for the lack of project definition of the H_2ub, GHD has made several assumptions that dictate the development of the cost competitiveness model. These assumptions can be found within Table 10 below.

Table 11 Key Assumptions for Cost Competitiveness Modelling

Assumption	Description
Accuracy Level	AACE Class V estimate meaning that capacity factored cost estimation was used due to low project definition (conceptual level). This will produce an accuracy value of ~ -50%/+100%
30 Year Basis	Assumed 30-year basis of operation for all levelized cost estimates
CAPEX Timing	CAPEX costs are incurred 1-year prior to commencement. Green hydrogen has additional 'development' costs which are incurred 2-years prior to commencement
CAPEX Scale – Hydrogen	All CAPEX production costs are based on real-world values scaled to the capacity that is estimated through the demand forecasts previously presented for Sarnia-Lambton
CAPEX Scale – CCUS	CCUS pricing is based off of actual projects located in the Northeast and Midwest USA.
Shared Infrastructure Timing	Shared Infrastructure is assumed to be completed once, upfront and sized to meet maximum demand

Assumption	Description
Utility Pricing	Power & Water prices are based on Aug 1 2022 Bluewater Power industrial park prices Electricity prices assumed were as follows: \$0.08/kWh off-peak, \$0.11/kWh mid-peak, and \$0.17/kWh at peak Natural Gas prices based on Enbridge Ontario South Zone Price
Utility Availability	All Utilities are assumed to be available on demand
Low Demand Scenario	Low demand scenario assumes the forecasts demand to 2050 as estimated in the Foundation Report. Demand is continuous and will be assumed to be met by production each year.
High Demand Scenario	High demand scenario assumes forecasted demand to 2050 as estimated in the Foundation Report. Demand is continuous and will be assumed to be met by production each year.
Blue Hydrogen Scenario	Blue hydrogen assumes a CCUS scenario; adding only CCUS infrastructure to existing Grey hydrogen production to meet low-carbon hydrogen demand (built on existing grey hydrogen production).
Hydrogen Type Mix	Blue hydrogen and Green hydrogen mix will change over the course of the H_2ub development. The current model assumes that low-carbon hydrogen production initially starts as all new development electrolytic hydrogen facilities, with blue hydrogen coming on overtime (as CCS is enabled or a CO_2 pipeline is put in place) and ends with a 50/50 split between the two production methods by 2050.
Hydrogen Production Utilization	Plant utilisation rate was set to 80% to account for planned and unplanned maintenance
CCUS Costs	CCUS Cost has been estimated to be approximately CAD \$200 per tonne of CO_2. While literature[7] has estimated cost to be approximately USD \$80 per tonne of CO_2, GHD adopted a conservative estimate approach.
Technical Inputs	All technical inputs have been based on GHD's previous projects and expertise and scaled to the appropriate value applicable to this project.
Carbon Price Escalation	Carbon Price assumed to escalate @ \$15/yr from \$65 at 2023 & cap at \$170 from 2030 onwards. While carbon price should grow past the \$170 mark, a cap here can be taken as a conservative estimate.
Carbon Savings Estimate Scope	Carbon estimation based on the saved carbon from the CCUS attachment to the existing grey H2 – This does not include scope 3 emissions.

4. Cost Competitiveness

GHD has developed a financial model that estimates the LCOH of low-carbon hydrogen that would be produced within the Sarnia Lambton region. From our estimates, it was found that the major cost for any hydrogen production was associated with the power required to operate these production facilities. After the production costs, CAPEX for electrolytic hydrogen production came out to be the 2nd highest cost. The LCOH breakdown of the hub can be found in the figures below for Low and High forecasted demand scenarios, respectively.

[7] Source: Schmelz WJ, Hochman G, Miller KG. 2020 Total cost of carbon capture and storage implemented at a regional scale: northeastern and midwestern United States. Interface Focus 10: 20190065. **https://royalsocietypublishing.org/doi/10.1098/rsfs.2019.0065**

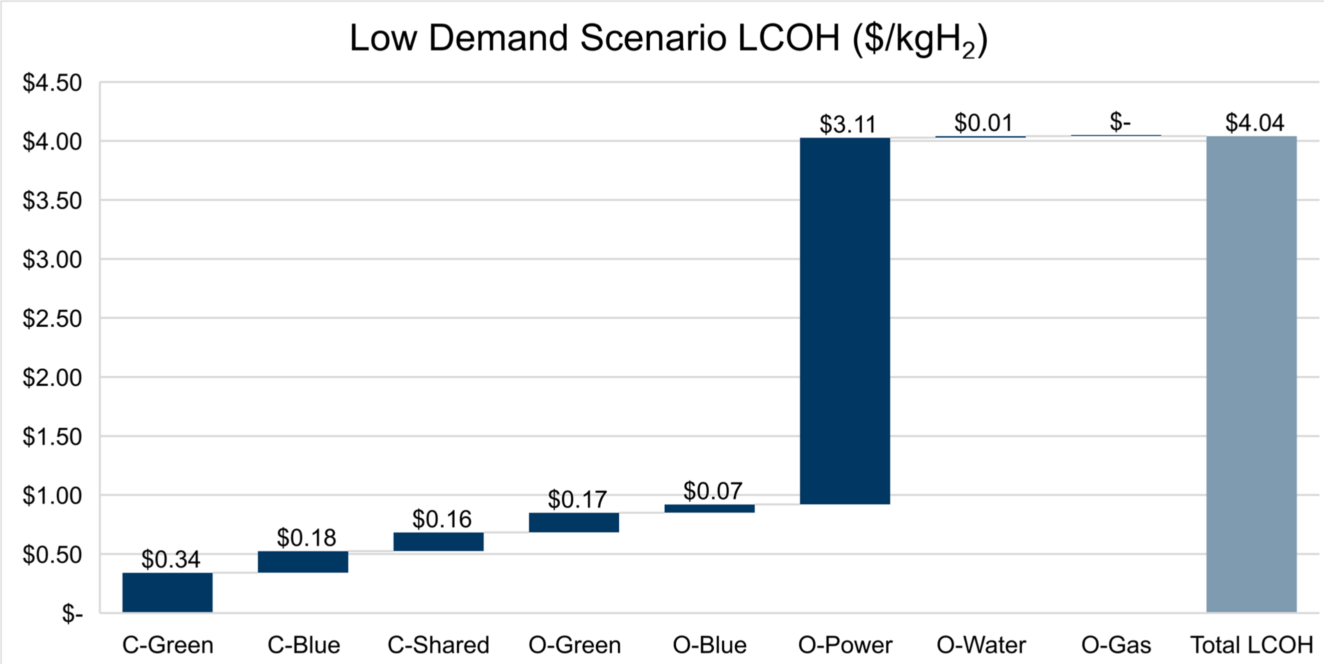


Figure 12 ***LCOH - Low Scenario (C- is for CAPEX, O- is for OPEX)***

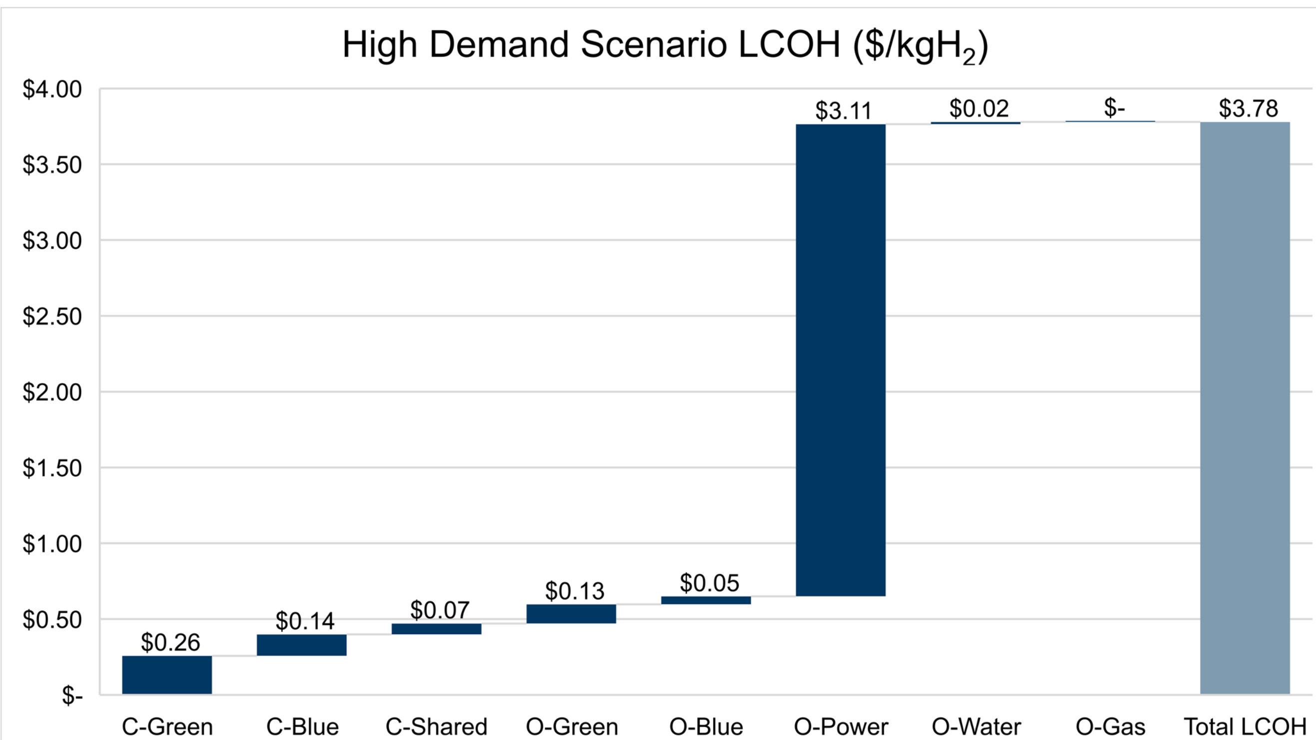


Figure 13 ***LCOH - High Scenario (C- is for CAPEX, O- is for OPEX)***

Note all costs are in CAD$.

The Sarnia-Lambton hub LCOH figures are above average when compared to other potential regional hubs, but these numbers need to be taken lightly considering they are a at an estimated -50%/+100% accuracy. The figure below shows the Sarnia-Lambton hub scenario costs compared to other regional hubs, utilizing outcomes from the 2022 NRCan Hydrogen Export Study completed by GHD and Zen Energy Solutions (not yet publicly available).

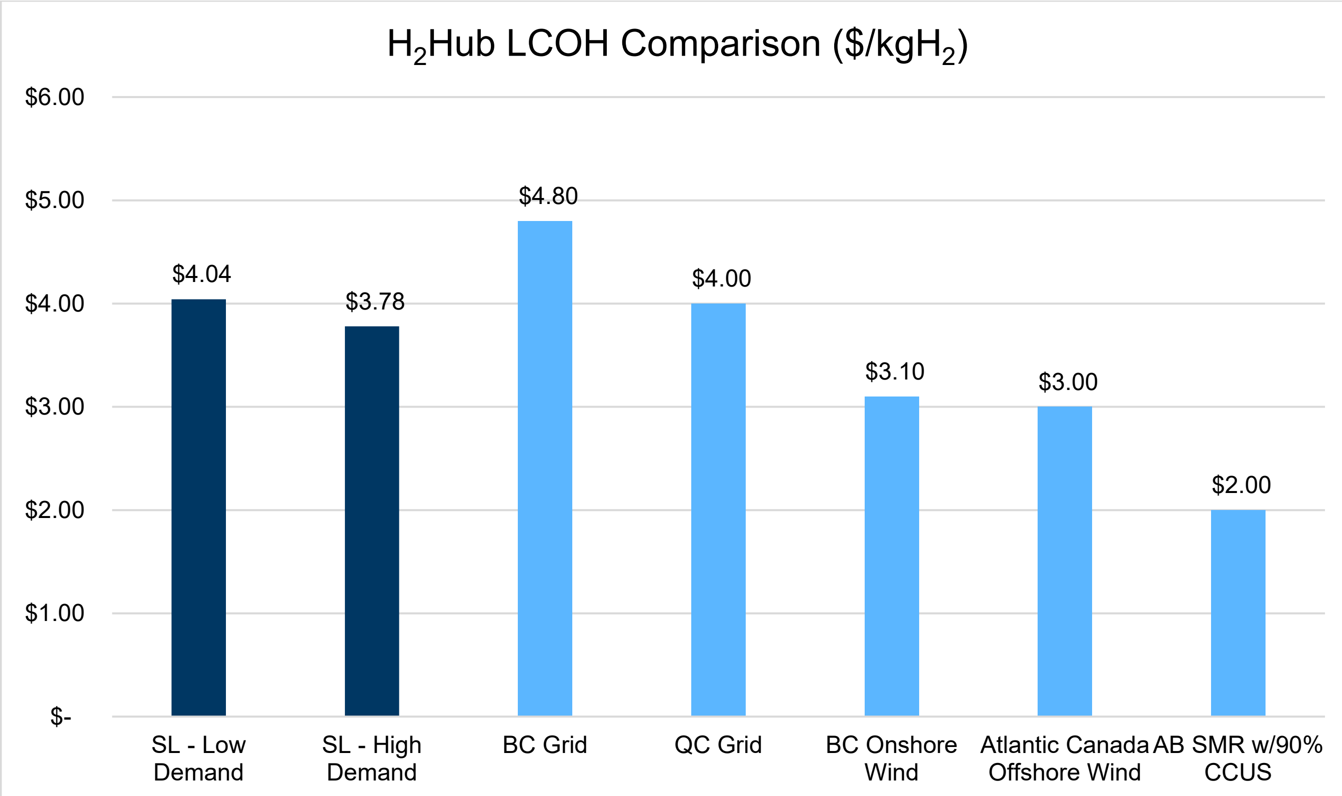


Figure 14 LCOH Cost Comparison[8]

To further incentivize the development of an H2Hub, one can look at increasing carbon prices as a driver for development. If looking at both the scenarios, there can be significant savings associated with the move from grey to blue H2 production. These savings were based on the assumption that carbon prices in Canada will rise to $170 by 2030 and remain at this cap for the project lifecycle. While this may likely not be the case, it will surely be a 'floor' estimate, as the number is expected to grow past $170 as Canada attempts to meet future carbon targets. Table 12 below shows the value of carbon sequestered over the evaluation period and Figure 16 shows this saving amount levelized to the H2 production of the hub.

Table 12 Lifetime Carbon Savings - Scope 1

Demand Scenario	Lifetime Carbon Savings (2025 $s)
Low Demand	$ 639,114,699.20
High Demand	$ 1,387,044,748.35

[8] Source: 2022 NRCan Hydrogen Export Study (GHD & Zen Energy project, not yet published)

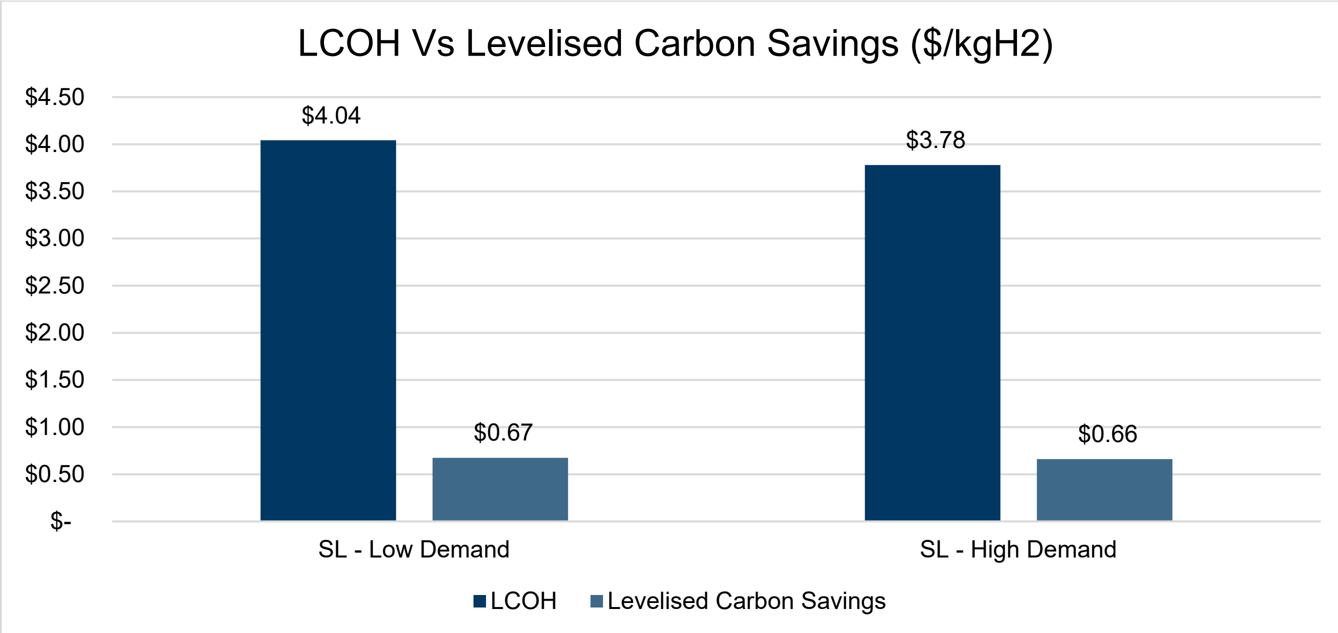


Figure 15 LCOH vs Levelized Carbon Savings

From both graphs, it can be seen that these numbers are not insignificant and can play a role in the incentivization of lowering production carbon footprints.

Overall the Sarnia-Lambton Hub was relatively aligned with the other regional hubs located around Canada. This being said these hubs take into account foreign export facilities for each of their dedicated H2 products. While this cost may be vary from hub to hub, if these costs were levelized to the same scope as the SL H_2ub, all other hubs' LCOH values can be expected to drop. Key takeaways are summarized below:

- Overall this hub aligns with the LCOH found of other hubs around Canada
- All LCOH values for the other hubs include the export infrastructure and operating costs
- Estimate is based on an AACE Class V level; numbers may vary quite drastically
- Levelized Carbon Savings can be used to offset the cost of the production hub
  - Carbon savings account for 16.5% of total LCOH for low demand scenario
  - Carbon savings account for 17.4% of total LCOH for high demand scenario

As electrolyzer efficiency increases and production capacity is increased, and other hydrogen production technologies become commercialized, the expectation is that capital and operating costs for equipment will decrease resulting in lower costs.

Part 4: Investment Attraction Action Plan

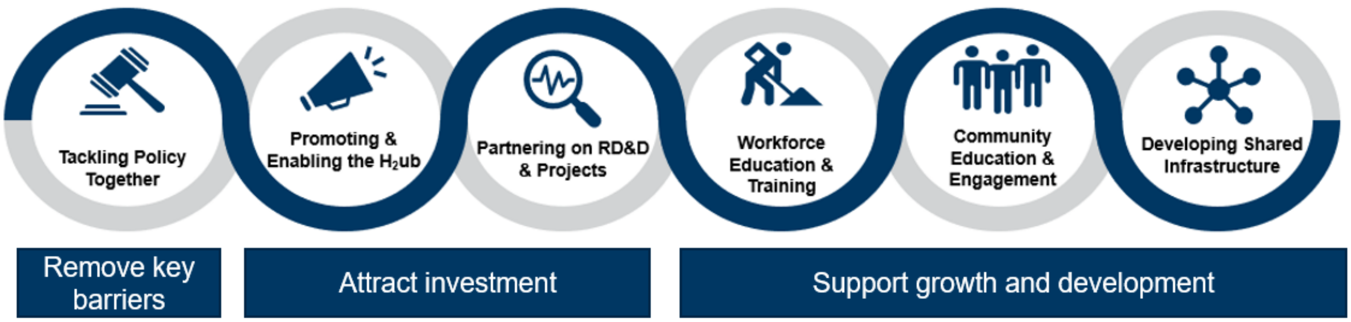
1. Introduction

The purpose of the Investment Attraction Action Plan is to provide recommended guidance on prioritized actions to address the key barriers and challenges identified in the Foundation Report. The Action Plan is focused on actions to be taken over the next 5-8 years to enable the local low-carbon hydrogen economy.

2. Investment Attraction Action Plan

To create an attractive environment for foreign and Canadian direct investment into the Sarnia-Lambton region in support of the Low-Carbon H_2ub requires first reducing or eliminating key policy and incentive barriers and developing a unified proposition to advertise the competitive advantages of the region. These are actions that can be led or supported by the SLEP and the H_2ub Working Group in collaboration with industry, academic, and government.

The Investment Attraction Action Plan is divided into the following key pillars:



The Investment Attraction Action Plan is detailed below. The majority of these items should be initiated in the coming years ahead of 2025 to form established task forces and enable stakeholders to seek public and private funding for prioritized projects and RD&D efforts. Actions within the pillars of Tackling Policy and Promoting and Enabling the H_2ub should be implemented with high priority in 2022/2023 to begin addressing the major barriers for the H_2ub (particularly policy and incentive barriers) and raising awareness with public and private investors on the many opportunities within the region.

Table 13 Pillars & Recommended Actions of the Investment Attraction Action Plan

Pillar	Purpose & Actions
Tackling Policy Together	Without a supportive regulatory environment, it will be extremely difficult to attract domestic and overseas investment. Through consultation with key stakeholders, it is clear that progressive policy and incentives are a pre-requisite to investment as the economic hurdle for low-carbon hydrogen is currently too high. Changes to policy and securing incentives to match best practice in other jurisdictions can be achieved through collaboration between industry and the local municipalities, industry groups, academia, and First Nations. This is an immediate priority for the H_2ub Working Group as the policy and regulatory barriers are the most significant threat to the potential low-carbon H_2ub. **Recommended Actions:** • Complete an evaluation of critical policy, regulatory barriers and potential changes that would benefit adoption of low-carbon hydrogen, utilizing learnings from other regions such as Alberta. ○ Key focus areas at provincial level include enabling CCS, lowering electricity costs for low-carbon hydrogen producers, incentives and policy/permitting

Pillar	Purpose & Actions
	support for industrial decarbonization through hydrogen utilization, attracting public investment and support ○ Key focus areas at federal level include attracting public investment and support, particularly for RD&D for emerging use-cases (ex. industrial decarbonization through hydrogen blending) and diversified low-carbon hydrogen production (ex. biomass-derived, methane pyrolysis, CCUS to enable blue hydrogen) ○ The evaluation should produce an agreed-upon list of priorities for lobbying for change at the provincial and federal levels and identify suitable candidates for advocating these changes (noting there is already such work under way by SLEP members). • Engage with local community leaders, First Nations, and politicians to educate on the H_2ub opportunities and need for lobbying for policy and incentives change • Engage with industry and local associations to educate on the H_2ub opportunities and needs for policy and incentives changes, to increase the potential impact of lobbying through these industry groups. Industry groups that members of the H_2ub Working Group are already a part of and who can be good avenues for tackling policy together include: ○ Canadian Hydrogen and Fuel Cell Association (CHFCA) ○ Hydrogen Business Council of Canada (HBC) ○ Clean Air Alliance ○ Chemical Manufacturing Association ○ Canadian Gas Association ○ Canadian Fuels Association ○ Electricity Distributors Association ○ Energy Storage Canada ○ Association of Major Power Consumers in Ontario (AMPCO) ○ Chemical Industry Association of Canada ○ Ontario Municipal Association ○ Transition Accelerator **Suggested performance measures** • Development of a critical policy review and identification of suitable champions to promote change • Securing support for policy change from at least one First Nation community • Realization of at least two critical policy changes within the next 5 years
Promoting & Enabling the H_2ub	SLEP can play a key role in developing materials for promoting and advertising the strategic advantages of the H_2ub, engaging potential market participants and investors with information on the opportunities, and connecting market players. **Recommended Actions:** • Develop a Sarnia-Lambton H_2ub campaign to promote the H_2ub at hydrogen and industry conferences, engage news organizations to publish the H_2ub narrative and potential opportunities, national television segments and updates. Develop a public storyboard or clear and succinct narrative to promote and sell the opportunities. • Broadcast and promote the Sarnia-Lambton H_2ub opportunities and competitive advantages; develop a public and investor attraction storyboard with a clear and succinct narrative to promote and sell the opportunities • Form an Investment Attraction Task Force to drive investment opportunities, including tasks such as: ○ Identify a list of larger private equity investors (International, US and Canada) and develop a plan to contact them to promote the Hub and attract funding ○ Develop "mini-business" cases for various production/infrastructure projects and various end uses/revenues. Identify key factors which drive costs and revenue, and share findings with investors.

Pillar	Purpose & Actions
	○ Actively track Federal and Provincial funding opportunities and support members applications to obtain funding, including for clean energy, hydrogen, RD&D, and brownfield projects ○ Prepare a risk register around strategy and roadmap implementation to identify and prioritize significant risks to manage to de-risk implementation. Plan ongoing reviews and updates (e.g., yearly) • Add further details and contact information to SLEP's website landing page at **www.ontarioshydrogenhub.com** for hydrogen opportunities in the region. The landing page for the H$_2$ub should serve as a central point for connecting in new stakeholders to the H$_2$ub, advertising landmark projects, and promoting the opportunities for investments and partnerships. • Develop a central point for connecting in new stakeholders to the H$_2$ub: potentially through a web-form or contact information provided on SLEP's website, provide potential H$_2$ub stakeholders and investors with a central point of contact for inquiries and requests to join the H$_2$ub working group • Engage with the Michigan H$_2$ub to encourage cross-border partnerships and trade and to get ahead of potential political challenges with pore space for CCS shared between Ontario and Michigan • Engage with other hubs and associations to encourage collaboration for advancing the case for Ontario's Hydrogen Hub (Canadian Hydrogen and Fuel Cell Association (CHFCA), Hydrogen Business Council of Canada (HBC), Atlantic Hydrogen Alliance (AHA), CanmetENERGY-Ottawa, Transition Accelerator) **Suggested performance measures** • Develop the Sarnia-Lambton H$_2$ub campaign and updated website. • Support (through involvement in) at least 5 major ($10M+ investment) hydrogen production projects within the next 10 years • Assist external parties to secure at least $5M in grant / funding within the next 10 years
Partnering on RD&D and Landmark Projects	SLEP can play a significant role in supporting future investment in RD&D activities, and particularly attraction foreign direct investment to these projects, with a focus on projects that enable the key opportunities for the H$_2$ub such as driving down costs for low-carbon hydrogen production, advancing the technology readiness levels of bio-hydrogen and pyrolytic hydrogen production, and tackling technical challenges for industrial decarbonization through hydrogen blending. Advances in these research efforts will in turn incentivise greater public and private investment in the local hydrogen economy. **Recommended Actions:** • Form a RD&D Task Force within the SLEP H$_2$ub Working Group to identify, plan, prioritize, and forge collaborations for defining RD&D projects and seeking funding / attracting investment for projects together. The Task Force should include leading industry and research institutions, such as Lambton College, Bowman Centre for Sustainability and CanmetENERGY-Ottawa. Funding support can be sought from NRCan's various funding programs, the federal Strategic Innovation Fund, Natural Gas Innovation Fund, and others, as well as private equity funding sources. Key recommended actions for the Task Force to tackle include: ○ Develop a list of RD&D priorities for enabling the H$_2$ub Roadmap, planned projects, and potential projects, and prioritize potential RD&D efforts to support the projects with the highest probability of success ○ Support the formation of cross-industry collaborations for key identified RD&D projects, such as hydrogen blending into industrial natural gas heating systems and power generation plants, bio-hydrogen and pyrolytic hydrogen production, advancing the case for CCS in Southern Ontario, etc. ○ Assist external parties to secure funding opportunities (whether private or public) by providing appropriate economic impact or marketing materials, or by connecting participants.

Pillar	Purpose & Actions
	○ Actively track Federal and Provincial funding opportunities particularly for RD&D projects and support project collaborations with applications to obtain funding • Support Atura Power in advancing the business case for the first landmark electrolysis facility in the H_2ub located (potentially) at the former Lambton Generating Station. This project could provide the first large-scale source of low-carbon hydrogen in the region. • Support and engage with Enbridge on assessing the potential and attracting investment for blending hydrogen into the local low-pressure natural gas network feeding residential, commercial, and light-industrial customers, and connecting in low-carbon hydrogen supply produced within the region • Compile a list of unused/ available industrial properties and evaluate their potential attributes (e.g., proximity) to support H_2ub development • Develop similar collaboration between industry and Lambton College as the Bio-Industrial Innovation Canada collaboration recently announced in Sarnia-Lambton **Suggested performance measures** • Form an RD&D Task Force • Support (through involvement in) at least $3M investment in research efforts over the next 10 years • Realize at least $5M in net economic benefit from successful RD&D projects in the region over the next 10 years
Workforce Education & Training	Collaborating to prepare for workforce needs and attract workers to hydrogen-related training programs to stay ahead of the industry demand. Encouraging greater collaboration between industry and educational providers through research endeavours. **Recommended Actions:** • Form a Program Advisory Committee (PAC) for Lambton College with industry and H_2ub stakeholders to advise on hydrogen programming at the College • Engage with local unions on the workforce opportunities and skills needed **Suggested performance measures** • Work with local education providers to define an appropriate target for securing locally trained graduates full time jobs within the region.
Community Education & Engagement	Early First Nations and community engagement will be key for early and landmark projects, which have higher risk of community opposition resulting in significant delays or shutting down projects entirely. Education is needed on low-carbon hydrogen production pathways (i.e. "it's not just green"), use-cases, potential emissions reductions, environmental and community benefits, safety and environment. **Recommended Actions:** • Prior to engagement, the H_2ub needs to agree upon the vision and opportunities to communicate. Education and communication needs to be backed by action and investment to avoid perceptions of greenwashing. A Community Engagement Task Force can be formed within the H_2ub Working Group to develop an engagement plan and approach. • Engage and build relationships with local First Nations to explore opportunities for collaboration and lasting community benefits through the H_2ub. Effective partnerships with First Nations can provide invaluable benefits to projects and the communities in which they operate, ensuring projects are developed with community benefits in mind from the start. Ideally, First Nations community leaders should be invited to participate and have a voice in the H_2ub Working Group and Task Forces. • Produce public education material about the need for decarbonization and the opportunities presented by a low-carbon hydrogen economy, engage with the public through social media, TV/news campaigns, and other public education platforms in collaboration with municipalities and community leaders • Pursue community engagement and education through Lambton College and other local organization with strong existing relationships with the community

Pillar	Purpose & Actions
	• Invite local politicians, community leaders, and First Nations leaders to join the H_2ub Working Group directly **Suggested performance measures** • Securing support for policy change from at least one First Nation community • Develop at least 1 public education campaign to engage the community on the benefits of a local hydrogen economy

Developing Shared Infrastructure	Collaborating and partnering to develop shared infrastructure to the broad benefit of enabling an interconnected H_2ub, connecting supply and demand with low-cost transport and storage will lower the cost of entry for potential investors in increase the region's overall attractiveness as a hydrogen hub. Shared infrastructure may include pipelines, storage facilities and caverns, etc.
	Recommended Actions:
	• Form a Shared Infrastructure Task Force within the H_2ub Working Group to collaborate and jointly-fund opportunities, costs, and needs for building out shared infrastructure. The purpose of the Task Force will be to develop a prioritized plan for implementation and investment, addressing the following key actions:
	    o Evaluate existing hydrogen pipeline network and opportunities/challenges with expanding or alternatively developing a secondary network that can connect hydrogen for lower-purity applications such as blending into natural gas (given that the existing Air Products network is required to be high-purity since it feeds Air Products' liquefaction plant). Air Products should be closely engaged or in a leadership role in this task given their extensive experience, expertise, and existing role.
	    o Determine which types and locations of shared infrastructure should be prioritized to align with the roadmap goals and timing
	    o Evaluate options and potential timelines for developing salt caverns for underground hydrogen storage in support of the H_2ub Roadmap. This is a lower priority item for the current time as salt cavern storage is envisioned to be needed in the 2030's to support at-scale growth. Pembina and Plains should be closely involved in these assessments.
	    o Complete a delivery infrastructure study to determine existing capacity for hydrogen export (tube trailers, road, rail, marine, pipeline) and the required increase in capacity to support strategy/roadmap implementation
	• Shared infrastructure opportunities may include:
	    o Expanding the existing high-purity hydrogen pipeline network owned and operated by Air Products
	    o Developing a new hydrogen pipeline network, which can have lower-purity requirements than the Air Products network for supplying industry for hydrogen blending in natural gas
	    o Converting existing salt caverns to hydrogen service to provide seasonal energy storage and grid balancing
	    o Developing new hydrogen export infrastructure, such as a dedicated export pipeline, to access high-demand markets that develop over time
	    o CCS opportunities and CO_2 transport pipelines
	Suggested performance measures
	• Support (through involvement/facilitation in) at least $5M investment in joint hydrogen infrastructure over the next 10 years.

3. Sequencing

The following timing is proposed for commencement of the Action Plan recommendations. Timings would need to be reviewed as progress occurs, and potentially accelerated or delayed based on eventual circumstances. Years are defined as following the finalized Strategic Plan, therefore Year 1 is late 2022 to late 2023.

Table 14 Proposed timing for commencement of Action Plan recommendations

	Year 1	Year 2	Year 3	Year 4-5
Tackling Policy Together				
Evaluation of critical policy, regulation barriers and potential changes	✓			
Engage with local community		✓		
Engage with industry and local associations	✓			
Promoting & Enabling the H_2ub				
Develop Sarnia-Lambton H_2ub campaign	✓			
Broadcast and promote the Sarnia-Lambton H_2ub		✓		
Form an Investment Attraction Task Force				✓
Update the SLEP website		✓		
Add centralized point of contact for H_2ub stakeholder engagement	✓			
Engage with Michigan H_2ub		✓		
Engage with other hubs and associations to advance the case for Ontario's Hydrogen Hub		✓		
Partnering on RD&D and Landmark Projects				
Form an RD&D Task Force	✓			
Support Atura Power for electrolysis facility		✓		
Support and engage with Enbridge on blending opportunities			✓	
Compile a list of unused/available industrial sites and evaluate for potential developments			✓	
Workforce Education & Training				
Form a PAC for Lambton College with industry and H_2ub stakeholders			✓	
Engage with local unions on the workforce opportunities and skills needed			✓	
Community Education & Engagement				
Form a Community Engagement Task Force	✓			
Engage with local First Nations to explore opportunities		✓		
Produce public education materials to educate and promote opportunities		✓		
Community engagement and education through Lambton College and other local community organizations				✓
Invite local politicians, community leaders, and First Nations leaders to join H_2ub working group		✓		
Developing Shared Infrastructure				
Form a Shared Infrastructure Task Force			✓	

4. Foreign Direct Investment

Canada is considered one of the most attractive countries in the world for foreign investment with global investment in Canada reaching a 15-year high of over $75.5 billion in Foreign Direct Investment (FDI)[9] in 2021. The majority of this investment was made through multi-national organizations already operating in Canada, and it is important to note that many of the major players in the hydrogen industry have significant foreign ownership – Air Products' largest shareholders are The Vanguard Group and Blackrock, Enbridge's 2nd and 3rd largest shareholders are GQG Partners and The Vanguard Group, Air Liquide is a French owned organization.

The incentives required to increase FDI from major international companies into Sarnia-Lambton's hydrogen economy are not dissimilar to those required to encourage investment from major domestic players. The focus should be on removing the regulatory barriers, promotion of the benefits of the region, and providing a centralized authority for information dissemination and facilitation of queries.

4.1 Organization and positioning

The following factors will be key for organizing and positioning for FDI:

- As discussed in previous sections, there are clear barriers (e.g. CCS restrictions, electricity pricing, emission reductions through blending) which need to be resolved through future regulation as a pre-requisite to future investment (domestic or foreign) in the H_2ub. While the Ontario provincial government has stated intentions to review and address these key barriers, monitoring, industry input, and support for changes to these policies needs to continue as a high priority.
- A "one-stop shop" or dedicated owner for the region to handle investor enquiries needs to be identified and stated on SLEP's H_2ub webpage. This owner should have a clear understanding of the current legal and economic context of the region as it relates to hydrogen infrastructure development. The logical organization to take this role is SLEP.
- A dedicated attempt to map local regulatory requirements against targeted countries for FDI would help reduce the barrier for overseas investors. This can include both hydrogen specific regulation but also more general regulation such as health and safety related to hydrogen, labour laws, relevant manufacturing standards, etc. This is all work that otherwise needs to be done by the investor and having it easily accessible effectively lowers that barrier to entry. It can also be an opportunity to clarify any legal ambiguity between two countries regulations, or the implications of importing machinery and parts.
- While the Sarnia-Lambton region has a clear advantage as a potential H_2ub, this potential and strong certainty of success needs to be communicated to provincial and national level Investment Promotion Agencies (IPAs) such as Invest Ontario and Invest Canada to ensure that the region is consistently recommended at the highest levels.
- The region needs to identify what specific incentives can be offered to prospective investors. A clear process for reviewing and negotiating incentives for FDI should also be established. Resources of entities such as Invest Canada who have a strong track-record of directly engaging with global investors to invest in Canada. Programs like Invest Canada-Community Initiatives (ICCI) and CanExport Community Investments are specifically established to assist local regions to attract foreign investment.

4.2 Attraction and facilitation

The following items can be considered for attracting and facilitating FDI:

- Websites can be a high-impact and cost-effective marketing tool, often these platforms can tailor information based on the location of the visitor. Some of the leading practices include providing specialized sector databases with contacts for local suppliers and contractors for potential investors to engage.

[9] Statistics Canada - **Table: 36-10-0473-01**

- – Local supplier capabilities should be well understood and a clear framework for evaluating potential suppliers against the requirements of specific investors should be established. Where gaps exist, foreign suppliers with strong partnerships with local SMEs should be identified.
- – Queries need to be well-managed and ideally centralized to ensure that information and advice provided is accurate and consistent.
- – “Supplier days” or match-making events focused on a particular theme or investor requirement can efficiently connect investors and pre-screen suppliers to discuss products and services.

4.3 Aftercare programs

It is also important to provide aftercare services to retain investors and encourage further investment. Clear responsibility for regular contact with investors should identified, and foreign investment and involvement in local projects accurately monitored and reported.

4.4 Target Subsectors and Target Markets

This Strategic Plan has identified a variety of target subsectors over the short and long term for Sarnia-Lambton’s potential low-carbon hydrogen economy. These, and potentially other subsectors or industry segments, represent opportunities to target foreign direct investment. These include the following that are highlighted in the Roadmap to 2050:

- Electrolytic hydrogen (Target markets for FDI include – Japan, USA, Germany, UK) – particularly near-term implementation with Atura Power and scale-up of electrolyzers, opportunities for grid-scale storage paired with Sarnia-Lambton’s salt cavern resources
- Pyrolytic Hydrogen (Target markets for FDI include – Europe, USA) – particularly for research and demonstration opportunities, Sarnia-Lambton is an attractive location for commercial demonstration projects considering local solid carbon product markets through Cabot Canada and uses in Hamilton’s steel industry
- Bio-Hydrogen (Target markets for FDI include – Japan, Netherlands, USA) – particularly for research and demonstration opportunities, Sarnia-Lambton is attractive location for RD&D and commercial demonstrations given the existing hydrogen demand and vast biomass feedstock resources from agriculture and animal raising industries
- CCS technologies (Target markets for FDI include – USA, Germany, Taiwan, South Korea) – particularly for development of CCS or carbon utilization opportunities in Southern Ontario

Additionally, many companies already operating in Canada, and even actively as part of the Sarnia-Lambton hub represent internationally-owned companies that may expand, diversity, or re-invest in their facilities or capabilities in Canada. Sarnia-Lambton could target the local and international parent offices of companies such as:

- Air Products (U.S.)
- Air Liquide S.A. (France)
- Shell PLC (UK)
- Linde PLC (Germany)
- Plains Midstream (parent company Plains All American Pipeline L.P.)
- Imperial Oil (majority owned by U.S. oil company ExxonMobil)

As indicated in the target subsectors and industry segments, there are key target markets to focus FDI attraction efforts. Across the low-carbon hydrogen industry, the following countries will represent the most opportunity to achieve capital investment into Sarnia-Lambton for reasons described:

- USA (focus on Michigan – hydrogen hub efforts and potential for CO_2 export from Sarnia-Lambton to Michigan for storage – as well as Gulf Coast, in addition to major hydrogen equipment manufacturers such as Plug Power [electrolyzers], Monolith Corp [pyrolysis technology],)
- Germany (particularly given Germany's investments into hydrogen partnerships in Canada through the Canada-Germany Hydrogen Alliance, and major equipment manufacturers such as Siemens, Thyssenkrupp)
- Japan (Japan is highly invested into diversifying energy away from oil and gas and towards low-carbon solutions including hydrogen and waste-to-energy, with investment into hydrogen infrastructure funds globally and significant push from Japanese automobile and mobile equipment manufacturers to advance global markets for fuel cell electric vehicles and equipment [Toyota, Honda, Kawasaki, Yamaha])
- France (target support and growth of Air Liquide and Linde facilities and operations in Sarnia-Lambton)
- Italy (Italian companies Enel and Maire Tecnimont (and subsidiary NextChem) are collaborating on investment into the U.S. to build hydrogen production plants, and may be attracted to invest in Canada as well. Italy's Snam is a world leader in hydrogen blending into natural gas networks.)
- South Korea (investing globally into advancement of Hyundai hydrogen-powered vehicle markets [NEXO])
- U.K. (investing in hydrogen production, blending, and full conversion of natural gas end-use systems to hydrogen, in addition to global manufacturers such as ITM Power [electrolyzers]

5. Associated budgets

The following budgets have been developed to provide a high-level indication of resourcing requirements to deliver the Action Plan recommendations:

Year 1

– 3 FTE ($360,000)
– Consultants ($300,000)
– Miscellaneous and contingency ($70,000)
– **Total: $730,000** (Note: Budget for media campaign not included. This will depend on defined scope of campaign)

Year 2

– 3 FTE ($360,000)
– Consultants ($300,000)
– Website update ($100,000)
– Miscellaneous and contingency ($80,000)
– **Total: $840,000** (Note: Budget for media campaign not included. This will depend on defined scope of campaign)

Year 3 & 4

– 2 FTE ($240,000)
– Consultants ($150,000)
– Miscellaneous and contingency ($40,000)
– **Total: $430,000**

6. Stakeholder Roles in Ontario's Hydrogen Hub Roadmap & Investment Attraction Action Plan

Key stakeholders in Ontario's H_2ub were identified and discussed in the Foundation Report. In support of implementing the Roadmap and Investment Attraction Action Plan, the below Call to Action for Key Stakeholders outlines recommended stakeholder roles and participation for advancing and enabling the many opportunities of Ontario's H_2ub. The Call to Action represents recommendations only – the role and level of participation is ultimately up to each stakeholder to decide.

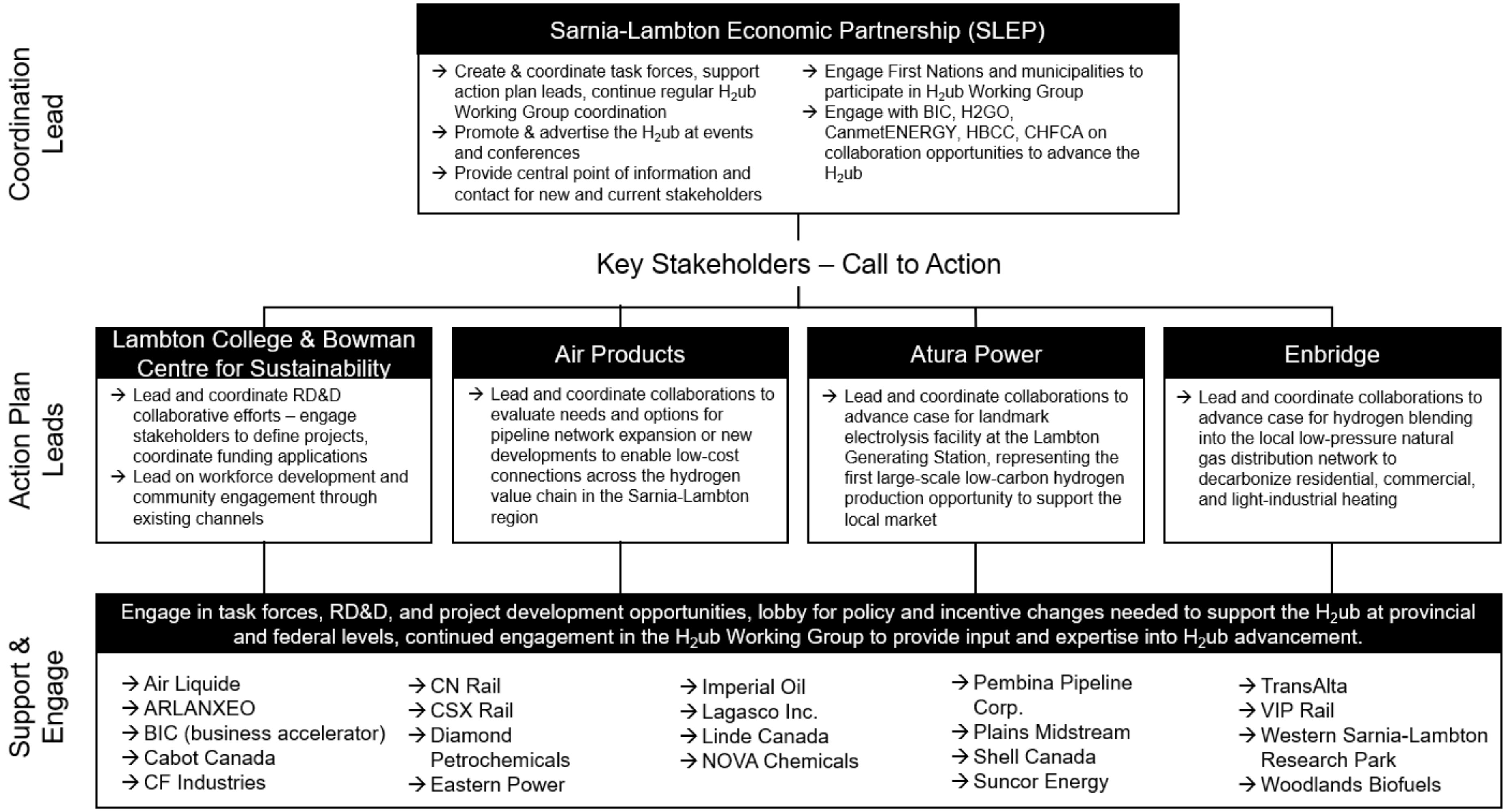


Figure 16 Call to Action for Key Stakeholders

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The Power of Commitment