Decarbonizing Industrial Heating

Report

Key findings and assessments from phase one of the research project, Decarbonizing Nova Scotia's Industrial Sector with Green Hydrogen.

December 2024

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Decarbonizing Nova Scotia's Industrial Sector with Green Hydrogen

Phase 1 – Use Cases of Hydrogen in Industrial Process Heating Within Nova Scotia

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Executive Summary

This study provides an analysis of cumulative efforts in Nova Scotia's transition towards the use of low-carbon alternative fuels, emphasizing the role of hydrogen in decarbonizing energy-intensive sectors.

Policy and regulations are examined first. In the province, the regulatory framework is shaped by federal initiatives such as Canada's Pan-Canadian Framework on Clean Growth and Climate Change, the 2030 Emissions Reduction Plan, Clean Fuel Regulations, and Clean Energy Regulations. These federal initiatives are complemented by provincial measures such as the Output-Based Pricing System and the Environmental Goals and Climate Change Reduction Act. Together, these policies aim to reduce greenhouse gas (GHG) emissions, enhance energy efficiency, and support the adoption of clean technologies, laying the foundation for a sustainable industrial landscape in Nova Scotia.

Key sectors examined as a part of this study include power generation, pulp and paper, cement, clay brick, chemicals, marine shipping, and food production, along with large institutions like hospitals and universities. These industries rely on high-temperature processes that demand substantial thermal energy and emit high amounts of GHG, underscoring the need for decarbonization to meet Nova Scotia's emissions reduction targets. Strategies overviewed in the study include electrification with renewable energy, carbon capture and storage (CCS), biomass utilization, and the integration of blue and green hydrogen. Among these, hydrogen options were a primary focus, with a review of their production, storage, transportation, and financial viability for industrial applications, while other technologies were presented as broader decarbonization pathways.

Nova Scotia's strategic position in the global clean hydrogen market is bolstered by its rich renewable energy resources, including onshore and offshore wind, which are pivotal for green hydrogen production. The province is actively enabling green hydrogen projects aimed at both export and domestic applications. Nova Scotia's deep-water harbors, proximity to European markets, and developing infrastructure position the region as an emerging hub for hydrogen export, aligning with federal policies and international collaborations, such as partnerships with other nations to establish a transatlantic supply corridor.

The study also explores the potential of hydrogen in decarbonizing industrial process heating, which accounts for nearly 25% of global energy demand and is currently dominated by fossil fuels. According to Canada Energy Regulator's data, in Nova Scotia in 2020, the end-use energy demand by fuels are 60% from refined petroleum products, followed by 39% electricity, 11% biofuels and 8% of natural gas. The financial analysis on green hydrogen production and its future cost indicates a promising downward trend in hydrogen cost over time. This is largely attributed to technological advancements in electrolysis and improved efficiencies in hydrogen production methods. As carbon pricing mechanisms become increasingly stringent, the cost parity between hydrogen and traditional fuels is expected to improve further.

Based on our findings, green hydrogen offers a viable pathway for high-temperature applications, although challenges persist, including modifications to flame characteristics, burner designs, and existing equipment. Despite these hurdles, hydrogen-ready technologies, such as boilers, burners, and turbines, are gradually being considered, driven by local hydrogen production initiatives and favorable infrastructure in Nova Scotia.

Furthermore, case studies from around the world demonstrate the growing role of hydrogen in industrial applications. For instance, CEMEX has integrated hydrogen into cement production in Europe and the Americas, while Hanson UK has achieved climate-neutral fuel blends in its cement kilns. In ceramics, Henan Zhongqi Ceramics in China has successfully utilized high-hydrogen blends, and in the pulp and paper sector, Palm's mill in Germany and the HYFLEXPOWER project in France showcase hydrogen's use in combined

heat and power systems. The steel industry is seeing transformative initiatives like HYBRIT in Sweden, which aims to produce fossil-free steel using hydrogen, and ArcelorMittal’s trials in Canada which aim to replace natural gas with hydrogen in iron reduction processes. These many examples illustrate hydrogen’s versatility and the complex challenges of scaling its use across diverse industrial sectors and paving the way for broader adoption in the journey towards a low-carbon economy.

Ultimately, Nova Scotia's potential for an integrated approach encompassing policy support, technological innovation, and geographic location places it in a competitive position within the global clean energy transition with the most significant potential for being a leader in the decarbonization of industrial and manufacturing sectors, both locally and internationally.

The study is supported by the Nova Scotia Department of Natural Resources and Renewables, Michelin North America Inc., Port Hawkesbury Paper, and The Shaw Group.

0. Introduction

0.1 Purpose

The purpose of this study is to explore the integration of hydrogen technologies into industrial process heating applications in Nova Scotia and provide valuable insights to all stakeholders, including policymakers, industry organizations, and the public, to support Nova Scotia's transition to low-carbon alternative fuels. This study assesses the potential of hydrogen to decarbonize industrial processes and contribute to sustainable economic growth in the province.

0.2 Study Scope

This study provides an overview of the integration of hydrogen technologies into industrial process heating in Nova Scotia, focusing on their potential to decarbonize the sector. It begins by reviewing the regulatory landscape and examining key policies and conditions influencing the transition to low-carbon fuels. The study overviews the heating needs of Nova Scotia's heavy industry and manufacturing sectors. It explores available technologies and alternative fuels for decarbonizing process heat, reviewing their readiness, costs, and applicability within the local context.

Additionally, the study analyses the current and future state of hydrogen production, distribution, and use in Nova Scotia, emphasizing the shift to green hydrogen. It assesses the feasibility of integrating hydrogen technologies into industrial heating, considering options such as hydrogen blending, hydrogen-ready equipment, and hydrogen-only systems. The study includes case studies of successful hydrogen integration in industrial processes, offering insights and lessons learned. Finally, it synthesizes the findings and conclusions, highlighting available funding mechanisms to support the adoption of hydrogen technologies in the province. This approach provides stakeholders with a valuable understanding of hydrogen's potential role in supporting Nova Scotia's decarbonization goals.

0.3 Acronyms and Definitions

0.3.1 Acronyms

Acronym	Definition
CAD	Canadian Dollars
CCUS	Carbon Capture, Utilisation and Storage
CI	Carbon Intensity
COMFIT	Community Feed-In Tariff
CFR	Clean Fuel Regulations
CTRI	Clean Technologies Research Institute
EGCCRA	Environmental Goals and Climate Change Reduction Act
ERP	Emissions Reduction Plan
EV	Electric Vehicle
FAEEIF	Fisheries and Aquaculture Energy Efficiency Innovation Fund

Acronym	Definition
FEED	Front-end Engineering Design
GHG	Greenhouse Gas
HCi3	Halifax Climate Investment, Innovation and Impact
IESO	Independent Energy System Operator
IPP	Independent Power Producer
IRP	Integrated Resource Plan
ITC	Investment Tax Credit
MOU	Memorandum of Understanding
NS	Nova Scotia
NSPI	Nova Scotia Power Incorporated
NSUARB	Nova Scotia Utility and Review Board
OATT	Open Access Transmission Tariff
OBPS	Output-Based Pricing System
PCF	Pan-Canadian Framework
PHP	Port Hawkesbury Paper
PPA	Power Purchase Agreement
REC	Renewable Energy Credit
RES	Renewable Energy Standards
SAF	Sustainable Aviation Fuel

0.3.2 Definitions

Term	Definition
Carbon Dioxide equivalent	A metric measure used to compare the emissions of the different GHGs based upon their global warming potential (GWP) over a defined return period (typically 20 or 100 years). This will normalise any GHG in terms of $CO_{2,}$ for example 1 kg Methane is equivalent to roughly 28 kg of CO_2.
Carbon Footprint	The life cycle carbon dioxide equivalent emissions generated per defined quantity of a product based principally on scope 1 and scope 2 emissions within the value chain
Global Warming Potential	A measure of how much infrared thermal radiation a GHG would absorb over a given time frame after it has been added to the atmosphere (or emitted to the atmosphere), expressed as a multiple of the radiation that would be absorbed by the same mass of added carbon dioxide (CO_2). The GWP allows the comparison of different GHGs in respect of their "effectiveness in causing radiative forcing".
Emission Factor	A coefficient that quantifies the GHG emissions per unit activity. Emission factors are often based on a sample of measurement data, averaged to develop a representative rate of emission for a given activity level under a given set of operating conditions.
Carbon Intensity	The amount of emissions of carbon dioxide (CO_2) released per unit of another variable, often per unit of energy or quantity of fuel consumed, as per the applicable international standards and norms
Carbon Capture	Carbon capture is the process of physically and/or chemically stripping CO_2 or elemental carbon from a fuel source in order to prevent it being released to the atmosphere through combustion. Carbon Capture can be implemented either pre- or post-combustion depending on the fuel source and application. Captured carbon as CO_2 is typically dehydrated and compressed and then either utilised as a feedstock for other industrial processes, used for enhanced oil and gas recovery or permanently stored in a geological formation or sequestered in a stable form that prevents future release to atmosphere. Capture of biofuel carbon has the theoretical potential to be 'carbon positive' in that it retains CO_2 already absorbed from the atmosphere through biological processes.
Grey, Blue, Green Hydrogen	The colour 'rainbow' of hydrogen is used to describe different production methods for hydrogen based on their relative emissions characteristics, although there is a general move away from this approach to instead simply refer to the carbon intensity of a given hydrogen production pathway. Grey hydrogen is produced from the reforming of natural gas with no carbon capture. Blue hydrogen is produced from the reforming of natural gas but with carbon capture. Green hydrogen is produced from renewable sources such as through electrolysis of water using solar or wind generated electricity.

Term	Definition
Net Zero	Net zero is achieved when the anthropogenic GHGs emitted by are balanced by the removal of GHGs over a specified period.
Carbon Neutral	When the greenhouses produced by a process or company is balanced by the amount of GHG removed. Achieving net-zero will result in Carbon Neutrality
Synthetic Fuels	Synthetic fuels are liquid fuels that are produced from sources other than natural crude oil. They are manufactured via chemical processes from raw materials such as natural gas, coal, or biomass. These synthetic fuels can be used in place of traditional petroleum-based fuels and have the potential to be cleaner burning and more environmentally friendly.
Green Shipping Corridor	A green shipping corridor is a specific maritime route where zero-emission shipping solutions are implemented and supported through technological, commercial, and regulatory initiatives. These corridors aim to reduce GHG emissions from shipping by showcasing and promoting the use of low- and zero-emission fuels and technologies.

1. Part 1- Overview of Regulations Driving Transition to Low-Carbon Fuel Alternatives in NS

1.1 Federal Regulations and National Context

Nova Scotia's efforts to transition to low-carbon alternative fuels are shaped significantly by federal regulations and policies set by the Government of Canada, which aims to achieve the goal of net-zero emissions by 2050. This influences provincial strategies and demands significant changes across all economic sectors, including energy, industry, and transport.

Key policies and regulations include:

- Pan-Canadian Framework on Clean Growth and Climate Change (PCF)
- Canada's 2030 Emissions Reduction Plan
- Clean Fuel Regulations (CFR)
- Carbon Pricing Mechanism
- Clean Electricity Regulation
- Bill C-49 - An Act to amend the Canada–Newfoundland and Labrador Atlantic Accord Implementation Act and the Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Act and to make consequential amendments to other Acts

1.1.1 Pan-Canadian Framework on Clean Growth and Climate Change (PCF)[1]

The Pan-Canadian Framework on Clean Growth and Climate Change (PCF) is Canada's national strategy to meet its Paris Agreement commitments by reducing GHG emissions, growing the economy, and building resilience to a changing climate.

Adopted in December 2016, the PCF is a collaborative effort between the federal government, provinces, and territories, with input from Indigenous peoples, businesses, and other stakeholders.

The PCF is structured around four key pillars that collectively aim to reduce Canada's GHG emissions and promote sustainable economic growth:

1. Carbon Pricing: It is based on establishing a national price on carbon to incentivize the reduction of GHG emissions. The provinces and territories are required to implement carbon pricing mechanisms, such as a carbon tax or cap-and-trade system, with the flexibility to choose the approach that suits their context. As carbon pricing directly affects industries by increasing the cost of fossil fuels, businesses are encouraged to reduce emissions through efficiency improvements, fuel switching, or adopting cleaner technologies.
2. Complementary Climate Actions: This includes the implementation of sector-specific regulations and programs to further reduce emissions beyond carbon pricing, some examples include:
    - Phasing out coal-fired electricity by 2030.
    - Reducing methane emissions from the oil and gas sector.
    - Promoting energy efficiency in buildings, transportation, and industry.
    - Supporting clean technology innovation and adoption.
3. Adaptation and Climate Resilience: Enhance Canada's ability to adapt to the impacts of climate

[1] The Pan-Canadian Framework on Clean Growth and Climate Change

change and build resilience in communities, infrastructure, and ecosystems by:

- Investing in climate-resilient infrastructure.
- Supporting adaptation planning at local and regional levels.
- Integrating climate risks into decision-making processes.

4. Clean Technology, Innovation, and Jobs: The objective is to promote clean technology development, drive innovation, and create jobs in a low-carbon economy by providing funding and support for research, development, and deployment of clean technologies.

1.1.2 Canada Emissions Reduction Plan (ERP)

The 2030 ERP presents a detailed and practical strategy, outlining the steps each industry must take for Canada to achieve a 40% reduction in emissions from 2005 levels by 2030, with the ultimate goal of net-zero emissions by 2050.[2]

In the 2030 plan, the Government of Canada is acting by:

- Helping to reduce energy costs for our homes and buildings
- Empowering communities to take climate action
- Making it easier for Canadians to switch to electric vehicles
- Driving down carbon pollution from the oil and gas sector
- **Powering the economy with renewable electricity** - The Government of Canada will work with provinces and utilities to establish a Pan-Canadian Grid Council to promote clean electricity infrastructure investments. This is in addition to the investment of $600 million in the Smart Renewables and Electrification Pathways Program to support renewable electricity and grid modernization projects and $250 million to support predevelopment work for large clean electricity projects in collaboration with provinces.
- **Helping industries develop and adopt clean technology in their journey to net-zero emissions -** introducing an investment tax credit to incentivize the development and adoption of CCUS technology and investing $194 million to expand the Industrial Energy Management System to support ISO 50001 certification, energy managers, cohort-based training, audits, and energy efficiency-focused retrofits for key small-to-moderate projects.
- Investing in nature and natural climate solutions
- Supporting farmers as partners in building a clean, prosperous future
- Maintaining Canada's approach for pricing pollution

The 2023 Progress Report marks the first of three mandated evaluations under the Canadian Net-Zero Emissions Accountability Act, setting the stage for further assessments in 2025 and 2027 as required by the Act.[3]

[2] The 2030 Emissions Reduction Plan
[3] The ERP 2023 Progress Report

1.1.3 Canada Clean Fuel Regulations (CFR)[4]

Formerly known as the Clean Fuel Standard, the Canadian Clean Fuel Regulations (CFR), implemented in 2021, are a cornerstone of Canada's strategy to reduce GHG emissions from the transportation sector, which is one of the largest sources of emissions in the country. The CFR aims to reduce the life-cycle carbon intensity of liquid fossil fuels used in transportation by 15% by 2030 compared to 2016 levels. This involves measuring the GHG emissions associated with the entire life cycle of fuels, from extraction and production to distribution and use.

The regulations encourage the production and use of alternative low-carbon fuels, such as biofuels, hydrogen, electricity, and renewable natural gas. The CFR incentivizes innovation in clean technologies and fuel production processes by creating a market demand for low-carbon fuels.

The CFR operates through the following mechanisms:

- CI Reduction Requirement: Fuel suppliers are required to reduce the CI of their fuel products. This reduction is measured in grams of CO2 equivalent per megajoule (g CO2e/MJ). Suppliers can achieve this by blending low-carbon fuels with traditional fossil fuels, improving the efficiency of their production processes, or purchasing compliance credits.
- Compliance Credits: The CFR introduces a market-based system where suppliers can generate or purchase compliance credits to meet their CI reduction obligations. Credits can be earned by producing or blending low-carbon fuels, reducing emissions in fuel production, or investing in technologies that reduce GHG emissions across the fuel life cycle. Companies that develop more efficient production processes or new low-carbon fuels can generate credits, which can be sold or used to offset compliance costs.
- Annual Reporting and Verification: Fuel suppliers must report their CI reductions and compliance activities annually. These reports are subject to third-party verification to ensure accuracy and transparency.

1.1.4 Canada's Carbon Pricing Mechanism[5]

Canada's carbon pricing system, either through a carbon tax or cap-and-trade, applies to all provinces, including Nova Scotia. This pricing is designed to make fossil fuels more expensive and economically incentivize the adoption of lower-carbon alternatives.

Canada has two pricing systems:

- Fuel charge: paid by fuel distributors and other registered persons, with varying rates by type. As of April 1, 2024, the cost of fuel charge is $80 per tonne for gasoline (3 cents per litre more than in 2023).
- The Output-Based Pricing System (OBPS): For industries, it gives a price incentive for industrial emitters to reduce their GHG emissions.

Canada's provinces and territories can choose the carbon pricing system that best suits their needs. Canada's carbon pricing system started in 2019 with an initial price of $20 per tonne of carbon dioxide equivalent. The price has been increasing annually since then, reaching $50 per tonne in 2022 and

[4] Clean Fuel Regulations (SOR/2022-140)
[5] Carbon pollution pricing systems across Canada

continuing to rise by $15 per tonne each year until it hits $170 per tonne by 2030.[6]

In the case of Nova Scotia, the Province has selected to apply the Federal fuel charge and an independent system for industries (Output-based pricing system). See Section 1.2.7 below.

1.1.5 Clean Electricity Regulations[7]

A clean electric grid is critical to building a prosperous, low-carbon future. To enable this, the Canadian government is developing its Clean Electricity Regulations.

The Regulations are being developed using three core principles:

- To enable significant GHG reductions to help transition towards a net-zero electricity grid
- To enable provinces and territories to maintain electricity affordability for Canadians and businesses
- To enable provinces and territories to maintain grid reliability as Canada's electricity needs grow.

An update on Clean Electricity Regulation was released on February 16, 2024, and the feedback period on the changes under consideration for the final Clean Electricity Regulations closed on March 15, 2024. The final regulations are expected to be published in the *Canada Gazette*, Part II, later this year.

1.1.6 Bill C-49

An Act to amend the Canada–Newfoundland and Labrador Atlantic Accord Implementation Act and the Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Act and to make consequential amendments to other Acts

Bill C-49 is crucial for the development of offshore petroleum resources and wind resources in Nova Scotia and Newfoundland and Labrador. It amends the Canada—Newfoundland and Labrador Atlantic Accord Implementation Act and the Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Act to include the regulation of offshore renewable energy, such as offshore wind.[8]

The bill establishes a framework for the federal and provincial governments to jointly manage offshore wind resources.[9] This collaboration is essential for the effective regulation and development of offshore wind projects. By aligning provincial legislation (section 1.2.9) with the changes proposed in Bill C-49, Nova Scotia ensures that its regulatory environment is consistent with federal standards. This alignment is necessary for the province to proceed with its call for bids to develop 5 GW of offshore wind energy in 2025.[10]

In summary, Bill C-49 facilitates the development of offshore wind energy by creating a cohesive regulatory environment and enabling joint management of resources, which is vital for Nova Scotia's ambitious offshore wind plans.

[6] The federal carbon pollution pricing benchmark - Canada.ca
[7] Clean Electricity Regulations - Canada.ca
[8] C-49 (44-1) - LEGISinfo - Parliament of Canada
[9] Canada Reforms Regulations to Attract Offshore Wind Investments (maritime-executive.com)
[10] Government Bill (House of Commons) C-49 (44-1) - Royal Assent - An Act to amend the Canada—Newfoundland and Labrador Atlantic Accord Implementation Act and the Canada-Nova Scotia Offshore Petroleum Resources Accord Implementation Act and to make consequential amendments to other Acts - Parliament of Canada

1.2 Provincial Regulations and Initiatives

Nova Scotia has been working towards increasing its renewable energy capacity, however, it currently still relies heavily on fossil fuels for electricity generation.

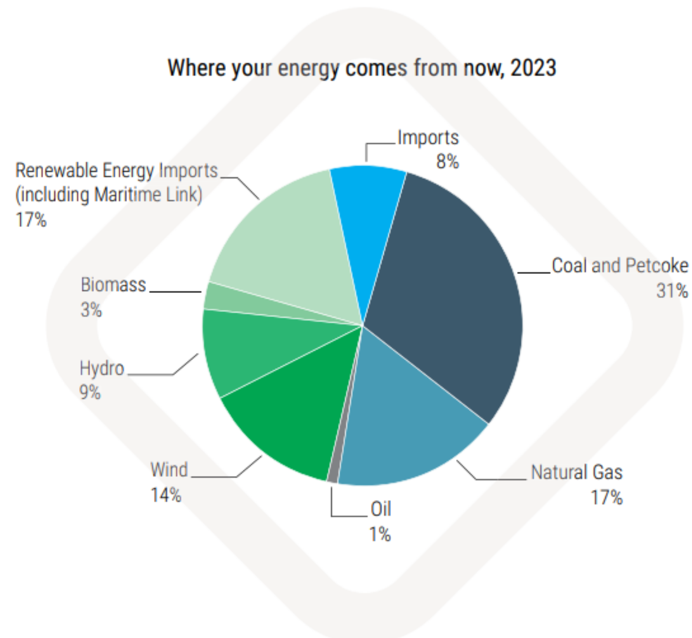

Figure 1 Nova Scotia Sources of Electricity Supply[11]

1.2.1 Nova Scotia Clean Power Plan[12]

This is the framework that underpins the overall strategy to achieve. Some key elements are:

- To close coal power plants by 2030.
- To achieve and exceed the 80% Renewable Energy Standard.
- To cut Nova Scotia's total GHGs by >53%.
- To move NS electricity onto long-term, steadily priced renewables.
- To create jobs in every community through solar, heat pumps, and wind.
- To ensure a more reliable, greener grid.
- To expand Atlantic regional ties.

[11] ns-climate-change-plan-progress-report-appendix-a-2024.pdf (novascotia.ca)
[12] Nova Scotia Green Power Plan

- To limit ratepayer risk by avoiding billions in locked-in new capital costs to 2075.

Figure 2 provides an overview of the Province's Strategy to Achieve NS CPP

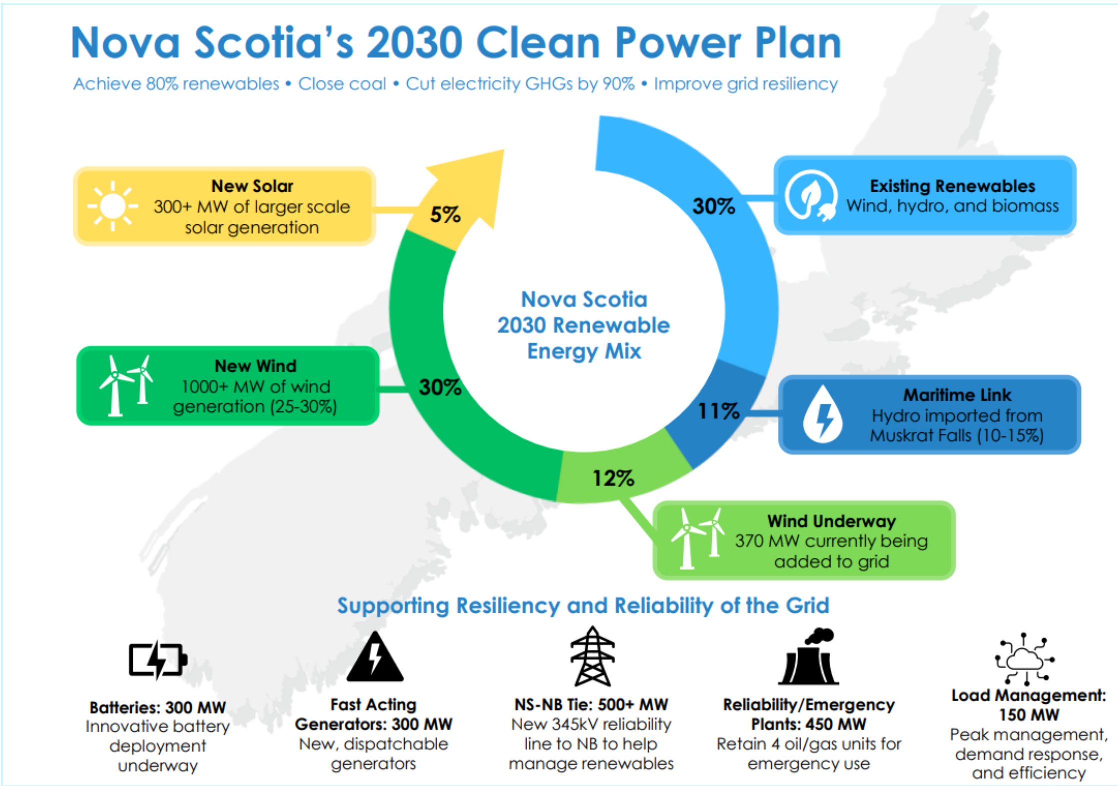

Figure 2 : Overview of Key Strategies to Achieve NS CPP[13]

1.2.2 Bill 57- The Environmental Goals and Climate Change Reduction Act (EGCCRA)[14]

Enacted in 2021, the Environmental Goals and Climate Change Reduction Act (EGCCRA), is a landmark piece of legislation aiming to address climate change and promote sustainable development within the province. This act replaces and expands upon previous environmental legislation, setting ambitious targets for GHG emissions reduction, environmental protection, and the transition to a low-carbon economy.

Some key objectives of this Act include:

- The reduction Nova Scotia's GHG emissions by 53% below 2005 levels by 2030 and net-zero emissions by 2050.
- The production of 80% of Nova Scotia's electricity generation from renewable sources by 2030, building on the province's existing strengths in wind and solar energy.
- The development and implementation of a zero-emissions vehicle mandate to ensure that at least 30% of new light-duty vehicle sales in the province will be zero-emission vehicles by 2030.

[13] Nova Scotia Green Power Plan
[14] Nova Scotia Legislature - Bill 57 - Environmental Goals and Climate Change Reduction Act (nslegislature.ca)

- To close coal power plants in the province by 2030.

The Climate Change Plan for Clean Growth[15] was developed for the execution of this EGCCRA Act in 2022 and contains 68 Actions grouped into the following areas:

- Responding to climate impacts
- Reducing our GHG emissions
- Seizing opportunities for a cleaner sustainable economy
- Reporting and evaluating progress

Appendix 1 summarizes the actions relevant to this study and the progress achieved in 2024.

1.2.3 Bill 404 - Energy Reform Act[16]

Bill 404 complements Bill 57 by reorganizing the regulatory framework to support the transition to renewable energy sources and enhance the infrastructure necessary for new energy technologies, including hydrogen. Key aspects include:

- **Alignment with Environmental Goals**: Ensuring that energy reforms align with the environmental objectives outlined in Bill 57, creating a coherent policy framework that addresses both energy and environmental sustainability.
- **Regulatory Overhaul**: Restructuring the provincial energy boards to streamline processes and support innovations in energy, including the integration of hydrogen and hydrogen blends in pipelines.
- **Support for Hydrogen Infrastructure**: Making legislative adjustments to include pipelines capable of transporting hydrogen, facilitating the development of a hydrogen economy in Nova Scotia.

The connection between Bill 57 and Bill 404 lies in their shared objective to foster an environment supporting significant reductions in GHG emissions through policy and physical infrastructure changes. Bill 57 sets the targets and principles, while Bill 404 provides the practical regulatory and infrastructural changes needed to achieve these goals. The detailed information on the restructuring of the energy boards, including the splitting of the board and the introduction of the IESO can be found in Section 4.3.1 of Bill 404. Together, they demonstrate a holistic approach to environmental policy and energy management, aiming to position Nova Scotia as a leader in sustainable development and climate action.

1.2.4 Renewable Electricity Regulations[17]

The Renewable Electricity Regulations are a critical part of the province's broader strategy to transition to a low-carbon economy and to reduce GHG emissions. These regulations, implemented under the Electricity Act, are designed to increase the proportion of electricity generated from renewable sources, thus decreasing the province's reliance on fossil fuels and enhancing energy security. The emphasis is on maintaining a diverse energy mix that includes community-led renewable energy initiatives.

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[15] Climate Change Plan for Clean Growth (https://climatechange.novascotia.ca/)
[16] An Act to Reform the Law Respecting Energy and Electricity (https://nslegislature.ca/)
[17] Renewable Electricity Regulation (https://novascotia.ca/)

Key Objectives of the Renewable Electricity Regulations include:

- Increasing Renewable Energy Generation: The regulations mandate a specific percentage of electricity in Nova Scotia to be generated from renewable or low-carbon sources, such as wind, solar, and biomass energy. The target is that 80% of the province's electricity will come from renewable sources by 2030.
- Reducing GHG Emissions: By shifting the energy mix towards renewables, the regulations aim to significantly reduce GHG emissions from the electricity sector, contributing to Nova Scotia's broader climate goals under the EGCCRA.
- Promoting Energy Security and Economic Development: The regulations are also intended to enhance energy security by reducing dependency on imported fossil fuels and stimulating economic development through local renewable energy projects.

Mechanisms of the Renewable Electricity Regulations:

- Renewable Energy Standards (RES): The RES sets mandatory targets for the percentage of electricity generated from renewable sources. Utilities are required to meet these targets by integrating renewable energy into their supply mix.
    - The Renewable Electricity Standard 2023 states that in each of the calendar years 2023, 2024, and 2025, Nova Scotia Power Incorporated (NSPI) must acquire at least 135 GWh of dispatchable renewable electricity from a renewable low-impact electricity generation facility located in the province. According to the Nova Scotia Power compliance plan for RES 2020, NSPI shall purchase renewable electricity generated from the biomass facilities at the additional $30/MWh above the current contract price, provided the biomass is derived from by-products of harvesting or processing primary forest products[18]. This payment does not apply to biomass fired renewable energy unless it meets specified conditions. Furthermore, NSPI will not spend more than $7 million annually to comply with this requirement.
    - Renewable Electricity Standard 2030: Beginning with the calendar year 2030, each load-serving entity must supply its customers with renewable electricity equal to or greater than 80% of the total amount of electricity supplied to its customers as measured at the customers' meters for that year. In addition to the obligations from The Standard 2023, NSP must acquire at least 1100 GWh from independent power producers of renewable, low-impact electricity.
- Compliance Mechanisms: Utilities that fail to meet the renewable energy targets face penalties, creating a strong compliance incentive.
- Community Feed-In Tariff (COMFIT) Program: COMFIT was in place until 2015 and supported community-based renewable energy projects by guaranteeing fixed prices for electricity generated by these projects. Although this program is no longer active, it helped establish a foundation for local renewable energy development.
- Power Purchase Agreements (PPAs): Utilities enter into PPAs with renewable energy developers to secure long-term contracts to purchase electricity at agreed-upon rates. This provides financial

[18] M09880 - Board Decision.pdf

stability for renewable energy projects and encourages investment in new capacity.

- Net Metering Program: The net metering program allows residential and commercial customers to generate their own renewable electricity (e.g., via rooftop solar panels) and feed excess electricity back into the grid. Customers receive credits against their electricity bills, promoting small-scale renewable generation.
- Tradable Certificates: Renewable Energy Credits (RECs) are certificates that represent the environmental benefits of generating one megawatt-hour (MWh) of electricity from renewable sources. Utilities and other entities can purchase RECs to meet their renewable energy obligations.

1.2.5 Prescribed Energy-Storage Projects Regulations[19]

This legislation mandates that NSPI install three (3) 50MW 4-h duration lithium-ion grid-scale batteries with an electricity storage energy rating of 200 MWh each. These facilities should be located next to the existing substations in Bridgewater (Lunenburg County), Canaan Road (Kings County), and Lake (Halifax County). The project is partially funded by the Federal Government and has a total cost of $354 million. Two of the three sites are expected to be operational by 2025, with the third coming online in 2026.[20]

In addition, NSPI must prepare and file an annual report with the Nova Scotia Utility and Review Board for each year up to and including the year 2030. This report must detail the use of each battery project, including information about the services provided.

1.2.6 Green Choice Program Regulations[21]

These regulations facilitate the integration of renewable energy into the electric grid by managing the application and approval process for new renewable energy projects, ensuring that they align with the provincial goals for clean energy.

This legislation also facilitates coordination among key stakeholders (applicants and bidders) by aggregating program participants (the applicants) based on a minimum annual demand of 10,000 MWh.

For the purposes of the Green Choice Program, eligible electricity refers to renewable, low-impact electricity that 1) is not already supplied to a customer under any other program under the Act that directly generates renewable electricity for customer accounts and facilities and 2) is not currently directly supplied under a procurement under Section 4B or 4BA of the Act. This ensures that the Program does not compete with existing ones.

The criterion for eligibility gives enough flexibility to the applicants to consolidate demand from multiples users, while allowing applicants to form strategic partnerships. Eligibility criteria is described below:

- A single corporate or commercial customer with a minimum subscription volume of 10,000 MWh per year in electricity load over 1 or more electricity meters.
- A public institution or its departments, agencies or Crown corporations with a minimum subscription volume of 10,000 MWh per year in electricity load over 1 or more electricity meters,
- An aggregated partnership of 2 or more separate public institutions who have aggregated their

[19] Prescribed Energy-Storage Projects Regulations (https://novascotia.ca/)
[20] https://stewartmckelvey.com/thought-leadership/lets-talk-about-batteries-nova-scotia-powers-latest-development-in-renewable-energy/
[21] Green Choice Program Regulations. (https://novascotia.ca/)

electricity load to achieve a minimum aggregated subscription volume of 10,000 MWh per year in electricity load over 1 or more electricity meters,

- A partner in an aggregated partnership with an electricity load of no less than 1,000 MWh per year or that subscribes a minimum of 10,000 MWh per year in the Green Choice Program.

Coho (formerly Customer First Renewables) is an independent advisor to the program, and a process for selecting applicants and participants is currently in place.[22]

1.2.7 Bill 208-Output-Based Pricing System[23]

Nova Scotia's Environment Act has been amended to introduce the OBPS, supplanting the previous cap-and-trade system for carbon pricing within the province's power and industrial sectors. This system establishes emission limits and compliance obligations for regulated industrial facilities that emit large amounts of GHGs, such as carbon dioxide, Nitrous Oxide, Ozone, Chlorofluorocarbons, methane, etc. The act creates a framework for managing and reducing GHG emissions through various compliance options, including performance credits, fund credits, and other mechanisms prescribed by regulations.

Differing from the cap-and-trade approach, the OBPS permits increases in emissions proportional to production growth while progressively enforcing stricter emission standards. The OBPS targets electricity producers and significant industrial polluters operating facilities that release over 50,000 tonnes of CO_2 equivalent of GHGs annually. This includes carbon dioxide, methane, nitrous oxide, and several other GHGs. Additionally, companies emitting between 10,000 and 50,000 tonnes of CO_2 equivalent can opt into the OBPS program. These companies that join OBPS Program benefit by avoiding the federal fuel surcharge (carbon tax), potentially resulting in significant cost savings while still being encouraged to reduce their emissions.

Facilities governed by the OBPS must adhere to emission standards set by the regulation or acquire performance credits from the Climate Change Fund if their emissions exceed these limits. These marketable credits are pegged to the national carbon price floor, starting at \$CAD 65/tCO_2e in 2023 and escalating by \$CAD 15 annually until it hits \$CAD 170/tCO_2e in 2030. The annual emissions limit is based on an emissions intensity benchmark.[24] If a facility's emissions are below its limit, it earns performance credits (compliance units), which can be banked for future use or sold.

Bill 208 establishes The Climate Change Fund. It prescribes that the money in the Fund must be managed following the regulations and is subject to the approval of the Treasury and Policy Board. The aim of the Fund is:

- To reduce, limit, avoid, or capture GHG emissions
- To mitigate the economic and social impacts of climate change and GHG emissions
- For the development, administration, and implementation of equitable approaches to adapt to a changing climate
- For efforts to reduce, limit, avoid, or capture GHG emissions
- To research, develop, and demonstrate measures that may reduce, limit, avoid, or capture GHG

[22] 8/13/2024 - For Proponents: RFP Addendum 4 & Timeline Update
[23] Bill 208-Output-Based Pricing System (https://nslegislature.ca/)
[24] https://icapcarbonaction.com/system/files/ets_pdfs/icap-etsmap-factsheet-88.pdf

emissions or help adapt to current and future climate conditions

- For public awareness, education, outreach, engagement, or capacity building related to climate change
- To adapt to the changing climate
- For the development of and participation in regional and international initiatives respecting climate change
- For the development of climate change policy and the measurement, tracking, and reporting of climate change initiatives [25]

1.2.8 Nova Scotia Offshore Wind Roadmap

Nova Scotia sits on a large continental shelf with vast areas of relatively shallow water ideal for floating and fixed wind platforms. It also has some of the best, consistently fast wind speeds in the world. These natural features create opportunities for wind farms.

Nova Scotia plans to offer leases for 5 gigawatts of offshore wind energy by 2030, with a first call for bids by 2025.[26] The roadmap project is funded through the province's climate plan – Our Climate, Our Future: Nova Scotia's Climate Change Plan for Clean Growth. The plan is helping to create a cleaner and more sustainable future for all Nova Scotians by reducing GHG emissions, supporting the growth of a clean energy sector and developing the skills to support it, empowering communities to act in response to the changing climate, fast-tracking the path to net-zero and more.

The roadmap includes three (3) modules:

- **Module 1** - maps the work to complete the legislative and regulatory regime for offshore wind
- **Module 2** - outlines the supply chain and infrastructure opportunities for offshore wind
- **Module 3** - will reflect input from the Mi'kmaq and other Indigenous peoples, as well as other groups like the fishing industry and other ocean users, environmental organizations, workers, and the research community

Nova Scotia and the federal government have started a regional assessment for offshore wind. It will help identify where and how offshore wind projects can be optimally developed and inform how projects should be built in the future.

Module 1

Module 1 focuses on establishing lines of sight for industry and other interested parties by mapping the federal and provincial regulatory path for offshore wind. There are four potential routes to market currently being considered for Nova Scotia's offshore wind resources:

1. Provincial demand for clean electricity or green fuels, particularly as post-2030 renewable energy demand may increase in connection with cross-sector decarbonization
2. Regional/national demand for clean electricity or green fuels under Canada's 2035 Clean Electricity Standard

[25] https://nslegislature.ca/sites/default/files/legc/statutes/environment.pdf
[26] Offshore wind - Government of Nova Scotia, Canada

3. Demand for clean electricity from the United States
4. International demand for low-carbon, green fuels and chemical feedstock (e.g., ammonia or other e-fuels)

The Government of Canada is establishing a framework to prioritize and support the energy transition, specifically offshore wind and green hydrogen production. In March 2023, Canada published Budget 2023, which introduces a suite of investment tax credits to support renewable energy and green hydrogen investments. This is discussed further in Section 1.3.6. These tax credits aim to make Canada a competitive environment for developing projects and supply chains supporting decarbonization. There are also various funds that may apply to the Offshore Wind Roadmap, such as the Canada Growth Fund, which aims to accelerate the deployment of technologies required to decarbonize by de-risking new clean energy projects. This is discussed further in Section 1.4.

Module 2

Module 2 outlines the government's plan to build the solid foundational pieces needed for the offshore wind industry supply chain. This includes planning and developing ports, helping businesses and communities prepare for industry participation, and training an essential, varied workforce. The offshore wind market is experiencing rapid growth worldwide, so building Nova Scotia's supply chain is necessary to avoid bottlenecks and ensure growth. The approach outlined in Module 2 is based on Nova Scotia's initial 5 GW offshore wind leasing target. This target supports various markets, including green hydrogen production for export and domestic use, local grid integration, direct energy export to the United States, and more. These early strategic actions are designed to support the first phases of development and build a foundation for long-term, sustainable growth beyond 5 GW.[27]

The province's strategy to develop a best-in-class supply chain includes:[28]

- Examining existing marine sector supply chains and emphasizing Nova Scotia's strengths, assessing gaps, and analysing future needs
- Ensuring equitable access to opportunities in the industry among First Nations, African Nova Scotian businesses, and other underrepresented and underserved groups
- Preparing infrastructure for future industry needs
- Ensuring regulatory coordination and efficiency for suppliers.

Module 3

The third and final module of the Offshore Wind Roadmap will be released next year. It will focus on feedback from the Mi'kmaq of Nova Scotia, fishers, environmental organizations, academia, communities, industry, the research community, ocean users, and other interested parties. Module 3 will also consider input gathered through the federal-provincial regional assessment on offshore wind development, which is expected to be completed in early 2025. Engagement will continue after the third module and throughout the life cycle of the offshore wind industry.

[27] offshore-wind-roadmap-module-2.pdf (novascotia.ca)
[28] Province Advances Work on Offshore Wind Roadmap | Government of Nova Scotia News Releases

1.2.9 Bill 471- Advancing Nova Scotia Opportunities Act[29]

The Advancing Nova Scotia Opportunities Act (Bill 471) is a comprehensive effort to boost the province's renewable energy sector. Here are some key points:[30]

- Expansion of the Canada-Nova Scotia Offshore Petroleum Board's Mandate: This now includes regulating offshore renewable energy projects and transmission lines, which is crucial for integrating new energy sources.
- Speeding Up Offshore Wind Developments: Amendments to the Marine Renewable-energy Act aim to facilitate quicker development of offshore wind projects.
- Investments in Low-Carbon Fuels: Changes to the Gas Distribution Act will support investments in hydrogen and renewable natural gas, helping to decarbonize the natural gas grid.

The amendments made to the Gas Distribution Act allows gas distributors to apply to the NSUARB for the ability to:

- Alternative Energy Resources: This includes the acquisition and use of alternative energy sources-hydrogen, renewable natural gas, or other gaseous fuels with a lower carbon-emission intensity than traditional natural gas, which can help diversify the energy mix and reduce reliance on traditional fossil fuels.
- Hydrogen-Production Equipment: This provision supports the development of hydrogen as a low-carbon fuel, enabling its integration into the existing natural gas grid.

These amendments are designed to facilitate the transition to low-carbon fuels and support the province's broader environmental and economic goals. By enabling investments in hydrogen and renewable natural gas, Nova Scotia aims to reduce GHG emissions and promote sustainable energy practices.

1.2.10 Other Legislative and Regulatory Changes in Nova Scotia

In November 2022, Nova Scotia amended its Liquid Fuel Regime (November 2022). This included updates to the Pipeline Act, Gas Distribution Act, and Subsurface Energy Storage Act, which now includes hydrogen, ammonia, carbon sequestration, and compressed air energy storage regulations. These amendments allow for the inclusion of hydrogen pipelines and the consideration of hydrogen in gas distribution systems, providing legal clarity for businesses involved in green hydrogen projects.

[29] Nova Scotia legislation paves way to develop new green energy sources - Atlantica Centre For Energy (atlanticaenergy.org)
[30] Nova Scotia Legislature - Bill 471 - Advancing Nova Scotia Opportunities Act (nslegislature.ca)

1.3 Hydrogen-Specific Regulations and Plans

1.3.1 Nova Scotia Green Hydrogen Plan[31]

The Green Hydrogen Action Plan for Nova Scotia lays out seven key goals and a series of actions to support the development of a sustainable and prosperous green hydrogen sector. Below is a summary focused on these goals and their associated actions:

Goal 1: Create a Sustainable and Prosperous Green Hydrogen Sector

Actions:

1. Foster collaboration across all levels of government to create an effective policy and regulatory framework.
2. Cultivate partnerships with the federal government to optimize financial support mechanisms.
3. Make strategic, evidence-based investment decisions using aggregated information.
4. Position Nova Scotia as a regional hub for green hydrogen by aligning with Canada's national hydrogen strategy.
5. Build relationships with other jurisdictions to share knowledge and best practices across the hydrogen supply chain.

Goal 2: Support the Development of Competitive Green Hydrogen Export Opportunities

Actions:

1. Map Nova Scotia's export infrastructure and supply chains in collaboration with industry and government agencies.
2. Identify opportunities to create value-added export commodities using green hydrogen.
3. Develop green hydrogen clusters that optimize natural resources, trade infrastructure, and co-located industries.
4. Ensure provincial investments benefit utility ratepayers.
5. Coordinate Crown land access for green hydrogen projects while safeguarding natural resources.
6. Promote Nova Scotia's green hydrogen opportunities on the global stage.

Goal 3: Align the Green Hydrogen Sector with Environmental and Climate Change Goals

Actions:

1. Ensure green hydrogen development aligns with Nova Scotia's climate change goals.
2. Prioritize sustainability, particularly in the use of freshwater, and ensure the protection of natural resources through environmental regulations.

Goal 4: Support Transparent Communication and Community Participation

Actions:

1. Coordinate with various groups to deliver accessible and credible information to the public.
2. Build community capacity for involvement in decision-making and ensuring local benefits.

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[31] https://novascotia.ca/green-hydrogen/docs/green-hydrogen-action-plan.pdf

3. Ensure meaningful participation by all Nova Scotians, including Indigenous communities and underrepresented groups, in the green hydrogen sector.

Goal 5: Ensure Safety Across the Green Hydrogen Supply Chain

Actions:

1. Review and harmonize safety legislation, regulations, codes, and standards with other jurisdictions to ensure best practices.
2. Collaborate with industry and training organizations to enhance knowledge and skills in safe hydrogen handling, storage, and use.

Goal 6: Invest in Skills Training and Development to Build a Strong Domestic Workforce

Actions:

1. Map the skills needed for the green hydrogen sector in collaboration with industry and training institutions.
2. Support workforce growth, focusing on including underrepresented and underserved communities in training programs.
3. Coordinate workforce development with federal programs like Canada's Sustainable Jobs Plan.

Goal 7: Promote Research and Innovation for Sector Development

Actions:

1. Support innovation projects that demonstrate domestic opportunities for green hydrogen.
2. Conduct research to identify safe, environmentally sound, and economic options for long-term hydrogen storage.

These goals and actions collectively aim to position Nova Scotia as a leader in the emerging green hydrogen economy, emphasizing sustainability, safety, community involvement, and innovation.

1.3.2 Bill 207- Hydrogen Innovation Program[32]

The Electricity Act broadens the scope of wholesale customers to encompass entities engaged in green hydrogen initiatives. A pivotal aspect of this legislation is the government's establishment of a Hydrogen Innovation Program, aimed at bolstering the sector while aligning with the province's climate objectives.

The legislation, known as the Hydrogen Innovation Program, was designed to streamline the integration of hydrogen facilities into Nova Scotia's power grid, enabling these facilities to purchase electricity wholesale through the province's Open-Access Transmission Tariff (OATT) system.

Key aspects of the bill include:

- Establishing a regulatory framework for the interconnection of hydrogen production and processing facilities to the electrical grid.
- Allowing hydrogen businesses to buy electricity on the open market to support the economic viability of hydrogen as a green energy source.
- Allowing eligible green hydrogen businesses to buy wholesale electricity via Nova Scotia's OATT and enabling them to connect hydrogen facilities to the power grid for hydrogen production and

[32] Nova Scotia Legislature - Bill 207 - Hydrogen Innovation Program (nslegislature.ca)

processing. (i.e., phase 1 of Everwind Fuels) [33]

- Setting out eligibility criteria, data reporting requirements, performance standards and compliance obligations for hydrogen projects, which include monitoring and reducing carbon emissions.

Additionally, amendments under this bill aim to clarify environmental assessment obligations for hydrogen projects and ensure that large-scale hydrogen production and storage facilities comply with Class I environmental assessments and operational approvals.[34]

The introduction of Bill 207 is a strategic move to position Nova Scotia as a leader in the emerging green hydrogen sector, which is crucial for the region's future in sustainable energy production and export.

1.3.3 Bill 206 – (Amended) Underground Hydrocarbons Storage Act

Bill 206, the Underground Hydrocarbons Storage Act (amended), plays a significant role in the province's green hydrogen development strategy by amending existing regulations to facilitate the production and use of green hydrogen.

The specific amendments made by Bill 206 include:

1. **Substitution of Terminology (Sections 16, 17, 19, 20, 21, 22, 24, 25, 26, 27, 28, 30)**: Each of these sections had amendments in which " hydrocarbon storage area" was substituted with "subsurface energy storage area." This consistent change across multiple sections signifies a shift in the legislative focus towards broader energy storage possibilities that include, but are not limited to, hydrocarbons.

2. **Modifications in Regulatory Language** (**Section 24)**: This section was amended to include additional regulatory flexibility. It added phrases that allow for codes of practice to be prescribed by regulations, which provides a mechanism for updating practices as new technologies and needs emerge without requiring further legislative changes.

3. **Broader Definitions and Flexibility**: The term "subsurface energy" is introduced to replace "hydrocarbons" in several instances, broadening the scope to potentially include various energy storage solutions like hydrogen and other renewable energy sources stored underground.

4. **Comprehensive Updates Across Chapters**: The bill also included comprehensive rephrasing within multiple chapters to ensure consistency with the new terminology, aiming to create a regulatory environment that is adaptable to innovation in the energy sector.

These amendments reflect a strategic shift towards embracing renewable energy technologies and preparing the legislative and regulatory landscape for future energy storage and management developments.

[33] EverWind Fuels

[34] https://www.mcinnescooper.com/publications/nova-scotias-green-hydrogen-sector-3-key-legislative-developments/

1.3.4 Pipeline Act and Gas Distribution Act

As discussed in Section 1.2.10, the Nova Scotia Liquid Fuel Regime was updated in 2022, confirming that the existing legal regime for liquid fuels now applies to new hydrogen fuels. This helps ensure that businesses undertaking new green hydrogen projects have clarity regarding rules, procedures, and standards that must be followed.[35]

The Pipeline Act will be revised to cover the construction of pipelines for hydrogen or hydrogen fuel blends. In addition, the new Energy and Regulatory Boards Act will split the Nova Scotia Utility and Review Board into two new boards. It will create the new Nova Scotia Energy Board with expertise in and a focus on regulating public utilities in the energy sector. The new Energy Board will be required to consider the Environmental Goals and Climate Change Reduction Act in its decisions. The remaining responsibilities of the Utility and Review Board will stay with a restructured and renamed Regulatory and Appeals Board.[36]

1.3.5 Environmental Assessment Regulations

Under Bill 206, the Environmental Act was updated to include large-scale hydrogen or ammonia projects. These changes aim to help green hydrogen developers understand their environmental obligations and streamline approvals for hydrogen facilities. This update introduces the term "Hydrogen facility" within the Definitions section. It defines a "Hydrogen Facility" as a facility that produces, generates, or stores hydrogen gas or ammonia, whether within the facility or in a standalone facility. The update also designates hydrogen facilities as Class 1 (only if the facility is otherwise designated as a Class I undertaking).

1.3.6 Clean Hydrogen Investment Tax Credit[37]

The federal Clean Hydrogen Investment Tax Credit (ITC) was first announced in the 2022 Fall Economic Statement and described in Budget 2023, provides a 15% to 40 % refundable tax credit for investments in projects that produce all or substantially all hydrogen through their production process. This measure would apply to property acquired from March 28, 2023, and that becomes available for use on or before December 31, 2034.

The credit applies to all eligible expenses incurred for projects that produce hydrogen from electrolysis or natural gas with emissions abated using CCUS.

The tax credit rate is based on the assessed CI of the hydrogen that is produced. The credit:

- If CI $<$ 0.75 kg, the tax credit rate is 75%
- If 0.75 kg $\leq$ CI $<$ 2 kg, the tax credit rate is 25 %
- If 2kg $\leq$ CI $<$4kg, the tax credit rate is 15 %.

It will also extend a 15% tax credit to equipment needed to convert hydrogen into ammonia for transportation. The clean hydrogen ITC rates will be halved in 2034 and fully phased out in 2035.

[35] https://www.mcinnescooper.com/publications/nova-scotias-green-hydrogen-sector-3-key-legislative-developments/
[36] https://news.novascotia.ca/en/2024/02/27/legislation-modernize-electricity-system-improve-regulation
[37] https://www.pbo-dpb.ca/

1.4 Funding Opportunities

The Government of Nova Scotia, along with federal initiatives, offers a range of funding programs to support projects that aim to reduce GHG emissions, improve energy efficiency, and foster innovation in clean technologies. These programs are designed to help various sectors transition to a low-carbon economy, contributing to broader climate change mitigation efforts. As discussed in previous sections, the Government of Nova Scotia has committed to developing programs to support the green hydrogen sector, including the Nova Scotia Clean Fuels Fund (Section 1.4.1) and the Hydrogen Innovation Program (Section 1.3.2).

Table 1 below summarizes some of the key funding opportunities available for industrial projects aimed at lowering emissions in Nova Scotia and Canada; it provides an overview of some of the significant funding opportunities currently available, though it is not an exhaustive list. The funds included in this table have been selected based on their relevance to energy efficiency, GHG reduction, and support for innovative clean technologies.

Table 1 : Funding Opportunities in Nova Scotia

Type	Description	Link
Efficiency Nova Scotia	This energy efficiency utility offers advice, technical assistance, and financial incentives to help Nova Scotian households and businesses reduce their energy costs.	https://www.efficiencyns.ca/
Green Industrial Facilities and Manufacturing Program	The Green Industrial Facilities Manufacturing Program (GIFMP) provides financial assistance to support the implementation of energy efficiency and energy management solutions designed to maximize energy performance, reduce GHG emissions, and increase competitiveness for industry in Canada	Green Industrial Facilities and Manufacturing Program (canada.ca)
The Halifax Climate Investment, Innovation and Impact (HCi3) Investing Programs	HCi3 offers novel financing structures to accelerate and enable the uptake of measurable, equitable and meaningful climate solutions by financing scalable projects to lower GHG emissions.	https://www.hci3.ca/
The Fisheries and Aquaculture Energy Efficiency Innovation Fund (FAEEIF)	The FAEEIF is a provincially funded program designed to help prepare the commercial fisheries and aquaculture sectors to reduce energy use and climate change impacts to at least 53% below 2005 levels by 2030 and achieve net-zero by 2050.	Fisheries and Aquaculture Energy Efficiency Innovation Fund - Efficiency Nova Scotia - Efficiency Nova Scotia (efficiencyns.ca)
The Low-carbon Stream of the Early-Stage Commercialization Fund	This fund helps researchers assess market potential, develop go-to-market strategies, perform strategic planning, develop intellectual property protection strategies, finish proof-of-concept development, build prototypes, and leverage other funds to advance clean technologies.	Early Stage Commercialization Fund: 2023-2024 Funded Projects | Invest Nova Scotia

Innovation Rebate Program	The Innovation Rebate Program (IRB) provides financial incentives for projects that innovate, support the principles and goals of Nova Scotia's Environmental Goals and Climate Change Reduction Act. This can include, but is not limited to, improving energy efficiency, integration of the use of renewable energy, waste reduction, circular economy activities, GHG emissions reduction and increasing resilience to the impact of climate change.	Innovation Rebate Program | Invest Nova Scotia
Canada Growth Fund	The $15 billion Canada Growth Fund is designed to attract large-scale private sector investment in low-carbon products, technologies, businesses, and supply chains on Canada's path to Net Zero.	https://www.cgf-fcc.ca/
Emerging Concepts and Technologies (ECT) Program	Supported by the Government of Nova Scotia, Net Zero Atlantic administers the Emerging Concepts and Technologies Program (ECT) to help projects move from laboratory to market scale. The program looks to identify gaps in carbon-reduction pathways for hard to abate emissions and to support made-in-Nova Scotia solutions to reduce GHG emissions required to achieve net-zero by 2050.	Net Zero Emerging Concepts and Technologies (ECT) Research Program - Nova Scotia | Net Zero Atlantic
Strategic Innovation Fund (SIF)	A federal program that provides funding to support large-scale, transformative, and collaborative projects across various sectors, including advanced manufacturing, agri-food, clean technology, clean resources, digital industries, and health and biosciences. It aims to foster innovation, enhance productivity, and create jobs in Canada.	Strategic Innovation Fund (canada.ca)
Smart Renewables and Electrification Pathways Program (SREPS)	This federal program supports the deployment of clean electricity infrastructure, such as wind turbines, solar panels, and batteries, and aims to modernize and strengthen the electricity grid. It focuses on reducing dependence on fossil fuels, enhancing grid reliability, and supporting Indigenous-led clean energy projects.	Smart Renewables and Electrification Pathways Program (canada.ca)
Sustainable Development Technology Canada (SDTC)	This federal program funds Canadian companies developing and deploying sustainable technologies. It provides critical funding support at various stages, from seed to commercialization, aiming to foster innovation in clean technology, promote collaboration among different sectors, and ensure the timely diffusion of new technologies across Canada.	Home ~ Sustainable Development Technology Canada (sdtc.ca)

Nova Scotia Clean Fuels Fund	The Nova Scotia Clean Fuels Fund supports the industrial and business sectors in transitioning to cleaner energy by replacing traditional fossil fuels with cleaner alternatives for heating, transportation, and industrial processes. Eligible projects include studies, existing facilities ready to implement clean fuels, and new infrastructure for clean fuels adoption, focusing on biofuels, clean wood energy, renewable natural gas, or hydrogen. Refer to section 1.4.1 for more details.	Clean fuels fund - Government of Nova Scotia, Canada
Canada Clean Fuels Fund	The fund focuses on building and expanding clean fuel production, establishing a biomass supply chain, developing enabling codes and standards, and encouraging Indigenous participation in wider Canada. Refer to section 1.4.2 for more details.	Clean Fuels Fund (canada.ca)

1.4.1 Nova Scotia Clean Fuels Fund

The Clean Fuels Fund gives the industrial and business sectors the support they need to begin making the shift toward cleaner energy. The fund helps industry replace traditional fossil fuels with cleaner fuels for heating, transportation and industrial processes.

Eligible projects include studies supporting the adoption of clean fuels, existing facilities ready to implement clean fuels use, and new infrastructure to facilitate clean fuels adoption. Projects may focus on biofuels, clean wood energy from forestry waste products, renewable natural gas, or hydrogen.

The fund started in 2023-24 with $3 million for seven ready-to-launch projects in a quick-start stream. The 2023-2024 Clean Fuels Fund recipients were:[38]

- Balodis Inc., Pictou County – Hydrogen electrolyzer and dual-fuel truck conversion; $1 million
- King Freight, Pictou County – Hydrogen dual-fuel truck conversion; $450,000
- Town of Bridgewater, Lunenburg County – Clean fuel feasibility and opportunity assessment framework; $112,500
- Pier Labs and Eastward Energy, Halifax Regional Municipality – Development of safety parameters for hydrogen blending; $189,250
- Net Zero Atlantic (provincewide) – Decarbonizing Nova Scotia industrial sector with hydrogen; $450,000
- Verschuren Centre, Cape Breton Regional Municipality – virtual modelling of biofuel facility; $442,000
- Greenspring Bio innovation (provincewide) – Phase 1 assessment of biofuel integration opportunities; $356,250

A further $3 million is available for eligible projects in the 2024-2025 Fiscal Year.[39] Nova Scotia hope to stay at the forefront of the exploration of green hydrogen and other clean fuels with the support of the Clean Fuels Fund.

[38] Province Helping Industries Move Toward Cleaner Fuels | Government of Nova Scotia News Releases
[39] https://novascotia.ca/clean-fuels-fund/

1.4.2. Canada Clean Fuels Fund

The Canadian Government established the Clean Fuels Fund in the 2021 Budget with an investment of $1.5 billion over five years.[40] This fund aims to help Canada transition away from fossil fuels and accelerate its progress toward its net-zero by 2050 target. It does this by de-risking the capital investment required to build new or expand existing clean fuels production facilities.

The focus areas of the Clean Fuels Fund are:

- Building or expanding domestic production capacity for clean fuels such as hydrogen, biofuels, and renewable natural gas.
- Establishing a wider biomass supply chain; biomass supply chain component of the Clean Fuels Fund will ensure a steady and usable supply of sustainable feedstock is available to clean fuel production facilities across the country.[41]
- Developing enabling codes and standards to facilitate the entry of new clean fuel technologies into the market.
- Encouraging Indigenous participation and leadership in clean fuel projects, acknowledging the unique opportunities these projects offer for Indigenous communities and businesses.

The fund from budget 2021 is still open Indigenous-led domestic production capacity projects; it is expected to be open till the allocated funds run out.[42,43] According to Budget 2024, the Clean Fuels Fund will receive an additional $776.3 million over the next six years (2024/25 to 2029/30) to further support the clean fuels industry.[44]

40 Clean Fuels Fund (canada.ca)
41 Clean Fuels Fund – Establishing Biomass Supply Chains (canada.ca)
42 Clean Fuels Fund - Building New Domestic Production Capacity (canada.ca)
43 Funding for Indigenous-led clean production capacity projects (canada.ca)
44 Budget 2024: A clean and safe environment for the next generation - Canada.ca

2. Part 2 - Nova Scotia Industry and Manufacturing Sector Process Heating and Needs

2.1 Introduction

This Section examines the process heating and energy needs within Nova Scotia's industry and manufacturing sectors, specifically focusing on power generation, pulp and paper, cement, clay bricks, chemicals, marine shipping, and the energy demands of large institutions like hospitals and universities. The study highlights the thermal and energy requirements across these sectors, emphasizing the need for sustainable solutions to reduce GHG emissions and improve energy efficiency.

Pulp and Paper: The pulp and paper industry is one of the most energy-intensive sectors in Nova Scotia, with significant thermal heating demands across its operations. These operations include pulp production, bleaching, drying, and finishing. The industry relies heavily on Combined Heat and Power (CHP) systems to provide heat and electricity. Notably, the Port Hawkesbury Paper mill in Point Tupper plays a crucial role in the province's economy and the North American market for supercalendered paper. This emphasizes the importance of sustainable energy practices while maintaining competitive operations.

Clay Bricks: Shaw Group is a leading manufacturer of clay bricks in Nova Scotia. The production process involves several energy-intensive stages, including the mining, forming, drying, and firing of raw materials such as clays and shales. Firing occurs in tunnel kilns with natural gas being the primary fuel. This high thermal demand, especially in the drying and firing stages, presents opportunities for integrating sustainable energy solutions to reduce carbon emissions while maintaining product quality.

Rubber and Tire: Michelin's tire plants in Bridgewater, Granton, and Waterville are vital to Nova Scotia's economy, and are among the largest consumers of natural gas in the province. Key stages, such as mixing, extrusion, and curing, require substantial heat, highlighting the energy-intensive nature of tire manufacturing.

Cement: Cement manufacturing in Nova Scotia, led by Lafarge Canada, involves high thermal energy demand. Clinker production is particularly energy intensive and requires sustained high temperatures of up to 1,450°C. The Brookfield plant has been a cornerstone of cement production for over 50 years, contributing to critical infrastructure projects across the region. The industry faces challenges in decarbonization due to its reliance on fossil fuels for high-temperature processes, as well as the CO_2 produced in the Calcination process, underscoring the need for innovative low-carbon technologies.

Chemicals: Nova Scotia's chemical industry, though modest, requires substantial thermal energy across key processes. Steam cracking heats hydrocarbons to 800–900°C to produce olefins, essential for plastics. Distillation, used to separate chemical mixtures, operates at 100–400°C. Chemical synthesis, including ammonia production, needs 400–600°C, while catalytic reforming for aromatics and hydrogen reaches 500–900°C. These processes highlight the industry's significant energy demands.

Marine Sector: Nova Scotia's marine sector, anchored by the Port of Halifax, is essential for global shipping, with high energy demands mainly for propulsion, auxiliary systems, and steam production. Propulsion, primarily powered by heavy fuel oils, drives ships over long distances, while auxiliary systems support onboard operations like lighting and HVAC. Steam production also meets needs like fuel heating and cargo maintenance. Transitioning to low-carbon fuels that align with current energy patterns is key for decarbonizing the sector.

Food Production: The food industry in Nova Scotia, including major companies like High Liner Foods and Clearwater Seafoods, relies heavily on thermal processes such as pasteurization, sterilization, drying, baking, and cooking. These processes require significant energy to ensure food safety and quality, with temperatures ranging from moderate (70-85°C) to high (above 120°C). Decarbonization challenges in this sector include dependence on fossil fuels for heating. Advanced technologies like electrification, heat pumps, microwave heating, and hydrogen technologies offer pathways to reduce emissions.

Besides the above-mentioned industry sectors, universities and hospitals are also large thermal energy users, however outside of industry and manufacturing. Nova Scotia is a prominent hub for higher education in Canada, with a remarkably high concentration of universities and colleges relative to its population of approximately one million people. The province is home to ten public universities and the Nova Scotia Community College, which operates across 13 locations, making it a significant center for post-secondary education in Atlantic Canada.[45] Nova Scotia has approximately 41 hospitals, which the Nova Scotia Health Authority and the IWK Health Centre operate. These hospitals include regional, community, and specialty hospitals that provide a range of services, from general medical care to specialized treatments.[46]

These universities and hospitals contribute significantly to the province's energy and heating demands, as these campuses require substantial resources to maintain their extensive facilities. These institutions typically meet their heating needs through central heating systems, often powered by fossil fuels such as natural gas or fuel oil. These systems generate steam or hot water that is distributed across campus buildings for space heating and domestic hot water. Some of these institutions have integrated Combined Heat and Power (CHP) systems, which produce both electricity and thermal energy from the same fuel source, enhancing overall energy efficiency. Both types of facilities face unique challenges in meeting their energy and heating demands but also present opportunities for integrating innovative and sustainable energy solutions. To convert to alternative energy sources economically, it's crucial to achieve the same characteristics as current fossil fuel systems.

Thermal power plants in Nova Scotia, primarily powered by coal and natural gas, operate at high temperatures (600–700°C) to generate steam for electricity production. While their primary purpose is electricity generation, the high-temperature operations underline the energy-intensive nature of such facilities. Opportunities for transitioning to lower-carbon fuels and improving energy efficiency in these plants could contribute to broader decarbonization goals.

2.2 Pulp and Paper

The pulp and paper industry in Nova Scotia significantly contributes to the province's industrial landscape, with operations that rely heavily on thermal energy for various production processes. One of the key players in this sector is Port Hawkesbury Paper's mill, located in Point Tupper. Established in 1962, this facility has played a central role in the region's economy and the North American paper market, particularly in producing supercalendered paper.[47]

Port Hawkesbury Paper is one of the largest pulp and paper mills in Nova Scotia. It produces nearly 400,000 tonnes of supercalendered paper annually, accounting for approximately 20-25% of the market in North America. The mill primarily exports its products to the United States, highlighting its importance in

[45] https://en.wikipedia.org/wiki/Higher_education_in_Nova_Scotia
[46] Health care in Nova Scotia, Canada
[47] https://en.wikipedia.org/wiki/Port_Hawkesbury

international trade and its influence on the local economy.

The mill's operating equipment includes a boiler installed in the 1960s and later retrofitted in the early 2000s to improve efficiency and adapt to evolving energy needs. The boiler uses approximately 70% natural gas and 30% No. 2 oil for fuel. Although the boiler is rated at a capacity of 47 kg/s, it typically operates below this maximum capacity, reflecting changes in production demands and efficiency improvements over time.

2.2.1 Processes overview

The mill's thermo mechanical pulp (TMP) process, the most energy-intensive part of the operation, utilizes approximately 100 MW of electrical power to produce pulp. A byproduct of this process is the production of low-pressure (30 psi) and low-temperature (150°C) steam, which can be used in various applications within the mill. The pulp is then bleached and sent directly to the paper machine without drying. A heat recovery system in the pulp mill captures steam generated during production, which is reused as thermal energy in the paper machine's dryer. Additionally, two boilers produce high-pressure steam (900 psi, 475°C), a portion of which supplies the remaining steam demand. This setup makes the mill a significant power consumer with relatively lower reliance on thermal energy from the boilers.

Figure 3 illustrates the configuration of a Fourdrinier-type paper machine.[48] The Fourdrinier-type paper machine is divided into four sections: forming, press, drying, and calendering. In the forming section, stock flows from the headbox and is evenly distributed onto a continuously running fabric felt, known as the wire. The sheet moves along the Fourdrinier table, where water is removed through gravity and suction mechanisms, leaving the paper web with 20% solid consistency.

In the press section, which typically consists of 1-3 rolling press nips, water is further squeezed out, and the paper web is consolidated and strengthened. The increased web strength improves runability in the drying section. The fastest paper machines can operate at speeds as high as 2,200 meters per minute.

The drying section includes multiple cylinders heated by high-temperature, high-pressure steam. Heat transfers from the steam to the paper surface, causing water to evaporate. Before entering the drying section, the paper web has around 50% solid consistency; by the end, this rises to 95%, meeting the required moisture specifications for the finished product.

In the final calendering section, the paper web passes through one or more calendering nips, where it is plastically deformed to improve surface properties. Depending on the type of paper, the objective may be to achieve a smooth surface for printing or to enhance the uniformity of properties like thickness.

[48] https://www.intechopen.com/chapters/16069

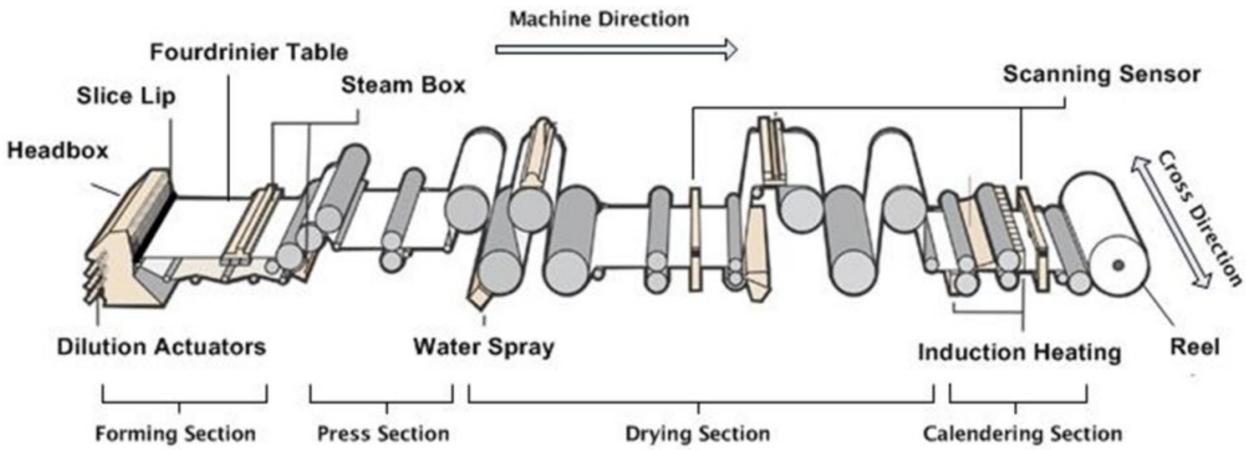

Figure 3: The configuration of a Fourdrinier-type paper machine[49]

2.2.2 Temperature Requirements:

Steam is generated at temperatures between 120-140°C from the heat recovery system, while the boiler generates steam at about 220°C.

2.3 Clay Bricks

The Shaw Group is one of Eastern Canada's leading community developers, residential builders and natural resource manufacturers. Founded in 1861, Shaw Brick is a leading manufacturer, distributor and retailer of high-quality clay brick, concrete block and natural stone products for the landscaping and building sectors in Atlantic Canada. Shaw Brick has continued to refine and grow its selection of products and is continually increasing their distribution of other products to include wall coverings such as metal, ceramic and fiber cement as examples.

The original clay brick we began manufacturing in Lantz, Nova Scotia 160 years ago were the building blocks of a company that would go on to become a local household name and change the landscape of Atlantic Canada. Today, Shaw Brick continues to manufacture brick, and over the years has added new products to enhance the beauty of homes, yards, and entire communities with high quality, sustainable, locally made and affordable products.

2.3.1 Processes Overview

A typical brick manufacturing process is shown in Figure 4. The manufacturing of brick and structural clay products involves several stages: mining, grinding, screening, and blending of raw materials (surface clays and shales). The raw materials are then formed, cut, or shaped before being dried, fired, cooled, stored, and shipped. The raw materials, typically containing 3-15% moisture, are mined onsite or transported, then crushed and ground into a fine material. This material is conveyed to storage and later formed into bricks using processes such as stiff mud extrusion or soft mud, with the majority of brick being formed by the stiff mud extrusion process. Bricks are stacked onto kiln cars and go through a drying process, followed by firing

[49] https://www.intechopen.com/chapters/16069

in kilns (mainly tunnel kilns), and finally cooling before storage and shipment.[50]

The entire process involves steps such as forming, stacking, drying, and firing, with natural gas being the most commonly used fuel, followed by coal, sawdust, and sometimes backup fuels like vaporized propane or fuel oil.

2.3.2 Temperature Requirements

Dryers typically operate at temperatures of about 400°F (204°C), often using waste heat from the kiln's cooling zone or gas-fired heating systems. The firing process, especially in tunnel kilns, involves a preheat zone, firing zone, and cooling zone. The maximum firing zone temperature is around 2,000°F (1,090°C), which is critical for vitrification. During flashing, which occurs after the firing zone, excess uncombusted fuel (e.g., natural gas or materials like zinc, tires, or used oil) is added to create a reducing atmosphere, imparting color to the bricks. Cooling follows the firing process, with bricks returning to near ambient temperature before being stored and shipped. The entire drying, firing, and cooling process typically lasts between 20 to 50 hours.

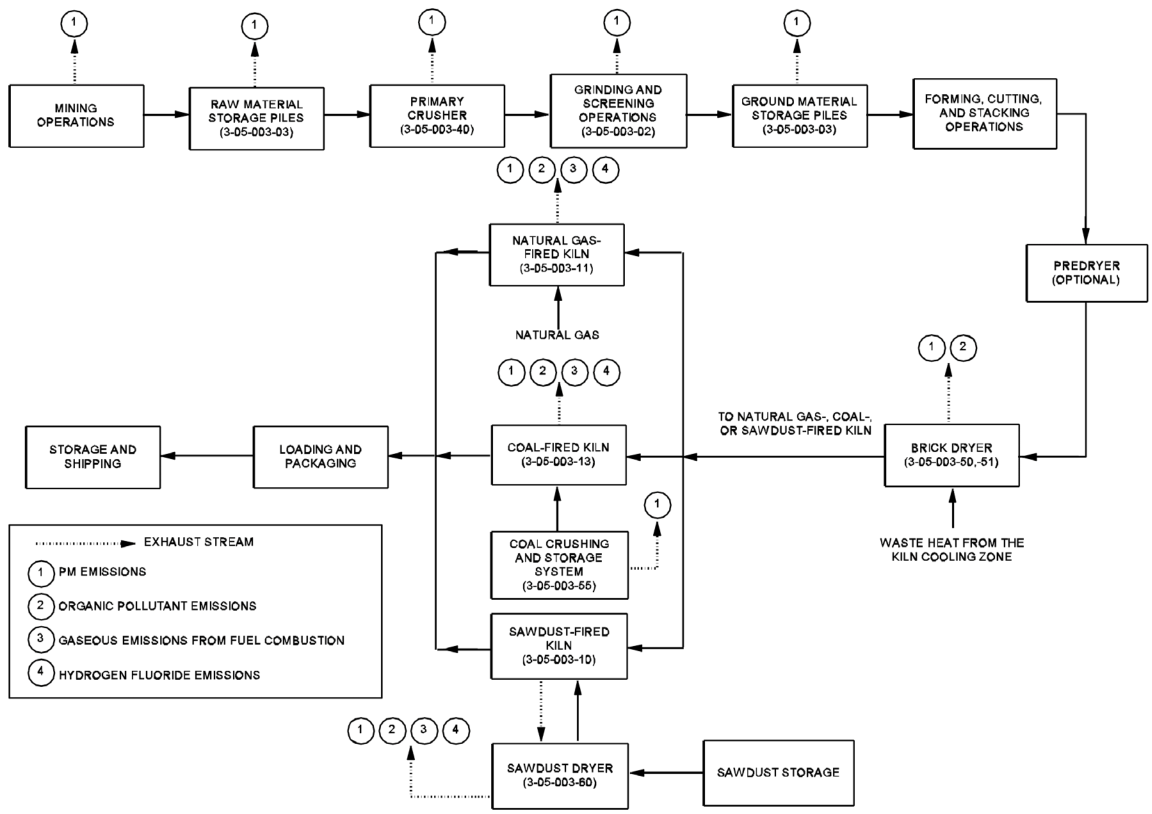

Figure 4: Typical brick manufacturing process

50 https://www3.epa.gov/ttnchie1/ap42/ch11/final/c11s03.pdf

2.4 Rubber and Tire Manufacturing

Michelin’s tire plants in Bridgewater, Granton, and Waterville play a significant role in the province's industrial landscape. The plants produce tires for passenger vehicles, light trucks, and commercial vehicles, making them essential to the regional economy.

Michelin is one of the largest consumers of natural gas in the province, using significant amounts of energy across its three sites for space heating and industrial processes. The plants are equipped with boilers installed in the 1970s and 1980s, primarily utilizing natural gas. These boilers are crucial to the operations, providing the necessary heat for both the facilities' production processes and space heating needs.

2.4.1 Process Overview

A typical tire manufacturing process is illustrated in Figure 5.

Mixing: The process begins with combining and mixing rubber compounds and additives in large, high-powered mixers. These mixers use counter-rotating rotors that shear the materials, generating considerable heat, which requires water-cooling to prevent premature vulcanization. The mixed rubber is then processed into sheets, cooled, and prepped for the next stages.

Component Preparation: Different tire components are prepared using processes like extrusion and calendering. Extruders push the rubber through dies under heat and pressure to create shapes such as treads, sidewalls, and inner liners, which are then vulcanized in ovens. Calenders use large rollers to layer rubber onto fabrics or steel cords, applying pressure to ensure adhesion and strength in the resulting sheets.

Making: All components are assembled onto a tire-building drum in a high-energy, labor-intensive process that involves precise alignment and splicing. The carcass of the tire is inflated, and the tread and belts are added.

Curing: The green tire is transferred to a mold for curing, where it undergoes high heat (around 177°C) and pressure (350 PSI) to achieve its final shape. A heated bladder inside the tire inflates, pressing it against the mold to form the tread pattern and sidewall. This step is highly energy-intensive, with steam, hot water, or gas used as a heat transfer medium.

Final Finish: After curing, tires are tested for uniformity, balance, and structural integrity using energy-powered machines like X-ray or magnetic inspection tools. Tires are also visually inspected for defects. Quality control measures ensure each tire meets performance standards, completing the production process.

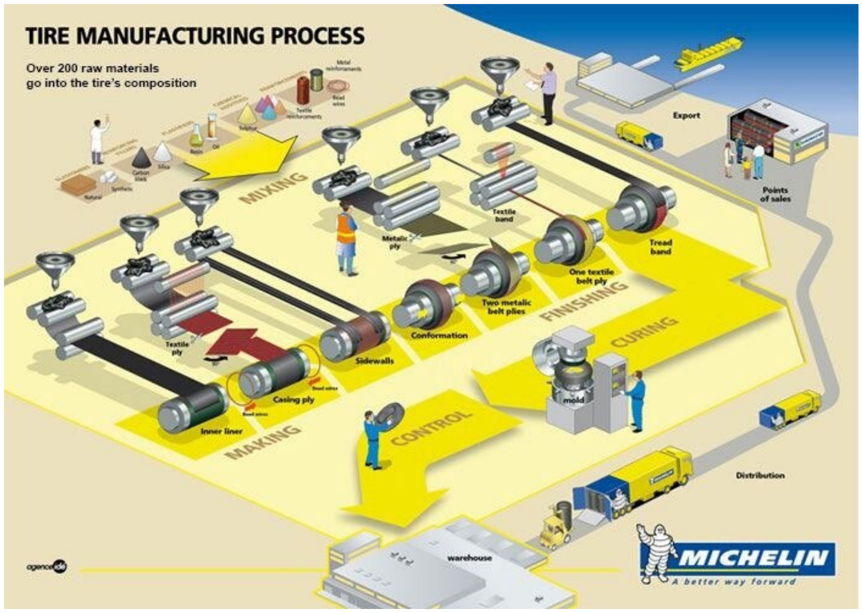

Figure 5: Typical tire manufacturing process[51]

2.5 Cement

The cement industry in Nova Scotia plays a pivotal role in supporting the province's construction and infrastructure sectors, with Lafarge Canada as a leading player in the market. Lafarge's operations in Nova Scotia, particularly at their Brookfield plant, underscore the importance of sustainable and innovative practices in cement production. Recently, Lafarge Canada, in collaboration with Geocycle and Natural Resources Canada, opened a new low-carbon fuel facility at the Brookfield plant. This $7.5 million initiative will repurpose 14,000 tonnes of waste materials annually into low-carbon fuels, reducing the plant's fossil fuel reliance and lowering carbon emissions by over 12,000 tonnes per year.[52]

2.5.1 Processes Overview

The cement manufacturing process is characterized by its high thermal energy requirements, primarily in the production of clinker, a key cement component. A general layout of a rotary klin is shown in Figure 6.

Preheating, calcination, and clinkerization all occur in the rotary kiln. A burner is located at one end, while the raw material is fed in from the other. Due to the kiln's rotation and slope, the material moves countercurrent to the gas stream. The burner must fire at approximately 1,850°C to heat the lime to the clinkerization temperature.

Whether gas, petcoke, or oil is used in the burner, as the lime moves toward the flame, it is preheated by the gas flow to the calcination temperature (900-1,050°C). It remains at that temperature (since energy is consumed to convert $CaCO_3$ into CaO, an endothermic process) as it continues toward the flame. Once the reaction is complete, the lime heats up further to 1,300-1,450°C, partially melting to form clinkers. The clinkers exit the kiln near the burner zone. The flue gas temperature at the feed end typically reaches around

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[51] How are tires made

[52] Geocycle and Lafarge Canada partner for low-carbon fuel facility at Brookfield plant

250°C. The product clinker is then cooled by the airstream used for combustion in the burner.

Grinding and Finishing: Once cooled, the clinker is mixed with gypsum and ground in the cement mill to produce cement powder. The final product is then stored in silos before being packed and dispatched to customers. While grinding consumes electricity, the thermal energy requirement is most critical during the preheating, calcination, and clinkerization stages.

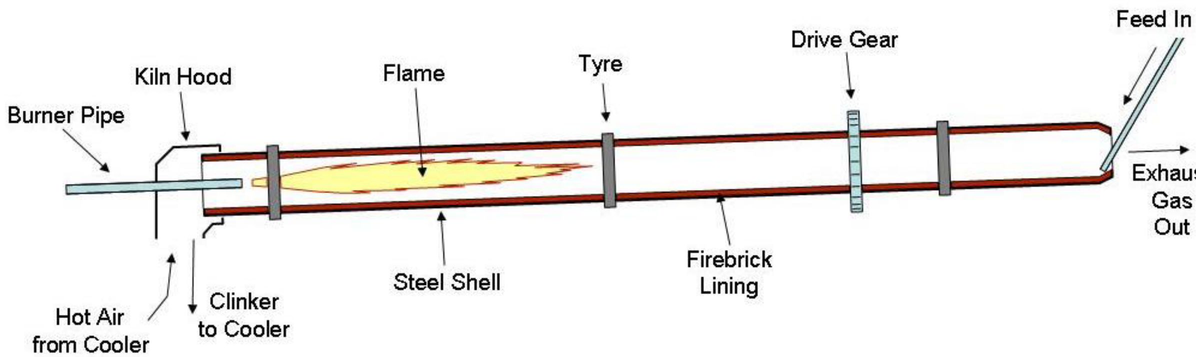

Figure 6: General Layout of a Rotary Kiln[53]

2.5.2 Temperature Requirements

Cement production processes require sustained high temperatures to achieve the chemical transformations necessary for clinker production. The kiln, where clinkerization occurs, operates at approximately 1,450°C, making it one of the highest-temperature industrial processes. Consistent very high temperatures are vital to maintain the quality and strength of the cement produced, and any deviation can affect the product's properties.

2.6 Chemicals

The chemical industry in Nova Scotia is relatively modest compared to other provinces in Canada, however, several key chemical manufacturing processes are briefly discussed below for reference. The chemical industry encompasses a broad range of processes that require significant amounts of thermal energy for various processes. These processes include:

Steam Cracking: Crucial for producing olefins such as ethylene and propylene, steam cracking involves heating hydrocarbons to high temperatures (approximately 800°C –900°C) using steam. The endothermic reaction breaks down larger hydrocarbon molecules into smaller ones, which is critical for producing plastics and other chemicals.

Distillation: This is a widely used separation process that involves heating liquid mixtures to boil off and condense components based on their boiling points. The temperature required for distillation can range from around 100°C for low-boiling-point compounds to over 400°C for heavier fractions. This process is commonly used in the refining of crude oil and the separation of chemical mixtures.

Chemical Synthesis: Various chemical synthesis processes, such as ammonia production via the Haber-Bosch process, require heat inputs at multiple stages to enable or accelerate chemical reactions. These

[53] https://en.wikipedia.org/wiki/Cement_kiln

processes often require temperatures between 400°C –600°C. For example, the Haber-Bosch process for ammonia synthesis typically operates at around 450°C –500°C.

Reforming: Processes like catalytic reforming convert lower-value feedstocks into higher-value products such as aromatics or hydrogen. Reforming processes generally require temperatures ranging from 500°C to 900°C, depending on the desired chemical output.

2.7 Marine Sector

Nova Scotia, particularly Halifax, has a rich maritime history and remains a pivotal player in the shipping sector. The Port of Halifax serves as a major hub for global shipping. The sector's energy demands align closely with propulsion systems, auxiliary power systems, and steam production requirements, which are vital for the operation and maintenance of marine vessels.

2.7.1 Energy Demand

Marine shipping is a crucial component of global trade, responsible for nearly 90% of the world's cargo transportation. This sector has significant energy demands that are primarily associated with the following processes:

Propulsion Systems: The primary source of energy demand in shipping. Most marine vessels use internal combustion engines (ICEs) fuelled with heavy fuel oil (HFO), marine diesel oil (MDO), or marine gas oil (MGO). These engines provide the mechanical energy required to propel ships across oceans. The combustion of these fuels generates substantial heat to maintain engine efficiency and ensure continuous operation. The energy demand in propulsion systems is particularly high in long-distance ocean shipping, where ships must operate continuously for extended periods. [54]

Auxiliary Power Systems: In addition to propulsion systems, ships have auxiliary power requirements. Auxiliary engines, boilers, and generators supply electricity for various onboard applications, including lighting, heating, ventilation, air conditioning, refrigeration, and other equipment operations. These auxiliary systems consume significant amounts of fuel and energy, especially on larger vessels like tankers, container ships, and cruise ships, with high electricity demand.[55]

Steam Production for Onboard Uses: Steam systems are utilized on many ships for propulsion (steam turbines) or to power auxiliary machinery. Boilers are commonly used to produce steam, steam is also used to heat fuel oil, maintain the temperature of cargoes, and provide power for various shipboard functions. These boilers require continuous input of energy to sustain steam production, making them another major contributor to the energy demand of marine vessels.[56]

[54] Wikramanayake, E., Acharya, P.V., Kapner, M. and Bahadur, V., 2021, April. Green hydrogen-based energy storage in Texas for decarbonization of the electric grid. In 2021 IEEE Green Technologies Conference (GreenTech) (pp. 409-415). https://doi.org/10.1109/GreenTech48523.2021.00070

[55] Hoang, A.T., Pandey, A., De Osés, F.J.M., Chen, W.H., Said, Z., Ng, K.H., Ağbulut, Ü., Tarełko, W., Ölçer, A.I. and Nguyen, X.P., 2023. Technological solutions for boosting hydrogen role in decarbonization strategies and net-zero goals of world shipping: Challenges and perspectives. Renewable and Sustainable Energy Reviews, 188, p.113790. https://doi.org/10.1016/j.rser.2023.113790

[56] Shi, J., Zhu, Y., Feng, Y., Yang, J. and Xia, C., 2023. A prompt decarbonization pathway for shipping: green hydrogen, ammonia, and methanol production and utilization in marine engines. Atmosphere, 14(3), p.584. https://doi.org/10.3390/atmos14030584

2.7.2 Transition Consideration

While specific temperature requirements are less critical in this context, the focus should be on replicating existing energy use patterns to facilitate a cost-effective transition to low-carbon technologies. Emphasizing fuels and technologies that can match current performance standards will help in adopting alternatives like hydrogen for both marine vessels and port equipment. This approach addresses the industry's reliance on fossil fuels and supports the development of effective decarbonization strategies in Nova Scotia's marine sector.

2.8 Food Production

Nova Scotia's food industry is a key contributor to the regional economy, featuring major companies like High Liner Foods, Clearwater Seafoods, Acadian Seaplants, Oxford Frozen Foods, Scotsburn, and among others. The industry relies heavily on energy-intensive processes, often using fossil fuels for heating, refrigeration, and processing.[57,58,59,60,61]

2.8.1 Processes Overview

The food industry extensively relies on thermal processes to ensure food safety, enhance product quality, and preserve shelf life. Key thermal processes include pasteurization, sterilization, drying, cooking, blanching, baking, evaporation, and dehydration, all of which involve the application of heat to achieve specific food processing goals as described below: [62,63,64]

Steam Systems: Steam generated by boilers powered with fossil fuels is commonly used for heating in processes like pasteurization, sterilization, and drying. Steam provides a controlled and uniform heat source essential for these applications.

Hot Water Systems: Hot water heating is used in blanching and some cooking processes. Boilers or heaters using fossil fuels heat water, which is then circulated through processing equipment.

Direct-Fired Heating: Processes such as baking, roasting, and frying often use direct-fired ovens or fryers. Fossil fuels are combusted directly to produce the high temperatures required for these methods.

Evaporation and Dehydration Equipment: These processes may use hot air or direct flame heating, with energy supplied by fossil fuels, to remove moisture from products like fruits, vegetables, and dairy powders.

The industry's reliance on these fossil fuel-based heating methods underscores the need to understand how energy is consumed and where opportunities for decarbonization exist within Nova Scotia's food sector.

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[57] https://www.highlinerfoods.com/
[58] https://www.clearwater.ca/
[59] https://www.acadianseaplants.com/
[60] https://www.oxfordfrozenfoods.com/
[61] https://www.scotsburnmilk.ca/
[62] WVU researchers develop hydrogen technology to curtail GHGes from food, beverage industry
[63] Atuonwu, J. and Tassou, S., 2021. Decarbonisation of food manufacturing by the electrification of heat: A review of developments, technology options and future directions. Trends in Food Science & Technology, 107, pp.168-182. https://doi.org/10.1016/j.tifs.2020.10.011
[64] https://repository.tudelft.nl/record/uuid:71089afc-d43e-41f7-90fe-de66298d9713

2.8.2 Transition Consideration

In Nova Scotia, the food industry's fossil fuel usage is significant due to the dependence on traditional heating methods:

Boilers and Steam Generation: Natural gas, fuel oil, or propane-fired boilers generate steam for various thermal processes. The efficiency of these boilers directly impacts fuel consumption and GHG emissions.

Direct Combustion Equipment: Ovens, fryers, and dryers often use burners fuelled by natural gas or propane. These systems transfer heat directly to the food product, requiring substantial energy input.

Refrigeration and Cooling Systems: Although primarily electrical, these systems may rely on electricity generated from fossil fuels, contributing to the overall carbon footprint.

Understanding the specific ways fossil fuels are used in Nova Scotia's food industry is crucial for developing effective decarbonization strategies. By focusing on how heat is transferred to processes—whether through steam, hot water, or direct firing—we can identify areas where alternative energy sources or more efficient technologies can be implemented to reduce reliance on fossil fuels.

3. Part 3 – Hydrogen's Potential to Decarbonize Process Heat Applications

3.1 Industrial Decarbonization Pathways

Heavy industry has one of the most challenging decarbonization pathways. These sectors, including cement, steel, pulp and paper, and chemicals, traditionally rely on energy-intensive processes that emit substantial amounts of GHGs into the atmosphere. Emissions from thermal heating demands and those that are created as a byproduct of chemical processes dominate the share of industrial emissions. Equation 1 below shows the complete combustion reaction undergone by many heating applications to burn natural gas to provide heat.

$$\mathrm{CH_4 + 2O_2 \rightarrow 2H_2O + CO_2 + heat}$$

Equation 1: Methane Complete Combustion Reaction

Fuel combustion is the predominant source of carbon emissions from heating applications in industrial processes. This reaction occurs in but is not limited to, boilers, furnaces, kilns, and fired heaters. Some chemical processes also release carbon dioxide as a byproduct of the chemicals that are reacted to make a final product. The cement industry is an example of this. The calcination process is a critical step in cement production where limestone or calcium carbonate ($CaCO_3$) is heated to high temperatures in a kiln. This process results in the decomposition of calcium carbonate into calcium oxide (CaO) and CO_2. The chemical reaction can be represented as follows:

$$\mathrm{CaCO_3 + heat \rightarrow CaO + CO_2}$$

Equation 2 : Limestone Calcination Reaction

The transition to sustainable practices requires additional technological innovation—such as adopting CCUS and the transition to low-carbon fuel sources—and a fundamental rethinking of supply chains and production methods. Additionally, heavy industry must navigate economic constraints, including the high costs associated with new technologies and the need for substantial investment in infrastructure. Regulatory pressures, market volatility, and the need for skilled labor further complicate this transition. As these industries work toward decarbonization, balancing economic viability with environmental responsibility will be essential for achieving net-zero targets.

3.1.1 Operational and Energy Efficiency Improvements

Operational and energy efficiency improvements play a critical role in decarbonization. Heavy industry can progress further in its emissions reduction goals by optimizing energy consumption, increasing equipment operating efficiency, and avoiding unplanned shutdowns. These efficiency improvements typically offer low-cost, readily available solutions that reduce emissions and have a positive return on investment due to reduced fuel costs and increased returns from additional product throughput.

In 2020, Canada's industrial sector used 3,518 PJ of energy. Figure 7 below depicts this sector's energy consumption by fuel type in 2020. This figure includes data from the manufacturing, mining (including all oil and gas extraction), forestry, and construction industries. Industrial energy consumption increased by 11% over twenty years, from 2000 to 2020. During this same period, excluding resource extraction industries, energy efficiency improvements of 9% were observed, resulting in a reduction of 209 PJ, and saving $2.5 billion in energy costs in 2020.[65]

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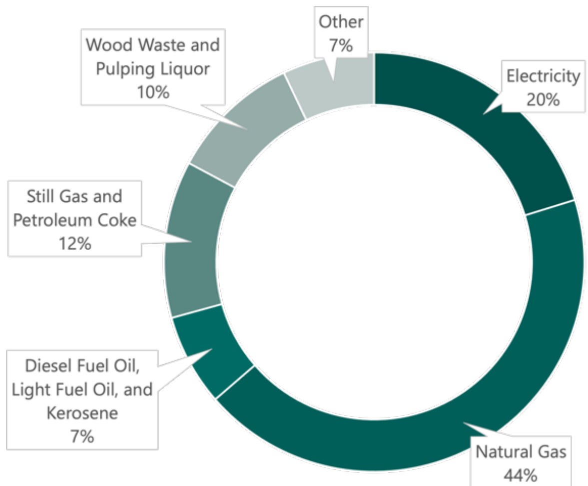

Figure 7: Canadian Industrial Sector Energy Use by Fuel Type, 2020

As discussed in Part 2, process heating applications play a significant role in the industrial sector. Currently, fossil fuels are burned to meet the considerable heating demand that the industry requires, releasing large amounts of CO_2 into the atmosphere. The majority of the energy efficiency opportunities in process heating involve reducing, recycling, and recovering waste heat losses from the production process. Implementing high-efficiency boilers, heat recovery systems, and digital optimization tools can significantly reduce the energy required for industrial processes like steelmaking, cement production, and chemical manufacturing.

Motors and machine drives such as pumps, fans, and compressors are widely used in various manufacturing processes, including fluid operations and processing. Inefficiencies caused by improper equipment sizing and inadequate system design lead to increased maintenance requirements, reduced control, and poor energy performance. These issues can be mitigated by employing high-efficiency or premium-efficiency motors, installing variable speed drives, optimizing system designs, and correctly sizing equipment.

3.1.2 Renewable Energy

Nova Scotia's Clean Power Plan is a comprehensive strategy aimed at transitioning to 80% renewable energy by 2030 and phasing out coal.[66] This plan leverages the province's strong wind resources, both onshore and offshore, to significantly expand wind energy capacity. The province has already made significant progress in wind energy, with over 300 commercial wind turbines generating approximately 603 MW. Additionally, the province aims to issue leases for five gigawatts of offshore wind energy by 2030, underlining its commitment to expanding wind energy capacity. Onshore wind is attractive to Nova Scotia because the province has some of the strongest and most consistent wind resources. This region's global and regional wind patterns are known to be world-class, with the potential for generating a high amount of electricity

[65] https://energy-information.canada.ca/sites/default/files/2023-10/energy-factbook-2023-2024-section4.pdf
[66] The Path to 2030: Nova Scotia's clean energy future| Nova Scotia Power (nspower.ca)

every year (known as the annual capacity factor).[67] The Clean power plan aims to add over 300 MW of large-scale solar projects by 2030.[68] However, the potential for solar energy is limited due to lower solar insolation levels, making wind energy the most viable option. Hydroelectric power also plays a role, with NSPI operating 33 hydroelectric plants with a total capacity of 400 MW. The province's renewable electricity standards mandate that 80% of electricity should come from renewable sources by 2030, primarily driven by new wind projects and imports via the Maritime Link from Labrador's Muskrat Falls.

3.1.3 Direct Electrification

Electrification refers to the replacement of technologies or processes that rely on fossil fuels with those that use electricity as the primary energy source. Direct electrification refers to the use of electricity as the primary energy source to power equipment directly. It differs from indirect electrification methods, such as electricity use to produce hydrogen or synthetic fuels for later combustion. Direct electrification is generally more energy-efficient because it minimizes energy conversion losses.

Increasing renewable energy availability and falling prices of clean electricity have increased direct electrification's feasibility and cost competitiveness for process heat applications. The varying thermal heat demands and temperature requirements across different industrial processes mean no one-size-fits-all approach for industrial electrification exists. Industries with very high temperature requirements, such as cement and steel, will require different solutions from industries with lower temperature requirements, such as paper mills and food production. Additionally, electric technologies that meet low and medium temperature requirements are readily available, while technologies for high and very high temperature requirements are still in early development. Table 2 below summarizes the electrification opportunities to meet process heating demands.

Table 2: Electrification Opportunities in Process Heating Applications

Temperature Classification	Low	Medium	High	Very High
Temperature Range	≤100 ℃	100-400 ℃	400-1000 ℃	≥1000 ℃
Process Examples	Washing Rinsing Food Preparation	Drying Evaporation Distillation Activation	Steam Reforming Steam Cracking	Glass Melting Limestone Calcination Iron Ore Reduction
Applicable Equipment Examples	Heat pumps	Heat Pumps Electric Boilers	Induction Heating Electric Resistance Heaters	Electric Furnaces Induction Heaters Electric Resistance Heaters
Technology Readiness	Commercially Available		Technology Still in Early Development	

To determine the economic viability of industrial electrification, both CAPEX and OPEX costs must be considered. From a CAPEX perspective, electric heat pumps and boilers for low and medium temperature heating requirements are commercially viable and readily available. Electric equipment to meet high and very high temperature requirements is still in development and has yet to reach economic viability. However, these technologies will likely benefit from the experience curve similar to what has recently been observed for solar PV panels, semiconductors, and batteries as production increases and economies of scale are reached. Electricity prices will make the most significant impact on OPEX costs. As Nova Scotia continues to decarbonize its grid by adding renewable energy sources, electricity prices are expected to fall, reducing OPEX costs associated with electrification. So, while direct electrification of equipment currently running on

[67] Onshore Wind Resources | Net Zero Atlantic
[68] nova-scotia-clean-power-plan-presentation-en.pdf (novascotia.ca)

fossil fuels may lead to higher costs in the short term, long-term economic viability is anticipated for many process heating applications in Nova Scotia.

3.1.4 Carbon Capture, Utilization & Storage

CCUS is another emissions reduction strategy important in decarbonizing industrial processes. While efficiency strategies aim to reduce CO_2 emissions and direct electrification applications aim to eliminate them, carbon capture captures emissions after they are generated and before they are released into the atmosphere.

3.1.4.1 CO_2 Capture

The first step in the CCUS value chain is capturing CO_2 from sources in industrial processes, such as combustion. Examples include process heaters such as boilers, fired heaters, and furnaces or power generation equipment such as gas turbine generators. This is known as point source carbon capture and is typically achieved through three main processes described below: pre-combustion, post-combustion, and oxy-combustion carbon capture. Additionally, technology for removing CO_2 directly from the atmosphere, known as Direct Air Capture (DAC), is also in development and is described below.

Pre-Combustion Carbon Capture: In pre-combustion carbon capture, CO_2 is removed from fossil fuels before combustion is completed. For example, in coal-fired processes, the coal is first reacted with steam and oxygen in a high-temperature and high-pressure environment to undergo a reaction known as partial oxidation or gasification. This reaction forms a mixture of hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), and smaller amounts of other gaseous components. This mixture is known as synthesis gas or syngas. The syngas is then mixed with steam to undergo the water-gas shift reaction to convert the CO and H_2O to CO_2 and H_2 and produce a gas mixture rich in CO_2 and H_2. The CO_2 can then be separated, captured, and compressed before transportation.

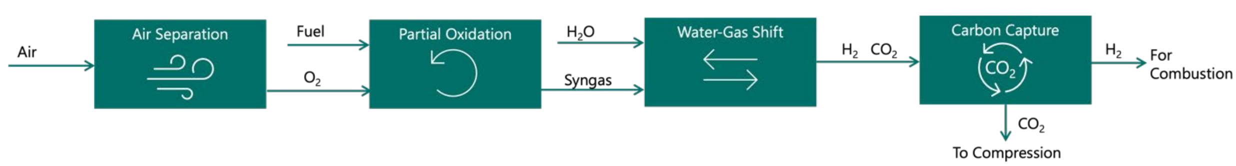

Figure 8: Pre-Combustion Carbon Capture Process

Post-Combustion Carbon Capture: In post-combustion carbon capture, CO_2 is removed from flue gas, the exhaust emitted after fuel is burned in power plants, industrial boilers, or other combustion processes. Flue gas consists primarily of nitrogen, CO_2, water vapor, and small amounts of other gases like sulfur dioxide (SO_2) and nitrogen oxides (NO_x). It is produced when fossil fuels, such as coal, oil, or natural gas, are combusted to generate heat or electricity. In this process, oxygen from the air reacts with carbon in the fuel, forming CO_2, a major flue gas component. Post-combustion carbon capture systems use chemical solvents, such as amines, to absorb the CO_2 from the flue gas. The captured CO_2 is then separated and compressed before transportation. Post-combustion technology is the most mature carbon capture technology and can be added to existing plants.

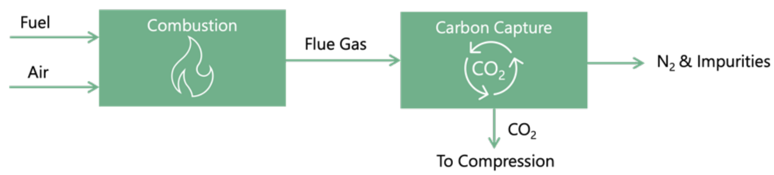

Figure 9 : Post-Combustion Carbon Capture Process

Oxy-Combustion Carbon Capture: In oxy-combustion carbon capture, pure oxygen is used instead of air in the combustion process. This results in a flue gas primarily composed of carbon dioxide (CO_2) and water vapor. This method enhances the concentration of CO_2 in the exhaust, making it easier and more efficient to capture and separate during carbon capture processes. In an oxy-combustion system, fuel is burned in an oxygen-rich environment, producing a more compact flue gas that is cooled, leading to water condensation and a concentrated stream of CO_2. Some of the CO_2 is then recycled back into the process to help to regulate the combustion temperature, as burning in pure oxygen would otherwise lead to excessively high temperatures.

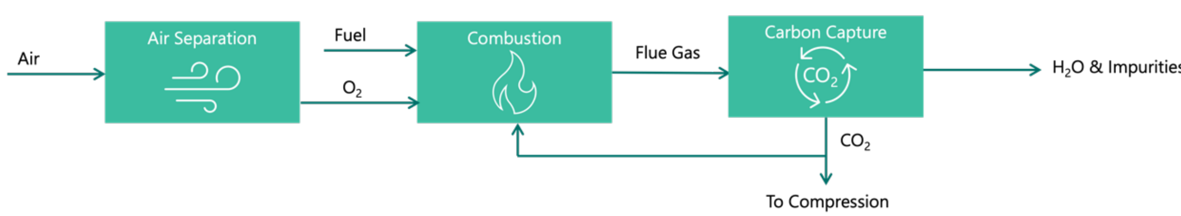

Figure 10: Oxy-Combustion Carbon Capture Process

Direct Air Capture (DAC): Direct Air Capture is the process of capturing CO_2 already in the atmosphere. DAC systems typically use chemicals, such as sorbents or solvents, to capture CO_2 in the air. This technology offers a scalable solution for reducing atmospheric CO_2 levels, especially as global emissions continue to rise. While DAC has garnered increasing attention in recent years, with pilot projects and commercial facilities being established, challenges remain regarding its economic feasibility and energy requirements. This is due to the much smaller concentration of CO_2 that exists in the atmosphere compared to CO_2 concentrations in point-source capture streams.

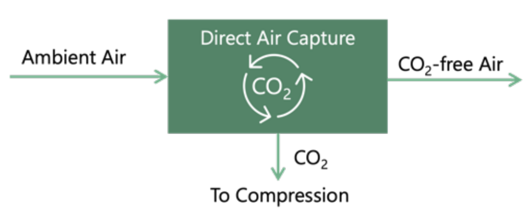

Figure 11: Direct Air Capture Process

3.1.4.2 CO_2 Transportation

After CO_2 has been captured and compressed into a liquid for transportation. Typically, CO_2 is transported via pipelines, the most cost-effective and common method, especially for large volumes. In some cases, CO_2 can also be transported by ship or truck, particularly for smaller quantities or when pipeline infrastructure is not feasible. The choice of transportation method depends on factors such as distance, volume, and the existing infrastructure. Ensuring the integrity and safety of transportation is critical, as high-pressure pipelines must be designed to handle CO_2's unique properties. Research and development are ongoing to optimize these transportation networks to facilitate the widespread adoption of carbon capture technologies.

Captured CO_2 can be either stored underground in geological formations, where it won't impact the atmosphere, or utilized for other processes. CO_2 utilization refers to the process of converting captured carbon dioxide into valuable products or materials, effectively recycling a GHG into useful resources. This can involve various methods and applications, including the production of chemicals like urea, synthetic fuels like methanol and synthetic natural gas, and building materials like concrete.

3.1.4.3 CO_2 Storage

The final step in the CCUS value chain is CO_2 storage. This process typically involves injecting CO_2 into geological formations, such as depleted oil and gas reservoirs, deep saline aquifers, or unmineable coal seams, where it can be stored indefinitely. The effectiveness of CO_2 storage depends on factors such as the geological characteristics of the storage site, including permeability, porosity, and cap rock integrity, which act as barriers to prevent leakage. Monitoring and verification are essential to ensure the long-term safety and stability of stored CO_2.[69]

Carbon Capture plays an important role in Canada's carbon management strategy, as shown in Figure 12 below. Managing CO_2 emissions through CCUS is one pathway for Nova Scotia to achieve its own and Canada's net-zero emissions goals. Many regions across Canada lack available CO_2 storage options, and some significant emitters do not have nearby storage solutions. Major CO_2-producing areas in Quebec and Ontario are near Nova Scotia but would require establishing a transport network similar to existing natural gas pipelines to facilitate CO_2 movement. Offshore Nova Scotia has well-characterized saline aquifers and reservoirs, supported by extensive data on reservoir porosity, permeability, and detailed three-dimensional and two-dimensional marine seismic studies. This understanding makes Nova Scotia an attractive location for further research into CCUS development.[70]

[69] https://natural-resources.canada.ca/climate-change/canadas-green-future/capturing-the-opportunity-carbon-management-strategy-for-canada/carbon-capture-utilization-and-storage-nova-scotia/26126#a2
[70] https://natural-resources.canada.ca/climate-change/canadas-green-future/capturing-the-opportunity-carbon-management-strategy-for-canada/canadas-carbon-management-strategy/25337

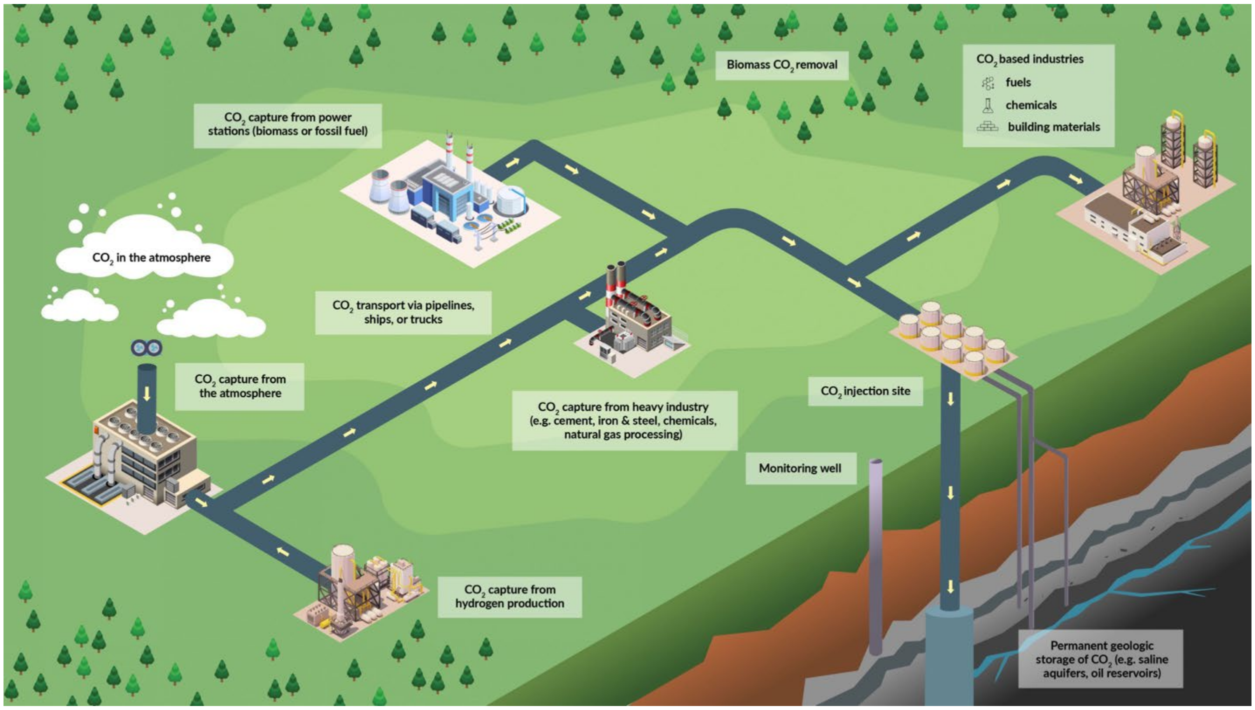

Figure 12: Canada's Carbon Management Strategy Process Diagram[71]

3.1.5 Hydrogen

Hydrogen offers significant potential to decarbonize industrial sectors by replacing fossil fuels in combustion processes that require high-temperature heat and as a feedstock for chemical reactions. In industries such as steel, cement, and chemical production, hydrogen can be used as a cleaner alternative to natural gas or coal. For example, in steelmaking, hydrogen can replace coal in the direct reduction process to produce "green steel," emitting water instead of CO_2. In chemical industries, hydrogen can also serve as a low-carbon feedstock, particularly for ammonia and methanol production. Hydrogen can also fuel industrial boilers, process heaters, and turbines, reducing emissions from process heat applications. Equation 3 below shows the combustion reaction using hydrogen as a fuel source:

$$2\mathrm{H_2} + \mathrm{O_2} \rightarrow 2\mathrm{H_2O} + \mathrm{heat}$$

Equation 3: Hydrogen Complete Combustion Reaction

Converse to the combustion reaction with methane as the fuel source in Equation 3 above, when hydrogen is used as fuel for combustion, no CO_2 is produced; rather, hydrogen burns "clean," producing water as a byproduct.

Hydrogen is a key component of Canada and Nova Scotia's decarbonization strategy due to its potential to significantly reduce emissions across multiple sectors. As a versatile and clean energy carrier, hydrogen can replace fossil fuels in industries that are hard to electrify. Canada, with its vast renewable energy resources,

[71] https://cdn.catf.us/wp-content/uploads/2023/11/15092028/solid-oxide-electrolysis-report.pdf

aims to produce low-carbon hydrogen through electrolysis powered by renewable energy and natural gas reforming with carbon capture. Nova Scotia is particularly well-positioned to leverage its variable renewable energy resources for green hydrogen production. The hydrogen ecosystem in Canada includes diverse production pathways, infrastructure for storage and transportation, and end-use applications in transportation, industry, and power generation. This ecosystem supports domestic decarbonization and export opportunities, contributing to Canada's net-zero goals. Figure 13 depicts what a mature hydrogen ecosystem will look like:

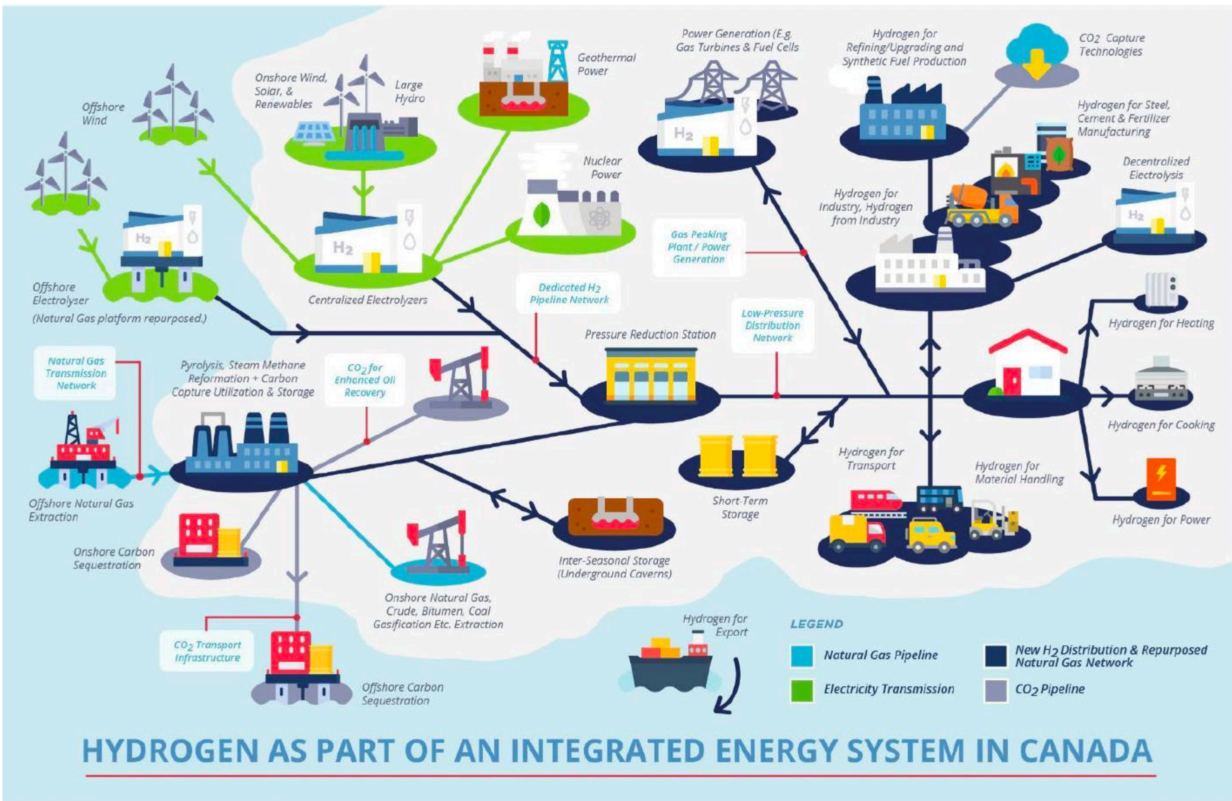

Figure 13 : Hydrogen Ecosystem[72]

3.2 Hydrogen Production Pathways

There are many different hydrogen production pathways, each varying in technological maturity and economic feasibility. Among the most advanced and economically viable pathways is methane reforming, often coupled with carbon capture and storage. Steam methane reforming (SMR) is the most widespread method for producing hydrogen today, primarily due to its relatively low cost and established infrastructure. However, it produces significant CO_2 emissions, which is why pairing it with CCS is a viable low-carbon option. Hydrogen produced through thermochemical pathways, such as SMR, that captures the produced CO_2 is commonly referred to as blue hydrogen. Autothermal reforming and partial oxidation are also

[72] https://natural-resources.canada.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

methane reforming processes that have advanced technologically over the last decade.

Electrolysis, particularly water electrolysis powered by renewable energy, is another pathway gaining momentum due to its potential for near-zero emissions, though it is currently more expensive than SMR in many regions. Hydrogen produced from this pathway is commonly referred to as green hydrogen. Other pathways, such as biomass gasification and methane pyrolysis, are emerging but are less developed. Figure 14 below shows the most common hydrogen production pathways in use or development today:

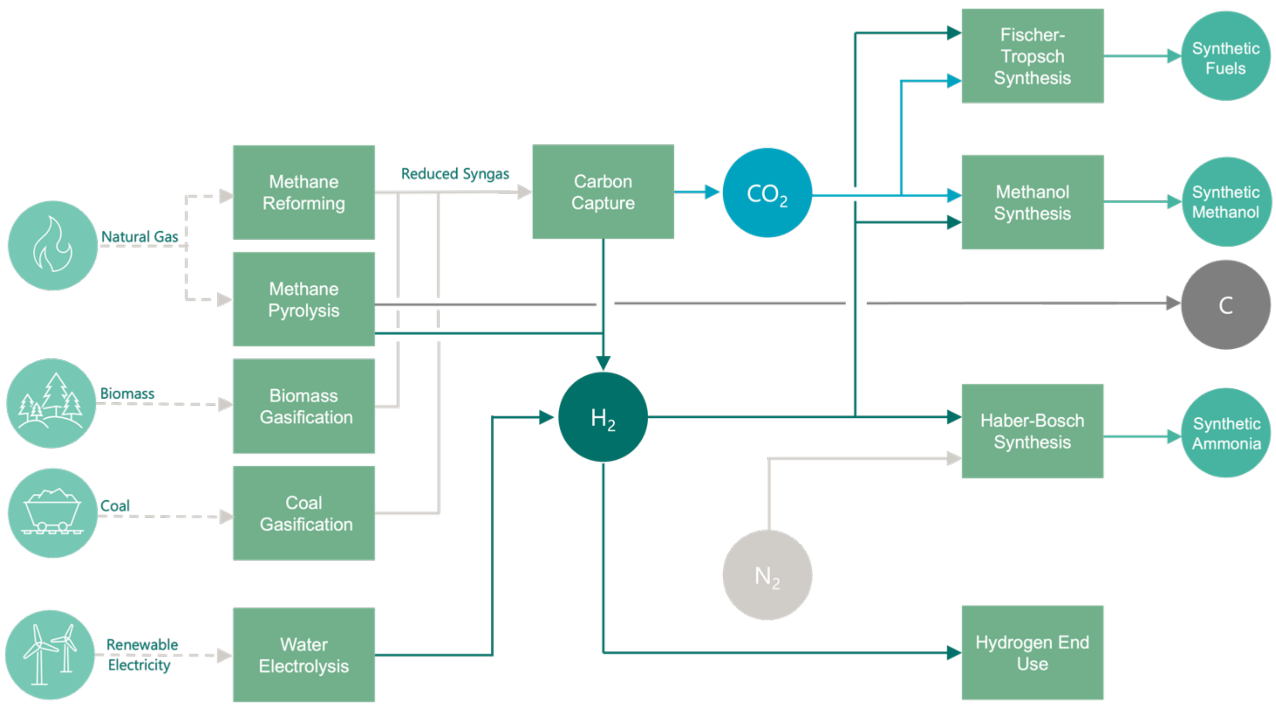

Figure 14: Hydrogen Production Pathways

The following section describes these pathways in more detail. It's important to know that there are other hydrogen pathways than those mentioned in the above figure. However, these pathways are less mature and will not be discussed in the following section.

3.2.1 Electrolysis

Electrolysis with renewable energy involves splitting water into hydrogen and oxygen using an electric current. This process typically uses renewable energy sources, such as solar, wind, or hydroelectric power, to generate the electricity needed for electrolysis. During electrolysis, water is subjected to an electric field, causing it to undergo a reaction at the electrodes; hydrogen is collected at the cathode, while oxygen is released at the anode. The chemical reaction for electrolysis is shown in Equation 4 below:

$$2H_2O \rightarrow 2H_2 + O_2$$

Equation 4: Water Electrolysis Reaction

There are several types of electrolyzers—*key equipment that splits water into hydrogen and oxygen*— used in this process, including Proton Exchange Membrane (PEM), alkaline, and solid oxide electrolyzers, each with distinct advantages and operating conditions.

Proton Exchange Membranes (PEM) Electrolyzers use a solid polymer membrane as the electrolyte. These systems operate at relatively low temperatures, typically between 50°C and 80°C, and can rapidly respond to fluctuations in power input, making them ideal for coupling with intermittent renewable energy sources. PEM electrolyzers are known for their high efficiency and ability to produce high-purity hydrogen, but they require expensive materials, such as platinum, for the electrodes, which can increase costs.

Alkaline Electrolyzers employ a liquid alkaline electrolyte, such as potassium hydroxide (KOH), and have been used for decades. Operating at higher temperatures, around 60°C to 80°C, these electrolyzers are less sensitive to fluctuating energy input and generally have lower capital costs compared to PEM systems. However, they typically have lower efficiency and slower response times to changes in power input, which can limit their effectiveness when paired with variable renewable energy sources.

Solid Oxide Electrolyzers operate at much higher temperatures, typically between 700°C and 1000°C, utilizing a ceramic electrolyte. This high-temperature operation allows for higher efficiencies, as the thermal energy can be used to facilitate the electrolysis process, reducing the electrical energy required. Solid oxide electrolyzers are capable of utilizing waste heat from industrial processes, making them suitable for integration in combined heat and power systems. However, their high operating temperatures can pose challenges related to material durability and system complexity.[73]

As technology advances and costs decrease, electrolysis using renewable energy is expected to play a vital role in the transition to a low-carbon economy. Each electrolyzer type offers unique benefits for different applications and operating conditions.

3.2.1.2 Levelized Cost of Electrolytic Hydrogen

The levelized cost of hydrogen (LCOH) from electrolysis is steadily falling due to advancements in technology, economies of scale, and increasing global demand for clean hydrogen. In particular, the price of electrolyzers has been dropping, driven by increased competition and manufacturing capacity. In Western markets, companies are scaling up production and improving efficiencies, leading to lower costs for electrolyzers and reduced energy consumption during the electrolysis process. However, Chinese manufacturers are emerging as major competitors, producing electrolyzers at significantly lower costs due to their larger-scale manufacturing and government support for green hydrogen initiatives. This competition is putting downward pressure on global prices, contributing to the overall decline in LCOH. Additionally, increased investments in renewable energy are reducing electricity costs, which is a major factor in the economics of hydrogen production. As these trends continue, the cost of producing green hydrogen via electrolysis is expected to reach parity with or even undercut hydrogen produced from fossil fuels in certain regions, accelerating the growth of the hydrogen economy. Figure 15 below summarizes the LCOH for electrolytic hydrogen utilizing alkaline and PEM electrolyzers today and the expected forecast for price drops between 2030 and 2050.

[73] https://cdn.catf.us/wp-content/uploads/2023/11/15092028/solid-oxide-electrolysis-report.pdf

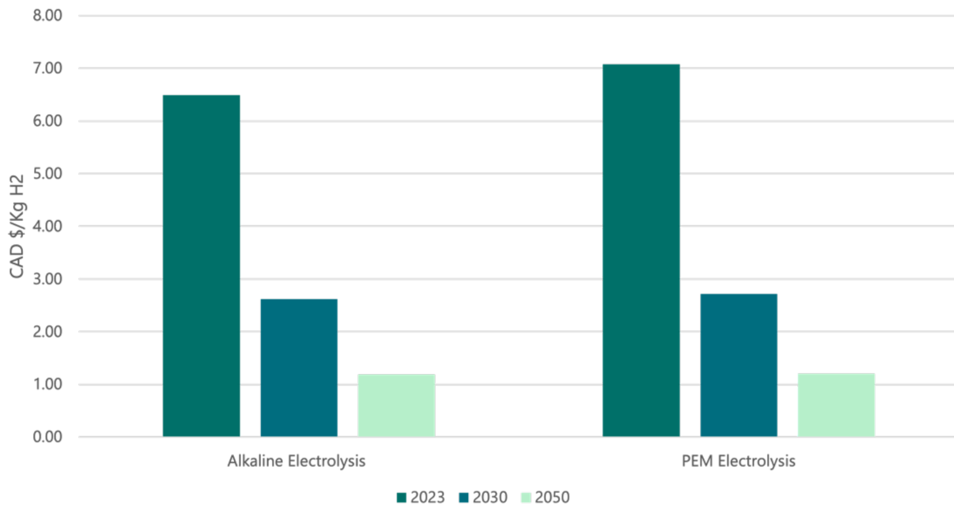

Figure 15: LCOH Electrolysis, Western Electrolyzers and Renewable Power, Canada [74]

The LCOH from electrolysis in Canada today, is approximately $CAD 6.49 and $CAD 7.70 for Alkaline and PEM electrolyzers respectively. That cost is expected to drop significantly by 2030 and continue to fall through 2050. Solid oxide electrolyzers are still less mature than PEM and alkaline electrolyzers as they are in earlier stages of commercialization and development.

3.2.2 Methane Reforming with Carbon Capture

Methane reforming is a widely used method for hydrogen production. It primarily involves converting natural gas, methane, or CH_4, into hydrogen and carbon dioxide through various chemical reactions. The three predominant methane reforming processes are steam methane reforming, autothermal reforming, and partial oxidation.

Steam Methane Reforming (SMR) is a process that reacts methane with steam at high temperatures of 700-1,000°C, producing hydrogen and carbon dioxide. Steam methane reforming occurs in two main steps. The first reaction involves the steam reforming of methane, where methane reacts with steam in the presence of a catalyst to produce hydrogen, carbon monoxide and a small amount of carbon dioxide. The carbon monoxide is then reacted with additional steam over a catalyst to produce more hydrogen and carbon dioxide. This process is endothermic, meaning that heat must be supplied to the process for the reaction to proceed. The chemical reactions are summarized in Equation 5 below:

$$\mathrm{CH_4 + H_2O \leftrightarrow CO + 3H_2}$$
(Steam Reforming Reaction)

$$\mathrm{CO + H_2O \leftrightarrow H_2 + CO_2}$$
(Water-Gas Shift Reaction)

$$\mathrm{CH_4 + 2H_2O \leftrightarrow 4H_2 + CO_2}$$
(Overall SMR Reaction)

Equation 5: Steam Methane Reforming

[74] (BNEF, 2023 Renewable LCOH forecast)

Autothermal Reforming (ATR) combines reforming and partial oxidation elements to convert methane into a hydrogen-rich syngas in a single reactor operated at high temperatures between 900-1,100°C. In the initial step, methane reacts with a limited amount of oxygen and produces hydrogen and carbon monoxide. Concurrently, steam is introduced, which reacts with the remaining methane and carbon monoxide to produce additional hydrogen. The carbon monoxide produced then further reacts with steam to yield more hydrogen and carbon dioxide. The chemical reactions for the ATR process are shown in Equation 6 below:

$$\mathrm{CH_4} + \frac{1}{2}\mathrm{O_2} \rightarrow \mathrm{CO} + 2\mathrm{H_2}$$

(Partial Oxidation Reaction)

$$\mathrm{CH_4} + \mathrm{H_2O} \rightarrow \mathrm{CO} + 3\mathrm{H_2}$$

(Steam Reforming Reaction)

$$\mathrm{CO} + \mathrm{H_2O} \rightarrow \mathrm{H_2} + \mathrm{CO_2}$$

(Water-Gas Shift Reaction)

$$\mathrm{CH_4} + \frac{1}{2}\mathrm{O_2} + \mathrm{H_2O} \rightarrow \mathrm{CO_2} + 3\mathrm{H_2}$$

(Overall ATR Reaction)

Equation 6: Autothermal Reforming

Partial Oxidation (POX) involves the reaction of methane with a limited amount of oxygen, typically from air, at very high temperatures ranging from 900-1,200°. This produces a hydrogen-rich syngas that is then converted to hydrogen and carbon dioxide through the water-gas shift reaction. Partial oxidation is an exothermic reaction, meaning it releases heat. Generally, this process is significantly faster than steam reforming and necessitates a smaller reactor vessel. However, it initially generates less hydrogen per unit of input fuel compared to steam reforming using the same fuel.

The chemical reactions for the POX process are shown in Equation 7 below:

$$\mathrm{CH_4} + \frac{1}{2}\mathrm{O_2} \rightarrow \mathrm{CO} + 2\mathrm{H_2}$$

(Partial Oxidation)

$$\mathrm{CO} + \mathrm{H_2O} \rightarrow \mathrm{H_2} + \mathrm{CO_2}$$

(Water-Gas Shift Reaction)

$$\mathrm{CH_4} + \frac{1}{2}\mathrm{O_2} + \mathrm{H_2O} \rightarrow \mathrm{CO_2} + 3\mathrm{H_2}$$

(Overall ATR Reaction)

Equation 7: Partial Oxidation

Project developers who plan to produce hydrogen through methane reforming typically perform technology evaluations to determine which reforming technology is best suited for their project. Steam methane reforming, autothermal reforming, and partial oxidation are all effective hydrogen production pathways, each with distinct advantages and trade-offs. SMR is the most common method due to its simplicity and established technology, though it requires external heat input. ATR balances heat management and hydrogen yield but requires significant power. POX accommodates a wide range of hydrocarbon feedstocks but has a lower hydrogen-to-carbon monoxide ratio. Overall, SMR remains the most widely adopted due to its economic feasibility, particularly when integrated with carbon capture. However, ATR and, to a lesser extent, POX applications are increasing in demand.

3.2.2.1 Levelized Cost of Thermochemical Hydrogen from Methane Reforming

The LCOH from reforming technologies, including SMR and ATR, is on a downward trend, primarily due to technological advancements and increasing operational efficiencies. As carbon capture and storage (CCS) technologies continue to improve, the cost associated with capturing CO2 emissions during the reforming process is expected to decrease, making these methods more economically viable. Additionally, the ongoing developments in the production of hydrogen from lower-cost natural gas feedstocks contribute to reduced overall production costs. Thermochemical hydrogen production costs are currently cheaper than the production costs of electrolytic hydrogen. They are expected to continue to drop through 2030, when they are expected to stabilize at costs that are likely to remain higher than their electrolytic counterparts, whose costs are expected to continue to drop until 2050.

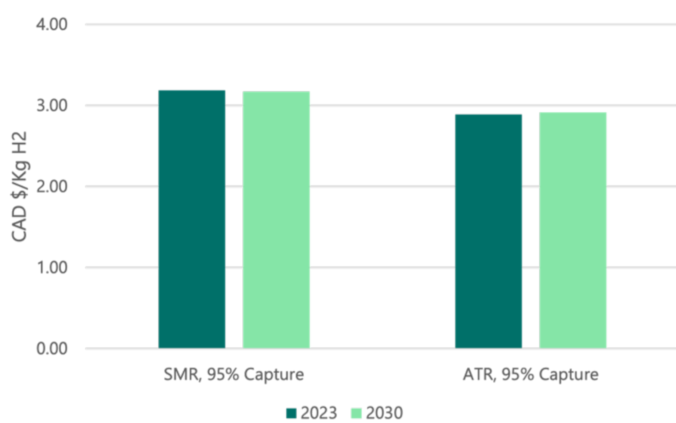

Figure 16: Levelized Cost of Hydrogen – ATR and SMR with Carbon Capture, Canada[75]

3.2.3 Biomass Gasification

Biomass is a renewable organic resource encompassing agricultural crop residues, forest residues, landfill gas, organic municipal solid waste, and animal waste. These renewable resources can be used to produce hydrogen through a process called gasification. Gasification involves converting organic or fossil-based carbon-rich materials at high temperatures (>700°C) without combustion, using a controlled amount of oxygen and/or steam to produce carbon monoxide, hydrogen, and small amounts of carbon dioxide. The

[75] 2023 Hydrogen Levelized Cost Update: Green Beats Gray | BloombergNEF (bnef.com)

carbon monoxide subsequently reacts with water to generate carbon dioxide and additional hydrogen through a water-gas shift reaction. Hydrogen can then be extracted from this gas stream using adsorbers or specialized membranes. The chemical reactions for biomass (glucose) gasification in the presence of steam are shown below:

$$C_6H_{12}O_2 + H_2O \rightarrow 6CO + 6H_2 + 6O_2$$
(Gasification Reaction)

$$6CO + 6H_2 + 6O_2 + H_2O \rightarrow 12H_2 + 6CO_2$$
(Water-Gas Shift)

$$C_6H_{12}O_2 + 6H_2O \rightarrow 12H_2 + 6CO_2$$
(Overall Gasification Reaction)

Equation 8: Biomass Gasification

Because growing biomass removes carbon dioxide from the atmosphere and is part of the natural carbon cycle, CO_2 emitted from biomass consumption may be considered carbon neutral.

3.2.4 Methane Pyrolysis

Methane pyrolysis is a process that decomposes methane into hydrogen and solid carbon through thermal decomposition at high temperatures in the absence of oxygen, typically ranging from 800°C to 1,200°C. The overall reaction is shown in Equation 9 below:

$$CH_4 \rightarrow C + 2H_2$$
(Methane Pyrolysis Reaction)

Equation 9: Methane Pyrolysis

The solid carbon produced, often referred to as carbon black, has several valuable applications, including its use as a reinforcement material in tires and rubber products, a pigment in inks, paints, and plastics, a conductive material in electronics and batteries, and as a solid fuel in combustion processes. Thus, methane pyrolysis represents an emerging method for hydrogen production that generates hydrogen and solid carbon without CO_2 emissions. In addition to the economic advantage of not requiring carbon capture equipment, carbon black can be sold to introduce an additional revenue stream.

3.3 Hydrogen Storage

Hydrogen storage technologies are divided into two main categories: physical-based storage, where hydrogen is stored in its elemental form, and material-based storage, where hydrogen is stored within or chemically bonded to other materials, as shown in Figure 17 below.

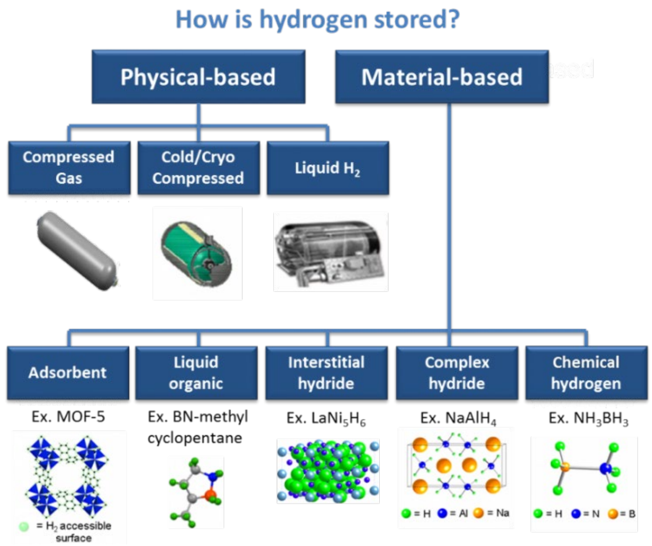

Figure 17:Hydrogen Storage Methods[76]

Physical-based storage includes compressed hydrogen gas, cryogenic compressed hydrogen, and liquid hydrogen (LH_2). Compressed hydrogen gas is stored at high pressures (350–700 bar) in pressurized tanks. It's a simple and widely used technology but has a low energy density, requiring large storage volumes. Cryo-compressed hydrogen combines aspects of compressed and liquid hydrogen by cooling hydrogen to cryogenic temperatures without fully liquefying it, offering a higher energy density but requiring cryogenic technology and energy-intensive cooling. Liquid hydrogen is fully cooled to cryogenic temperatures (-253°C), achieving the highest energy density among physical storage options, making it ideal for long-distance transport and large-scale applications. However, it comes with challenges like high energy costs for liquefaction and boil-off losses.

On the material-based storage side, hydrogen can be stored in adsorbent materials, liquid organic hydrogen carriers (LOHCs), interstitial metal hydrides, complex hydrides, and chemical hydrogen storage systems. Adsorbent materials, such as carbon nanotubes and metal-organic frameworks, store hydrogen on their surface at low temperatures and moderate pressures, but their storage density is generally lower. LOHCs allow hydrogen to be chemically bonded to liquids like toluene and released via a dehydrogenation reaction. These carriers are stable at ambient conditions and use existing fuel infrastructure, but the hydrogenation and dehydrogenation processes involve energy losses. Interstitial metal hydrides store hydrogen in the lattice structure of metals or alloys, offering high volumetric storage density and safe storage, though they are heavy and require significant energy to release hydrogen. Complex hydrides, like sodium borohydride or lithium aluminum hydride, provide high gravimetric density, but their use is complicated by high-temperature requirements for hydrogen release and challenges with dehydrogenation.

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[76] https://www.energy.gov/eere/fuelcells/hydrogen-storage

Chemical hydrogen storage systems, such as ammonia or methanol, leverage existing infrastructure and offer high energy density, but extracting hydrogen requires energy-intensive catalytic reforming processes.

Each storage method has its strengths and limitations. Compressed gas and metal hydrides are suited for short-term, on-site storage where space constraints are less of an issue, while liquid hydrogen and LOHCs are more applicable for long-distance transport due to their higher energy densities. For large-scale or seasonal storage, LOHCs or underground storage using metal hydrides could be appropriate for grid-scale energy management, particularly when storing surplus renewable energy. Ultimately, the choice of hydrogen storage method depends on the specific application, infrastructure availability, and energy requirements.

Salt Cavern storage is another method of hydrogen storage that is currently being explored. Salt cavern storage for hydrogen involves storing compressed hydrogen gas in large underground salt formations, where the impermeable nature of salt prevents gas from leaking. This method offers high capacity, low cost, and long-term stability, making it ideal for large-scale hydrogen storage and grid balancing in regions with suitable geology. Nova Scotia has identified several potential hydrogen storage salt caverns: Alton Salt Deposit, Kingsville Salt Deposit, and Orangedale Salt Deposit, but these caverns have not yet been developed.[77] The province's strong wind energy potential could align well with compressed hydrogen gas or liquid hydrogen storage as short-term solutions to balance intermittent renewable power generation. Compressed hydrogen could be used in smaller applications, such as local fueling stations.

3.4 Hydrogen Transportation

Hydrogen transportation is a crucial part of the hydrogen economy. It can occur through various pathways, including pipelines, trucks, ships, and tube trailers. Hydrogen can be transported either in its pure form as cryogenic liquid or gas or converted into chemical derivatives to increase transportation efficiency and safety and leverage existing infrastructure.

Chemical Hydrogen Carriers are compounds that can store and transport hydrogen in a stable, chemically bound form. They facilitate hydrogen's safe and efficient movement by converting it into a more manageable substance, such as ammonia, methanol, or LOHCs. Ammonia (NH_3), for instance, is a widely studied hydrogen carrier because it can be easily liquefied and transported using existing infrastructure. It can release hydrogen through catalytic or thermal processes. Methanol (CH_3OH) also serves as a hydrogen carrier, with the added benefit of being used as a fuel itself. LOHCs involve organic compounds that absorb hydrogen through chemical reactions, allowing for safe storage and transport without the need for high pressure or cryogenic temperatures. While chemical hydrogen carriers enable long-distance transportation and integration into existing supply chains, they may introduce challenges related to conversion efficiency, energy requirements for hydrogen release, and potential safety concerns during handling and processing. Overall, these carriers play a crucial role in expanding the logistical options for hydrogen distribution while addressing safety and stability issues.

Pipelines are the most efficient and cost-effective method for transporting large volumes of hydrogen over long distances. They facilitate continuous flow and can integrate hydrogen into existing natural gas infrastructure. However, challenges include the need for specialized materials to prevent hydrogen embrittlement and ensure safety measures due to hydrogen's flammability.

Liquid Hydrogen Trailers are specialized vehicles designed to transport hydrogen in its liquid form, which

[77] A Feasibility Study of Hydrogen Production Storage Distribution and Use in the Maritimes.pdf (oera.ca)

is achieved by cooling hydrogen to cryogenic temperatures of around -253°C. These trailers are equipped with highly insulated, double-walled tanks to maintain the low temperatures required to keep hydrogen in a liquid state, minimizing boil-off during transport. Liquid hydrogen has a much higher energy density compared to gaseous hydrogen, making it more efficient to transport over long distances. However, the liquefaction process is energy-intensive, and maintaining the cryogenic temperatures throughout the journey adds complexity and cost.

Hydrogen tube trailers are vehicles designed to transport compressed hydrogen gas in high-pressure cylinders, or "tubes," mounted on a trailer. These tubes store hydrogen at pressures typically ranging from 200 to 300 bar. The trailer consists of multiple cylinders, allowing for the transport of a relatively large volume of hydrogen gas compared to single-tank systems. While the lower pressure limits the energy density compared to liquid hydrogen transport, hydrogen tube trailers provide a flexible and relatively straightforward solution for distributing gaseous hydrogen, leveraging existing infrastructure. However, their efficiency over long distances is lower compared to liquid hydrogen transport, as the compressed gas requires larger volumes.

Ships are used for international hydrogen transportation, in liquid form or as ammonia or LOHCs, which can be converted back to hydrogen at the destination. Shipping hydrogen by sea allows for transporting large quantities over vast distances, making it suitable for global trade. However, this method requires advanced cryogenic technology and infrastructure, which can be costly and complex.

Determining appropriate transportation methods often depends on the distance, volume of hydrogen to be transported, and existing infrastructure. Figure 18 from the International Renewable Energy Agency (IRENA) summarizes the most cost-effective hydrogen transport pathways in 2050 as a function of project size and distance.

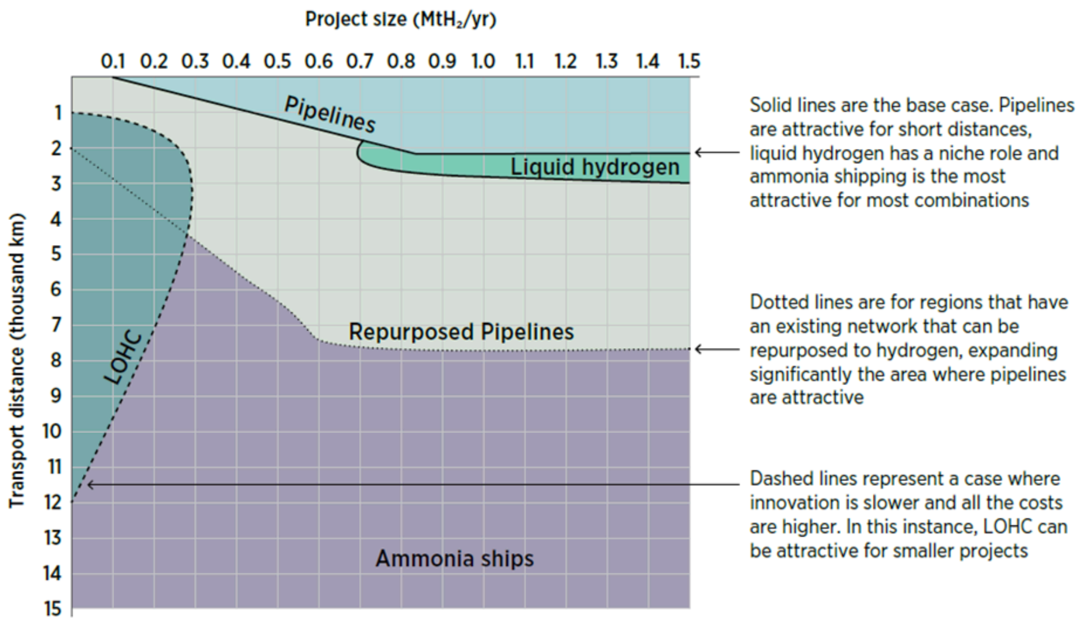

Figure 18: Cost-Effective Hydrogen Transport Pathways[78]

Hydrogen transportation within Nova Scotia is likely to occur in its pure form because of the relatively small transportation distance required to move hydrogen around the province. The subsequent sections will discuss transport costs associated with pipeline and road transportation.

3.4.1 Pipeline & Road Transportation Costs

Hydrogen transportation through pipelines is expected to be the most cost-effective method for both transportation and distribution lines. Transmission pipelines transport gas long distances, typically from production regions to demand centers. Distribution pipelines carry gas for the remainder of its journey from the distribution hub to the end user.

This form of transportation does, however, come with additional challenges compared to natural gas, specifically related to embrittlement and energy density. Embrittlement is a critical concern, as hydrogen can diffuse into the steel of pipelines, leading to material degradation and increased susceptibility to fractures, which can compromise pipeline integrity and safety. This necessitates the use of specialized materials or coatings, adding to costs and complicating maintenance. Additionally, hydrogen has a lower energy density by volume compared to natural gas, making transportation efficiency a challenge. To transport the same amount of energy, hydrogen must be compressed to high pressures or cooled to very low temperatures, requiring extra energy and infrastructure investments. This complexity can render hydrogen transportation less economically viable than natural, particularly over long distances. Although these challenges must be addressed, they can be overcome.

Although pipelines have a lower levelized cost of transport (LCOT), new pipelines are capital-intensive, and pipeline infrastructure does not reach all parts of Nova Scotia. For places where new pipeline installations are not feasible, hydrogen can be transported via existing roads by specialized trucks, such as liquid

[78] https://www.irena.org/Energy-Transition/Technology/Hydrogen/Global-hydrogen-trade

hydrogen and tube trailers described above.

Figure 19 below summarizes the LCOT for various transportation methods.

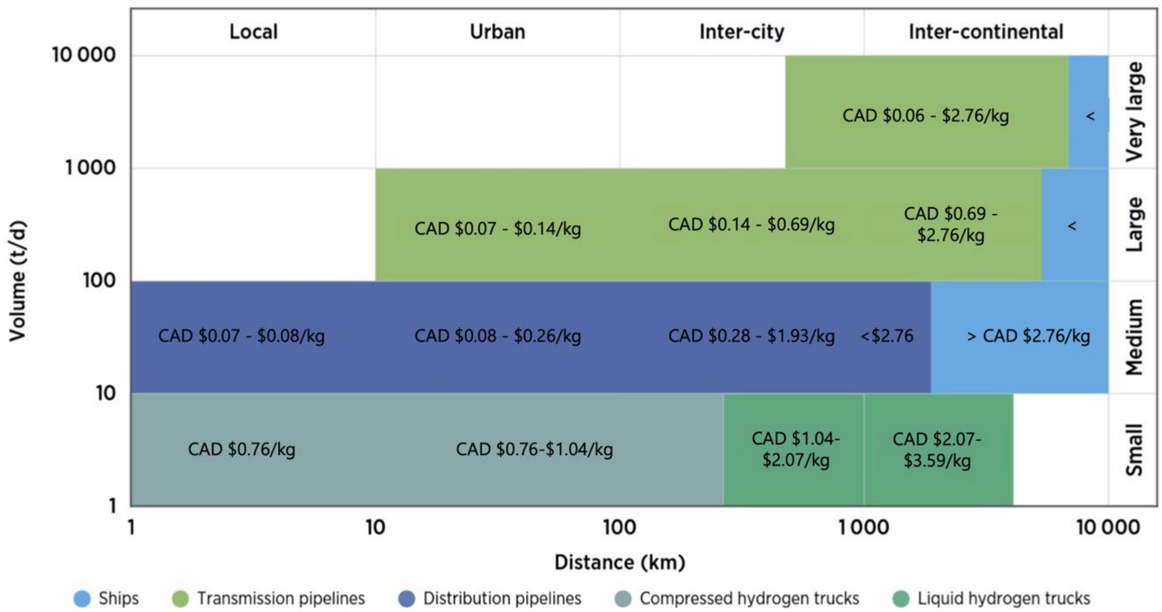

Figure 19: Hydrogen Transport Costs by Distance and Volume[79]

Today, Nova Scotia has one natural gas transmission pipeline, the Maritimes & Northeast Pipeline (M&NP), that runs from Goldsboro, Nova Scotia, to Dracut, Massachusetts, in the United States. The entire pipeline is approximately 1,400 km long, with the Canadian section that runs through Nova Scotia and New Brunswick making up approximately 567 km. The natural gas infrastructure in Nova Scotia is relatively new and uses mostly polyethylene pipes, in contrast to the steel pipelines used throughout much of North America. These modern, hydrogen-compatible pipelines position Nova Scotia, and Atlantic Canada, as having the most hydrogen-ready gas grid in the region. It is expected that between 5% and 20% hydrogen can be blended into the current natural gas supply without requiring any equipment modifications. An equivalent fully hydrogen-compatible transmission pipeline serving Nova Scotia would have an LCOT between $CAD 0.14-$0.68, while distribution lines covering the same distance would range between $CAD 0.68-$1.35, and road transportation falls in the $CAD 0.74-$2.03.

3.5 Hydrogen's Financial Viability for Industrial Applications

For hydrogen to become a viable decarbonization solution for industrial use in Nova Scotia, it must either compete with the cost of natural gas, or hydrogen users must be willing to pay a premium for the clean-burning fuel. Hydrogen production, especially renewable hydrogen through electrolysis, is currently more expensive than natural gas. To reach cost parity, advancements in hydrogen technology are needed to reduce production costs. Supportive government policies, such as subsidies and carbon pricing, can provide

[79] IRENA. Global Hydrogen Trade to Meet the 1.5 °C Climate Goal: Part II—Technology Review of Hydrogen Carriers. 2022. Available online: www.irena.org/publications

incentives to stimulate the hydrogen economy. The Canadian government has taken steps to provide incentives for hydrogen production, as well as penalties for carbon emissions, as discussed in Part 1 of this report, that have already spurred movement in this direction.

3.5.1 Nova Scotia Natural Gas Availability

Eastward Energy is a key utility provider in Nova Scotia, dedicated to delivering reliable and sustainable energy solutions to its customers. Eastward provides many of Nova Scotia's industrial customers with the natural gas they require to maintain operations. With a focus on innovation and environmental stewardship, Eastward Energy offers a comprehensive range of natural gas services, supported by a structured rate system and a growing commitment to clean energy projects, including the exploration of hydrogen as a fuel source. Eastward Energy provides multiple tiers of service to its customers depending on their energy requirements, as shown in Table 3 below. Natural gas prices for industrial customers are typically lower than for residential service customers but can vary widely during periods of increased demand.

Table 3: Eastward Energy October 2024 Rate Table, $CAD /GJ[80]

Residential Service	General Service	Rate Class 3	Rate Class 3 Demand Charge
$23.08	$20.49	$12.04	$30.85
	≤ 50,000 GJ	> 50,000 GJ	> 50,000 GJ

3.5.2 Canadian Output Based Pricing System's Impact on Natural Gas Combustion

Canada's OBPS, discussed in Part 1, imposes a carbon tax on every metric ton (MT) of CO_2 an industrial facility emits above its prescribed limit. This carbon tax was $65/MT in 2023 and will increase by $15 annually until 2030 when it will max out at $170/MT.

Table 4: Carbon Tax Conversion Table

	2023	2030
Carbon Tax ($CAD /MT CO_2)	$65.00	$170.00
Carbon Tax ($CAD /GJ Natural Gas)	$3.27	$8.55

The OBPS Carbon Tax is shown in $CAD /GJ natural gas in Table 4 above. Using Eastward Energy's rate table and including the OBPS carbon tax, the total residential and industrial (Rate Class 3) prices are calculated in Table 5 below. An escalation of 5% has been added between 2030 and 2050.

Table 5: Nova Scotia Natural Gas Forecast, CAD$/GJ

	2023	2030	2050
Residential	$26.76	$31.63	$33.21
Rate Class 3	$12.61	$20.59	$21.62

[80] https://eastwardenergy.com/wp-content/uploads/2024/10/October-Rate-Table-2024-FINAL.pdf

3.5.3 Nova Scotia's Hydrogen Landscape

Hydrogen presents significant opportunities across all regions of Canada, capitalizing on the unique strengths and resources available in different jurisdictions. These include the potential for renewable electricity, access to natural gas reserves, geological formations suitable for carbon capture and storage, and critical minerals essential for hydrogen and fuel cell technologies. Additionally, biomass and clean fuels contribute to this potential. Regional hydrogen priorities differ based on the varied resources, energy mixes, and economic drivers found within each province.

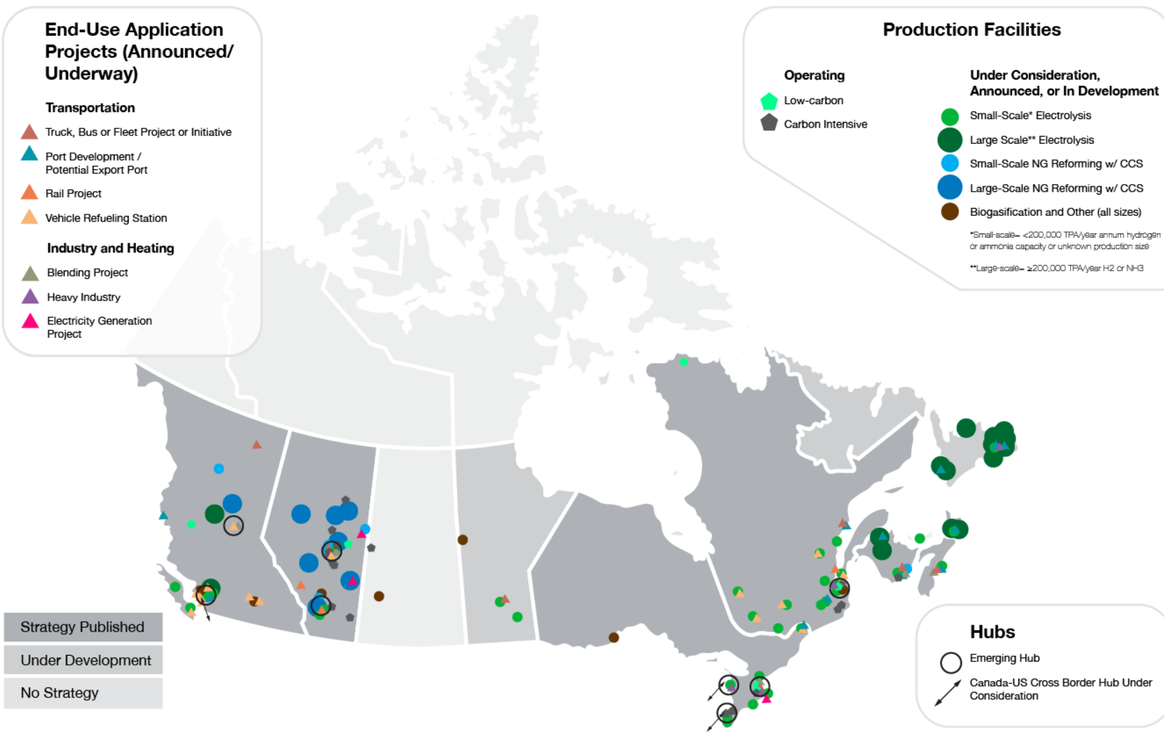

Figure 20: Hydrogen Developments in Canada since 2020

As shown in Figure 20 above, Nova Scotia, like much of Atlantic Canada, is best positioned for hydrogen production through electrolysis because of the province's rich potential for wind power. Therefore, the cost analysis below compares the cost of natural gas to the present and projected costs of hydrogen produced through electrolysis.

Table 6 shows the levelized cost of hydrogen build-up for hydrogen production in 2023 and forecasts for 2030 and 2050. The upper bound was used to determine the transmission pipeline costs, and the lower bound was used for distribution pipeline costs. A 10% profit margin was added to the total levelized cost, and subsidies were not considered.

Table 6: Total Levelized Cost of Hydrogen Build-up

	Electrolysis, Alkaline			Electrolysis, PEM		
	2023	2030	2050	2023	2030	2050
LCOH, Production ($CAD /kg H2)	$6.49	$2.62	$1.19	$7.07	$2.71	$1.20
LCOT, Pipeline Trans ($CAD /kg H2)	$0.68	$0.68	$0.68	$0.68	$0.68	$0.68
LCOT, Pipeline Dist ($CAD /kg H2)	$0.27	$0.27	$0.27	$0.27	$0.27	$0.27
Total LCOH (CAD$/kg H2)	$7.44	$3.56	$2.13	$8.02	$3.66	$2.15
Total LCOH ($CAD / GJ)	$61.99	$29.70	$17.78	$66.83	$30.49	$17.89
Purchase Price ($CAD / GJ)	**$68.19**	**$32.67**	**$19.55**	**$73.51**	**$33.54**	**$19.68**

As seen in the table above, although quite high today, the total levelized cost of hydrogen is expected to fall more than 50% by 2030 and another 40% by 2050.

3.5.4 Hydrogen – Natural Gas Cost Parity

Although clean hydrogen production costs are currently high in Nova Scotia, particularly when compared to traditional fuels like natural gas, substantial reductions in these costs are expected over the next few decades. By 2030, advancements in hydrogen production technologies—such as increased efficiency in electrolysis, scaling of green hydrogen projects, and declining costs for renewable energy—are projected to significantly lower hydrogen prices. Estimates suggest that clean hydrogen could reach cost parity with natural gas as early as 2030 and drop below natural gas prices by 2050, primarily as carbon pricing continues to raise the effective cost of fossil fuels. Figure 21 below demonstrates the period over which cost parity may be achieved:

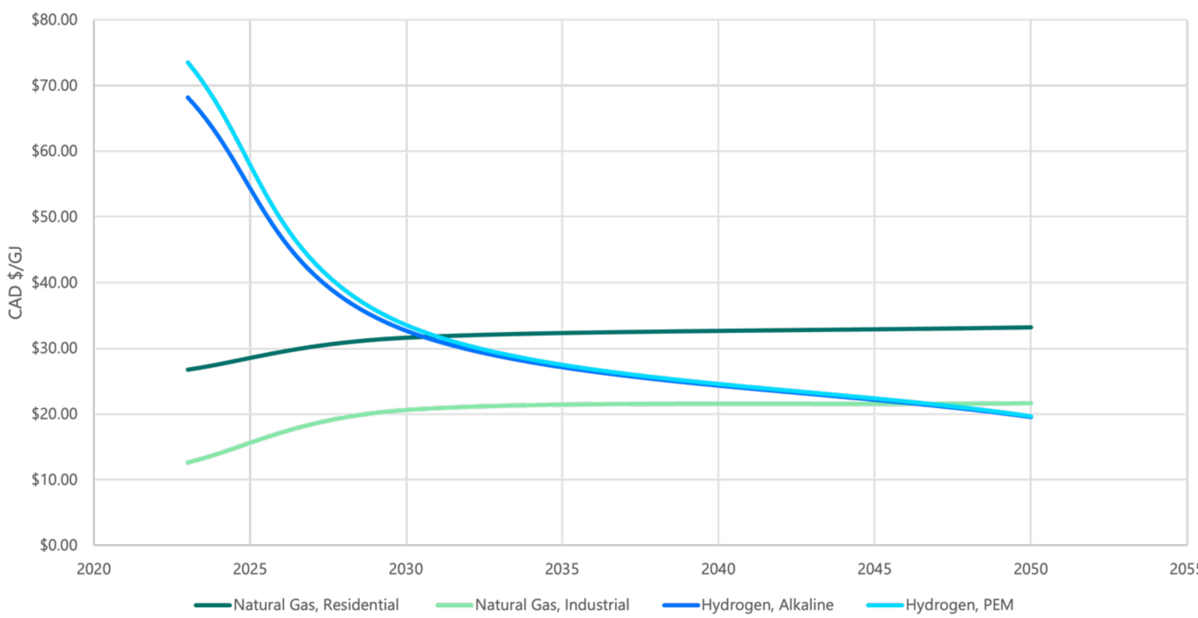

Figure 21: Cost Parity

Given this outlook, industrial users should consider hydrogen-ready infrastructure when planning future investments. Timing these investments to coincide with necessary equipment upgrades can help mitigate costs and ensure a smooth transition to hydrogen as it becomes more financially viable. Early adoption of hydrogen-ready technology positions industries to reduce future operational costs and helps them align with evolving carbon reduction policies.

4. Part 4 - Hydrogen Landscape in Nova Scotia

Nova Scotia has the potential to become a significant player in the global clean hydrogen market, leveraging its renewable energy resources, predominantly onshore and offshore wind projects, to produce low to zero-carbon fuels like green hydrogen, ammonia, and sustainable aviation fuel (SAF). Nova Scotia's strategic deep-water harbours make it an ideal export hub for European markets, especially as global demand for clean hydrogen increases.

Key initiatives include:

1. **Advancing Green Hydrogen Production and Export Opportunities:** Canada and Nova Scotia are collaborating to create a hydrogen export industry, supported by federal policies like the Clean Hydrogen Investment Tax Credit, and partnerships, which aim to establish a transatlantic supply corridor.
2. **Supporting Domestic Hydrogen Use-Cases:** The province is working to develop domestic applications of hydrogen, such as blending it with natural gas, and supporting industrial manufacturers exploring hydrogen use. Research institutions, like Dalhousie University, are also contributing by studying hydrogen integration into existing systems.
3. **Ensuring a Skilled Hydrogen Workforce:** There is a focus on workforce development to meet the needs of a growing hydrogen industry. Nova Scotia Community College is developing specialized training programs, including micro-credentials in hydrogen production.
4. **Atlantic Hydrogen Alliance:** The Atlantic provinces and Canadian government have set ambitious targets to drastically reduce emissions and reach net-zero by 2040, a challenging endeavour.[81] The Atlantic Hydrogen Alliance has been established to enhance regional hydrogen opportunities and address associated challenges. Its goal is to develop an economically viable clean hydrogen value chain, facilitating the transition to a prosperous low-carbon economy in Atlantic Canada.

Initial successes include regulatory reforms, financial incentives, partnerships with Indigenous communities, and international collaboration to establish a strong hydrogen economy in the province.[82]

Nova Scotia has the necessary resources and expertise for developing a green hydrogen economy as the province has:

- Abundant wind resources (onshore and offshore)
- Gas distribution system that can be used to transport green hydrogen
- Proximity to European markets seeking clean fuel options
- Fresh water in large quantities
- Land for facilities
- Deep, ice-free, and underused harbours
- Well-established port services
- Strong foundation to develop capable workforce and competitive supply chain

[81] Atlantic Hydrogen Alliance
[82] https://natural-resources.canada.ca/

- Academic researchers with expertise in clean technology
- Reputation as a leader in emerging technologies

4.1 Nova Scotia's Hydrogen Market Landscape

Nova Scotia's local demand for hydrogen is primarily focused on fostering a green hydrogen economy and is in the early stages compared to more mature hydrogen markets like Europe. The province's strategy centres on leveraging its abundant wind resources to develop green hydrogen, positioning itself as a leader in clean energy production, particularly for export markets.

The province has established a comprehensive Green Hydrogen Action Plan that outlines its approach to developing this sector and aims to utilize green hydrogen to reduce GHG emissions and support the clean energy transition. This plan includes domestic use of green hydrogen, particularly in transportation and other high-energy sectors.[83]

Europe, on the other hand, has a much larger and more immediate demand for hydrogen, projected to significantly grow over the coming decades. The European hydrogen market is driven by the need to decarbonize heavy industries and transport sectors. Forecasts suggest a surge in total hydrogen demand in Europe for the coming decades, with a projected 127% surge from 2030 to 2040, followed by a 63% increase from 2040 to 2050. This reflects a broad spectrum of future demand across various sectors including industry, transport, buildings, and electricity.[84] European countries are in urgent need of large-scale, secure, low-cost energy sources like green hydrogen to meet their needs and reduce reliance on natural gas. In 2022, Germany and Canada formed an alliance agreement to build a transatlantic supply chain for green hydrogen, with deliveries from Atlantic Canada to Germany to begin as early as 2025.

Nova Scotia aims to tap into this growing market by developing its local resources to not only meet internal demands but also to become a significant player in the global hydrogen market. The province has implemented legislative reforms, such as amendments to the Pipeline Act and Gas Distribution Act, to facilitate the development of hydrogen infrastructure which aligns with the broader Canadian strategy to promote clean hydrogen technologies and projects.

Overall, while Nova Scotia's current local demand for hydrogen is relatively small, its strategic initiatives and potential for green hydrogen production position it as a future key supplier, especially for markets with higher demand like Europe.

4.2 Nova Scotia's Transition to Green Hydrogen

Significant legislative developments have been made to support the transition to green hydrogen production. Amendments to Nova Scotia's energy-related legislations have been geared towards creating a favorable environment for green hydrogen projects by streamlining regulations and encouraging investments.[85]

Below is a summary of recent legislative and regulatory changes in Nova Scotia aimed at facilitating the transition to green hydrogen:

1. **Amendments to Nova Scotia's Liquid Fuel Regime (November 2022),** as discussed in Section

[83] Green hydrogen - Government of Nova Scotia, Canada
[84] Scenarios for future hydrogen demand | European Hydrogen Observatory (europa.eu)
[85] Green Hydrogen: 3 N.S. Legislative Developments | McInnes Cooper

1.2.10. These amendments allow for the inclusion of hydrogen pipelines and the consideration of hydrogen in gas distribution systems, providing legal clarity for businesses involved in green hydrogen projects.

2. **Facilitating New Green Hydrogen Projects (Bill 207),** as discussed in Section 1.3.2. Established a "Hydrogen Innovation Program" to support green hydrogen projects which allows eligible green hydrogen businesses to buy wholesale electricity via Nova Scotia's OATT, enabling them to connect hydrogen facilities to the power grid for hydrogen production and processing.
3. **Clarity on Environmental Assessments for Hydrogen Projects,** as discussed in Section 1.3.5. Large-scale hydrogen or ammonia projects must undergo a Class I environmental assessment to help green hydrogen developers understand their environmental obligations and streamline approvals for hydrogen facilities. This helps provide a clear framework and support for businesses in the sector.
4. **Advancing Nova Scotia Opportunities Act (Bill 471)**, as discussed in section 1.2.9. The amendments to the Gas Distribution Act allow gas distributors to apply to the NSUARB for the ability to acquire and use alternative energy sources such as hydrogen, renewable natural gas, or other low-carbon gaseous fuels. This supports the development of hydrogen as a low-carbon fuel and facilitates its integration into the existing natural gas grid, helping to diversify the energy mix and reduce reliance on traditional fossil fuels.
5. **Energy Reform Act (Bill 404)**, as discussed in section 1.2.3. This legislation introduces two new acts: The Energy and Regulatory Boards Act and The More Access to Energy Act, while repealing the Utility and Review Board Act. The Energy and Regulatory Boards Act significantly reforms the regulatory framework by splitting the NSUARB into two new boards, enhancing the focus on energy sector regulation. Section 4.3.1 included more details on this reform.

In the private sector, substantial investments are underway. The federal government has provided financial support to key projects, for the development of a green hydrogen facility in Nova Scotia's Strait of Canso area. This project benefits from federal loans and is expected to significantly contribute to the province's green hydrogen production capabilities.

Nova Scotia's strategic use of offshore wind resources is also crucial to its green hydrogen economy. The Nova Scotia Offshore Wind Roadmap is designed around these resources and details plans for leveraging wind energy for green hydrogen production. This includes legislative support and investment tax credits to encourage these projects to move forward.[86]

The Advancing Nova Scotia Opportunities Act supports Eastward Energy's efforts to incorporate renewable natural gas and hydrogen into its distribution network. The Act allows the company to apply to the NSUARB to either construct a domestic hydrogen production facility or purchase hydrogen and RNG.[87]

These efforts are complemented by research activities, such as those at Dalhousie University's Hydrogen Applications Research Lab and CTRI, which explores innovative uses of hydrogen in the province's energy systems and optimizing hydrogen production respectively.

Together, these strategies form a robust framework aiming to position Nova Scotia as a leader in green

[86] Winds of Change for Green Hydrogen: The Nova Scotia Offshore Wind Roadmap and its Implications - McMillan LLP

[87] New Legislation Paves the Way for Hydrogen and Renewable Natural Gas | Eastward Energy

hydrogen, driven by the combination of government policies, legislative adjustments, and private sector engagement.

4.3 Main Stakeholders

4.3.1 Key Regulators

Government of Nova Scotia is Supporting the development of green hydrogen through various legislation. Bill 404 - The Energy Reform Act creates two new acts (The Energy and Regulatory Boards Act and The More Access to Energy Act) and repeals the Utility and Review Board Act.[88]

The new Energy and Regulatory Boards Act introduces significant changes to Nova Scotia's regulatory framework by splitting NSUARB and creating two new boards:

4.3.1.1 Nova Scotia Energy Board:

The board will specialize in regulating public utilities within the energy sector. It will be required to consider the EGCCRA (Bill 57) in its decisions, ensuring that regulatory actions align with the province's climate change goals.

The board will consist of members with specific expertise in energy regulation, enhancing the board's ability to make informed decisions that support the transition to clean energy. The Nova Scotia Energy Board is expected to be established this year.

4.3.1.2 Regulatory and Appeals Board:

This board will take over the remaining responsibilities of the former Utility and Review Board, focusing on broader regulatory and appeals functions. It will handle various regulatory issues and appeals. This restructuring is expected to enhance the transparency of the regulatory process, providing stakeholders with clearer and more efficient pathways for addressing regulatory issues and appeals.

4.3.1.3 Independent Energy System Operator (IESO):

The new More Access to Energy Act also establishes an IESO.

The IESO will manage the operations of the electricity system, ensuring that electricity is delivered where and when it is needed. It will oversee the connection of renewable energy projects to the grid, system planning, and procuring new energy sources. The IESO will be an independent, non-profit organization managed by a Chief Executive Officer who reports to a board of directors.

As an independent, non-profit organization, the IESO will bring a level of impartiality and expertise that is essential for managing the complexities of modern electricity systems. This change aims to enhance transparency and accountability in the energy sector, ensuring that the system operates efficiently and meets the needs of the Nova Scotians. As an independent, non-profit organization, the IESO will bring a level of impartiality and expertise that is essential for managing the complexities of modern electricity systems. The new Independent Energy System Operator fully operational by late 2025.[89]

These changes are designed to modernize Nova Scotia's electricity system, making it more accountable, transparent, and competitive. The new boards and the IESO are expected to play crucial roles in supporting

[88] Nova Scotia Legislature - Bill 404 - Energy Reform (2024) Act (nslegislature.ca)
[89] Legislation to Modernize Electricity System, Improve Regulation | Government of Nova Scotia News Releases

the province's transition to a clean energy future.

4.3.2 Utilities

Nova Scotia's utility landscape includes major players like NSPI, which provides 95% of the province's electricity, and Eastward Energy, which focuses on integrating renewable natural gas and hydrogen into its distribution system.

4.3.2.1 Nova Scotia Power Inc.

NSPI is a subsidiary of Emera Inc., which provides 95% of the generation, transmission, and distribution of electrical power to approximately 540,000 residential, commercial, and industrial customers.[93] Currently, about 43% of the electricity generated comes from renewable sources, and the company is working towards 80% renewable energy by 2030. NSPI owns and operates wind farms on Nuttby Mountain and Digby Neck.

4.3.2.2 Eastward Energy

Eastward Energy, a key utility provider in Nova Scotia, is dedicated to delivering reliable and sustainable energy solutions to its customers. Eastward Energy is collaborating with Pier Labs, a non-profit organization, to develop a 'safety case' for integrating green hydrogen into Eastward Energy's distribution system.[90] Eastward Energy is set to explore various hydrogen supply options over the coming months, as part of their efforts to integrate hydrogen into their system. This will include evaluating options on whether to build their own electrolysis plant or to buy supply from a third party.

4.3.3 Independent Power Producers[91]

Natural Forces, delivers renewable energy projects across Nova Scotia through community partnerships, with around 300 MW of wind, solar, and hydropower projects in operation. RMS Energy specializes in developing and managing wind and solar power projects, contributing significantly to Nova Scotia's renewable energy goals. Scotian WindFields focuses on community-based wind energy projects, promoting local ownership and benefits.

Independent power producers own many wind farms across Nova Scotia, and more than 300 have commercial wind power contracts that sell their electricity back to NSPI. These IPPs play a crucial role in diversifying Nova Scotia's energy mix and advancing the province's renewable energy initiatives, supporting the transition to a sustainable and low-carbon energy future.

4.3.4 Green Hydrogen Producers and Users

This section highlighting the diverse applications and significant potential for both producers and users in the region. Nova Scotia is becoming a key player in the green hydrogen sector, with major producers like EverWind Fuels and Bear Head Energy leading the way. EverWind Fuels is developing a clean energy hub in Point Tupper to produce green hydrogen and ammonia, while Bear Head Energy plans to build a facility in the same area to produce hydrogen and ammonia. Section 4.5 gives a detailed view on the green hydrogen production landscape in Nova scotia.

In Nova Scotia, potential users of green hydrogen include:

Transportation Sector: Green hydrogen can be used to fuel buses, trucks, and even ships, significantly

[90] Province Helping Industries Move Toward Cleaner Fuels | Government of Nova Scotia News Releases
[91] Clean Energy Sources| Nova Scotia Power (nspower.ca)

reducing reliance on fossil fuels and lowering emissions. Efforts are underway to develop the necessary infrastructure, such as hydrogen refueling stations, to support the adoption of hydrogen-powered vehicles.

Industrial Applications: Industries can utilize green hydrogen as a clean energy source for processes that traditionally rely on natural gas or other fossil fuels, helping to decarbonize industrial operations. Major industrial players in Nova Scotia, such as manufacturing and processing plants, are exploring the integration of green hydrogen into their energy mix. Equipment that can use hydrogen or hydrogen blends for various processes using process heating are being tested and studied.

Power Generation: Green hydrogen can be used in power plants to generate electricity, providing a stable and clean energy supply. This can help balance the grid, especially during peak demand periods. Hydrogen can be produced using excess renewable energy, such as wind or solar, and then stored for later use in power generation.

Heating: Green hydrogen offers a clean alternative to natural gas for heating homes and commercial buildings, contributing to lower carbon emissions. Pilot projects are being considered to demonstrate the feasibility and benefits of using hydrogen for heating purposes.

Export Opportunities: Nova Scotia's strategic location on the Atlantic Coast, with deep-water harbors, makes it an ideal hub for exporting green hydrogen to European markets. There is growing demand for green hydrogen in Europe, driven by the region's commitment to reducing carbon emissions and transitioning to renewable energy sources.

Port of Halifax: The Port of Halifax is enhancing its infrastructure to support bunkering and handling green hydrogen and its derivatives, including identifying suitable locations for storing green fuels[92]. The port is fostering partnerships with shipping lines, industry stakeholders, and other ports to advance the use of green energy. Acting as a hub for industry, it supports domestic use cases, with trucking traffic through the port being a major opportunity. The port has also signed a MoU with the Port of Hamburg to create a decarbonized shipping corridor. By supporting the growth of the hydrogen economy, the Port of Halifax aims to enhance ties between nations, create economic opportunities, and further decarbonize their own operations.

4.4 The Nova Scotia Power Path to 2030[93]

The Nova Scotia Power Path to 2030 document outlines Nova Scotia's clean energy initiatives with a significant focus on hydrogen production, distribution, and integration into the energy system as part of the broader 2030 Clean Power Plan. The emphasis on hydrogen as a clean energy source is particularly notable, as it places the province in line with international energy goals aimed at reducing carbon emissions. The focus on green hydrogen reflects a growing recognition of the need for versatile and low-emission energy carries to support various industries, especially those traditionally heavily reliant on fossil fuels. Below are the key points related to hydrogen: [94]

Hydrogen Production

Green Hydrogen Projects: Nova Scotia is exploring the production of green hydrogen as a future resource for domestic use and export. The strategic emphasis on green hydrogen aligns with global decarbonization

[92] Ports of Halifax and Hamburg working to decarbonise shipping corridor | Port of Halifax
[93] NSUARB Board Decision - Nova Scotia Power Incorporated - M11017.pdf
[94] The path to 2030| Nova Scotia Power (nspower.ca)

efforts, as it offers a renewable, low-emission alternative to fossil fuels.

Hydrogen Sensitivity in the IRP: The IRP considers scenarios where system load increases to support hydrogen production facilities. These scenarios also evaluate the potential benefits of having a domestic hydrogen supply for future energy needs, especially for hydrogen-enabled fast-acting generation.

Hydrogen Use and Integration

Fuel Flexibility for Generation: The plan places significant focus on integrating clean fuels like green hydrogen into fast-acting power generation projects. This move is not only about reducing emissions but also about ensuring grid resilience. By Using Hydrogen as a flexible energy source, the plan aims to bolster system strength and frequency response, addressing the critical need for stability in a renewable-based energy system. Hydrogen's rapid response capability makes it well-suited for filling gaps left by intermittent renewable energy sources.

Natural Gas Conversions**:** An essential step in Nova Scotia's Transition involves converting existing coal-fired plants to natural gas facilities that can blend with hydrogen in the future. Existing coal-fired plants, such as the Point Tupper Generating Station, are slated for conversion to natural gas, with future considerations for hydrogen blending, further supporting the transition to a low-carbon grid. This gradual shift ensures operational continuity while simultaneously reducing emissions, this balancing economic feasibility and environmental responsibility.

Hydrogen Distribution and Infrastructure

Supporting Infrastructure: Emphasis is placed on ensuring that the necessary infrastructure, such as interconnection facilities and transmission networks, is in place to support the production and distribution of hydrogen, both domestically and for export. Without this infrastructure, the large-scale adoption of hydrogen as a clean energy source would be impractical. The planning here reflects a recognition that hydrogen's potential cannot be realized uncles supported by an extensive supply chain, from production to end-use.

Grid Stability: Hydrogen-enabled facilities are considered for providing ancillary services like voltage control and load following, supporting the grid's overall stability and reliability as it integrates more renewable energy.

Export and Economic Opportunities

Export Potential: The plan positions Nova Scotia as a Key player in the emerging global green hydrogen market, with a particular focus on exports to Europe. Europe's increasing demand for clean hydrogen, driven by strict decarbonization goals, presents a lucrative opportunity for Nova Scotia. The province is aiming to capitalize on its strategic location and international partnerships, especially through initiatives like the transatlantic hydrogen supply corridor.

Regulatory Support

Legislative and Policy Framework: To facilitate the transition, the plan highlights the importance of legislative backing. Amendments to existing laws, such as Electricity Act, are crucial for enabling hydrogen production and use at scale. These legal frameworks provide the foundation for building hydrogen economy by encouraging innovation, reducing regulatory barriers and creating an investment-friendly environment. These changes are crucial to developing a regulatory environment that supports hydrogen development and integration into the broader energy system.

These hydrogen-related initiatives reflect a bold and forward-looking strategy to decarbonize Nova Scotia's energy system by 2030.The provinces' approach to integrating green hydrogen, building necessary infrastructure, and positioning itself for export aligns with the global clean energy trends. Nova Scotia can not only reduce emissions but also support grid durability and economic growth, through leveraging renewable energy, storage, and flexible generation technologies.

4.5 Current Green Hydrogen Projects in Nova Scotia

At least five active green hydrogen projects are under development in Nova Scotia, including three large export projects to deliver low-carbon energy to European markets. These projects represent a key component of Nova Scotia's energy transition strategy, aimed at decarbonising industries and support the global shift to clean energy.

The government's Green Hydrogen Action Plan highlights the benefits of Nova Scotia for development into a green hydrogen production hub. It outlines strategies to develop the sector further, including potential uses in industrial processes, heavy transportation, and the marine sector. Overall, Nova Scotia's focus on green hydrogen is a vital part of its strategy to transition to a clean and sustainable energy future.

4.5.1 EverWind Project at Point Tupper[95]

Early site works have begun on this multi-phase green hydrogen and ammonia project in Point Tupper, Nova Scotia. Developed by EverWind Fuels ("EverWind"), this project aims to be the first large-scale project to produce green hydrogen and green ammonia in Canada with construction anticipated to begin in the first half of 2025. EverWind Fuels plans to start with 240,000 tonnes of green ammonia per year, expanding to 1 million tonnes of annual ammonia production following the construction of a 2-GW onshore wind farm. The plan is to scale the site up to over 10 million tonnes per year of green hydrogen and ammonia. These fuels will be produced in compliance with international clean hydrogen certification standards, including the European Commission for Renewable Fuels of Non-Biological Origin (RFNBO). The first two phases of the project represent $13.7 billion dollars of investment, and the project has received $125 million in federal loans.

The progress of each of the three phases of the project is shown below:

Phase 1: Green ammonia production from onshore wind and solar power (Operational 2026/2027)

- Environmental approval for the production facility
- Environmental approval for Bear Lake, Kmtnuk, and Windy Ridge wind farms
- FEED engineering completed with Black & Veatch
- Offtake MOUs in place
- Key equipment secured

Phase 2: Green ammonia production from onshore Wind Development (Operational 2028) Pre-FEED engineering underway

- Offtake MOUs in place; discussions for domestic and international supply

[95] https://everwindfuels.com/projects/point_tupper

- Land for wind farms secured

Phase 3: Green fuels from offshore wind (2030)

- In Development

The existing infrastructure supporting this development includes:

- An ice-free deep-water port at Point Tupper, capable of handling large vessels
- Rail loading facilities and pipeline networks in proximity to the production site, that facilitates the transportation and distribution of hydrogen to domestic and regional markets.
- Extensive storage capacity, of 7.7 million barrels of liquid storage available that enhances the site's ability to manage and distribute produced hydrogen and ammonia efficiently.

Furthermore, EverWind has entered a strategic partnership with Eastward Energy. This partnership focuses on leveraging the existing natural gas distribution infrastructure, which spans almost 500 km across seven counties in Nova Scotia. This partnership aims to integrate green hydrogen into the energy mix, supporting the province's transition to net-zero emissions and enhancing the local hydrogen supply chain.[96,97,98]

4.5.2 Bear Head Project at Point Tupper[99]

In addition to the EverWind Project, Nova Scotia's Minister of Environment and Climate Change approved a second green hydrogen production plant in Point Tupper. Bear Head Energy plans to construct the green hydrogen and ammonia facility in the Point Tupper Industrial Park on the Strait of Canso, where it once planned to build a liquefied natural gas plant.[100] The project is expected to leverage Nova Scotia's substantial wind resources and government support, including financial incentives like the Clean Hydrogen Investment Tax Credit.

The facility is designed to produce up to 350,000 tonnes of hydrogen and two (2) million tonnes of ammonia annually by installing 2 GW of hydrogen electrolyzers. It is scheduled to begin construction in 2024, with commissioning and initial production targeted for 2027.

The project site will include production, storage, and loading infrastructure, utilizing the existing deep-water port facilities for global shipping. Bear Head Energy plans to produce green hydrogen by drawing water from Landrie Lake and using renewable energy from wind turbines for electrolysis. It will then convert the hydrogen into ammonia for export. Ammonia can also be used in various industrial processes, including the production of agricultural fertilizer. Interest in green hydrogen and ammonia is growing internationally as industries and governments seek alternatives to carbon-based fossil fuels.

[96] EverWind Fuels to Establish A Regional Green Hydrogen Hub In Nova Scotia Reducing Carbon Emissions And Bringing Clean Energy Jobs To Nova Scotia (fuelcellsworks.com)
[97] Pioneering partnership to provide green hydrogen in Nova Scotia - The Environment Journal
[98] EverWind Announces Strategic Partnership with Eastward Energy For Domestic Transportation And Supply Of Green Hydrogen In Nova Scotia - FuelCellsWorks
[99] https://www.bearheadenergy.ca/
[100] https://www.cbc.ca/news/canada/nova-scotia/bear-head-green-hydrogen-approval-1.6807735

4.5.3 Green Shipping Corridor

The Ports of Halifax and Hamburg are collaborating on a green shipping corridor that aims to significantly reduce emissions and advance clean energy technologies like green hydrogen in maritime operations. This collaboration was formalized through an MOU signed on September 29, 2022, and involves developing port infrastructure for bunkering and exporting green hydrogen and its derivatives.[101,102,103]

Key stakeholders involved in this initiative include port authorities, local governments, various shipping lines, and companies specializing in energy solutions. The corridor also plans to address the necessary regulatory, financial, and safety frameworks to support decarbonization efforts. This partnership not only aims to decarbonize the shipping routes between Halifax and Hamburg but also seeks to establish a model that could be replicated in other regions, fostering global collaboration on sustainable maritime practices.

Through the Canada-Germany "Hydrogen Alliance," both countries have committed to facilitating investment in hydrogen projects, bolstering secure H_2 supply chains, creating a transatlantic supply corridor, and exporting clean Canadian hydrogen by 2025 to contribute to German energy security. Therefore, this initiative aligns with broader efforts by both Germany and Canada to enhance their hydrogen economies and reduce the maritime industry's carbon footprint, reflecting a growing trend in the global shipping industry towards environmental responsibility and innovation in clean energy use.

Notably, Everwind Fuels hydrogen and ammonia production facilities in Cape Breton, Nova Scotia is scheduled to come online in 2026/2027 (as discussed in Section 4.5.1) and is a 15–18-hour voyage to the Port of Halifax[101]. The Port of Halifax and EverWind Fuels have an MOU in place to explore opportunities in green fuel production and bunkering, power generation, and energy storage. The Green Corridor could result in the Port of Halifax acting as a secondary off-taker of hydrogen and its derivatives. This would facilitate the movement of these fuels by coastal tankers to Halifax where hydrogen and its derivatives could be stored, distributed, and bunkered. Container ships may opt to use these services for commercial and logistical reasons, even if cargo offloading is not required.

4.5.4 Simply Blue

In September, Irish renewable energy developer Simply Blue Group announced plans to develop a major SAF hub in Goldboro, Nova Scotia. Approximately 755 acres of contiguous land have been secured for the project. The Renewable Energy Park in Goldboro will utilise the electricity generated from Simply Blue Group's planned ~1GW of solar and wind farms in the Municipality of the District of St. Mary's. A dedicated transmission line will connect these facilities, ensuring a seamless flow of self-produced power. This renewable energy, along with Nova Scotia's sustainable biomass and water resources, will be utilized to produce approximately 150,000 tonnes of SAF per year. Simply Blue has a team of ten staff based in Halifax specifically focused on this project. The SAF that they produce there will play an essential part in reducing dependence on fossil fuels and combating climate change.[104]

101 Green Corridor Interview: Halifax Port Authority - AIVP
102 Ports of Halifax & Hamburg plan green shipping corridor (seatrade-maritime.com)
103 Ports of Halifax and Hamburg forge ties on hydrogen, green energy corridor - Offshore Energy (offshore-energy.biz)
104 Simply Blue Group | Simply Blue Group to develop major sustainable aviation fuel hub in Goldboro, Nova Scotia - Simply Blue Group

4.6 Hydrogen research in Nova Scotia

Ongoing research and development are being conducted to enhance hydrogen applications in the province. Dalhousie University has established labs to explore low-carbon energy alternatives, including integrating hydrogen into the existing natural gas infrastructure and using it in household appliances.[105, 106]

Clean Technologies Research Institute (CTRI)

The CTRI focuses on developing innovative solutions for renewable energy. The institute focuses on advancing hydrogen production technologies and improving methods for storing and utilizing hydrogen.

Hydrogen Applications Research Laboratory

The Hydrogen Applications Research Laboratory is dedicated to exploring the potential of hydrogen as a low-carbon energy source. In collaboration with Eastward Energy, the lab is testing the integration of hydrogen into the existing natural gas infrastructure. This includes evaluating the use of hydrogen-enriched natural gas, produced using green hydrogen, in household appliances. These efforts are crucial for reducing carbon emissions and supporting Nova Scotia's goal of achieving net-zero GHG emissions by 2050.

[105] Canada announces support for new hydrogen project in Nova Scotia - Canada.ca
[106] Dal lab explores how to unlock the power of green hydrogen in Nova Scotia - Dal News - Dalhousie University

5. PART 5- Hydrogen Equipment for Process Heating

According to Bloomberg New Energy Finance (BNEF), in 2016, industrial heating accounted for nearly 25% of the global energy demand. As shown in Figure 22, approximately 72% of these industrial heating needs are sourced from fossil fuels such as coal, oil, and natural gas.

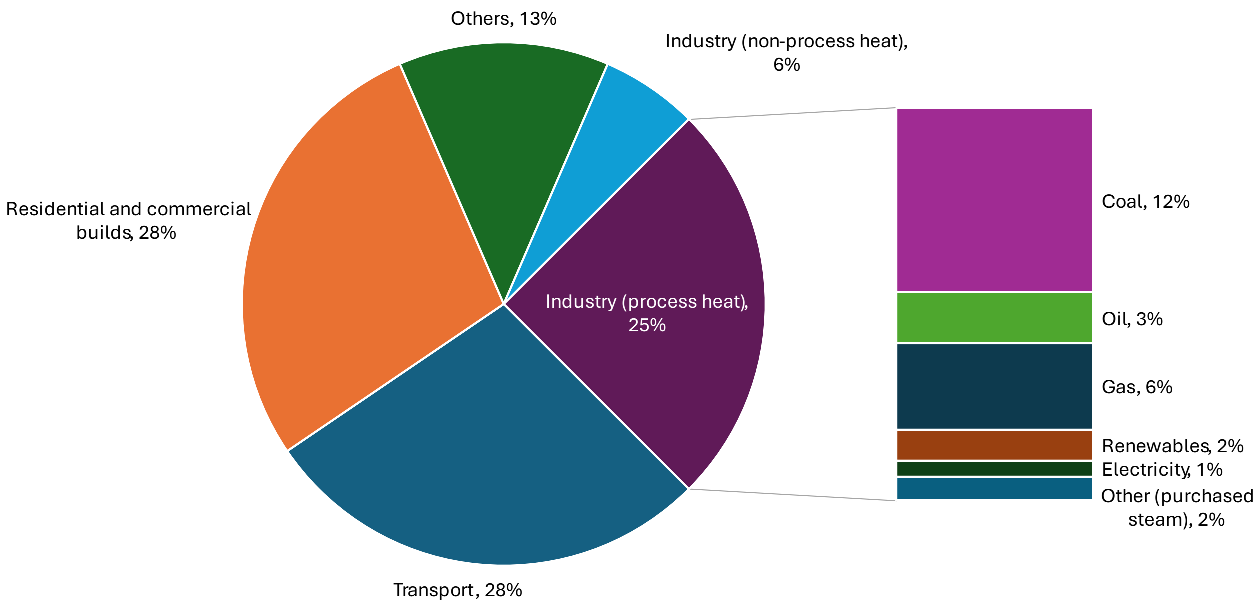

Figure 22: Distribution of global energy demand in 2016, split by category, based on Bloomberg NEF and IEA reports[107]

Industries have diverse process heating requirements based on the type of processes involved and the temperatures at which these processes occur. Process heating can be classified into four categories based on temperature:

i. Low temperature heating (<100°C)
ii. Medium temperature heating (100°C to 400°C)
iii. High temperature heating (400°C to 1000°C)
iv. Very high temperature heating (>1000°C)

Low- and medium-temperature heating applications are generally served by steam produced through industrial boilers that traditionally burn fossil fuels. Higher process temperatures may be achieved through the use of electric furnaces or the combustion of fossil fuels through direct or indirect heat transfer to the process fluid. A higher process temperature directly translates to a higher energy demand[166].

[107] Savut I., 2019, Industrial Heat: Deep Decarbonization Opportunities, Bloomberg NEF,

5.1 Process Heating Technologies and Equipment

The types of process heating technologies and the equipment linked to each are briefly discussed below:[108]

Steam-based process heating

Steam-based process heating involves a direct or indirect transfer of the latent heat from steam, to the process material. Steam heating may be used for low to medium- temperature industrial heating needs as well as in cogeneration units for the simultaneous production of steam and electric power (combined heat and power). Equipment and systems commonly associated with steam heating include boilers, water or process fluid heaters, steam-heated dryers, and steam spargers.

Fuel-based process heating

Fuels such as pulverised coal, oil, natural gas, and wood chips are combusted to provide heat directly from hot fuel gases or indirectly through heat exchangers to the process material or fluid. Fuel-based process heating is essential for steam generation and is thus involved in most steam-based heating processes. Process heating equipment that uses fuel-based heating includes furnaces, ovens, kilns and the combustion units of boilers.

Electricity-based process heating

Electricity heats the process either directly through resistance, heating, or immersion or indirectly through electromagnetic radiation. This type of heating is commonly used for material melting, preheating, drying, and curing. Examples of electric process heating equipment include electric arc furnaces, duct heaters, immersion heaters, and flanged heaters.

A number of different pathways may be considered for decarbonizing the carbon-intensive industrial heating sector ranging from waste heat recovery, process efficiency improvements, fuel switching, or the integration of CCUS. This section primarily focuses on switching combustion fuels to hydrogen in fired heaters and the key challenges involved in this path to decarbonization.

5.2 Fired Heater Equipment

In order to determine the feasibility of using hydrogen to partially or fully replace existing combustion fuels, it's important to understand how fired heaters work. Figure 23 below shows a schematic of a basic fired heater.

Fuel-based heaters consist of five zones:

- Radiant section: The radiant section, or firebox, is comprised of radiant tubes that carry the process fluid. These are located along the walls of the heater and are heated by radiant heat transfer from the combustion gases. The majority of the heat transfer takes place in this section of the heater. The walls of the heater are lined with high temperature resistant material called refractory.
- Shield section: This section contains rows of radiant tubes that shield the downstream convective section from radiant heat transfer. Critical process control measurements, such as flue gas temperature, draft, and oxygen content, are made in this section.
- Convective section: This section marks the first entry point for the process fluid, which gets

[108] DOE. 2015c. *Quadrennial technology review: An assessment of energy technologies and research opportunities.* http://energy.gov/sites/prod/files/2015/09/f26/Quadrennial-Technology-Review-2015_0.pdf.

preheated through convection from the hot flue gases before re-entering the heater through the radiant tubes.

- Breeching and Stack: The breeching is a duct that conveys the flue gases from the fired heater to its outlet- the stack. Dampers are fitted in this section to allow control over the heater's draft. Measurements are made in this section to ensure the safe outlet of flue gases.

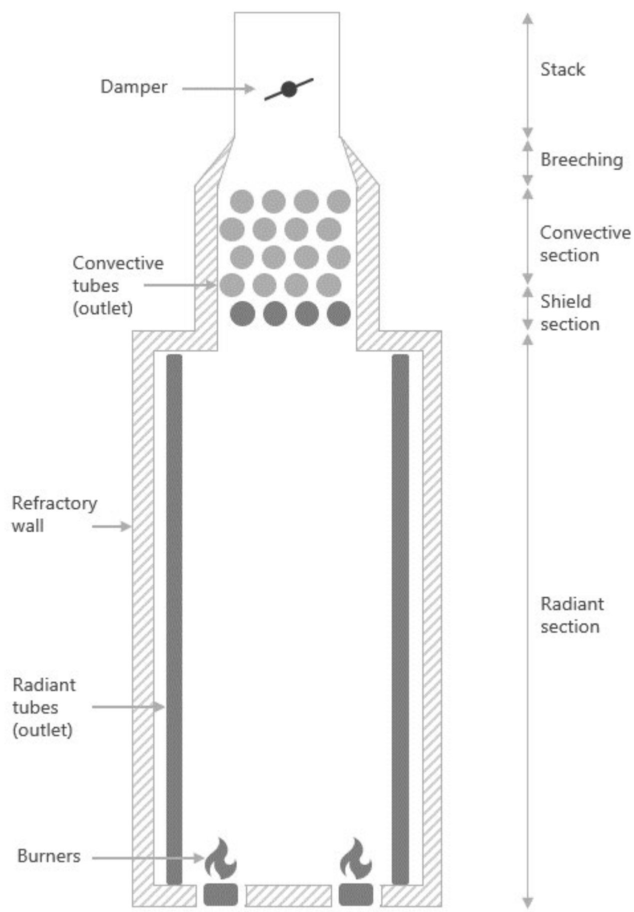

Figure 23: Basic Process Heater Schematic

5.3 Feasibility 100% Hydrogen Fuel Switching

Industries with high-temperature heating requirements are among the most energy-intensive and hardest to decarbonize. Replacing incumbent fossil fuel-based heating applications with renewable electricity-based heating options to achieve temperatures >500°C requires a high capital investment for new electric process heating units. Blending green hydrogen into existing fuels, such as natural gas (methane), serves as an intermediate option to aid in decarbonisation with relatively lower capital costs.

Hydrogen, when produced through low or zero-carbon production processes, can significantly reduce CO_2 emissions in the industrial heating sector. Using blends of hydrogen and natural gas is not uncommon in industry today. Hydrogen from refinery fuel gas and other waste gas streams from chemical plants are often used to supply the heating needs of upstream processes or adjacent industries. While it is widely accepted that industrial burners can accommodate up to 20% of hydrogen by volume with their existing designs, there is insufficient literature to validate this.[109]

Figure 24 shows the potential to reduce yearly CO_2 emissions in a typical 30 MW fired heater. A 20% H_2 fuel results in a 5% reduction in tonnes of CO_2 per year.

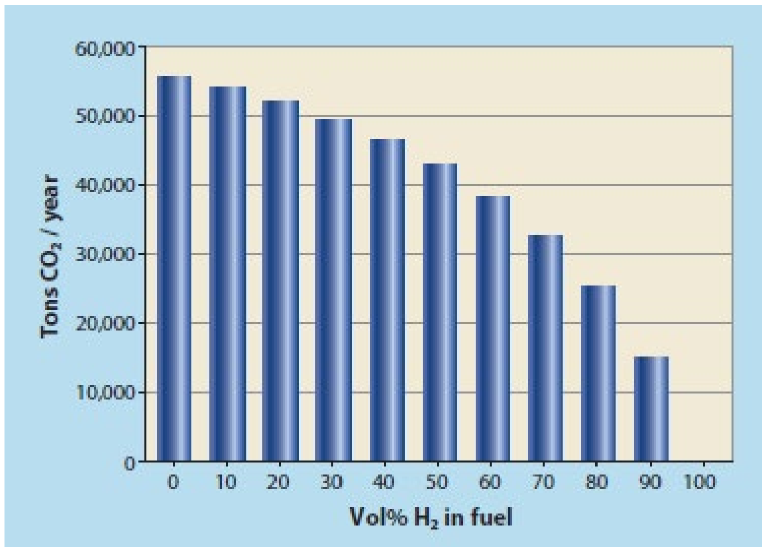

Figure 24: Yearly CO_2 emissions in tonnes per year vs. vol% H_2 in fuel for a 30MW (~100 MMBtu/hr) (fired duty) heater. Assumes balance of fuel is methane and 15% excess air [Source: Wood whitepaper[110]]

To reduce CO_2 emissions by 50% per year, the process heater fuel must contain at least 80% H_2 by volume. Switching to 100% H_2 fuel or even a partial H_2 blend introduces a number of challenges in industrial fired heaters. Wood's Fired Heater Group, leveraging its extensive experience in blended and 100% H_2 firing, published a whitepaper to address these challenges. Each issue is discussed in detail in the subsequent sections.

5.3.1 High-temperature flame

Increasing the amount of H_2 in fuel gas significantly impacts the flame temperature, as shown in Figure 25.

Although Figure 25 is based on the adiabatic (theoretical) flame temperature, it shows that a 100% H_2 flame can be significantly hotter than a flame from hydrocarbon fuels. The main concern with this effect is that thermally generated nitrous oxides (NOx) formation increases proportionally with flame temperature.[111] API 535 offers general guidance on the potential increase in NOx levels with higher hydrogen content in fuel

[109] Franco, A.; Rocca, M. Industrial Decarbonization through Blended Combustion of Natural Gas and Hydrogen. Hydrogen 2024, 5,519–539. https://doi.org/10.3390/hydrogen5030029.
[110] Glashan A, Wood; The potential to reduce CO2 emissions in fired heaters is unlimited if 100% hydrogen fuel is utilised (digitalrefining.com), 2023.
[111] Baukal Jr., The John Zink Combustion Handbook, CRC Press, Boca Raton Florida, 2001.

gas (a 55% increase from 0 to 100% hydrogen).[112] However, this guideline may vary depending on specific burner designs and fuel compositions. Interestingly, many in the industry have noted that NOx levels tend to decrease once hydrogen concentrations exceed a certain threshold (around 80-90 vol.%). This decrease in NOx at higher H_2 levels is thought to be related to a localised cooling effect from the increased water content in the combustion gases.

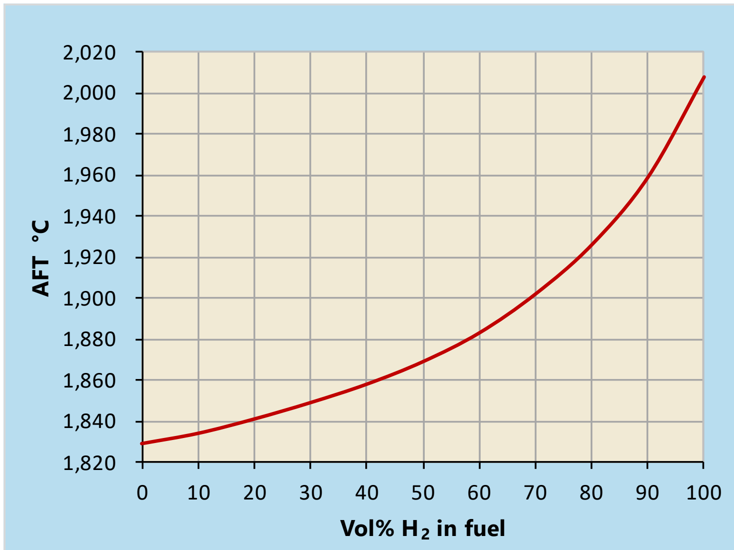

Figure 25: Adiabatic flame temperature (AFT) in °F vs vol% H_2 in fuel. Assumes balance of fuel is methane and 15% excess air

Mitigation: Fortunately, there are several options to counteract the increase in NOx emissions. Burner design modifications (such as retrofit) should be considered first. External flue gas recirculation and/or steam injection may also be implemented to lower the flame temperature. If these methods are insufficient, selective catalytic reduction (SCR) may be required.

With higher flame temperatures present, the adequacy of refractory materials, burner tiles, and burner internals in contact with the flame should also be considered.

5.3.2 High flame speed

Flame speed is a critical variable in fired heater design and operation. It describes the rate at which a combustion reaction occurs for a given fuel and can be conceptualized as the speed at which a gas will fully combust if contained in a long tube and ignited at one end. In actual practice, flame speed depends on several factors, including pressure, temperature, fuel composition, excess air, turbulence, and surrounding cooling effects.[113] However, in an idealised environment consisting of laminar flow at 25°C and 100 kPa of pressure, a tube filled with H_2 and lit at one end will complete the combustion reaction at the opposite end of the tube roughly seven times sooner than a tube filled with natural gas (see Figure 26). To ensure reliable, safe combustion in a process burner, it is vital to control the speed of the uncombusted air/fuel mixture so

[112] API 535 – Burners for Fired Heaters in General Refinery Services, 3rd Ed., May 2014.
[113] North American Combustion Handbook – A Basic Reference on the Air and Science of Industrial Process Heating with Gaseous and Liquid Fuels, Vol I (3rd Ed.), Fives North American Combustion Inc., 2001.

that it is appropriately matched to the combustion or flame speed. If the air/fuel speed is lower than the flame speed, the combustion reaction can travel backwards into the burner and upstream equipment ('flashback'). Flashback potential is especially important to consider for pre-mix burners[170].

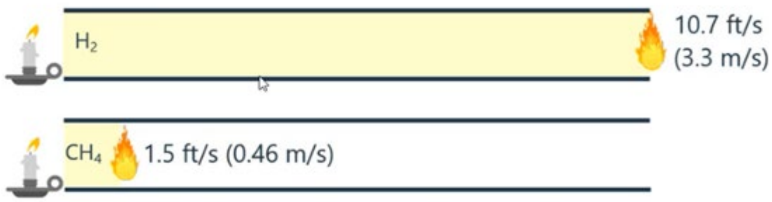

Figure 26: Approximate laminar flame speed of H_2 vs natural gas at 25°C and 100 kPa of pressure. Flame speeds taken from Combustion, Glassman and Yetter, 2008[114]

Mitigation: Before switching to H_2 fuel from hydrocarbon fuel, it is essential to review the burner design to ensure it can accommodate the air/fuel speeds necessary for safe operation. API 535 recommends using no more than 70 mol% H_2 in fuel gas for pre-mix-style burners[171]. However, this will vary based on the specific burner design used.

5.3.3 Flame visibility

Verifying the presence of a stable flame at each burner is critical to safely operating fired heaters. Usually, this can be done by visual inspection or with conventional flame scanners when firing hydrocarbon fuel gases. However, when 100% H_2 is used as a fuel source, the flame becomes virtually invisible. This is demonstrated by Figure 27 (left) of a burner firing 100% H_2. In contrast, Figure 27 (right) depicts nearly all H_2 combustion with a small percentage of natural gas.[115] These figures demonstrate how a small quantity of natural gas in the fuel can dramatically enhance the ability to see the flame.

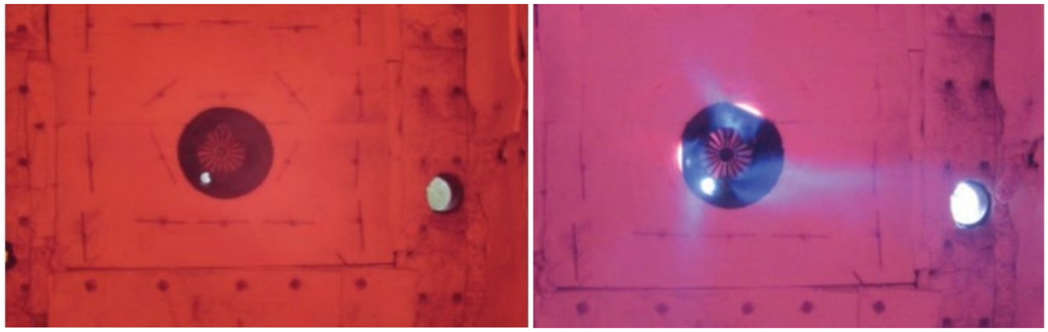

Figure 27: (Left) Process burner firing 100% H_2; (Right) Process burner firing mostly H_2 with a small percentage of natural gas

Mitigation: In situations where hydrocarbon fuel gas is unavailable or not allowed, alternate methods of detecting the flame, such as specialised ultraviolet or infrared flame scanners, may be required. Currently, there are commercial flame scanner models available that use different sensing elements to detect either a hydrocarbon or H_2 fuel flame.

[114] Glassman, Yetter, *Combustion,* Academic Press, Cambridge Massachusetts, 2008.
[115] Guarco, Langstine, Turner, *Practical Considerations for Firing Hydrogen Versus Natural Gas*, Zeeco.

5.3.4 Radiative/convection duty split

As represented in Figure 28, increasing the H_2 content in the fuel can significantly decrease the quantity of flue gas generated. For an existing heater being revamped to run on H_2 fuel, this reduction in thermal mass traveling through the convection section decreases the amount of heat absorbed.

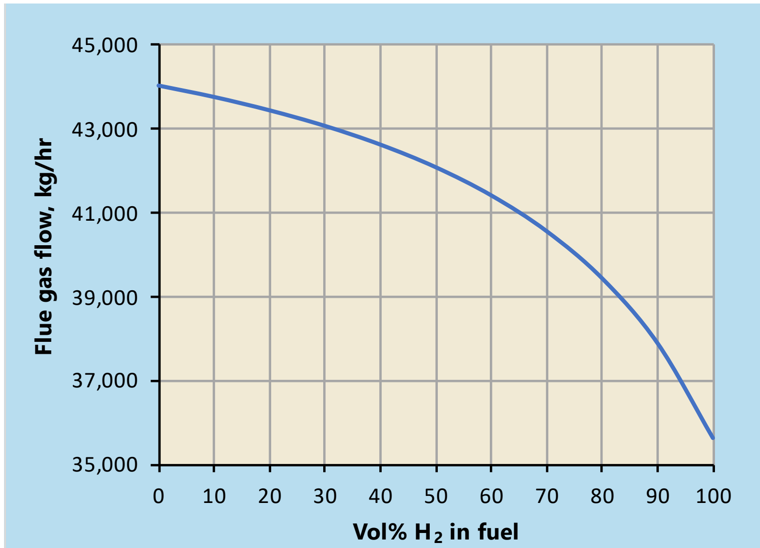

Figure 28: Flue gas flow rate vs vol% H_2 in the fuel for a 30 MW (fired duty) heater. Assumes balance of fuel is natural gas and 15% excess air

Mitigation: In a single service heater (same service in the convection and radiant section), this may be counteracted by increasing the heat absorbed in the radiant section, by paying careful attention to the increased radiant flux, bridge wall temperature, and tube metal temperatures. However, if there is a second, independent service in the convection section, the convection coil must be reconfigured to maintain the original heat absorbed. The effects on draft and fan operation should also be considered. Excess air may be increased to generate more thermal mass, but doing so will also increase NOx emissions and reduce efficiency.

However, it may not be practical to completely restore the flue gas mass flow rate by increasing excess air alone. In a recent study, Wood found that the excess air of a coker heater firing 21 vol% H_2 would need to be increased from 15% to approximately 40% excess air to maintain the flue gas mass flow rate. This approach is not recommended.

5.3.5 Impact on radiant heat transfer

In the firebox (radiant section), heat is transferred to the process tubes by three main methods of radiation as stated below:[170]

- Direct radiation from the flame (such as flame burst)
- Reradiation from flue gases
- Reradiation from refractory surfaces.

The radiation from the flame is related to its luminosity and may impact heat transfer. Luminous radiation refers to the radiation from solid particles suspended in the flame.[116] For example, an oil flame has three to four times more flame radiation due to increased luminosity created by soot content. In a pure H_2, flame, luminosity is reduced to virtually zero, which may decrease radiant heat transfer slightly. However, the contribution from direct flame radiation is typically low compared to other forms of radiation in the firebox, as evidenced by the combination of oil and gas burners that have been successfully used in operation with little change in performance noted between fuels fired.

Mitigation: While a reduction in luminosity may reduce direct radiation from the flame, increased emissivity of flue gas molecules and increased refractory temperatures will likely offset this effect, suggesting that current methods for radiant heat transfer calculation are adequate for H_2 firing.

Reradiation from flue gases in conventional heaters occur primarily from CO_2, H_2O, and SO_2 molecules.[117] Symmetrical molecules (N_2, O_2, and CO) are considered 'transparent' and do not reradiate heat. An all-H_2 flame produces significantly more H_2O, which has higher emissivity than CO_2. Since CO_2 is eliminated from the flue gas and essentially replaced with H_2O, this will have the tendency to increase radiant heat transfer.

As mentioned previously, a H_2 flame has a higher temperature than a CH_4 flame, which may increase the surface temperature of the refractory close to the flame. This may also increase heat transfer in the radiant section.

Wood recently performed a study on a petrochemical heater designed for and operating with up to 90 vol% H_2 fuel. The study found that the predicted firebox and field-measured temperatures matched very closely (within 3°C).

5.3.6 Corrosion mechanisms

The industry standard for corrosion mechanisms, API 571 – 'Damage Mechanisms Affecting Fixed Equipment in the Refining Industry,' mentions three major corrosion mechanisms involving H_2:[118]

- Hydrogen embrittlement (HE)
- Hydrogen stress cracking from exposure to hydrofluoric acid (HSCHF)
- High-temperature H_2 attack (HTHA).

HSCHF can be ruled out with the assumption that no hydrofluoric acid is involved in this application. That leaves HTHA and HE:

- HTHA typically occurs at high temperatures and pressures (Refer to API 941 for temperature and pressure limits for various materials).
- HE typically occurs at a lower temperature (<149°C) and pressure at or near atmospheric.

In both mechanisms, atomic H_2 (as opposed to molecular H_2) forms and diffuses into steel. Once inside the steel, it can react with the carbon to form natural gas, which can create pressure and cause cracking.[177]

Mitigation: Fuel gas delivery systems typically do not operate at high enough temperatures for HTHA to be a concern.

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[116] Sherman, *Radiation from Luminous and Non-Luminous Natural-Gas Flames*, Transactions of the America Society of Mechanical Engineers, 1934.
[117] Mekler, Fairall, Evaluation of Radiant Heat Absorption Rates in Tubular Heaters, *Petroleum Refiner*, 1952.
[118] API 571 – Damage Mechanisms Affecting Fixed Equipment in the Refining Industry, 2nd Ed., April 2011.

High-strength steels with high hardness numbers can be susceptible to HE. According to API 571, the effect is pronounced at temperatures from ambient to about 149˚C, corresponding to the range of most fuel gas systems.

While the softer carbon steel piping typically used is generally not susceptible to HE, welds, bolted connections, and burner internals made of high-strength steel may be areas of concern. Careful review of the fuel gas delivery system should be performed before blending high volumes or completely switching to H_2 fuel. For natural gas - H_2 blends, introducing the H_2 through a separate network directly into the H_2-ready burner or slightly upstream could be a starting point for achieving partial decarbonisation using H_2 without replacing the existing gas delivery system.

5.3.7 Changes to safety and control methods:

Hydrogen has a wide range of flammability in air, approximately 4-75% by volume.[119] These properties give H_2 the National Fire Protection Association's (NFPA) highest flammability rating of 4.9. While natural gas also has a flammability rating of 4, it requires more energy to ignite and is easier to detect.

Due to its low molecular size, H_2 may be susceptible to leakage in fuel gas piping designed for hydrocarbon fuels. H_2 gas is colourless and odourless. Due to its high diffusion rate in air, H_2 does not work well with the comparatively heavier mercaptans that are added to natural gas to give it an odour for assistance in leak detection.

H_2 fuel also requires significantly less air to combust stoichiometrically compared to natural gas. This is a key point to remember, especially if switching between H_2 and natural gas fuels while the heater is in operation.

Mitigation: H_2 leak detection instruments may need to be added to fuel gas systems before switching to 100% H_2 firing. When firing H_2, the heater controls should be adjusted to reduce the combustion air. However, if a switch back to natural gas fuel is made quickly, without sufficient adjustments to increase combustion air, the natural gas will not fully combust and create a potentially unsafe, fuel-rich environment. Figure 29 demonstrates this phenomenon. The horizontal line represents the airflow required for stoichiometric combustion (just enough to combust the fuel with no excess air) of natural gas, while the declining line represents the airflow with 15% excess air at varying H_2 percentages.

To avoid leaks, all connection points must be thoroughly assessed. Welds are preferred to prevent leaks, but if welding is not feasible, flanges and gaskets must be securely fastened and tested for their suitability to the application.

[119] Rivkin, Burgess, Buttner, H*ydrogen Technologies Safety Guide*, National Renewable Energy Laboratory, 2015

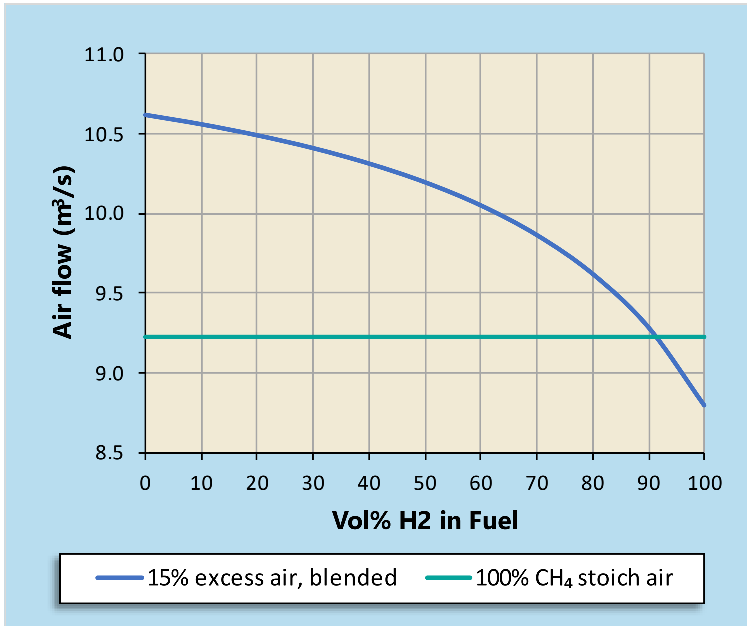

Figure 29: Volumetric combustion air flow rate with increasing vol% H_2. Assumes a 30 MW (fired duty) heater, balance of fuel is natural gas, and 15% excess air

As shown above, although excess air is at 15%, operation above approximately 90 vol% H_2 represents a sub-stoichiometric region for natural gas. A fuel gas system that accurately measures fuel gas composition and controls combustion air accordingly is thus critical.

5.3.8 Burner piping and fuel gas skid resizing

For a given heat release, 100% H_2 fuel requires significantly less mass flow rate than natural gas. However, due to hydrogen's low density, the volumetric flow rate required is more than three times as high. Larger pipelines will thus be needed to convey equivalent hydrogen volumes compared to natural gas.

Mitigation: The fuel gas skid and burner piping leading to the heater should be carefully reviewed to ensure proper pipe sizing for acceptable hydraulics.

5.3.9 Stack plume visibility

The key variable contributing to the visibility of flue gas exiting a stack is its water content.[120] After exiting the fired heater, hot flue gas cools down, and the water present in the flue gas condenses, often creating a visible, white 'fog.' Although not necessarily harmful, this visible water plume may become a nuisance to neighbouring communities and act as a transport medium for other pollutants in the gas. This poses a potential challenge, as combusting higher quantities of H_2 yields higher quantities of water in the flue gas. As demonstrated in Figure 30 , with 100% H_2 fuel, the water content in the flue gas increases to approximately one-third of the flue gas volumetrically.

[120] Herssens, Safariyeganeh, Supressing the Steam Plume, *Digital Refining*, 2021.

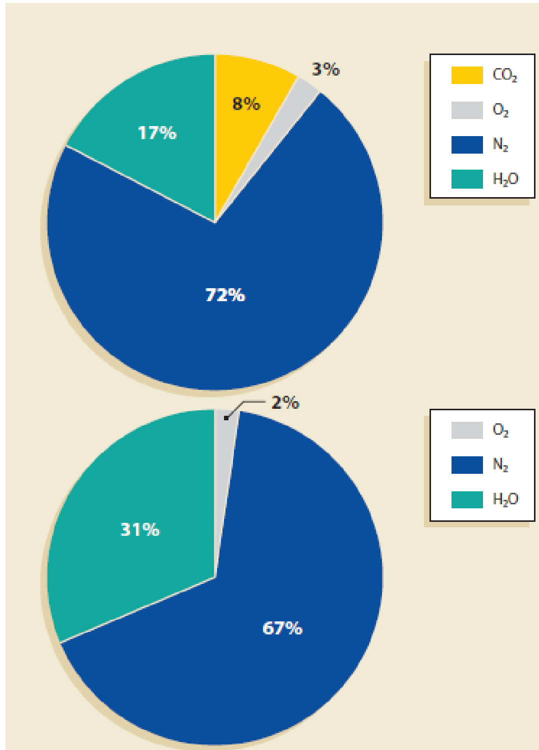

Figure 30: (top) Vol% flue gas composition with 100% natural gas fuel and 15% excess air; (bottom) Vol% flue gas composition with 100% H_2 fuel and 15% excess air

Mitigation: The water content may be reduced by burning less H_2 in the fuel. If this is not an option, the end user may consider implementing a system to reduce the water content in the flue gas. This could be accomplished by diluting or reheating the gas before it exits the heater. Alternatively, methods to condense and collect the water from the flue gas may also be considered.

Note, increasing the water content in the flue gas will also tend to raise flue gas acid dewpoint if not burning 100% pure H_2. The increased water content could also lead to corrosion in the stack of the fired heater/ colder ends of the boiler.

5.4 Hydrogen-ready equipment

With an increased focus on hydrogen as a significant pathway for industrial decarbonisation, several top process heater manufacturers have introduced hydrogen-ready offerings. While most of these boilers or furnaces are designed to operate with a mix of natural gas and hydrogen, some can operate exclusively on hydrogen.

Switching to hydrogen fuel, as discussed in section 5.3, requires carefully evaluating the entire system to ensure safe and reliable operation. It is important to note that due to the diversity in the type of heating requirements across different industries, no one solution fits all. Hydrogen integration for each industrial heating application will require varying levels of retrofits and modifications based on the process involved.

Indirect heat transfer involving boilers is anticipated to require minimal modification in boiler design as compared to furnaces and kilns that use direct flame heating, due to the complexity of flame temperature and flame speed associated with hydrogen. Burner design, fuel delivery systems, and safety measures are key factors to consider. Additionally, the impact on system efficiency, emissions, and operational costs is essential for a sustainable transition to hydrogen fuel.

Table 7 provides examples of boilers, furnaces and kilns that can use natural gas/hydrogen blends up to 100% hydrogen by vol. 'Hydrogen-ready' is typically used in the industry to define equipment and processes that are ready for integrating varying blends of hydrogen in natural gas, with a maximum of 100% H_2 by vol.

Table 7: 'Hydrogen-ready' industrial boilers, furnaces and kilns

Manufacturer	Model	Type	Capacity	Maximum H_2
Viessmann	Vitomax [121]	High pressure hot water/ steam boilers	0.35 MW to 20 MW	Up to 100%
Bosch	Uni Condens[122]	Condensing hot water boiler	145 kW to 640kW, and up to 10MW	100% H_2 or 100% natural gas options
Babcock and Wilcox	BrightGen™ technology[123]	Steam generation boiler	Wide range (tailored to different projects)	Up to 100%
Hydrogen Technologies LLC	DCC™ Boiler 3000[124]	Hot water and steam boiler	2.3 MW to 23.4 MW	Only 100%
SACMI	FMH Maestro[125] 'Maestro' Kilns (custom prototype)[126]	Roller Kiln	Unavailable	Up to 50% Up to 100%
CarboLite Gero	HTRH-H_2 (based on HTRH 16/100/600)[127]	Tube furnace	heated length of 600 mm up to 1600 °C.	Up to 100%

Burner manufacturers claim that up to 20% hydrogen can be mixed with natural gas without changing burner technology, provided process parameters are met.[168] Burners that can accommodate 100% H_2, on the other hand, need significant modifications, including new fuel delivery lines, burner management systems, and additional safety features. Table 8 below shows a list of burners announced to be compatible with blends comprising natural gas and up to 100% hydrogen by volume.

[121] Viessmann Vitomax product range
[122] Bosch Hydrogen Boiler – Uni Condens 8000 F
[123] B&W BrightGen™ Hydrogen Combustion
[124] Hydrogen Technologies LLC DCC Boiler 3000
[125] Ceramic Bangladesh: SACMI's Challenge ZERO-EMISSION CERAMIC KILNS
[126] SACMI-Foshan-Uniceramics-Expo-2024
[127] Hydrogen tube furnace up to 1600°C HTRH-H2

Table 8: 'Hydrogen-ready' burners

Manufacturer	Model	Type	Maximum H2
Metso	Ferroflame™ Low NOx[128]	Gas burner	Up to 100%
John Zink (Coen)	WALFIRE™ Radiant Wall Burner[129]	Gas burner	Up to 100%
Zeeco	FREE JET® Gen 3™[130]	Gas burner	Up to 100%
Fives' Group	Hy-Ductflam™[131]	Hydrogen duct burner	Up to 100%
Toscotec	TT Hydrogen Burner[132]	Gas burner	Up to 100%
Tenova	200-KW TRKSX[133]	Gas burner	Up to 100%

Another piece of key equipment used in energy-intensive industries, including pulp and paper, chemicals, rubber and plastic, ceramics, cement and power generation is the gas combustion turbine that supplies both heat and power through co-generation. Gas combustion turbines can handle 1%-5% hydrogen by volume without needing any modifications.[134] Modifications necessary for >5% hydrogen blends in gas turbines are similar to those identified in Section 5.3. Existing gas turbines designed to operate on syngas have already been designed to operate on up to 100% H_2 fuel. Table 9 shows a list of hydrogen-ready gas turbine manufacturers in the market.

Table 9: 'Hydrogen-ready' gas combustion turbines

Manufacturer	Model	Type	Capacity	Maximum H2
Kawasaki Heavy Industries	GPB17MMX[135]	Gas turbine	1.8 MW	50% and 100% switching options available
General Electric	7HA, 9HA[136] (with DLN2.6e combustor) 9F.05	Gas turbine	- 288 MW	Up to 50% H_2 5% to 100% H_2 blends in natural gas
Siemens Energy	SGT-400[137] Modified SGT-400[138]	Gas turbine	10-15 MW 12 MW	Up to 30% H_2 with DLE burners, up to 65% with diffusion burners Up to 100%

128 Metso launches the first hydrogen LowNOx burner for traveling grate pelletizing plants
129 WALFIRE™ Radiant Wall Burner
130 Zeeco Free Jet Gen
131 https://www.fivesgroup.com/energy-combustion/burners-systems/hy-ductflam
132 TT Hydrogen Burner
133 Hydrogen ready smart burner for heat treatment furnace
134 Erdener, B., Sergi, B., et al. A review of technical and regulatory limits for hydrogen blending in natural gas pipelines. International Journal of Hydrogen Energy 2022, https://doi.org/10.1016/j.ijhydene.2022.10.254
135 GPB17MMX 1.8 MW Class Hydrogen Gas Turbine Wins Hydrogen Technology of the Year 2024 at Connecting Green Hydrogen MENA 2024
136 GE innovates Australia's first hydrogen-blend power plant
137 SGT-400 Gas Turbine
138 HYFLEXPOWER: The world's first integrated power-to-X-to-power hydrogen gas turbine demonstrator

Kawasaki Heavy Industries, Ltd has pioneered the integration of hydrogen in gas turbines by developing and commercializing the world's first 100% hydrogen-fueled, dry-combustion combustor called the Micromix (MMX) Combustor that is integrated into its commercially available GPB17MMX gas turbine.

GE advertises that its H-class, F-class, B/E-class, and aeroderivative gas turbines, are all currently capable of running on different levels of H_2, with due consideration that actual hydrogen levels may differ based on the gas turbine model, combustion model, combustion system, and overall fuel consumption.[139] GE H_2 has over 100 gas turbines installed worldwide with various levels of hydrogen blending[140] – an experience they are channelling towards generating their 100% H_2 ready gas turbines.

Siemens has also advanced its hydrogen capabilities, by developing and testing a modified version of its SGT-400 turbine capable of running on pure hydrogen, natural gas, and any mix of the two as part of EU's Horizon 2020 HYFLEXPOWER project.

Despite the interest in hydrogen, the commercial use of hydrogen-specific boilers, burners, and other process heaters is currently limited. Aside from the major industry players, who are frequently driven by government-funded demonstration projects, most other fired-equipment manufacturers have been reluctant to invest in the design modifications needed for 100% hydrogen-compatible equipment. Most commercial process heater manufacturers limit their offerings to around 20% hydrogen blends by volume, primarily due to concerns about low adoption rates stemming from insufficient infrastructure for green hydrogen production and transport. However, this situation is evolving rapidly, particularly in Nova Scotia, where two major hydrogen production projects are currently being established (see Section 4.5).

As part of this study, Wood reached out to three industrial process heater manufacturers who serve Nova Scotia to gauge their level of hydrogen readiness:

1. Thermogenics: Headquartered in Aurora, Ontario, Thermogenics manufactures coiled tube steam, hot water, and thermal fluid boilers as well as related equipment for industrial, commercial, and institutional applications across North America. They serve a variety of end markets, including healthcare and hospitals, food and beverage, and pharmaceuticals. Thermogenics' path to reducing carbon emissions includes advancing the efficiency of their heating systems by introducing external flue gas economisers, installing summer boilers, using advanced controls, and designing innovative retrofits.[141] In terms of hydrogen, they advertise a 20% (by volume) hydrogen readiness, like most other industrial players who await clarity on the standards and regulations as well as hydrogen production and transportation infrastructure before accommodating 100% hydrogen readiness. Thermogenics informed Wood that with the current national focus on hydrogen and the accompanying infrastructure plans around production and transport, the maximum hydrogen blending figure for Thermogenics' offerings will likely increase in the coming months.
2. Babcock and Wilcox (B&W) - Fossil Power Systems (FPS): Located in Nova Scotia, FPS is a manufacturer of ignitors, flame scanners, and drum level probes, supplying the combustion equipment in power, petrochemical, pulp and paper, and other process industries. In 2022, FPS was acquired by B&W to expand its business offering to steam generation equipment and associated control technologies.[142] FPS currently offers custom ignitors allowing up to 100% hydrogen blends

[139] GE Vernova: Hydrogen fueled gas turbines
[140] GE Vernova: Hydrogen Overview
[141] Thermogenics Boilers
[142] FPS Ignitors, Scanners, Valves, Controls and Level Measurement Equipment

in natural gas. The primary design modification for a 100% H_2 ignitor includes using an optical scanner to detect the invisible flame. No significant costs are expected to be associated with the ignitor-specific design modifications. FPS has been active in the field of hydrogen readiness by also participating in the Battle River Carbon Hub (BRCH) hydrogen-fired electricity generation facility. As an EPC contractor on the project, FPS was involved in replacing one of the burners on site with a hydrogen-ready one, modifying the H_2 valve train, ignition system controls, flame scanning method, and commissioning the change.

3. Zeeco – A prominent name in the combustion equipment sector, Zeeco's offerings include industrial burners, flare systems, thermal oxidizers, vapor control systems, combustion electronics and rental products. While headquartered in the USA, Zeeco has a local office in Ontario and works with several major industrial players across Canada. Zeeco informed Wood of its decades of experience in firing H_2-blended fuels showing a record of firing fuel with H_2 content as high as 85% to 95% specially in the petrochemical and power sectors, thereby establishing its preparedness for future green H_2 firing. Zeeco has recently announced a dedicated new Free Jet Gen 3 burner that allows up to 100% hydrogen fuel-firing while keeping NOx emissions under control. These burners are intended to be deployed via a collaborative project at ExxonMobil's petroleum refinery-Baytown Complex in Texas.[143]

5.5 Standards and regulations

As the industry advances towards hydrogen-based decarbonisation, national and international bodies for standards and regulations are striving to keep up with the pace of development minimise delays in safe implementation efforts. A list of international standards and regulations, though not exhaustive, is given below:

5.5.1 ANSI/CAN/UL 795 Standard

The ninth edition of the ANSI/CAN/UL 795:2024 was published in February 2024 and provides a path for hydrogen blending up to 25% in commercial and industrial gas fired package boilers. The scope of UL 795 provides a certification path for not only hydrogen-natural gas blends but also other traditional fuel blends and includes requirements for:

- Gas-fired package boilers
- High-pressure steam and high-temperature water gas-fired boiler assemblies for the following fuel gases: natural gas, hydrogen-natural gas blends (up to 25%), liquefied petroleum (LP)-gas, LP-gas/air blends, manufactured gas
- Furnaces
- Air heaters (United States only)

UL Standards & Engagement, the publisher of the UL 795 Standard, is accredited by the American National Standards Institute (ANSI) and the Standards Council of Canada (SCC) as a Standards Development Organization (SDO).[144]

[143] Zeeco News: 21 March 2024
[144] New Certification Path for Boilers Up to 25% Hydrogen Blending

5.5.2 CSA Group (Canadian Standards Association)

The 2023 edition of CSA Z662: Oil and gas pipeline system standard includes several significant updates, such as a new clause on hydrogen and hydrogen blend pipeline systems. It also features revisions throughout the standard to address the unique design, material, construction, and operational considerations for pipelines containing hydrogen.[145]

The Canadian Standards Association (CSA Group) develops standards and codes for the safe generation, storage, delivery and use of hydrogen in Canada.

5.5.3 BNQ (Bureau de normalisation du Québec) Standard

The CAN/BNQ 1784-000: Canadian Hydrogen Installation Code outlines the installation standards for hydrogen-generating equipment for non-process end use, as well as hydrogen utilization, dispensing, storage containers, piping systems, and related accessories. This code has been approved by the Standards Council of Canada (SCC). This code covers all gaseous and liquid hydrogen applications except for

- hydrogen production or use in petroleum refineries and chemical plants as feedstock and directly in process production,
- industrial facilities where hydrogen is produced, handled, and stored for off-site end use, and other specific exclusions.[146]

5.5.4 NFPA (National Fire Protection Association) Standard

The NFPA 2: Hydrogen Technologies Code issued by the National Fire Protection Association provides essential safety guidelines for the generation, installation, storage, piping, use, and handling of hydrogen in both compressed gas (GH_2) and cryogenic liquid (LH_2) forms. It covers various aspects such as general fire safety requirements, explosion protection, and specific applications like hydrogen fueling facilities and fuel cell power systems. The code aims to ensure safe practices and mitigate risks associated with hydrogen technologies.[147]

5.5.5 CGA (Compressed Gas Association) Standard

The CGA G-5 standard, issued by the Compressed Gas Association, provides comprehensive guidelines for the safe handling, storage, and use of hydrogen. It covers the properties of hydrogen, its various uses, and the methods for its production. The standard includes detailed instructions on the design, installation, and operation of hydrogen vent systems to ensure safety during the release of hydrogen into the atmosphere. It also addresses the requirements for hydrogen piping systems, emphasizing the importance of preventing leaks and ensuring proper venting to avoid ignition hazards.[148]

[145] CSA Standards for hydrogen delivery and storage
[146] Canadian Hydrogen Installation Code
[147] NFPA 2 Code Development
[148] CGA's G-5.5 Publication Provides Methods for Safe Venting of Hydrogen - Compressed Gas Association (cganet.com)

5.5.6 ISO (International Organization for Standardization) Standard

The ISO 14687: Hydrogen Fuel Quality – Product Specification states the minimum quality characteristics of hydrogen fuel for use in both vehicular and stationary applications. It outlines the necessary purity levels and acceptable limits for various contaminants to ensure the safe and efficient operation of hydrogen fuel cells. The standard also provides guidelines for sampling, analytical methods, and quality control measures to maintain consistent hydrogen fuel quality.[149]

5.5.7 ASME (American Society of Mechanical Engineers) Standard

The ASME B31.12: Hydrogen Piping and Pipelines standard provides comprehensive guidelines for the design, construction, inspection, operation, and maintenance of piping and pipelines used for hydrogen and hydrogen blends in gaseous and liquid form. It covers materials, welding, brazing, heat treating, forming, testing, inspection, and examination to ensure safety and reliability. The standard applies to hydrogen piping systems up to the joint connecting the piping to associated pressure vessels and equipment, but not to the vessels and equipment themselves.[150]

5.5.8 EIGA (European Industrial Gases Association) Guidelines

The EIGA Doc 121: Hydrogen Pipeline Systems, issued by the European Industrial Gases Association (EIGA), covers various aspects including design, construction, operation, and maintenance of hydrogen pipelines. It also provides comprehensive guidelines for the safe operation of metallic transmission and distribution piping systems carrying pure hydrogen and hydrogen blends.[151]

[149] ISO 14687:2019 - Hydrogen fuel quality — Product specification. https://www.iso.org/standard/69539.html
[150] ASME B31.12-2019 - Hydrogen Piping and Pipelines - ANSI Webstore. https://webstore.ansi.org/standards/asme/asmeb31122019
[151] EIGA: Hydrogen Pipeline Systems

6. PART 6 - Case Studies

Green hydrogen, as a versatile energy carrier, is expected to play a significant role in the decarbonisation of the hard-to-abate, energy-intensive industrial and transport sectors in the coming decade. A growing number of countries are formulating national strategies and concrete policies to become the first movers for green hydrogen adoption. The current section highlights noteworthy demonstrations of hydrogen utilisation in industrial process heating from across the world.

6.1 Demonstration Projects for up to 100% Hydrogen Firing

The national and international interest in green hydrogen has led to several demonstration projects showing the successful integration of hydrogen and hydrogen blends with natural gas for industrial process heating applications. Some international pilot projects integrating hydrogen for industrial needs are highlighted below.

6.1.1 Cement and Ceramics

6.1.1.1 CEMEX (Europe, Americas)

CEMEX is a global construction materials company headquartered in Mexico. CEMEX potentially pioneered hydrogen integration in cement plants by initiating hydrogen injection trials at Spain's Alicante Cement Plant as early as 2019.[152] This was followed by a retrofit of all its European plants to operate on hydrogen as part of their fuel mix in 2020-2021. CEMEX's hydrogen injection technology was also implemented in their plants in Mexico and the Dominican Republic.[153] Between 2022 and 2023, Cemex invested in HiiROC,[154] a UK-based startup that produces zero-emission, cost-competitive hydrogen, with the aim of increasing the uptake of hydrogen in their cement plants in Europe, the Middle East and Africa (EMEA). Despite CEMEX being an early mover in the installation of hydrogen injection equipment in its cement plants, there is no publicly available information on the actual blend of hydrogen utilised in their operations or the specific equipment retrofits that have been implemented to allow this operation.

6.1.1.2 Heidelberg Materials/ Hanson (UK)

In 2021, Heidelberg Materials (formerly Hanson UK) successfully operated its cement kiln in Ribblesdale, UK, on a 100% blend of net-zero fuels, including hydrogen. The demonstration project was led by the British Mineral Products Association (MPA) and funded by the British Department for Business, Energy and Industrial Strategy (BEIS).[155]

During the demonstration at Ribblesdale, the fuel mix in the cement kiln's main burner was gradually adjusted to achieve a complete net-zero composition. This mix included hydrogen delivered by tanker, biomass components, and glycerine, which are by-products from other industries. While the demonstration project used grey hydrogen to establish a proof of concept, the intention was to have a system that could be substituted with green hydrogen in the future. The cement kiln's fully climate-neutral mixture comprised roughly 39% hydrogen, 12% meat and bone meal (MBM), and 49% glycerine.

According to Heidelberg, the use of 100% hydrogen is not feasible. However, this particular blend included

[152] CEMEX Press Release: 22 February 2021
[153] CEMEX Press Release: 23 August 2023
[154] CEMEX Press Release: 19 December 2023
[155] Heidelberg Materials Press Release: 1 October 2021

39% hydrogen along with other carbon-neutral fuels to achieve 100% climate neutrality and, if fully implemented, would avoid 180,000 toingnes of CO_2 emissions per year. There is limited information on the specific learnings of this trial; the consortium intends to share project results with cement producers globally as a best-practice example.

6.1.1.3 Henan Zhongqi Ceramics (China)

February 2024 marked two years of successful operation for the intelligent production line for sintered stones and large slabs, built by HLT&DLT for Henan Zhongqi Ceramics.[156] This wide-body kiln, which has been operating continuously since its launch in 2022, uses a fuel mix of 60% hydrogen, has an inner width of 3.1 meters, and currently produces 38,000m^2 of ceramic slabs daily. The company claims about 30% savings in fuel costs since the switch from natural gas to the hydrogen-natural gas blend, with no compromise to the quality of its products. The high-hydrogen blend wide-body kiln is also anticipated to cause a 26% reduction in CO_2 emissions.

Lessons Learned:

- Hydrogen produces a short flame and burns with a higher flame speed. In contrast, the high-output, wide-body kiln exhibits significant cross-sectional variations in temperature. The high-speed injection was managed through careful burner selection and design to adapt to these conditions. Additionally, the short flame and intense heat from hydrogen combustion can impact the durability of kiln materials, such as kiln walls and silicon carbide sleeves. These factors were intrinsic in developing the kiln design.
- Hydrogen, being highly reactive compared to natural gas, introduced the potential challenge pre-ignition in the hydrogen blended fuel (backfire risk). Check valves and other auxiliary components were introduced as a mitigant.
- Considering hydrogen's high flammability and susceptibility to leakages, the project pipelines were designed in adherence to the Chinese national standard GB 4962-2008 Technical safety regulation for gaseous hydrogen use.

6.1.2 Pulp and Paper

6.1.2.1 Papierfabrik Palm, Germany

In 2020, Palm paper mill launched a modernization of its corrugated base paper mill in Worth, Germany, to align its fuel consumption towards lower CO_2 emissions. The modernization efforts comprised a second residue boiler to increase the uptake of biomass and residual material from paper waste processing and reduce natural gas usage. The steam and gas turbines on site were replaced with a high-efficiency cogeneration/CHP unit.[157] Siemens supplied their state-of-the-art gas turbine SGT 800, capable of firing 50% hydrogen and 50% natural gas.[158] The steam from the cogeneration plant would be used for paper drying while the electricity would serve the mill's power needs, with the excess exported to the grid. While this project was an early mover and has been operational for over two years, it has not been used extensively with hydrogen due to the region's lack of a hydrogen supply chain. Nevertheless, it is reported that Palm is in contact with local authorities for the conversion of the gas network to hydrogen to get closer to 100%

[156] HLT China Press Release: 05 September 2021
[157] Ceremonial inauguration of the combined heat and power plant in Wörth
[158] Palm Worth Paper Mill, the world's first hydrogen-powered paper mill

decarbonisation targets.

6.1.2.2 Smurfit Kappa Plant, France

HYFLEXPOWER is a multi-partner consortium project launched in 2020, funded by the European Commission's Horizon 2020 programme, set up to test an entirely green hydrogen-based power supply for a carbon-free energy mix. The consortium includes Siemens Energy, ENGIE via its subsidiary ENGIE Solutions, Centrax, Arttic, the German Aerospace Center (DLR), and four European universities. Per its October 2023 press release, [159] the Hyflexpower consortium successfully operated a gas turbine on 100% hydrogen at the Smurfit Kappa paper mill in the French village of Saillat-sur-Vienne. In an earlier stage of the project in 2022, the consortium achieved successful operation with a 30% blend of hydrogen with natural gas. The latest demonstration proved the technical feasibility of operating a paper mill using gas turbine-powered combined heat and power with up to 100% green hydrogen and any blends. Key features of the project included:[160]

- A modified SGT-400 Siemens Energy gas turbine that produced 10 MW of power operating on 100% hydrogen, consuming 810 kg of fuel per hour
- The test ran for nearly 90 hours on blended fuel, including approximately 10 hours on a blend with over 80% hydrogen (by vol) and 4 hours on 100% hydrogen
- For the fuel range from 100% natural gas to 100% hydrogen, the burner was seen to perform consistently within design margins and NOx emissions<25 ppm under all operating conditions

Lessons learned:

- Hydrogen's high reactivity and wide flammability range introduced complexity for the premix combustion process typical of dry low emission (DLE) burners. An approach backed by simulations helped design new hydrogen-capable burners to avoid flashback damage to burner hardware that could result from hydrogen's faster flame speed and higher temperatures.
- Design and testing - A new DLE burner, advised by simulations and aided by 3D printing, was designed and extensively tested before integration in the paper mill. Rig testing was followed by engine tests as the rig tests are never sufficient to replicate real-world conditions of the power plant, such as variable temperature and air flows.
- The fuel delivery system underwent significant changes due to hydrogen's lower volumetric energy density compared to natural gas, necessitating increased fuel flow and a larger capacity fuel system. A third fuel injection port had to be added to fine-tune the premixed combustion system, reducing NOx emissions. Safety modifications included equipotential bonding and grounding of the vent line, minimizing flow rate, and cleaning the pipe system to prevent hydrogen ignition. The gas detection system was adjusted for hydrogen, and computational fluid dynamics ensured adequate ventilation to prevent hazardous gas clouds. Over 200 sensors were added to monitor the gas turbine engine, and the control software was upgraded for real-time data oversight.

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[159] HYFLEXPOWER consortium press release: 13 October 2023, Berlin

[160] Witzel B., Siemens Energy, *HYFLEXPOWER project demonstrates 100% hydrogen operation*, Gas Turbine World, 2024.

6.1.3 Iron and Steel

6.1.3.1 HYBRIT, Sweden

The European Commission-funded HYBRIT initiative is a collaboration between the steel company SSAB, the mining company LKAB, and the energy company Vattenfall. The project was set up with the aim of virtually eliminating carbon dioxide emissions in the steel-making industry by replacing coal and coke in steel production with fossil-free hydrogen and electricity. The project is the first in the world to showcase the possibility of a fossil-free conversion from iron ore to steel on a semi-industrial scale. So far, more than 5,000 tonnes of hydrogen-reduced iron have been produced at HYBRIT's pilot plant in Luleå. Key features of the pilot phase that extended from 2018 to 2024 include:

- Development of a new hydrogen-based technology for efficient fossil-free iron and steel production with 0.0 tonnes of CO_2 emissions per tonne of steel. (Less than 0.05 tonnes CO_2e/tonne of steel result from the consumption of graphite electrodes and the addition of slag formers in the electric arc furnace, rounded to 0.0 tonnes CO_2e/tonne of steel)
- Development of a new fossil-free iron product (sponge iron) that has significantly better properties than iron reduced with fossil gases such as natural gas.
- Successful long-term operation of alkaline electrolyzers for the production and storage of hydrogen.
- Development of an efficient process practice for melting fossil-free sponge iron into crude steel in an electric arc furnace.
- Development of a new fossil-free and competitive industrial process where 175 process modes have been tested to identify the most optimised way to produce iron with hydrogen.
- Direct reduction with hydrogen and melting in an electric arc furnace produces 42 kg of biogenic CO_2 per tonne of directly reduced iron, compared to 383 kg of fossil CO_2 per tonne in a conventional natural gas process where the heating of the reduction gas is excluded from the comparison.

The results from the pilot phase are expected to pave the way for HYBRIT's process on an industrial scale.[161] Learnings at every stage of the pioneering pilot phase, from the production of hydrogen, hydrogen-reduced iron ore, and fossil-free iron ore pellets to overcoming market barriers, are collated in the form of 40-odd research papers on the Project's webpage.[162]

6.1.3.2 Arcelor Mittal, Canada

In 2022, the global steel manufacturer Arcelor Mittal announced the successful use of green hydrogen in direct reduced iron (DRI) production at its steel plant in Contrecoeur, Quebec. The pilot project aimed to evaluate the feasibility of replacing natural gas with hydrogen in the iron ore reduction process. This first attempt at integration involved replacing 6.8% of natural gas with hydrogen over 24 hours.[163]

As a major player in the global iron and steel industry, Arcelor Mittal is striving to commercially pioneer a hydrogen route to the decarbonisation of iron and steel production. Its Hamburg plant, currently under development, is designed to assess the feasibility of replacing natural gas with hydrogen to reduce iron ore

[161] SSAB Press Release: 27 August 2024
[162] HYBRIT: Learn about our research
[163] Arcelor Mittal News Articles: 02 May 2022

and form DRI on an industrial scale. The plant is also testing how the carbon-free DRI reacts in an electric arc furnace. The reduction of iron ore using hydrogen will initially be tested with grey hydrogen, produced by capturing waste gases at the steel plant and then processing them through pressure swing absorption. The plant is expected to be operational by the end of 2025, with an initial annual production target of 100,000 tonnes of DRI.[164] Despite the extensive activity underway and the federal funds pumped into this project, Arcelor Mittal was reported to have raised concerns earlier this year, on the financial feasibility of the process.[165]

6.1.3.3 Tenaris (Tenova), Italy

European energy infrastructure operator Snam, pipe manufacturer TenarisDalmine, and Tenova, a provider of sustainable solutions for the metals and mining industry, launched the first trial for the decarbonisation of the steel industry with hydrogen in July 2024. The collaboration will last for six months with the goal of evaluating the feasibility of using hydrogen in the steel industry.[166]

The project involves using hydrogen produced on-site to power the newly developed Tenova burner (100% H_2 ready) installed in a reheating furnace for hot rolling seamless pipes at the TenarisDalmine plant in Dalmine, Italy. This test will also help establish safety guidelines and plant management procedures and create integrated solutions for CO_2 reduction. The site and reheating furnace are provided by TenarisDalmine, leveraging its expertise in installation, operation, and performance monitoring of steel plants. Snam supplies the alkaline electrolysis system to produce the hydrogen. The project also includes Techint Engineering & Construction for its support with project design and project management services, risk analysis, and ensuring compliance with legal and safety standards. As the test phase is still ongoing, little information is currently available in the public domain.

6.1.4 Rubber and Tires

6.1.4.1 Sumitomo Rubber, Japan

Sumitomo Rubber Industries (SRI) achieved a significant milestone in tire manufacturing by starting mass production using hydrogen and solar energy at its Shirakawa plant in Fukushima, Japan. This achievement was announced on 15 January 2024 following the successful completion of a proof-of-concept project. The project began in August 2021 and involved using a hydrogen boiler and solar panels at the Shirakawa factory to generate steam for tire production. This steam powers the Neo-T01, an advanced high-precision metal-core production system, used within the the vulcanization process.

Since January 2023, SRI has used this combination of net-zero energy sources to produce its Falken Azenis FK520 tires at the Shirakawa facility. This process has significantly reduced net GHG emissions, bringing CO_2 emissions close to zero. Additionally, SRI aims to establish a local-production-for-local-consumption model for hydrogen energy. This involves sourcing hydrogen from a production plant in Fukushima, a region active in renewable energy development, with over 40% of its energy consumption from renewable sources.[167]

Details on operational modifications and the percentage of hydrogen in the fuel mix have not been publicly disclosed.

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[164] Arcelor Mittal: Hamburg H2
[165] Yermolenko H., *Green hydrogen is too expensive for ArcelorMittal Europe's plants – CEO*, GMK Center, 2024
[166] Tenova press release: 03 July 2024
[167] Seifield N., *Sumitomo Rubber Taps Hydrogen Energy to Manufacture Tire*, Chemical Analyst News, 2024

6.2 Historic Use Cases of Hydrogen Use in Process Heating

6.2.1 Chemical Industry

6.2.1.1 National Chlorine Industries, Jordan

The National Chlorine Industries (NCI) in Jordan is a producer of chemical products, including chlorine, caustic soda, hydrochloric acid, and sodium hypochlorite. Chlorine is primarily manufactured for its use in the chemical industry and water treatment plants. Chlorine production generates hydrogen as a byproduct, most of which is generally wasted and vented to the atmosphere, while a small portion is retained to produce hydrochloric acid. To reduce its fuel consumption and CO_2 emissions, NCI decided to channel the waste hydrogen stream as a fuel source for steam generation. Viessman's Vitomax steam boiler was used for the hydrogen blended combustion, resulting in fuel savings of 600 EUR per day and an 1,800-tonne reduction in CO_2 of per year. Specifics of the blending ratio were not publicly available.

6.2.2 Pulp and Paper

6.2.2.1 CMPC Pacífico Mill, Chile

CMPC, or Empresas CMPC S.A., is a Chilean company that produces and markets a wide range of products derived from natural fibers. It operates in several key areas, including pulp and paper, bio packaging, tissue, and sanitary products. One of CMPC's pulp mills- the Pacífico mill, is located in central-southern Chile and produces 530,000 tonnes of bleached softwood kraft pulp (BSKP) yearly. It is located next to ERCO Company, which supplies the mill with sodium chlorate.

Sodium chlorate is an essential chemical used for pulp bleaching and produces hydrogen as a byproduct. Previously, this hydrogen was released into the atmosphere without any use. However, from 2007 to 2010, a project was implemented to replace part of the fuel oil used in the lime kiln with this residual hydrogen.[168] The goals were to utilize the available hydrogen, a byproduct that was previously wasted, to achieve cost savings by cutting down on fuel oil consumption and simultaneously reducing GHG emissions. The lime kiln is essential in the kraft pulp production process because it produces lime, which is used to create white liquor. This white liquor is a cooking chemical in the digesters that helps separate cellulose from lignin.

Key features of the project retrofits included:

- Installation of a hydrogen purification and pressurization unit, both located at ERCO's facilities.
- Pipeline installation connecting the sodium chlorate plant to the lime kiln
- Installation of a multipurpose oil burner capable of burning hydrogen along with fuel oil and other fuels (e.g., methanol)
- Updating the process control system

In 2010 and 2011, the project utilized 30% of the available residual hydrogen for combustion, and gradually increased this amount over time. By early 2012, the usage reached 60%, negatively impacting the evaporator plant and ultimately causing the project to be suspended. Following the implementation of several corrective measures, the mill resumed operations in 2021 and is successfully operating to date with approximately 5-6% of the lime kiln's total fuel consumption supplied by hydrogen. The remaining residual

[168] Empresas CMPC S.A., *Reduce fuel oil through hydrogen substitution*, The Climate Drive

hydrogen is intended to be used in one of the steam boilers in the Pacífico mill.

Lessons learned:

The relatively higher calorific value of hydrogen along with the unique flame speed and visibility issues, resulted in the rapid degradation of the kiln's refractory lining at high hydrogen concentrations. The degraded material in the refractory bricks mixed with the liquors in the cellulose manufacturing process which was precipitated downstream in the evaporators and caused blockages. The evaporator was washed during plant shutdown, and the hydrogen blend in the fuel was reduced to 20%.

6.2.3 Petroleum Refineries

This section of the report does not reference a specific case study since the use of hydrogen in process heating applications at refineries is a common practice. Hydrogen plays a role in the refining industry, primarily removing impurities to enhance the yield of high-quality refined products. Hydrogen applications are used in several (energy-intensive) refinery processes, including hydrocracking, catalytic reforming, hydrotreating, desulfurization, and hydrodesulfurization. Several steam methane reformers (SMR) used to generate hydrogen are coupled with a pressure swing adsorption (PSA) process to further extract hydrogen from the SMR off-gas. Due to its extensive use in refineries, hydrogen finds its way into the waste stream of gases or off-gas, collectively known as refinery fuel gas (RFG). Process heating contributes significantly to refinery emissions, accounting for 30–60% of the total emissions.[169] Refineries primarily rely on natural gas and refinery fuel gas (RFG) for their heating needs. RFG is typically composed of H_2, CO_2, CO, CH_4. An example of a typical off-gas composition at the end of the PSA could be 30-40% H_2, 50-60% CO_2, and 5-10% CO and CH_4.[170] Depending on different process conditions- such as the absence of a common refinery off-gas PSA system- the concentration of hydrogen could be higher (between 50% and 90% to).[171] These situations are not uncommon in refinery process heating, and the experience gained by firing hydrogen-rich RFGs in process heaters can be leveraged for the use of green hydrogen in powering process heaters in heavy industrial sectors.

6.3 Canadian Initiatives

In recent years, Canada has also seen several pilot projects and initiatives for integrating hydrogen into various energy-intensive sectors.

6.3.1 Pulp mill in Prince George- Teralta, Chemtrade

Teralta, a, utility-scale clean hydrogen solutions provider, partnered with Chemtrade and CANFOR Pulp to form the Prince George Project in 2022.[172] Teralta is an active promoter for the inclusion of by-product hydrogen in the definition of clean hydrogen; this project is aimed at using waste hydrogen from the chemical industry to supply the heating needs of their customers in the pulp industry. Chemicals supplier Chemtrade generates hydrogen as a by-product during the production of sodium chlorate that is used for pulp bleaching. The vented hydrogen from Chemtrade will be collected by Teralta who will scrub, purify

[169] Bains P., Psarras P., Wilcox J.; *CO_2 capture from the industry sector*, in Progress in Energy and Combustion Science, 2017

[170] Sircar S., Waldron W.E., Rao M.B., Anand M.; *Hydrogen production by hybrid SMR–PSA–SSF membrane system*, Separation and Purification Technology, Vol 17, 1999 https://doi.org/10.1016/S1383-5866(99)00021-0

[171] Mukherjee R., Singh S., *Evaluating hydrogen rich fuel gas firing*, Digital Refining, 2021

[172] Teralta and Chemtrade produce clean hydrogen for pulp mill in Prince George, Canada

and compress the hydrogen with the help of its partner AdvanTec. The purified, compressed hydrogen will be redirected to CANFOR's Intercon Pulp Mill in Prince George. The project was launched by Premier David Eby in January 2024.[173] Once implemented, this project will supply hydrogen to cover 25% of the pulp mill's heating needs, and significantly reduce the plant's CO_2 emissions. Because redirected waste hydrogen is used in this process, it is unaffected by the absence of green hydrogen supply and shielded from the high prices associated with green hydrogen. This subsequently makes for a stronger business case. Due to the latest developments in CANFOR, including the closing of two pulp mills in Prince George, due to low fibre supply, the project is delayed and awaiting an official decision.

6.3.2 Iron and Steel – Arcelor Mittal Dofasco

Announced in July 2021, the ArcelorMittal Dofasco project, represents a significant $1.8 billion investment in partnership with the governments of Canada and Ontario.[174] This initiative aims to transform steel production at the Dofasco site (Hamilton, Ontario) by transitioning to a direct reduced iron-electric arc furnace (DRI-EAF) process. This new method is expected to drastically reduce the carbon footprint by eliminating the use of coal in ironmaking.

The project includes a new 2.5 million tonne capacity DRI furnace, which will initially operate on natural gas but is designed to be ready for future use of green hydrogen as a clean energy source when it becomes available. The project will employ ENERGIRON technology, an innovative direct reduction method developed by Tenova S.p.A. and Danieli & C. S.p.A., to produce 2.5 million tonnes of DRI annually. This DRI will be used in Hamilton's electric arc furnaces (EAFs) to produce nearly 2.4 million tonnes of high-quality steel, utilizing ArcelorMittal Dofasco's existing casting, rolling, and finishing facilities. The DRI plant is anticipated to be Canada's largest single-module direct reduction facility.

At the time of its inaugural ceremony in 2022, construction was slated to begin in January 2023 with the demolition of the decommissioned No.1 Coke Plant to make way for the new DRI plant. The construction of the new assets was expected to be completed by 2026, followed by a 12 to 18-month transition period, concluding in 2028. As of September 2024, the project is delayed and has not begun construction.[175] The project is now expected to reach its targets by 2030 instead of 2028.

6.3.3 City of Markham – Enbridge Pilot

In 2022, Enbridge Gas and its partner Cummins announced the successful operation of its first blended hydrogen pilot to meet the gas needs of the city of Markham. In 2020, Ontario's Energy Board (OEB) approved the pilot for blending up to 2% of hydrogen into an isolated section of Enbridge Gas' existing network in the city of Markham. Since hydrogen's lower volumetric heating value amounts to a larger volume of gas being supplied to the end user in comparison to conventional natural gas, OEB also approved a rate rider for the extra volume that would be consumed in the target region to maintain equal pricing for all end users- a major facilitator for the feasibility of the pilot.[176] The hydrogen gas used for the blending pilot was generated at Enbridge's Markham Power-to-Gas facility, a large-scale operation set up in 2018 by Enbridge and Cummins, with funding from Sustainable Development Technology Canada (SDTC), the

[173] Clarke T., Clean energy hydrogen project announced in Prince George, Prince George Citizen, 2024
[174] Arcelor Mittal press release: 13 October 2022
[175] Beattie S., *ArcelorMittal Dofasco misses key milestones in $1.8B 'green' steel project promised for 2028*, CBC News, 03 September 2024
[176] Stevens D., *Ontario Energy Board Approves Hydrogen Blending Pilot Project*, Energy Insider, 2020

Canadian Gas Association (CGA), and NGIF Capital Corporation. The pilot is expected to eliminate the release of 117 tonnes of CO_2 from the atmosphere per year. [177] The success of the initial trial is anticipated to result in the implementation of higher hydrogen blends in different sections of the network and bring down the utility's GHG emissions.

[177] Enbridge: Clean Hydrogen enters the Markham energy mix, 13 January 2022

7. Conclusions

The global momentum towards reducing GHG emissions and transitioning to sustainable energy sources has positioned green hydrogen as a key enabler in the decarbonization landscape. Green hydrogen's versatility as an energy carrier and its potential to replace carbon-intensive fuels across various industrial sectors have sparked increasing interest and investment. With its ambitious climate goals and strategic initiatives, Nova Scotia is advancing in this transition, supported by regulatory support and technological advancements. This study explores the regulatory environment, the landscape of hydrogen adoption in Nova Scotia, and the challenges and opportunities in various sectors, highlighting the province's commitment to achieving net-zero emissions through the integration of green hydrogen and other clean technologies.

7.1 Regulatory Environment and Nova Scotia Hydrogen Landscape

Nova Scotia's transition to low-carbon fuel alternatives is driven by both federal and provincial regulations aimed at reducing GHG emissions and achieving sustainability goals. Federal initiatives such as the Pan-Canadian Framework on Clean Growth and Climate Change and the 2030 ERP provide a foundation for Nova Scotia's policies, while local legislative measures like the EGCCRA and the CFR emphasize renewable energy adoption and the reduction of CI across the economic sectors.

Nova Scotia's strategy involves significant efforts in increasing renewable energy capacity, phasing out coal by 2030, and implementing hydrogen and green technology innovations. Key provincial measures include the Renewable Electricity Regulations, the Hydrogen Innovation Program, and the Offshore Wind Roadmap, all aimed at positioning Nova Scotia as a leader in green energy. This approach supports environmental sustainability and enhances energy security, drives innovation, and creates economic opportunities across the province. Through ongoing investments in clean technology, energy infrastructure, and regulatory frameworks, Nova Scotia is aligning itself with national and global targets for net-zero emissions, aiming to foster long-term environmental and economic resilience.

7.2 Nova Scotia Industry and Manufacturing Sector Process Heating

Pulp and Paper: The pulp and paper industry in Nova Scotia is energy-intensive, with substantial thermal demands for processes like pulp production, bleaching, drying, and finishing. The sector relies on Combined Heat and Power (CHP) systems to meet its heating and electricity needs, with drying being the most energy-intensive stage. Facilities like the Port Hawkesbury Paper Mill play a crucial role in the local economy and highlight the importance of sustainable energy practices to enhance efficiency and reduce emissions.

Clay Bricks: Shaw Brick, a prominent manufacturer in Atlantic Canada since 1861, is a key supplier of clay bricks, concrete blocks, and natural stone products. Their production process involves mining, grinding, and forming raw materials like surface clays and shales before drying and firing them at temperatures up to 2000°F (1090°C) in tunnel kilns. Natural gas is the primary fuel used in this energy-intensive process, with additional use of coal, sawdust, and propane. The reliance on high-temperature firing highlights the need for energy-efficient technologies and low-carbon alternatives to reduce emissions while maintaining high production quality.

Rubber and Tire: Michelin's tire plants in Nova Scotia are vital to the regional economy. The manufacturing process, from mixing rubber compounds to curing and finishing, requires substantial heat and energy, particularly for equipment such as mixers, extruders, and curing molds. With natural gas-fueled boilers supporting these operations, the energy-intensive nature of tire manufacturing demonstrates the importance of sustainable practices to reduce the sector's environmental impact.

Cement: Cement manufacturing in Nova Scotia, led by Lafarge Canada, is characterized by its high thermal energy requirements, especially during clinker production. The Brookfield plant has been a key player in the industry for over 50 years, contributing to significant infrastructure projects. Decarbonizing cement production is challenging due to its reliance on fossil fuels for high-temperature processes, necessitating innovative low-carbon technologies to reduce emissions while maintaining product quality.

Chemicals: Nova Scotia's chemical industry, though modest in scale, involves energy-intensive processes that require substantial thermal inputs across various applications. Key processes like steam cracking, distillation, chemical synthesis, and reforming operate at high temperatures, often between 100°C and 900°C, to produce essential chemicals and materials. These thermal needs highlight the industry's dependence on considerable energy resources, presenting opportunities for improved energy efficiency and decarbonization within the sector.

Marine Sector: Nova Scotia's marine sector, centered around the Port of Halifax, plays an important role in global shipping and has notable energy demands, especially in propulsion, auxiliary power, and steam production systems. These systems rely heavily on fuel-intensive internal combustion engines and boilers, supporting both vessel operation and onboard functions. As the industry explores decarbonization, transitioning to low-carbon fuels that align with existing energy patterns offers a promising path forward, helping to reduce fossil fuel reliance while maintaining operational efficiency.

Food Production: Nova Scotia's food industry relies heavily on energy-intensive thermal processes such as pasteurization, sterilization, drying, and baking. These processes are crucial for ensuring food safety, quality, and shelf life. The sector faces significant decarbonization challenges due to its dependence on fossil fuels for heating and processing. Integrating renewable energy sources, advanced electrification technologies like heat pumps, and green hydrogen can substantially reduce GHG emissions and improve energy efficiency.

Power Generation: Nova Scotia's power generation relies heavily on coal and natural gas for electricity generation. These facilities operate at high temperatures and generate steam for turbines. The province is transitioning towards renewable energy, with an increasing reliance on wind, hydro, biomass and solar resources. However, the shift from fossil fuels to renewables will require advanced energy storage solutions and efficient management of thermal energy demands to maintain grid stability and support the province's goal of phasing out coal by 2030.

7.3 Hydrogen's Potential to Decarbonize Process Heat Applications

Industrial Decarbonization Pathways: Decarbonizing Nova Scotia's industrial sector is a challenging task, particularly for industries like cement, pulp and paper, and chemicals, which rely on energy-intensive processes that emit significant amounts of GHGs. The primary source of emissions comes from the combustion of fossil fuels for heat generation, as well as chemical reactions in processes like cement production. The shift to sustainable practices, such as adopting CCUS technologies and transitioning to low-carbon fuels, is essential for these industries. Energy efficiency improvements, such as optimizing equipment and recovering waste heat, can provide immediate emissions reductions while technological advancements, like hydrogen-based solutions, offer long-term potential for decarbonization in the province.

Hydrogen Production Pathways: Hydrogen presents a critical opportunity to decarbonize Nova Scotia's industrial sector by providing a clean alternative to fossil fuels for process heating and chemical reactions.

There are multiple pathways to produce hydrogen, with green hydrogen, produced through electrolysis using renewable energy, being particularly relevant for Nova Scotia. With the province's variable renewable energy resource, electrolysis could become a viable method for large-scale hydrogen production. Blue hydrogen, produced from natural gas with carbon capture, offers a transitional solution but requires the development of CCUS infrastructure. As hydrogen production technology matures and costs decrease, hydrogen is poised to become a key component of Nova Scotia's decarbonization strategy.

Hydrogen Storage: Effective hydrogen storage is essential for supporting hydrogen's role in Nova Scotia's industrial decarbonization. Hydrogen can be stored in compressed gas, cryogenic liquid form, or through advanced material-based methods like liquid organic hydrogen carriers (LOHCs) or metal hydrides. Compressed hydrogen gas storage is currently the most common method, though it requires significant space. Salt caverns, identified in areas such as Alton and Kingsville, offer potential for large-scale underground hydrogen storage in Nova Scotia. These caverns provide long-term stability, high capacity, and cost-effectiveness, making them ideal for balancing the province's renewable energy production with hydrogen storage needs.

Hydrogen Transportation: Transporting hydrogen within Nova Scotia will likely involve a combination of pipelines, road transportation, and possibly shipping for larger distances. Hydrogen can be transported as a gas or in liquid form via trucks, or through chemical carriers like ammonia or methanol for easier handling. Pipeline transport is the most efficient method for large volumes, but challenges such as hydrogen embrittlement and the need for specialized materials must be addressed. The Maritimes & Northeast Pipeline could provide a blueprint for hydrogen transportation, but new infrastructure would need to be developed to accommodate hydrogen, especially as production scales up to meet industrial demand.

Hydrogen's Financial Viability for Industrial Applications: For hydrogen to be financially viable in Nova Scotia's industrial applications, it must become cost-competitive with traditional fuels like natural gas, or industries are willing to pay a premium for decarbonization. Currently, hydrogen production costs, especially for green hydrogen via electrolysis, are higher than those of natural gas. However, the costs are expected to decline significantly by 2030 as hydrogen technology improves and renewable energy prices fall. Nova Scotia's strong potential for renewable energy positions the province well to capitalize on these advancements, and with supportive policies such as carbon pricing, hydrogen could reach cost parity with natural gas. This transition will require strategic planning and investment in hydrogen-ready infrastructure to ensure that industries can adopt hydrogen solutions as costs decrease over time.

7.4 Hydrogen Equipment for Process Heating

Hydrogen has been blended with natural gas and used for process heating applications for decades in varying compositions, especially due to the varying concentrations of hydrogen in refinery fuel gas that was used for firing process heaters. Most process equipment is compatible to work with fuel comprising a blend of natural gas and up to 20% hydrogen by vol. Switching to 100% H_2 fuel or even a high H_2 blend introduces a number of challenges in process heaters. These challenges and some mitigations for each challenge are summarized in Table 10.

Table 10: Summary of challenges faced in blending high volumes of hydrogen in process heating

	Challenge	Effect of the challenge	Mitigation
1	High temperature flame	Increase in NOx with higher flame temperatures. High quantities of NOx pose a health hazard	Burner design modification, external flue gas recirculation, or selective catalytic reduction (SCR) as a last resort
2	High flame speed	Risk of flashback if the air/fuel speed is lower than the flame speed, where the flame could travel backwards into the burner and upstream equipment	Burner design review to ensure it can accommodate the air/fuel speeds necessary for safe operation
3	Flame (in)visibility	The H_2 flame becomes virtually invisible, jeopardizing the safety of the operation	Alternate methods of detecting the flame, such as specialised ultraviolet or infrared flame scanners, may be required
4	Decrease in the quantity of flue gas generated	Reducing the heat absorbed in the convective section of the heater or process	Reconfiguring the convective coil to maintain the same heat absorption, excess air may be provided to increase thermal mass, checking impact on draft and fan
5	Non- luminous H_2 burning	Reduced direct heat transfer from flame to the radiant coils	increased emissivity of flue gas molecules and increased refractory temperatures will likely offset this effect
6	Corrosion	Embrittlement of fuel gas delivery system	Welds, bolted connections, and burner internals made of high-strength steel may need to be replaced with material that is not susceptible to embrittlement
7	Low molecular weight, high flammability, odourless, colourless H_2, stoichiometric less air required for H_2 burning,	Susceptible to leakage in fuel gas piping, ignites easily, risk of explosion if the air volume is not well controlled during fuel switching	Addition of H_2 detection instruments, adjustment of controls to ensure adequate air for both natural gas rich and hydrogen rich fuel blends
8	Low volumetric energy density	Three times the volumetric flow rate required	Resizing of burner piping and fuel gas skid
9	Stack plume visibility	Appearance of a white H_20 condensate flue gas fog at the stack exit	Heating or condensing and collecting the flue gases to avoid plume

Despite the challenges, several process heater manufacturers have developed hydrogen-ready prototypes and commercial products to help their clients meet decarbonization targets. These allow varying blends of H_2 by vol in natural gas, all the way up to 100%. Table 11 shows a summary of some of the players identified:

Table 11: Industrial players with hydrogen-ready offerings

Equipment type	Industry players
Boilers, furnaces, kilns	Viessmann, Bosch, Babcock and Wilcox, Hydrogen Technologies LLC*, SACMI, CarboLite Gero
Burners	Metso, John Zink (Coen), Zeeco, Fives' Group, Toscotec, Tenova
Gas turbines	Kawasaki Heavy Industries, General Electric, Siemens Energy

***only allows a 100% H_2 option with no blend capabilities**

In the local context, supplier of boilers- Thermogenics in Ontario, supplier of ignitors- Fossil Power Systems (B&W) in Nova Scotia and supplier of burners- Zeeco in Ontario, were identified to be motivated for hydrogen readiness.

The latest regulation for hydrogen uses in industrial process heating is the ninth edition of the ANSI/CAN/UL 795:2024 that was published in February 2024 and provides a path for hydrogen blending up to 25% in commercial and industrial gas fired package boilers. While this percentage is not very high, it is likely that standards will be catching up based on the pace of commercial development of hydrogen use cases in the industry.

7.5 CASE STUDIES

A number of pilot projects across the globe have been identified. These are split into three categories- implemented demonstrators for use of 100% H2 and other H2 blends, historic uses of H2 for process heating, new initiatives and pilots (not necessarily in industrial process heating) exploring hydrogen's role in decarbonisation in Canada. A summary of projects for each of three categories is shown below in Table 12, Table 13 and Table 14:

Table 12: CATEGORY 1 – International Pilot Projects

Industry	Project	Project location	Use Case
Cement and Ceramics	CEMEX	Europe, Americas	Currently uses H_2 blended fuel for all cement plants across Europe and some in the Americas
	Heidelberg Materials/ Hanson	UK	Operated a cement kiln using 39% H_2 and other climate neutral fuels as a pilot project
	Henan Zhongqi Ceramics	China	Uses a fuel mix of 60% hydrogen for producing sintered stones and large slabs. Operational since two years with the blended fuel arrangement.
Pulp and Paper	Papierfabrik Palm	Germany	Modernised paper mill, capable of firing 50% H_2. Awaiting green hydrogen supply
	Smurfit Kappa Plant	France	EU funded Hyflexpower project successfully ran the gas turbine at the paper mill for 90 hours on blended fuel; including 10 hours on a blend with over 80% hydrogen (by vol) and 4 hours on 100% hydrogen
Iron and Steel	SSAB	Sweden	EU funded Project HYBRIT showcased the possibility of a fossil-free conversion from iron ore to steel on a semi-industrial scale.
	Arcelor Mittal	Canada	Replaced 6.8% of natural gas with hydrogen over a 24-hour period test for the production of direct reduced iron (DRI) at their plant in Quebec.
	Tenova	Italy	Launched their first trial for the decarbonisation of the steel industry with hydrogen in July 2024.
Rubber and Tires	Sumitomo rubber	Japan	Started mass production using hydrogen and solar energy at its Shirakawa plant in Fukushima

Table 13: CATEGORY 2 – Historic Use Cases

Industry	Use Case
Chemicals	H_2 from the chlorine production offgas in chemical plants was utilized in the fuel mix for process heating in the plant itself to reduce fuel costs and emissions. (Example: NCI, Jordan)
Pulp and Paper	Byproduct hydrogen generated during sodium chlorate production in chemical plants that is used for bleaching paper was channelled to provide the heating needs of the adjacent paper mills. (Example: CMPC Pacífico Mill, Chile)
Petroleum Refineries	Use of H_2 rich fuels in a fired equipment is common in the Refining industry. Refinery fuel gas which is a blend of all the waste streams with calorific value from all the process units is known to contain varying percentages of H_2, sometimes as high as 90%

Table 14: CATEGORY 3 – Noteworthy Canadian Initiatives

Industry	Initiative
Pulp Mill	Launched in 2022, the Prince George Project is a partnership between H_2 infrastructure facilitator Teralta, chemicals supplier Chemtrade and Canfor Pulp. The project aims at utilizing the vented hydrogen from the production process of bleaching agent sodium chlorate in Chemtrade as a fuel in the process heaters at CANFOR's Intercon Pulp Mill. The closing of two pulp mills in Prince George due to a shortage of fibre seems to have delayed the start of the Project.
Iron and Steel	A $CAD 1.8 billion investment between Arcelor Mittal and the governments of Ontario and Canada, the Dofasco project aims to transform steel production to a direct reduced iron-electric arc furnace (DRI-EAF) process. The DRI furnace will be designed to operate on green H_2 as well as natural gas (until the green H_2 is commercially available). The project is facing some delays and is expected to reach its targets two years later than scheduled, in 2030.
Residential gas supply	In 2022 Enbridge together with Cummins successfully trialled a blended hydrogen pilot for meeting the gas needs of the city of Markham. Ontario's Energy Board (OEB) approved the pilot for blending up to 2% of hydrogen in a section of the gas network and also approved a rate rider for the extra volume of fuel consumed. The success of the initial trial is anticipated to result in the implementation of higher hydrogen blends in different sections of the network.

Appendix1 –Climate Change Plan for Clean Growth Commitments - 2024 Progress

Action Number	Milestone	Progress in Commitments 2024[178]
17	Create provincial regulations to phase out coal-fired electricity generation by 2030 with the goal of achieving at least a 90 per cent reduction in GHG emissions from the electricity sector by 2035.	Nova Scotia's 2030 Clean Power Plan sets a vision for an electricity grid powered by a diverse mix of solar, wind, hydro and biomass by 2030. Additionally, converting some coal plants to gas will provide backup power during emergencies and ensure grid reliability. Nova Scotia also implemented the Output-based Pricing System targeting large industrial emitters and the electricity generation sector: • Currently, seven companies with 15 facilities are registered under this system in Nova Scotia • Facilities must meet specific performance standard for emissions
18	Increase the amount of renewable energy used for electricity generation by building at least 500 megawatts of new local, renewable energy by 2026 and an additional 50 megawatts of new community solar.	Up to 1,020 megawatts of new, local renewable energy capacity is planned for construction by 2026. Some key highlights include: • 373 megawatts of new onshore wind projects, approved last year through the Rate Base Procurement program • 148.5 megawatts from a private wind facility by Port Hawkesbury Paper Wind • 50 megawatts from a private wind facility by Natural Forces • Up to 350 megawatts of wind energy is anticipated to be awarded through the Green Choice Program • Up to 100 megawatts of community solar power through the Community Solar program, which opened on March 1, 2024
19	Provide funding support for farms and other businesses to adopt more solar power	The Department of Natural Resources and Renewables has funded EfficiencyOne to hire a Solar Navigator to help farms, fisheries, and other businesses to lower their emissions and energy bills by adopting solar energy solutions.
20	Research how we can use battery technologies or electric vehicles for electricity storage and backup power supplies to make our electricity system more reliable.	In December 2023, Government approved a 150 megawatts, three-site battery energy storage project with NSPI, enhancing the province's energy storage capacity. This project was approved under Section 4D of the Electricity Act, which was amended last year to allow for

[178] ns-climate-change-plan-progress-report-appendix-a-2024.pdf (novascotia.ca)

		unsolicited battery storage projects if they provide system benefits and reduce costs to ratepayers. the Department of Natural Resources and Renewables funded two projects to explore vehicle-to-grid technologies: • A project with Université Sainte-Anne to test the integration of an electric school bus with on-site renewable energy sources • A project with Volta Research to develop a comprehensive vehicle-to-grid roadmap
21	Work with our neighbouring provinces to transfer more electricity across Atlantic Canada and Québec through projects like the Atlantic Loop, Muskrat Falls, and stronger connections with New Brunswick.	The Clean Power Plan acts as the roadmap for transitioning the province's electricity sector towards cleaner, more sustainable power sources. In 2022 it was imported 1,820 gigawatt hours of electricity from other provinces or approximately 16.6 per cent of total electricity sales in Nova Scotia in 2023. Maritime Link, Labrador Island Link, and Muskrat Falls facilities are already providing clean electricity and there will be a new 345 kilovolts line known as the 'Reliability Tie' to expand the connections to New Brunswick. The aims This is increase the grid's ability to handle more renewable energy resources like wind.
22	Help Nova Scotians reduce their demand for electricity by continuing and expanding programs delivered by Efficiency Nova Scotia and their partners.	In 2022, Government supported EfficiencyOne in administering their Demand Side Management Plan for 2023-2025, which was approved by the Nova Scotia Utility and Review Board. The plan aims to reduce overall consumer demand for electricity which will reduce air emissions and benefit Nova Scotians by reducing energy bills. In 2023, EfficiencyOne's programs exceeded their targets. Across programs: • 131.6 gigawatt hours of electricity was saved, 109 per cent of the target • Energy demand was reduced by 27.6 megawatts, 103 per cent of the target
23	Support businesses and communities in reducing their energy demand by expanding access to on-site energy managers and continuing support for energy efficiency programming for businesses.	The Onsite Energy Manager program, delivered by EfficiencyOne, has been instrumental in assisting businesses and communities across Nova Scotia to identify energy savings and support applications to clean technology programs
34	Launch the Green Choice Program in 2023, which will allow government to purchase 100 per cent renewable electricity for our operations as it	The Green Choice program is helping to accelerate our transition to cleaner electricity resources. Participants in the program will switch to 100 per cent green energy. The Green Choice program will help more Nova Scotians switch

	becomes available.	to green energy, including government buildings.
35	Build more EV charging stations across the province so Nova Scotians can access them when and where they need to.	-Eight EV Charger/EV Ready rebates have been issued. -The Department of Natural Resources and Renewables has started working with community partners to deploy new level 3 fast chargers. Electrify Nova Scotia Rebate Program - EV Assist
36	Increase the number of zero-emissions vehicles and e-bikes to meet the 2030 30 per cent zero-emissions vehicle sales target by continuing to offer rebates and continuing to provide education and outreach programs	Incentives supported the purchase of 1,813 electric vehicles Additionally, 2,089 e-bike owners received rebates to facilitate their transition to electric Combined with last year's incentives, over 3,000 Nova Scotians have been supported in their purchase of an EV along with over 6,000 e-bike owners
37	Increase the number of zero-emissions medium- and heavy-duty, freight, and marine vehicles through new incentives. 38. Develop a greening fleets strategy for government vehicles	In April 2024, a rebate program for medium- and heavy-duty zero-emission vehicles was launched to support the transition of commercial and industrial vehicles like vans, trucks, and ice resurfacers. Detailed program information is available at Clean Foundation. Some vehicles may qualify for federal incentives as well through Transport Canada. The Fisheries and Aquaculture Energy Efficiency Innovation Fund was launched in June 2024 by the Department of Natural Resources and Renewables and the Department of Fisheries and Aquaculture. This program aims to reduce emissions in the maritime sector, aligning with broader environmental goals.
40	Electrify public transit across the province by partnering with municipalities and the federal government.	In November 2023, the Province invested $17.9 million in the Cape Breton Regional Municipality for the purchase of six new electric buses and the construction of a new maintenance facility. This facility will provide charging and maintenance infrastructure to eventually support 44 electric buses, In March 2024, the Province, in partnership with the Federal Government and the Halifax Regional Municipality, announced an investment of $65 million to support the purchase of five electric ferries and the construction of two terminals and a maintenance facility to serve the municipality
56	Create a new funding navigator at the Department of Environment and Climate Change to connect Nova Scotians to climate change funding opportunities.	The Funding Navigator service began in spring 2023 and continues to offer services to Nova Scotians. Key activities include: • Meeting with individuals to help them navigate various funding programs and processes • Throughout 2023-24, 14 sessions were held, attended by

		120 individuals from 18 departments and 2 crown corporations • Over 150 organizational representatives were invited to participate in strategic conversations aimed at building a deeper understanding of the climate funding application landscape in Nova Scotia. These discussions focused on hearing ideas on improving support options for those applying for funds and began the conversations on options for program development under the Funding Navigator umbrella
57	Develop a clean investment plan that takes deliberate and strategic actions to ensure the Nova Scotia economy is prepared to respond to the needs of a low-carbon economy.	The Clean Investment Plan approach was developed in May 2023. The plan involves implementing activities to enable Nova Scotia businesses and the local workforce to benefit from the transition to a low-carbon economy. Three projects were launched, which focused on offshore wind, other renewable energy, and green hydrogen
58	Create a green hydrogen action plan by 2023 to support the development of the green hydrogen sector in Nova Scotia.	The Green Hydrogen Action Plan has been completed and was publicly released on December 15, 2023. It includes seven goals and 23 actions to support the domestic use and export of green hydrogen, including considerations of safety, developing a skilled workforce for the industry, research and innovation, and opportunities for public engagement
59	Issue leases for five gigawatts of offshore wind energy by 2030, with a first call for bids by 2025.	The Department of Natural Resources and Renewables is actively collaborating with federal partners and the future regulator, the Canada-Nova Scotia Offshore Petroleum Board, to develop comprehensive legislative and regulatory frameworks. These frameworks will guide licensing and calls for bids in Nova Scotia's offshore wind sector. Additionally, the Department is engaging with stakeholders and rights holders to ensure the development process includes multiple voices and perspectives
60	Create a clean fuels fund to support industries and businesses in adopting low-carbon and renewable fuels such as green hydrogen, renewable natural gas, biofuels, and sustainable biomass.	Through the new Clean Fuels Fund, the Department of Natural Resources and Renewables invested $3 million in seven ready-to-launch clean fuels projects. The awarded projects will receive up to 75 per cent of project costs up to a maximum of $1 million to do the work needed to transition to cleaner fuels for heating, transportation, and industrial processes
61	Implement the Innovation Rebate Program and pilot a low-carbon stream of the Early-Stage Commercialization Fund through Invest Nova Scotia to create an environment that supports	The Innovation Rebate Program provides funding to help Nova Scotian companies grow and increase their competitiveness. This past year 25 projects received support from the Innovation Rebate Program. 72 per cent of the Innovation Rebate Program applicants indicate increased sustainability (e.g., reduced GHG emissions or

	innovative businesses.	reduced waste) as a potential outcome. Innovation Rebate Program Disclosures - 2023/24 | Invest Nova Scotia Five projects have been approved in the Early-Stage Commercialization Fund since it was introduced in 2021-2022. This past year, the fund supported researchers from Dalhousie University in a project focused on optical gas imagers to find natural gas leaks in oil and gas sectors
63	Invest in research needed for new clean technologies and practices to help us meet our net-zero by 2050 target.	Expansion of the Verschuren Centre into a national bioprocessing centre will attract 10 new companies to Nova Scotia per year. This investment is helping to grow Nova Scotia's bioeconomy sector
64	Launch the Green Choice Program in 2023, which will allow large industrial energy consumers to purchase 100 per cent renewable electricity as it becomes available	The Green Choice Program launched in December 2023. Eligible customers and customer groups, consuming at least 10,000 megawatt hours per year, expressed their interest last year. The Request for Proposals for energy projects closed in June 2024, with awards expected to be announced in September