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Canada's Opportunity Playbook:
Pathways to Strategic Decarbonization

ENERGY CARRIERS

Hydrogen



7.2 HYDROGEN

Function	Today: Used as a feedstock for the chemical industry, fertilizer production, bitumen upgrading, and oil refining. Future: Could play an expanded role as a clean energy carrier in transportation, and industrial heating, alongside emerging roles in energy storage, grid balancing, and in the production of biofuels and steel.
GHG emissions	Currently, Canada lacks a hydrogen-specific national accounting system for production volumes, pathways, and associated emissions. Production methods vary in carbon intensity, and most hydrogen produced today is higher-emission “grey” hydrogen, with only limited low- or net-zero-emissions hydrogen deployed. A rough estimate suggests emissions from Canadian hydrogen production could be 38 Mt of CO_{2e} in 2024 (already reflected in our inventory, largely under oil and gas and refining categories—not additional to reported totals).¹
Options for decarbonization	Decarbonization Pathways: Autothermal reforming with carbon capture and storage, electrolysis with low-emission electricity. As an emerging but highly uncertain opportunity, some companies are exploring natural hydrogen, which should have very low carbon intensity. Bridge Pathways: Steam methane reforming with carbon capture storage. Niche Pathways: Methane pyrolysis, biowaste gasification, byproduct of industrial processes.
Stage of transition	Emerging: Methane autothermal reforming and pyrolysis, hydrogen derived from carriers (i.e., ammonia, methanol, liquid organic hydrogen carriers, etc.) Early Diffusion: CCS applied to methane reforming and electrolysis supported by low-emission electricity.
Nature of the problem today	There is currently limited demand and production for hydrogen as a fuel, and very limited distribution infrastructure. Very little low-carbon-emission hydrogen is now being produced. Substantial investment risk with the uncertainty in infrastructure development and downstream demand. High production, storage, and delivery costs.
Other systemic issues	Fugitive emissions from natural gas extraction. Requirements of high volumes of decarbonized electricity and water availability for electrolysis. Hydrogen leaks could elevate levels in the atmosphere and increase the half-life of atmospheric methane. In this way, hydrogen is an indirect greenhouse gas, so leaks must be managed.
Strategic opportunities and concerns	Opportunities: Hydrogen is a decarbonization energy option for hard-to-abate sectors. Potential for societal and economic benefits from development of a new industry. Co-located demand and production hubs offer high economic potential. Concerns: Infrastructure/demand feedback loop stalls investment and growth. Decarbonization of existing production methods requires expensive retrofits or new market demand. Hydrogen leakage across production, storage, and transport infrastructure could undermine climate benefits if not effectively managed.
Priorities for action	Use policy to encourage production and demand and co-location of production with demand. Establish carbon intensity thresholds and reduction schedules to ensure a clear pathway to zero emissions. Additional research and demonstration for compatibility with existing infrastructure, equipment, and safety requirements.

¹ National production: 4 Mt of hydrogen
Energy density: 120 GJ/t
Carbon intensity of grey hydrogen: ~80 kg CO_{2e}/GJ
4,000,000 t * 120 GJ/t * 0.08 t CO_{2e}/GJ = 38,400,000 t CO_{2e} = 38.4 Mt CO_{2e}

Longer-term issues	Buildout of infrastructure to meet broader applications. Address fugitive methane and hydrogen emissions and data gaps. Demand on water.
Indicators of progress	Total emissions from hydrogen production, carbon intensity of hydrogen, production and retail costs, deployment of fuel cell vehicles and other technologies that efficiently convert hydrogen into energy services, proportion of energy use for which low-carbon hydrogen, ammonia or methanol displace fossil fuels in end-use sector.

7.2.1 Current Status

Hydrogen is light, abundant, and highly reactive, and bonds with elements like oxygen to form water or carbon to form hydrocarbons. Releasing hydrogen from oxygen bonds (as in water) requires significant energy input; releasing it from hydrocarbon bonds generates energy. Some industries, like the chlor-alkali sector, produce hydrogen as a byproduct.

Hydrogen is currently used mostly as a chemical feedstock for hydrocarbon refining, ammonia and methanol production, and fertilizer production. Additionally, it can be used as an energy carrier that can generate electricity in a fuel cell, be combusted to generate heat, added to improve the energy density of carbon in biomass, or leveraged to reduce iron oxide in the production of green steel.

Several factors make hydrogen attractive:

- **Zero-emissions Potential:** Hydrogen combustion or electrochemical conversion in a fuel cell emits no greenhouse gases. It is technically feasible to produce hydrogen with zero emissions.¹
- **Flexibility:** Hydrogen is a versatile molecule that can be stored or transported as a gas or cryogenic liquid. It can be used to make energy-rich chemicals (e.g. ammonia) for transportation or heating, generate electricity, make steel, or produce drop-in biofuels.
- **Complementarity to Electricity:** Hydrogen can fill gaps where electrification is difficult, such as with rail and heavy-duty vehicle transport, and can store renewable electricity as chemical energy. A hydrogen “grid” of pipelines and salt cavern storage could improve the economic viability of large-scale, low-carbon electricity deployment (wind, solar, nuclear), since the production of hydrogen would add value to surplus electricity generation while creating a zero-emission fuel that can be stored for long periods. As a northern country, Canada’s surplus power generation in the summer could be stored as hydrogen for use as a zero-emission heat source in the winter.
- **Regional Benefits:** Hydrogen could support regional transitions away from fossil fuels. Areas with abundant natural gas or renewable energy could have a future role as hydrogen producers. Some argue the Canadian Shield is a promising geology for the discovery of natural hydrogen sources.

Canada has many advantages when it comes to hydrogen production. There are abundant feedstocks, including natural gas, clean electricity, fresh water, as well as space for geological carbon storage. Canada is already established in the hydrogen fuel cell sector with more than 100 companies and 2,400 employees in the value chain.[143,144]² Today, Canada produces roughly 4 Mt of hydrogen annually, ranking among the top 10 global producers.[145]

1 Although hydrogen combustion does not produce direct greenhouse gas emissions, it does produce NOx as the air is heated to high temperatures during the combustion process. NOx is not considered a direct greenhouse gas, but it does contribute indirectly to greenhouse gas emissions through the formation of ozone. Additionally, NOx leads to local air quality concerns and is associated with human health impacts.

2 All noted references can be found in the full Playbook document.

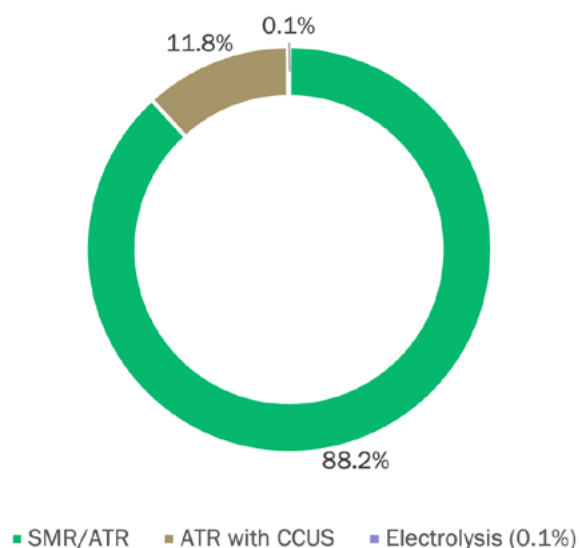


Figure 14. Canadian hydrogen production by method (2024)

Source: CER and AER[146–148]

Virtually all the hydrogen produced in Canada in 2020 was consumed by industrial processes, chiefly oil upgrading and refining, ammonia, and methanol production. Western Canada produces and consumes Canada's hydrogen. Alberta consumes the largest share of hydrogen produced in Canada, about 61%.[149] Alberta also produces 65% of the hydrogen in Canada.[146] Hydrogen-based steelmaking remains a future pathway rather than a current source of demand, with existing direct reduction of iron (DRI) facilities operating on natural gas and only limited pilot-scale hydrogen-use tests conducted to date.

There is consensus that hydrogen will be required to reach net zero, but uncertainty in the required quantities and its use cases. Canada's hydrogen strategy, updated in 2024, envisions hydrogen providing between 3% and 18% of the country's end-use energy by 2050.[148]

7.2.2 Nature of the Problem

The hydrogen economy is confronted with a “chicken and egg” dilemma: infrastructure depends on demand, and demand depends on infrastructure. This mutual dependency fuels market instability and deters investment. Hydrogen has potential as a net-zero fuel, but low-emission hydrogen supply in Canada is extremely limited, distribution networks are fragmented and mostly reliant on trucking, and end-use equipment is only available in niche, early-market applications.

Currently, around 3.5 Mt of hydrogen is generated from unabated natural gas, while only 0.5 Mt is confirmed to employ low-carbon methods.[146–148] According to Canada's updated hydrogen strategy, between 6 Mt and 20 Mt of low-carbon hydrogen will be needed for net zero in 2050.[148] This highlights the need to scale production and shift to lower-emitting methods. However, widespread adoption of hydrogen is constrained by several infrastructure-related barriers.

Infrastructure

Production: Hydrogen's emerging role as an energy carrier requires significant investment in production infrastructure. Achieving low-carbon hydrogen at scale requires retrofitting existing facilities with CCS and building new facilities with either natural gas and CCS or electrolysis. Both options are associated with significant costs and planning. Natural or geological hydrogen is an additional longer-term alternative that, if proven at scale, could bypass some of these production costs entirely.

Transport: Governments and natural gas utilities are exploring repurposing natural gas networks for hydrogen transport, as this minimizes the need for new infrastructure and enables the continued use of gas networks. The picture varies by network type: lower-pressure distribution pipelines are generally more

compatible with hydrogen, while high-pressure transmission pipelines made of high-carbon steel are prone to hydrogen embrittlement and would likely need to be replaced for pure hydrogen service. End-use equipment such as meters, appliances, and industrial burners would also require modification or replacement in either case.³ Only newer polyethylene (PE) networks might accommodate pure hydrogen, but such a transition would likely still require the replacement of end-use equipment. Where pipelines are not available, hydrogen must be compressed or liquefied for transport on trucks or trains. This can be expensive, energy-intensive and safety-sensitive.[150]

Storage: Unlike electricity, hydrogen can be stored as a physical fuel, making it a valuable complement to variable renewable generation. However, hydrogen is challenging to store due to its low density and small molecular size. It can be compressed at moderate pressure (i.e., 350 bar) or high pressure (i.e., 700 bar), or liquefied to reduce volume, but these options involve trade-offs in cost, energy use, and safety similar to those in transport. Hydrogen can also be converted into ammonia for easier handling, but this has not yet proven to be cost-effective at scale. Storing hydrogen underground in geological formations shows promise as a low-cost option. Salt cavern storage in particular has been demonstrated commercially, though it is only economical at large scale, reinforcing the need for substantial demand before this alternative is viable.[150]

Distribution: Canada currently has only a handful of accessible hydrogen fuelling stations, leaving most of the country without refuelling options for hydrogen vehicles.[151] High capital costs per station, low utilization, and no self-reinforcing demand cycle yet in

place create a financing gap that private operators are unlikely to bridge without targeted government support.

In all cases infrastructure safety remains a foundational concern. Hydrogen is non-toxic and disperses quickly, reducing some risks. However, its high flammability and low ignition-point demand specialized safety protocols that are currently limited to a few industrial settings. To the extent that hydrogen expands into sectors like transport, the need for broader expertise, standardized guidelines, and public education will grow significantly.

Market size and cost competitiveness

Infrastructure challenges contribute directly to uncertainty in market size and cost competitiveness. Without clear infrastructure pathways, the scale of hydrogen adoption in Canada remains unclear. Hydrogen will continue to serve as an essential feedstock for the chemical and fertilizer sectors and may support difficult-to-electrify applications. However, its potential beyond this, including its role in building heating and transportation, remains less certain. Until infrastructure policies, funding, and plans are in place, investment at scale will remain a challenge.

Hydrogen is currently expensive, largely due to high capital and operating costs and limited end uses. Today it is not cost-competitive with most other fuel types. Cost would go down with infrastructure buildout and greater demand. Ongoing development of multiple technologies will influence its evolving cost competitiveness. While natural gas-based hydrogen is generally cheaper today, electrolysis is expected to become cheaper as technology improves and scales.

³ The specific threshold will vary according to the characteristics of the system in question, but 20% hydrogen by volume is often cited as an upper limit for typical natural gas networks. Hydrogen is less energy dense per unit volume than methane, meaning a 20% blend of hydrogen could be expected to reduce emissions by approximately 6-7% over natural gas alone.

7.2.3 Net-Zero Pathways

Hydrogen can be produced by steam methane reformation, autothermal reforming or pyrolysis using natural gas as a feedstock, or electrolysis using water as a feedstock. This section explores decarbonizing these technological pathways. Hydrogen can in principle also be derived from alternative sources, such as biomass. However, due to the limited availability of biomass feedstocks and their likely small role in the market, this is not explored further in this report. Hydrogen generated as a byproduct from industrial processes, like chlor-alkali processes, was also excluded as the supply is limited.

Steam Methane Reforming (SMR)

SMR is the most common method of hydrogen production by reacting methane with steam and air, generating both hydrogen and CO₂. To reach net zero, CO₂ must be captured. Current capture systems typically address only about 60% of process emissions. The remaining emissions are found in flue gas, and there is currently no commercial-scale capture of these. While 90% capture rates have been demonstrated in pilots, no commercial plants exist. It is, however, very difficult to achieve net zero with SMR and carbon capture, as flue gas is very dilute.

Autothermal Reforming (ATR)

ATR is a commercial methane reforming process similar to SMR except that it uses pure oxygen in place of air and carries out the reaction in a closed vessel. This produces a concentrated CO₂ stream, making carbon capture more efficient. There are ATR's commissioned in the United States and facilities planned for Canada; all have target capture rates of 95%.^[152–154] The absence of flue gas simplifies capture, making ATR a more viable near-term pathway for low-carbon hydrogen compared to SMR.

Methane Pyrolysis

Pyrolysis is less developed than SMR and ATR, and has a higher natural gas consumption rate, but recent commercial projects have been announced in Canada.^[155] This method decomposes methane without oxygen to yield hydrogen and solid carbon (carbon black), eliminating the need for carbon capture from process emissions. While carbon black is a valuable product, the development of supply chains would be necessary as its market potential is believed to be limited.⁴

To fully meet net-zero requirements, methane-based hydrogen production pathways (SMR, ATR and pyrolysis) might require negative-emissions technologies to negate fugitive methane emissions, while those involving carbon capture would require such technologies to account for the residual carbon emissions.

Electrolysis

Electrolysis is a process that uses electricity to split water into hydrogen and oxygen. This method produces no direct emissions and does not require carbon capture. The emissions associated with electrolysis are from the source of electricity. Electrolyzers can be found in various sizes, enabling both small-scale distributed units and larger centralized facilities to be deployed as needed. Electrolysis projects are planned in British Columbia, and Canadian Pacific Kansas City has deployed a retrofitted hydrogen-electric locomotive, complete with on-site electrolysis-based hydrogen refuelling facilities, that is reported to be cost-competitive with purchasing a new Tier 4 diesel-electric locomotive.^[144,156,157]

Energy decarbonization across pathways

Regardless of production method, hydrogen pathways rely heavily on energy inputs for heat, processing, or other facility operations. SMR,

4 Carbon black is manufactured today for use in various industries such as the production of pigments, and manufacture of tires and other rubber goods.

ATR, and pyrolysis require industrial-scale heat either directly or in the form of steam, while electrolysis requires substantial electricity for processing. To achieve net zero, these energy-related emissions must also be addressed through electrified heating, clean electricity sources, or the use of low-emission fuels.

Hydrogen production methods may be more viable in some regions than others. Alberta's abundant natural gas may favour thermal methods, while British Columbia's clean electricity makes electrolysis more suitable. This highlights the need for location-specific strategies.

Storage and transportation

Storage and transport methods are critical in determining hydrogen's carbon intensity and net-zero compatibility. The most suitable option depends on transport distance, volume, and infrastructure availability. Compressed gas trucks are typically used for short hauls and small volumes, while liquefied hydrogen

becomes more cost-effective at longer distances and larger loads. Pipelines are the lowest-cost option for high-volume regional transport once demand is established, though they require the highest upfront investment. For overseas transport, conversion to ammonia, methanol or liquid organic hydrogen carriers is only economical at large scale due to higher capital requirements. In some cases, it may be more cost-effective to produce hydrogen at the point of use where local natural gas or clean electricity is available, though this should be weighed against the economics of dedicated hydrogen infrastructure, which can be significantly cheaper per unit of energy at scale. Techno-economic analyses that compare capital and operating costs, alongside existing infrastructure and location-specific energy prices, are needed to evaluate trade-offs between these options. Table 3 outlines the main hydrogen transport methods and the distance and volume ranges where each becomes economically viable.

Table 3. *Hydrogen transport method distance and amount requirements for economic viability*

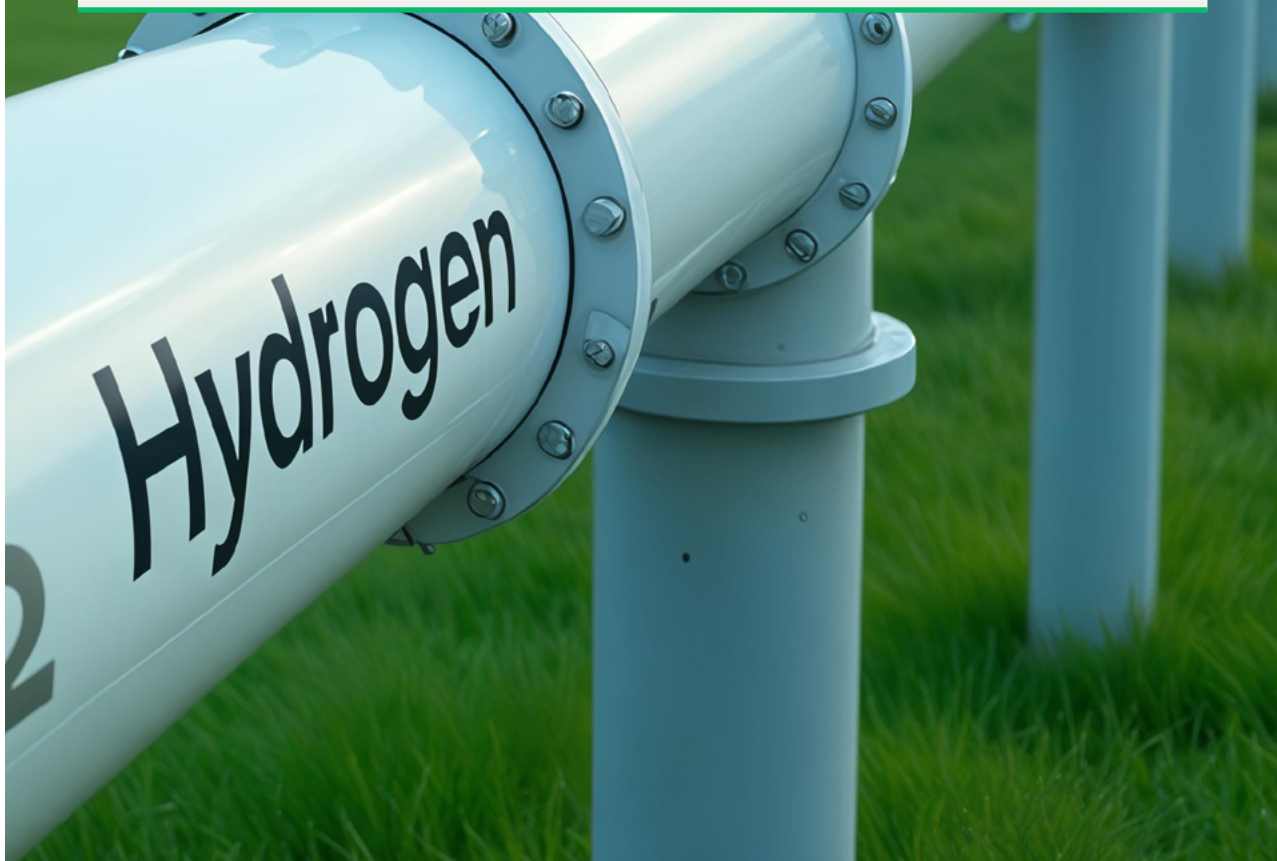
Transport Method	Distances	Amount
Compressed Gas Truck	<320 km	500 kg
Liquefied Hydrogen (Truck/Train)	320 km – 960 km	4 tonnes
Transmission Pipeline	Regional (inter-city or province)	1-2 tonnes/day per km of pipeline
Ammonia (Marine)	>4000 km	Substantial demand required for economy

Competitiveness Implications

The harder problem in Canada's hydrogen export ambitions is market-formation timing. The architecture of international hydrogen trade (carbon-intensity certification thresholds, bilateral offtake commitments, port and carrier infrastructure) is being built now by jurisdictions furthest ahead in deploying certified supply. Producers who lock in these frameworks will set the terms of access others must accept.

Canada has not yet resolved a prior question: whether its export value lies in the hydrogen molecule itself, in derived carriers like ammonia, or in production technology and equipment. These are three different strategies requiring different infrastructure, different partnerships, and different certification pathways.

This is compounded by the divergence between Canada's two regional production tracks: western natural-gas-based hydrogen must demonstrate verified CCS capture rates sufficient to meet emerging carbon-intensity thresholds; eastern electrolytic hydrogen must demonstrate additionality of clean electricity supply. Neither certification pathway is resolved. The risk is not production capability; it is that bilateral offtake relationships and carbon-intensity benchmarks may be substantially set before Canada's export proposition is defined.



7.2.4 Priorities for Action

Identifying viable, no-regrets applications

To accelerate hydrogen deployment and reduce investment risk, decision-makers should start by identifying the most viable and impactful use cases in their jurisdictions—applications where hydrogen is already close to being cost-effective, technically compatible, and operationally necessary. These “no-regrets” opportunities are typically found in sectors where hydrogen has few substitutes, such as heavy industry, refining, and long-haul or high-utilization transport fleets. In regions with clean electricity and surplus grid capacity, electrolytic hydrogen may also be viable for local energy storage or the displacement of high-emissions fuels.

Once these priority applications are identified, policy frameworks can be structured to support them. Focusing early investment and policy effort on these foundational use cases enables capacity building across the value chain, reduces uncertainty for infrastructure development, and establishes the institutional expertise needed to scale hydrogen more broadly in the future. These early steps are not just about technology readiness; they are about creating credible pathways for growth that align with local strengths and decarbonization needs.

Developing viable hydrogen hubs and corridors

A key solution to hydrogen infrastructure challenges is co-locating hydrogen production and demand in a hub, where production, storage, distribution, and end-use are all in one place. These hubs reduce the need to transport hydrogen over long distances and allow the sharing of costs. Offtake agreements, which commit buyers to purchase goods from suppliers in advance of their production, can provide producers with demand certainty and can help to diversify end-use applications. Even

so, it's expected that governments will need to support the initial buildout of infrastructure to get the hubs started. That support should be focused on a limited number of hubs where potential exists to reach commercial scale, delivering hydrogen to end users at a reasonable price for multiple years.

Hydrogen hub development is already underway in Alberta, where strong industrial demand aligns with production potential. Both Edmonton and Calgary host active coordination hubs that focus on connecting hydrogen producers with demand centres and facilitating project development. While these early ventures serve coordination and development functions, fully integrated physical infrastructure hubs with co-located production, storage, distribution, and end-use facilities are still in development. Future clusters are likely to emerge near existing hydrogen demand centres (e.g., refineries, chemical plants), emerging demand (e.g., steelmaking), or transportation nodes (e.g., ports, railyards).

Demand-side support

Demand-side support is vital to the development of the hydrogen ecosystem. Measures that encourage hydrogen demand could include:

- Market development tools and projects for potential key end users, with piloting, testing, and awareness-building around hydrogen technologies.
- Clean fuel standards (such as Canada's Clean Fuel Regulations) to create demand-pull for hydrogen by allowing it to generate compliance credits when substituted for higher-carbon fuels.
- Offtake agreements and contracts of difference to de-risk investment by securing long-term prices and demand.

- End-use incentives to reduce upfront costs for fuel switching and equipment adoption.
- Carbon pricing to increase the cost-competitiveness of hydrogen as fossil fuel costs rise. The exact carbon price needed to make hydrogen cost-effective varies by end use and industry.
- Mandates and procurement requirements for low-carbon fuels like hydrogen in key sectors (e.g., transport, industry).
- Supply chain coordination, including OEM engagement to ensure equipment availability.
- Targeted subsidies or production incentives for electrolytic hydrogen producers.
- Tax credits and financial incentives to offset capital investment and support the whole value chain including transport and storage.
- Carbon intensity thresholds and reduction schedules to ensure hydrogen decarbonizes over time.
- Streamlined regulations and standards to ensure safe deployment and industry clarity.
- Continued decarbonization of electricity grids.

Supply-side support

In addition to co-locating production and demand, coordinated supply-side and demand-side policies are required. Supply side policies to encourage hydrogen production can include:

- Government investment in enabling infrastructure including storage and distribution systems.
- Support for pilot and demonstration projects that improve production technologies and reduce costs, as well as validate the technical compatibility of hydrogen with various end uses.

Canada's hydrogen strategy envisions Canada becoming an exporter of hydrogen and hydrogen-related technologies. However, the specifics of where and how this export will happen are not clear, nor is Canada's comparative advantage as compared to production in other jurisdictions evident.[158] Based on current potential, it is anticipated that eastern Canada will primarily produce hydrogen from electricity, while western Canada will focus on hydrogen from natural gas. Further analysis is required to determine the size of the opportunity and the specifics regarding the return on investment that can be expected for Canadians.

Criteria Status

- Fails to meet criteria
- Meets in some respect
- Not promising
- Potentially meets criteria
- Meets criteria

7.2.5 Hydrogen Pathways Table

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Autothermal Reformation with Carbon Capture and Storage (ATR & CCS)	Potential Decarbonization Pathway Provides significant GHG reductions in hydrogen production.	Enable Invest in oxygen production, and CO ₂ supply in regions with natural gas and geological storage. Support demonstration and prioritize regulatory and infrastructure frameworks.	 Significant GHG reductions. Very high capture feasible via pure O ₂ feed. May require removals for residual emissions. Requires upstream methane capture.	 Moderate premiums from incumbent. More efficient capture process than steam methane reformation + CCS.	 Drives oxygen and CCS services. Regional job growth.	 Demonstration phase.	 High capture efficiency with simplified CO ₂ capture. Requires oxygen production and integration.	 Requires hydrogen pipelines and storage or nearby industrial users. Needs O ₂ supply, CO ₂ compression hubs and storage.	 Generally accepted but public concern over hydrogen safety and CCS leakage.	 Hydrogen producers and natural gas industry as a longer-term net-zero hydrogen production strategy.	 Some concerns about CO ₂ and hydrogen leakage and continued upstream methane emissions.
Steam Methane Reformation with Carbon Capture and Storage (SMR & CCS)	Bridge Pathway Cannot eliminate emissions. Use as an opportunity to codevelop CCS.	Don't Prioritize Do not lead with new investment in CCS retrofits for SMR. Focus investments on ATR and CCS. Allow existing assets to run through their lifespans.	 Offers moderate emissions reduction but cannot reach net zero without combination with negative emissions due to dilute flue gas.	 Moderate premiums from incumbent. High capital costs for retrofit with CCS infrastructure and ongoing operational complexity.	 Maintains existing industrial base and jobs in regions with natural gas resources. Drives CCS services.	 Mature and deployed in Canada.	 Compatible with existing SMR plants, but flue gas capture retrofit is complex.	 Requires hydrogen pipelines and storage or nearby industrial users. Needs CO ₂ compression hubs and storage.	 Generally accepted but public concern over hydrogen safety and CCS leakage.	 Hydrogen producers and natural gas industry as near-term emissions reduction strategy.	 Air pollution concerns. Some concerns about CO ₂ and hydrogen leakage and continued upstream methane emissions.
Pyrolysis of Natural Gas	Potential Niche Pathway Beneficial in regions with natural gas supply and with technical maturity. Provides significant GHG reductions in production.	Incubate Fund R&D and pilot projects to prove commercial viability. Develop markets for carbon black.	 Enables net-zero hydrogen with solid carbon byproduct. May require removals for residual emissions. Requires upstream methane capture.	 Moderate premiums from incumbent. Higher gas consumption. Emerging tech with pilot costs.	 Potential market for carbon black. New manufacturing opportunities.	 Pilot/ demonstration stage.	 Operates similarly to SMR but yields solid carbon. Requires reactor modifications.	 Requires solid carbon- handling supply chain. Nascent support. Requires hydrogen transport and storage or nearby users.	 No particular concerns. Public is unfamiliar with carbon black products.	 Hydrogen producers. Maturity and markets for products limiting uptake.	 Avoids flue gas emissions. Produces marketable carbon black product. Risk of continued upstream methane emissions.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION-MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA-STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Electrolysis with Clean Power	Decarbonization Pathway Can produce net-zero hydrogen.	Enable Invest in electrolyzer supply chains and grid interconnections. Support deployment in regions with surplus clean electricity.	 Fully decarbonizes when powered by clean electricity.	 High premiums compared to SMR. Cost declines with renewables.	 Stimulates electrolyzer manufacturing and grid integration.	 Mature but limited commercialization.	 Compatible with existing water and power infrastructures with minor adjustments. Flexible scaling.	 Requires grid upgrades, high-voltage interconnects, electrolyzer supply chain. Requires hydrogen transport and storage or nearby users.	 Highly favourable where clean power exists.	 Hydrogen producers and utilities have begun developing some commercial projects.	 Complements renewable electricity generation. Integration as storage and transportation option. Supports grid balancing.
Biowaste Gasification	<i>Potential Niche Pathway</i> Likely only economical and net-zero in very niche circumstances.	Don't Prioritize Watch for improvements in feedstock costs and conversion efficiency. Prioritize investments if site-specific conditions demonstrate viability.	 Moderate GHG reduction. Dependent on sustainable feedstock availability.	 High operation, maintenance, and feedstock costs.	 Creates rural jobs. Supports waste management and circular economy.	 Demonstration stage.	 Requires biomass pre-processing. Fits waste-to-energy sites.	 Needs certified biomass supply chains. Limited scalability. Requires hydrogen transport and storage or nearby users.	 Waste management supportive. Public views mixed.	 Waste operators and municipalities.	 Reduces landfill emissions. Provides local feedstock management. Competition with other sectors for feedstocks.
Byproduct of Industrial Processes	Niche Pathway Only available from limited chemical production pathways.	Deploy Support capture and utilization of existing byproduct hydrogen streams where economical.	 Moderate GHG reduction. Leverages concentrated process streams.	 Highly viable where hydrogen concentrated. Minimal incremental cost depending on purity of hydrogen byproduct.	 Very limited opportunity to expand as hydrogen supply is dependent on other industries and finite.	 Fully commercial.	 Direct integration into existing process off-gas capture systems.	 Uses on-site infrastructure.	 Broadly accepted as efficient waste valorization.	 Supported by chlor-alkali and petrochemical industries.	 Cost-effective hydrogen supply. Reduces flaring. Improves overall plant efficiency.

PATHWAY ELEMENTS	ROLE IN NET-ZERO SYSTEM	SIGNAL TO DECISION- MAKERS	ALIGNMENT WITH CARBON NEUTRALITY	Economic		Technical			Social		
				ECONOMIC VIABILITY	ECONOMIC DEVELOPMENT OPPORTUNITY	MATURITY	OPERATIONAL FIT	INFRA- STRUCTURE AND SUPPLY CHAIN SUITABILITY	SOCIAL ACCEPTABILITY	RELEVANCE TO STAKEHOLDERS	RELATED BENEFITS AND COSTS
Natural or Geological Hydrogen	Potential Decarbonization Pathway Potential for large GHG reductions but maturity is currently too low to determine overall role.	Don't Prioritize Track geological exploration results and early research. Commit capital when resource potential and extraction methods are clear.	 Fully decarbonized hydrogen.	 Potential to be very low cost, but still speculative.	 Opportunity to develop hydrogen production in in regions that find geological potential.	 Research phase; no real-world applications.	 Some geological hydrogen production methods fit with existing utility systems; others would require modification.	 Requires build out and supply of new facilities and technologies.	 Similar concerns to other resource extraction operations	 Some research and early geological exploration are occurring in Canada.	 Some concerns with water pollution depending on the method of production.