2021

Alberta Hydrogen Roadmap

Alberta

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Message from the Premier

Alberta's long and proud history of innovation in the energy sector has been one of our province's greatest economic strengths. From the development of the oilsands to the use of carbon capture, utilization and storage technology, Alberta has been a pioneer in responsible and environmentally conscious natural resource production. We have continually taken our experience and knowledge and combined it with our abundant natural resources to benefit Albertans and energy customers around the world.

Hydrogen is the next horizon on which we can set our sights to meet the growing demand for sustainable energy.

With our enormous natural gas reserves, land well-suited to storing carbon emissions, and a rapidly growing renewable energy sector, we have the assets needed to make clean hydrogen at a low cost. With our robust energy infrastructure, early investments and expertise in carbon capture, and decades of experience in natural gas and hydrogen production, we have all the knowledge and tools needed to grow hydrogen development. And with the right set of policies, we can accelerate that growth to solidify Alberta's place as a leader in the emerging clean hydrogen economy.

The Hydrogen Roadmap lays out how we plan to achieve just that. It not only shows how we will build up Alberta's use of hydrogen, but also how we expand our role as a global supplier of responsible energy. With a growing global market – estimated by the Hydrogen Council to be worth $2.5 trillion a year by 2050 – hydrogen has the potential to be the next big chapter in Alberta's energy story.

It's a story that will continue to be written by the dedicated workers and business leaders across Alberta's energy sector. Their knowledge, experience, and entrepreneurial spirit have always propelled the sector forward and have laid the foundation for the future we are looking to build with the Hydrogen Roadmap. The continued commitment of our industry to advance technology and keep Alberta at the forefront of what's possible in hydrogen are absolutely critical to our future success.

As we follow the steps laid out in the Hydrogen Roadmap, we will ensure Alberta remains an essential part of the global energy system and that energy remains a core part of Alberta's economy. We will remain at the forefront of the world's shifting energy landscape, ready to advance in step with global demand and build a brighter future for our province, its people, and our many customers around the world.

Jason Kenney
Premier

Message from the Associate Minister

The Hydrogen Roadmap represents the next step on our path to revitalizing Alberta's natural gas sector – and to integrating clean hydrogen into our existing energy systems. Over the last two years, we have seen the industry go from high to low and back again as it has weathered global competition, infrastructure constraints, and, most recently, the complicated effects of the COVID-19 pandemic. Through it all, Alberta's natural gas companies have worked tirelessly to ensure this crucial part of our energy system remains strong and ready to move into new opportunities. And perhaps no opportunity is greater than that presented by hydrogen.

Our natural gas sector is already a significant part of efforts to reduce emissions and move towards a cleaner energy future. But hydrogen offers an even greater opportunity to advance towards this future. Our natural gas industry will provide the fuel that powers entire generations of low-emission energy for decades to come.

To be clear, it's not just the natural gas sector itself that stands to benefit from hydrogen. Our roadmap sees a future for all types of hydrogen production in addition to Alberta's booming renewable electricity sector. There are many areas that hydrogen can be used across Alberta's economy, stretching from industrial processes on oilsands sites right into the homes of everyday Albertans. Our Hydrogen Roadmap details how Alberta can benefit from hydrogen now and into the future, as well as the steps the Government of Alberta will take to ensure that Alberta families and businesses feel those benefits.

This roadmap follows in the footsteps of the Natural Gas Vision and Strategy, which highlighted hydrogen as one of the key growth areas for Alberta's natural gas sector. Hydrogen as an economic driver gives Alberta's energy industry – and our natural gas sector in particular – a chance to leverage our existing strengths in new and exciting ways. It's also an important element of the Alberta Recovery Plan, with its robust strategy for getting Albertans back to work and building a more diverse economy.

I would like to thank all the industry leaders, academics, Indigenous organizations, environmental groups, and other organizations and individuals who provided their insight and input throughout the Hydrogen Roadmap's development. This document is the result of significant collaboration to ensure Alberta achieves everything it is capable of in the bright hydrogen future.

Dale Nally
Associate Minister of Natural Gas and Electricity

Executive summary

Hydrogen is the most abundant element in the universe. It is a versatile energy carrier that is expected to play an important role in the lower carbon energy future because when combusted, hydrogen produces no greenhouse gas emissions.

The global hydrogen economy is gaining momentum. During the past few years, national hydrogen strategies are emerging and worldwide deployment and investments across the hydrogen value chain are accelerating. Hydrogen supports the global mandate to reduce emissions and accelerate clean energy transitions, and could provide up to 24 per cent of global energy demand by 2050. Countries around the world are taking swift action to deploy hydrogen domestically and secure supply from international markets.

In 2020, Alberta's Recovery Plan and Natural Gas Vision and Strategy articulated an ambition to incorporate hydrogen into Alberta's current portfolio of energy systems. Clean hydrogen, which is hydrogen produced with minimal emissions, is set to become a major part of Alberta's integrated energy system, advancing critical environmental outcomes and unlocking significant economic value.

Alberta's Hydrogen Roadmap is the path forward for Alberta to remain competitive in the global clean energy economy by leveraging our existing strengths and expertise. Alberta is already among the largest global manufacturers of hydrogen, and Canada's largest producer of hydrogen. We have an established oil and gas industry that produces more than half of Canada's natural gas and a fast-growing renewable energy sector. Alberta is home to world-scale carbon capture, utilization, and storage (CCUS) projects, multiple industrial clusters, and is leading Canada's oil refining and petrochemical sectors. These are all the building blocks to build a clean hydrogen economy.

Alberta's hydrogen ambition

Clean hydrogen is integrated at scale into Alberta's domestic energy system for use in transportation, heat, power generation and renewable energy storage as well as industrial use, and Alberta has established itself as the global supplier-of-choice in clean hydrogen exports by 2030.

In creating our provincial Hydrogen Roadmap, the Government of Alberta considered advice provided by industry, academia, municipalities, Indigenous organizations and non-governmental organizations. Stakeholders discussed key requirements needed to enable a hydrogen economy in Alberta, which informed the following seven policy pillars to achieve our ambition and advance core policy actions:

1. **Build new market demand.** Establishing hydrogen demand is required to build out supply and commercialization pathways.
2. **Enable Carbon Capture, Utilization and Storage (CCUS).** For Alberta to deploy clean hydrogen into the economy, CCUS infrastructure must be widely available.
3. **De-risk investment.** Long-term investment certainty and funding are required as hydrogen is an emerging opportunity with challenging economics.
4. **Activate technology and innovation.** Demonstration projects, research, and innovation are needed to prove and scale up emerging clean hydrogen technologies. Training and development with Alberta's world-class universities and technical schools are important to support a labour force capable of working within the hydrogen economy.

5. **Ensure regulatory efficiency, codes, and standards to drive safety.** As the clean hydrogen economy is emerging, a regulatory regime including codes and standards must be inclusive of hydrogen and enshrine a safety-first mindset across the value chain.
6. **Lead the way and build alliances.** Public-private partnerships and government-to-government relationships, including with Indigenous partners, are essential to advance the hydrogen economy, send coordinated signals to investors, and build public education and acceptance.
7. **Pursue hydrogen exports.** The international community is looking to lock in hydrogen supply agreements now. Alberta must move aggressively to establish market access and close intra-Alberta and hydrogen export gaps in supply chain logistics.

The Hydrogen Roadmap identifies four leading domestic markets for clean hydrogen, which include heating (residential and commercial), power generation and storage, transportation and industrial processes. The roadmap also recognizes hydrogen exports as a significant economic opportunity for Alberta beyond its borders.

Action plan

Alberta's Hydrogen Roadmap connects ambition to action to outcome. It is an action plan that integrates hydrogen with the province's existing energy system and propels Alberta into the global hydrogen economy. The emerging clean hydrogen economy requires a concerted effort on behalf of industries, governments, and consumers to grow supply and demand. For Alberta to become a major player in the global hydrogen economy, the province will be required to take bold steps – leverage core strengths, catalyze technology development, and orchestrate the pathway to self-sufficiency and growth for the sector.

As next steps to realize our 2030 ambition, the Government of Alberta will implement the Hydrogen Roadmap using the seven policy pillars and underlying actions using a phased approach. In the first phase, Alberta will establish policy foundations, close technology gaps with research and innovation, reduce the carbon intensity of existing hydrogen production, and deploy clean hydrogen into end-use markets. The second phase marks a shift to a focus on growth and commercialization. These actions will be implemented by working closely with partner agencies, federal, provincial and municipal governments, industry and other key partners and stakeholders.

Once these actions are implemented, the Government of Alberta will closely monitor local and international developments in the hydrogen economy and will adjust the Hydrogen Roadmap as needed. The Hydrogen Roadmap will be revisited in 2025 to switch the focus to actions for the 2030-2050 timeframe and fully realize benefits to Albertans.

1. Introduction

1.1 Background

In 1923, a 130-kilometre natural gas pipeline was built from Viking to Edmonton, Alberta, allowing a switch from coal to natural gas for heating, lighting, and cooking. Nearly 100 years later, Alberta is leading another energy shift with clean hydrogen. We recognize the important role clean hydrogen plays in our integrated energy system, diversifying our energy sector, and decarbonizing provincial and international economies.

Hydrogen is a versatile energy carrier that supports clean energy systems across various end-uses. Alberta has been producing hydrogen for over 50 years, using natural gas as a production feedstock. With established CCUS in place and other innovative hydrogen production technologies emerging, Alberta has the opportunity to build a world-leading hydrogen industry. Alberta's resources enable large-scale production of low-cost and low-carbon intensity hydrogen — also known as clean hydrogen — that is highly competitive in the rapidly growing global hydrogen market.

In 2020, Alberta's Recovery Plan and Natural Gas Vision and Strategy articulated an ambition to incorporate hydrogen into Alberta's current portfolio of energy systems.

Alberta's Hydrogen Roadmap connects ambition to action to outcome. It is an action plan that integrates hydrogen with the province's existing energy system and propels Alberta into the global hydrogen economy. However, to be successful, a number of gaps and challenges must be resolved. The hydrogen economy is nascent and requires a concerted effort on behalf of industries, governments, and consumers. For Alberta to become a major player in the global hydrogen economy, the province will be required to take bold steps — leverage core strengths, catalyze technology development, and orchestrate the pathway to self-sufficiency and growth.

GLOBAL HYDROGEN OPPORTUNITY

Market share of hydrogen to meet global energy demand by 2050 — **24%**

Investment by 2050 to produce, transport, and store hydrogen — **$11 trillion**

$700 billion — Expected annual sales of hydrogen by 2050

200+ — Recently announced hydrogen projects worldwide

1.2 Current state

The concept of integrating clean hydrogen with our energy systems is gaining strong momentum. Since 2019, worldwide deployment and investments across the hydrogen value chain have accelerated rapidly. Countries are taking swift action to deploy hydrogen domestically and secure supply from international markets.

Hydrogen could provide up to 24 per cent of global energy demand by 2050, growing to almost 700 million tonnes per year.[1] This represents an almost eight-fold increase from the current global consumption of over 90 million tonnes in 2020.[2] Meeting this global demand requires more than US$11 trillion of investment in production, storage, and transport infrastructure. The global sale of hydrogen could exceed US$700 billion by 2050, with billions more spent on end-use equipment.[3] The growing global interest in the hydrogen economy is shown with over 200 large-scale hydrogen projects announced worldwide.[4]

Clean hydrogen provides large-scale opportunities to decarbonize Alberta's industries. Hydrogen's value proposition to reduce emissions is strengthened by its near-term ability to decarbonize hard-to-abate sectors of the economy, as part of an integrated energy system.

Alberta's oil and gas, power generation, and other heavy industrial sectors collectively contribute nearly C$100 billion annually to the provincial and Canadian economy and account for approximately 70 per cent of the province's greenhouse gas (GHG) emissions. Reducing emissions in these sectors with a range of solutions, including incorporating clean hydrogen in the production of conventional fuels and creating new energy products such as low-carbon synthetic fuels using hydrogen as a feedstock, can be done with a positive long-term impact on the provincial economy.

The movement toward low-carbon fuel sources in Canada and around the world also offers Alberta the opportunity to diversify its energy portfolio and drive economic development. Alberta is poised to greatly expand its low-cost, low-emissions production of hydrogen in order to serve new domestic and international markets. Alberta's clean hydrogen can be part of the emissions reduction solution across Canada and globally, further strengthening the province's environmental, social and governance (ESG) positioning in capital markets.

As the world transitions to cleaner energy and fuel sources, Alberta's clean hydrogen economy will allow the province to continue growing and diversifying while meeting global market demand for cost competitive, low-emission fuels.

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1 Bloomberg NEF, "Hydrogen Economy Outlook," March 30, 2020. https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf.

2 International Energy Agency, "Global Hydrogen Review 2021," October 2021. https://www.iea.org/reports/global-hydrogen-review-2021

3 Bloomberg NEF, "Hydrogen Economy Outlook," March 30, 2020.

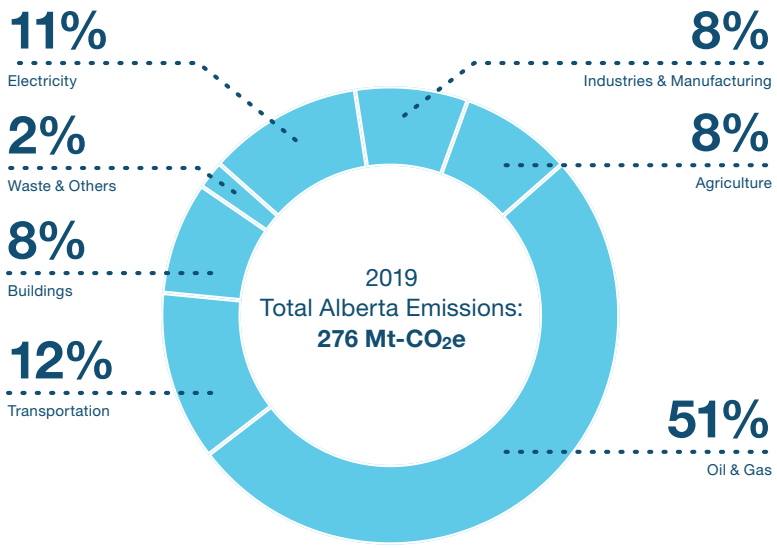
4 Hydrogen Council, "Hydrogen Insights," February 2021. https://hydrogencouncil.com/wp-content/uploads/2021/02/Hydrogen-Insights-2021.pdf.

1.3 Drivers for change

Reduce emissions and decarbonize economies

The transition to low-carbon energy systems is one of the largest drivers in global demand for clean hydrogen. Under the Paris Agreement, 195 countries, including Canada, committed to reducing GHG emissions 30 per cent below 2005 levels by 2030. Many countries have set ambitious climate objectives and lower emission targets, which will rapidly increase hydrogen demand.

In 2019, Alberta's provincial GHG emissions were 275.8 million tonnes (Mt) of carbon dioxide equivalent (CO2e). The largest emitting sectors in Alberta are oil and gas production at 51 per cent of emissions, electricity generation at 11 per cent, and transportation at 12 per cent.[5]



Adoption of clean hydrogen in Alberta has the potential to reduce GHG emissions. Modelling conducted for the Alberta Hydrogen Roadmap shows that under a 2030 transformative scenario,[6] where hydrogen is widely integrated into Alberta's energy systems at a large scale, the province could reduce GHG emissions by 14 Mt per year. This represents a reduction of five per cent of Alberta's 2019 emissions.

The emissions reductions by 2030 represent a solid starting point. Between 2030 and 2050, clean hydrogen could contribute to greater GHG emissions reductions as hydrogen deployment gains momentum across the province.

Energy markets are decarbonizing. In order to preserve market access for Alberta's energy products, Alberta needs to reduce emissions to remain competitive. Alberta's industries are already recognizing and accepting the challenge to address climate change, and are meeting both government and industry-set climate and environmental goals and commitments, such as emissions reduction targets by 2030 and 2050.

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[5] Canada, "Canada's Official Greenhouse Gas Inventory," Environment and Climate Change Canada, February 20, 2019.

[6] Alberta's 2030 Transformative Scenario is described in Section 6.

Increase investment attraction and competitiveness

Global investments in hydrogen are set to continue increasing at a rapid pace. The investment process is likely to consider non-financial performance using ESG factors to assess a company's future market value. Financial institutions and institutional investors increasingly use ESG data in capital allocation strategies and when determining long-term valuations.

Investors often consider ESG leaders to have stronger competitive advantages, healthier balance sheets, and lower volatility compared to companies with low ESG performance. Consequently, ESG factors are considered as an essential predictor of risk and return. This is relevant to Alberta's energy sector and clean hydrogen deployment, as companies with superior ESG performance are expected to perform better in the future and transition to a low carbon economy.

Many companies that operate in Alberta's energy and chemical sectors are vulnerable to environmental risks, particularly ESG considerations such as climate-related financial risks. Climate-related financial risks include physical risk to assets such as operating facilities and equipment that can be affected by climate and weather, and transition risk that results from climate-driven shifts in policy, legal, technology, or markets.

As a result, investors, lenders, and regulators are seeking companies that are prepared and willing to adapt. Many companies in Alberta have already committed to rebuilding their business models to adapt to the changing energy mix, shifting their focus to clean hydrogen, CCUS, and other low-carbon solutions. Market participants will need to choose how they reduce emissions in order to meet consumer demand for low-cost, clean energy solutions and remain competitive.

As ESG requirements continue to gain prominence, retail and institutional investors will increasingly demand low-carbon investment opportunities, and investment firms will develop, structure, and issue new green products. Many of these new investment products will centre on low-carbon segments of the industrial and energy sectors.

While hydrogen cost competitiveness is a key factor for investors, other factors influence investment and purchase decisions. These include expected environmental policy and regulations, government targets, and premiums placed by customers on low-carbon solutions. As hydrogen gains momentum, government policy support will be key in attracting investment.

Leverage existing advantages for transformation

Alberta can take a systems approach and leverage its existing natural resources, infrastructure, human capital, and expertise to drive innovation and growth to transform our energy sector and reach international markets. For example, hydrogen can be integrated into Alberta's existing and extensive natural gas pipeline network, creating instantaneous large-scale market demand to advance the sector.

Hydrogen also provides opportunities for an integrated natural resource system in the province to connect the energy sector with the forestry and agricultural sectors. For example, Alberta already has strong advantages in its forestry and agriculture sectors to provide biomass residues that could supply hydrogen produced from biomass resources. In turn, hydrogen use as a fuel has opportunities to decarbonize the agricultural and forestry sector and its products, providing competitive advantages in global export markets that demand products that produce less GHGs.

1.4 Alberta's competitive and business advantage

Alberta has a distinct competitive advantage in place to lead Canada's clean hydrogen economy and support the global transition to a sustainable energy future. By leveraging Alberta's competitive and business advantages, Alberta has the opportunity to expand into several clean hydrogen value chains and attract investment into Alberta as one of the lowest-cost producers of clean hydrogen in the world.

ALBERTA'S CLEAN HYDROGEN ADVANTAGES

Alberta's competitive advantages

- **Experience and scale:** Alberta is the largest hydrogen producer in Canada today, producing approximately 2.4 million tonnes of hydrogen per year for various industrial applications. Alberta's industries and workforce know how to produce, handle, and use hydrogen safely at the industrial scale. Today, hydrogen is predominantly produced from fossil fuels such as natural gas. Using our natural resources, Alberta has the potential to match large-scale, clean hydrogen production with abundant local baseload demand from the industrial, transportation, heating, and agricultural sectors. Being able to rapidly scale hydrogen production and demand in parallel is a key advantage for Alberta.
- **Energy resources:** Canada is the world's fourth largest producer and sixth largest exporter of natural gas.[7] More than 60 per cent of Canada's natural gas production comes from Alberta, producing an average of 10.2 billion cubic feet per day.[8] Alberta can leverage its existing natural resources such as our world-class natural gas reserves, renewable energy resources, extensive energy infrastructure, and subsurface geologic storage capacity to play a leading role in Canada's hydrogen economy.

[7] Canada, "Natural Gas Facts," Natural Resources Canada, October 2020. https://www.nrcan.gc.ca/science-data/data-analysis/energy-data-analysis/energy-facts/natural-gas-facts/20067.

[8] Canada Energy Regulator, "Marketable Natural Gas Production in Canada," June 2021. https://www.cer-rec.gc.ca/en/data-analysis/energy-commodities/natural-gas/statistics/marketable-natural-gas-production-in-canada.html.

- **CCUS capacity:** Alberta is the first jurisdiction in Canada with an established regulatory and risk management framework in place for large-scale CCUS projects and pore space management. In 2011, the Carbon Sequestration Tenure Regulation was issued and several other acts were amended to clarify pore space ownership and the acceptance of long-term liability to the province, and to establish a post-closure stewardship fund. Alberta has two world-scale commercial CCUS projects to reduce GHG emissions from large industrial emitters. Alberta also has the ideal geology for safe, secure, and permanent storage of carbon dioxide.
- **Leadership innovation:** Alberta is a committed leader in innovation, GHG emissions reduction research, and carbon management. The Alberta Energy Research Institute was established in 2000, focusing on technologies related to energy and GHG emissions reduction research, then growing into what is now Alberta Innovates — Alberta's largest research and innovation agency. In 2007, Alberta became the first jurisdiction in North America to regulate industrial emissions from large facilities and put a price on carbon with the Specified Gas Emitters Regulation. Alberta continues to advance climate actions that protect the environment while supporting new investment and economic growth.
- **Environmental commitment:** Alberta has best-in-class environmental standards and practices in place. As a commitment to lowering GHG emissions, the Government of Alberta enacted the Methane Emission Reduction Regulation, which sets targets to reduce methane emissions 40 to 45 per cent below 2012 levels by 2025 from oil and gas activities, and improving the measurement, monitoring, and reporting of methane emissions. The province is also in the process of developing a forward looking ESG strategy, allowing Alberta to build on its strong ESG record and further push the boundaries as a leader in this space.
- **Partnership with Indigenous communities:** Alberta's Indigenous communities are foundational to developing Alberta's energy resources and Alberta is committed to ensuring Indigenous communities are partners in Alberta's future prosperity and clean hydrogen economy. To support Indigenous communities in participating in resource development projects, the Government of Alberta stood up the Alberta Indigenous Opportunities Corporation (AIOC). The AIOC has the authority to provide up to C$1 billion in loan guarantees to support the ability of Indigenous communities to raise capital and invest in natural resource projects.
- **Educated and inclusive workforce:** Alberta has a highly educated and diverse workforce made of people who pioneered Canada's energy industry, advanced innovation and technologies across the energy sector, and have the expertise and skills to support global demand for the emerging clean hydrogen economy.

Alberta has the key building blocks in place to create a clean hydrogen economy. Large-scale deployment of clean hydrogen presents new opportunities for economic diversification, while supporting global emissions reductions. In addition to the competitive advantages described above, Alberta offers compelling business advantages for project developers by offering established incentive programs and supporting cross-sector hydrogen partnerships. Alberta also has industrial clusters in place that support production and use of clean hydrogen at scale in concentrated regions.

Alberta's business advantages

Competitive business environment

Alberta is committed to ensuring certainty and flexibility for investors by establishing Alberta as the most attractive and welcoming investment destination in North America.

Alberta's investment attraction programs

- As part of Alberta's Recovery Plan, the Government of Alberta accelerated the Job Creation Tax Cut, reducing the general corporate income tax rate to eight per cent on July 1, 2020, a year and a half sooner than originally planned.
- The Alberta Petrochemicals Incentive Program (APIP) provides direct financial incentives to attract investment in hydrogen production facilities using CCUS.
- The Alberta government created the Alberta Indigenous Opportunities Corporation to provide Indigenous communities access to up to C$1 billion in financial support and loan guarantees for participation in the equity ownership of natural resource projects.
- In 2020, Alberta created Invest Alberta, a Crown corporation dedicated to investment attraction with a mandate to engage the world and provide high-end, tailored support to investors and major new investment projects.
- As part of Alberta's Budget 2021, the Government of Alberta has invested up to C$750 million over three years through the Technology Innovation and Emissions Reduction (TIER) fund for innovative projects that reduce emissions and create investment opportunities.

Emerging partnerships

Alberta's industry, local governments, and academia are collaborating to champion a regional approach to clean hydrogen by leveraging existing industrial hubs in order to attract and secure large-scale investment. Recent cross-industry collaborations are emerging to support long-term growth and economic diversification.

Emerging hydrogen partnerships

- In April 2021, Canada's first hydrogen hub was announced in the Edmonton region. The Edmonton Region Hydrogen HUB was launched by the Alberta Industrial Heartland Hydrogen Task Force, a partnership between municipal, provincial, and federal governments; local Indigenous communities; the Transition Accelerator; and industry. The hydrogen hub will accelerate hydrogen deployment in the region, and lay a blueprint for building out a strong regional hydrogen economy.
- In August 2021, the Southeast Alberta Hydrogen Task Force was announced, which aims to create a framework that supports the regional hydrogen economy. The task force is modelled after the Alberta Industrial Heartland Hydrogen Task Force, and is led by Invest Medicine Hat. Other members include the City of Medicine Hat, the City of Brooks, Prairies Economic Development Canada, the Palliser Economic Partnership, CF Industries, Methanex Corporation, APEX Regional Innovation Network, RockPoint Gas Storage, Campus Energy, Envoy Energy and the Transition Accelerator.

Industrial clusters

Alberta has several large-scale industrial clusters located strategically throughout the province, some already with existing hydrogen production or industrial use of hydrogen in place. These industrial clusters are ready to advance clean hydrogen hubs that support industrial processes, while building a stable and cost competitive clean hydrogen supply for other emerging opportunities over time.

Alberta's industrial clusters

Industrial clusters are important to Alberta's regional economies as it provides technology leadership and innovation, and supports development and economic growth. The industrial cluster concept is broadly defined as interrelated industries, specialized suppliers, and associated institutions, which benefit from being in close physical proximity to each other and share common infrastructure. Industrial clusters are competitive but cooperate on mutual outcomes.

Alberta's existing petrochemical and hydrocarbon industrial clusters include:

1. **Alberta's Industrial Heartland, northeast of Edmonton**
   - Includes refining, petrochemicals, and other heavy industries.
   - Rail access to reach export markets.
   - CCUS infrastructure in place.
2. **Central Alberta and Joffre**
   - Established petrochemical industrial cluster with one of the largest ethylene and polyethylene production complexes in the world.
   - Rail access to reach export markets.
3. **Medicine Hat, southeast Alberta**
   - Established petrochemical cluster, including methanol and nitrogen fertilizer production.
   - Rail access to reach export markets.
4. **Grand Prairie, northwest Alberta**
   - Upcoming world-scale clean methanol facility (C$2-billion investment).
   - Energy hub to regional oil and gas activity.
   - Rail access to export markets.
5. **Yellowhead County (Edson, Hinton)**
   - Established energy hub to regional oil and gas activity.
   - Strong forestry sector (potential for bioenergy with CCUS).
   - Rail connection to the Canadian west coast.
6. **Oil sands region (Fort McMurray)**
   - One of the world's largest deposits of heavy crude oil.
   - Established oil sands industry since the late 1960s.

1.5 Alberta's hydrogen ambition

To enable Alberta's hydrogen ambition, Alberta will capitalize on our existing strengths — abundant natural gas feedstock, world-leading engineering expertise, and world-class CCUS infrastructure — to become a Global Centre of Excellence for clean hydrogen production, transportation, and use.

Alberta intends to accelerate the deployment of clean hydrogen into the provincial economy by collaborating with industry, partnering with Canadian governments, and unlocking our research and innovation support to accelerate technology breakthroughs. Alberta will build strong connections and alignment in technology-neutral frameworks to attract investment and diversify our economy.

In creating this roadmap, the Government of Alberta considered advice provided by industry, academia, non-government organizations, Indigenous organizations, municipalities, and third-party research. Stakeholders advised of key requirements needed to enable a hydrogen economy in Alberta. These requirements informed the following seven policy pillars to achieve our ambition:

Ambition for 2030

Clean hydrogen is integrated at scale into Alberta's domestic energy system for use in transportation, heat, power generation, and renewable energy storage, as well as industrial use. Alberta has established itself as the global supplier-of-choice in clean hydrogen exports.

1. **Build new market demand.** Establishing hydrogen demand is needed to build out supply and commercialization pathways.
2. **Enable CCUS.** For Alberta to deploy clean hydrogen into the economy, CCUS infrastructure must be widely available.
3. **De-risk investment.** Long-term investment certainty and funding are required as hydrogen is an emerging opportunity with challenging economics.
4. **Activate technology and innovation.** Demonstration projects, research, and innovation are needed to prove and scale up emerging clean hydrogen technologies. Training and development with Alberta's world-class universities and technical schools are important to support a labour force capable of working within the hydrogen economy.
5. **Ensure regulatory efficiency, codes, and standards to drive safety.** As the clean hydrogen economy is emerging, a regulatory regime including codes and standards must be inclusive of hydrogen and enshrine a safety-first mindset across the value chain.
6. **Lead the way and build alliances.** Public-private partnerships and government-to-government relationships, including with Indigenous governments, are essential to advance the hydrogen economy, send coordinated signals to investors, and build public education and acceptance.
7. **Pursue hydrogen exports.** The international community is looking to lock in hydrogen supply agreements now. Alberta must move aggressively to close intra-Alberta and hydrogen export gaps in the supply chain and logistics.

2. Clean hydrogen in Alberta

2.1 Hydrogen production

Hydrogen is the most abundant element in the universe. However, it is rarely found as a gaseous molecule on earth. Instead, hydrogen is typically bound with other elements in molecular form such as water, hydrocarbons (for example, methane), and biomass. Hydrogen is an energy carrier that can move or store energy and is considered a clean fuel at the point of use. When oxygen is chemically reacted with hydrogen, such as when it is consumed as a fuel in a fuel cell, it produces no emissions other than water and heat.

As a result, there is significant global interest in the role that hydrogen can play in low-carbon energy systems. Hydrogen also has a high gravimetric energy density—or the amount of energy stored per unit of mass—compared to common fuels, making it a promising option for energy storage. There are a number of different processes to produce hydrogen including thermochemical, electrochemical, and biological methods. Emissions released during the production of hydrogen define the carbon intensity of the production pathway, which along with cost and capacity are the most important factors in determining the long-term viability of production pathways in Alberta.

Thermochemical production of hydrogen from natural gas via steam methane reforming is already well-established in Alberta. When combined with carbon abatement through CCUS, this production method can supply low-carbon intensity and low-cost hydrogen. Other low carbon intensity production pathways such as autothermal reforming with CCUS and electrolysis using renewable wind power are also expected to gain traction in Alberta.

Steam Methane Reforming

SMR is a well-developed industrial thermochemical process that converts hydrocarbons and steam into hydrogen and carbon monoxide, resulting in a syngas—a fuel mixture of hydrogen and carbon oxides. A water-gas shift reaction then produces additional hydrogen and carbon dioxide. A final separation process is used to remove the waste gases from the hydrogen, resulting in a stream of high-purity hydrogen.

Conventional hydrogen production technologies

Most of the world's hydrogen is produced from hydrocarbons, such as natural gas and coal. Natural gas-based **steam methane reforming (SMR)** is the most common and cost effective method for hydrogen production, contributing to over half of the world's hydrogen production. In Alberta, SMR is the dominant hydrogen production method for industrial processes, such as chemical production and oil refining and upgrading.

While cost effective, SMR processes are not considered clean hydrogen production methods on their own. An additional process step combines SMR with CCUS technologies (SMR+CCUS) to reduce the carbon intensity of produced hydrogen. SMR+CCUS is considered the most cost effective strategy in the near term to produce clean hydrogen with large-scale deployment in Alberta.[9]

[9] University of Alberta, "Identification and Assessment of Opportunities for Hydrogen in Alberta's Low-Carbon Economy," June 2021. Unpublished report commissioned for Alberta Department of Energy, Natural Resources Canada, and British Consulate-General Calgary.

Clean hydrogen production in Alberta

Clean hydrogen is already produced in Alberta with projects that capture emissions from hydrogen production, such as at the Scotford Complex, Nutrien's Redwater Fertilizer Facility, and the North West Redwater Partnership's Sturgeon Refinery. The Alberta Carbon Trunk Line, the world's largest CCUS system with carbon dioxide gathering and transportation infrastructure, is another example of critical infrastructure in our clean hydrogen economy.

Recently, there have been several proposals to construct new clean hydrogen production facilities in Alberta:

- Air Products announced plans to construct a new clean hydrogen energy complex in Edmonton, which includes the first hydrogen liquefaction facility in Western Canada.
- Suncor and ATCO are collaborating on early stage planning for a clean hydrogen production facility near Fort Saskatchewan.
- Japan's ITOCHU Corporation announced a partnership with a Canadian subsidiary of Petronas to explore and plan for a natural gas-based ammonia facility with CCUS in Alberta to export ammonia as a hydrogen carrier to Asian markets.

Autothermal Reforming (ATR) of natural gas is another established steam-reforming technology used in the large-scale production of syngas or methanol. Hydrogen can then be extracted from these gases. The process has a different reforming process than SMR, using natural gas, steam, and oxygen. ATR produces a high-purity stream of carbon dioxide, which lowers the cost for carbon capture, making it possible to capture over 90 per cent of the carbon. This provides an advantage over SMR to reduce emissions.

There has been increased global interest in ATR coupled with CCUS to reduce emissions from industrial processes. Compared to SMR+CCUS, producing clean hydrogen with ATR+CCUS shows potential for better long-term economics and performance in a future with higher carbon prices.[10] Clean hydrogen production using ATR+CCUS is expected to be widely adopted by the mid-2020s and may be a preferred process for Alberta to produce ultra-low carbon hydrogen.[11]

Both SMR and ATR hydrogen production processes with CCUS are sensitive to the price of natural gas (which is used for heating and as feedstock), carbon price, the length of time the facility is assumed to be operating, and the proximity of the CCUS storage site.

[10] University of Alberta, "Identification and Assessment of Opportunities for Hydrogen in Alberta's Low-Carbon Economy," June 2021.

[11] Equinor, a Norwegian multinational energy company, is currently developing the Hydrogen to Humber Saltend (H2H Saltend) project in the United Kingdom. This is one of the world's first large-scale ATR facilities coupled with CCUS to produce clean hydrogen.

Renewable-based production (electrolysis)

There has been considerable interest in producing hydrogen using renewable and non-carbon emitting power—such as solar, wind, hydroelectric, geothermal, and nuclear energy—to reduce GHG emissions. However, the economic and technical aspects of hydrogen production from renewable resources needs to improve to be cost competitive and operate at a large scale.

Alberta already has significant renewable energy capacity, representing 19 per cent of Alberta's total electricity capacity in 2020.[12] By 2023, projections show that Alberta's renewable capacity will represent around 27 per cent of the total provincial capacity.[13]

Using renewable electricity as an energy source, hydrogen is produced by an electrochemical process called electrolysis. In this process, water molecules are split into hydrogen and oxygen gas, resulting in high-purity and low-carbon intensity hydrogen.

Water electrolysis can be used to balance intermittent renewable energy on the electricity grid by converting excess power into hydrogen for long-term storage. When the resultant hydrogen is injected into the natural gas pipeline network, this process is known as "power-to-gas" and can provide opportunities for sector coupling between the electric and natural gas grids. With this integrated energy system, surplus renewable power is converted into hydrogen gas, which can then be blended into natural gas grids or stored for later use. This integrated energy concept can improve both resiliency and economics of the energy system.

Although technically viable, electrolysis production facilities are typically much smaller scale than SMR and ATR plants, and as a result are more suited to distributed production near sources of demand. Further research is needed to improve efficiency for electrolysis technologies to make them cost competitive with other hydrogen production methods.

In Alberta, wind-powered hydrogen production via electrolysis presents significant opportunities to produce clean hydrogen with the lowest lifecycle GHG emissions footprint in the medium to long term (approximately 10 years or more) compared to other methods.

[12] Alberta Utilities Commission, "Alberta Electric Energy Net Installed Capacity by Resource," https://www.auc.ab.ca/Shared Documents/InstalledCapacity.pdf.

[13] Alberta Electric System Operator, "2021 Long-Term Outlook," https://public.tableau.com/app/profile/market.analytics/viz/LTO_Annual_Chart/Introduction.

Emerging technologies for hydrogen production

There are several other emerging technologies that could be viable in Alberta for large-scale clean hydrogen production in the medium to long term.[14] These emerging technologies vary by technology readiness level, capacity potential, scale, and GHG emissions footprint, which impact their long-term viability in Alberta. These emerging technologies include:

- **Natural Gas Decomposition (NGD) –** The NGD process involves the thermal decomposition of methane (also called pyrolysis or cracking) into hydrogen gas and solid carbon (also known as carbon black). The NGD process is unique since the by-product carbon does not need to be sequestered, rather it can be sold for other industrial processes, such as rubber manufacturing, graphite for batteries, or as a substitute for metallurgical coke. NGD is an emerging process that is not yet fully developed.
- **Biomass-derived hydrogen –** Biomass, such as municipal waste or agriculture and forest residues, can be used as a feedstock for hydrogen production. Biomass-derived hydrogen production using thermochemical processes, such as gasification and pyrolysis, are in the exploratory phase, but show promise to produce hydrogen with reduced environmental impact. There is an opportunity for Alberta resources in the agriculture and forest sectors to be integrated with biomass-based hydrogen production.
- **Chemical Looping and Partial Oxidation of Methane (CL-POM) –** Chemical looping is an innovative technology at the pilot and demonstration stage that converts natural gas (methane) to synthetic gas, using electricity as the energy source rather than natural gas combustion. As a result, chemical looping is considered a clean combustion technology. The GHG emissions footprint depends on the emissions factor of the electricity source. Chemical looping technologies produce an almost pure stream of carbon dioxide, which is ideal for carbon capture.
- **Underground Gasification (UG) –** Underground gasification of crude oil, bitumen, or coal is considered a clean, fossil fuel-based hydrogen production method when integrated with CCUS. Underground gasification has the potential to emerge as a viable clean hydrogen production method in Alberta.

Underground gasification and membrane separation

In-situ gasification is an emerging technology currently being developed in Alberta and Saskatchewan for crude oil and bitumen feedstock. In this process, gasification takes place deep underground, such as in existing oil fields, and the hydrogen is filtered using a selective membrane. This has the advantage of leaving the carbon underground and sequestered, reducing both costs and emissions. The selection of reservoirs with appropriate geological properties to hold carbon emissions underground in a stable state is an important consideration for this technology.

In 2016, Calgary-based Proton Technologies developed a technology to generate and extract hydrogen from depleted geologic reservoirs where hydrocarbons have already been recovered, leaving hydrocarbons in the ground. The process is based on technology developed as part of the Alberta oil sands Marguerite Lake pilot project, conducted by BP Canada in the 1980s. Proton Technologies is currently demonstrating its technology at commercial scale in Northern Saskatchewan. The extracted hydrogen is currently transported by truck, with plans to blend hydrogen in natural gas pipelines for transport.

[14] University of Alberta, "Identification and Assessment of Opportunities for Hydrogen in Alberta's Low-Carbon Economy," June 2021.

2.2 Safe storage, transmission, and distribution of hydrogen

Hydrogen is an energy carrier with great potential to store and distribute large amounts of energy. The hydrogen supply chain, both in Alberta and globally, is immature and requires investment to close knowledge gaps and build out critical infrastructure, including distribution systems.

Alberta can realize large-scale energy storage in the form of hydrogen by leveraging its existing pipeline network and rail infrastructure. However, a barrier to hydrogen storage and distribution is its low volumetric energy density, meaning that hydrogen needs to be compressed or stored in liquid form, which results in increased costs. In preparing for a hydrogen economy, additional research with partners is needed to evaluate and develop Alberta's potential for hydrogen safety, storage, and distribution.

Hydrogen storage

Hydrogen production facilities typically have short-term hydrogen storage on site, where hydrogen is safely stored as a compressed gas or cryogenic liquid in tanks. Large volumes of hydrogen can also be compressed and stored in underground salt caverns or depleted hydrocarbon reservoirs. This provides an opportunity to store surplus energy from renewable power generation and accommodate shortages from plant outages and seasonal variations in energy demand. Alberta has used salt caverns since the 1940s to store natural gas liquids and crude oil and has also stored natural gas in depleted hydrocarbon reservoirs.

Alberta's underground salt caverns

Alberta has the largest capacity available in Canada to store hydrocarbons in underground storage, which includes both depleted hydrocarbon reserves and underground salt caverns. Research has indicated that salt caverns are a technically feasible solution for hydrogen storage as well.

Alberta is part of the Western Canadian Sedimentary Basin, which has large geologic salt formations located throughout. Alberta already hosts several large-scale salt cavern storage projects.

ATCO Energy Solution's salt cavern storage facility in Alberta's Industrial Heartland has the potential to develop up to 40 caverns for storing hydrocarbon products. The Strathcona Salt Cavern Storage Project includes four storage caverns that have the potential to hold up to 400,000 cubic metres of hydrocarbons.

Keyera operates several underground salt cavern storage facilities in Alberta's Industrial Heartland with storage capacity of approximately 12 million barrels for natural gas liquids (such as propane, butane, and condensate). Keyera also holds salt rights on undeveloped land in the region.

Hydrogen distribution and transport

Hydrogen is typically transported as a compressed gas or cryogenic liquid by truck or rail, or transmitted by pipeline. Low volumes of hydrogen can be safely blended with natural gas in existing pipeline infrastructure at volumetric concentrations of up to 15 per cent.[15] Blending hydrogen into Alberta's existing natural gas system can be safely implemented in the near term, providing opportunities to integrate hydrogen into the intra-provincial transmission and distribution systems.

Hydrogen distributed by pipeline offers the most economic means for large-scale and long-distance hydrogen distribution and export. Alberta currently has over 100 kilometres of pipelines in the province that can transport pure hydrogen to industrial users, where hydrogen is produced as a byproduct from industrial processes, or by independent producers. However, there currently are no large high-pressure pipelines in Canada that deliver pure hydrogen to demand markets.

Research today is focusing on resilient pipeline materials, hydrogen compression technology, controls for potential leaks and inspections, maintenance, risk management, and the conversion of legacy natural gas pipelines to pure hydrogen. Canadian pipeline standards may need to be revised to address requirements for hydrogen in transmission and distribution networks.

Alternative hydrogen carriers

Ammonia and methanol are hydrogen carriers that are major contributors to Alberta's hydrogen economy today. Ammonia and methanol can safely and efficiently transport hydrogen in a liquid state over long distances by pipeline and rail, and be converted back into hydrogen at their destination. Other hydrogen carriers, such as liquid organic hydrogen carriers, which can store hydrogen by reversible chemical reactions, are also promising opportunities for Alberta to transport hydrogen to international markets. Current research is focusing on extracting hydrogen from energy carriers in an efficient and economic manner.

Ammonia is typically transported by rail. However, ammonia pipelines can carry approximately twice as much energy as hydrogen pipelines, and less energy is required to compress liquid ammonia when compared to gaseous hydrogen. More energy is required by end users to reform the ammonia into hydrogen. In-depth risk assessments for ammonia pipelines in Canada are needed for the long-distance transport of ammonia, including through non-industrial areas.

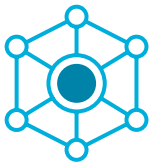
Methanol is a hydrogen carrier that is manufactured from natural gas, coal, or biomass. Methanol has many uses in the petrochemical industry. It is blended with gasoline to reduce the carbon intensity of burning fuel in vehicle internal combustion engines, and it expands gasoline production for refiners. Methanol can be stored and transported at ambient temperatures and pressures for easier handling. However, the conversion process into hydrogen is considered energy intensive and efficiencies will need to be improved.

Liquid organic hydrogen carriers can be transported in liquid systems such as pipelines and ships. These carriers are being piloted with some adoption occurring. However, further advancement is required for liquid organic hydrogen carriers to play a major role in moving large volumes of hydrogen to international markets.

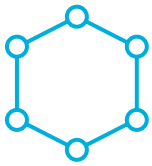
[15] University of Alberta, "Identification and Assessment of Opportunities for Hydrogen in Alberta's Low-Carbon Economy," June 2021.

Hydrogen production and distribution models

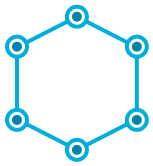
Integrating clean hydrogen into Alberta's existing infrastructure can be managed by either a centralized, decentralized, or semi-centralized approach to delivering hydrogen.



The **centralized** energy management approach takes clean hydrogen produced from large-scale facilities and stores it in a central location to mitigate supply disruptions. Pure hydrogen is then delivered to major end-use sectors in new infrastructure or blended with natural gas in existing infrastructure. Hydrogen transport is often long-range to meet end-use demand, increasing required capital investment. The centralized approach could be preferred by large hydrogen producers that export their product to domestic and international markets, or industrial facilities that require large volumes of hydrogen for their industrial processes.



In the **decentralized** energy management approach, smaller scale hydrogen facilities produce hydrogen close to demand locations. Hydrogen transport for end-use demand is significantly minimized or even eliminated, saving cost on transportation infrastructure and storage. The decentralized delivery approach is considered flexible for near-term hydrogen production and distribution, and may be considered by the transportation and industrial processes sectors.

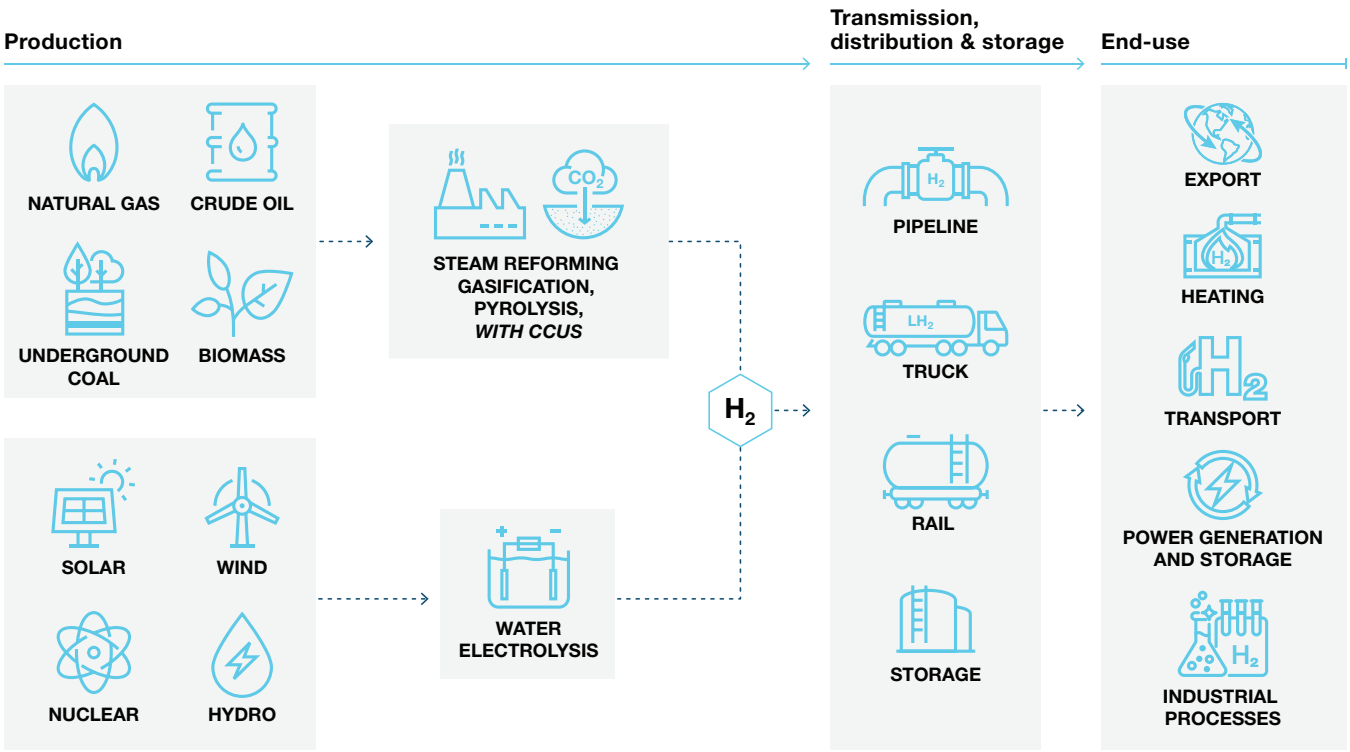


A **semi-central** energy management approach combines both, where intermediate-sized hydrogen production facilities are located relatively close to end-use delivery. This approach could be considered in industrial clusters, to allow for economies of scale and shared infrastructure.

2.3 Alberta leading the way in clean hydrogen

Alberta, as a world leader in hydrogen production and CCUS technology, is in a position to rapidly advance a clean hydrogen economy. Natural gas-based hydrogen production processes are mature and currently in place throughout the province. Clean hydrogen can be realized in the near term by retrofitting existing SMR infrastructure with CCUS and building new ATR facilities with CCUS. Over time, further emissions reductions can be realized with technologies such as renewable energy-based hydrogen production or emerging natural gas decomposition, once they are cost effective and competitive.

THE POTENTIAL HYDROGEN SUPPLY CHAIN IN ALBERTA



Alberta's hydrogen cost advantage

Alberta can be one of the world's lowest cost producers of clean hydrogen, particularly when hydrogen is sourced from natural gas. Alberta's Hydrogen Roadmap was informed by a cost analysis across various hydrogen production methods in the province.[16] Figure 1 below shows that hydrogen production costs in Alberta are competitive compared to other global jurisdictions such as the United States and Europe, when hydrogen is derived from natural gas coupled with CCUS. Alberta offers one of the cleanest, safest, and most cost competitive supplies of natural gas in the world, which is available as a feedstock for clean hydrogen production at an industrial scale. While higher cost today, hydrogen produced via electrolysis from Alberta's wind resources also has the potential to be cost competitive in the medium to long term.

FIG. 1: 2020 GLOBAL HYDROGEN PRODUCTION COSTS

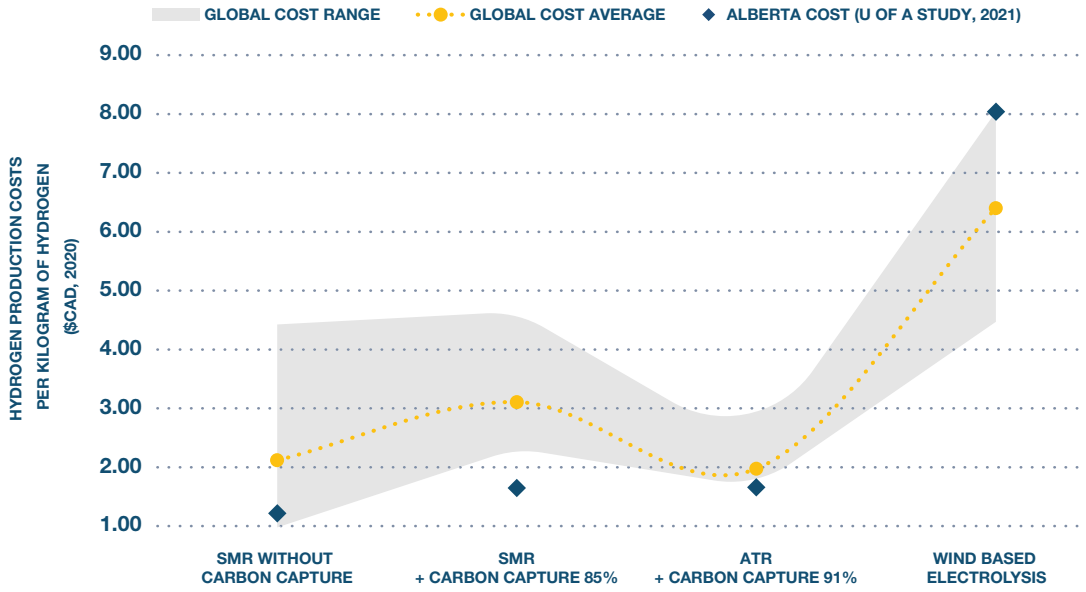


Figure 1. Alberta's hydrogen production costs against global averages. Hydrogen production costs vary depending on facility size, type, feedstock, and energy use.[17]

[16] University of Alberta, "Identification and Assessment of Opportunities for Hydrogen in Alberta's Low-Carbon Economy," June 2021.

[17] Alberta hydrogen production costs are sourced from the University of Alberta Report (2021). Global hydrogen production cost ranges are sourced from IHS United States, US Department of Energy, International Agency Europe, and the Transition Accelerator.

FIG. 2 CARBON INTENSITY OF HYDROGEN PRODUCTION IN ALBERTA

As set by CertifHy, a European based guarantee of origin program for clean hydrogen. This threshold is also recommended by Canada.

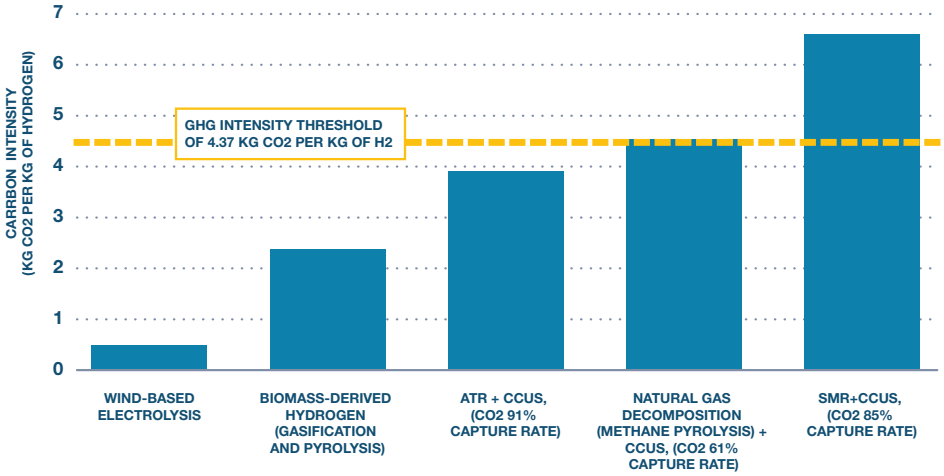


Figure 2. Comparison of carbon intensity by production technology in Alberta (2020). The carbon intensity data is sourced from the University of Alberta Report (2021) and includes upstream and hydrogen production emissions.

Alberta's low-carbon hydrogen advantage

To integrate clean hydrogen in the provincial economy, Alberta will focus on low-carbon intensity production pathways that are cost effective and capable of large-scale production volumes. Alberta's Hydrogen Roadmap is inclusive of all current and emerging clean hydrogen production methods best suited to the province's different geographic regions and distinct industrial demand centres.

Today, global jurisdictions are establishing carbon intensity thresholds to define clean hydrogen. The CertifHy project, which is Europe's first Guarantee of Origin for low-carbon hydrogen, identifies a carbon intensity threshold of approximately 4.37 kg CO2 per kg of hydrogen, including upstream emissions.[18]

Analysis done for the Hydrogen Roadmap highlights how different hydrogen production methods in the province compare against this carbon intensity threshold, as shown in Figure 2. As Canadian and other global low-carbon hydrogen thresholds are established, Alberta will collaborate with other governments and international partners to support the development of science-based carbon intensity thresholds for hydrogen production. This collaboration will be important to establish carbon intensity threshold targets, definitions, and measurement and reporting standards.

For electrolytic hydrogen production in Alberta, the source of grid power is important when assessing lifecycle emissions of different production pathways. Canada's Hydrogen Strategy indicates that lifecycle emissions of electrolytic hydrogen production based on Alberta's grid will be larger than lifecycle emissions from natural gas-based production pathways coupled with CCUS.

The carbon intensity of GHG emissions from hydrogen production is only one consideration when assessing the environmental benefits of energy systems. Other considerations include environmental impacts from land use changes, energy storage, water availability, biodiversity impacts, and public concerns. These additional social and environmental impacts should be assessed when deciding on hydrogen production pathways according to regional circumstances.

[18] Canada is considering a carbon intensity threshold for clean hydrogen, which is aligned with the carbon intensity threshold set by "CertifHy," a European-based Guarantee of Origin program for clean hydrogen.

3. CCUS

3.1 Current state

CCUS represents a suite of technologies. In the first step, carbon dioxide emissions are captured from industrial processes, such as SMR. These emissions are then transported by pipeline to a utilization or storage site. At storage sites, the emissions are injected and stored deep underground in dedicated geologic formations. Captured carbon dioxide can also be utilized for other processes, such as enhanced oil recovery (EOR) or converted into various products rather than be injected underground. There are several different types of technologies that capture carbon dioxide from other gases, depending on the industrial process and the technology available.

CCUS is internationally recognized as a necessary pathway to reduce emissions from existing energy systems, large industrial sectors with hard-to-abate emissions, and fossil fuel-based hydrogen production.[19] Large, stationary industrial processes that generate a concentrated carbon dioxide stream are ideal for CCUS, such as natural gas processing and hydrogen production from natural gas.

Alberta is among the leaders in CCUS, first as a pioneer injecting solvents into subsurface reservoirs for enhanced oil recovery in the late 1950s, then later conducting subsurface disposal of acid gases (including carbon dioxide) associated with natural gas processing. In 2010, Alberta developed Canada's first comprehensive carbon sequestration legislation.

Alberta currently hosts two large-scale CCUS projects that reduce industrial emissions. Alberta is also recognized as having excellent and vast potential for safe and reliable geological sequestration of carbon dioxide in the Western Canadian Sedimentary Basin. With initial CCUS infrastructure in place, Alberta is in a good position to support the scale-up of a clean hydrogen economy as part of our integrated energy system.

Alberta's CCUS infrastructure

In 2015, the Quest project began operations to the northwest of Edmonton, capturing over five Mt of carbon dioxide by the end of 2020. The carbon dioxide emissions are captured from hydrogen production at three SMR units at the Scotford Upgrader complex, which is owned by the Athabasca Oil Sands Project consortium and is operated by Shell Canada. Hydrogen is required to upgrade oil sands and heavy oil into synthetic crude oil, increasing its overall quality and efficiency to transport by pipeline. The captured carbon dioxide is transported 65 kilometres to the north by pipeline and injected by three wells into a two kilometre deep underground geologic reservoir for permanent storage.

In 2020, the Alberta Carbon Trunk Line (ACTL) commenced operations as one of the world's largest CCUS systems with carbon dioxide gathering and transportation infrastructure, and the capacity to transport up to 14.6 Mt of carbon dioxide per year. The ACTL currently transports approximately 1.6 Mt of captured carbon dioxide per year by a 240-kilometre pipeline from the North West Redwater Partnership Sturgeon Refinery and the Nutrien Redwater Fertilizer Facility to mature oilfields in Central Alberta for EOR and permanent storage. Multiple partners are involved with the ACTL, including Wolf Midstream which owns and operates the pipeline and Enhance Energy, which owns and operates the geologic storage reservoir. Based on its current capacity, the ACTL could support an additional 12 Mt of carbon dioxide per year.

In 2021, Pembina and TC Energy announced a partnership to jointly plan a world-scale carbon transportation and sequestration system, called the Alberta Carbon Grid. If advanced, the project would create a CO2 infrastructure backbone that connects the Fort McMurray region to central Alberta.

[19] International Energy Agency, "Special Report on Carbon Capture Utilisation and Storage: CCUS in Clean Energy Transitions," September 2020. https://www.iea.org/reports/ccus-in-clean-energy-transitions.

3.2 Opportunities for clean hydrogen and CCUS

CCUS is considered a key enabler for clean hydrogen production, providing Alberta a near-term opportunity to competitively produce clean hydrogen and reduce emissions from existing industrial hubs and facilities that already use or produce hydrogen from fossil fuels. Developing additional world-class CCUS infrastructure will create an important competitive advantage for Alberta's industries relative to competing jurisdictions and help meet global demand for low-carbon commodities.

The Alberta Industrial Heartland region is an industrial cluster that presents an opportunity to accelerate clean hydrogen production while leveraging existing carbon dioxide infrastructure, reducing emissions, and attracting investment. The industrial cluster approach can be replicated in other regions of the province, developing hydrogen hubs that scale up clean hydrogen production and demand around existing infrastructure. The benefit of hydrogen hubs also includes improved economies of scale, reduced risk to industrial stakeholders, and connecting cost competitive hydrogen supply with demand markets that leverage shared infrastructure.

3.3 Integrating CCUS with Alberta's clean hydrogen economy

CCUS systems are proven and can be used in Alberta today to reduce emissions from hard-to-abate sectors at an industrial scale while supporting an emerging clean hydrogen economy.

By 2030, CCUS could play a crucial role in Alberta's natural gas value chain by either retrofitting existing facilities with carbon capture and transport infrastructure or building new hydrogen projects with CCUS. Alberta recognizes that over time, clean hydrogen may also be produced competitively from renewable energy and electrolysis, biomass gasification, and natural gas decomposition with and without CCUS.

Alberta has critical research and innovation capabilities in place to quickly advance and contribute to the clean hydrogen economy. There is significant investment in research and innovation at both the private and public level with world-class research universities and lab facilities.

4. Technology and innovation

Alberta Emissions Reduction Alberta (ERA) projects

Alberta is already leading in technology innovation for clean hydrogen. ERA is funding pilot and early demonstration projects to explore new deployment applications and emerging methods of clean hydrogen production:

- Canadian Utilities, a subsidiary of ATCO, is commencing a pilot project in late 2021 to test hydrogen blending of five per cent by volume into a portion of the residential natural gas distribution system in Fort Saskatchewan.
- The Alberta Zero Emissions Truck Electrification Collaboration (AZETEC) is a prototype project to test the ability of hydrogen to fuel the province's heavy freight transportation sector. The project, led by the Alberta Motor Transport Association, features the development of two long-range fuel cell trucks for operation between Edmonton and Calgary. The project intends to test and demonstrate a 700-kilometre plus range fuel cell truck performance in Alberta conditions.
- Ekona Power is developing and demonstrating a novel system for low-cost, clean hydrogen production for industrial processes. The project will demonstrate a direct carbon fuel cell, which converts solid carbon by-product from the hydrogen production process to electrical power, thereby enhancing the economics of hydrogen production.
- Standing Wave Reformers is testing a new innovative process of clean hydrogen production that uses no water and produces no carbon dioxide. This technology could be cost effective and suitable for distributed production close to demand.

Closing technological gaps and reaching higher technology readiness levels for some production and deployment applications will allow for a smoother transition to a future where clean hydrogen becomes widespread and integrated as both an energy carrier and commodity. Areas for additional research and accompanying technology, innovation, and demonstration support may include:

- Methane-based technologies such as methane pyrolysis and chemical looping which show significant promise but are not yet at a high technology-readiness level.
- Underground coal gasification with CCUS and biomass conversion, which both show promise as clean hydrogen production methods for Alberta.
- Research and analysis to better understand hydrogen impacts on high-pressure steel pipes as well as other system-wide impacts (for example, compression requirements, welding, and maintenance) to ensure operational safety as hydrogen is transported across the province to an expanding base of end users.
- Research to determine ideal carbon sequestration locations and available pore space for permanent carbon dioxide storage in the province. Clean hydrogen production will require accompanying incremental carbon sequestration.
- Research for hydrogen storage options with natural gas, including salt caverns. Given its small molecular size, hydrogen may be prone to migration from storage compared to natural gas. As such, it will be critical to better understand the ability of salt cavern storage to contain hydrogen.

As the provincial hydrogen economy progresses, technology and innovation will continue to expand clean hydrogen opportunities that can be successfully and safely integrated into provincial energy systems.

Government research and innovation agencies, such as Alberta Innovates and ERA, are important to close technology gaps, and action required research and innovation supports to accelerate technology commercialization. Dedicated innovation support focused on key hydrogen technology gaps will position Alberta to be a global leader in the development of technology and innovation solutions for a clean hydrogen economy.

With public and private support and dedicated innovation funding, existing technology barriers to low-cost, clean hydrogen market deployment can be removed through new technology implementation at scale. This will in turn ensure cost-effective hydrogen value chain development.

The leadership of the Government of Alberta and its agencies, such as Alberta Innovates and ERA, on the clean hydrogen innovation file will be important to develop the next generation of clean hydrogen technologies. These have the potential to disrupt the existing market status quo, in addition to innovating and improving efficiency in existing technologies.

Partnership with industry associations (such as the Canadian Oil Sands Innovation Alliance, Petroleum Technology Alliance Canada, and Clean Resource Innovation Network), non-government organizations (such as the Transition Accelerator), academia, and other provincial and federal government departments and agencies (such as Innovation, Science and Economic Development Canada, and Natural Resources Canada's CanmetENERGY), will drive a coordinated innovation ecosystem that can foster technology advancements in key research areas to maximize the potential for hydrogen deployment locally, nationally, and internationally.

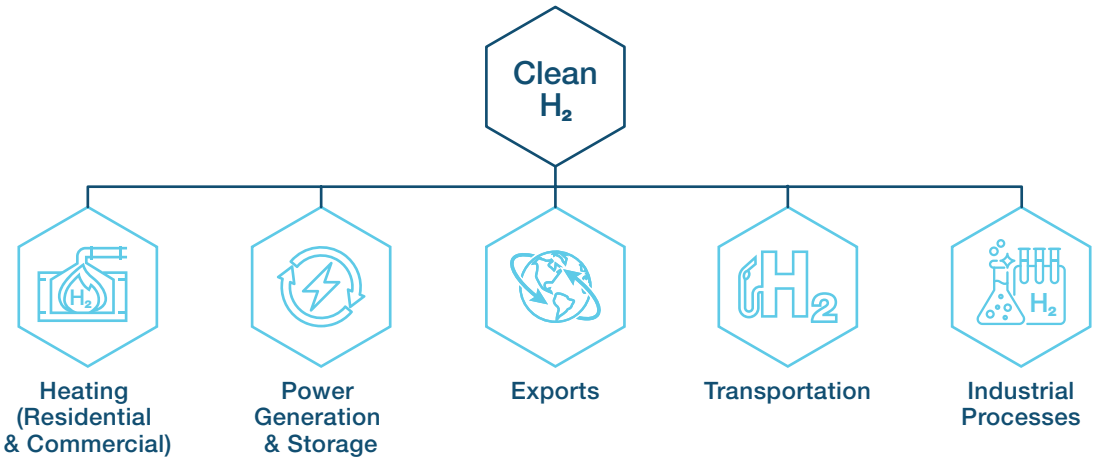
Innovation and partnerships

Partnerships can work together to leverage existing resources. For example, the University of Calgary and Innovate Calgary are developing a hydrogen test centre at the University of Calgary research park. C-FER, a subsidiary of Alberta Innovates, is developing a large-scale hydrogen test centre at its facilities. These developments provide natural synergies to build partnerships and coalitions focused on de-risking and advancing hydrogen technologies.

5. Alberta's hydrogen markets

Alberta has identified five leading markets for clean hydrogen end-use opportunities. The markets include the following sectors:

- **Heating –** where hydrogen is blended with natural gas or burned directly and is used for residential and commercial heating.
- **Power generation and storage –** includes generating electricity using hydrogen turbines and fuel cell generators, and producing hydrogen via electrolysis from intermittent renewables as an energy storage medium.
- **Export market –** considers Alberta's future energy competitiveness while meeting growing international demand for clean hydrogen in key North American, Asia Pacific, and European markets.
- **Transportation –** includes hydrogen fuel cell cars, buses, trucks, trains and aviation equipment, and hydrogen co-combustion engines primarily for heavy-duty applications.
- **Industrial processes –** includes fossil fuel refining and bitumen upgrading, ammonia and fertilizers, chemicals, and liquid synthetic fuels.



5.1 Industrial processes

Current state

Alberta is the largest hydrogen producer in Canada, producing approximately 2.4 million tonnes of hydrogen per year for various industrial applications, including chemical production and oil refining and upgrading. Alberta also has one of Canada's largest concentrations of nitrogen-based fertilizer producing facilities that produce ammonia, urea, and other nitrogen products.

There are several industrial gas producers in Alberta, including Air Products, Air Liquide, and Linde Gas Canada, which manufacture industrial gases for use in energy, transportation, and industrial applications and have an interest in hydrogen production. Currently, Air Products is the most significant merchant supplier of hydrogen in the province. Today, most hydrogen used in industrial processes is produced by SMR technology.

Hydrogen is produced and used as a feedstock for many industrial processes, including ammonia production, methanol production, heavy oil refining, and bitumen upgrading. Approximately 55 per cent of Alberta's hydrogen production is used for heavy oil upgrading, 38 per cent is used for the chemical sector and for chemical industry by-products, and seven per cent is used for oil refining.

Alberta accounts for nearly 30 per cent of Canada's oil refining with a capacity of 560,000 barrels per day.[20] The majority of bitumen oil is upgraded in Alberta, with a capacity of approximately 1.3 million barrels per day. The upgraders add hydrogen to improve the viscosity of crude oil products for easier pipeline transport.

Industrial processes that produce and use hydrogen are considered energy intensive and trade exposed (EITE) industries. These industries, including chemical manufacturing and bitumen extraction, are highly competitive with the global market, and risk investment and carbon leakage to other jurisdictions if there are changes to their energy use and production costs.[21]

Ammonia

Approximately 80 per cent of global ammonia production is used in agriculture as fertilizer. Hydrogen gas is needed to create ammonia. Ammonia is a chemical compound of one nitrogen atom and three hydrogen atoms, used mainly in agriculture for nitrogen fertilizer, which is essential for global food production.

Ammonia is also a starting material for many commercial and industrial applications, including the textile industry to manufacture synthetic fibres, the mining and metallurgic sectors, industrial refrigeration, and the manufacturing of pharmaceuticals.

Ammonia is a hydrogen carrier that can be transported by existing infrastrucutre and has a high capacity for hydrogen storage. Liquid ammonia has a higher energy density compared to liquid hydrogen.

Methanol

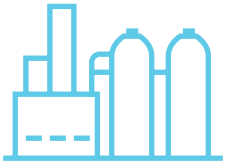
Hydrogen gas is needed to create methanol. Methanol is a simple alcohol, composed of four hydrogen atoms, one carbon atom, and one oxygen atom.

Methanol can be produced using natural gas as a feedstock or through renewable or alternative sources.

Methanol is commonly used in many commercial and industrial chemical applications, such as producing foams, resins, plastics, paints, cleaning products, formaldehyde, and pharmaceutical products.

Methanol is also used as a clean-burning fuel with turbines and internal combustion engines.

Methanol is a hydrogen carrier — it can produce and store hydrogen and is considered easy to transport.



Bitumen upgrading and oil refining

Hydrogen is used as part of the oil refining process to lower the sulfur content of fuels and upgrade heavy crude to more viscous synthetic crude oil.

Hydrogen can be produced on-site using SMR processes or purchased as by-product from suppliers.

Alberta has five existing refineries with a total capacity of 560,000 barrels per day. The refineries convert crude oil to higher value petroleum products, such as gasoline, diesel, and aviation fuel.

Alberta has four existing upgraders with a total capacity of over 1.4 million barrels of oil per day.

[20] Oil Sands Magazine, "Canadian Refineries," accessed September 21, 2021. https://www.oilsandsmagazine.com/projects/canadian-refineries.

[21] Canadian Energy Research Institute, "Industrial Competitiveness and Energy Efficiency," March 2020. https://ceri.ca/assets/files/Study%20184%20Full%20Report%20FINAL.pdf.

Opportunity for industrial processes

The greatest opportunity for clean hydrogen in the industrial sector is converting existing high carbon intensity sources of hydrogen to clean hydrogen sources. Current global demand for hydrogen is over 90 million tonnes per year. However this is projected to increase with demand for low carbon hydrogen for clean energy transitions.

Global ammonia consumption is forecast to grow, with projected increases of nearly 13 per cent by 2025.[22] Alberta has the existing ammonia supply chain with manufacturing, infrastructure, workforce expertise, and transportation networks in place that can help meet global market demand for clean hydrogen and ammonia. Other opportunities include identifying new end uses for low carbon ammonia as a fuel within Alberta and emerging markets. Alberta has demonstrated clean ammonia production at the Nutrien Redwater facility, capturing carbon dioxide during ammonia manufacturing and injecting it into the Alberta Carbon Trunk Line.

Methanol also presents a readily available opportunity as a liquid hydrogen carrier at atmospheric temperature and pressure, and high energy density. Clean methanol can be exported from Alberta to demand markets, where clean methanol can be reformed back to hydrogen. Methanol fuel cells may also produce electrical energy from chemical energy, but this process requires incentives and demonstration. Methanex Corporation is the world's largest methanol producer and is headquartered in Canada with operations in Medicine Hat.

Regional industrial hubs present an opportunity to establish a clean hydrogen economy in Alberta in particular near refineries and upgraders where there is initial carbon dioxide infrastructure in place and existing hydrogen and natural gas pipeline infrastructure. Ammonia and other chemical-producing facilities should be considered in the regional hub approach, as these facilities generate a pure stream of carbon dioxide, which is ideal for carbon capture.

5.2 Residential and commercial heating

Current state

Hydrogen has received significant global interest as a compelling option to decarbonize commercial and residential heating systems. Hydrogen use in heating applications includes appliances such as furnaces, boilers, water heaters, gas fireplaces, stoves, and laundry dryers. Hydrogen blending in low volumes with natural gas, eventually transitioning to pure hydrogen networks, is being considered by builders and utilities as they examine options to decarbonize their residential and commercial networks.

[22] IHS Markit, "Chemical Economics Handbook: Ammonia," July 2020. https://ihsmarkit.com/products/ammonia-chemical-economics-handbook.html.

Hydrogen blending in natural gas networks

Hydrogen blending into natural gas represents a demand market that can act as a springboard to introduce hydrogen into a wider provincial energy system outside of its traditional industrial use. In 2019, there were 37 global demonstration projects examining hydrogen blending into natural gas distribution systems. Most of these projects propose to blend hydrogen to isolated sections of gas distribution networks or are confined to off-grid lab projects.

Natural gas utilities in Canada are interested in hydrogen for its potential to decarbonize heat. Hydrogen blending with natural gas provides an opportunity to decarbonize residential and commercial heating in the near term, as introducing it at blend volumes of up to 15 to 20 per cent generally does not require device retrofits from the end customer, while also leveraging existing gas distribution networks with minimum physical changes required.

ATCO is actively exploring hydrogen use in Alberta, launching the Fort Saskatchewan Blending Project. The demonstration project will blend five per cent hydrogen by volume into the natural gas distribution system for home heating. The project is a first-of-its-kind for Alberta, but is demonstrated in other countries.

Opportunity for heating markets

Hydrogen blending represents an opportunity to decarbonize the natural gas distribution grid while slowly transitioning to higher blends of hydrogen. This provides a new demand market for hydrogen, making a strong investment case for hydrogen suppliers. Hydrogen blending also provides learning opportunities for the natural gas distribution system to transition towards 100 per cent pure hydrogen networks.

Significant GHG reduction benefits will largely start to occur at higher-blend volumes given the low volumetric energy density of hydrogen, which is at about one-third of natural gas. However, transitioning with low-blend levels needs to occur now in order to build the necessary knowledge and identify system-wide barriers such as technology, infrastructure, codes, and standards.

Blending low volumes of hydrogen (up to 15 per cent) into the natural gas network is an early and important market for Alberta. Existing natural gas distribution infrastructure can be leveraged to start introducing hydrogen into the provincial natural gas system without substantial infrastructure upgrades, which reduces initial investment risk and provides a new demand market.

It is likely that hydrogen blending would begin at low volumes and increase gradually over time as distribution infrastructure and end-use equipment are shown to successfully operate with hydrogen. Early advancements will involve pilot and demonstration projects. These early efforts will provide an indication of safe levels of hydrogen blending in different parts of regional distribution networks.

5.3 Power generation and energy storage

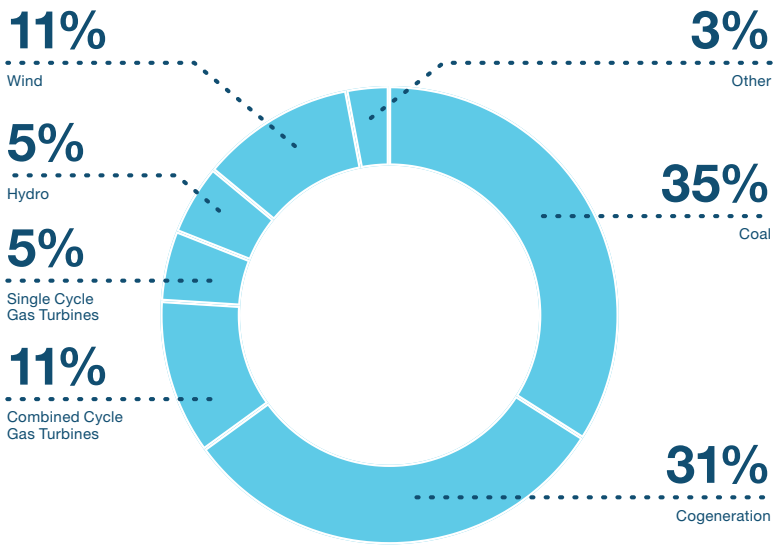
Current state

Hydrogen does not currently play a large role in the commercial power sector, accounting for less than 0.2 per cent of global electricity generation.[23] However, hydrogen-fired gas turbines and combined-cycle gas turbines could play a future role to reduce emissions in the sector. As the renewable power generation market grows, surplus renewable energy can be converted to hydrogen for energy storage to address challenges with renewable energy variability and uncertainty.

Alberta has a competitive, energy-only deregulated market, where a power generator is paid for the electricity it produces based on a fluctuating wholesale price of electricity. The lowest clearing energy supply price in any given hour is dispatched by the Alberta Electric System Operator (AESO), which operates Alberta's Power Pool. To remain competitive, power generators decide on the type of generation they produce and the location of their facilities.

In 2019, Alberta's installed power generation capacity was approximately 16,532 megawatts (MW), meeting an average hourly demand for power of 9,695 MW.[24] Approximately one third of Alberta's electricity capacity is for designated industrial systems that generate their own electricity for industrial processes, such as chemical manufacturing and oil and gas production and refining.[25]

Most of Alberta's electricity is produced by combustible fuels, with approximately 52 per cent from natural gas and 35 per cent from coal. However, coal power is set to be retired by 2023. Figure 5 below shows Alberta's installed power generation capacity by fuel type.



[23] International Energy Agency, "The Future of Hydrogen," Report prepared by the IEA for the G20, Japan, June 2019. https://www.iea.org/reports/the-future-of-hydrogen.

[24] Power demand includes behind-the-fence from industrial use.

[25] Alberta Utilities Commission, "Self-supply and export – Alberta Utilities Commission discussion paper," June 5, 2020. https://www.auc.ab.ca/regulatory_documents/Reference/Self-supply%20and%20export%20–%20AUC%20discussion%20paper.pdf.

Opportunity for power generation and storage

The power generation sector has the potential to both produce hydrogen and be a hydrogen end user. The power generation sector has many options to decarbonize, which could include renewable energy and CCUS. Hydrogen opportunities include:

- Producing hydrogen using renewable energy.
- Using pure hydrogen or hydrogen blended with natural gas in turbines.
- Employing long-term and large-scale energy storage, where hydrogen produced via electrolysis using intermittent renewables can be stored and converted back to electricity by fuel cells or hydrogen turbines to produce on-demand power generation when needed.

Hydrogen-rich gas can provide flexible power generation opportunities for gas turbines that could run on hydrogen. Hydrogen can ensure energy system security while adding flexibility of power generators.

Hydrogen can also be stored as either a compressed gas, cryogenic liquid, synthetic methane, or other compounds for later use.[26] This provides opportunities for long-term and large-scale energy storage, such as using salt caverns for hydrogen storage, and supports reliable back-up and off-grid power supply for smaller-scale applications, such as replacing diesel generators and other conventional battery systems.

5.4 Transportation

Current state

Fuel cell electric vehicles (FCEVs) for passenger and freight transport are an emerging market. To date, the transportation sector has seen the largest uptake of hydrogen as a fuel, largely driven by FCEV market developments in California.

FCEVs currently represent a small fraction of global vehicle fleets, compared to both internal combustion engine vehicles and battery electric vehicles. However, FCEV potential is promising and the number of transportation applications is growing. Countries are looking at opportunities to decarbonize transportation, especially medium and heavy duty transportation segments, where FCEVs could represent a compelling zero-emission vehicle option.

While hydrogen-fueled passenger vehicles, buses, and forklifts are available, hydrogen fuel cell use in other transportation segments is currently at the prototype and demonstration phase. Wider demonstrations are required to assess feasibility of FCEVs across different transportation fleets, in particular for medium and heavy duty vehicles.

[26] International Energy Agency, “The Future of Hydrogen,” June 2019.

TABLE 1. TECHNOLOGICAL AVAILABILITY OF HYDROGEN FUEL CELL VEHICLES
Adapted from Deloitte and Ballard Power, "Fuelling the Future of Mobility," 2020

	Fuel Cell Electric Vehicle (FCEV)	Battery Electric Vehicle (BEV)	Internal Combustion Engine (ICE)	Deployed in Alberta
Light-Duty Vehicles				
Passenger Vehicles	Commercially available	Accepted	Incumbent	No
Commercial Vehicles				
Bus	Commercially available	Accepted	Incumbent	No
Van	Demonstration	Accepted	Incumbent	No
Medium-Duty Truck	Demonstration	Demonstration	Incumbent	No
Heavy-Duty Truck	Prototype	Demonstration	Incumbent	Yes - Demonstration (Class 8 Truck)
Special-Use Vehicles				
Forklift	Commercially available	Incumbent (Indoor Warehouse)	Incumbent (Outdoor Warehouse)	Yes
Mining Truck	Prototype	Prototype	Incumbent	No

Status:

Prototype: Development phase
Demonstration: Prototype is being testing on a small scale
Commercially Available: Product is launched and sold for commercial use
Incumbent: Products are currently in use
Accepted: Products are generally accepted by end users

Light-duty Vehicles

Light-duty vehicles have seen the largest penetration of FCEVs, largely driven by policy developments and incentives in California. Globally, the United States has the largest share of FCEVs with Japan in second place.

Light-duty FCEVs and fuelling stations are also increasing across Canada, largely in British Columbia and Quebec. This has been supported by the Government of Canada and these two provinces through vehicle purchase rebates, incentives, and zero-emission vehicle mandates.

Forklifts

Hydrogen fuel cell forklifts are commercially operated in North America and are viewed favourably in terms of their economics and operational efficiencies. Alberta currently has 230 fuel cell electric forklifts operating at the Walmart Fresh Food Distribution Centre in Balzac. Walmart Canada projects that its deployment at the Balzac Distribution Centre will reduce operating costs by C$1.1 million over seven years, compared to using battery-powered forklifts.

Buses

Municipalities are interested in fuel cell electric buses (FCEBs) to reduce their fleet emissions. The technology is generally mature and provides opportunities to bring Canadian-manufactured fuel cell electric buses to Alberta. New Flyer Industries, based in Winnipeg, is a leading North American supplier of fuel cell electric buses. Globally, there are 2,129 commercially available FCEBs, of which 2,000 are deployed in China.[27] In Alberta, the City of Edmonton is considering a trial of FCEBs as part of a fleet replacement project.

Medium-duty vehicles

Medium-duty trucks (Class 1 to 6) are deployed globally, with China having the largest fleet for intra-city deliveries, logistics, and e-commerce.

Heavy-duty vehicles

Hydrogen-powered Class 8 heavy-duty trucks for freight transport are newly emerging with recent prototype and demonstration projects. Most major original equipment manufacturers are in the research and demonstration phase, and only limited projects are launched or being tested.[28] Despite the current technology immaturity, heavy-duty trucks are an emerging area of opportunity for hydrogen fuel cells. The value proposition of hydrogen in this sector is considered promising given the hydrogen fuel cell's ability to support heavy payloads, long ranges, and shorter refuelling times—attributes where battery electric trucks may be at a disadvantage.

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[27] Ballard Power Systems and Deloitte China, "Fueling the Future of Mobility: Hydrogen and fuel cell solutions for transportation," January 2020. https://info.ballard.com/deloitte-vol-1-fueling-the-future-of-mobility.

[28] Ibid.

The Alberta Zero-Emissions Truck Electrification Collaboration (AZETEC) project

The AZTEC project includes the design, manufacture, and deployment of two prototype heavy-duty extended-range hydrogen fuel cell electric trucks that will move freight between Edmonton and Calgary, and includes a demonstration fuelling station. The C$15-million project is led by the Alberta Motor Transport Association and has received more than $7.3 million from Emissions Reduction Alberta.[29] Following the trial period, the next phase of the project envisions a fleet of several dozen hydrogen-powered trucks and a network of fuelling stations.

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[29] Emissions Reduction Alberta, "Alberta Zero Emissions Truck Electrification Collaboration (AZETEC)," https://eralberta.ca/projects/details/alberta-zero-emissions-truck-electrification-collaboration-azetec/.

Rail

Rail is another transportation application that is attracting increasing global interest. Calgary-based Canadian Pacific Railway is conducting a pilot project to test hydrogen fuel cell use in a locomotive for rail freight. In addition, Invest Alberta Corporation, Alberta Transportation, and the Canada Infrastructure Bank have signed a memorandum of understanding to assess a Calgary to Banff hydrogen rail passenger project.

Mining trucks

Ultra heavy-duty mining trucks equipped with fuel cell technology provide an opportunity to further decarbonize oil sands mining operations. These trucks can take advantage of proximity to existing hydrogen production in the Athabasca oil sands, representing a hub approach to deployment. Each mining truck is anticipated to use approximately one tonne of hydrogen per day, which is equivalent to running approximately 33 buses. This shows the potential for a single mine site to deploy hydrogen at significant scale.[30]

Aviation

The aviation industry is traditionally considered a hard-to-abate sector. Hydrogen, as a clean energy carrier, offers opportunities to this sector to reduce emissions since it can be combusted similar to natural gas and jet fuel, or converted electrochemically in a fuel cell.

Many industries in Alberta use smaller commercial aircraft for transportation, surveying, agriculture treatment, wildfire aviation, and tourism. Several companies in Europe are testing and developing hydrogen combustion engine and hydrogen fuel cell aircraft, planning for mid-2030 deployment.

In 2021, Canada's SAF+ Consortium[31] recently announced a project in Montreal to produce clean hydrogen for sustainable aviation fuel, the first-of-its-kind in North America. The Edmonton International Airport and Air Canada have also announced a partnership to reduce emissions by exploring hydrogen fuel cell technologies for their operations.

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[30] Canada, "Canada Hydrogen Strategy: Seizing the Opportunities for Canada," December 2020. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf.

[31] The SAF+ Consortium is a sustainable aviation fuel consortium, which includes Airbus, Air Transat, Aeroports de Montreal, and others.

Opportunity for transportation

The hydrogen business case in transportation is reinforced by the fuel's ability to compete with liquid fuels on a per-mile operating cost basis, when production costs and efficiency gains from fuel cells are considered. This cost competitiveness is important to enable market penetration and technology adoption.

Projections to 2030 by the Hydrogen Council forecast that hydrogen vehicles are more competitive than conventional and other low-carbon alternatives in transportation segments with long ranges, heavy payloads, and short refuelling time requirements. This includes large passenger cars and SUVs, forklifts, medium and heavy duty trucks, long-distance buses, taxi fleets, and trains.

HYDROGEN FUEL CELL VEHICLE COMPETITIVENESS COMPARED TO CURRENT TRANSPORT OPTIONS

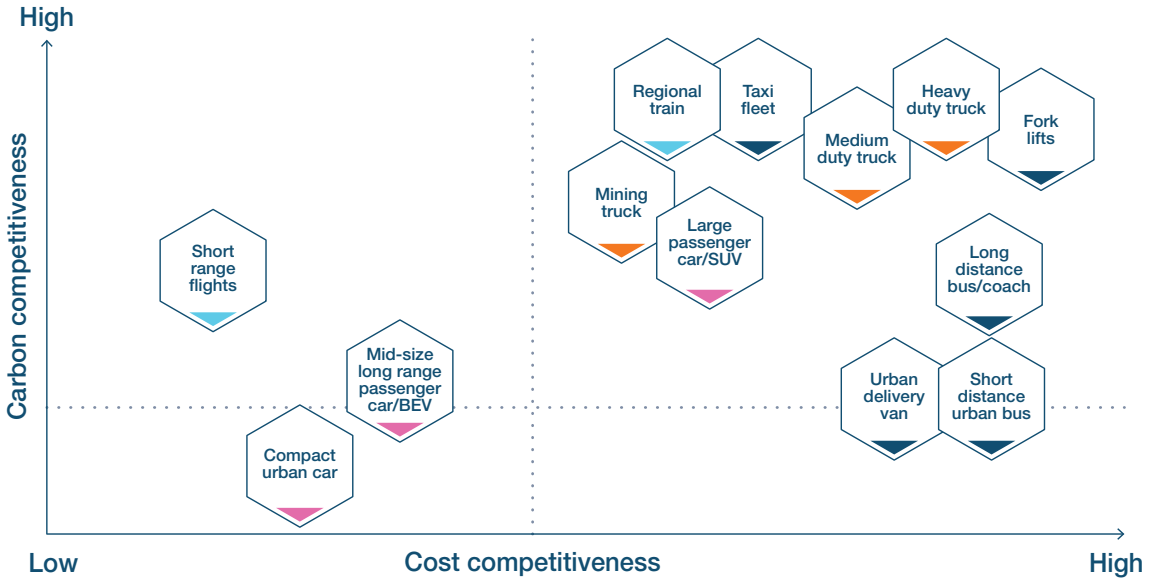

Figure 2. Transportation and Hydrogen Competitiveness in 2030 (adapted from the Hydrogen Council and McKinsey & Co, 2021).

Alberta has the potential to be a supplier-of-choice for clean hydrogen as a transportation fuel once zero-emission vehicles are more widely adopted. Adoption of hydrogen fuel cell vehicles within the province will provide an important reference case to enable growth of the clean hydrogen export market for transportation applications.

5.5 Export

Current state

Alberta has the energy resources to produce significant volumes of clean, cost competitive hydrogen for global markets. Alberta currently produces ammonia, a hydrogen carrier, and exports it by rail to the United States. Ammonia-by-rail provides a near-term opportunity to export clean hydrogen to North American markets and ports. However, ammonia export by rail is limited by rail capacity and public interest.

As long as there are no existing long-distance hydrogen pipelines in Canada, global market access is limited. Despite the lack of market access, investors have shown significant interest in producing clean hydrogen in Alberta for export markets.

Opportunity for hydrogen exports

Canada's Hydrogen Strategy estimates that by 2050 the Canadian domestic market for hydrogen could be up to 20 million tonnes per year, and the demand for clean hydrogen in international exports in that timeframe could more than double that amount.[32] Alberta's capacity for clean hydrogen production is projected to be approximately 45 million tonnes per year,[33] demonstrating that Alberta has production capacity to satisfy local demand, and provide significant export quantities to other Canadian provinces as well as international markets.

Hydrogen export could play a major role in Alberta's future energy competitiveness. Potential target export markets include Canadian and North America jurisdictions, Europe, and Asia Pacific customers. To meet overseas demand for clean hydrogen, liquid hydrogen carrier ships are currently under development.

Hydrogen export by pipeline could use a dedicated gaseous hydrogen pipeline or blend hydrogen into existing natural gas pipeline networks. Existing high-pressure natural gas pipelines could also be converted to deliver pure hydrogen, however this must be evaluated and assessed as a suitable business case.

Hydrogen export by pipeline, along with Alberta's relative proximity to California — a leading hydrogen adopter — could help establish a foothold in a key North American market. California's projected clean hydrogen demand is expected to be one to four million tonnes per year by 2050, with demand for clean hydrogen in the entire U.S. forecast to be approximately 22 to 40 million tonnes per year.

A cost competitive opportunity for Alberta is to export hydrogen in the form of ammonia. Major Japanese power utilities are interested in burning clean ammonia in gas turbines or co-burning with coal to reduce GHG emissions for power generation. Moving hydrogen in the form of ammonia could improve export cost competitiveness, especially if end-use sectors can use ammonia directly in their applications. Other hydrogen carriers, such as methanol or liquid organic hydrogen carriers, will also be explored as Alberta evaluates its export opportunities.

Additional economic analysis and feasibility studies are required to better understand the hydrogen export opportunity. In addition, technological barriers need to be overcome and standards for carbon intensity need to be aligned with import regions. For example, technology for deep-water shipping is still developing, hydrogen storage is not readily available, and hydrogen pipelines require significant time and investment to build.

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[32] Canada, "Canada Hydrogen Strategy: Seizing the Opportunities for Canada," December 2020.

[33] University of Alberta, "Identification and Assessment of Opportunities for Hydrogen in Alberta's Low-Carbon Economy," June 2021.

6. Alberta's hydrogen future

6.1 Hydrogen scenarios

In evaluating the potential hydrogen economy, Alberta modelled two possible scenarios for the future of Alberta in 2030:

- **An incremental future** where clean hydrogen has slow uptake into the provincial economy. This scenario assumes incremental (business-as-usual) hydrogen demand based on existing policy and regulations, with some initial momentum from industry, incremental progress on technology, and less optimistic growth rates.
- **A transformative future** where clean hydrogen is integrated into provincial energy systems on a larger scale. This scenario assumes a supportive policy environment that facilitates demand creation and technological development, favourable socio-economic conditions, and growth rates that will lead to large-scale domestic hydrogen deployment and exports by 2030.

Industrial processes

Upgrading current hydrogen production methods to include CCUS represents an early opportunity for clean hydrogen leadership in Alberta.

	Incremental future	Transformative future
	CCUS is added to existing hydrogen production at bitumen upgrading and/or oil refining sites to reduce emissions by 6 Mt per year.	CCUS is added to hydrogen production facilities at bitumen upgrading and/or oil refining sites, and CCUS is added to hydrogen production at ammonia and methanol facilities to reduce emissions by 12 Mt per year. A project for clean ammonia production is operating.

Residential and commercial heating

Over the next five to ten years, Alberta's focus will be on enabling hydrogen blending into natural gas distribution systems while piloting higher concentrations of hydrogen blending and pure hydrogen networks in contained areas such as isolated portions of the natural gas network. Clean hydrogen may play a significant role in residential and commercial heating, along with other alternatives that reduce emissions.

	Incremental future	Transformative future
	Pilot projects are testing hydrogen blended at five per cent by volume with natural gas into municipal and/or rural residential, low-pressure distribution infrastructure.	Hydrogen blended at 15 per cent by volume is occurring in municipal and/or rural distribution infrastructure across the province. Pure hydrogen networks and communities are demonstrated for 200,000 residences, taking advantage of expected continued growth in the Alberta housing market.

Power generation and storage

Power generation facilities in Alberta continue to undergo coal-to-gas conversions, with the majority of coal-fired electricity being replaced by natural gas. This provides the opportunity for clean hydrogen to be integrated with natural gas as a fuel source and also support energy storage.

Hydrogen can serve as large-scale energy storage for intermittent renewables and can fuel hydrogen-capable turbines or stationary fuel cells. The future state of integrating hydrogen into the power generation and storage sector will ultimately depend on proving technology at the commercial scale and ensuring competitiveness. The transition toward a clean hydrogen economy will need to support market competition and affordability of power generation for end users.

	Incremental future	Transformative future
	The power generation sector is largely business-as-usual with feasibility and demonstration projects in place. There is public-private partnership support for pilot projects that demonstrate hydrogen energy storage in underground salt caverns or depleted oil and gas reservoirs.	1200 MW of Alberta's power generation is using 15 per cent volume of blended clean hydrogen with natural gas in regional clusters. In addition, there is a power generation project demonstrating hydrogen powered turbines. Hydrogen is also used as a seasonal storage system from surplus renewable power through power-to-gas.

Transportation

Large captive vehicle fleets such as buses and commercial trucks are seen as having the highest potential for adoption in Alberta. FCEVs offer the greatest advantages over other low-emission alternatives in energy intensive, long-range applications such as heavy-duty trucking. Fleets with return-to-base operations can leverage shared infrastructure, reducing transition costs in the early deployment phase. The higher daily hydrogen usage per vehicle in heavy-duty applications also builds deployment scale and improved economics with a smaller number of vehicles.

	Incremental future	Transformative future
	One per cent of gasoline vehicles and five per cent of diesel vehicles have transitioned to FCEVs.	Five per cent of gasoline vehicles and 10 per cent of diesel vehicles have transitioned to FCEVs.

Exports

Hydrogen export is currently restricted by the developing global supply chain. Existing infrastructure, such as rail, can be used to ship hydrogen carriers such as ammonia today, before dedicated pipelines and export infrastructure are established. Achieving significant hydrogen exports in Alberta is dependent on the supply chain reaching maturity with the establishment of infrastructure to tidewater and large-scale liquefaction ships available to export hydrogen or hydrogen carriers to global markets. Support from Canada, British Columbia, and Indigenous and local communities will be critical to establish hydrogen export supply chains.

	Incremental future	Transformative future
	Alberta is exporting clean hydrogen carriers (for example, ammonia) by rail to the United States. Alberta has a framework and plan in place, developed with other provincial and federal governments in Canada, to export clean hydrogen to global markets.	Alberta exports 1 million tonnes of gaseous hydrogen, noting this would require a fully permitted and constructed pipeline to the west coast, liquefaction, and export infrastructure. In addition, Alberta also exports 1 million tonnes of hydrogen carriers (such as ammonia) to global markets by 2030.[34]

[34] On August 3, 2021, Japan's ITOCHU announced a partnership with Petronas to explore and plan for a natural gas-based ammonia facility with CCUS in Alberta, to export ammonia as a hydrogen carrier to Asian markets.

6.2 Plan for action

Alberta's phased implementation approach

The Hydrogen Roadmap focuses on policy actions up to 2030 given the early stages of a clean hydrogen economy in Alberta. This focus will ensure that Alberta takes a measured approach in clean hydrogen development that drives gradual transition from pilot and demonstration stages to scale up, while playing a role in ensuring public safety and regulatory harmonization across the supply chain.

In the first phase of implementing the Hydrogen Roadmap, the Government of Alberta will focus on establishing policy foundations, closing technology gaps and accelerating commercialization across the supply chain with dedicated research and innovation support, reducing carbon intensity of existing hydrogen production, and deploying clean hydrogen into the most promising end-use markets.

In the second phase of implementation, the focus will shift to growth and achieving scale through technology maturation and commercialization. During this phase, Alberta is expected to see a rapid evolution of its hydrogen value chain. Hydrogen deployment will increase as technologies move from concept to pilot and demonstration and eventually to wider hydrogen use and commercialization.

Policy actions

1. Build new market demand

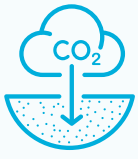
Alberta's current hydrogen economy is a balanced system where current hydrogen production meets demand for existing industrial processes. Establishing new hydrogen demand, outside of its traditional use as an industrial feedstock, will be critical to move into new markets.

Policy actions need to support emerging hydrogen markets, initially focusing on markets that provide opportunities to immediately deploy hydrogen into the provincial economy.

Policy pillar →	From policy to action →	From action to implementation
 Build new market demand	Near term (2021-23) - Support hydrogen blending in the utility market. Long term (2023+) - Advance pure hydrogen communities.	Near term (2021-23) - Amend the Gas Utilities Act and Gas Distribution Act to remove a key roadblock for hydrogen blending into natural gas distribution systems. - Assess mechanisms to build demand for hydrogen in the utility heat market, including options for cost recovery. Long term (2023+) - Explore and advance pure hydrogen communities and networks.

2. Enable CCUS

In order for Alberta to realize a clean hydrogen economy, CCUS needs to be in place to facilitate cost-effective, large-scale production. Although initial CCUS infrastructure is currently in place, the Government of Alberta is considering competitiveness and CCUS accessibility to various industries across the province.

Policy pillar →	From policy to action →	From action to implementation
 Enable CCUS	Near term (2021-23) - Advance CCUS hubs and explore opportunities to improve economics.	Near term (2021-23) - Continue implementing and enhancing Alberta's CCUS regulatory framework to address more current challenges. - Advance CCUS hubs and partnerships. - Leverage federal funding and incentives to provide Alberta decarbonization funding for carbon capture infrastructure.

3. De-risk investment

Clean hydrogen is an emerging opportunity with challenging economics compared to conventional, higher-emission fuel sources. Long-term investment certainty and funding are needed to ensure investments can happen today to position Alberta for the long-term. Alberta's support to de-risk investment is focused on working in partnership with industry and other governments to enable new clean hydrogen production, improve access to capital, de-risk hydrogen use in transportation, and consider establishing a hydrogen trading hub.

Policy pillar	From policy to action	From action to implementation
 De-risk investment	Near term (2021-23) - Support clean hydrogen production. - Enable access to capital for clean hydrogen investment. Long term (2023+) - Advance fuel switching and refuelling infrastructure. - Explore the concept of a hydrogen trading hub to enable global trade.	Near term (2021-23) - Support clean hydrogen production through the Alberta Petrochemicals Incentive Program. - Increase access to capital to support hydrogen deployments and infrastructure developments. Long term (2023+) - In conjunction with federal and municipal governments, pursue incentives for fuel switching in transportation and development of distribution and refuelling infrastructure. - Evaluate the merits of a Hydrogen Trading Hub to drive price transparency in Alberta.

4. Activate technology and innovation

Demonstration projects, research, and innovation are needed to prove and scale up emerging clean hydrogen technologies. Training and development with Alberta's world-class universities and technical schools are important for the labour force to support the clean hydrogen economy.

Policy pillar	From policy to action	From action to implementation
 Activate technology and innovation	Near term (2021-23) - Support technology and innovation across the hydrogen value chain. - Conduct feasibility studies and demonstration projects.	Near term (2021-23) - Establish a Clean Hydrogen Centre of Excellence. - Conduct hydrogen feasibility studies to inform market development and exports. - Support pilots and early demonstration projects for domestic and export market development.

5. Ensure regulatory efficiency, codes, and standards

Public safety must be prioritized by creating hydrogen codes and standards and regulatory requirements. A performance-based regulatory framework will allow hydrogen markets to move forward while reducing risk. Alignment of codes, standards, and regulatory harmonization with other jurisdictions is needed to ensure Alberta's competitiveness across the hydrogen economy.

Policy pillar	From policy to action	From action to implementation
 Ensure regulatory efficiency, codes, and standards to drive safety	Near term (2021-23) - Harmonize hydrogen regulations with other jurisdictions. - Develop codes and standards. - Improve natural gas infrastructure tie-ins.	Near term (2021-23) - Harmonize and clarify hydrogen regulations with federal and provincial governments. - Support the development of national and provincial codes and standards. - Improve access to natural gas and ensure its quality to support incremental hydrogen production.

6. Lead the way and build alliances

Public-private partnerships and government-to-government relationships, including with Indigenous governments, are essential to advance the hydrogen economy, send coordinated signals to investors, and build public awareness and understanding.

An emerging narrative against natural gas-based hydrogen production can disrupt Alberta's efforts to build a clean hydrogen economy. As Canadian and global carbon intensity benchmarks and Guarantee of Origin schemes are proposed and developed, Alberta needs to actively inform their development with data grounded in robust analysis and science.

Policy pillar	From policy to action	From action to implementation
 Lead the way and build alliances	Near term (2021-23) - Develop hydrogen hubs. - Inform carbon intensity thresholds for clean hydrogen. - Promote hydrogen literacy.	Near term (2021-23) - Coordinate the development of clean hydrogen hubs and partnerships across the province. - Support establishment of Canadian and global carbon intensity thresholds for clean hydrogen. - Improve public literacy on clean hydrogen.

7. Pursue hydrogen exports

Alberta has several advantages to supply global demand for clean hydrogen. However, Alberta needs to overcome operational constraints for export, such as an unavailable global supply chain, which includes infrastructure, transportation, liquefaction, and storage. Alberta will need to have an established export supply chain in place to benefit from the international export opportunity.

Policy pillar	From policy to action	From action to implementation
 Pursue hydrogen exports	Near term (2021-23) - Establish market access. - Lock in export markets.	Near term (2021-23) - Pursue market access through establishment of a clean energy corridor with connection through British Columbia and other jurisdictions. - Pursue hydrogen export Memoranda of Understanding.

Measures of success by 2030

To evaluate the success of the proposed policy actions, the Government of Alberta will use the following measures, as outlined under the 2030 Transformative Scenario:

- Domestic Hydrogen Deployment: Clean hydrogen is integrated into provincial energy systems (heating, power generation and storage, transportation, and industrial processes) on a large scale.
- Export: Alberta is exporting clean hydrogen (gaseous or as hydrogen carriers) to global markets.
- Investment: Over C$30 billion in new capital investment is allocated to clean hydrogen production and development in Alberta, not including ammonia export.
- Economic Activity:
  - Tens of thousands of jobs and billions of dollars of economic activity during the construction phase.
  - Thousands of jobs and hundreds of millions of dollars of economic activity during the project operations phase.
- GHG Reductions: 14 Mt per year from integrating clean hydrogen into Alberta's markets, with most of the emissions reductions from industrial processes.

6.3 Benefits to Alberta

The clean hydrogen economy has the potential to grow Alberta's energy sector, providing economic growth and creating jobs. This relies on the ability to integrate clean hydrogen across Alberta into sectors such as power generation, residential and commercial heating, industrial processes, the transportation sector, and the potential for meeting international demand for hydrogen by export.

Widespread direct and indirect economic benefits are expected, where new employment opportunities are created to develop infrastructure and other parts of the labour market supporting the new hydrogen economy. These jobs include employment for professionals, scientists, and trades as infrastructure and world-scale operational projects are developed and operating for over 20 years.

Environmental benefits to Alberta include reducing our GHG emissions across all sectors, and reducing negative impacts and environmental costs to human health and biodiversity. In addition, reducing emissions leads to increased investment attraction where investors are looking for companies that demonstrate a positive performance on ESG considerations.

The hydrogen economy is an emerging opportunity for Alberta's future generations. Alberta is positioned to participate in a global clean energy transition and retain a long-term competitive advantage of its natural resources, providing investment economic security and benefits for years to come.

Clean hydrogen export potential

Establishing a hydrogen export market has tremendous potential for Alberta.

The 2030 transformative scenario would require approximately **0.7 billion cubic feet of new natural gas demand in Alberta**, should hydrogen be integrated across Alberta into sectors such as power generation, residential and commercial heating, industrial processes, transportation, and for exports.

A hydrogen market exporting **10 million tonnes of clean hydrogen per year** from Alberta to international markets by 2050 could demand about **4 billion cubic feet per day in natural gas**, supporting jobs and revenue in Alberta and global emissions reductions. This would grow Alberta's natural gas value chain, which is already one of the cleanest in the world with best-in-class environmental standards.

7. Conclusion

The Government of Alberta recognizes that the province has a significant role to play in safely growing the hydrogen economy. Establishing Alberta as a reliable partner in export markets will be paramount to ensuring our hydrogen economy plays a key role in global de-carbonization, and our sector achieves significant economies of scale.

While Alberta drives to unlock global supply chains, supporting hydrogen use in Alberta will play an integral role in decreasing Alberta's emissions, strengthening our expertise in this value chain, and lowering hydrogen costs for consumers. Residential and commercial utilities markets are poised for early hydrogen adoption given the considerable existing infrastructure that can be used with minimal upgrades. Hydrogen represents a de-carbonization opportunity for utilities markets and will allow Alberta to grow our hydrogen sector, while making the necessary technological advancements towards achieving Alberta's hydrogen ambitions.

Hydrogen in transportation markets has a strong economic position against diesel and gasoline today. Some transportation technology is ready to be applied today, such as buses and forklifts, however further demonstration for heavy duty transportation and other markets is required. Transportation markets will be promising markets to advance in the near term once the current state of technology improves and increased refuelling infrastructure is in place.

The largest opportunities to introduce clean hydrogen into the industrial sector is by adding carbon capture to existing hydrogen production in Alberta and encouraging hydrogen adoption as a fuel. This supports a broader opportunity to lower the carbon intensity of Alberta's oil and gas sector. Similarly, Alberta's power generation sector can consider integrating hydrogen to support a portfolio of de-carbonization options to maintain competitiveness.

Once the Hydrogen Roadmap policy actions are implemented, the Government of Alberta will closely monitor local and international developments in the hydrogen economy and will adjust the Hydrogen Roadmap as needed, treating it as a living document. The Hydrogen Roadmap will be revisited in 2025 in order to switch the focus to actions for the 2030-2050 timeframe to fully realize benefits to Albertans.