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Hydrogen RD&D Collaboration Opportunities: Canada

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Executive summary: Canada

Canada has a well-established hydrogen production sector based on its natural gas resources, and has begun shifting towards carbon capture technologies, renewable hydrogen, hydrogen from biomass, and expanding hydrogen use across multiple sectors. Canada has flagged it is open to high-quality proposals for international collaborations or MoUs.

The *Hydrogen RD&D Collaboration Opportunities: Canada* chapter aims to enhance country-to-country engagement by providing an overview of Canada's hydrogen priorities and ecosystem. This report also includes a publication and intellectual property (IP) scan, identifying the key stakeholders in Canada actively undertaking hydrogen RD&D, both at the early research and commercialisation stages.

Canada's hydrogen strategy

In December 2020, Canada released the federal *Hydrogen Strategy for Canada.* The hydrogen strategy is driven by Canada's legislative commitment to decarbonise the economy, the opportunity to stimulate economic growth and job creation, the potential to cement Canada's role as a global science and technology innovation leader, and to ensure energy security and grid resilience. In addition to the federal hydrogen strategy, several Canadian provinces have also developed their own hydrogen strategies or discussed the role of hydrogen within strategic planning documents more broadly.

Canada's federal and provincial-level strategic priorities in hydrogen include: the use of hydrogen in power generation; transportation (including light-, medium- and heavy-duty fuel cell vehicles); industrial decarbonisation (including in Canada's oil and gas and other hard-to-abate industries such as steel, chemical and paper manufacturing); and heat for buildings through natural gas blending. Approaches to implementing the Hydrogen Strategy will vary between provinces in Canada, in line with each region's comparative advantages. Canada is focussed on supporting increased RD&D to accelerate the development and commercialisation of hydrogen technologies in support of these priorities.

Canada's targets and RD&D priorities

The *Hydrogen Strategy for Canada* outlines a 'Vision for 2050' which articulates ambitions for hydrogen production, utilisation and demand across Canada. Canada aims to be a global top three producer of hydrogen from renewables, and to develop a strong domestic supply of low carbon-hydrogen at roughly CAD 1.5-3.5 per kg. Canada aims for more than 30% of its energy to be delivered by hydrogen, and more than 50% of its natural gas supply to be blended with hydrogen through existing and reproposed pipeline infrastructure. Canada's light vehicle sales target by 2026 is 20%, 60% by 2030, 100% by 2035.[1] This includes fuel cell vehicles but also electric and plug-in hybrid vehicles. Ultimately, Canada aims for hydrogen production and utilisation to directly contribute to 190 Mt-CO_2-e emission reductions per year.

[1] https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030/sector-overview.html

To achieve these goals, Canada is investing in RD&D in a variety of areas.

Production
Electrolysis: polymer electrolyte membrane, alkaline, solid oxide, anion exchange membrane
Fossil fuel conversion: CCS, coal gasification, methane pyrolysis, methane reforming
Biomass and waste conversion
Electrolysis: nuclear

Storage and distribution
Compression and liquefaction: pressurised storage, pipelines, underground storage
Chemical: ammonia
Synthetic fuels
Physisorption
Other: tube trailers and tank lorries, carrier ships

Utilisation
Gas blending: pipelines, appliances, gas separation
Transport: fuel cells, refuelling stations, aviation, internal combustion engines, fuel cell trains, fuel cell ships
Electricity generation: hydrogen turbines, fuel cells
Industrial processes: steel processing, combustion, synthetic fuels
Other: agricultural fertilizer

Cross-cutting
Policy and regulation
Codes and standards
Social licence

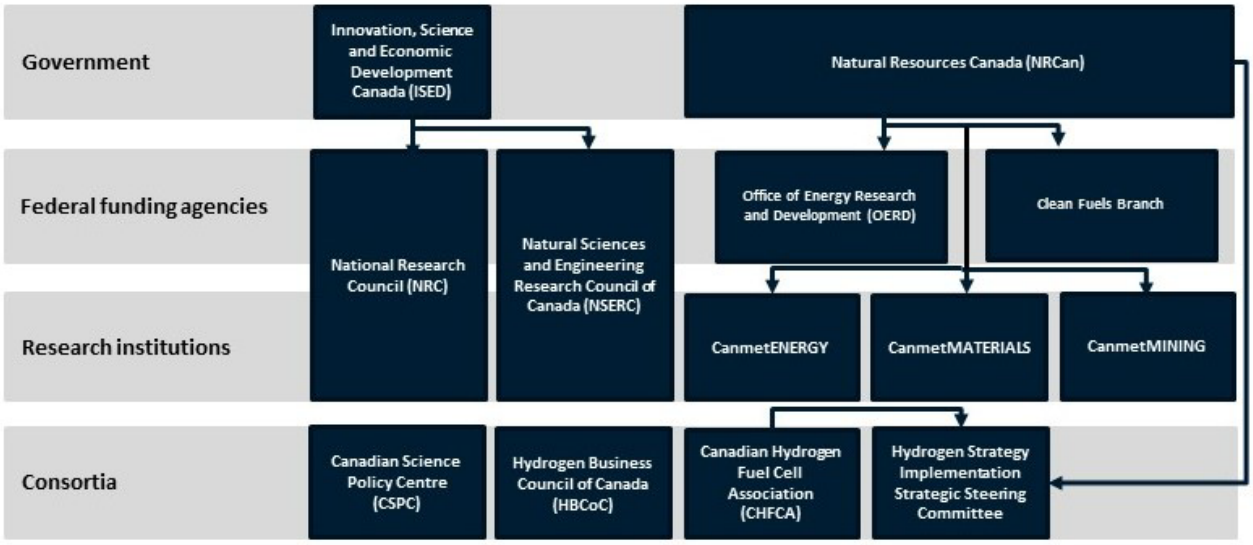
Canada's domestic hydrogen landscape

The main government bodies driving hydrogen strategy and RD&D policy in Canada are Innovation, Science and Economic Development Canada (ISED) and Natural Resources Canada (NRCan), which includes the Office of Energy Research and Development (OERD). Provincial governments also have a remit to develop regional-scale hydrogen strategies and often allocate funding to achieve their priorities. The recently formed 'Hydrogen Strategy Implementation Strategic Steering Committee' will coordinate and monitor the implementation of Canada's hydrogen strategy at a federal level. The Committee's role is to identify strategic priorities, share knowledge, and monitor the progress of the strategy's implementation.

Implementation of hydrogen RD&D in Canada takes place in a decentralised manner across research institutions and industry. Notable bodies include the National Research Council and the Natural Sciences and Engineering Research Council of Canada, which administer Canada's research and development (R&D) funding mechanisms – including the Strategic Innovation Fund. In this way, these bodies have tangential oversight of R&D activities across Canada's research institutions.

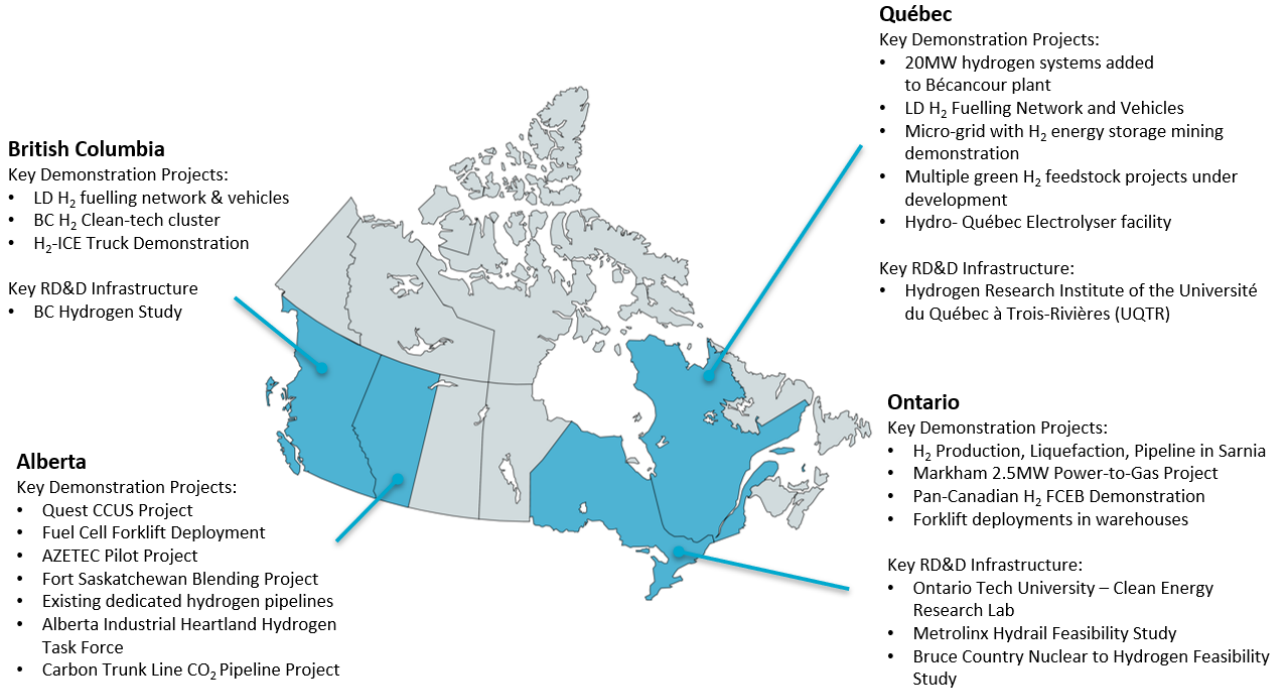
Canada has several active consortia and industry associations which support Canada's transition to a hydrogen economy, including the Canadian Hydrogen and Fuel Cell Association (CHFCA), the Hydrogen Business Council (HBCoC) of Canada and the Canadian Science and Policy Centre (CSPC).

Figure 1: Country's hydrogen RD&D ecosystem



Industry, academia and government are collaborating to bring about hydrogen clusters (also known as hydrogen valleys or ecosystems) by 2025. These are hydrogen value chain demonstrations and pilot projects that cut across sector applications. Currently, there are four regions with strong hydrogen RD&D activity:

Figure 2: Canada's hydrogen clusters



Adapted from Natural Resources Canada (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen

IP and publications scan

Several universities, public research institutions and private companies are highly active in early-stage hydrogen research and late-stage technology commercialisation. This is reflected in hydrogen research publication output and patent output data.

Table 1: Top organisations active in early-stage and late-stage hydrogen RD&D

Rank	Top organisations (Research publication output)	Top organisations (Hydrogen patent output)
1	Ontario Tech University	Westport Fuel Systems Canada
2	University of Toronto	Expander Energy
3	University of Alberta	Air Products & Chemicals; Hydrogenics
4	University of Waterloo	LANZATECH
5	Western University (University of Western Ontario)	Battelle Memorial Institute; Toyota Motor; Next Hydrogen; SUNCOR Energy; Honeywell Intl.; Michigan State University; Nemaska Lithium; NOVA Chemicals; SIGNA Chemistry

International collaboration

The *Hydrogen Strategy for Canada* recognises strategic partnerships between countries and industry on pilot projects, technology sharing, and collaboration as key to accelerating hydrogen RD&D. Additionally, Canada is a founding member of several international hydrogen initiatives which facilitate increased collaboration across the value chain, including the IEA Technology Collaboration Program, the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), Mission Innovation, and the Hydrogen Initiative under the Clean Energy Ministerial. Bilaterally, Canada has formalised hydrogen-specific partnerships with Chile, Germany, Japan, Netherlands and the United States. Canada has also issued bilateral joint funding calls, such as the Canada-Germany R&D Funding call which covers 10 hydrogen projects.

Activity levels for hydrogen and net-zero initiatives is high. While effort has been made to capture major announcements and key information as at 18 August 2022, the content is intended to provide a starting point for informing international engagement, particularly when used in conjunction with other reports in the series, and is non-exhaustive.

1 Country analysis: Canada

1.1 Introduction

Canada has a well-established hydrogen sector across the value chain. Canada currently produces an estimated 3 million tonnes of hydrogen annually, or 4% of global hydrogen production – primarily from steam methane reforming (SMR) of natural gas.[2] However, Canada has recognised the limitations of this production method and recently legislated the *Canadian Net Zero Emissions Accountability Act* to transition to net-zero by 2050. As such, Canada has recognised the need to adopt low- and carbon-neutral hydrogen[3] production alternatives.

In December 2020, the Canadian Government published the *Hydrogen Strategy for Canada*.[4] In addition to Canada's legislative commitment to decarbonise the economy, the hydrogen strategy is driven by the opportunity to stimulate economic growth and job creation, the potential to cement Canada's role as a global science and technology innovation leader and to ensure energy security and grid resilience. The National Research Council (NRC) estimates that between CAD 5 to 7 billion of public and private sector investment will be necessary to sufficiently develop Canada's hydrogen economy, and several funding mechanisms are already in place for hydrogen RD&D. This is key to achieving Canada's key objective of developing regional clusters by 2025 (also known as hubs, valleys, or ecosystems), with a view achieving a full rollout of a hydrogen economy including inter-provincial connectivity by 2050.

The *Hydrogen RD&D Collaboration Opportunities: Canada* chapter presents an overview of the hydrogen RD&D landscape in Canada, starting from the national strategy level, down to activity in specific hydrogen technology areas.

1.2 Canada's hydrogen drivers, strategy and RD&D priorities

1.2.1 Canada's key drivers

Natural Resources Canada (NRCan) highlights that the development of a low-carbon hydrogen industry will complement Canada's economic recovery from COVID-19 and as such, is a strategic priority. The following drivers have been identified to guide Canada's hydrogen strategy and transition to a low-carbon hydrogen economy:

- **Decarbonisation:** Canada's two emissions reduction targets are the primary driver for developing a hydrogen economy. First, Canada has pledged to reduce greenhouse gas emissions by 30% of 2005 levels by 2030; and second, to achieve net-zero emissions by 2050. Specifically, hydrogen will play a central role in decarbonising energy intensive end-use applications – including long-range transport and hard-to-abate industries. It is estimated that hydrogen could deliver 30% of Canada's end-use

[2] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[3] Canada refers to low-carbon and clean hydrogen as hydrogen that is produced from renewables, biomass, nuclear or from fossil fuel conversion with CCUS. Canada also considers other methods of production as low-carbon so long as CO_2 emissions can be offset, for example through direct air capture of emissions. See NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[4] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

energy requirements by 2050, and abate 190 megatonnes of carbon dioxide equivalent ($MtCO_2$-e) of greenhouse gas emissions.[5]

- **Economic growth:** Growth is a key driver for the development of a hydrogen economy in Canada. A hydrogen economy will have broad economic benefits: generating new jobs in research and development (R&D), manufacturing, and end-use applications; and allowing Canadian companies to take advantage of trade opportunities across the hydrogen value chain – such as fuel cell technology exports and energy exports. As a result, NRCan has forecast that Canada's domestic hydrogen market could be worth CAD 50 billion by 2050, with additional indirect revenues not accounted for.[6] It is expected Canada's hydrogen economy will support 350,000 jobs by 2050 and provide an opportunity for 800,000 jobs to transfer from the traditional energy sector to hydrogen and hydrogen-related industries.[7]
- **Technology innovation and industry position:** Developing a hydrogen economy is seen as central to stimulating private and public sector innovation and R&D capability in Canada. As of 2017, there were more than 100 hydrogen-related companies across the value chain. Canada has recognised that increased global demand for hydrogen presents an opportunity for Canadian companies to innovate and supply technology and services to support hydrogen production, storage, distribution and utilisation.[8]
- **Energy security and resilience:** Wide-scale hydrogen production can ensure a strong, resilient energy sector able to provide clean energy in indigenous, rural and remote communities. Canada has a broad energy mix (including nuclear, hydro, solar and wind) and hydrogen can act as a vector to tie together disparate energy sources, creating an integrated energy system. Additionally, hydrogen has been identified as a suitable option for utility-scale energy storage.[9]

1.2.2 Canada's strategic hydrogen industry priorities

The 2020 *Hydrogen Strategy for Canada*[10] complements many of the net-zero transition initiatives identified in Canada's broader climate plan, *A Healthy Environment and a Health Economy*.[11] Canada has also articulated hydrogen-specific strategic priorities in provincial-level hydrogen plans. In this section, sector-wide themes and strategic priorities from the national strategy have been overlayed with strategic priorities identified in provincial-level plans released by British Columbia, Ontario and Quebec.

[5] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[6] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[7] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[8] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[9] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[10] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[11] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

Canada's key strategic hydrogen industry priorities are outlined below:[12]

- **Power generation:** Hydrogen is expected to play a major role in Canada's power generation mix going forward. Canada has outlined an ambition for hydrogen to deliver 30% of domestic power supply by 2050. Hydrogen has been identified as a key fuel because it provides load management, energy storage capability and stability for off-grid solutions, it increases the viability of intermittent renewables, and it complements Canada's existing power generation mix and infrastructure – particularly hydroelectricity.
- **Transportation:** Hydrogen offers an opportunity to decarbonise transport in Canada. The current focus is on commencing further demonstration projects for medium- and heavy-duty fuel cell electric vehicles (FCEVs), with a view to accelerate commercialisation. Canada's speciality fuel cell vehicles (including marine, rail and aviation applications) will play a significant role once they reach technological maturity. To support the commercial up-take of FCEVs, the Canadian Government legislated federal targets for zero-emission vehicles (ZEVs) to reach 30% of light-duty passenger vehicles by 2030 and 100% by 2040. Provincial governments, including British Columbia and Quebec, have established regulations and subsidy programs to support this.
- **Decarbonising industry:** Hydrogen will be utilised to support industry decarbonisation. For example, the *Hydrogen Strategy for Canada*[13] proposes hydrogen used in Canada's oil and gas sector, and chemical and ammonia sector needs to be decarbonised. Clean hydrogen can be used to replace fossil fuels in steel manufacturing. Specific to decarbonising the oil and gas sector, the most viable options identified are to either retrofit existing hydrogen production technology with carbon capture, utilisation and storage (CCUS) infrastructure or alternatively, develop clean hydrogen technology that does not emit CO_2. Additionally, hydrogen may be used as a substitute for natural gas in end-use applications within heavy industries such as the oil and gas sector, cement manufacturing, and the pulp and paper sector where high-grade heat is required, and other substitutes are not technologically or economically viable.
- **Heat for buildings:** Hydrogen blending with natural gas will be considered as a potentially viable method to reduce emissions in Canada's natural gas supply. At present, several jurisdictions in Canada are conducting natural gas blending in heating pilot projects to assess the techno-economic feasibility of commercial-scale hydrogen blending.

Approaches to implementing the hydrogen strategy will vary across Canadian provinces. Importantly, the *Hydrogen Strategy for Canada*[14] notes that Canada's hydrogen ambitions will only be realised if provinces tailor strategies to local profiles and various factors specific to the region, such as natural resource availability, existing infrastructure and economic needs. Several Canadian provinces have developed their own hydrogen-specific strategies, or tangentially discussed the role of hydrogen in planning documents more broadly.

[12] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[13] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[14] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

Provincial-level strategic hydrogen priorities – to the extent they have been articulated in planning documents – are outlined in Table 2 below.

Table 2: Provincial-level hydrogen priorities

Province	Hydrogen Priorities
British Columbia	In June 2021, British Columbia released the *B.C Hydrogen Strategy.*[15] The Strategy identifies 63 hydrogen-specific actions to support the transition to net-zero emissions. Key strategic priorities include scaling-up hydrogen production from renewables, development of hydrogen hubs and the roll-out of transport applications, fuel cells, and zero emission vehicles.[16]
Alberta	In December 2020, Alberta released the *Alberta Hydrogen Roadmap*[17] which identified the region's existing oil and gas infrastructure as an advantage to produce hydrogen through SMR with CCUS.
Ontario	In November 2020, Ontario released the *Ontario Low-Carbon Hydrogen Strategy Discussion Paper.*[18] This paper identifies hydrogen production from renewables and natural gas blending as key priorities to facilitate the transition towards net-zero emissions.
Quebec	In November 2020, Quebec released the *2030 Plan for a Green Economy*[19] which outlined the region's desire to be a leader in hydrogen production from renewables. In 2022 Quebec released its strategy on clean hydrogen and biofuels.[20]

Canada's hydrogen targets

Though Canada has not prescribed targets, the *Hydrogen Strategy for Canada* outlines a 'Vision for 2050' which establishes ambitions for hydrogen utilisation, production and demand across Canada. These include: [21]

- **Production:** For Canada to be a global top 3 producer of hydrogen from renewable sources. To produce 4 Mt per year of clean hydrogen by 2030 and 20 Mt per year by 2050;
- **Emissions reduction:** For hydrogen production and utilisation to directly contribute to a 190 Mt-CO_2-e greenhouse gas emission reduction per year;
- **Cost:** To develop a strong domestic supply of low-carbon hydrogen, with prices ranging from CAD 1.5-3.5 per kg;

[15] Government of British Columbia and CleanBC (2021) B.C. Hydrogen Strategy: A sustainable pathway for B.C.'s energy transition. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/electricity/bc-hydro-review/bc_hydrogen_strategy_final.pdf

[16] Government of British Columbia and CleanBC (2021) B.C. Hydrogen Strategy: A sustainable pathway for B.C.'s energy transition. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/electricity/bc-hydro-review/bc_hydrogen_strategy_final.pdf

[17] Government of Alberta (2021) Alberta Hydrogen Roadmap. https://open.alberta.ca/dataset/d7749512-25dc-43a5-86f1-e8b5aaec7db4/resource/538a7827-9d13-4b06-9d1d-d52b851c8a2a/download/energy-alberta-hydrogen-roadmap-2021.pdf

[18] Government of Ontario (2020) Ontario Low-Carbon Hydrogen Strategy [Discussion Paper]. https://prod-environmental-registry.s3.amazonaws.com/2020-11/Ontario%20Low-Carbon%20Hydrogen%20Strategy%20-%20discussion%20paper%20%28November%202020%29.pdf

[19] Quebec Government (2021) 2030 Plan for a Green Economy. https://www.quebec.ca/en/government/policies-orientations/plan-green-economy

[20] Québec Green Hydrogen and Bioenergy Strategy | Gouvernement du Québec (quebec.ca)

[21] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

- **Electricity generation:** 30% of Canada's energy delivered by hydrogen, with domestic supply of >20 Mt per year;
- **Gas networks:** For >50% of Canada's natural gas supply to be blended with hydrogen through existing and repurposed pipeline infrastructure;
- **Mobility:** Federal targets for zero-emission light vehicles (including hydrogen vehicles and battery electric vehicles, and plug-in hybrid vehicles), of 10% by 2025 (light vehicles), 30% by 2030, and 100% by 2050; and
- **Export:** Canada's strategy notes that exports could reach CAD ~50 billion by 2050.[22]

1.2.3 Canada's hydrogen RD&D priorities

Whilst research institutions and industry have been active in hydrogen RD&D activities, Canada is yet to formally outline specific RD&D priorities. However, some RD&D priorities can be identified from the 2020 *Hydrogen Strategy for Canada*.[23] Table 3 summarises Canada's RD&D priorities by sub-technology area, and these were supplemented by in-country consultations.

Table 3: Canada's Hydrogen RD&D priorities

Supply chain Area	Sub-technology Areas	Canada's key RD&D priorities
Production	Electrolysis (renewable)	Electrolysis from renewable energy (particularly hydroelectricity, and to a lesser degree wind, possibly offshore wind). Decrease cost of and improve efficiency of electrolysis. Polymer electrolyte membrane electrolysis (PEM) and alkaline electrolysis (AE) are considered but R&D priorities are not articulated. Solid oxide electrolysis cells (SOE) commercialisation and improved cost effectiveness. Pairing SOE with output heat from geothermal and solar thermal systems. An emerging area of research in Canada is anion exchange membrane (AEM) electrolysis.[24]
	Fossil fuel conversion with CCUS	Gasification of crude oil and bitumen with CCUS. Retrofitting existing SMR technology with CCUS, Canada's current primary hydrogen production method. Improvements in CCUS technology, including reducing CO_2 capture and compression technology costs. Autothermal reforming with CCUS is also considered but R&D priorities are not articulated in the strategy document.

[22] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf; The Transition Accelerator (2020) Towards Net-Zero Energy Systems in Canada: A key Role for Hydrogen. https://transitionaccelerator.ca/wp-content/uploads/2020/09/Net-zero-energy-systems_role-for-hydrogen_200909-Final-print-1.pdf

[23] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[24] Additional priorities from in-country stakeholder consultations

Supply chain Area	Sub-technology Areas	Canada's key RD&D priorities
	Low carbon fossil fuel conversion	Developing methane pyrolysis (thermal and plasma). An alternative to SMR which provides the benefit of generating solid carbon which can be readily captured (alleviating the need for gaseous CO_2 capture and geological sequestration).
	Biomass and waste conversion	Biomass gasification with CCUS and methane conversion from waste is identified but specific R&D priorities are not articulated in the strategy.
	High temperature nuclear and electrolysis	Techno-economic analysis to assess the feasibility of nuclear hydrogen production (currently underway at the Bruce Nuclear Generating Station). Continued development of small modular reactors. Commercial scale-up in the long term. SOE commercialisation and improved cost effectiveness. Pairing SOE electrolysers with output heat from nuclear energy systems. Steam methane reforming could use steam produced by nuclear energy systems as the reactant, which could eliminate the need to use natural gas.
Storage and distribution	Compressed hydrogen	Commercialise greater than 450 bar storage and transportation vessels by 2030 using composite materials. Scale-up distribution networks in urban areas and clusters.
	Liquid hydrogen	Large-scale insulated tanks (including tanker trucks), decreasing cost of liquefaction and reduced boil-off. On-board storage of liquefied hydrogen (e.g. marine and rail vessels, heavy duty trucks). Scale-up distribution networks in urban areas and clusters.
	Chemical carriers	Ammonia and methylcyclohexane (MCH) are identified as priorities, but R&D priorities are not articulated.
	Physisorption	Adsorbent storage, further research to ascertain potential.
	Underground storage	Commercial scale underground storage in salt caverns by 2030- 2050. Depleted gas well storage in the medium term.
	Gas networks and pipelines	By 2030, commercialise blended hydrogen in utility distribution and transmission systems, and demonstrate dedicated hydrogen pipelines. Establish mini grids at industrial sites and transportation corridors. R&D to overcome material embrittlement, gas metering and end use appliance challenges (e.g. boilers, compressors, stoves and fireplaces). Separation technologies (separating hydrogen from natural gas).
Utilisation	FCEVs (passenger and commercial)	By 2025, commercial deployment of light and commercial vehicles. Specifically, developing cost-effective fuel cells, technology advancements and greater production scale to drive down costs of light hydrogen vehicles.

Supply chain Area	Sub-technology Areas	Canada's key RD&D priorities
		Pilot bus fleets and associated refuelling stations for fleets of >20 buses to support broader rollout. By 2030, commercial deployment of trucks and long-range vehicles and associated refuelling infrastructure. Specifically, hydrogen-diesel co-combustion in trucks (as an intermediate solution towards FCEVs, and a mechanism to support demand for refuelling network expansion). Hydrogen blending in compressed natural gas vehicles) including improvements to mitigate tank embrittlement and nitrous oxide (NOx) emissions. Refuelling stations with dual fuel sources (compressed natural gas and hydrogen). This requires separation technology.
	Fuel cells (other transport)	By 2030, demonstration deployments for fuel cells in rail, mining equipment, marine vessels, and ships. Commercial deployment of specialty equipment (e.g. seaport equipment and aviation applications). Integration of train and marine vessel pilots into port demonstration hubs. Technology procurement from overseas to enable 'leapfrogging'.
	Transport fuels	Methanol, synthetic fuel production, and carbon-neutral energy-dense liquid fuels for aviation and marine vessels). Demonstrate liquid synthetic fuels by 2030. Renewable ammonia as a shipping fuel is identified but no RD&D priorities are articulated.
	Electricity generation	Hydrogen combustion turbines. Increasing the proportion of hydrogen blended in existing power plants. Stationary fuel cell power plants. By 2030, demonstrations of off-grid and remote area power systems, back-up power, and shore power for ships in harbour. In the long term, grid integration.
	Industrial applications	By 2025, demonstration deployments of hydrogen combustion for industrial heat (blended hydrogen or pure hydrogen). Demonstrate clean hydrogen as a feedstock for chemical production and oil and gas upgrading by 2025. Retrofitting hydrogen production technologies in refineries, chemical plants, and ammonia plants with CCUS (noting that hydrogen use in refineries is responsible for significant CO_2 emissions). Move beyond experimental and pilot projects for hydrogen in the direct reduction of iron to produce steel. The steel sector is also considering the use of hydrogen (as a heat source, and for partial replacement of reduction agent) in existing assets to reduce their GHG footprint.[25] Cement manufacturing, pulp and paper production, and processes relying on steam production.

[25] Additional priorities from in-country stakeholder consultations.

Supply chain Area	Sub-technology Areas	Canada's key RD&D priorities
	Agriculture	Renewable nitrogen fertilizer production.
Cross cutting	Policy and regulation	Policy settings to incentivise rollout of the hydrogen economy in different sectors.
	Codes and standards	Development of hydrogen certification schemes. Harmonisation of codes and standards across jurisdictions. Development of hydrogen industry codes, technical standards and regulations. This also includes a carbon standard. Codes and standards related to pipeline blending and large-scale high pressure gas distribution (450 bar)
	Social license	Increasing public awareness of economic benefits and safety.

1.3 Canada's hydrogen RD&D ecosystem

1.3.1 Public bodies and policy ecosystem

Overview of Canada's STI policy landscape

Canada's science, technology, and innovation (STI) policy landscape is established at multiple levels of government: federal, provincial and territorial, and municipal. Several departments and agencies are tasked with delivering programs and services within the STI landscape, enabling activities such as RD&D.

Innovation, Science and Economic Development Canada (ISED) is a department responsible for fostering a competitive and innovative Canadian economy. ISED's portfolio consists of 18 organisations that leverage resources across their respective domains to provide nation-wide benefits in areas of trade and investment, SME growth, community development, and innovation through science and technology.[26] Moreover, the ISED is responsible for administering acts and regulations for these areas. Member organisations particularly relevant to RD&D include the National Research Council (NRC) and the Natural Sciences and Engineering Research Council Canada (NSERC).

Research in Canada occurs across various bodies, each with their own respective grant and funding system. Public research is often conducted in federal laboratories and occur through government agencies such as the NRC and NRCan. For industrial research, NRC offers support for technological innovation through its Industrial Research Assistance Program (NRC IRAP) aimed at small and medium enterprises (SMEs), with much of the STI research in universities being funded by Natural Sciences and Engineering Research Council (NSERC) – a leading Canadian federal agency.[27] Further, ISED and Health Canada have also developed the Strategic Science Fund (SSF), which aims to mobilise independent third-party science and research organisations through a principles-based framework that allocates federal funding to these groups.[28]

[26] ISED (2021) Innovation, Science and Economic Development portfolio. https://www.ic.gc.ca/eic/site/icgc.nsf/eng/h_00022.html

[27] BRC (2021) Support for Technology Innovation. https://nrc.canada.ca/en/support-technology-innovation; Natural Sciences and Engineering Research Council of Canada (NSERC) (2021) About. https://www.nserc-crsng.gc.ca/NSERC-CRSNG/Index_eng.asp

[28] Government of Canada (2021) Strategic Science Fund. Innovation, Science and Economic Development Canada. https://www.ic.gc.ca/eic/site/155.nsf/eng/h_00000.html

Despite funding for scientific research predominately coming from the federal government, there is a wide array of provincial and municipal-level initiatives and organisations that support innovation and competitiveness, typically complementing federal policies and programs.[29] Provincial and municipal academic institutions often operate their own schemes for scientific research, with a number of R&D companies also participating in the STI space.[30] As such, Canada's federal STI policies and programs form a network structure which places emphasis on provincial and cluster development.[31]

Overview of Canada's hydrogen policy landscape

The 'Hydrogen Strategy Implementation Strategic Steering Committee' will coordinate and monitor the implementation of Canada's hydrogen strategy.[32] The Committee's role is to identify strategic priorities, share knowledge, and monitor the progress of the Strategy's implementation.

Within Canada's STI system, the governing bodies for the transportation, infrastructure, and energy sectors are of particular relevance to hydrogen. NRCan operates as a leading research body and represents Canada at an international level with regard to global commitments to the sustainable development of natural resources.[33] NRCan also led the development of the *Hydrogen Strategy for Canada*.[34] Transport Canada's Innovation Centre plays a national role in transport-related RD&D to support emerging technologies and ensure a safe, clean and integrated transportation system. This includes zero-emissions vehicles and hydrogen FCEVs. To achieve this, Transport Canada's Innovation Centre engages with a range of government programs including ITS Architecture for Canada, Innovation Solutions Canada, the Build in Canada Innovation Program, and the Program to Advance Connectivity and Automation in the Transportation System (ACATS).[35]

As has been noted in *Section 1.2.2* Canada's strategic hydrogen industry priorities *Canada's strategic hydrogen industry priorities,* individual provinces have developed their own hydrogen-specific strategies. This suggests variations in regulatory, policy and legal frameworks between regions as each province seeks to incentivise RD&D investments that align with their provincial strategic priorities and areas of economic development. A key issue noted in the *Hydrogen Strategy for Canada*[36] is the lack of comprehensive regulatory and policy frameworks across provinces.[37] While robust in nature, the lack of a broader policy framework may ultimately hinder the uniform implementation of new and emerging hydrogen technologies.[38] In response, in April 2021 the Minister of Natural Resources announced the establishment

[29] Salazar M and Holbrook (2007) Canadian Science, Technology and Innovation Policy: The Product of Regional Networking?, Regional Studies, 41:8. DOI: 10.1080/00343400701530865

[30] Research Infosource Inc. (2020) Canada's Top 100 Corporate R&D Spenders 2020. https://researchinfosource.com/top-100-corporate-rd-spenders/2020/list

[31] Salazar M and Holbrook (2007) Canadian Science, Technology and Innovation Policy: The Product of Regional Networking?, Regional Studies, 41:8. DOI: 10.1080/00343400701530865

[32] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[33] NRCan (2021) About Us. <https://www.nrcan.gc.ca/home/about-us/10838>

[34] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[35] Transport Canada (2019) Innovation Centre. https://tc.canada.ca/en/innovation-centre

[36] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[37] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[38] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

of the Hydrogen Strategy Implementation Strategic Steering Committee.[39] Several working groups are in the process of being established to work alongside the steering committee, ultimately forming the general structure for Canadian hydrogen governance.[40] These working groups cover hydrogen development, codes and standards, and innovation across various sectors.

Figure 3: Summary of Canada's hydrogen RD&D policy ecosystem

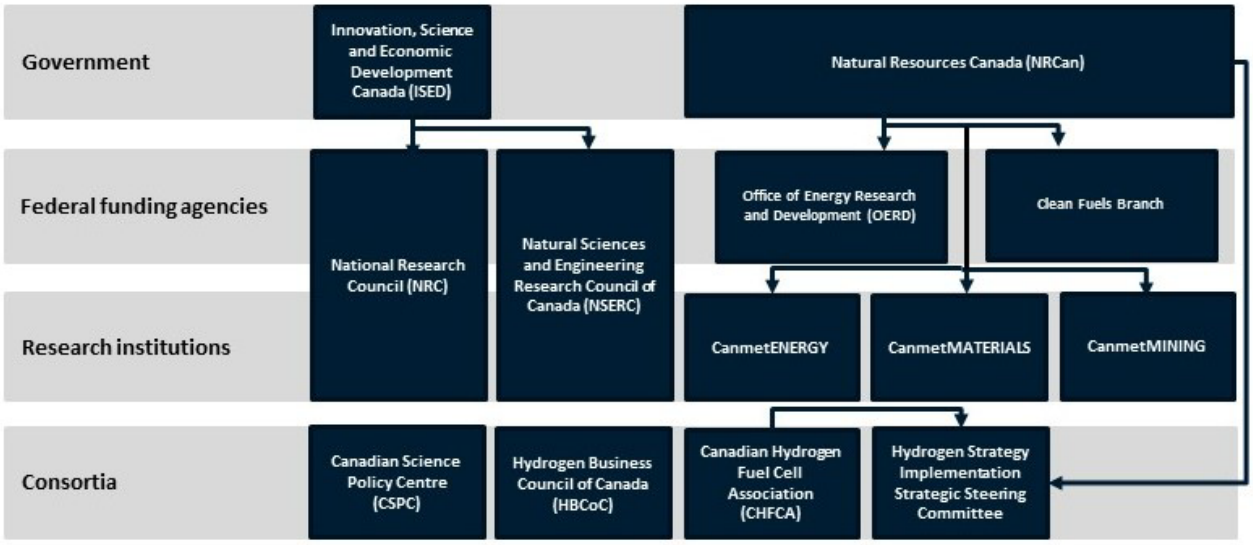


Table 4: Summary of key regulatory bodies

Body	Role in RD&D Ecosystem	Hydrogen Initiatives
ISED *Innovation, Science and Economic Development Canada*	ISED is a department of the Canadian government responsible for fostering a competitive Canadian economy.[41] Its core responsibilities are to oversee: the growth and investment of Canadian companies; people, communities and skills; and RD&D and commercialisation of science and technology.[42]	ISED supports hydrogen-related RD&D projects through the distribution of grants, the provision of programs and services, and overseeing regulation and legislation.[43]
NRCan *Natural Resources Canada*	NRCan plays a leading role in clean energy RD&D at a federal level as a funder through the OERD (see below), and as an actor through its CanmetENERGY,	NRCan was the federal department responsible for the collation and publishing

[39] Government of Canada (2021) Canada Launches Hydrogen Strategy Steering Committee. https://www.canada.ca/en/natural-resources-canada/news/2021/04/canada-launches-hydrogen-strategy-steering-committee.html

[40] Consultation with in-country stakeholders

[41] Government of Canada (2021) Innovation, Science and Economic Development Canada., https://www.ic.gc.ca/eic/site/icgc.nsf/eng/home

[42] Government of Canada (2021) Infographic for Innovation, Science and Economic Development Canada. https://www.tbs-sct.gc.ca/ems-sgd/edb-bdd/index-eng.html#orgs/dept/130/infograph/results

[43] Government of Canada (2021) Infographic for Innovation, Science and Economic Development Canada. https://www.tbs-sct.gc.ca/ems-sgd/edb-bdd/index-eng.html#orgs/dept/130/infograph/results; Government of Canada (2021) Programs and Initiatives. https://www.ic.gc.ca/eic/site/icgc.nsf/eng/h_07654.html

Body	Role in RD&D Ecosystem	Hydrogen Initiatives
	CanmetMATERIALS and CanmetMINING laboratories.[44]	of the *Hydrogen Strategy for Canada* published in 2020.[45] NRCan is co-chair of the Hydrogen Strategy Steering Committee, alongside the CHFCA.[46] NRCan typically funds demonstration projects, whereas R&D projects are typically funded by the NSERC (see below).
OERD *The Office of Energy Research and Development*	The OERD sits under NRCan and is responsible for overseeing the management and development of energy RD&D across the federal government.[47] It is a chief funding mechanism for energy-related RD&D activities.	The OERD has sponsored several CCUS RD&D projects in Canada including applications to hydrogen production such as the Alberta Carbon Trunk Line (ACTL) which became operational in 2020 and Shell Quest that became operational in 2015.[48] Further, it manages the Energy Innovation Program (EIP) which has an annual funding of CAD 24 million for projects through a targeted calls mechanism - including rounds for proposals focussed on CCUS and clean fuel/industrial fuel switching projects. OERD also has a long history of funding transportation RD&D projects, including the ongoing Alberta Zero Emissions Truck Electrification Collaboration (AZETEC) project.[49]
NSERC *Natural Sciences and Engineering Research Council of Canada*	NSERC sits under IESD and is the major federal agency responsible for funding natural sciences and engineering research and wider RD&D projects.[50]	Broadly, NSERC funds and supports RD&D hydrogen projects. NSERC has entered into a partnership with the German Federal Ministry of Education and Research to conduct collaborative research on fuel cell and hydrogen technologies.[51]

[44] Mission Innovation. Canada: Plans and Priorities., http://mission-innovation.net/our-members/canada/plans-and-priorities/

[45] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[46] Government of Canada (2021) Canada Launches Hydrogen Strategy Steering Committee [News Release]. https://www.canada.ca/en/natural-resources-canada/news/2021/04/canada-launches-hydrogen-strategy-steering-committee.html

[47] Government of Canada (2021) Federal Internal Energy R&D. https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/funding-grants-incentives/program-energy-research-development/4993

[48] Dalziel M and Walker A (2020) Natural Resources Canada Office of Energy Research and Development Carbon Capture and Storage Investments 1990-2020. The Evidence Network. DOI: 10.13140/RG.2.2.14495.89763

[49] Government of Canada (2021) Energy Innovation Program. https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/funding-grants-incentives/energy-innovation-program/18876

[50] NSERC (2021) About. https://www.nserc-crsng.gc.ca/NSERC-CRSNG/Index_eng.asp

[51] NSERC (2020) Pre-announcement of call for joint Canada-Germany projects on hydrogen and fuel cell technologies. https://www.nserc-crsng.gc.ca/Media-Media/NewsDetail-DetailNouvelles_eng.asp?ID=1204

Body	Role in RD&D Ecosystem	Hydrogen Initiatives
		Academic R&D projects are typically funded by NSERC, whereas NRCan funds both R&D and demonstration.
Hydrogen Strategy Implementation Strategic Steering Committee	The steering committee is co-chaired by NRCan and the CHCFA, with the remaining members being a consortia of industry leaders, provincial partners, indigenous partners, and NGOs. The role of the steering committee is to implement the recommendations and track progress of the *Hydrogen Strategy for Canada*.[52]	In implementing the recommendations of the *Hydrogen Strategy for Canada*, the steering committee commits to actions supporting and facilitating the 8 pillar recommendations and encouraging actions of others in areas outside its direct purview.[53]
CanmetENERGY	Sits under NRCan. CanmetENERGY is Canada's leading research and technology organisation for clean energy and consists of three research centres located in Alberta, Ontario and Quebec.[54]	Current hydrogen related RD&D includes on-site hydrogen production for iron-making (Ontario); advanced hydrogen production from methane using natural gas decarbonisation (Ontario); hydrogen production from unconventional petroleum sources (Alberta); and optimising hydrogen consumption during bitumen upgrading and refining procedures (Alberta).[55]
CanmetMATERIALS	Sits under NRCan. CanmetMATERIALS is the largest research centre in Canada in fabricating, processing and evaluating materials and consists of two centres located in Hamilton and Calgary.	CanmetMATERIALS participates in transportation, building and industry areas, which may involve the use of hydrogen energy produced from renewables.[56]
CanmetMINING	Sits under NRCan. CanmetMINING is the science and technology branch of the Minerals and Metals sector of NRCan. Key sectors of application include energy (renewable and fossil); environmental technologies; and mining, minerals and metals.	In 2016 CanmetMINING released the *CanmetMINING research plan 2016-2021: Green Mining Initiative,*[57] which outlines plans to deploy green technologies, manage risks in the mining ecosystem, and employ science-based regulations. CanmetMINING has been active in reviewing and revising the *Canadian Hydrogen Installation Code*.[58] Other key projects include feasibility and field tests for large-scale hydrogen

[52] Government of Canada (2021) Canada Launches Hydrogen Strategy Steering Committee [News Release]. https://www.canada.ca/en/natural-resources-canada/news/2021/04/canada-launches-hydrogen-strategy-steering-committee.html

[53] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[54] NRCan (2021) CanmetENERGY research centres. https://www.nrcan.gc.ca/energy/energy-offices-and-labs/canmetenergy/5715

[55] NRCan (2021) CanmetENERGY research centres. https://www.nrcan.gc.ca/energy/energy-offices-and-labs/canmetenergy/5715

[56] NRCan (2021) CanmetMATERIALS https://www.nrcan.gc.ca/mining-materials/materials-technology/17539

[57] NRCan (2016) CanmetMINING Research Plan 2016-2021: Green Mining Initiative. https://publications.gc.ca/collections/collection_2017/rncan-nrcan/M154-107-2016-eng.pdf

[58] NRCan (2019) Towards Deployment of Vehicle Hydrogen Power by the Canadian Mining Industry. https://worldcongress.energyandmines.com/files/2-40-Implementing-Hydrogen-for-Mines-and-Building-a-Regulartory-Framework-Marc-Betournay-Natural-Resources-Canada.pdf

Body	Role in RD&D Ecosystem	Hydrogen Initiatives
		infrastructure, underground refuelling infrastructure planning, and the demonstration of a fuel cell locomotive for use in underground mining and tunnelling.[59]
NRC *National Research Council*	The NRC is Canada's largest federal R&D organisation. The NRC partners with Canadian industry and universities to take research impacts from the laboratory to the marketplace. The NRC is a federal agency under ISED. The NRC supports RD&D efforts through its strategic and collaborative research centres, advisory services, and licencing opportunities.[60] Within the NRC is the Industrial Research Assistance program (NRC-IRAP), which provides an avenue for local SMEs to receive funding for science and innovation-based initiatives.[61]	Currently the NRC is running 5 programs related to hydrogen technologies: the Advanced Clean Energy program; Clean and Energy-efficient Transportation program; Low-emission Aviation program; Materials for Clean Fuels Challenge program; and the NRC Capabilities in clean energy and resources.[62]

1.3.2 Hydrogen consortia

Table 5: Hydrogen consortia

Consortium	Description
CHFCA *Canadian Hydrogen and Fuel Cell Association*	The CHFCA is a national association comprised of industry, academia, government agencies, and financial organisations, focussed on enhancing and commercialising hydrogen and fuel cell technologies. The CHFCA facilitates the RD&D projects of its members by offering market development and business opportunities; promoting hydrogen and fuel cell technologies with policy makers; and supporting the development of regulations, codes and standards of hydrogen-related products.[63] Member projects are broad but may include fuel cell vehicle systems; hydrogen fuelling infrastructure; hydrogen storage and production; stationary, portable or back-up energy solutions; and vehicle manufacturing.[64]

[59] NRCan (2019) Towards Deployment of Vehicle Hydrogen Power by the Canadian Mining Industry. https://worldcongress.energyandmines.com/files/2-40-Implementing-Hydrogen-for-Mines-and-Building-a-Regulartory-Framework-Marc-Betournay-Natural-Resources-Canada.pdf; R Sage and M Bétournay (2003) Application of Fuel Cells in Underground Mining and Tunnelling. JS International Mining Congress and Exhibition of Turkey https://www.maden.org.tr/resimler/ekler/6869a35be893ac2_ek.pdf

[60] Government of Canada (2021) Research and Development, National Research Council. https://nrc.canada.ca/en/research-development

[61] Government of Canada (2021) Support for Technology Innovation, National Research Council. https://nrc.canada.ca/en/support-technology-innovation

[62] Government of Canada (2021) Programs, National Research Council. https://nrc.canada.ca/en/research-development/research-collaboration/programs?search_api_fulltext=hydrogen

[63] CHFCA (2021) About. http://www.chfca.ca/about/who-we-are/

[64] CHFCA (2021) The Canadian Hydrogen and Fuel Cell Association.http://www.chfca.ca/

Consortium	Description
Hydrogène Québec and Hydrogen BC	Hydrogène Québec and Hydrogen BC are provincial branches of the CHFCA that support the commercialisation of hydrogen and fuel cell technology in Québec and British Columbia respectively. Like the CHFCA, they are a coalition comprised of research institutions, end users, key stakeholders, and companies that operate within the space of the hydrogen value chain.[65] Key focuses include communications, advocacy, the establishment and maintenance of partnerships, and supporting and encouraging the development of hydrogen projects.
HBCoC Hydrogen Business Council of Canada	The HBCoC is an association made up of corporate stakeholders, government agencies, non-governmental organisations, academic and start-up organisations, local distribution companies, and individuals/students, with the overarching goal to apply and benefit from the utilisation of hydrogen.[66] The HBCoC supports and facilitates the uptake of hydrogen in global centres across the Greater Toronto Area, with its main priorities relating to awareness and education, infrastructure road-mapping, and enabling hydrogen projects.[67]
CSPC Canadian Science Policy Centre	The CSPC is a non-profit and non-partisan organisation that operates as a hub to assist the development of effective science and innovation policy through four pillars of action: convening; connecting stakeholders including scientists, society sectors, and international organisations; building capacity by offering science policy training; and catalysing research in areas of science policy.[68]
The Transition Accelerator	The Transition Accelerator is a pan-Canadian charity that seeks to support Canada's transition to a net zero future. The Accelerator brings together innovators, progressive industry, and researchers. Developing Canada's hydrogen economy is one of the Accelerators current priorities.[69] The Accelerator is part of Alberta's Industrial Heartland Hydrogen Task Force (AIHH).[70]

1.3.3 Funding mechanisms

Overview of Canada's hydrogen public budget allocations

The Canadian Government continues to prioritise science and technology RD&D, which is reflected in government expenditure and budget allocations. In FY 2019/2020, government expenditure on science and technology activities – which includes R&D projects – reached CAD 12.8 billion.[71] R&D activities accounted for 60.9% of science and technology expenditure in FY 2019/2020 and increased by 3.3% to CAD 7.8 billion.[72]

[65] FuelCellsWorks (2020) Canadian Hydrogen and fuel Cell Sector Applauds National Strategy Released by Federal Government, FuelCellsWork. https://fuelcellsworks.com/news/canadian-hydrogen-and-fuel-cell-sector-applauds-national-strategy-released-by-federal-government/

[66] HBCoC (2021) Our Word & Events http://www.h2gta.ca/our_work_events/

[67] FuelCellsWorks (2020) Canadian Hydrogen and fuel Cell Sector Applauds National Strategy Released by Federal Government, FuelCellsWork. https://fuelcellsworks.com/news/canadian-hydrogen-and-fuel-cell-sector-applauds-national-strategy-released-by-federal-government/

[68] CSPC (2018) Canadian Science Policy Centre Strategic Plan: Strengthening science through Convening, Connecting, Capacity Building and Catalysing. < https://cdn.sciencepolicy.ca/wp-content/uploads/2020/10/cspc_strategicplan_01_digital_03_21_2018_1.pdf>

[69] https://transitionaccelerator.ca/our-work/hydrogen/

[70] https://transitionaccelerator.ca/our-work/hydrogen/alberta-industrial-heartland-hydrogen-task-force/

[71] Statistics Canada (2021) Federal government spending on science and technology, 2021/2022. https://www150.statcan.gc.ca/n1/daily-quotidien/210610/dq210610e-eng.htm

[72] Statistics Canada (2021) Federal government spending on science and technology, 2021/2022. https://www150.statcan.gc.ca/n1/daily-quotidien/210610/dq210610e-eng.htm

The NRC estimates that between CAD 5 to 7 billion of public and private sector investment will be necessary to sufficiently develop Canada's hydrogen economy.[73] However, the 2020 *Hydrogen Strategy for Canada*[74] notes that both public and private sector funding for hydrogen RD&D has fallen since 2012.[75] This figure is not specific to RD&D but is an estimate of total expenditure required to develop the hydrogen industry more broadly. More recently, Canada's 2021 budget allocated CAD 5 billion to the Net Zero Accelerator initiative, which accelerates clean technology R&D.[76]

In addition to increasing hydrogen funding commitments and budget allocations, the Hydrogen Strategy also recommends the following measures to 'de-risk' investments and stimulate hydrogen RD&D expenditure:[77]

- Implementing long-term policies which increase market demand for hydrogen, thus de-risking private sector investment;
- Facilitating co-funding opportunities with key stakeholders, including international public and private-sector collaborations; and
- Establishing strong procurement policies, which may increase the viability of demonstration projects.

Public funding mechanisms for hydrogen RD&D

Canada has well-established RD&D funding mechanisms, many of which are administered by government bodies and funding agencies including the NRC IRAP and NSERC.[78] Key funding mechanisms, including funding calls administered by government agencies, are outlined in Table 6 below.

Table 6: Federal-level R&D funding mechanisms

Program	Type	Details	International eligibility to participate
Canada Infrastructure Bank (CIB)[79]	Demonstration; Commercialisation	Whilst not hydrogen-specific, the Canada Infrastructure Bank's role is to provide funding to revenue-generating infrastructure projects that are in the public interest. This includes projects that reduce greenhouse gas emissions and facilitate the transition to net-zero emissions, such as hydrogen production projects.	No data.

[73] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[74] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[75] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[76] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[77] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[78] Karaca A and Dincer I (2021) An updated overview of Canada's hydrogen related research and development activities. Hydrogen Energy Publications LLC. DOI: 10.1016/j.ijhydene.2021.07.235

[79] CIB (2021) Home page. https://cib-bic.ca/en/

Program	Type	Details	International eligibility to participate
		However, funding is limited to revenue-generating projects at the commercialisation or deployment stage. CAD 35 billion has been allocated to fund infrastructure projects. It is hoped this funding will attract further private and institutional investment in Canada.	
Strategic Innovation Fund (Net-Zero Accelerator)[80]	R&D	A part of the Strategic Innovation Fund, the Net Zero Accelerator initiative seeks to promote R&D, facilitate increased investment, and support national deployment of clean technology.[81] The initiative will allocate CAD 8 billion to fund decarbonisation and clean-technology R&D and commercialisation projects – including hydrogen – across the following focus areas:[82] • Decarbonisation of large and hard-to-abate emitters; • Clean-technology and industrial transformation; • Battery innovation and the industrial ecosystem more broadly.	Potentially. Various conditions apply depending on the stream; however, the Lead applicant must be a Canadian entity.[83]
Low and Zero-Carbon Fuels Fund	RD&D; Commercialisation	The Low-Carbon and Zero Emissions Fuels Fund provides funding to RD&D and commercialisation projects to increase the production and utilisation of low-carbon fuels, including hydrogen. CAD 1.5 billion in funding is available for allocation.	No. Eligible applicants must be incorporated or registered in Canada.
Energy Innovation Program (EIP) (NRCAN)	RD&D	The EIP funds RD&D projects which accelerate clean energy technologies. Administered by OERD, the EIP runs targeted funding calls.[84]	No. Eligible applicants must be incorporated

[80] Environment and Climate Change Canada (2020) A healthy environment and a healthy economy: Canada's strengthened climate plan to create jobs and support people, communities and the planet, Government of Canada. https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf

[81] Government of Canada (2021) Net Zero Initiative, Innovation, Science and Economic Development Canada. https://www.ic.gc.ca/eic/site/125.nsf/eng/00039.html

[82] Environment and Climate Change Canada (2020) A healthy environment and a healthy economy: Canada's strengthened climate plan to create jobs and support people, communities and the planet, Government of Canada. https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf

[83] Government of Canada (2021) Strategic Innovation Fund – Program Guide, Innovation, Science and Economic Development Canada. https://www.ic.gc.ca/eic/site/125.nsf/eng/00007.html#b

[84] NRCan (2021) Energy Innovation Program, Government of Canada. https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/funding-grants-incentives/energy-innovation-program/18876

Program	Type	Details	International eligibility to participate
		An example of a funding call is the 'Clean Fuels and Industrial Switching' program, which is accepting applications up to 2 February 2022. Key focus areas for this funding call include:[85] • Industrial fuel switching; • Clean fuels production; and • Hydrogen codes and standards. CAD 53 million is available for allocation.	or registered in Canada.[86]
Sustainable Development Technology Canada – Clean Tech Fund (SDTC)[87]	RD&D; Commercialisation	Whilst not hydrogen-specific, the Clean Tech Fund provides funding to a variety of clean technology companies seeking to start or scale up RD&D, market research, commercialisation, or deployment activities. Since 2001, the Fund has invested CAD 1.38 billion in 460 companies.	No. Eligible applicants must be a registered company in Canada.[88]
Alliance Grants (NSERC)	R&D	The Alliance Grants have replaced several research partnerships, including the Collaborative Research and Development (CRD) Grants and the Strategic Partnership Grants (SPG).[89] The Alliance grants are funded by the NSERC for university researchers collaborating with research partners from the public, private and not-for-profit sectors.[90] Grants range from CAD 20,000 to 1 million per year for one to five years.[91] These grants are not hydrogen-specific but are aligned with Canada's key R&D areas, of which hydrogen is included.	Potentially, but must have a minimum 3-year contract at a Canadian institute or university upon applying.[92]

[85] BRCan (2021) Energy Innovation Program – Clean Fuels and Industrial Fuel Switching. https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/funding-grants-incentives/energy-innovation-program/energy-innovation-program-clean-fuels-and-industrial-fuel-switching/23956

[86] NRCan (2021) Innovation and Clean Growth Research, Development, and Demonstration Programs, Government of Canada. https://www.nrcan.gc.ca/science-data/funding-partnerships/funding-opportunities/funding-grants-incentives/energy-innovation-program/innovation-and-clean-growth-research-development-and-demonstration-programs/20024

[87] SDTC (2020) Clean Tech Fund. https://www.sdtc.ca/en/cleantech-fund/

[88] SDTC (2020) Clean Tech Fund. https://www.sdtc.ca/en/cleantech-fund/

[89] NSERC (2019) Strategic Partnership Grants, Government of Canada. https://www.nserc-crsng.gc.ca/professors-professeurs/rpp-pp/spg-sps_eng.asp

[90] NSERC (2021) Alliance Grants, Government of Canada. https://www.nserc-crsng.gc.ca/innovate-innover/alliance-alliance/index_eng.asp

[91] NSERC (2021) Alliance Grants, Government of Canada. https://www.nserc-crsng.gc.ca/innovate-innover/alliance-alliance/index_eng.asp

[92] NSERC (2021) Eligibility Criteria for Faculty, Government of Canada. https://www.nserc-crsng.gc.ca/NSERC-CRSNG/Eligibility-Admissibilite/faculty-corpsprof_eng.asp

Program	Type	Details	International eligibility to participate
Business Development Bank of Canada Clean Tech Practice	Demonstration; Commercialisation	The Business Development Bank of Canada (BDC) funds equity and commercial loans to clean technology companies that have market-ready or at-scale products. The BDC has committed CAD 600 million over the 2018-2023 period.[93]	No data.
Clean Fuels Fund (CFF) **(NRCAN)**	RD&D; Commercialisation	The CFF is administered by NRCan. The CAD 1.5 billion fund was established to overcome key barriers identified in Canada's hydrogen strategy; particularly the lack of private investors willing to back expensive projects with high capital without a proven market.[94] There are three core components of the fund designed to support various aspects of the RD&D process; the first two of these components will be delivered through the NRCan Clean Fuels Program:[95] • CAD 1.38 billion to support the construction, upgrade and expansion of facilities associated with clean energy; and any related feasibility, engineering and front-end engineering and design (FEED) studies. • CAD 30.4 million to aid to development of biomass supply chains and related feasibility assessments. • CAD 19.4 million to support the first two components through the development of codes, standards and regulations associated with clean fuel technologies. Funding is provided through conditionally repayable contribution agreements up to 30% of project cost.	No. Eligible applicants must be incorporated or registered in Canada.[96]
Ontario Clean Technology Industry Association –	Development; Demonstration; Commercialisation	Up to CAD 15,000 available for Canadian SMEs that are developing or have developed a technology or service that can be used in the hydrogen value chain.	No. Eligible applicants must be incorporated or registered in Canada.

[93] BDC (2021) Cleantech firms: Capital and advice for every stage of growth. https://www.bdc.ca/en/i-am/clean-technology-firms

[94] NRCan (2021) Clean Fuels Fund - Building New Domestic Production Capacity, Government of Canada. https://www.nrcan.gc.ca/climate-change/canadas-green-future/clean-fuels-fund/clean-fuels-fund-building-new-domestic-production-capacity/23726

[95] NRCan (2021) Clean Fuels Program – Building New Domestic Production Capacity, Government of Canada. https://www.nrcan.gc.ca/sites/nrcan/files/energy/clean/CFP%20Applicant's%20Guide.pdf

[96] NRCan (2021) Clean Fuels Program frequently asked questions - Building new domestic production capacity, Government of Canada. https://www.nrcan.gc.ca/climate-change/canadas-green-future/clean-fuels-fund/clean-fuels-fund-building-new-domestic-production-capacity/climate-changecanadas-green-futureclean-fuels-fundclean-fuels-fund-building-new-domes

Program	Type	Details	International eligibility to participate
Hydrogen Connect			
Export Development Canada (EDC)	Demonstration; Commercialisation	Provides project financing to Canadian companies seeking to undertake high-impact clean technology projects overseas.	No data.
Electric Vehicle Infrastructure Demonstration (EVID) Program (NRCAN)	Development; Demonstration	The Electric Vehicle Infrastructure Demonstration (EVID) is allocating up to $76M (2016 to 2024) to support the demonstrations of next-generation and innovative ZEV charging and hydrogen refuelling infrastructure.	No. Eligible applicants must be incorporated or registered in Canada.
Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative (NRCAN)	Deployment	Under NRCan, this initiative provides CAD 96.4 million over six years (April 2016 to March 2022) for the establishment of refuelling infrastructure, including the deployment of hydrogen refuelling stations.	Yes, must be a legal entity incorporated or registered either within Canada or abroad.[97]
Zero Emission Vehicle Infrastructure Program (ZEVIP) (NRCAN)	Deployment	Under NRCan, this CAD 280 million program was established to address the lack of charging and refuelling stations in Canada. The funding is delivered through cost-sharing contribution agreements for selected projects.	No data.

Table 7: Provincial-level R&D funding mechanisms

Program	Funding	International eligibility to participate
Advanced Research and Commercialisation (ARC) Program[98] In September 2018, the British Columbia Ministry of Energy, Mines and Petroleum Resources launched the Advanced Research and Commercialisation (ARC) Program. The Program provides British Columbia-based companies with individual grants to undertake RD&D and commercialisation activities for zero-emission vehicles, including hydrogen FCEVs.	CAD 4.18 million as per 2020 funding call. Individual grants average between CAD 200,000 – 250,000	Potentially. Eligible applicants must be incorporated or registered in Canada, however. There may be avenues to participate as a member of consortia operating in BC.[99]

[97] NRCan (2021) Electric Vehicle and Alternative Fuel Infrastructure Deployment Initiative – Eligibility. https://www.nrcan.gc.ca/energy-efficiency/transportation-alternative-fuels/electric-and-alternative-fuel-infrastructure/electric-vehicle-alternative-fuels-infrastructure-deployment-init/eligibility/20197

[98] Accessible Resource Centre – British Columbia (ARCBC) (2020) Home. https://arcbc.ca/

[99] ARC (n.d.) ABOUT ARC. <https://arcbc.ca/about/>; ARC (n.d.) SUBMISSION REQUIREMENTS. https://arcbc.ca/how-to-apply/

Funding for International hydrogen RD&D

Canada provides several funding mechanisms for joint RD&D collaborations and for Canadian technology commercialisation overseas. While several of these mechanisms are general in nature, many have supported hydrogen initiatives in the past, and could support hydrogen related projects going forward.

Program	Funding	International eligibility to participate
The Canadian International Innovation Program (CIIP) The Trade Commissioner Service (TCS) of Global Affairs Canada has developed the Canadian International innovation Program (CIIP) which supports Canadian companies to pursue international R&D in collaboration with foreign partners on projects with potential for commercialisation. Partner countries under this program are Brazil, China, India, Israel and South Korea.[100] Recent calls for proposals have included some hydrogen related topics such as clean fuels, clean mobility, transport infrastructure, renewable energy and energy storage.	The program funds up to 50% of eligible costs with a cap of CAD 600,000.[101]	No.
Canadian Technology Accelerators (CTA) [102] The TCS offers Canadian Technology Accelerators in the areas of cleantech; digital industries and information and communications technologies (ICT); and life sciences and digital health. Projects under the cleantech area can include hydrogen projects. The program currently has 12 global tech hubs, 1,200 strategic partnerships. For details on recent hydrogen-related projects under the CTA, *see Section 1.5.3 Canada's joint international RD&D projects*.	The program has raised a total of $742 million in capital.	Potentially. Support is provided to Canadian companies.
Going Global Innovation[103] Provided by the TCS, this program supports Canadian SMEs, universities and non-governmental research centres to undertake collaborative RD&D overseas. This program is focused on commercialisation of Canadian technologies overseas that will generate revenue in the short term. In 2019 roughly 18% of funded projects were related to clean technologies.	Up to 75% of eligible expenses, capped at CAD 75,000.	Potentially. Support is only provided to Canadian SMEs, however other countries are a potential location for the commercialisation of Canadian technologies.

[100] TCS (2021) Canadian International Innovation Program, Global Affairs Canada. https://www.tradecommissioner.gc.ca/funding-financement/ciip-pcii/index.aspx?lang=eng&_ga=2.42316195.707757921.1638324339-1230572738.1638324339

[101] Canadian Government (2022) Collaborative research and development projects. CIIP. https://www.tradecommissioner.gc.ca/funding-financement/ciip-pcii/crdp-pcrd.aspx?lang=eng

[102] TCS (2021) Canadian Technology Accelerators, Global Affairs Canada. https://www.tradecommissioner.gc.ca/cta-atc/index.aspx?lang=eng

[103] TCS (2021) Program Expands the reach of Canadian Innovation, Global Affairs Canada. https://www.tradecommissioner.gc.ca/canadexport/0003487.aspx?lang=eng

Program	Funding	International eligibility to participate
The NSERC offers several international grants for joint RD&D: • **NSERC Collaborative Research and Development grant (CRD):**[104] supports collaborations between universities, private sector and public sector within the domains of science and engineering. Topics bust be of mutual industrial relevance and benefit. partners on topics of mutual interest. • **NSERC Strategic Network Grant (SNG):**[105] Supports RD&D in complex areas involve multiple sectors. Support is tied to topics that will provide a positive economic, social or environmental impact to Canada within a 10 year timeframe. • **NSERC Strategic Project Grant (SPG):**[106] Supports early-stage project research. Support is tied to topics that will provide a positive economic, social or environmental impact to Canada within a 10 year timeframe.	CRD: The cap for project grants are CAD 500,000 per project. SNG: Funding is between CAD 500,000 – 1,000,000 for five years. SPG: Funding is between CAD 60,000 – 250,000 for five years.	Yes. CRD partners must collaborate on all stages of the project (including proposal) and contribute to direct project costs.[107] SNG allows foreign universities or companies to join the networks. No data on financial contribution requirements.[108] SPG allows foreign universities or companies to collaborate on projects. No data on financial contribution requirements.[109]

Private funding for hydrogen RD&D

The Canadian private sector actively funds hydrogen RD&D activities and projects across the value chain. In the 2020 financial year, energy-specific private sector R&D expenditure was CAD 1.7 billion. Of this, CAD 65 million was spent on hydrogen and hydrogen fuel cell technology R&D.[110]

1.3.4 Other key hydrogen policies, regulation and legislation

In addition to governance, strategy and funding mechanisms for hydrogen RD&D programs, Canada has several key policies, regulations and laws to incentivise the development and commercialisation of hydrogen technology across the value chain.

[104] NSERC (2020) Collaborative Research and Development Grants (including DND/NSERC Research Partnership Grants). https://www.nserc-crsng.gc.ca/professors-professeurs/rpp-pp/crd-rdc_eng.asp

[105] TCS (2021) Bi-/Multilateral Research Project-based Cooperation, Global Affairs Canada. https://www.tradecommissioner.gc.ca/innovators-innovateurs/141547.aspx?lang=eng

[106] TCS (2021) Bi-/Multilateral Research Project-based Cooperation, Global Affairs Canada. https://www.tradecommissioner.gc.ca/innovators-innovateurs/141547.aspx?lang=eng

[107] NSERC (2020) Collaborative Research and Development Grants (including DND/NSERC Research Partnership Grants). https://www.nserc-crsng.gc.ca/professors-professeurs/rpp-pp/crd-rdc_eng.asp

[108] TCS (2021) Bi-/Multilateral Research Project-based Cooperation, Global Affairs Canada. https://www.tradecommissioner.gc.ca/innovators-innovateurs/141547.aspx?lang=eng

[109] TCS (2021) Bi-/Multilateral Research Project-based Cooperation, Global Affairs Canada. https://www.tradecommissioner.gc.ca/innovators-innovateurs/141547.aspx?lang=eng

[110] Statistics Canada (2021) Characteristics of research and development in Canadian industry, Government of Canada. https://www150.statcan.gc.ca/n1/pub/71-607-x/71-607-x2019016-eng.htm

At both a federal and provincial-level, there is a lack of hydrogen-specific laws and regulatory frameworks. However, there are existing provincial-level laws and regulations which tangentially regulate and incentivise hydrogen RD&D and commercialisation. The Federal Government has recognised that without centralised, sector-specific regulatory frameworks, it will be difficult to achieve the country's hydrogen targets as well as its net-zero ambitions more broadly.[111] As such, work is currently underway to prepare a suite of hydrogen-specific laws, policies and regulatory frameworks which incentivise and facilitate RD&D and commercialisation.[112]

Regulations, laws and policies

Canada has existing climate-related regulations and laws which tangentially de-risk investment and therefore incentivise and facilitate hydrogen RD&D and commercialisation. These are as follows:

- The **Canadian Net-Zero Emissions Accountability Act** establishes Canada's federal emissions reduction targets in law and legislates new oversight and accountability mechanisms to monitor progress.[113]
- The **Greenhouse Gas Pollution Pricing Act** which establishes a federal carbon pricing system**.** As of 2022, the minimum carbon price (the 'benchmark') will be CAD 50 per tonne.[114] Under the federal carbon pricing system, each province and territory has a remit to develop their own pricing system – but only if the price meets the federal benchmark – otherwise the federal pricing system applies in those regions by default.[115]
- The **Clean Fuel Standard,** which will create a credit trading scheme and require liquid fossil fuel suppliers (such as gasoline, diesel and home heating) to reduce the Carbon Intensity (CI) by 13% on 2016 levels by 2030. [116] That is, to reduce the amount of cumulative CO_2 emissions produced over the fuel's entire lifecycle, in relation to energy produced by the fuel during usage.

Technical standards

In addition to ISO standards, various domestic safety and technical codes regulate aspects of the hydrogen value chain, which may therefore impact RD&D and commercialisation activities. For example:

- The **Transport of Dangerous Goods** regulations outline minimum safety standards and technical specifications for the transport of dangerous goods, including hydrogen.[117]
- **CAN/CSA B51 Boiler Pressure Vessel and Pressure Piping Code** outlines requirements for high-pressure cylinders used in automotive storage of natural gas, hydrogen blended gas, and hydrogen

[111] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[112] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[113] Grantham Research Institute on Climate Change and the Environment (2021) Canadian Net-Zero Emissions Accountability Act. https://climate-laws.org/geographies/canada/laws/canadian-net-zero-emissions-accountability-act

[114] Government of Canada (2021) Carbon polluting pricing systems across Canada. https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work.html

[115] Government of Canada (2021) Carbon polluting pricing systems across Canada, Government of Canada. https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work.html

[116] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[117] Girard M (2021) CETA & CANADA STANDARDS 101: Supporting EU business in Canada. Commissioned by the EU Delegation in Canada. https://trade.ec.europa.eu/doclib/docs/2021/february/tradoc_159450.pdf

fuel. The code also outlines requirements for hydrogen refuelling station piping systems and ground storage vessels.[118]

- **CSA Z662:19 Oil and Gas pipeline system standards**, which outlines standards and technical specifications for oil and gas pipeline infrastructure.
- **CAN/BNQ 1784-000 Canadian Hydrogen Installation Code,** approved by the Standards Council of Canada (SCC), establishes installation requirements for hydrogen generating and powered equipment, dispensing infrastructure, hydrogen storage containers, piping systems and related infrastructure.[119]

However, the Canadian hydrogen strategy has identified gaps in current technical standards, specifications and codes. For example, there is currently no technical specifications for hydrogen injection and natural gas blending, which will slow network adoption. A broad range of hydrogen-specific technical standards are currently being developed by the Standards Council of Canada in conjunction with various provincial and regional governments and ISO/TC 197 – the ISO hydrogen technologies technical committee.

Provinces and Territories

Provinces and territories have their own laws and regulations which tangentially regulate the hydrogen value chain and incentivise RD&D. Whilst a comprehensive legal analysis of each province and territories' laws is beyond the scope of this paper, these generally relate to the following thematic areas:

- Low-carbon and clean fuel standards, such as British Columbia's **The Greenhouse Gas Reduction (Renewable and Low Carbon Fuel Requirements) Act** and Quebec's **Zero-Emission Vehicle (ZEV) standard**;[120]
- Technical and safety specifications; and
- Environmental impact assessment obligations – such as Québec's **Environment Quality Act** which requires an environmental impact assessment to be undertaken – and authorised by the Québec Minister of the Environment and the Fight against Climate Change – prior to the construction of hydrogen production projects.[121]

1.4 Canada's domestic hydrogen RD&D projects

A significant number of hydrogen-related RD&D projects are currently underway in Canada. Many of these projects are funded by centralised research programs, sponsored by the National Research Council of Canada or coordinated by provincial-level governments and agencies.

[118] Techstreet Store (2019) CSA B51:19. https://www.techstreet.com/standards/csa-b51-19?product_id=2042685

[119] SCC-CCN (2020) Search Standards: Hydrogen. https://www.scc.ca/en/search/standardsdb/Hydrogen?page=1

[120] Crossman T and Adamson P (2021) The Environment and Climate Change Law Review: Canada, the Law Reviews. https://thelawreviews.co.uk/title/the-environment-and-climate-change-law-review/canada#footnote-006

[121] MELCC (2021) The organisation and its commitments. < https://www.quebec.ca/en/government/ministere/environnement/statutes-and-regulations>; Québec Government (2021) Environment Quality Act. Publications Québec. <https://www.quebec.ca/en/government/ministere/environnement/statutes-and-regulations>

1.4.1 Major domestic hydrogen RD&D projects

Projects led by government bodies

Advanced Clean Energy Program: Hydrogen

Hydrogen is a key pillar of the NRC's Advanced Clean Energy Program. The program fosters collaboration with industry to develop technologies which produce, distribute and utilise low-carbon hydrogen. The Program welcomes collaboration from industry, standards organisations, governmental bodies, academia and global R&D organisations. Key focus areas of the program are outlined in Table 8.

Table 8: Advanced Clean Energy Program – hydrogen research areas[122]

Value chain area	Sub-technology and research areas	International eligibility to participate
Production	• Electrolysis • Catalytic and biological technologies • Hydrogen purification (particularly membrane-based and electrochemical technologies)	No data.
Distribution and storage	• Pipeline conversion, capability and natural gas blending testing • Sensors to detect and measure hydrogen • Development of standards, codes and material evaluation frameworks	
System integration and utilisation	• Multi-scale, validated modelling • Techno-economic and lifecycle analysis modelling to facilitate decision-making • Development of technical specifications, safety regulations and codes for system integration • Safety assessments • Conversion technologies, including fuel cells, combustion and chemical conversion	

Materials for Clean Fuels Challenge[123]

The NRC's Material for Clean Fuels Challenge program, which will run from 2019 to 2026, aims to accelerate the R&D and commercialisation of 'high-risk, high-reward' technologies which produce feedstock chemicals and fuels from air and water.[124] At a high level, the aim of the Challenge is to advance technologies as quickly as possible from low technology readiness levels to commercialisation.[125] 'Industrial-scale hydrogen

[122] NRCan (2021) Advanced Clean Energy Program: Hydrogen, Government of Canada. https://nrc.canada.ca/en/research-development/research-collaboration/programs/advanced-clean-energy-program-hydrogen

[123] NRCan (2021) Materials for Clean Fuels Challenge program, Government of Canada. https://nrc.canada.ca/en/research-development/research-collaboration/programs/materials-clean-fuels-challenge-program

[124] NRCan (2021) Materials for Clean Fuels Challenge program, Government of Canada. https://nrc.canada.ca/en/research-development/research-collaboration/programs/materials-clean-fuels-challenge-program

[125] NRCan (2021) Materials for Clean Fuels Challenge program, Government of Canada. https://nrc.canada.ca/en/research-development/research-collaboration/programs/materials-clean-fuels-challenge-program

production' is a key area of focus for the Challenge. Hydrogen-related projects, in collaboration with NRC researchers, which have been funded by the program are outlined in Table 9 below:[126]

Table 9: Projects funded under the Materials for Clean Fuels Challenge program

Project title	Partner(s)	NRC funding	International eligibility to participate
'High performance membrane electrode assemblies for alkaline solid electrolyte water electrolysers'	NRC; Forschungszentrum Julich GmBh	CAD 534,000	Yes. Grant and contribution funding is available for international collaborators where there is a benefit to Canada. While the first round of projects has already been selected, there will be opportunities in future rounds.
'Development and testing of a pulse methane pyrolysis (PMP) reactor and brass-board system for clean hydrogen production'	NRC; Ekona Power Inc.	CAD 468,000	
'Advanced electrolysis for chemical production and clean fuels'	NRC; The University of British Columbia	CAD 548,090	
'In situ and operando characterisation of catalyst and electrode structures for electrochemical CO_2 reduction'	NRC; McMaster University	CAD 480,579	
'Converting carbon solutions into value-added chemicals using a bicarbonate electrolyser'	NRC; The University of British Columbia	CAD 486,778	
'The environmental and techno-economic assessments of carbon conversion technologies'	NRC; The Governors of the University of Calgary	CAD 541,200	
'Renewable hydrogen through photocatalytic CO_2 reduction'	NRC; The University of British Columbia	CAD 486,778	
'A materials acceleration platform for the development of membrane electrode assemblies'	NRC; The University of British Columbia	CAD 1,203,433	

[126] NRCan (2021) Materials for Clean Fuels Challenge program, Government of Canada. https://nrc.canada.ca/en/research-development/research-collaboration/programs/materials-clean-fuels-challenge-program

Alberta

Natural Gas Challenge[127]

In 2021, Emissions Reduction Alberta (ERA) announced CAD 58.4 million in funding under the Natural Gas Challenge. The Challenge funded 20 RD&D projects that seek to increase cost-effectiveness and reduce emissions from Alberta's natural gas sector.[128] Hydrogen-related projects funded by the Challenge are outlined in Table 10. Submissions to this program are now closed.

Table 10: Hydrogen-related projects funded by the Natural Gas Challenge[129]

Project title	Partner(s)	ERA funding
Fort Saskatchewan Hydrogen Blending A pilot project to test the efficiency of hydrogen in ATCO's natural gas infrastructure. More specifically, the project will test equipment and assess the suitability of legislation, codes and standards.	ATCO Gas and Pipelines Ltd.	CAD 2.8 million
R&D and pilot-stage testing of a Tri-Generation Pyrolysis (TGP) system for clean hydrogen production Development of a prototype method to convert natural gas to hydrogen and a solid carbon by-product. This may be a new clean hydrogen production method.	Ekona Power Inc.	CAD 5 million
New-wave hydrogen production R&D, techno-economic analysis, demonstration and commercialisation of deployment plans for a new natural gas decarbonisation system	Standing Wave Reformers Inc.	CAD 3 million
Hydrogen centre of excellence Advancing hydrogen-competition One is the first round of funding available with the goal of developing and deploying hydrogen-focused technologies to strengthen a clean hydrogen economy in Alberta.[130]		CAD 50 million

[127] Emissions Reduction Alberta (2021) Natural Gas Challenge: Unlocking Innovation Across Alberta's Value Chain. https://eralberta.ca/funding-technology/natural-gas-challenge-unlocking-innovation-across-albertas-value-chain/

[128] Emissions Reduction Alberta (2021) Natural Gas Challenge: Unlocking Innovation Across Alberta's Value Chain. https://eralberta.ca/funding-technology/natural-gas-challenge-unlocking-innovation-across-albertas-value-chain/

[129] Emissions Reduction Alberta (2021) Natural Gas Challenge: Unlocking Innovation Across Alberta's Value Chain. https://eralberta.ca/funding-technology/natural-gas-challenge-unlocking-innovation-across-albertas-value-chain/

[130] https://albertainnovates.ca/programs/advancing-hydrogen-competition-one/

Projects by consortia

- In November 2020, Enbridge Gas Inc. and Cummins Inc. announced a CAD 5.2 million demonstration whereby up to 2% hydrogen was to be blended into a portion of an already existing natural gas network owned by Enbridge Gas in Markham Ontario.[131] The demonstration is supported by Sustainable Development Technology Canada (STDC).[132] Hydrogen production from renewables will be generated at a power-to-gas electrolysis facility within Markham that was established through a partnership between the two corporations in 2018 with the support of the Province of Ontario.[133] The current project was announced to serve approximately 3,600 clients in 2021, however, there have been no updates to date.
- In July 2020, ATCO Gas and Pipelines Limited announced the first hydrogen blending project in Alberta, with up to 5% hydrogen blended into a portion of the Fort Saskatchewan natural gas system. The project will involve the construction of a hydrogen production unit with commissioning expected to occur September-November 2022.[134] To date the project has received CAD 2.8 million from the Emission Reductions Alberta (ERA) Natural Gas Challenge.[135]
- Moreover, both British Columbia and Quebec have enacted provincial policies that have stimulated RD&D pilots for the blending of hydrogen into the natural gas grid; British Columbia largely through its CleanBC Initiative and Quebec through its renewable fuel mandates.[136]

1.4.2 Canada's hydrogen RD&D clusters

Canada's strategy includes developing regional hydrogen clusters (also referred to as hubs, valleys or ecosystems) incorporating full value chains at scale by 2025. By 2030 Canada wants to expand these hubs, establish corridor connections and initiate new hubs. By 2050 Canada hopes to achieve a full rollout and inter-provincial trade and cooperation between regional hubs.[137]

While the majority of Canadian states have hydrogen related activity occurring within their borders, the four provinces of British Columbia, Alberta, Ontario, and Quebec host the majority of RD&D efforts within the scope of the hydrogen value chain.[138] These provinces also host most of Canada's of hydrogen and fuel cell SMEs who are contributing the development of these clusters. [139]

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[131] NS Energy (2020) Enbridge Gas to pilot hydrogen blending to green gas grid in Ontario, NS Energy Business. https://www.nsenergybusiness.com/news/enbridge-gas-hydrogen-blending-pilot-project/

[132] Enbridge Gas Inc. (2020) Enbridge Gas announces a $5.2M Hydrogen Blending Pilot Project to further explore greening of the natural gas grid, Cision. https://www.newswire.ca/news-releases/enbridge-gas-announces-a-5-2m-hydrogen-blending-pilot-project-to-further-explore-greening-of-the-natural-gas-grid-849137548.html

[133] Lalach J and Bellini A (2021) Canada: How About Some Clean, Green Hydrogen With That Natural Gas? Gowling WLG, https://www.mondaq.com/canada/renewables/1078758/how-about-some-clean-green-hydrogen-with-that-natural-gas-

[134] ATCO (2021) Natural Gas: Hydrogen. https://www.atco.com/en-ca/for-home/natural-gas/hydrogen.html

[135] Government of Alberta (2021) Hydrogen Blending Project. https://majorprojects.alberta.ca/details/Hydrogen-Blending-Project/4169

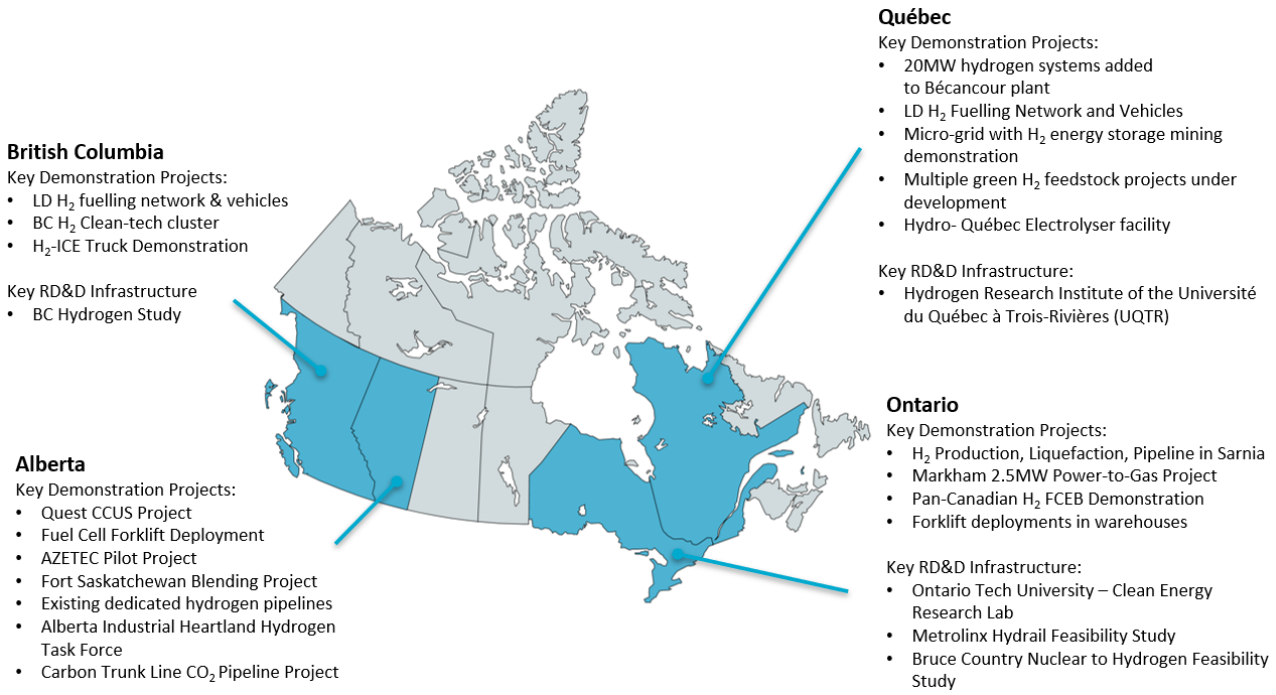
[136]NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf; FortisBC (2020) FortisBC takes significant step towards implementing hydrogen in the natural gas system, Cision. https://www.newswire.ca/news-releases/fortisbc-takes-significant-step-towards-implementing-hydrogen-in-the-natural-gas-system-820738965.html; Renewable Industries Canada (2017) Statement regarding the Quebec Government's 2017-2020 Action Plan under the 2030 Energy Policy. http://ricanada.org/wp-content/uploads/2017/06/Quebec-Government-2017-2020-Action-Plan-Announcement-EN.pdf

[137] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[138] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[139] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

Figure 4: Canada's existing and emerging hydrogen clusters[140]



Province	Projects/Notes
British Columbia (BC)	**Hydra Energy Corporation Commercial Demonstration Project:** This project will capture and purify waste hydrogen, for use in 53 hydrogen internal combustion engine (H2-ICE) trucks. The company will collaboration with UBC around fuel efficiency improvements and emissions reductions.[141] **The UBC Renewable Energy Hub:** Announced in May 2021, UBC will establish an energy innovation hub at the University of British Columbia which is set to convert a 'city-sized' block of the university campus into a smart energy district. This project will also involve the production of renewable hydrogen using an on-site advanced solar array, and a hydrogen refuelling station.[142] Many of BC's initiatives and industrial practices are being supported by a cluster of BC-based hydrogen clean-tech companies that are driving progress towards the goals of the CleanBC initiative (BC's climate action plan) and BC's provincial hydrogen strategy.[143]
Alberta	**Quest CCUS project:** CCUS initiatives are currently underway with Alberta's Quest CCUS project, which produces hydrogen by steam methane reformation and captures the resulting CO_2 emissions. **Alberta Carbon Trunk Line** (ACTL) also facilitate CCUS uptake.[144] **Northwest Redwater Sturgeon Refinery** produces blue hydrogen from refinery bottom gasification, separates the CO_2 and supplies the clean hydrogen to the ACTL

[140] Adapted from NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action, https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[141] Mitacs (2021) Development and Demonstration Engine Technology for Class 8 Heavy Duty Trucks Fuelled by Waste Hydrogen. https://www.mitacs.ca/en/projects/development-and-demonstration-engine-technology-class-8-heavy-duty-trucks-fueled-waste

[142] UBC (2021) UBC Renewable Energy Hub. https://research.apsc.ubc.ca/initiatives/integrated-energy-testbed/

[143] Government of British Columbia (2021) Clean-tech companies put B.C.'s Hydrogen Strategy into Action, BC Gov News. https://news.gov.bc.ca/releases/2021EMLI0051-001650

[144] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

Province	Projects/Notes
	Fort Saskatchewan Blending Project: With regard to pipeline initiatives, the Fort Saskatchewan Blending Project is currently underway to test the blending of hydrogen into residential natural gas distribution systems. Similarly, the Alberta Industrial Heartland Hydrogen Task Force has access to an existing hydrogen pipeline and two CO_2 pipelines. However, its mission is broader: to bring together production, distribution, and supply industries in the area. With access to these pipelines, natural gas, CCUS sites, and its location in a geographical area with great potential demand across transport, heating and electrical sectors, this task force represents an example of an early hub for deployment of hydrogen technology.[145] **Alberta Zero Emissions Truck Electrification Collaboration (AZETEC):** AZETEC is a key pilot project currently operating to better understand the ability of hydrogen to fuel heavy freight transport. The project is demonstrating the design, manufacture, and operation of two long-range fuel cell electric trucks and the supporting hydrogen-fuelling infrastructure for operation between Calgary and Edmonton Alberta. [146]
Ontario	**The Markham 2.5MW Power-to-Gas Project:** The project is a joint venture between Cummins and Enbridge with support from the Ontario Province, that produces renewable hydrogen to help manage supply-and-demand imbalances related to the Ontario electricity grid.[147] **The Enbridge and Cummins Hydrogen-Blending Project:** Announced in 2020, the pilot project that will blend hydrogen produced from renewables at the Markham plant into the Enbridge natural gas network.[148] **The Sarnia hydrogen facility**: This facility participates in hydrogen production, liquefaction and distribution via a 30km pipeline. The facility was constructed in Sarnia in 2006 and is owned and operated by Air Products Canada.[149] **Pan-Canadian Hydrogen Fuel Cell Electric Bus Demonstration and Integration Trail:** This project is Canada's first fuel cell electric bus (FCEB) trial utilising hydrogen produced from renewables.[150] **The Metrolinx Hydrail Feasibility Study**: This feasibility study discusses the viability of using hydrogen fuel cells in the GO Transit network.[151] **The Bruce Country Nuclear to Hydrogen Study:** This feasibility study investigating the role of nuclear power in supporting a growing hydrogen economy.[152]

[145] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[146] Government of Alberta (2021) Alberta Hydrogen Roadmap. https://open.alberta.ca/dataset/d7749512-25dc-43a5-86f1-e8b5aaec7db4/resource/538a7827-9d13-4b06-9d1d-d52b851c8a2a/download/energy-alberta-hydrogen-roadmap-2021.pdf

[147] Cummins Inc. (2020) In its Second Year, North America's First Multi-Megawatt Power-To-Gas Facility Shows Hydrogen's Potential. Cummins Newsroom. https://www.cummins.com/news/2020/11/12/its-second-year-north-americas-first-multi-megawatt-power-gas-facility-shows

[148] Enbridge (2020) Groundbreaking $5.2M hydrogen blending project aims to green Ontario's natural gas grid, @Endridge Blog. https://www.enbridge.com/Stories/2020/November/Enbridge-Gas-and-Hydrogenics-groundbreaking-hydrogen-blending-project-Ontario.aspx

[149] Air Products (2021) Air Products Announces Multi-Billion Dollar Net-Zero Hydrogen Energy Complex in Edmonton, Alberta, Canada. Cision PR Newswire. https://www.prnewswire.com/news-releases/air-products-announces-multi-billion-dollar-net-zero-hydrogen-energy-complex-in-edmonton-alberta-canada-301308810.html

[150] Crituc (2021) PAN-CANADIAN HYDROGEN FUEL CELL ELECTRIC BUS DEMONSTRATION AND INTEGRATION TRIAL. https://cutric-crituc.org/wp-content/uploads/2021/08/FCEB_Brochure_v2_August2021.pdf

[151] CH2M HILL Canada Ltd, Ernst & Young Orenda Corporate Finance Inc, Canadian Nuclear Laboratories (2018) Regional Express Rail Program Hydrail Feasibility Study Report: Revision B. https://www.metrolinx.com/en/news/announcements/hydrail-resources/CPG-PGM-RPT-245_HydrailFeasibilityReport_R1.pdf

[152] NuclearNewswire (2021) Feasibility study for nuclear hydrogen under way in Canada, Nuclear News. https://www.ans.org/news/article-3016/feasibility-study-for-nuclear-hydrogen-under-way-in-canada/

Province	Projects/Notes
Québec	**Air Liquide and HTEC mobility project:** A light-duty hydrogen fuelling station will be established in 2022 by Air Liquide and the Hydrogen Technology & Energy Corporation (HTEC).[153] **The Glencore RAGLAN Mine Renewable Electricity Smart-Grid Pilot Demonstration:** demonstrates hydrogen energy storage (installed 2014), has been deemed a success; Tugliq Energy Co, owner of the wind turbine and energy storage systems, has announced plans to implement similar systems at other remote sites.[154] Multiple feedstock projects that utilise hydrogen produced from renewable sources are currently under development. Examples include: [155] **Recyclage Carbone Varenne (RCV):** Hydro-Québec, Canada's largest electricity producer, is establishing an electrolyser facility to generate renewable hydrogen and oxygen to supply to the Recyclage Carbone Varenne (RCV) project (a plant that produces biofuels and renewable chemicals from non-recyclable materials).[156] **ArcelorMittal Port-Cartier pellet plant:** In November 2021, and the government of Québec announced a CAD 205 million investment to convert its 10 million tonne p.a. iron pellet production to direct reduced iron (DRI) with natural gas by 2025. ArcelorMittal will pilot the replacement of natural gas with hydrogen for its DRI process before 2025.[157] **Hy2gen[158]:** Hy2Gen is active in two locations in Quebec. Courant will host a green ammonia production platform, producing 3.2 MT per hour from hydropower. Construction is expected to commence in 2022, and production in 2026. Boyen will host an e-Methanol production platform using 18MT per day of hydrogen from hydropower and 250mt per day of forest biomass. Construction is expected to commence in 2022, and e-methanol production in 2026.[159]

1.4.3 Major domestic commercial hydrogen projects

The scope of this report is on research, development and demonstration (RD&D) projects. For information on commercial hydrogen projects, see *HyResource*, an online knowledge sharing platform across the hydrogen community led by CSIRO, Future Fuels CRC, NERA and the Australian Hydrogen Council.

HyResource provides a directory of publicly available databases and information sources on international projects:

- https://research.csiro.au/hyresource/projects/international/

[153] PetrolPlaza Correspondent (2021) Canada: New light-duty hydrogen station in Quebec in 2022. https://www.petrolplaza.com/news/27766

[154] Matrix (2015) Hatch Microgrid helps manage wind power storage at Raglan, International Mining. https://im-mining.com/2015/11/24/hatch-microgrid-helps-manage-wind-power-storage-at-raglan/; Tugliq Energie Co. (2018) Raglan I – Hybrid Wind, Diesel and Storage Energy Generation in Arctic Canada. https://tugliq.com/en/realisation/raglan-i/

[155] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[156] Ingram E (2020) Hydro-Québec to build hydrogen electrolyzer facility powered primarily by hydropower, Renewable Energy World. https://www.renewableenergyworld.com/hydrogen/hydro-quebec-to-build-hydrogen-electrolyzer-facility-powered-primarily-by-hydropower/#gref

[157] ArcelorMittal (2021) ArcelorMittal announces CAD 205 million decarbonisation investment in its flagship Canadian mining operations with support from the Quebec government. Press Releases. https://corporate.arcelormittal.com/media/press-releases/arcelormittal-announces-cad-205-million-decarbonisation-investment-in-its-flagship-canadian-mining-operations-with-support-from-the-quebec-government

[158] Hy2Gen is also active in France, Germany and Norway.

[159] Hy2Gen (2021) Hy2Gen Canada Inc. https://hy2gen.com/canada/

1.5 International collaboration and joint RD&D projects

1.5.1 Overview of Canada's approach to international collaboration

The *Hydrogen Strategy for Canada*[160] and Canada's *A Healthy Environment and a Healthy Economy*[161] both highlight the importance of international collaboration to accelerate the development and deployment of hydrogen technologies to achieve decarbonisation ambitions.[162]

International scientific collaboration

Canada has developed formal science and technology partnerships with established and emerging international partners.[163] These agreements establish guidelines to facilitate greater collaboration between international science and technology researchers. The Canadian government notes that whilst formal partnerships or Memorandums of Understanding (MoUs) cannot be negotiated with all countries, Canada is open to high-quality proposals.[164] Canada's existing international science and technology partnerships can be found here.

Hydrogen-specific collaboration

In the *Hydrogen Strategy for Canada,*[165] Canada signalled their strong intention to collaborate with international partners on hydrogen RD&D and commercialisation.[166] The development of strategic international partnerships was 1 of 8 key recommendations proposed by the Strategy, with a particular focus on knowledge and technology sharing. Canadian industry, research institutions and government agencies have a strong history of international collaboration across the hydrogen value chain. These collaborations span across various aspects of the value chain and research phases, including RD&D, commercialisation, deployment and standards and policy development.[167] Canada is open to hydrogen-specific strategic partnerships in the following areas:[168]

- International trade and export opportunities;
- the development of policies, standards and technical specifications; and
- R&D in mutual areas of interest.

[160] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[161] Government of Canada (2020) A healthy environment and a healthy economy. < https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf>

[162] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[163] Global Affairs Canada (2021) Collaborative Opportunities, Trade Commissioner Service, Government of Canada. https://www.tradecommissioner.gc.ca/innovators-innovateurs/agreements-ententes.aspx?lang=eng

[164] Global Affairs Canada (2021) Collaborative Opportunities, Trade Commissioner Service, Government of Canada. https://www.tradecommissioner.gc.ca/innovators-innovateurs/agreements-ententes.aspx?lang=eng

[165] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[166] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[167] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[168] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

It should be noted that while Canada seeks to collaborate in technology areas of mutual interest, some sectors (namely the mining sector) are highly competitive. In its hydrogen strategy, Canada states it may seek to protect Canadian IP in order to maintain a competitive advantage.[169]

Hydrogen-specific bilateral and multilateral programs

Canada has entered into several hydrogen-specific bilateral and multilateral agreements, which foster enhanced collaboration, knowledge and technology sharing to help achieve mutual hydrogen-related ambitions. These country-specific international agreements are outlined in *Section 1.5.2 Canada's bilateral hydrogen relationships.*

Canada is a founding member of the following international hydrogen initiatives across the value chain:[170]

- The IEA hydrogen Technology Collaboration Programs (TCPs), which coordinate public and private sector research to accelerate global hydrogen RD&D. Canada is also a member of the Advanced Fuel Cells TCP, which focuses extensively on fuel cell technologies, applications and systems modelling;
- The International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), which commits members to commercialising fuel cell and hydrogen-related technologies;
- The Hydrogen Initiative under the Clean Energy Ministerial (CEM), comprising 20 nations of which Canada is a founding leader. Key objectives of the CEM include facilitating enhanced collaboration; addressing barriers; driving the commercialisation and deployment of fuel cell technologies and FCEVs; and identifying opportunities for hydrogen across global markets;[171] and
- Mission Innovation – a global alliance with goals to accelerate public and private innovation, and increase RD&D investment of technologies that address climate change. The 'Clean Hydrogen Mission' is one of seven focus areas of Mission Innovation.

1.5.2 Canada's bilateral hydrogen relationships

The Canadian Government has various formal and informal hydrogen-specific relationships, which underscore Canada's commitment to international collaboration. Table 11 outlines Canada's formal hydrogen-related international partnerships.

[169] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[170] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[171] Clean Energy Ministerial (2021) Hydrogen Initiative: An initiative of the Clean Energy Ministerial. https://www.cleanenergyministerial.org/initiative-clean-energy-ministerial/hydrogen-initiative

Table 11: Formalised relationships with other countries[172]

Country	Relationship	Description
Netherlands	MoU	In October 2021, Canada and the Netherlands agreed to the Canada-Netherlands Hydrogen Memorandum of Understanding. The MoU seeks to facilitate greater bilateral cooperation and knowledge sharing in the following areas: standards, trade rules, policies, technologies and investment. Additional objectives of the MoU include promoting public and private sector investment in clean hydrogen projects, and strengthening collaboration in multilateral hydrogen forums, such as the IPHE.[173]
United States of America	MoU	In August 2021, the Department of Natural Resources of Canada and the Department of Energy of the United States of America signed an MoU regarding 'cooperation on energy.' Whilst not hydrogen-specific, the MoU formalises collaboration between Canada and the USA and has various cooperative objectives. These include, but are not limited to: knowledge and technology sharing; collaboration on codes, standards and policy developments; promoting adoption of zero-emission light and medium-duty FCEVs; exploring partnerships among research institutions; renewable energy integration studies; and enhancing regional and global engagement on energy issues.[174]
Germany	Partnership/MoU	In March 2021, the Canadian and German Governments entered an energy partnership, which establishes a formal collaboration across a range of shared energy priorities – including hydrogen – with the aim of facilitating industry engagement and investment opportunities. The partnership will establish a High-Level Steering Committee that will facilitate knowledge sharing and project development across the following areas: energy policy and regulations; renewable energy integration; energy efficiency; sector coupling; low-carbon fuels; and innovation and applied research.[175]
Japan	MoU	In June 2019, Canada and Japan signed two MoUs regarding clean energy technology and the transition to net-zero emissions more generally. The first MoU seeks to facilitate increased collaboration regarding clean energy and energy efficiency more broadly. The second MoU commits both states to increase collaboration on clean energy and CCUS R&D and commercialisation activities.[176]

[172] NRCan (2021) International Energy Cooperation, Government of Canada. https://www.nrcan.gc.ca/energy/resources/international-energy-cooperation/17924

[173] NRCan(2021) Memorandum of Understanding between the Government of Canada and the Government of the Netherlands on cooperation in the field of hydrogen energy, Government of Canada. https://www.nrcan.gc.ca/climate-change/canadas-green-future/the-hydrogen-strategy/memorandum-understanding-between-the-government-canada-and-the-government-the-netherl/23907

[174] NRCan (2021) Memorandum of Understanding, Government of Canada. https://www.nrcan.gc.ca/energy/resources/international-energy-cooperation/memorandum-understanding/23749

[175] NRCan (2021) Canada Strengthens Energy Partnership with Germany [News Release], Government of Canada. https://www.canada.ca/en/natural-resources-canada/news/2021/03/canada-strengthens-energy-partnership-with-germany.html?utm_source=miragenews&utm_medium=miragenews&utm_campaign=news

[176] PR Newswire (2019) Canada and Japan Announce Clean Energy Cooperation at G20, Market Insider. https://markets.businessinsider.com/news/stocks/canada-and-japan-announce-clean-energy-cooperation-at-g20-1028284423

1.5.3 Canada's joint international RD&D projects

Canada participates in hydrogen RD&D projects jointly with international partners. Recent projects are summarised in Table 12.

Table 12: Canada's joint international RD&D projects

Country	Projects
Japan	In September 2021, Shell Canada and Japan's Mitsubishi signed an MoU to produce low-carbon hydrogen. As part of the MoU, Mitsubishi will build a low-carbon hydrogen production located near Shell's Scotford facility in Alberta in the second half of the decade. Once constructed, the facility will aim to produce 165,000 tonnes of hydrogen per year and will be converted to ammonia for export. Shell will provide CO_2 storage capability at a proposed CCUS facility near Edmonton.[177]
Australia	The MoU held between the Canadian Hydrogen and Fuel Cell Association (CHFCA) and the Australian Hydrogen Council (AHC) *(see Section 1.5.2 Canada's bilateral hydrogen relationships)* outlines identifying opportunities for joint projects, including R&D and commercialisation efforts, as a key area of cooperation. The MoU seeks to foster innovation across the value chain, particularly in the commercial deployment of hydrogen production infrastructure and fuel cell technologies in the mining and transportation sectors.[178] However, no joint projects have been announced to date. Canadian-based AMP Energy plans to expand its growing Australian portfolio with an announcement of an CAD 2.01 billion Renewable Energy Hub in South Australia, which will include large-scale photovoltaics and battery energy systems. The hub will also contain wind-harnessing infrastructure and be linked to a hydrogen production facility.[179]
Germany	Germany and Canada have a longstanding R&D relationship under the German-Canadian Intergovernmental Agreement on Scientific and Technological Cooperation (signed 1971).[180] In June 2021, the NERSC and the German Federal Ministry of Education and Research (BMBF) announced a collaborative partnership that will provide CAD 1 million for ten hydrogen R&D projects through the Canada-Germany funding call.[181] These one-year collaborative research projects will encompass technologies at various stages of development, including those that are considered commercially ready in attempt to reduce their costs, and will lay a foundation for longer collaborations on hydrogen and fuel cell technologies in the future. Further, an agreement announced in early 2021 will see the 'Green Hydrogen product division' of Thyssenkrupp Uhde Chlorine Engineers, a German subsidiary of the larger Thyssenkrupp group that provides technologies and systems for high-efficiency electrolysis plants, install an 88MW water electrolysis plant for Hydro-Quebec (an energy firm backed by the Quebec provincial government).[182]

[177] Reuters (2021) Japan's Mitsubishi partners with Shell Canada in clean energy push. https://www.reuters.com/business/energy/japans-mitsubishi-partners-with-shell-canada-clean-energy-push-2021-09-08/

[178] NRCan (2020) Hydrogen Strategy for Canada: Seizing the Opportunities for Hydrogen – A Call to Action. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

[179] Scully J (2021) AMP Energy plans 1.3GW of Solar at South Australia renewables hub, PVTech. https://www.pv-tech.org/amp-energy-plans-1-3gw-of-solar-at-south-australia-renewables-hub/

[180] Mission Innovation. Canada: Plans and Priorities. http://mission-innovation.net/our-members/canada/plans-and-priorities/

[181] NSERC (2021) Canada-Germany collaboration supports ten R&D partnerships on hydrogen technologies. https://www.nserc-crsng.gc.ca/Media-Media/NewsDetail-DetailNouvelles_eng.asp?ID=1276

[182] Thyssenkrupp (2020) Thyssenkrupp Uhde Chlorine Engineers. https://www.thyssenkrupp-uhde-chlorine-engineers.com/en/company; Frangoul A (2021) Canada is set to have one of the world's biggest green hydrogen plants , CNBC News. https://www.cnbc.com/2021/01/19/canada-is-set-to-have-one-the-worlds-biggest-green-hydrogen-plants.html

Country	Projects
South Korea	In December 2017, Canada and South Korea established the Canada-Korea Science, Technology and Innovation cooperation Joint Action Plan, which includes clean energy R&D projects between the two states.[183]
United Kingdom	In September 2017, Canada and the UK announced the Canada-UK Partnership on Clean Growth and Climate Change which seeks to accelerate and improve clean and renewable energy.[184] This relationship was strengthened in May 2018 with the announcement of the Canada-UK Power Forward Challenge that provides Canadian and UK researchers and innovators with up to CAD 3 million to develop pilot demonstrations of high-impact innovative smart grid solutions, with the winning group awarded a further CAD 1 million. Applicant teams include researchers and power, technology and software companies from both countries. At least 20% of the project team should include firms from the partnering country.[185]

CTA Projects

Hydrogen-related projects under the CTA are detailed in Table 13. For more information on the CTA mechanism, see *Section 1.3.3 Funding mechanisms.*

Table 13: CTA projects related to hydrogen

Country/Region	Projects	Program dates
Germany	This initiative supports scale up of Canadian companies commercialising CCUS in Germany, including the decarbonisation of hydrogen production and H2 based synthetic fuels. The initiative also supports companies seeking to commercialise products in the areas of hydrolyser materials and hydrogen applications in industrial processes; fuel cells; and hydrogen handling equipment	Program ended in April 30 2022
Southeast Asia	Based in Singapore, this initiative includes supporting scale up of clean technologies in Singapore, Vietnam, Malaysia and the Philippines.	Program ended in April 2022
US	This initiative supported the growth of Canadian 'climatech' businesses in New York, San Francisco, Boston and Denver.	Program ended in October 2021

[183] Mission Innovation. Canada: Plans and Priorities. http://mission-innovation.net/our-members/canada/plans-and-priorities/

[184] Mission Innovation (2021) Canada: Plans and Priorities. http://mission-innovation.net/our-members/canada/plans-and-priorities/

[185] Mission Innovation (2021) Canada: Plans and Priorities. http://mission-innovation.net/our-members/canada/plans-and-priorities/; Impact Canada (2021) Power Forward Challenge, Government of Canada. https://impact.canada.ca/en/challenges/power-forward/challenge

1.5.4 Canada's joint international commercial projects

The scope of this report is on research, development and demonstration (RD&D) projects. For information on commercial hydrogen projects, see *HyResource*, an online knowledge sharing platform across the hydrogen community led by CSIRO, Future Fuels CRC, NERA and the Australian Hydrogen Council.

HyResource provides a directory of publicly available databases and information sources on international projects:

- https://research.csiro.au/hyresource/projects/international/

1.6 Data insights: Canada's hydrogen RD&D activity

The following section provides data-driven insights on Canada's RD&D activity in hydrogen technologies. Research publication data, patent data, and commercial project data has been used to understand hydrogen related activity. While limitations exist with such an approach, these data sources do provide an opportunity to consider activity across the innovation spectrum from basic research to demonstration. It also aims to help identify technology areas that have received significant focus in each country and key organisations to support international collaboration efforts.

The data for this section was sourced from CSIRO's publications team, CSIRO's IP team, IP Australia, and the IEA's hydrogen projects database.

Figure 5: Hydrogen innovation activity data

1.6.1 Research publication data

Research publications in hydrogen are an indicator of basic and applied research activity. CSIRO's publications team has conducted a research publication scan to identify Canadian organisations conducting research across the hydrogen value chain. The publications search approach was developed in 2019 to support the report *Hydrogen Research, Development and Demonstration: Priorities and opportunities for Australia*. This search approach was applied in 2021 to provide an updated dataset for this report. The details of the search approach can be found in the *National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository*.[186]

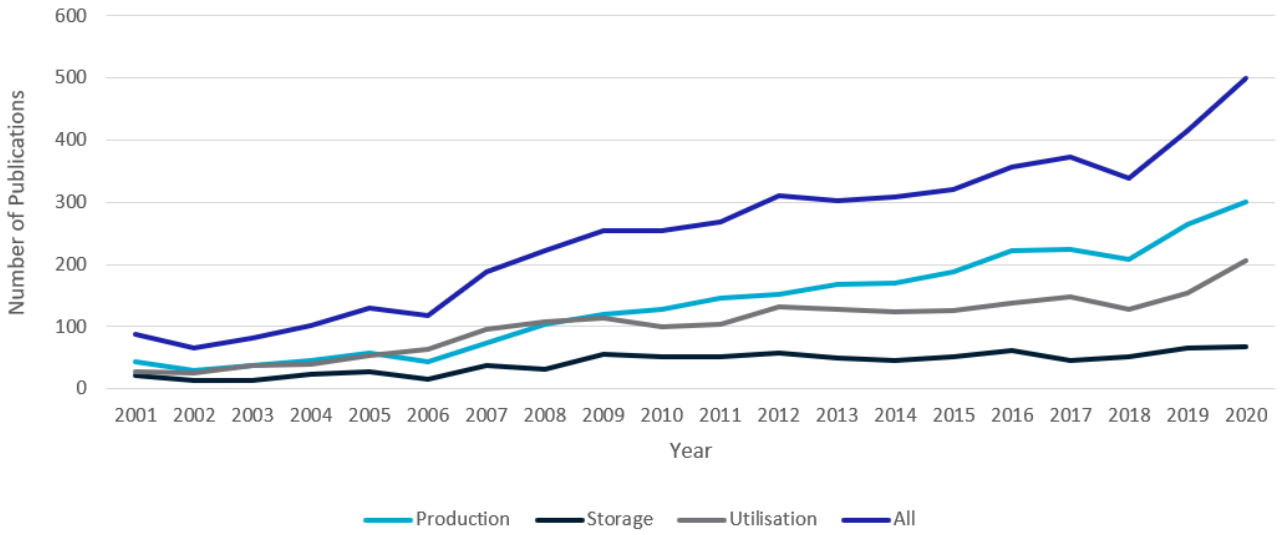
[186] CSIRO (2019) National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository. Available at https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/futures-reports/hydrogen-research

Figure 6 shows the Canadian institutions ranked in terms of publication output across hydrogen production, storage and distribution, and utilisation from 2016-2020. Figure 7 shows Canada's country-wide research publication output trends across the hydrogen value chain.

Figure 6: Top institutions by publication output (2016-2020)

Domestic Ranking	Production	Storage and Distribution	Utilisation	Overall
	10th Global Rank	*12th Global Rank*	*9th Global Rank*	*10th Global Rank*
1st	Ontario Tech University	University of Quebec Trois Rivieres	Ontario Tech University	Ontario Tech University
2nd	University of Alberta	Ontario Tech University	University of Toronto	University of Toronto
3rd	Western University (University of Western Ontario)	University of Waterloo	University of Waterloo	University of Alberta
4th	University of Toronto	University of Toronto	University of Alberta	University of Waterloo
5th	University of Waterloo	University of British Columbia	Simon Fraser University	Western University (University of Western Ontario)

Figure 7: Canada's hydrogen-related publication output (2001-2020)



1.6.2 Patent data

Patent activity in hydrogen is an indicator of applied R&D and innovation occurring across the value chain. This section draws on two different patent analytics approaches. CSIRO developed a search approach in 2019 to support the *Hydrogen Research, Development and Demonstration: Priorities and opportunities for Australia* report. CSIRO applied this approach to provide a patent landscape across the hydrogen value chain for each country. The details of the search approach and any limitations can be found in the *National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository*.[187] The second

[187] CSIRO (2019) National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository. Available at < https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/futures-reports/hydrogen-research

approach, performed by IP Australia, builds on the hydrogen technology taxonomy developed in CSIRO's 2019 report to provide information on specific hydrogen technologies that sit within production, storage and utilisation. The full data visualisations, details of the search approach and any limitations can be found at *Patent analytics of hydrogen technologies: an interactive visualisation.*[188]

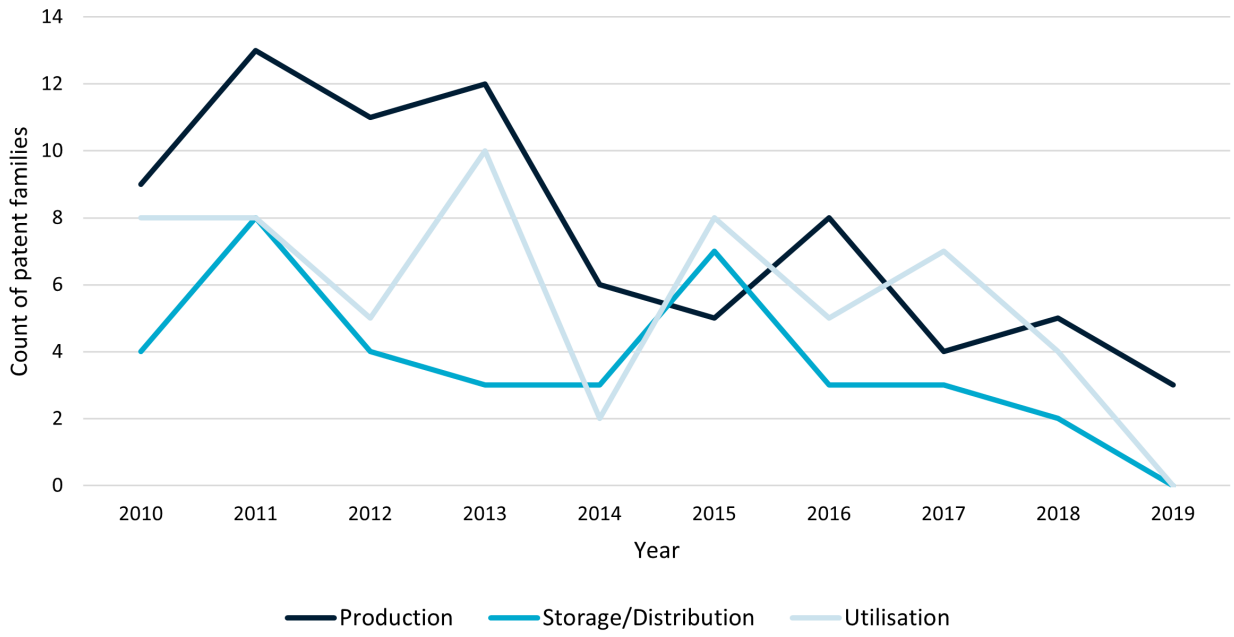
It should be noted that analysis of patent data is not necessarily representative of patent impact. As such, this data should be viewed holistically with the other data presented in this section, particularly project deployment.

Patent landscape of hydrogen value chain

Performed by the CSIRO, this patent landscape analyses patent family[189] filings across the hydrogen value chain. Figure 8 outlines patent filings over time across the areas of hydrogen production, storage/distribution and utilisation. Figure 9 shows the jurisdictions in which Canadian patent applicants are filing patents, outside of Canada. This provides an indication of which global markets, or manufacturing/commercialisation destinations are of interest to Canadian patent applicants or inventors.

Note that patent databases have a delay of roughly 18 months, therefore 2020 and 2021 have been omitted from the graphs below. Some patent filings may also be counted twice as the categories of production, storage and utilisation may not be mutually exclusive in all instances and some could relate to multiple areas of the hydrogen value chain.

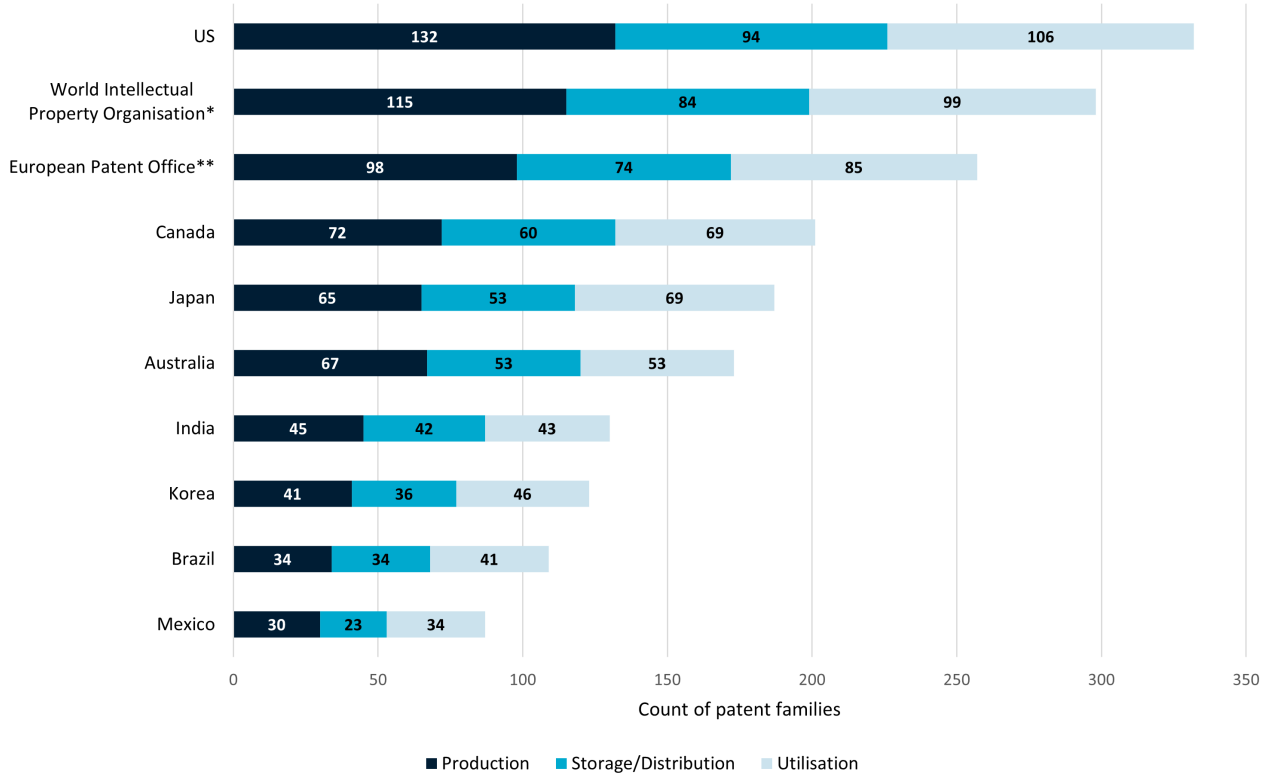
Figure 8: Patent filings over time across production, storage/distribution and utilisation



[188] IP Australia (2021) Patent Analytics on Hydrogen Technology, Australian Government. Available at https://www.ipaustralia.gov.au/tools-resources/publications-reports/patent-analytics-hydrogen-technology

[189] Applications with the same priority, but filed in different jurisdictions, are known as patent families. Patent families enable us to analyse inventive activity regardless of the number of countries in which protection is sought. Patent families are used in analytics to represent a single invention.

Figure 9: Location of patent filings by Canadian patent applicants



*** The World Intellectual Property Organisation (WIPO) is an international organisation that promotes the protection of intellectual property and supervises administrative cooperation amongst the intellectual unions regarding protection of intellectual property. Patents filed in the WIPO enable applicants to obtain protection for their inventions in up to 153 of the parties to the Patent Cooperation Treaty.**

**** The European Patent Office enables investors, researchers and companies to obtain protection for their inventions in up to 44 countries, including all 27 EU member states.**

Patent analytics of specific hydrogen technologies

Data extracted from IP Australia's interactive visualisation provides an in-depth analysis of specific hydrogen technology developments. Figure 10 shows the number of patent families filed since 2010 for specific technology areas by Canadian applicants.

Table 14 shows the number of patent families filed by Canadian applicants since 2010 by sub-technology area, expressed as a percentage of total global patent family filings. Table 14 also shows the top organisations in Canada filing patents in each technology area. It should be noted that the majority of fuel cell technologies are categorised under the 'electricity generation' category.

Figure 10: Canada's patent family output by sub-technology area (2010-2020)

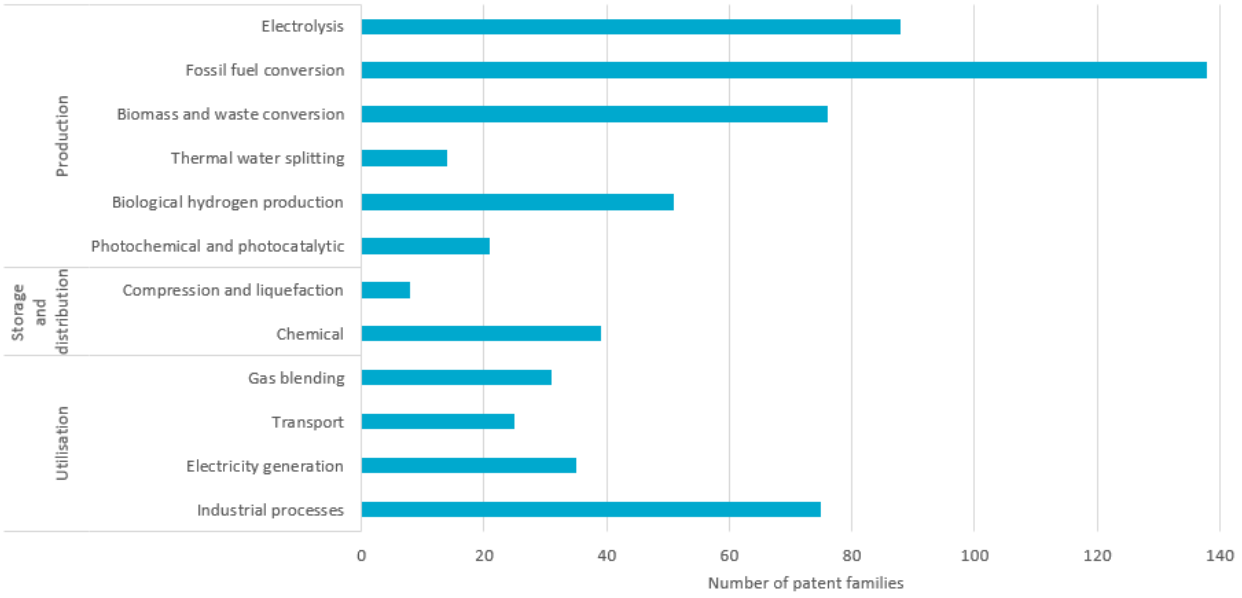


Table 14: Canada's IP output (number of patent families filed by Canadian applicants) by sub-technology area from 2010-2020

Technology area		IP output (% of global)	Leading companies	Leading non-profits and universities
Production	Electrolysis	1.1%	Dynacert, Blackberry, Axine Water Technologies, Next Hydrogen Corporation, Clummins, Imagia Cybernetics	University of British Columbia, University of Ontario Institute of Technology, University Health Network, University of Toronto
	Fossil fuel conversion	2.2%	Expander Energy, Enerkem, Iogen Corporation, G4 Insights, 1304342 Alberta, Ekona Power, Aurora Technology	University of Regina, NRC, Lakehead University, University of Toronto,
	Biomass and waste conversion	2.6%	Enerkem, Alter NRG, IOGEN, G4 Insights, Expander Energy	Saskatchewan Research Council, Lakehead University, University of Regina, McGill University, Queens University
	Thermal water splitting	1.9%	N/A	McGill University
	Biological hydrogen production	2.1%	IOGEN, Greenfield Specialty Alcohols, Greenfield Ethanol, Greenfield Specialty Alcohols	Centre National de la Recherche Scientifique (CNRS), NRC, Institut De Recherche En Agroenvironnement Inc. (IRDA), University of Western Ontario, University of Alberta

Technology area		IP output (% of global)	Leading companies	Leading non-profits and universities
	Photochemical and photocatalytic	1.1%	Enlighten Innovations, Solarship, Field Upgrading	McGill University
Storage and distribution	Compression and liquefaction	1.1%	N/A	N/A
	Chemical storage	1.6%	Luxfer Canada, Westport Power, Dynetek Industries, Atomic Energy of Canada Limited, IOGEN	McGill University, University of Toronto, Université Du Québec A Trois-Rivieres
Utilisation	Gas blending	2.2%	1304342 Alberta, Valiant, 1304338 Alberta, ISCA Management, Quadrogen Power Systems, FortisBC, Enbridge	CNRS, University of Manitoba, University of British Columbia
	Transport	1.0%	Dynacert, Empire Hydrogen Energy Systems, Next Hydrogen Corporation, Boom Energy, Sheer Technology	N/A
	Electricity generation	0.8%	Ballard Power Systems, UTI Limited Partnership, Ekona Power, Neos Alternatives, Boom Energy	University of Alberta, University of Windsor, University of Toronto, IRDA
	Industrial processes	1.7%	Fluid Energy Group, Expander Energy, Orbite	University of New Brunswick, University of Guelph

IP Australia patent analytics on hydrogen technology

IP Australia has developed an interactive visualisation tool to provide hydrogen insights to the Australian research, academics, business and policy sectors. For more hydrogen IP statistics including key destination markets, origin profiles, applicant profiles, collaborations and specific patent searches, refer to IP Australia's Hydrogen Patent Landscape tool:

- https://www.ipaustralia.gov.au/tools-resources/publications-reports/patent-analytics-hydrogen-technology

1.6.3 Project data

Data from the IEA Hydrogen Projects Database (as at October 2021)[190] provides insight on clean hydrogen technology value chains deployed at pilot and commercial scale across Canada. Note that the following limitations should be taken into account:

1) The database does not indicate whether the technologies used are indigenous or purchased from an overseas provider. While many countries often deploy their own technologies at scale, many countries purchase technologies from overseas to deploy locally. As such the database indicates deployment activity, but not necessarily the ability to translate indigenous R&D into commercial scale-up.
2) This dataset counts only low-carbon hydrogen projects and their associated value chains. As such hydrogen production projects from gas, coal and oil without CCUS are not included. Similarly, utilisation projects not related to a clean hydrogen project source are not included.
3) The dataset reflects only projects occurring domestically, and therefore does not count projects undertaken by Canadian companies outside of Canada. As such, the table may understate Canada's activity, particularly its contribution to international supply chain development. This data should therefore be considered holistically with the rest of this report.
4) Any limitations stated in the data collection methodology, definitions and assumptions should be taken into account (see IEA Hydrogen Projects Database for details).

For the purposes of this report, the dataset has been filtered to include only projects from 2010 through to projects expected to be operational by 2030, as this timespan best reflects current activities. Projects without a specified date have been excluded from the table below. Further, only projects that are at feasibility study, final investment decision, demonstration, or operational stage are included. Projects at the 'concept' stage are not included. It should be noted that the majority of projects listed span production, storage and multiple end-uses, and as such can be counted in more than one technology category.

Table 15: Canada's domestic clean hydrogen project data

Technology	Sub-technology		Domestic project count	% of global
Production	Electrolysis	PEM	2	1.1
		Alkaline	4	3.4
		SOE	-	-
		Other or unspecified	4	1.6
	Fossil fuel conversion	Coal gasification with CCUS	-	-
		Natural gas with CCUS	5	13.9
		Oil with CCUS	1	16.7
		Methane pyrolysis	-	-

[190] IEA (2021) Hydrogen Projects Database. Available at https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database

Technology	Sub-technology		Domestic project count	% of global
	Biomass and waste conversion		-	-
	Photochemical and photocatalytic		-	-
	Biological production		-	-
	Thermal water splitting		-	-
Storage and distribution	Compression and liquefaction		15	3.0
	Chemical carriers	Ammonia	1	3.6
		Methane	-	-
		Methanol	-	-
		Synfuels	-	-
Utilisation	Gas blending		2	1.5
	Transport		3	1.3
	Electricity generation		5	3.7
	Industrial processes	Refining	-	-
		Ammonia	-	-
		Methane	-	-
		Iron and steel	-	-
		Biofuels	-	-
		Synfuel	-	-
		Other industry	9	6.6

IEA Hydrogen Projects Database

The latest version of the IEA Hydrogen Projects Database can be found at:

- https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database

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