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ASSESSING THE WORKFORCE REQUIRED TO ADVANCE CANADA'S HYDROGEN ECONOMY

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The Transition Accelerator
L'Accélérateur de transition

Assessing the Workforce Required to Advance Canada's Hydrogen Economy

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ABOUT THE TRANSITION ACCELERATOR

The Transition Accelerator (The Accelerator) exists to support Canada's transition to a net zero future while solving societal challenges. Using our four-step methodology, The Accelerator works with innovative groups to create visions of what a socially and economically desirable net zero future will look like and build out transition pathways that will enable Canada to get there. The Accelerator's role is that of an enabler, facilitator, and force multiplier that forms coalitions to take steps down these pathways and get change moving on the ground.

Our four-step approach is to understand, codevelop, analyze and advance credible and compelling transition pathways capable of achieving societal and economic objectives, including driving the country towards net zero greenhouse gas emissions by 2050.

1. UNDERSTAND the system that is being transformed, including its strengths and weaknesses, and the technology, business model, and social innovations that are poised to disrupt the existing system by addressing one or more of its shortcomings.

2. CODEVELOP transformative visions and pathways in concert with key stakeholders and innovators drawn from industry, government, indigenous communities, academia, and other groups. This engagement process is informed by the insights gained in Stage 1.

3. ANALYZE and model the candidate pathways from Stage 2 to assess costs, benefits, trade-offs, public acceptability, barriers and bottlenecks. With these insights, the process then re-engages key players to revise the vision and pathway(s), so they are more credible, compelling and capable of achieving societal objectives that include major GHG emission reductions.

4. ADVANCE the most credible, compelling and capable transition pathways by informing innovation strategies, engaging partners and helping to launch consortia to take tangible steps along defined transition pathways.

ABOUT THE AUTHOR

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CREATIVE LINKS INTERNATIONAL INC.

Pat Hufnagel-Smith is a partner at Creative Links International Inc. Pat has over 20 years consulting experience offering expertise on assignments focused on social factors associated with energy development. She specializes in providing insights into the dynamics of Canada's labour market, emerging trends and occupations, and workforce requirements. Two areas Pat is most passionate about are: the effective transition of skilled and experienced workers between industries, and assisting clients use labour market intelligence to develop evidence-based strategies that ensure communities share in the long-term benefits and value that accompanies energy development. In addition to a Bachelor of Arts degree in Sociology and Certificate in Adult Education and Facilitation, Pat holds a Master's Certificate in Project Management.

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EXECUTIVE SUMMARY

Canada's strengths in low-cost hydrogen production, fuel cell technology, and carbon capture and storage (CCS) can advance our national drive to net zero emissions by 2050. When combined with a skilled and ready workforce we are in a unique position to be a global leader, user and exporter of low-carbon hydrogen.

How Canada's low-carbon hydrogen economy is being developed provides insights into the pace for which an expanded workforce will be required. The transition will initially be characterized by deploying technologies to decarbonize production and by creating demand beyond today's uses. Development will use a HUB approach that focuses on scaling a region's hydrogen supply and demand assets. Knowledge of the workforce required, and its availability are also important considerations for establishing a hydrogen HUB. If workforce development, attraction and retention is not managed well during the acceleration of the hydrogen economy, competition for talent can escalate wages and overall labour costs.

> Availability of talent qualified for the hydrogen economy is a factor in attracting investment. Proactively addressing potential labour shortages help to mitigate cost and schedule risks. Developing the local labour market for jobs associated with hydrogen HUBs enhances local socio-economic benefits.

WORKFORCE REQUIRED TO ADVANCE OUR HYDROGEN ECONOMY

Canada's hydrogen industry already employs a workforce that knows how to produce, handle and use hydrogen safely. Advancing our low-carbon hydrogen economy will drive additional quality employment opportunities. There is a need for technical workers to know how to design, operate and maintain hydrogen infrastructure and vehicles given the unique properties of hydrogen. This includes a variety of Engineers, Trades workers, Technologists and Technicians, Plant operators and Truck drivers.

Occupations with the skills and knowledge to create the ecosystem that achieves the desired pace of hydrogen development are also needed. They include Business and commercial specialists, Government relations professionals, Stakeholder engagement specialists, Indigenous relationship specialists, Inspectors, Policy and Regulatory analysts and digital occupations. Shortages of qualified talent for these occupations can cause bottlenecks and impede progress towards a hydrogen economy.

Even with an established industry, innovation is ongoing to further advance hydrogen technology. Today's innovation ecosystem is modelled on collaboration, agility, transparency and trusting relationships. Advancing hydrogen requires a workforce that possesses not only technical skills but also employability skills, attitudes and behaviours that align with how an effective innovation ecosystem operates.

TALENT OPPORTUNITIES

Canada has tremendous opportunity to enhance the existing industrial labour force with hydrogen-related skills and knowledge. Short-term, focused training such as micro-credentials, bootcamps and work-integrated learning will support workforce development for the hydrogen industry. These emerging approaches to training also help facilitate workforce transition and, if proactively implemented, lessen the potential employment disruption associated with decarbonizing the energy system.

> The low-carbon hydrogen industry can build its brand as a climate solution and attract talent that want to be part of a sustainable energy system.

Accelerating the development of the hydrogen workforce will rely on collaboration. Partnerships have been established to pilot and test hydrogen value chains and applications in real time. Pilots designed to develop the workforce along with the technical aspects of the hydrogen value chains offer real time learning on how to best mitigate talent risks. Leveraging training, certification and best practices from other jurisdictions offers a cost-effective and efficient approach to developing needed upskilling programs.

TALENT RISKS

The hydrogen economy will have to contend with labour market challenges. Talent supply constraints already exist for some of hydrogen's core occupations including Power engineers, Instrumentation & control technicians, Maintenance trades and Truck drivers.

> Companies indicate that the widespread shortage of some core hydrogen occupations is a greater talent risk than a lack of hydrogen specific skills

Addressing barriers to inclusivity expands the availability of qualified candidates and offers a solution to labour shortages. Investors have heightened expectations for companies to advance toward a more diverse and inclusive workforce for both environmental, social and governance (ESG) and financial performance reasons.

Fuel cell technology is a cornerstone for advancing the hydrogen economy. Few jurisdictions can compete with Canada's experience and expertise in fuel cell research and development and engineering. However, the training to acquire the skills and knowledge to install, maintain and repair hydrogen fuel cell applications is lagging. These skillsets need to be developed alongside advancing the hydrogen economy.

A limited understanding of hydrogen careers and workforce transferability is a barrier to proactively preparing the workforce. Post-secondary and other training institutions are reluctant to develop relevant programming without evidence there is a high likelihood for a return on their investment.

ADVANCING HYDROGEN CAN OFFER A "JUST WORKFORCE TRANSITION"

Canada's net zero economy will only thrive if we have a well-functioning labour market. A hydrogen economy offers an opportunity for a "just transition" that maximizes participation, is equitable, inclusive and diverse, and optimizes the skills and knowledge of available workers by matching them with hydrogen careers.

1 INTRODUCTION

Canada is one of the world's largest and lowest cost producers of hydrogen. Strengths in hydrogen production, fuel cell technology, and carbon capture, utilization, and storage (CCUS) can advance our national drive to net-zero by decarbonizing many of the heavy-emitting sectors important to the Canadian economy.[1] Areas that hydrogen can impact include resource extraction, freight, transportation, heating, power generation, and the manufacturing of essential products like fertilizer, steel and cement. In addition, hydrogen has potential as an energy storage mechanism to support renewable energy from wind and solar.

When combined with a skilled and ready workforce, Canada is in a unique position to become a global leader as both user and exporter of low-carbon hydrogen. The purpose of this document is to outline the workforce required to advance Canada's hydrogen economy. In it, we point out the opportunities to leverage skilled and available labour and the degree to which an additional workforce must be developed, while also identifying the potential risks to meeting hydrogen's talent needs.

A key objective of this work is to establish a common, foundational understanding of the core occupations needed to advance Canada's hydrogen economy. This report does not quantify hydrogen workforce requirements. Forecasting hydrogen workforce demand based on investment and activity scenarios could be a valuable exercise that leverages this assessment of workforce requirements by occupation. Given the emerging nature of the hydrogen economy, this report and the accompanying *Hydrogen Workforce Assessment Tool*, are intended to be living documents, providing an initial overview of workforce requirements that can be updated as hydrogen value chains develop.

It is important to note that advancing a hydrogen economy requires infrastructure, and hydrogen production relies on a variety of feedstocks such as renewable energy (solar, wind and hydropower) and fossil fuels. The occupational requirements for the engineering, procurement and construction (EPC) industry and the production feedstock sectors are not included in this report. Advancing low-carbon hydrogen will have a positive and sustaining impact on these related workforces as well.

1.1 Towards a Low-Carbon Hydrogen Economy

Understanding how Canada's hydrogen economy is being developed provides insights into the pace for which an expanded hydrogen workforce will be required. The transition to low-carbon hydrogen will initially be characterized by deploying technologies to decarbonize production and by creating demand beyond today's industrial uses.[2]

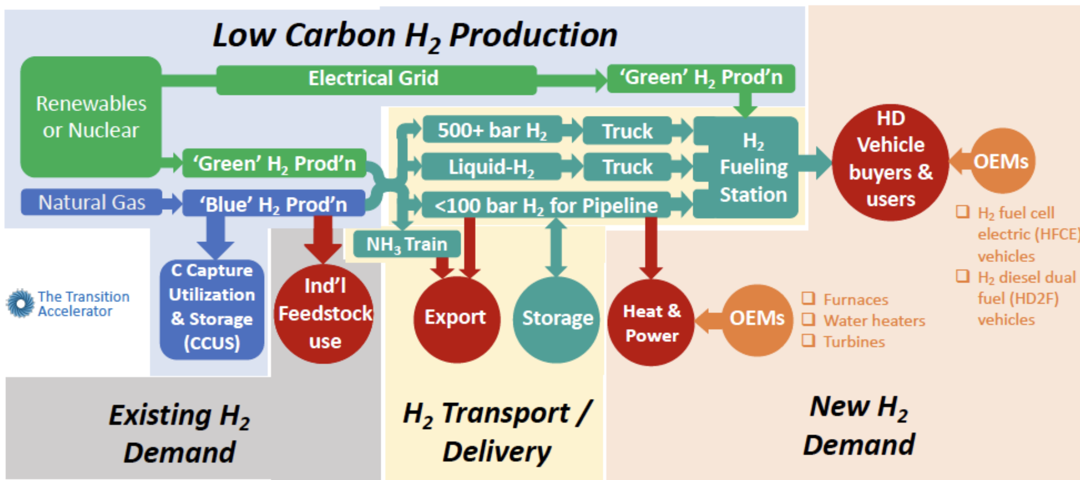

Figure 1 Towards a New Hydrogen Economy

SOURCE: The Transition Accelerator

1.1.1 Low Carbon Hydrogen Production

The majority of Canada's current hydrogen is produced by reforming natural gas or by upgrading oil sands bitumen. While this form of production is low-cost, it produces carbon. To be part of a net zero energy system, this type of hydrogen production needs to be coupled with carbon capture and storage (CCS) and is referred to as "blue" hydrogen. Low carbon (blue) hydrogen has been produced in Alberta since 2015 at the Quest CCS facility. Two additional plants in Alberta that capture emissions are Nutrien's Redwater Fertilizer Facility, and the North West Redwater Partnership's Sturgeon Refinery. With a fourth commercially operating capture facility at the Boundary Dam Power Plant in Saskatchewan and the world's largest carbon dioxide gathering and transportation infrastructure system in the Alberta Carbon Trunk Line,[3] Canada has CCS expertise that can be leveraged to accelerate the low-carbon hydrogen economy.[4]

Expanding the use of electrolyzer technology powered by renewable electricity to separate water into hydrogen and oxygen offers the opportunity to increase the supply of "green" hydrogen. This type of electrochemical production of hydrogen results in a pure, low or no carbon product and likely presents the greatest opportunity for provinces with baseload renewable electricity generation such as hydropower.[5]

1.1.2 Hydrogen Storage, Transport and Delivery

Hydrogen production facilities, including onsite production for fueling stations, typically have short-term storage onsite. Hydrogen is safely stored as a compressed gas or cryogenic liquid in tanks. As demand for hydrogen grows, there will be a need to increase storage capacity. Underground salt caverns and depleted hydrocarbon reservoirs are emerging as feasible, large-scale solutions for storing compressed hydrogen. Underground storage also offers the opportunity to store surplus energy generated from renewable sources by first electrolyzing it into hydrogen and then storing it in caverns or reservoirs for power, industrial and transport applications as demand dictates.[6]

Hydrogen supply and demand value chains are connected by a distribution system of pipelines, roads for truck transportation and rail. Hydrogen can be transported as a gas or a liquid or as part of a chemical compound such as ammonia (NH_3). In the case of using a chemical carrier to transport hydrogen, processing to separate hydrogen molecules from the compound is required at its destination. The process by which hydrogen is removed from an organic compound is called dehydrogenation.

Currently, transporting hydrogen by truck is most common. Gaseous hydrogen is transported in compressed tube trailers and liquid hydrogen in super-insulated, cryogenic liquid tankers. As demand for hydrogen grows, there will be a need for safe, low-cost delivery of large volumes of hydrogen across long distances.

Canada has several hundred kilometers of hydrogen pipelines including process pipelines transport hydrogen inside industrial facilities and transmission pipelines connecting hydrogen production to customers in industrial hubs in Alberta and Ontario. Expanding the hydrogen pipeline network is a distribution solution. However, there currently are no large high-pressure pipelines that deliver pure hydrogen to demand markets in Canada and there are challenges that need to be addressed to make this mode of transporting hydrogen technically and economically feasible.[7]

In the near-term blending hydrogen with natural gas in natural gas pipelines is the strategy being implemented to provide a lower carbon gas product to consumers and establish demand. Hydrogen can be transported in natural gas pipelines and used by existing household appliances with blends of up to 20%.[8] Blending provides time to continue to conduct research into hydrogen resilient materials, compression technology, controls for potential leaks and inspections, maintenance, risk management, and the potential to convert natural gas pipelines to pure hydrogen.

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Ammonia is an effective chemical carrier for hydrogen because it can be produced using low-carbon methods,[9] has high hydrogen storage density and can be liquefied for transport by rail or ship.[10] Canada is already a major ammonia producer thanks to our well-established hydrogen production capabilities and available infrastructure.[11] The ability to produce and transport low-cost, low-carbon hydrogen as liquid ammonia offers Canada an opportunity to export supply to jurisdictions that do not have the same capacity.

1.1.3 Existing and New Demand for Hydrogen

Hydrogen producers will not invest in increasing low-carbon supply if demand is not established. Expanding existing and creating new markets for low-carbon hydrogen is a pre-requisite to attracting investment in supply infrastructure.

Today's industrial uses include petroleum refining, oil sands processing and upgrading, synthetic fuel manufacturing, ammonia and fertilizer production and petrochemicals. Expanding hydrogen as an industrial feedstock for steel, cement, and mineral and metal manufacturing would drive additional demand.

Additional opportunities for growing demand include increasing use of hydrogen as an energy source for the transportation and freight sectors. Hydrogen fueling stations are required to enable the use of hydrogen as a transportation fuel.

Hydrogen can also play a role in decarbonizing heating and power generation. Canada has two projects demonstrating the ability to blend hydrogen and natural gas for heating: Enbridge's initiative at its Markham Power-to-Gas facility and ATCO's Fort Saskatchewan Hydrogen Blending Project. Blending offers the opportunity to build demand for hydrogen using existing natural gas utility pipelines and heating appliances while technology required to transition to pure hydrogen for industrial, residential and commercial heating continues to be tested and proven.[12]

There are a number of applications for hydrogen to be used in power generation.[13] Stationary and portable fuel cells, similar to those used for FCEV's, can be used to generate power. This technology is well suited for back-up power, electricity for large residential and institutional complexes such as hospitals and universities and a replacement for diesel-generated power for remote locations. Modern natural gas turbines are capable of operating using hydrogen-natural gas blends offering the opportunity for base load electricity grids that rely on fossil fuels to reduce emissions.

Hydrogen also has energy storage capability.[14] Surplus renewable energy can be converted to hydrogen using electrolysis, compressed and stored underground, and then accessed and re-electrified to address challenges associated with intermittent supply and variable demand.

1.1.4 Manufacturing for Hydrogen Value Chains

The development of Canada's manufacturing sector to ensure the availability of hydrogen appropriate equipment and technology is important to derisk the potential for supply chain bottlenecks. Ramping up the manufacturing of fuel cells, hydrogen fuel cell vehicles and drivetrains, and electrolyzers may be the most obvious need to support the advancement of hydrogen; but the need for equipment, systems and components compatible with hydrogen is much greater. As examples, cost-effective transition to hydrogen will require hydrogen-diesel dual fuel technology and conversion kits, mobile power generation integrators and end-use devices such as household appliances including furnaces, boilers, water heaters, fireplaces and laundry dryers that can use hydrogen.

Companies that currently manufacture piping and pressure vessels, compressors, valves, turbines and other equipment for Canada's industrial and natural resource sectors have the opportunity to diversify their market by making their products suitable for hydrogen infrastructure. This also includes the fabrication and manufacturing of modularized process packages that are needed for hydrogen and CCS infrastructure.

1.2 HUB Approach for Advancing Low-Carbon Hydrogen

A significant challenge in advancing an affordable low-carbon hydrogen economy is simultaneously building the supply and demand value chains, and the distribution systems required to connect them. HUBs have been identified as the prominent approach for developing a viable hydrogen economy.[15]

A hydrogen HUB is a region where hydrogen supply and demand can be significantly scaled. The first step in the development of a HUB is to conduct a feasibility study to determine if sustainable economics exist for hydrogen supply and demand value chains. Criteria to consider include the availability of:

- Resources needed to produce and supply low-cost, low-carbon hydrogen
- Nearby market demand
- The ability to connect supply and demand through roads, rail and/or pipelines
- Potential to scale the supply and demand without sustained public investment
- Engaged stakeholders including industry, governments and academics

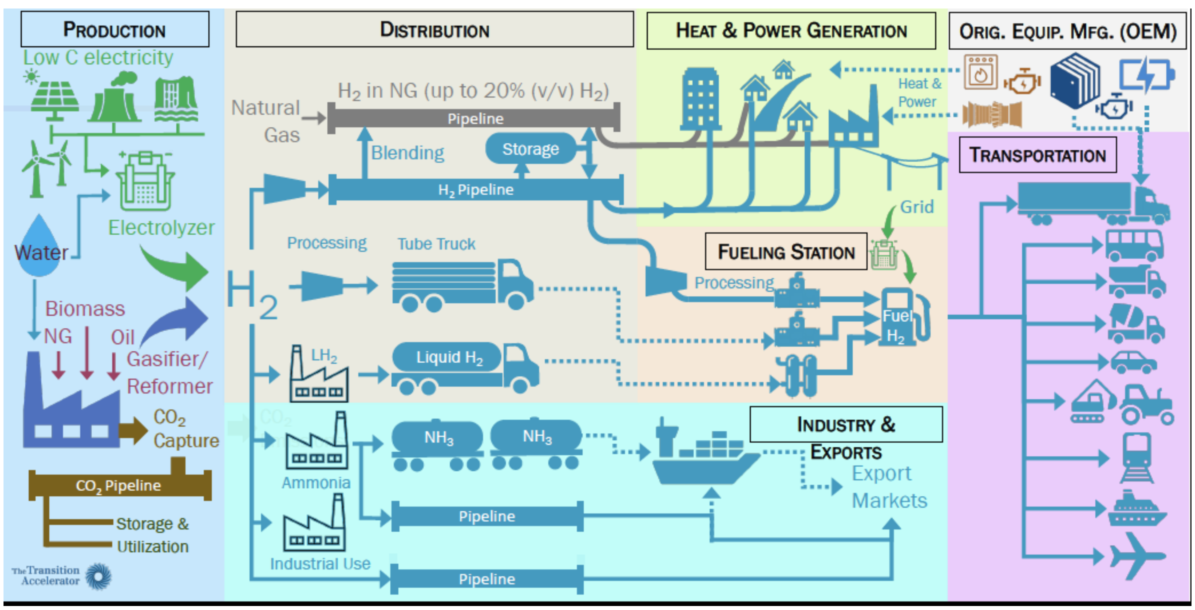

Figure 2 Key Value Chains in an Established Hydrogen Economy

SOURCE: Edmonton Hydrogen Hub and The Transition Accelerator

Table 1 Hydrogen Supply and Demand Value Chains & Technologies Included

Value Chain	Technology
Production (supply)	Proton Exchange Membrane (PEM) electrolysis Steam methane reforming (SMR) and Autothermal reforming (ATR) Carbon capture and storage (CCS)
Storage, Upgrading & Transporting (distribution)	Underground storage Pipeline transmission Truck distribution of compressed gas and cryogenic liquid hydrogen Ammonia as a chemical carrier
Fueling Stations (distribution)	Design and operation of a network of hydrogen fueling stations
Heat & Power Generation (demand)	Hydrogen initially blended with existing natural gas system to build demand while improving the economic and technical feasibility of using pure hydrogen
Transportation (demand)	Heavy and medium-duty transport and freight trucks, trains and return-to-base vehicles such as municipal transit systems and delivery trucks
Manufacturing for Hydrogen (enabling)	Manufacturing, fabrication and assembly of a broad range of equipment, components and modules that will enable the advancement of hydrogen

1.3 Talent Needed to Scale Affordable Hydrogen Economy

A qualified talent pool is also an asset that increases the scalability and affordability of hydrogen as a pathway to net zero. Knowledge of the required workforce and its availability to develop, construct, operate and maintain supply and demand value chains are important considerations for establishing a HUB. Talent availability is a factor in attracting investment.[16] Understanding and proactively addressing potential labour shortages are important elements for mitigating project cost and schedule risks. Developing and transitioning the local labour market so they may qualify for well-paid hydrogen employment opportunities enhances local socio-economic benefits.

This report, and the *Hydrogen Workforce Assessment Tool (Tool)*, have been created to support the HUB approach to assessing the feasibility of building a viable low-carbon hydrogen economy. The report offers a summary of workforce requirements and potential talent opportunities and risks. The report also introduces a framework and offers insights into potential next steps for accelerating workforce transition and development for the hydrogen economy. The *Tool* presents a detailed assessment of the occupations required for each value chain involved in the low-carbon hydrogen economy. Using the *Tool*, readers can contemplate a HUB's specific talent needs, opportunities and risks based on the HUB's associated value chain components.

2 CORE WORKFORCE REQUIREMENTS ACROSS HYDROGEN VALUE CHAINS

Canada's existing hydrogen industry already employs a workforce that knows how to produce, handle and use hydrogen safety at industrial scale. Developing a low-carbon hydrogen economy will drive additional employment opportunities for a highly skilled, well-paid, technical and professional workforce. It will contribute to sustaining employment for workers involved in high-emitting industries by offering these sectors a pathway to sustainability and achieving net zero through decarbonization. Advancing the hydrogen economy also offers career transition opportunities for workers whose employment is disrupted by the evolving energy mix.

Many of the core technical occupations and foundational skills required by the hydrogen economy are already found within Canada's labour market. Core occupations are defined as those that are key to the industry's ability to sustain operations. They are often hired in significant numbers but can also represent occupations that have a significant impact on the business or industry's ability to succeed.

The following table identifies the core occupations for each of the in-scope value chains. Some of the value chain workforces are made up of similar occupations. This is a consideration for the HUB approach to developing hydrogen as it may amplify the potential for occupational and/or skill shortages in a particular geographic region. If not managed well, competition for talent can escalate wages and overall labour costs.

Details regarding their qualifications, key activities, and hydrogen-specific requirements are outlined in the *Hydrogen Workforce Development Assessment Tool*, found at https://transitionaccelerator.ca/assessing-the-workforce-required-to-advance-canadas-hydrogen-economy.

Table 2 Core Occupations Across the Hydrogen Value Chains

Production Technologies			
Proton Exchange Membrane (PEM) Electrolysis		**Steam Methane Reforming (SMR) & Autothermal Reforming (ATR)**	
Automation & control specialist Chemical/Process engineer Control room operator Electrical engineer Electrical & instrumentation engineer Facility engineer Lab technician Maintenance planner Maintenance trades: Electrical, Instrumentation & control, Mechanical	Mechanical engineers: Equipment & piping, Reliability Measurement specialist Plant manager Plant operator Process control engineer Process safety engineer Production engineer Renewable interconnect specialist	Automation & control specialist Control room operator Electrical & instrumentation engineer Facility engineer Lab technician Maintenance planner Maintenance trades: Electrical, Instrumentation & control, Mechanical Measurement specialist	Mechanical engineers: Equipment & piping, Reliability) Plant manager Plant operator Process control engineer Process engineer Process safety engineer Production engineer

Carbon Capture & Storage (CCS)			
Carbon capture	**Pipeline transmission**	**Underground storage**	**Measurement, Monitoring, Verification (MMV)**
Automation & control specialist Control room operator Electrical & instrumentation engineer Facility engineer Lab technician Maintenance planner Maintenance trades: Electrical, Instrumentation & control, Mechanical Measurement specialist Mechanical engineers: Equipment & piping, Reliability) Plant manager Plant operator Process control engineer Process engineer Process safety engineer Production engineer	Automation & control specialist Compression specialist Control centre operator Corrosion specialist Electrical & instrumentation engineer Hydraulics engineer Measurement specialist Pipeline engineer Pipeline integrity specialist Pipeline scheduler Pipeline technician: Electrical &, instrumentation, Mechanical Process safety engineer Station operators: Compression, Pump	Drilling & completion engineer Drilling crew Geoscience professionals: Geologist, Geophysicist Heavy duty mechanic Reservoir engineer Reservoir technologist Service rig crew Well completions operator Well completions supervisor	Geoscience professionals: Geologist, Geophysicist Instrumentation technician Measurement specialist Reservoir engineer Reservoir technologist Sampling and analysis technician Seismic crew

Storage, Upgrading & Transportation (Distribution)			
Underground storage	**Pipelines**	**Distribution by truck transportation (compressed & liquid hydrogen)**	**Ammonia as a chemical carrier**
Cavern engineer	Automation & control specialist	Cylinder technician	Automation & control specialist
Control centre operator	Compression specialist	Heavy duty mechanic	Control room operator
Compression specialist	Control centre operator	Logistics coordinator	Electrical & instrumentation engineer
Drilling & completion engineer	Corrosion specialist	Tank tester/inspector	Facility engineer
Drilling crew	Electrical & instrumentation engineer	Truck drivers (classes 1 & 3)	Lab technician
Geoscience professionals: Geologist, Geophysicist, Geotechnical specialist	Measurement specialist		Maintenance planner
Heavy duty mechanic	Pipeline engineer		Maintenance trades: Electrical, Instrumentation & control, Mechanical
Maintenance trades: Electrical & instrumentation, Mechanical	Pipeline integrity specialist		Measurement specialist
Measurement specialist	Pipeline scheduler		Mechanical engineers: Equipment & piping, Reliability)
Reservoir technologist	Pipeline technicians: Electrical & Instrumentation, Mechanical		Plant manager
Service rig crew	Process safety engineer		Plant operator
Well completions operator	Station operator: Compression		Process control engineer
Well completions supervisor			Process engineer
			Process safety engineer
			Production engineer

Transportation	**Fueling Stations**	**Heating**
Dual fuel heavy duty mechanic	Automation & control specialist	Asset performance manager
Fleet manager	Electrical & instrumentation engineer	Hydrogen integration specialist
Fuel cell electric vehicle (FCEV) technician	Fueling station technician	Gas fuser
Locomotive engineer	Logistics coordinator	Gasfitter
Locomotive mechanics: Field, Shop	Maintenance technicians: Compression, Electrical & mechanical	HVAC technician
Transportation solutions advisor	Mechanical engineers: Compression, Equip & piping, Reliability	Utility inspector
Truck drivers (classes 1 & 3)	Process controls engineer	Utility operator
	Process engineer	Utility services planner
	Process safety engineer	Utility service technician
	Product engineer	Welding engineer
	Quality engineer	
	Truck drivers (classes 1 & 3) – Hydrogen fuel delivery	

Power Generation	Manufacturing	
Automation & control specialist	Applications engineer	Production scheduler
Control room operator	Assembly technician	Production supervisor
Compression specialist	Compliance specialist	Quality control specialist
Electrical engineer	CNC fabrication technician	Sourcing specialist
Electrical & instrumentation engineer	Design engineer: Electrical & instrumentation, Mechanical, Mechatronics	Test technician
Facility engineer	Facility maintenance planner	Test validation engineer
Hydrogen integration specialist	Maintenance trades: Electrical, Electromechanical, Instrumentation & control, Mechanical	Welder
Maintenance planner	Manufacturing engineer	
Maintenance trades: Electrical, Instrumentation & control, Mechanical	Materials specialist	
Mechanical engineers: Equipment & piping, Reliability)	Mechatronics engineer: Facility	
Plant manager	Pipefitters/Steamfitters	
Plant operator		
Power scheduler		
Process control engineer		
Process engineer		
Process safety engineer		

2.1 Hydrogen-specific Knowledge Required to Strengthen Foundational Technical Skills

Despite the opportunity to leverage occupations present within existing industries, there is still work to be done to expand a safe and technically competent hydrogen workforce. Hydrogen is no more or less safe than other fuels, it's just different. The risks associated with hydrogen are known and well understood, but not necessarily by workers who have not had the opportunity to work with it. There is a need for workers to know how to design, manufacture, operate and maintain hydrogen infrastructure, equipment and vehicles given the unique properties of hydrogen.

Expanding hydrogen-related infrastructure, technologies and operations will require:

- Process engineering and controls skills specific to hydrogen including hazard risk analysis and reviews, mechanical integrity and instrumented system analysis, and operation readiness inspection[17]

- Selection and application of materials, coatings and sealants, equipment, and measurement and detection technologies appropriate for hydrogen
- Understanding of electrochemical processes and ability to install, troubleshoot, service and maintain equipment and technology associated with deployment of hydrogen fuel cells, electrolyzers, etc.
- Rigorous materials and equipment inspection, testing, and integrity management programs
- Knowledge and understanding of regulations, codes and standards as they pertain to hydrogen
- Safety training for all workers involved in handling hydrogen
- Expanded training for fire, law enforcement and emergency medical personnel required to respond to incidents involving hydrogen and hydrogen fuel cell vehicles[18]

Table 3 Properties of Hydrogen, Implications and Skill & Knowledge Considerations

Hydrogen Properties	Design, Operations & Maintenance Implications	Skill & Knowledge Considerations
Smaller molecule with low molecular weight and density	• More easily absorbed by some metallic alloys (including steel) causing degradation or embrittlement • Avoidance and prevention of cracks and ruptures in materials that can lead to leakage are priorities	• How hydrogen gas behaves, and the hazards created if a leak occurs • Appropriate type of cathodic protection, materials, insulators, coatings, inhibitors to use to protect from hydrogen corrosion • Non-destructive testing to monitor the condition of materials and components
Odourless, colourless, tasteless, and burns with an invisible flame	• Leak detection is difficult • Leak prevention, early detection and mitigation are priorities	• Appropriate type of fittings, threaded steel joints, valves, seals and sealants to use • Type of leak detection equipment required and how to undertake calibration, testing, analysis and maintenance checks • Appropriate odorants to use to assist with leak detection • Procedures to trace, locate and repair leaks
Highly flammable	• Ignites more easily than natural gas or gasoline	• Appropriate ventilation design and equipment selection • Type of combustion analyzer required, and how to use the analyzer, calibrate it and carry out maintenance checks
Low volumetric energy density	Impacts storage and distribution: • Gaseous hydrogen must be stored at very high pressures	• Appropriate selection and design of vessels, compressors, piping systems and fitting, valves and seals to withstand hydrogen gas pressure and temperatures

Hydrogen Properties	Design, Operations & Maintenance Implications	Skill & Knowledge Considerations
	• Liquid hydrogen needs to be stored at low pressure and very low, cryogenic temperatures • Compression more challenging as it requires increased system pressure	• Appropriate selection and design of vessels, piping systems and fitting, equipment and seals for liquid hydrogen pressure and ability to withstand extremely cold temperatures • Assessment of technical and economic viability of sub-surface salt caverns for utility scale hydrogen storage, and their engineering

2.2 Creating the Desired Pace of Development

There are core occupations employed across all value chains that are focused on creating the ecosystem required to achieve the desired pace of development of the hydrogen economy. While some of these occupations are not required in great numbers, shortages of qualified talent could cause bottlenecks and impede progress. Some of these jobs are technical in nature and need hydrogen-specific expertise as described in Table 3. Other roles support the expansion of the hydrogen economy using specialized skills and knowledge as related to achieving sustainability, regulatory compliance, safety, public engagement and relationship building.

Table 4 Core Occupations that Support the Development of Hydrogen Value Chains

Core Occupational Groupings		
Business & commercial development specialist Digital occupations: • Cybersecurity specialist • Data analyst • Data engineer • Data scientist • Software developer • Systems integration specialist	Environmental, Social and Governance (ESG) roles such as: • Environmental specialist • Environment, Social, Governance: Analyst, Leader • Government relations specialist • Health & safety advisor • Indigenous relations professional • Regulatory analyst and compliance specialist • Stakeholder engagement and communications specialist • Sustainability specialist	Inspectors • Cathodic protection technician • Coating inspector • Construction inspector • Corrosion specialist • In-service pressure equipment inspectors • Non-destructive (NDE) inspector and technician • Safety codes inspector • Welding inspector

Business and commercial development occupations are required by all companies that promote hydrogen projects, technologies, products and/or services. The skills and knowledge these occupations contribute are crucial for building market pull to drive the hydrogen economy. Candidates for these positions need a solid understanding of hydrogen technologies, their costs, as well as their carbon advantages and disadvantages, so they can evaluate project opportunities and feasibility against commercial, technical and non-technical requirements, also known as a techno-economic analysis.

Environmental, Social and Governance (ESG) factors are a consideration across many sectors, including the hydrogen value chains and their respective project lifecycles. Companies are increasing their focus on improving sustainability and their ESG-related performance in order to meet values-driven goals and attract investment and employees. It is not enough for low-carbon hydrogen producers and end-user companies to say they are advancing ESG and sustainability, they need to provide data-driven evidence and demonstrate commitment through their decisions and activities. The focus on ESG is driving demand for a broad range of associated roles.

Companies indicate that skills and knowledge related to environmental factors are currently most in demand. There is a growing need to go beyond reporting environmental compliance driving the need to employ experts who offer insights into climate solutions and guidance on achieving the organization's net zero by 2050 commitments.[19] Government relations specialist with the ability to assist their company navigate an evolving regulatory and policy environment and take advantage of funding and incentive programs are also increasingly in demand. Other in-demand skills include:

- Ability to align company metrics with existing ESG frameworks and monitor progress and impact of International Sustainability Standards Board (ISSB) efforts to deliver a global baseline of sustainability disclosures for the capital markets[20]
    - Climate Disclosure Standards Board (CDSB)
    - Global Reporting Initiative (GRI)
    - International Integrated Reporting Council (IIRC)
    - Sustainability Accounting Standards Board (SASB)
    - Task Force for Climate-related Financial Disclosures (TCFD)
- Carbon accounting and credit management
- Circular economy planning and implementation
- Climate-scenario analysis
- Emissions reduction strategies and technologies for mitigating scope 1, 2 & 3 emissions
- Engineering and design solutions for environmental and greenhouse gas (GHG) emissions concerns
- GHG regulations compliance reporting
- Knowledge of current and emerging climate-related provincial and federal regulations and their impact on business strategy

Beyond the environmental considerations associated with advancing the hydrogen economy, there are social impacts that need to be assessed and risks mitigated when deciding on expanding the value chains.[21] As a result, Stakeholder engagement and communication roles are gaining prominence with organizations of all sizes across the value chains. Public confidence and support for the hydrogen economy are critical to its success. Technology can become polarizing when its benefits, risks and mitigation strategies are not fully understood or communicated. The range of technologies employed across the hydrogen value chains need to be deemed acceptable towards meeting the goal of a low-carbon energy supply.[22]

Stakeholders want to understand the value proposition of the hydrogen industry, and what it means to them. Companies across the value chains need employees with the skills and knowledge to understand public concerns, acknowledge potential risks associated with developing the hydrogen economy, and communicate steps that will be taken for acceptably mitigating those risks. These employees must be able to explain hydrogen projects as they pertain to employee and public safety, environmentally responsible development, and the socio-economic impacts.

The hydrogen industry as a whole and companies specifically require skills and knowledge to:

- Develop and conduct qualitative and quantitative research to gain an understanding of the broad range of concerns and attitudes towards hydrogen expressed by diverse stakeholders
- Develop and implement strategies for transparent and two-way communication
- Develop and implement strategies that foster and maintain positive stakeholder relationships, reciprocal trust, and ongoing, respectful stakeholder involvement[23]

Relationships with Indigenous communities are distinct from other industry and company relationships due to Indigenous rights to their land and traditions, and federal laws regulating environmental assessment and consultation processes. Many hydrogen-related projects will take place on or near Indigenous communities and fostering relationships early in the planning process is critical to earning acceptance and accelerating the hydrogen economy. Indigenous ownership in hydrogen projects, including as founding partners, create pathways to economic reconciliation for First Nations.[24] In addition to consultation and engagement skills, an understanding and appreciation for Indigenous cultures, history, rights and other fundamental issues relating to land use, traditional knowledge and governance structures are “must-have” capabilities to advance hydrogen value chain infrastructure and operations. Indigenous leaders are looking to establish partnerships with industry that create sustainable economic, social and cultural outcomes for their communities.

Digital occupations like software developers, systems integration engineers, and data scientists and analysts will be in high demand in the hydrogen economy for several reasons.

- The value chains associated with the hydrogen economy will be highly digitized. Digital and automated operations are not only cost effective, but they are also key enablers of safety and decarbonization. Digitization reduces costs and environmental impacts and improves workforce and public safety by:[25]

  - Improving response times to operational problems or interruptions, including early leak detection, thereby potentially reducing their impact
  - Using predictive analysis to reduce unplanned operational and environmental events
  - Reducing energy waste through energy-efficiency technologies
  - Automating process control, production optimization and remote operations, decreasing the potential for human error, improving safety, and allowing workers to focus on higher value activities
  - Employing 3D digital twins, or digital replicas of real-world assets and processes, to let companies plan and coordinate activities virtually and remotely, reducing costs, increasing efficiency and safety, and reducing travel-related emissions
- Investigating novel hydrogen technologies, processes and uses relies on digital modelling and simulation. Data collection and analysis play important roles in gathering evidence and identifying opportunities to increase the efficiency, affordability and viability of evolving hydrogen technologies.
- "Advanced manufacturing" refers to the use of technology to increase the efficiency of processes and improve capacity and competitiveness. It relies on digital skills to install, program, operate and maintain computerized equipment.[26] Canadian manufacturing companies, including those that have been at the cornerstone of hydrogen fuel cell research and development, are investing in advanced manufacturing facilities to enhance cost-effective deployment of their products and technology.[27]
- Digital technologies and software applications designed to gather ESG data improve transparency and real-time visibility into the actions a business is taking towards sustainability.
- Hydrogen will be part of Canada's critical energy system and security will be paramount. Expertise in cybersecurity to manage risks and protect systems will be critical.

As with any major industrial infrastructure, the hydrogen industry requires regular inspections starting with manufacturing and fabrication, construction and installation through to ongoing operations. The hydrogen industry may require additional inspections due to its unique characteristics, the complexity of its processes, the need to mitigate the risk of embrittlement and its requisite for robust safety regulations. The emerging nature of some hydrogen technologies is also likely to drive the need for more regular inspections. It is anticipated growth of the hydrogen economy will drive greater demand for occupations such as:

- Coating inspectors that ensure protective coatings are applied correctly to equipment and piping to minimize corrosion
- Corrosion specialists that develop and implement strategies to slow or prevent corrosion that can damage equipment and infrastructure
- Non-destructive test (NDT) technicians and inspectors that use non-destructive evaluation methods where the properties of components, materials or systems are tested without causing any damage
- Welding inspectors to ensure the integrity of all metal joints by confirming they fused together using correct techniques

2.3 Establishing Canada's Hydrogen Regulatory & Policy Frameworks

Canada is lagging other jurisdictions in the development of hydrogen-related regulations and standards.[28] As uncertainty detracts from investment, a framework that includes results-based regulations, stable policies and coordinated incentives and programs is critical to attracting the investment required to accelerate and scale a hydrogen economy.[29]

Procurement is a lever that can drive domestic manufacturing capacity, investment, and innovation.[30] Government programs designed to encourage regional procurement can have a positive impact on expanding and diversifying Canada's manufacturing sector and related employment.

Establishing Canada's hydrogen regulatory and policy frameworks and related programs requires expertise in technical and economic factors, as well as in the social landscape associated with the industry. Canada's regulatory and policy workforce needs to include analysts and advisors with a combined knowledge across a broad range of hydrogen-related topics including hydrogen technologies, low-carbon fuels, carbon pricing/offsets, vehicle emissions, zero-emission vehicle mandates, carbon sequestration rights and pore space allocation, emissions reduction compliance credits, hydrogen blending into natural gas, and investment tax credits, etc.

2.4 Beyond Technical Skills & Knowledge

While Canada has an established hydrogen industry, innovation is ongoing. There is substantial focus on research and development, and the implementation of pilot programs are necessary to continue to enhance the environmental, technical and economic feasibility of hydrogen, and progress on the path to commercialization and widespread deployment.[31]

How industry innovates is changing. Companies and organizations are recognizing that no single entity can go it alone and succeed.[32] Accelerating innovation, technology development and the deployment of the hydrogen economy requires an ecosystem approach, which involves collaboration among a variety of stakeholders including industry, government, technology accelerators, subject matter experts, academia/research institutions and investors.[33]

An ecosystem modelled on collaboration, where sometimes competitors and non-traditional partners work together towards common goals, requires a workforce that possesses a set of aligned employability skills, attitudes and behaviours that complement technical skills, education and experience.[34] Talent that is more familiar with an organizational culture built around competition and secrecy may be challenged to adjust to a more open, cooperative culture.

Figure 3 Employability Skills Required for Collaborative Innovation Ecosystem

SOURCE: Clean Resource Innovation Network (CRIN)

3 TALENT OPPORTUNITIES AND RISKS FOR CANADA'S HYDROGEN ECONOMY

As it looks to further its hydrogen economy, Canada has tremendous opportunity to leverage industrial knowhow, occupations and skills that are available in the existing labour market. Even some emerging, hydrogen-specific occupations such as fuel cell electric vehicle (FCEV) technicians are likely to be developed from the current workforce of heavy duty and automotive technicians.[35] In fact, many would say that prioritizing the transition of the workforce impacted by energy transition to fill the talent needed for net zero by 2050 not only makes economic sense but is foundational to a just transition.

The hydrogen economy and its value chains will also have to contend with labour market challenges that are likely to be exacerbated as hydrogen-related investment increases and employment grows. Canada's workforce is ageing. Workers retiring from the labour force are outpacing new entrants, which is a factor contributing to general labour shortages.[36] Some of the hydrogen industry's core occupations are already challenged to attract the talent needed to fill job vacancies. Many of the occupations the hydrogen value chains employ lack diversity. This may hinder the industry's ability to attract a diverse and inclusive workforce that is an increasingly important ESG metric for investors.

3.1 Talent Opportunities

3.1.1 Leverage Existing Expertise

There is opportunity to increase the readiness of the workforce required to advance the hydrogen economy by expanding on existing expertise, including:

- The engineering, project development and construction activities, skills and occupations associated with building the hydrogen infrastructure are very similar to those required for other industrial projects.
- Canada's oil, gas and utilities industries already have deep expertise in the processing, compression, pipeline transmission, truck transportation, and safe handling of gas and liquid fuels.
- The heavy-duty and medium-duty vehicle manufacturing sector is at the forefront of developing low-carbon technologies for medium and heavy truck and rail transportation.

- Hydrogen infrastructure requires mechanical equipment and systems such as pressure vessels, cylinders, valves, turbines, piping systems, heating and cooling systems, etc., that are already manufactured in Canada. The skills, knowledge and supply chains to design and develop these high value, low volume, high mix products are well established for the traditional energy sector.
- The development of the hydrogen economy will benefit from the modular fabrication and assembly facilities and workforce that have been established to maximize efficiency, quality and cost-effective construction of other industrial process operations including oil sands and petrochemicals.
- Advanced instrumentation and control systems and skills required to ensure safe operations are well established in Canada's process manufacturing sectors, including mining, oil & gas, pulp & paper, power generation, agriculture and food manufacturing, and petrochemicals.
- CCS is required for the production of low-carbon "blue hydrogen". Canada has extensive experience with carbon capture and underground storage technology, world class sub-surface engineering, geoscience, well integrity and well drilling and completions expertise and the geological formations required for permanent storage of carbon.
- Underground storage of hydrogen gas will leverage existing expertise found in the natural gas sector. This includes specialized knowledge for assessing salt caverns, cavern construction using drilling and completions, maintenance using mechanical integrity testing (MIT) and well workovers, and surface infrastructure for ongoing operation and controls.
- Hydrogen fuel cell technology is important to encouraging market demand for hydrogen. Canada has extensive research and development (R&D) success in hydrogen fuel cell technology and exports this expertise globally. These same companies are expanding their national operations to include advanced manufacturing of their equipment and technology to support widespread deployment. These companies are also growing their capability to install, operate and maintain hydrogen technology and equipment. Expansion beyond R&D creates prime opportunities for employment growth.[37]

3.1.2 Learning System to Support Workforce Transition and Development

As the hydrogen economy expands, it is likely that the traditional post-secondary training system will incorporate hydrogen-related topics into mainstream degree, diploma and trades programming to a greater level than it currently exists. In the meantime, there is tremendous opportunity to accelerate workforce development by creating learning opportunities that add hydrogen-related skills and knowledge to the existing expertise found in the labour force. The hydrogen industry can leverage workforce transition and development trends such as:

- Micro-credential programs that allow learners to earn the specific credentials they require through short, competency-based courses that align with industry needs and standards
- Intensive study programs like bootcamps that are designed to accelerate the development of technical skills and employability over a compressed timeframe
- Work-integrated instruction that engages workers in hands-on, experiential learning in a workplace setting to accelerate skill development for those who have related foundational skills

The success of training programs designed to accelerate the transition and upskilling of the existing workforce relies heavily on collaboration across industry and training organizations to ensure delivery of the skills most in demand. Leveraging the training and certification available or being developed in other jurisdictions is also an opportunity to accelerate the development of upskilling programs for the hydrogen value chains. As examples, Ontario's Technical Standards and Safety Authority (TSSA) has a hydrogen certification for utilities workers, and there are post-secondary institutions in British Columbia already working on a fuel cell technician training program.

3.1.3 Low-carbon Hydrogen as an Industry of Choice

Hydrogen, as a viable contributor to the net zero pathway for Canada and the world, has an opportunity to attract employees that prefer to work for an industry that reflects their values around sustainability. Low-carbon hydrogen can build its brand as an industry of choice for environmentally conscious talent.

3.1.4 Collaboration to Accelerate Workforce Transition & Development

A significant number of collaborations have been established to accelerate hydrogen supply and demand value chains.[38]

Many of the players involve in these partnerships have technical expertise that are of great value to the development of the workforce for the hydrogen economy. While the post-secondary system and other training organizations would need to be engaged, the same concept of bringing a range of experts together to design and implement pilot programs focused on workforce transition and development is applicable. A pilot approach offers the opportunity to learn in real time how to best mitigate talent risks and increase the awareness of the careers associated with the hydrogen value chains. All the while, driving continuous improvement and sharing costs.

Figure 4 Alberta Zero-Emission Truck Electrification Collaboration (AZETEC)

SOURCE: The Transition Accelerator

3.2 Talent Risks

3.2.1 Existing Labour Supply Constraints

Labour supply constraints already exist for some of the core occupations required across the hydrogen value chains. Some hydrogen companies indicate that the widespread shortage of certain occupations is more concerning than the lack of hydrogen-specific training. For some companies, especially those that already have established training programs, addressing gaps in hydrogen-specific skills and knowledge is easier than tackling the shrinking talent pool of certain core occupations.

Canada's supply of trades workers is extremely tight. Challenges associated with attracting new entrants to the trades are intensified by an increased level of construction and maintenance activity, as well as the retirement of experienced workers. These issues must be addressed to ensure adequate talent availability for advancing the hydrogen economy.[39]

The need for qualified trades workers is paramount to ensuring safe and efficient operations. The certified trades most commonly required by the hydrogen production, upgrading and transporting, and end-use value chains (including fueling stations) are Electricians, Instrumentation & control technicians and Industrial mechanics. Welders and Pipefitters/Steamfitters are important for equipment manufacturing. Gasfitters are also necessary for heating. Instrumentation & control technicians are of particular importance as they are responsible for the installation and maintenance of sensors, control and safety systems, measurement instrumentation and Supervisory Control and Data Acquisition (SCADA) used in a digitized and automated operations environment. This occupation is reported as being in short supply.

Trades workers are also critical to the timely and cost-effective construction of hydrogen infrastructure and the installation of hydrogen equipment. A major infrastructure project on the books is *Air Products'* net-zero hydrogen energy complex in Edmonton, Alberta. *Air Products* estimates its Autothermal Reforming (ATR) hydrogen facility will require a workforce of 2,500 during the engineering and construction phases.[40] Similarly, *Air Liquide*'s recently completed 20 MW Proton Exchange Membrane (PEM) electrolyser green hydrogen project in Bécancour, Quebec generated the equivalent of 1,500 full-time construction jobs over its two-year construction period.[41]

Other core occupations that are already in short supply in Canada's labour market, and that put the advancement of the hydrogen economy at risk, include:

- Plant operators with third class and higher power engineering certification are needed for hydrogen and ammonia production, carbon capture plants and power generation
- Truck drivers with class 1 or 3 licenses potentially impedes distribution of hydrogen and the adoption of hydrogen in the transportation and freight sector
- Inspectors that are required across all hydrogen value chains. Inspectors are typically experienced workers with related post-secondary education and additional certifications. This occupation often draws from the pool of journey-certified trades workers that are already in short supply.[42]

- Digital/high tech talent as the Information Communication Technology Council (ICTC) forecasts the need for 55,000 additional digital workers by 2025 to support Canada's transition to cleaner resources, including the increased use of low-carbon hydrogen[43]

Foundational skills and knowledge found in the traditional oil & gas workforce are of value for accelerating the hydrogen economy. This includes unique expertise ranging from responsible development of natural gas as feedstock for hydrogen production to sub-surface geological analysis, and drilling and well completions know-how for safe and secure underground storage of hydrogen and carbon. The University of Calgary, a key talent pipeline for oil & gas engineers and geoscientists, has seen a decrease in enrolment in related programs.[44] The lack of new entrants into these roles coupled with retirements of existing professionals could result in talent shortages that impact the hydrogen economy as well as oil & gas. Companies involved in drilling and well completions are reporting significant challenges in attracting and retaining workers. This current shortage of labour is hindering the oil & gas industry's ability to expand.[45] If workforce issues aren't resolved in the near-term, the shortage of drilling and completions workers may also effect the hydrogen industry as it readies to use this technology to expand production, CCS and underground storage activities.

The manufacturing sector is expected to play a key role in Canada's transition to net-zero including the advancement of hydrogen value chains.[46] The Canadian Manufacturers and Exporters (CME) has identified labour and skills shortages among the most pressing challenges for the sector today.[47] As with the oil & gas services sector, manufacturers are seeing their capacity to expand impeded by their inability to attract the talent they need.

3.2.2 Training Required for Emerging Occupations

There are new occupations and skillsets emerging alongside the development of the hydrogen economy. There is a risk that talent will not be available to the extent needed to fill these roles if a qualified workforce is not proactively developed.[48]

Fuel cell technology is a critical foundation for the advancement of the hydrogen economy. A hydrogen fuel cell is an electrochemical reactor that converts hydrogen into electricity. Fuel cells can be configured into a wide array of sizes by layering single cells together. This is referred to as a fuel cell "stack". This scalability means hydrogen fuel cells can be used for a variety of applications including fuel cell electric vehicles (FCEV) and both portable and stationary sources of power and heat.[49]

Important from a workforce perspective is the need for those working with hydrogen fuel cells to understand the electrochemical reactions and systems that allow them to generate power. The rapid interest in electrification using hydrogen as a climate solution has driven an increased demand for expertise in fuel cells and their many applications. As a result, there is a global shortage of electrochemical engineers.[50] Canada is a pioneer in fuel cell technology and has an established expertise at a research and development and engineering level.[51] As the market demand for fuel cells is just now gaining traction, the training to acquire the skills and knowledge to install, maintain and repair hydrogen fuel cells and fuel cell electric vehicles (FCEV) has not been fully developed.

Pilot programs across Canada are testing the use of hydrogen to fuel the heavy-duty freight and medium-duty transport sectors.[52,53] CP Rail is pioneering the use of hydrogen to power its locomotives.[54] These pilots are designed to learn about the potential to decarbonize the transportation sector by replacing the use of diesel with hydrogen as a fuel source.

To support the adoption of hydrogen as a transportation fuel, there is a need for heavy-duty technicians with the ability to install, repair and maintain FCEV's. The unique skills required by to work on FCEV heavy and medium-duty trucks relate to the difference between the internal combustion engine (ICE) and the FCEV propulsion system.[55] Rather than diesel powered motors, FCEV vehicles have an electric motor fuelled by electricity generated by a hydrogen-powered fuel cell stack. Rather than a diesel fuel tank, the hydrogen fuel is stored in a pressurized tank, and power generated is stored in a battery. Aside from propulsion, the chassis, electronics, steering, brakes and body are common for ICE and FCEV.

Until fueling station infrastructure is available to support long-haul trucking, many freight and transport trucks will be dual fuel: diesel and hydrogen. In fact, freight and transport companies are likely to have all three types of trucks: ICE, FCEV and dual fuel. Technicians with the ability to work on both ICE and FCEV propulsion systems are likely to be in high demand given efficiency and economies of scale realized by combining both skillsets. Only a small talent pool with this skillset is currently available in Canada's labour market.

Rail locomotives already operate with electric powertrains. The transition to hydrogen involves converting the locomotive's diesel-fuelled electric powertrains to hydrogen-electric powertrains. Conversions will require technicians with the appropriate technical know-how to install and maintain the hydrogen-fuelled system. As with heavy and medium-duty trucks, many of the other mechanical aspects of the locomotive will remain the same and the related maintenance and repair skills and knowledge continues to be relevant.

Two additional categories of occupations lacking homegrown talent are:

- Business and commercial development specialists with a deep understand of hydrogen technologies that give them the ability to complete necessary techno-economic assessments
- ESG and Sustainability specialists with the technical, economic and social expertise to lead hydrogen companies through an ever-changing business, social and regulatory environment

For both these groups of occupations, companies report hiring candidates with high-level expertise from other jurisdictions that are further ahead in progressing their hydrogen and sustainability strategies, including the Netherlands and the European Union.

3.2.3 Lack of Diverse Talent Pools from which to Hire

Many of the occupations required by the hydrogen value chains are male-dominated including engineers, trades, technologists and technicians, and leadership positions. There are several reasons why developing more diverse talent pools for these occupations is an important consideration for accelerating the workforce required for the hydrogen economy:

- Expanding the pool of qualified candidates to include additional talent from under-represented groups including women, Aboriginal peoples, visible minorities, and persons with disabilities is a solution to labour shortages.
- Investors have heightened expectations for companies to advance toward a more diverse and inclusive workforce. The expectation is not simply because it is the right thing to do. Rather, there is a growing body of evidence that companies with diverse workforces achieve improved financial and growth performance.[56]
- There are public and investor expectations that energy transition and decarbonization is an opportunity to address socio-economic inequities and discriminations that have been barriers to greater diversity and inclusivity in the existing energy workforce.
- Many of the companies included in the hydrogen value chains are federally regulated by the Employment Equity Act and/or are publicly traded corporations governed by the Canada Business Corporations Act (CBCA). Companies that fall within these categories are required to disclose representation of equity groups and the steps they have taken to achieve full representation. Federally regulated industries include rail, pipelines and road transportation services that cross provincial or international borders.[57]

Addressing the lack of diverse talent in the labour force at an occupational level is complex. Data suggests that lack of diversity among the student population is a key issue. For example, women make up 22% of the engineering students and 21% of the newly licensed engineers in Canada.[58] Only 4.5% of registered apprentices in Canada are women. Organizations such as the *Canadian Apprenticeship Forum*'s Task Force for Supporting Women in Trades, and *Engineers Canada* have set "30 by 30" goals, namely 30% of women in trades and engineering respectively by 2030.[59,60] Similar strategies and action plans would be beneficial for increasing participation from the other under-represented groups including Aboriginal people, visible minorities and persons with disabilities.

3.2.4 Lack of Industry Standards for Hydrogen

Standards help to identify relevant skills and knowledge required for a particular occupation. The lack of industry-endorsed standards for hydrogen skills and knowledge impedes the development of relevant training. The development of workforce skills and knowledge required to support an expanded hydrogen economy is not currently incorporated into post-secondary curriculum or training programs to the level that is needed.

3.2.5 Limited Labour Market Information About the Hydrogen Economy

In general, there is limited understanding of the occupations, skills and career transferability opportunities associated with advancing Canada's low-carbon hydrogen economy.

Just as investors are looking for a level of certainty prior to investing in hydrogen supply and demand value chains, post-secondary education and other training organizations are looking for a level of certainty about hydrogen employment opportunities prior to investing in the development of relevant programming. Encouraging talent to prepare for a career in the hydrogen industry relies on their understanding of the potential career opportunities available to them.

Beyond the identification of occupational requirements associated with the hydrogen economy outlined in this report, there is interest among stakeholders for quantitative forecasting of the hydrogen labour market requirements. Developing insights into what hydrogen workforce demand and supply could look like based on different industry investment and activity scenarios would help provide data to support the development of evidence-based workforce transition and development strategy and actions.

4 ACCELERATING WORKFORCE TRANSITION AND DEVELOPMENT TO ADVANCE THE HYDROGEN ECONOMY

The workforce transition associated with energy transition, including establishing a hydrogen economy, is unlike any other labour adjustment the Canadian economy has experienced. Most of the existing research on workforce transitions profiles the phasing out of a sector or the closing of a plant. If well managed, advancing the hydrogen economy has the potential to lead to a more positive workforce transition.

- Expanding hydrogen supply and demand value chains will create desirable and well-paying jobs that can leverage the existing labour force. Not all sectors associated with energy transition offers this opportunity.
- The phasing in of hydrogen as an affordable part of the energy system allows workforce transition to be paced with job creation associated with demand and supply value chain development. Increased demand for hydrogen will initially be marked by deployment of technology that requires retrofitting and conversion of existing systems, equipment and infrastructure to accommodate fuel-switching, co-combustion and blending of hydrogen with other fuels including natural gas and diesel.[61] This provides opportunity to augment the skills and knowledge of workers so that they can work in both systems, transitioning to full-time hydrogen roles at the same pace the industry advances.
- For the most part, the technical skills and knowledge required by the hydrogen economy can be found within the existing labour market. There are enough similarities to enable workers to acquire hydrogen skills and knowledge through accelerated training programs such as micro-credential programming, bootcamps and work-integrated learning.
- Investment in hydrogen technology and infrastructure is being made by oil and gas producers, pipeline and utility companies, and end-use industrial and transportation sectors looking to decarbonize and advance sustainability. The hydrogen jobs created by these companies provide opportunities to offset job losses that are likely to occur during the pending energy system transitions. Training, reassignments and redeployments will help to facilitate effective workforce transitions. Companies report this is already happening.

It is very possible for the workforce transition and development required to advance the hydrogen economy to be well managed. However, it is not automatic. Nor will workforce transition be orderly without a strategic and collaborative approach among stakeholders.

4.1 Not Just a Transition but a "Just Transition"

The concept of a "just transition" of the workforce is that caring for the environment, implementing climate solutions and transitioning our energy system does not have to be mutually exclusive to job security and resilient career opportunities.[62]

Canada's net zero economy will only thrive if we have a well-functioning labour market that maximizes participation, is equitable, inclusive and diverse, and optimizes the skills and knowledge of workers by matching them with appropriate jobs.[63] Expectations from governments, workers and communities are that workforce transitions associated with the energy transition will be managed, and any negative impacts will be minimized.[64] Investors view a just workforce transition as an ESG imperative, especially as it relates to the social impact.

Realizing a just workforce transition requires a proactive, evidence-based approach to addressing barriers to talent attraction, diversity and inclusivity such as those described in the *Talent Risks* section of this report.

No jurisdiction nor case study offers a playbook for accelerating an effective workforce transition driven by energy transition. Rather, many countries are also grappling with developing their own strategy. The digital transformation taking place across industries offers some insights into practices that are applicable to the energy sector's transition. Previously described micro-credential and bootcamp approaches to upskilling are examples from the digital sector. Other concepts and principles that seem applicable for accelerating workforce transition align with those that have been developed to accelerate technology innovation and deployment.

4.2 Framework for Managing a Just Workforce Transition

The following framework leverages the steps developed by The Transition Accelerator to accelerate hydrogen innovation, technologies, and supply and demand value chains, while also managing any disruption associated with energy transition. We suggest that the same framework can be applied to workforce transition and development to minimize disruption. This suggestion aligns with research that indicates an effective approach to building workforce capacity for industrial or economic transformation is to strategically integrate social research, innovation and development with the activities being undertaken to advance technology.[65]

The Transition Accelerator's four-step approach to accelerating a hydrogen economy, inclusive of advancing workforce transition and development, emphasizes the following:

- Moving from critical analysis to practical action
- Combining imaginative thinking with evidence-based analysis
- Integrating quantitative and qualitative perspectives, including workforce demand modelling based on hydrogen industry investment and activity
- Collaborating to develop, pilot and demonstrate, then scale pathways for effective workforce transition and development

Table 5 Framework for Accelerating Workforce Required to Advance the Hydrogen Economy

Step	Application to Workforce Transition & Development	Recommended Actions
1 UNDERSTAND the system that is being transformed, including its strengths and weaknesses, and the technology, business model, and social innovations that are poised to disrupt the existing system by addressing one or more of its shortcomings.	Identify strengths, weaknesses, opportunities and risks associated with the labour market required to advance the hydrogen economy.	• Identify core occupations and skills requirements to advance the hydrogen supply and demand value chains • Conduct quantitative modelling and analysis to assess demand at an occupational level • Determine the capacity of the talent supply to address the demand • Assess the talent opportunities and risks, including skills and occupational gaps ○ Identify talent pools, occupations and communities most vulnerable to the advancement of hydrogen • Assess the capacity of the current talent supply system to address gaps • Gain an understanding of practices from other jurisdictions that could be adopted or adapted for hydrogen
2 CODEVELOP transformative visions and pathways in concert with key stakeholders and innovators drawn from industry, government, indigenous communities, academia, and other groups. This	Engage a broad range of key stakeholders to develop an evidence-based strategy to ensure that the hydrogen workforce will be ready	• Develop a transformative vision and mission, supported by strategic objectives and actions, towards achieving a successful hydrogen workforce transition • Develop key messages and promote hydrogen career opportunities to targeted talent pools

Step	Application to Workforce Transition & Development	Recommended Actions

engagement process is informed by the insights gained in Step 1.	The above may require reimagining the training and learning ecosystem, talent sourcing strategies, etc.	• Design a portfolio of initiatives to close skills gaps and enhance transition opportunities
		  ○ Incorporate hydrogen learning requirements into existing training
		  ○ Accelerate skills acquisition with bootcamps, micro-credentialling and work-integrated learning
		  ○ Train for emerging occupations
		  ○ Certify for hydrogen-specific technical skill and knowledge requirements
		• Tailor transition and development plans for the most impacted talent pools and occupations
		• Prioritize actions based on the timing of hydrogen industry investment and activity

3 ANALYZE and model the candidate pathways from Step 2 to assess costs, benefits, trade-offs, public acceptability, barriers and bottlenecks. With these insights, the process then re-engages key players to revise the vision and pathway(s), so they are more credible, compelling and capable of achieving societal objectives that include major GHG emission reductions.	Pilot and demonstrate strategic actions that were prioritized during the co-develop phase	• Identify measure of success for each of the prioritized actions • Develop and implement measurement tracking • Re-engage key stakeholders as required to revise strategic actions and ensure workforce transition and development objectives are achieved
4 ADVANCE the most credible, compelling and capable transition pathways by informing innovation strategies, engaging partners and helping to launch consortia to take tangible steps along defined transition pathways.	Scale the most impactful workforce transition and development initiatives	• Refine workforce transition and development strategies and actions based on evidence gathered during the analysis phase • Establish a consortium and monitoring system to ensure that strategies and systems continue to deliver the desired results

SOURCE: The Transition Accelerator and Mckinsey & Company

5 CONCLUSION

Canada is about to embark on unprecedented investment in innovation, technology and infrastructure to achieve net zero by 2050. Advancing the hydrogen supply and demand value chains will play a key role in moving us towards decarbonization. Quality job opportunities across many occupation and skill levels will be generated by the advancement of a hydrogen economy. This offers tremendous opportunity to manage workforce transition and development to ensure it is "just" and effectively contributes to the ability for Canada's labour market to thrive in a net zero economy.

The readiness of the required hydrogen workforce can be enhanced by:

- Developing and incorporating short-term training practices that expand on existing expertise
- Developing a narrative that promotes low-carbon hydrogen as an industry of choice to attract talent interested in being part of climate solutions
- Expanding collaboration established to accelerate hydrogen technology and value chains to include addressing workforce transition and development requirements

There are also risks that must be proactively addressed to ensure the lack of qualified talent does not impede the advancement of the hydrogen economy.

- There are labour supply constraints that already exist for some of hydrogen's core occupations including higher class Power engineers, Instrumentation technicians and Truck drivers
- There is a need to develop training programs to develop talent for new occupations and skillsets emerging alongside the development of the hydrogen economy
- There is a lack of diverse talent pools from which to hire
- A lack of industry-endorsed standards for hydrogen skills and knowledge hinders the development of relevant training including emerging occupations
- Lack of understanding of the hydrogen economy and the potential career and workforce transition opportunities creates a level of uncertainty that causes stakeholders from investing in workforce development and career decision-makers from pursuing relevant training

The primary objective of this report is to create an understanding of the workforce required to advance the hydrogen economy. As outlined by the framework for accelerating workforce transition and development for hydrogen, creating an understanding is the foundational step, but it is just an initial step. To ensure that the impacts of the pending disruption to Canada's workforce are minimized and lead to a just transition, there is a need to develop a deeper understanding of the labour market required for hydrogen and inform the other steps of the framework that also need to be implemented.

REFERENCES

1. Allan, B., Eaton, D., Goldman, J., Islam, A., Augustine, T., Elgie, S., and Meadowcroft, J. (2022). *Canada's Future in a Net-Zero World: Securing Canada's Place in the Global Green Economy.* Smart Prosperity Institute, Transition Accelerator and Pacific Institute for Climate Solutions.
2. Layzell DB, Young C, Lof J, Leary J and Sit S. 2020. Towards Net-Zero Energy Systems in Canada: A Key Role for Hydrogen. Transition Accelerator Reports: Vol 2, Issue
3. Wildeman. Jodi. *Western Canada Leads the Way with Carbon Capture Utilization & Storage*. 2022. https://www.mltaikins.com/energy/western-canada-leads-the-way-with-carbon-capture-utilization-storage/ (Accessed March, 2022)
4. Allan, B., Eaton, D., Goldman, J., Islam, A., Augustine, T., Elgie, S., and Meadowcroft, J. (2022). *Canada's Future in a Net-Zero World: Securing Canada's Place in the Global Green Economy.* Smart Prosperity Institute, Transition Accelerator and Pacific Institute for Climate Solutions.
5. Natural Resources Canada. *Hydrogen Strategy for Canada.* 2020. https://www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf (Accessed April, 2022)
6. Alberta Ministry of Energy. *Alberta Hydrogen Roadmap*.2021. https://open.alberta.ca/dataset/d7749512-25dc-43a5-86f1-e8b5aaec7db4/resource/538a7827-9d13-4b06-9d1d-d52b851c8a2a/download/energy-alberta-hydrogen-roadmap-2021.pdf (Accessed March, 2022)
7. Khan, M.A., Young, C. and Layzell, D.B. (2021). *The Techno-Economics of Hydrogen Pipelines. Transition Accelerator Technical Briefs* Vol. 1, Issue 2, Pg. 1-40. ISSN 2564-1379.
8. Khan, M.A., Young, C. and Layzell, D.B. (2021). *The Techno-Economics of Hydrogen Pipelines. Transition Accelerator Technical Briefs* Vol. 1, Issue 2, Pg. 1-40. ISSN 2564-1379.
9. Zhijian, Wan., Youkun, Tao., Jing, Shao., Yinghui, Zhang., Hengzhi, You. *Ammonia as an effective hydrogen carrier and a clean fuel for solid oxide fuel cells.* Energy Conversion and Management. Volume 228, January 15, 2021. https://www.sciencedirect.com/science/article/abs/pii/S019689042031253X#! (Accessed April, 2022)
10. McDonald, Jeffrey. *Blue ammonia to comprise bulk of hydrogen transportation due to lower costs: HSBC.* S&P Global Commodity Insights. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/natural-gas/011821-blue-ammonia-to-comprise-bulk-of-hydrogen-transportation-due-to-lower-costs-hsbc (Accessed April, 2022)
11. Ferland, Philippe. Why Canada is a Leader in Ammonia, A Fuel of the Future. Invest in Canada. https://www.investcanada.ca/blog/why-canada-leader-ammonia-fuel-future (Accessed April, 2022)
12. Aarnes, Jorg., Alvik, Sverre. Hydrogen Forecast to 2050. DNV. 2022. https://www.dnv.com/focus-areas/hydrogen/forecast-to-2050.html (Accessed June, 2022)
13. Goldmeer, Dr. Jeffrey. Power to Gas: Hydrogen for Power Generation. GE. 2019. https://www.ge.com/content/dam/gepower/global/en_US/documents/fuel-flexibility/GEA33861%20Power%20to%20Gas%20-%20Hydrogen%20for%20Power%20Generation.pdf (Accessed June, 2022)

14. Alberta Ministry of Energy. *Alberta Hydrogen Roadmap*.2021. https://open.alberta.ca/dataset/d7749512-25dc-43a5-86f1-e8b5aaec7db4/resource/538a7827-9d13-4b06-9d1d-d52b851c8a2a/download/energy-alberta-hydrogen-roadmap-2021.pdf (Accessed March, 2022)
15. Bayley, C., Ikeman, A. *Towards a Western Hydrogen Network*. 2021, https://transitionaccelerator.ca/blog-towards-a-western-hydrogen-network/ (Accessed April, 2022)
16. Financial Times. *Canada's commitment to clean hydrogen Is driving a 'green collar' revolution*. https://canada-next-best-place-to-home.ft.com/canadas-commitment-to-clean-hydrogen-is-driving-a-green-collar-revolution (Accessed April, 2022)
17. Office of Energy Efficiency & Renewable Energy. *Safe Use of Hydrogen.* https://www.energy.gov/eere/fuelcells/safe-use-hydrogen (Accessed April, 2022)
18. HydrogenTools. *Hydrogen Safety Training Materials*. https://h2tools.org/training-materials (Accessed April, 2022)
19. Deloitte, Skillsnet Ireland. *Sustainable Finance Skillnet Deep Dive Skills Report*. **2019**, https://www2.deloitte.com/ie/en/pages/sustainablity/articles/Sustainable-Finance-Skillnet-Report.html (Accessed April, 2022)
20. International Sustainability Standards Board. https://www.ifrs.org/groups/international-sustainability-standards-board/ (Accessed May, 2022)
21. Alberta Ministry of Energy. *Alberta Hydrogen Roadmap*.2021. https://open.alberta.ca/dataset/d7749512-25dc-43a5-86f1-e8b5aaec7db4/resource/538a7827-9d13-4b06-9d1d-d52b851c8a2a/download/energy-alberta-hydrogen-roadmap-2021.pdf (Accessed March, 2022)
22. Allan, B., Eaton, D., Goldman, J., Islam, A., Augustine, T., Elgie, S., and Meadowcroft, J. (2022). *Canada's Future in a Net-Zero World: Securing Canada's Place in the Global Green Economy*. Smart Prosperity Institute, Transition Accelerator and Pacific Institute for Climate Solutions.
23. Ashworth, P., Bradbury, J., Feenstra, C., Greenberg, S., Hund, G., Mikunda, T., Wade., S., Shaw., H. *Communication/Engagement Toolkit for CCS Projects*. Global CCS Institute. **2011**, https://www.globalccsinstitute.com/resources/publications-reports-research/communication-engagement-toolkit-for-ccs-projects/ (Accessed April, 2022)
24. First Nations Major Projects Coalition. *The First Nations Major Projects Coalition (FNMPC) is leading the way in developing this new approach.* https://fnmpc.ca/about-fnmpc/ (Accessed April, 2022)
25. Clean Resource Innovation. *Cleantech and Transitioning Careers in Oil & Gas: Career opportunities Across Alberta's oil and gas Innovation ecosystem: Digital Oil & Gas*. https://cleanresourceinnovation.com/preview/resource/files/3/CRIN-LabourMarket-DigitalO&G-f.pdf (Accessed April, 2022)
26. Conference Board of Canada. Rising Skills: *Digital Upskilling for Advanced Manufacturing Workplaces Summary for executives.* 2020 https://www.conferenceboard.ca/temp/a9fe6596-cc78-4cff-8f40-bd9b93534309/10917_fsc_se_digital_skills_in_the_manufacturing_trades_en.pdf (Accessed April, 2022)
27. Ballard. Ballard Expanding MEA Production Capacity 6x to Meet Expected Growth in Fuel Cell Electric Vehicle Demand. 2020. https://www.ballard.com/about-ballard/newsroom/news-releases/2020/09/28/ballard-expanding-mea-production-capacity-6x-to-meet-expected-growth-in-fuel-cell-electric-vehicle-demand (Accessed April, 2022)
28. Natural Resources Canada. *Hydrogen Strategy for Canada.* 2020. https://www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf (Accessed April 2022)

29. Study Task Force of the Hydrogen Council. *Hydrogen scaling up*. Hydrogen Council. 2017. https://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf (Accessed April, 2022)
30. Canadian Manufacturers & Exporters. Manufacturing Our Future: Leveraging Manufacturing For Long-term Canadian Prosperity. 2020. https://cme-mec.ca/wp-content/uploads/2020/06/Manufacturing-Our-Future-Print-Ready-.pdf (Accessed April, 2022)
31. Layzell, DB. *Towards Canada's New Hydrogen Economy: A Base Case for the Edmonton Region H2 Hub*. Transition Accelerator. 2021. https://transitionaccelerator.ca/webinar-towards-canadas-new-hydrogen-economy-a-base-case-for-the-edmonton-region-hydrogen-hub/ (Accessed April, 2022)
32. McKinsey Sustainability. *Watch the replay: Leading voices discuss implications of the net-zero transition.* 2022, https://www.mckinsey.com/business-functions/sustainability/our-insights/sustainability-blog/watch-the-replay-leading-voices-discuss-implications-of-the-net-zero-transition (Accessed April, 2022)
33. Foresight Cleantech Accelerator Centre. *Accelerating British Columbia's Clean Economy*. Foresight. 2020. https://foresightcac.com/wp-content/uploads/2021/04/CCC-Report_Final_20July20.pdf (Accessed April, 2022)
34. Clean Resource Innovation Network. *Cleantech and Transitioning Careers in Oil & Gas: Addressing climate change and other environmental challenges creates new career pathways and skill development opportunities for all workers.* 2021. https://cleanresourceinnovation.com/preview/resource/files/3/CRIN-LabourMarket-Overview-AH-f1.pdf (Accessed April, 2022)
35. Financial Times. *Canada's commitment to clean hydrogen Is driving a 'green collar' revolution*. https://canada-next-best-place-to-home.ft.com/canadas-commitment-to-clean-hydrogen-is-driving-a-green-collar-revolution (Accessed April, 2022)
36. Statistics Canada. *In the midst of high job vacancies and historically low unemployment, Canada faces record retirements from an aging labour force: number of seniors ages 65 and older grows six times faster than children 0-14.* **2022** https://www150.statcan.gc.ca/n1/daily-quotidien/220427/dq220427a-eng.htm?HPA=1 (Accessed April, 2022)
37. Ballard. Ballard Expanding MEA Production Capacity 6x to Meet Expected Growth in Fuel Cell Electric Vehicle Demand. 2020. https://www.ballard.com/about-ballard/newsroom/news-releases/2020/09/28/ballard-expanding-mea-production-capacity-6x-to-meet-expected-growth-in-fuel-cell-electric-vehicle-demand (Accessed April, 2022)
38. Layzell, DB. *Towards Canada's New Hydrogen Economy: A Base Case for the Edmonton Region H2 Hub*. Transition Accelerator. 2021. https://transitionaccelerator.ca/webinar-towards-canadas-new-hydrogen-economy-a-base-case-for-the-edmonton-region-hydrogen-hub/ (Accessed April, 2022)
39. Buildforce. *Construction and Maintenance Looking Forward: An Assessment of Construction Labour Markets From 2022 to 2027*. 2022 https://www.buildforce.ca/en/terms?fid=2121 (Accessed April, 2022)
40. Air Products. *Blue, but better. Western Canada's Net-Zero Hydrogen Energy Complex*. 2022. https://www.airproducts.com/campaigns/alberta-net-zero-hydrogen-complex (Accessed April, 2022)
41. Air Liquide. *Inauguration of the world's largest PEM electrolyzer to produce decarbonized hydrogen.* **2021**, https://www.airliquide.com/stories/industry/inauguration-worlds-largest-pem-electrolyzer-produce-decarbonized-hydrogen (Accessed April, 2022)
42. The Coating Inspector. *Industrial Coating Sector Labour Shortage. 2021*. https://thecoatinginspector.ca/industrial-coating-sector-labour-shortage/ (Accessed June, 2022)

43. Ivus, M; Kotak, A. *Onwards and Upwards – Digital Talent Outlook 2025*. Information and Communications Technology Council (ICTC). Ottawa, Canada. 2021. https://www.ictc-ctic.ca/wp-content/uploads/2021/08/digital-talent-outlook-for-2025.pdf (Accessed April, 2022)
44. *University of Calgary hits pause on bachelor's program in oil and gas engineering.* 2021. https://www.cbc.ca/news/canada/calgary/university-of-calgary-engineering-1.6092648 (Accessed May, 2022)
45. *Amid global energy crisis, labour shortage constrains growth of Canadian oilpatch.* 2022. https://www.cbc.ca/news/canada/calgary/canada-oil-gas-labour-shortage-russia-1.6382160 (Accessed May, 2022)
46. Atiq, Mohsina. Coutinho, Aline. Islam, Anik. McNally, John. *Jobs and Skills in the Transition to a Net-Zero Economy: A Foresight Exercise.* Smart Prosperity Institute. 2022. https://institute.smartprosperity.ca/sites/default/files/Jobs_and_Skills_in_the_Transition_to_a_Net-Zero_Economy.pdf (Accessed May, 2022)
47. Arcand. Alan. *2021 Year in Review & 2022-2023 Outlook*. Canadian Manufacturers & Exporters. https://cme-mec.ca/blog/initiatives/2021-year-in-review-2022-23-outlook/ (Accessed May, 2022)
48. Consultation with Bill Elrick, Executive Director, California Fuel Cell Partnership (CAFCP) revealed that not aligning technology development and rollout with the train of Mechanical technicians for fuel cells and hydrogen fueling stations has caused shortage of this talent in the state. March 4, 2022.
49. Canadian Hydrogen and Fuel Cell Association. http://www.chfca.ca/fuel-cells-hydrogen/about-fuel-cells/ (Accessed April, 2022)
50. Bullen, Dr. C., Power & Water. *Electrochemical Engineering Education – What is the Future?* 2020. https://www.powerandwater.com/news/2020-07-10-electrochemical-engineering-education-what-is-the-future (Accessed April, 2022)
51. Canadian Hydrogen and Fuel Cell Association. http://www.chfca.ca/fuel-cells-hydrogen/about-fuel-cells/ (Accessed April, 2022)
52. Layzell, DB. *Towards Canada's New Hydrogen Economy: A Base Case for the Edmonton Region H2 Hub*. Transition Accelerator. 2021. https://transitionaccelerator.ca/webinar-towards-canadas-new-hydrogen-economy-a-base-case-for-the-edmonton-region-hydrogen-hub/ (Accessed April, 2022)
53. HydraEnergy. *Project marks the first hydrogen transoportation collaboration of its kind in Canada and the world's first hydrogen-diesel armoured vehicle.* 2022. https://www.hydraenergy.com/news/eiavexsl (Accessed April, 2022)
54. CP Rail. *Canadian Pacific expands Hydrogen Locomotive Program to include additional locomotives, fueling stations with Emissions Reduction Alberta grant.* 2021. https://www.cpr.ca/en/media/canadian-pacific-expands-hydrogen-locomotive-program-to-include-additional-locomotives-fueling-stations-with-emissions-red (Accessed April, 2022)
55. Deloitte, Ballard. *Fueling the Future of Mobility. Hydrogen and fuel cell solutions for transportation.* Deloitte China. Volume 1. https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/finance/deloitte-cn-fueling-the-future-of-mobility-en-200101.pdf (Accessed April, 2022)
56. Responsible Investment Association. *Canadian Investor Statement on Diversity & Inclusion.* https://www.riacanada.ca/investor-statement-diversity-inclusion/ (Accessed April, 2022)
57. MacDougall, A., Valley, John., Jeffrey, J. *Report: 2021 Diversity Disclosure Practices - Diversity and leadership at Canadian public companies.* Osler. **2021**, https://www.osler.com/en/resources/governance/2021/report-2021-diversity-disclosure-practices-diversity-and-leadership-at-canadian-public-companies?gclid=Cj0KCQjw37iTBhCWARIsACBt1IxIafhuXqK8YFn_3paMDMfvED-7-nHiqfBnP8FoSEty1Hqem2Eli4EaAiiLEALw_wcB (Accessed April, 2022)

58. Engineers Canada. *Environmental scan report: 30 by 30 and beyond.* https://engineerscanada.ca/sites/default/files/diversity/SP3-Environmental-Scan.pdf (Accessed April, 2022)
59. Engineers Canada. *Women in Engineering 30 by 30.* https://engineerscanada.ca/diversity/women-in-engineering/30-by-30 (Accessed April, 2022)
60. Canadian Apprenticeship Forum. *National Strategy for Supporting Women in the Trades.* (Accessed April, 2022)
61. Gregory, Jim. *The Critical Role of Conversion to Realise the Hydrogen Revolution*. H2 View. **2022**, https://www.luxfercylinders.com/news/hydrogen-conversion-revolution (Accessed April, 2022)
62. Energy and Climate Change Directorate. *Just Transitions: a comparative perspective.* Scottish Government. **2020**, https://www.gov.scot/publications/transitions-comparative-perspective/pages/3/ (Accessed April, 2022)
63. Noteboom, B. *Making labour markets inclusive*. OECD. **2013**, https://www.oecd.org/employment/making-labour-markets-inclusive.htm (Accessed April, 2022)
64. Natural Resources Canada. *Just Transition*. Government of Canada. https://www.rncanengagenrcan.ca/en/collections/just-transition (Accessed April, 2022)
65. Hellström, T. *Centres of Excellence as a Tool for Capacity Building.* OECD. https://www.oecd.org/sti/Draft_OECD%20synthesis%20report_final.pdf (Accessed April, 2022)

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