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Green Hydrogen Manufacturing: Value Chain Development

Final Report

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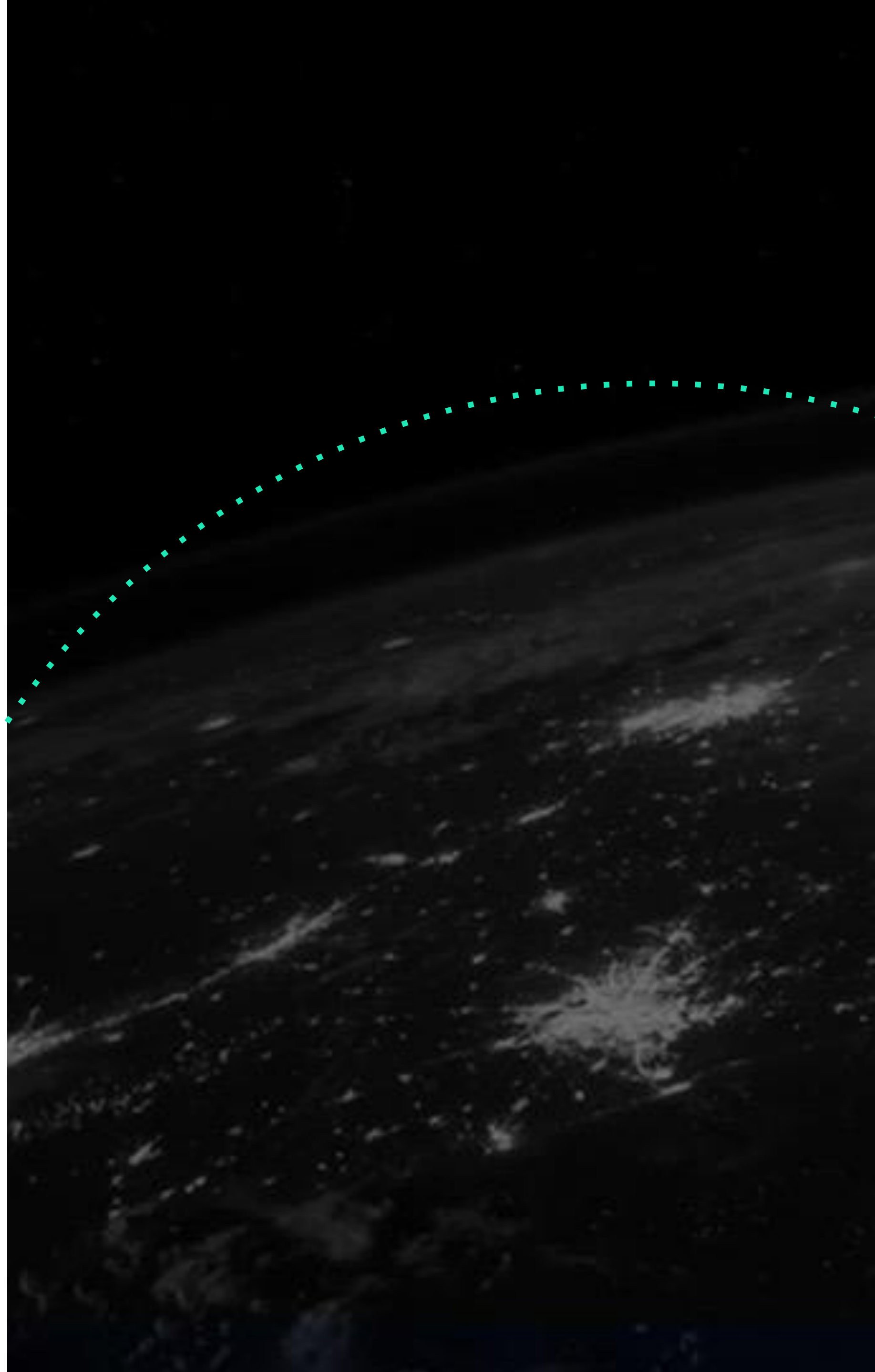
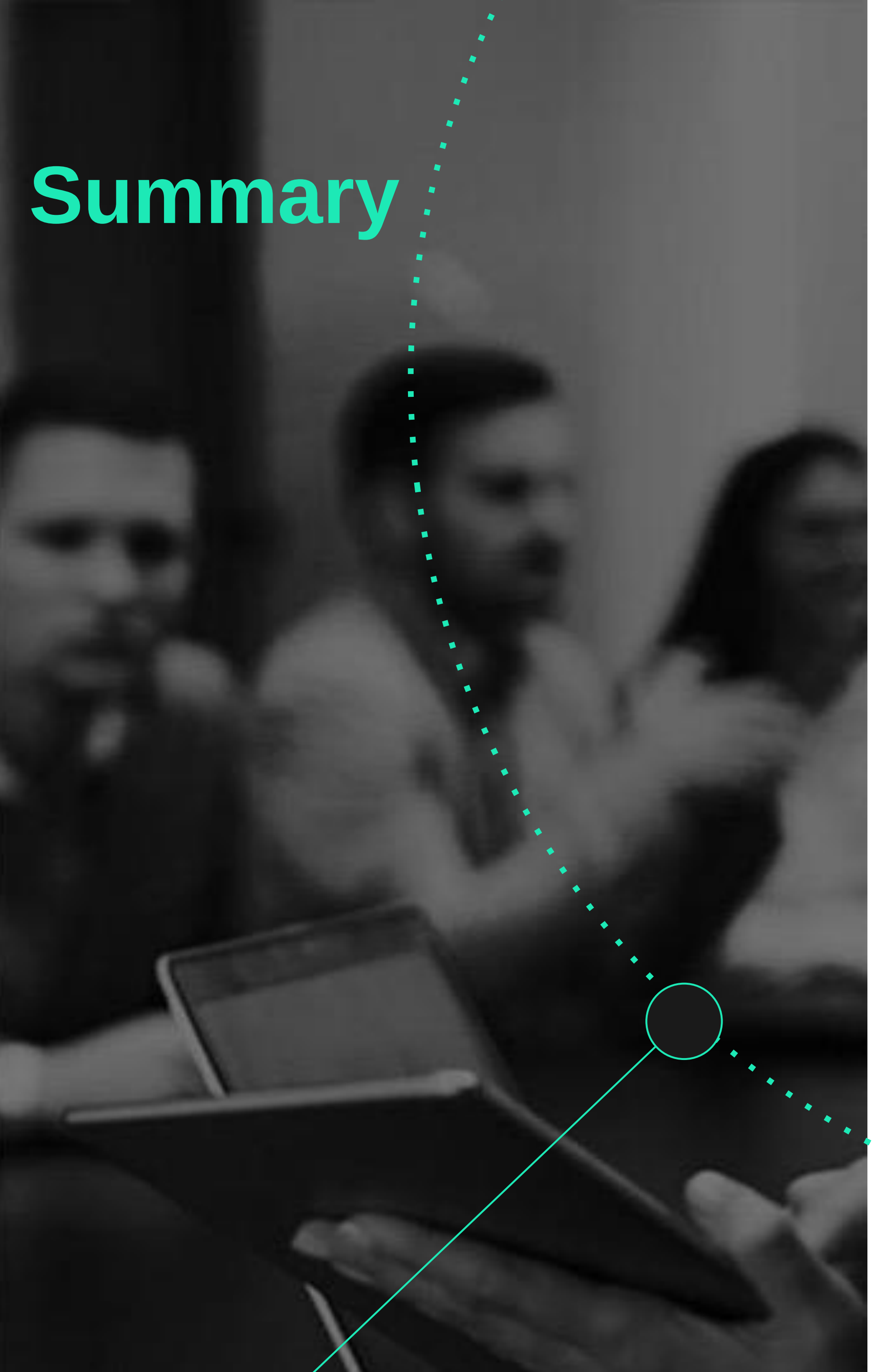


Summary



Executive Summary

This study **evaluates the importance of strengthening support for Quebec's hydrogen manufacturing sector**. Conducted by Sia Partners under the supervision of PRIMA Québec and mandated by the MEIE, it builds on two previous NRC reports. Collaborative efforts by IRH and UQTR's I2E3 showcase the latest advancements in hydrogen technologies.

A comprehensive analysis of the **manufacturing ecosystem in Quebec and internationally** was conducted. Over **350 stakeholders** were involved, including nearly **200 established manufacturers** and approximately **30 industrial and institutional players**, whose insights contributed to the conclusions of this study.

The analysis initially focuses on **14 manufacturing segments** encompassing the entire hydrogen (H2) value chain. An in-depth examination of these segments identified four priority equipment categories for Quebec: **electrolyzers, fuel cells, stationary tanks, and reactors for H2 production** (including plasma pyrolysis and biomass gasification).

A study on **the socio-economic impact of developing these manufacturing sectors in Quebec** was conducted. The four segments were first compared with each other and then with the battery sector, highlighting several synergies in terms of critical and strategic minerals, technologies, workforce, and policies.

Finally, this study highlights **eight (8) key findings regarding the hydrogen (H2) manufacturing chain, along with nine (9) recommendations** for government institutions. These findings emphasize the urgent need to develop a comprehensive manufacturing industrial policy, while also addressing the importance of clarifying priority technological directions, fostering cross-industry synergies, and understanding the international regulatory context.

Glossary | Abbreviations *1/2*

AFC	Alkaline Fuel Cell
ALK	Alkaline Electrolyser
PSA	Pressure Swing Adsorption
Aux.	Auxiliary
BoP	Balance of Plant
CRD	Construction, Renovation, Demolition
DOE	Department of Energy (United States)
Electro.	Electrolyser
RE	Renewable Energy
EU	Europe
USA	United States
RNG	Renewable Natural Gas
GW	Gigawatt
H2	Hydrogen
AI	Artificial Intelligence

Indu.	Industrial
Integ.	Integration
IRA	Inflation Reduction Act
kg	Kilogram
kW	Kilowatt
LOHC	Liquid Organic Hydrogen Carrier
MCFC	Molten Carbonate Fuel Cells
SCM	Strategic and Critical Mineral
NA	No-applicable
TRL	Technology Readiness Level
NZE	Net Zero Emission
FC	Fuel Cell
PAFC	Phosphoric Acid Fuel Cell
PEM	Proton Exchange Membrane Electrolyser
PEMFC	Proton Exchange Membrane Fuel Cell

Glossary | Abbreviations *2/2*

QC	Quebec
R&D	Research and Development
SOEC	Solid Oxyde Electrolyzer
SOFC	Solid Oxyde Fuel Cell
T°	Temperature
CAGR	Compound Annual Growth Rate
Techno.	Technology
m.t	Metric Tons
FTE	Full-Time Equivalent

Glossary | Terminology and Acronyms *1/2*

Actors present in Quebec	Actor with an existing plant, project or site in Québec
TRL	Technology readiness levels 1 - Observation of the basic principle 5 - Validation of technology in real-life environment 9 - Real system demonstrated in operational environment
Small company/manufacturer	Between 1 and 99 employees
Medium company/manufacturer	Between 100 and 499 employees
Large company/manufacturer	More than 500 employees
Multinational company	Operates facilities in at least one foreign country
Canadian leader	Top-performing Canadian manufacturer in its segment
H2-Hub	Region with a high concentration of hydrogen-related activities
CQFA	Carrefour québécois de la fabrication additive - Quebec additive manufacturing hub
INRS	Institut national de la recherche scientifique - National Institute of Scientific Research.
NRCC	National Research Council Canada
UQTR	Université de Québec à Trois-Rivières - University of Quebec at Trois-Rivières.

Glossary | Terminology and Acronyms *2/2*

ULaval	Université de Laval – Laval University
CSA	Canadian Standards Association
MEIE	Ministère de l’Économie, de l’innovation et de l’Énergie – Ministry Economy & Energy
CMQ	Centre de métallurgie du Québec - Quebec Metallurgy Center
CEPROCQ	Centre d’études des procédés chimiques du Québec – Chemical Process Research Center
ETS	École de technologie supérieure – University of superior technology
CDCQ	Centre de développement des composites du Québec - Quebec Composite Development Center
SME	Small and medium-sized entreprise
STIQ	Sous-traitance industrielle Québec - Industrial Subcontracting Sector of Quebec
RICQ	Regroupement des industries des composites du Québec - Group of Composite Industries of Quebec

1. Introduction and Global Methodology

Context | Key Project Challenges

The primary objective of the project is to assess the importance of expanding support for **Quebec's hydrogen manufacturing chain** by leveraging assets like its critical and strategic minerals, while pinpointing unique niches that can distinguish Quebec on the global stage.

Conducted by the NRC and the UQTR

Presented in this report

1. STATE OF PLAY
2. INDUTRIAL ECOSYSTEM
3. POTENTIAL MARKETS
4. NEEDS AND PRIORITIES
5. CONCLUSION AND RECOMMENDATIONS

Version révisée - 04 octobre 2023

Identification des principaux équipements et matériaux utilisés dans les systèmes de production d'hydrogène ainsi que leurs composants et sous-composants

Objectif

Activités

UQTR - *Identification of the main equipment and materials used in hydrogen production systems, as well as their components and sub-components*

CNRC·NRC

DÉVELOPPER LA CHAÎNE MANUFACTURIÈRE LIÉE À L'HYDROGÈNE VERT

Revue de litérature sur les systèmes de transport, stockage et utilisation de l'hydrogène

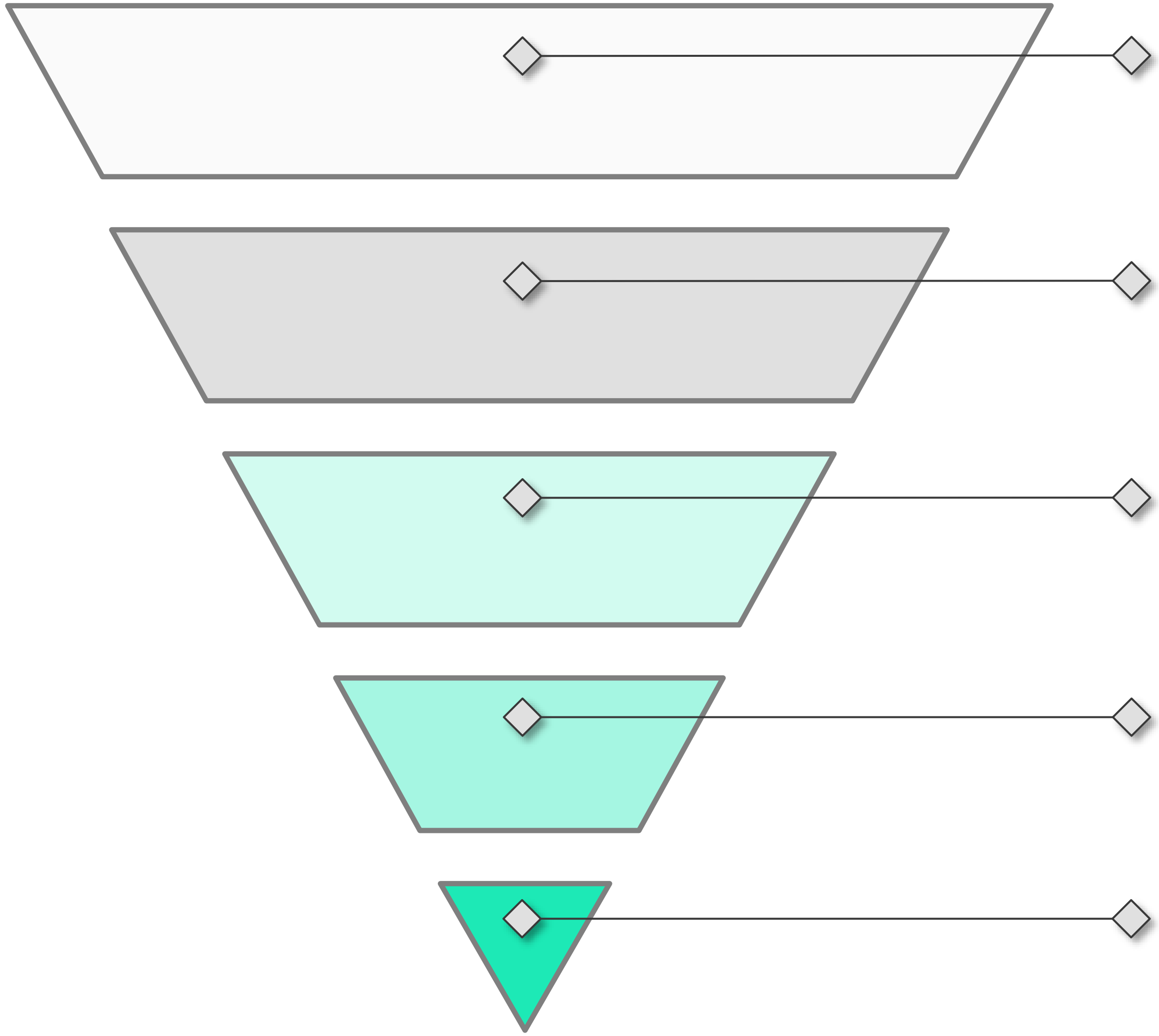
François Girard, Manuel Hernandez & Salar Salehi

Pour PRIMA-Québec, 2023

Canada

NRC - *Literature review on hydrogen transport, storage and utilization systems*

Methodology | Funnel Approach Overview



1. IN-DEPTH STUDY OF THE MANUFACTURING ECOSYSTEM

- **Analysis of 350 H_2 actors** *(Appendix 1.A).*
- **Selection of 200 actors** for in-depth analysis
- **Study** of their strategies, ambitions, projects, partnerships, etc.
- **Meeting with 30 industry players** *(Appendix 1.B).*

2. IN-DEPTH ANALYSIS OF H_2 EQUIPMENT

- **Segmentation of the value chain into 14 segments** of equipment for detailed analysis
- **In-depth analysis of associated markets,** major projects, critical minerals, R&D dynamics, etc.

3. SELECTION OF 4 STRATEGIC EQUIPMENT SEGMENTS

- Identification of key criteria for prioritizing segments: alignment with H_2 strategy, Quebec capabilities, etc.
- Calculation of a score for each segment, then selection of the 4 most promising segments

4. ANALYSIS OF SOCIO-ECONOMIC IMPACTS

- **Selection of 9 indicators** reflecting the socio-economic impact of manufacturing sector development
- **Study of these indicators for the 3 most mature segments**
- **Specific analysis** of the emerging segment

5. CONCLUSION AND RECOMMENDATIONS

- **Definition of 8 major findings** from previous analyses
- **9 recommendations** associated with these findings

Segmentation of the Value Chain | Study of 14 Equipment Segments

The hydrogen value chain has been divided into 14 equipment segments. Certain equipment were not studied as it falls outside the scope of the mandate (e.g., production by SMR) or is considered less relevant (e.g., piping). For each of these segments, in addition to interviews, 56 manufacturers were analyzed in detail to examine major trends, such as ambitions, partnerships, strategies, needs, and expectations.

1 Production

Electrolyzers
35 manufacturers analyzed

Other Reactors for the Production of H_2
TRL>7
52 actors analyzed*

Auxiliary Equipment
19 manufacturers analyzed

2 Transport/Delivery

H_2 Stations
21 manufacturers analyzed

Heavy-Duty Mobility *(for transport)*
15 manufacturers analyzed

3 Storage

Portable Tanks
18 manufacturers analyzed

Tanks for Stationnary Applications
23 manufacturers analyzed

4 Applications

Fuel Cells
31 manufacturers analyzed

Equipment for Industrial Applications *(Synthetic fuels, iron reduction, etc.)*
10 manufacturers analyzed

H_2 Buses and Trucks
19 manufacturers analyzed

5 Other

Compressors
17 manufacturers analyzed

Fittings and Valves
15 manufacturers analyzed

Instrumentation
16 manufacturers analyzed

Liquefiers
10 manufacturiers analyzed

**Since H_2 reactors are still emerging, the players analyzed are both manufacturers and technology solution providers.*

2. The Hydrogen Manufacturing Ecosystem

Study of the Ecosystem | Key Challenges and Objectives

The main objectives of this stage are **to analyze and understand the positioning of Quebec and international industrial and manufacturing players** across the entire H2 value chain. The idea is to **draw a global vision of the dynamics and market opportunities in Quebec**, as well as for export, and to **identify potential application sectors for the Quebec industrial and manufacturing ecosystem**.

Overall Methodology

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Main Challenges

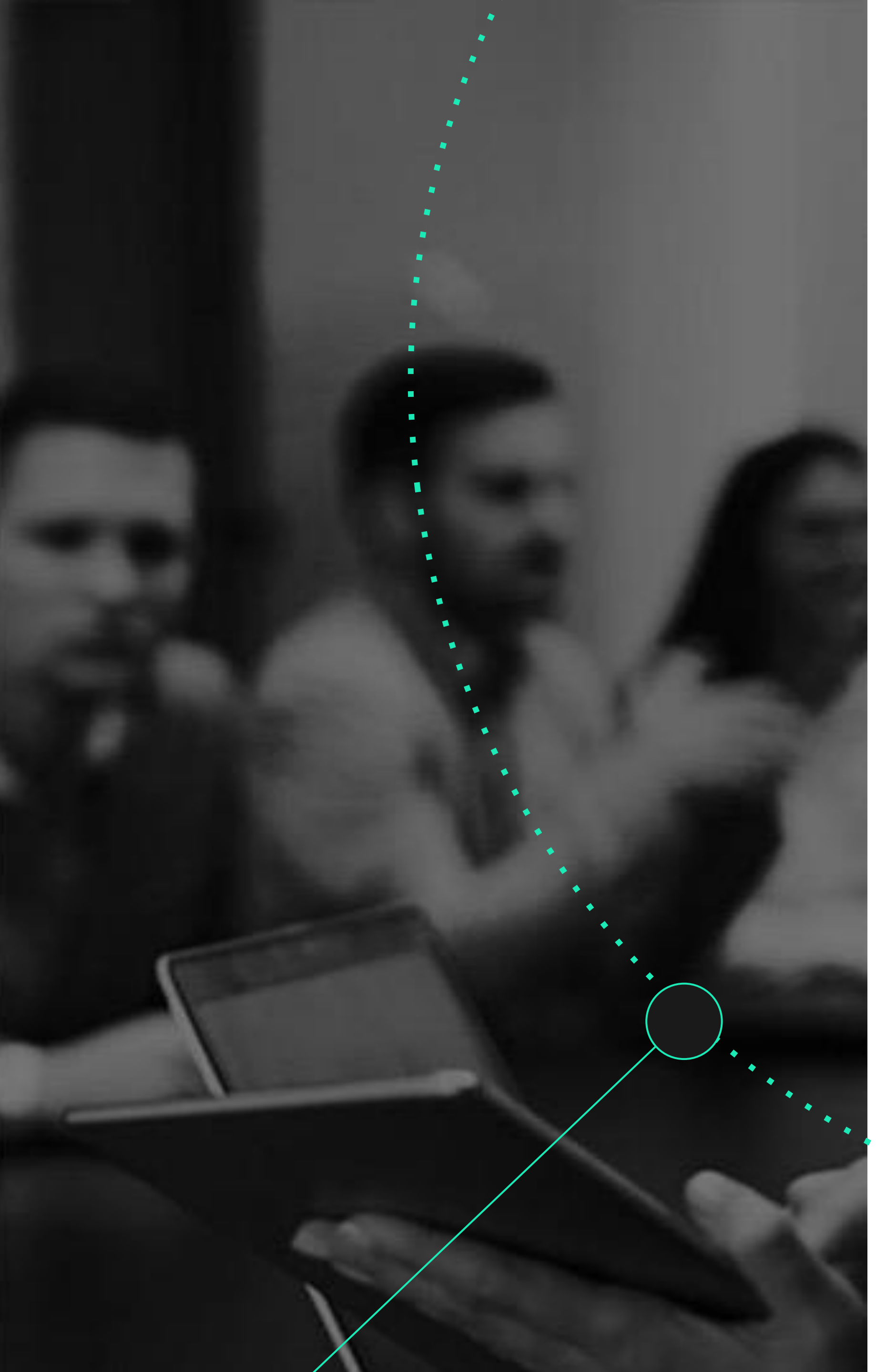
- Establish analysis at the appropriate level of detail based on a sufficient quantity of data to make informed decisions, while prioritizing efforts of **which H2 equipment to study in depth**
- Consider the **realities and specific challenges faced by manufacturers** by engaging directly with them.

Scope of Analysis

- The entire H_2 manufacturing sector for the *"1. In-depth Study of the Manufacturing Ecosystem" phase*
- The 14 H_2 equipment segments for *"2. In-Depth Analysis of H_2 Equipment"*

Analysis of the 14 Equipement Segments | Overview of the Study’s Focus Areas

THEMATIC	DESCRIPTION
State of play of technology and R&D issues	> Main applications and markets > Critical and strategic components & minerals > Technologies, TRL, utility > R&D perspectives
Global and Quebec market outlook	> Global Market Value and Growth and Regional Variations > Dominant technology > Quebec’s vision of these markets > Project dynamics in Quebec and R&D in presence
Actor typology and main manufacturing projects	> Size and nationality of manufacturers > Typology of industrialists present > Positioning and diversification/specialization strategies > Classic partnerships developed
General observations on the segment and study of best practices	> Analysis of the 3 most developed manufacturers > Study of their best practices > Segment Specific Observations > List and classification of issues identified by manufacturers
Quebec’s capacity and interest in developing this segment	> Analysis of Quebec's current manufacturing capacities > R&D players with expertise useful for the segment > Integration into the provincial H_2 strategy > Added value for the province to develop this segment



2.A. Electrolyzers

Ecosystem analysis | Global Portrait of Electrolyzers

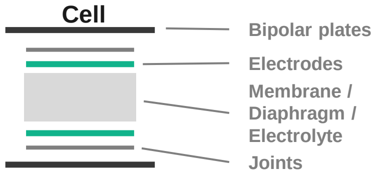
Electrolyzers are a key technology for low-carbon hydrogen production, and the decarbonisation ambitions of many countries are expected to drive demand in the coming years. The completion of all ongoing projects could result in an installed electrolyser capacity of 135 to 365 GW by 2030, while IEA scenarios predict a need for up to 3300 GW by 2050 (NZE). In 2023, 2.4 GW of electrolysers have been installed, and nearly 33.5 GW of electrolysers have been manufactured—a 145% increase compared to 2022.

SCM

Copper
Titanium
Nickel
Molybdene
Scandium

Zirconium
Iron
Iridium
Ruthenium
Platinum
Silver

Gold
Cobalt
Yttrium
Gadolinium
Lanthanum
Manganese



Technologies (Current and future)

Techno.	TRL	Cost *($/kW)*	Barriers
PEM	***9***	***2500-3000***	***Costs***
ALK	***9***	***1000-1500***	***Sustainability/ Energy***
SOEC	**6**	***1000-2000***	**Performance / Durability**
AEM	**3**	***1000-1500***	**Performance / Durability**
PCCEL	**2***	***N/A***	**Performance / Durability**

R&D perspectives

> **Discovery of new materials** : To replace critical metals. AI could help model new, more economical and sustainable alloys.

> **Improved sustainability:** Work on the degradation of membranes and catalytic materials

> **Recyclability of materials** : As in the battery sector, there is a need to find ways to recover the metals that make up electrolysers

MARKET OUTLOOK

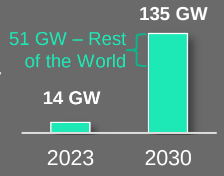
World Vision

PEM & ALK Technology

It is currently unclear which electrolyser technology will dominate by 2030 but the dominant technologies are **ALK and PEM.**

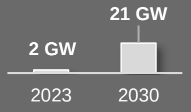
$92 billion in 2030 *($2021)*

CAGR of 32% globally by 2030



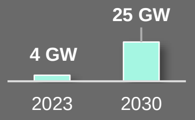
North America

Driven by **IRA** and **H_2 Hubs**, the US will represent a large part of the market



Europe

With the development of the **H_2 investment bank**, Europe is rapidly deploying capacities



Asia Pacific

Currently ahead, Asia (China + India) **will be the largest manufacturer** in 2030 to support local demand

Quebec Vision

Green Hydrogen and Bioenergy Strategy 2022

Quebec identifies hydrogen production as a solution aimed at decarbonizing mainly local applications (industry, transport) – no exports envisaged

Development of H_2 production is limited by electrical capacities

Despite increasing pressure on electrical usage: part **of the capacities delivered by Hydro-Québec in November 2023 concerned H_2 projects**

Ongoing projects and significantly increasing demand

Large-scale hydrogen production projects that have been allocated part of the necessary electrical capacities (TES CANADA – 150 MW, Greenfield – 60 MW, etc.) **the demand for electrolysers is growing.**

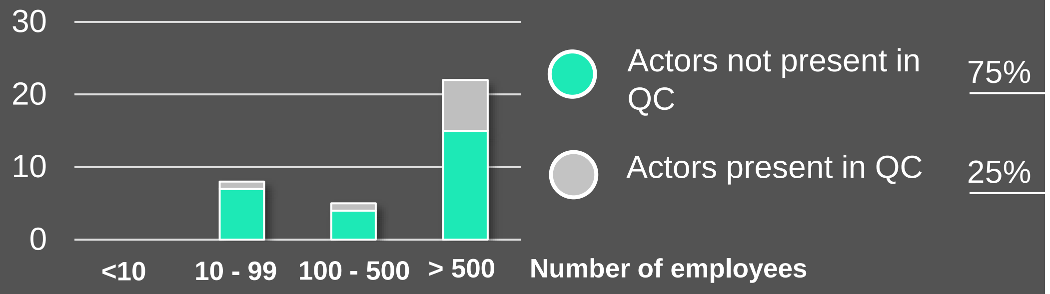
Expertise present in Quebec

R&D in membranes , **catalysts, materials, digital modeling and recyclability of components (INRS, McGill, UQTR, etc.)**

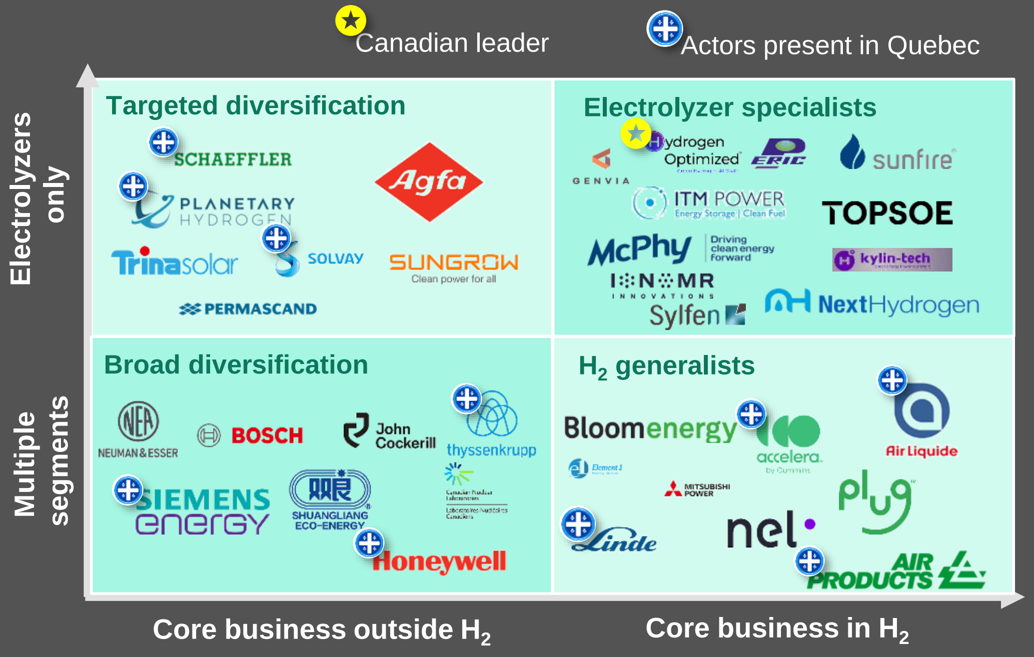
**Still under development, the price of composite materials limits commercial applications*

Projects and Actors Involved | Electrolyzers

Origin and size of the actors



Positioning of manufacturers



Typology of existing actors

1. Typology of actors

- > Several types of player can be found in this segment: **large industrial manufacturers diversifying by acquiring H_2 specialists**, **Chinese solar manufacturers**, **electrolyzer specialists** (often focusing on a single technology) and **chemical manufacturers** for membrane production in particular.
- > Most of the companies studied are multinationals (over 66% have more than 500 employees), with a **strong capacity to invest in new production lines and experience in scaling up**.

2. Positioning in the H_2 value chain

- > In this segment, **manufacturers specializing in electrolyzers coexist with players diversifying within the H_2 value chain**. Those who are diversifying are mainly positioned in auxiliary equipment, **H_2 stations and FCs (significant technological complementarity between FCs and electrolysers).**

3. Typical partnerships

- > Players **wishing to expand in Asia often form alliances** to develop their plants (Genko & John Cockerill; Cummins & Sinopec).
- > Manufacturers join forces with **historical H_2 players** to secure their order books and share expertise and risk (Siemens & Air Liquide).
- > Partnerships are also being formed with **upstream chemical manufacturers** to secure membrane supplies (Plug Power & Johnson Mattey) or **downstream to offer complete solutions** (Hydrogen Optimized & ABB).

Major manufacturing projects

Cummins	John Cockerill	Siemens	Hydrogen Optimized
4 GW under construction	**4 GW under construction**	**1 GW in Berlin**	**5000 electrolysers/year**
1 GW in Minnesota 1 GW in Belgium 1 GW in Spain 1 GW in China	1 GW in the US 1 GW in Europe 1 GW in China 1 GW in India	Plans to expand the plant's capacity to 3GW by 2025	Plans to expand their factory which will create up to 50 jobs

Positioning and Quebec Vision | Electrolyzers

Manufacturers are expanding rapidly, mainly in response to demand, and where infrastructure and manpower are available. Quebec meets the majority of manufacturers' needs but faces the challenge of a shortage of skilled labor and relatively low demand compared to the rest of Canada and the US.

Observations on the electrolyser segment

Analysis of key players

Cummins | PEM & ALK

73 600 employees (total)
Strong presence in Quebec: Bécancour, Varennes, etc.
500 MW Electro. with Chevron

John Cockerill | ALK

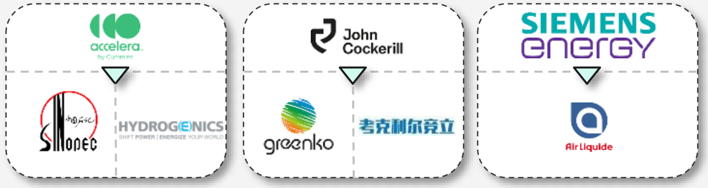
6 500 employees (total)
Ambition of 8 GW by 2025
Most powerful ALK cells (6.5 MW/cell)

Siemens | PEM

92 000 employees (total)
Uses its know-how to offer complete solutions (BoP , etc.)

Developed partnerships

Manufacturers often expand through takeovers and alliances in search of **H_2 expertise or local knowledge**.



Other observations on the segment

SOEC technology - Although less mature, this **technology is developing very rapidly**, with players such as Topsoe (5 GW by 2025), Genvia and others.

SCM - Some of the manufacturers we met are well aware of the tensions on certain SCM and **do not publish their ambitions** to avoid driving up prices.

Issues Identified

1. Ability of ecosystem players **to scale**	●●●●
2. Difficulty **in anticipating demand to calibrate capacities**	●●●◐
3. **Standardization of technologies / projects**	●●●○
4. Component **supply issues**	●●◐○

Focus on Quebec's manufacturing capabilities

From a manufacturing point of view, **several manufacturers operate in Quebec, but no electrolyser production plants are located there**.
Interviews with manufacturers **show a growing interest in Canada and Quebec**, with major projects such as TES, Greenfield, etc. helping to secure demand.

Quebec's Strategic Interest

H_2 production helps decarbonize local needs

Provincial

- The strategy identifies green H_2 as a significant opportunity to decarbonize industries locally

Complementary sectors

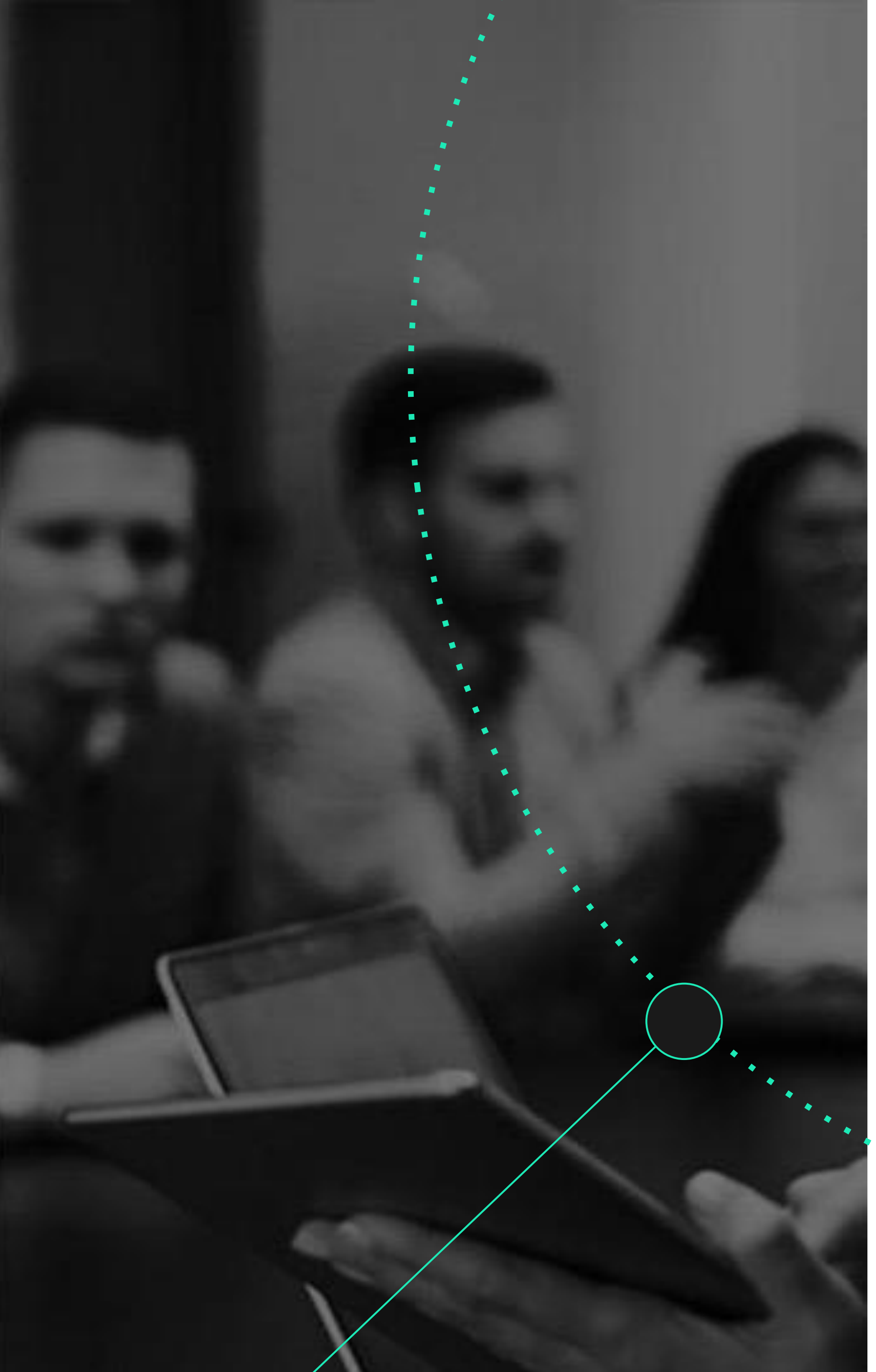
- Polluting industries in QC, particularly chemicals, steel and refineries, would benefit from the presence of green H_2

Quebec's Capacity

Quebec's strengths partially meet the needs of industrial actors

1. Need for very strong local demand	**Average**
2. Proximity to train/deep water port	**Important**
3. Political will to support manufacturers	**Important**
4. Presence of existing infrastructure/spaces	**Important**
5. Skilled workforce and subcontractors present	**Average**

Relative importance of indicators Low ○ ● ● ● ● High

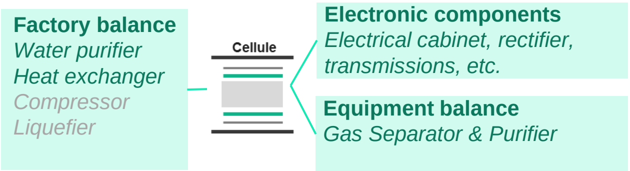


2.B. Auxiliary Equipment

Ecosystem Analysis | Auxiliary Equipment

Auxiliary equipment comprises **components and systems required for the efficient operation of an electrolyser**. These play a critical role in the overall performance and economic viability of projects. In the drive to make electrolysers more efficient and profitable, auxiliary equipment is essential for reducing costs and enhancing system durability. From a market perspective, the **dynamics vary significantly for each piece of equipment**; however, all are closely linked to the dynamics of electrolyser cells and will therefore be treated as similar in this analysis.

SCM



Factory balance
Water purifier
Heat exchanger
Compressor
Liquefier

Electronic components
Electrical cabinet, rectifier, transmissions, etc.

Equipment balance
Gas Separator & Purifier

Technologies *(Current and future)*

Equipment	Purpose
Water purifier	The water used for electrolysis must be demineralized and deionized, particularly for PEMs.
Heat exchanger	Getting the right operating
Power electronics equipment	Supply the electrolyser with a **direct current and at the correct intensity**
Gas Separator & Purifier	**To separate** $_{H2}$ water vapor and oxygen

R&D perspectives

- \> **Heat exchanger:** improve system safety (leaks), reduce size and simplify maintenance
- \> **Water purifier:** reduce purification costs and energy requirements
- \> **Electronic equipment:** ability to manage intermittent power supply (renewables, peak management)
- \> **Gas separator:** reduce process energy requirements and associated

MARKET OUTLOOK *FOR ELECTROLYZERS*

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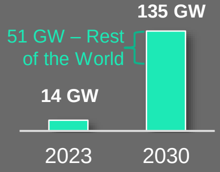

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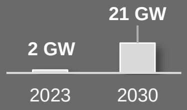

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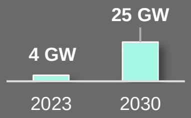

Asia Pacific
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Ongoing projects and significantly increasing demand
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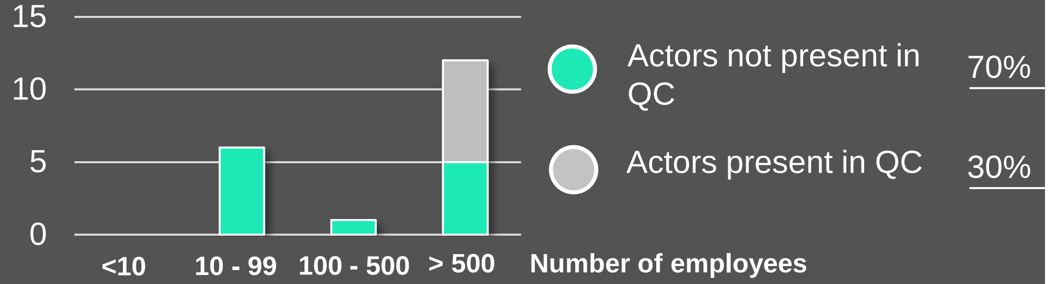
Expertise present in Quebec
R&D in membranes , **catalysts, materials, digital modeling and recyclability of components (INRS, McGill, UQTR, etc.)**

Projects and Actors Involved | Auxiliary Equipment

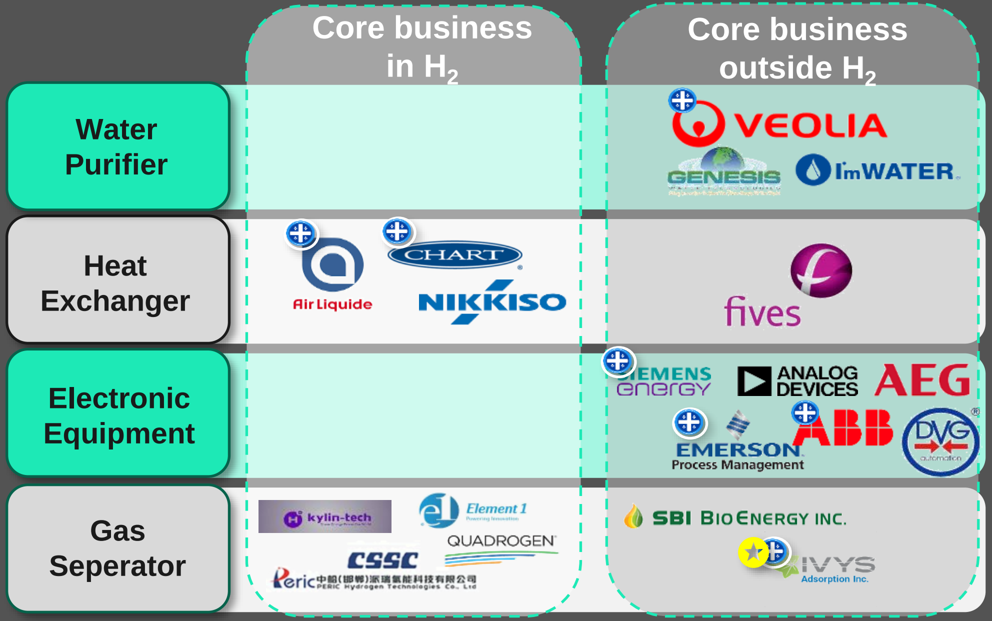
Origin and size of the actors



Positioning of manufacturers

⊕ Actors present in Quebec

★ Canadian leader



Typology of present actors

1. Typology of actors

- > The majority of players in these segments are **specialists in their respective equipment** (purifier, exchanger, power electronics, etc.), whose **core business is generally not H_2.**
- > Players positioning themselves in H_2 separation/purification are **mainly companies with a history in the oil and gas sector**, who are converting to low-carbon H_2 (SBI Bioenergy Inc., Ivys Adsorption). The processes are in fact similar, enabling these companies to capitalize on their expertise.

2. Positioning in the H_2 value chain

- > In addition to **players specializing in their segment**, several companies are **H_2 generalists** (Air Liquide, Chart) or **electrolyser producers** seeking to internalize several components of the final solution (Kylin Tech, Peric, Siemens).

3. Typical partnerships

- > Auxiliary equipment manufacturers are developing **through partnerships with electrolyser manufacturers** (Véolia & PEM electrolyser manufacturer confidential; Chart & McPhy).

Major manufacturing capacities

AEG	**Veolia**	⊕ **Ivys adsorption**
Spain, Germany, Singapore, China	*Spain, Germany, Slovakia, etc.*	*Quebec*
+20 Transformers-Rectifiers sold for H_2 production projects	**+8000 water treatment units** built and installed (not only H_2)	**+350 AMP for H_2 installations** Factory in Montreal employs +80 employees

Positioning and Quebec Vision | Auxiliary Equipment

Given the **complexity of each piece of equipment** in this segment, and the **diversity of associated expertise** (fluid mechanics, power electronics, thermodynamics, chemistry, etc.), few electrolyzer manufacturers venture to integrate this stage. Nevertheless, Quebec has recognized **expertise in gas separation**, with the presence of Ivys and its plant in Montreal.

Observations on the auxiliary equipment segment

Analysis of key players

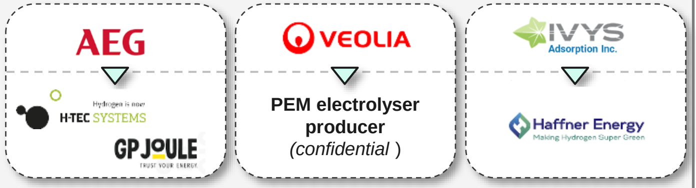
AEG
11 000 employees
Develops complete turnkey systems (transformers, rectifiers, etc.) for H_2

Veolia
220 000 employees
Possibility to adapt to electrolyzer technology and obtain powers >500 MW

Ivys adsorption
130 employees
Formerly Xebec , was acquired in 2023 by Ivys following its bankruptcy

Developed partnerships

Les manufacturiers se développent en construisant des relations avec **des porteurs de projets H_2** ou des **manufacturiers d'électrolyseurs**



Other observations on the segment

Secondary sector - For the majority of auxiliary equipment manufacturers, H_2 is a **secondary market** accounting for **a small share of sales.**

Difficulty of integration - Few electrolyser manufacturers are positioned in these segments, which **require specific expertise**.

Issues Identified

1.	**Standardization of projects and technologies**	●●●●
2.	**Component supply issues**	●●●○
3.	Technologies & markets **interdependent** with other solutions	●●○○
4.	**Risk of developing specific H_2 solutions**	●●○○

Focus on Quebec's manufacturing capabilities

On the manufacturing side, Ivys Adsorption (formerly Xebec Adsorption) has a **major manufacturing center in Montreal** that develops gas purification systems.
Despite the takeover in 2023 by Ivys (based in the USA), the Montreal plant continues to recruit, and prospects for green gas production (H_2 & RNG) benefit the company.

Quebec's Strategic Interest

The interest is slightly less than for electrolysers

H_2 Strategy & Industries to Decarbonize

- To produce H_2 locally , this auxiliary equipment will be necessary to accompany the electrolysers

Added value a little less important

- Due to its dependence on the electrolyser market and the lower technological content, the added value is lower

Quebec's Capacity

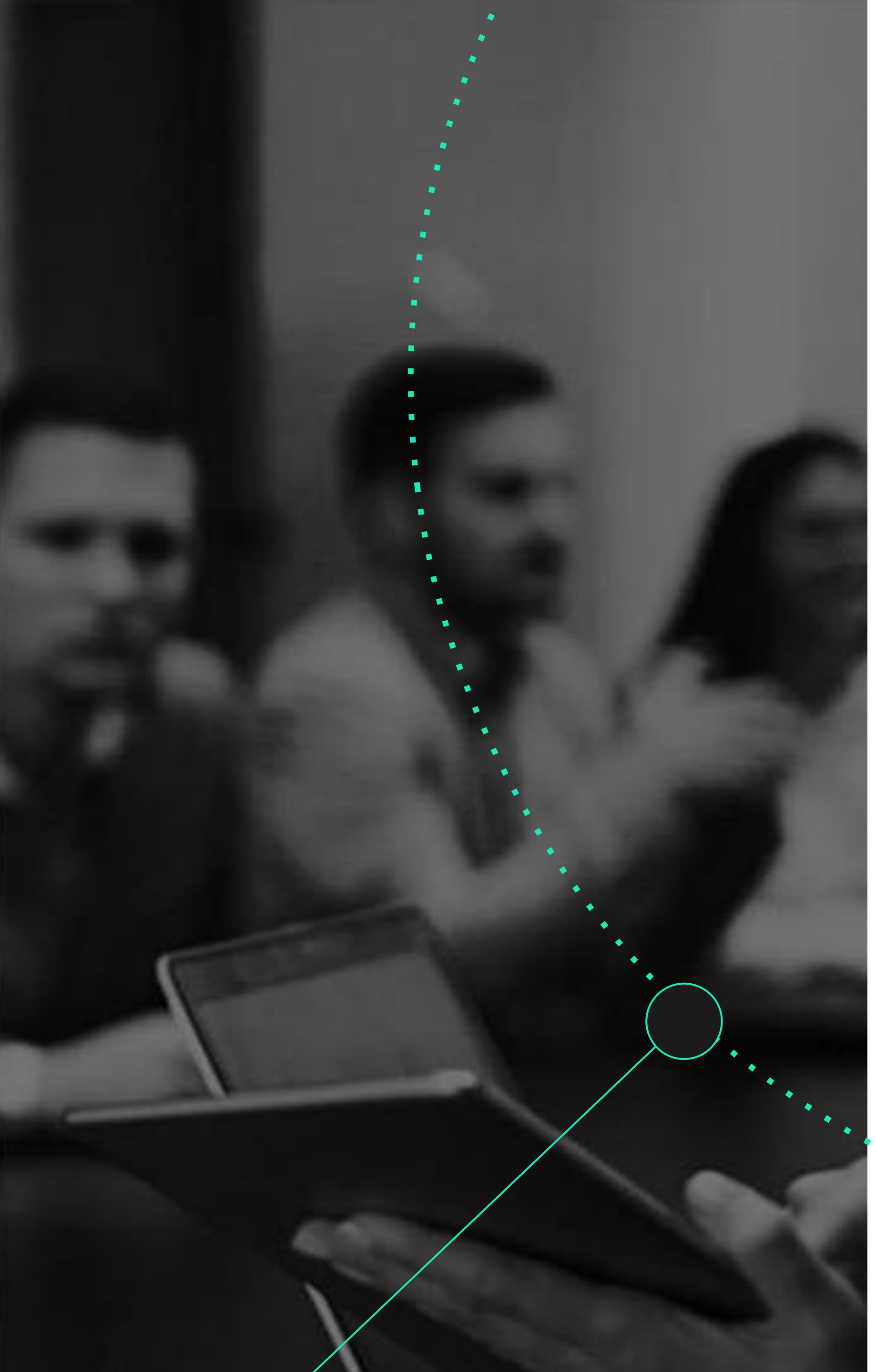
Quebec's capacity is strengthened by the presence of Ivys

Manufacturing

- In addition to Ivys and its factory in Montreal which employs 130 people, **several players in this segment are very present in Quebec** but without a local equipment production plant (Veolia, Air Liquide, Chart Ind ., etc.)

Relative importance of indicators

Low ○ ○ ○ ● ● High



2.C. H_2 Reactors

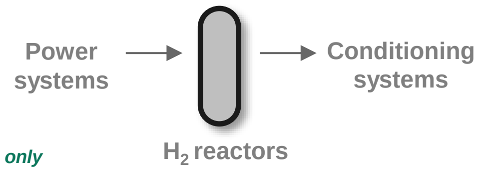
Ecosystem Analysis | H$_2$ Reactors

Although electrolysis production is at the heart of hydrogen projects and announcements, hydrogen is still predominantly produced through steam reforming (SMR: grey H2). Other hydrogen production methods fall into two categories: **thermochemical processes and biological processes**. This equipment segment includes reactors used in processes such as biomass gasification, plasma pyrolysis of biomethane, dark fermentation, photo-fermentation, and sequential fermentation (NMT >7). The selection and commercialization of green hydrogen production equipment rely on comprehensive techno-economic analyses, including cost driver assessments, exploration of cost-competitiveness strategies, and identification of factors influencing production costs. Additionally, the **elimination and/or valorization of co-products from these reactions are critical challenges** for achieving sufficient hydrogen purity and developing robust business models

SCM*

Copper
Titanium
Iron
Ruthenium

Nickel
Molybdene
Cobalt
Platinum
Palladium



Power systems → H$_2$ reactors → Conditioning systems

Thermochemical processes only

Technologies (*Current and future*)

Process	TRL	Barriers and needs	
SMR	*9*	*Improved catalysts*	THERMOCHEMICAL
POX	*9*	*CO management and control*	
Biomass gasification	9	Profitability and by-products (Sulfur)	
Plasma pyrolysis	9	MTR Performance/Durability	
Dark fermentation	8	Adapted microorganisms	BIOLOGICAL
Photofermentation	8	Adapted microorganisms	
Sequential ferm.	7	Adapted microorganisms	

R&D perspectives

> **Thermochemical processes** : **AI** to model new types of catalysts (zeolites) and model the logistics of biomass collection and transport (biomass gasification)

> **Biological processes** : Further studies to develop **dark fermentation, photofermentation and enzymatic approaches**

> **Synergistic approaches** : R&D to design **hybrid thermochemical and biological systems** to address the limitations of individual processes

MARKET OUTLOOK

World Vision

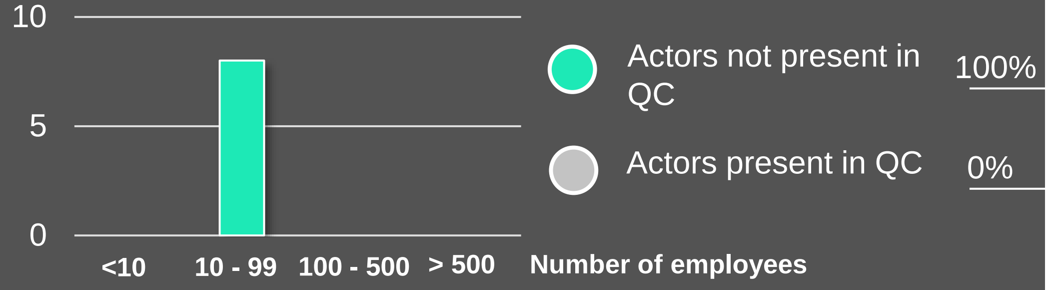
$1.9 billion by 2050	The green hydrogen production market will result in **increasing demand for production equipment** (electrolyzers and other H$_2$ reactors)
A transition to electrolysis	Historically produced by steam reforming, the transition to green H$_2$ is mainly **driven by electrolysis technologies, but several other production routes are possible** and are detailed below.
Positive repercussions (2030-2050)	The green hydrogen production market will make it possible to: - Create **2 million jobs** per year cumulative CO$_2$ emissions by **85 gigatonnes**
North America and Europe	Policies and investments are multiplying at the level of green H$_2$ The major projects announced are primarily focused on electrolysers (with import/export partnerships for example), but the **momentum is growing on other green**

Quebec Vision

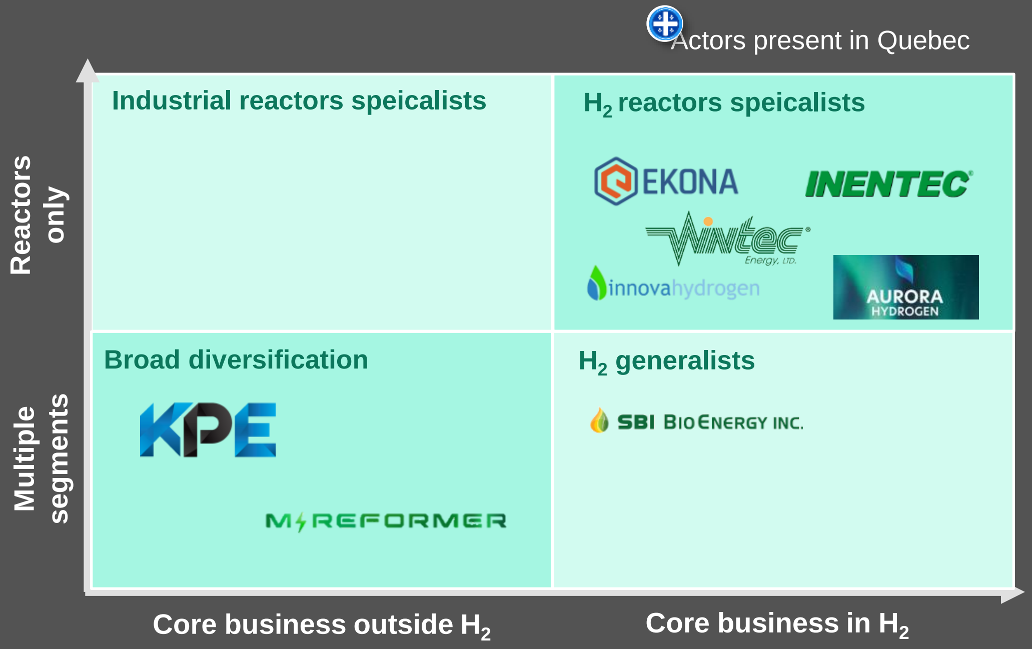
Green Hydrogen and Bioenergy Strategy 2022	Quebec identifies hydrogen production as a solution aimed at decarbonizing mainly local applications (industry, transport) – no exports envisaged.
Majority demand for electrolysers	With recent large-scale hydrogen production projects , **electrolysis processes are the most dynamic** among the means of producing green hydrogen; in particular because the reduction in GHG emissions is often greater
Supporting the biomass recovery sector	Biomass gasification is an alternative to its incineration which reduces GHG emissions It is also an alternative to the burial of waste which is still very widespread in QC (CRD, medical, etc.)
R&D expertise	Expertise in plasma pyrolysis processes held by universities and research centers (Polytechnique, McGill, INRS, UQTR, CEPROCQ, Concordia, Sherbrooke, etc.)

Projects and Actors Involved | H_2 Reactors

Origin and size of the actors



Positioning of manufacturers



Industrial reactors speicalists

H_2 reactors speicalists

Broad diversification

H_2 generalists

Reactors only

Multiple segments

Core business outside H_2

Core business in H_2

Typology of existing actors

1. Typology of actors

- The majority of players in this segment are small companies **specializing in H_2 reactors**.
- Most manufacturers provide solutions for thermochemical processes, since biological processes are still at laboratory or pilot scale.
- Players are distinguished by their **technologies and patents held**

2. Positioning in the H_2 value chain

- The majority of players are **hydrogen reactor specialists** who are not positioned in other equipment segments of the value chain.
- The majority of players are **assemblers of hydrogen production equipment**; low TRL and to market their technologies, technology owners **outsource manufacturing** (e.g. KP Engineering manufactures Omni Conversions systems; MMM Energy manufactures for Element One).

3. Typical partnerships

- Most manufacturers are developing **strategic partnerships with research and development organizations** (Aurora Hydrogen & University of Toronto; Inentec & MIT; Innova Hydrogen & University of Alberta...) to optimize their technologies.
- Partnerships are also being forged **with industry to develop customized solutions** (Development of a new methane pyrolysis technology: Ekona & TransAlta; Integrated hydrogen production system: Integrated solution for hydrogen production from waste: KP Engineering & Omni Conversions).

Major manufacturing capacities

🇨🇦 **SBI Bioenergy**	🇺🇸 **KP Engineering**	🇨🇦 **Ekona**	🇺🇸 **Wintec Energy**
Edmonton	*Texas, United States*	*British Columbia*	*UNITED STATES*
Reactors producing H_2 from bioethanol **1 site of 35,000 sq. ft**	**Omni200 Units from Omni Conversions** **2 sites in the United States**	**Reactors: No-catalytic pyrolysis of methane** **1 site in CB**	**Demonstration of H2SX technology: microwave plasma**

Positioning and Quebec Vision | H_2 Reactors

The majority of technology owners in this segment outsource reactor manufacturing to specialized engineering firms**. R&D plays a central role in this segment**, and industry players often collaborate with research organizations. Quebec is well-positioned to address the R&D needs of this segment; however, its manufacturing expertise remains less developed compared to the rest of Canada.

Observations on the H_2 reactors segment

Analysis of key players

SBI Bioenergy
25 employees
Expands by creating partnerships to implement its Golu-H2 reactor

KP Engineering
118 employees
Develops through expertise in the manufacturing of hydrogen systems

Ekona
59 employees
Expands by outsourcing the marketing of its technology platform for xCaliber reactors

Developed partnerships

Manufacturers often grow through partnerships **with technology owners or end users** for specific applications.

Industrial, transportation and residential applications

Omni200 Units Manufacture

Marketing of xCaliber reactors

Other observations on the segment

Competition – This segment is in close competition with that of electrolysers which for the moment attracts the most interest and investments

R&D – Highly dynamic R&D to accelerate the commercialization of low TRL technologies (dark fermentation, photofermentation and sequential fermentation)

Issues Identified

1. Ability of ecosystem players **to scale**	●●●●
2. Demand still too low to justify large-scale manufacturing	●●●◐
3. **Risk in the choice of the marketed process**	●●●○
4. **Custom manufacturing dynamics**	●●◐○

Focus on Quebec's manufacturing capabilities

From a manufacturing standpoint, **no player operates in QC**. The majority of players have operations in Canada or the United States. In Quebec, the focus is more on electrolyzers as the equipment of choice for green hydrogen production by both manufacturers and project developers. However, Quebec has **distinguished R&D expertise i**n this segment, and investments will help future commercialization of the associated technologies.

Quebec's Strategic Interest

Meeting decarbonization needs

- The development of a **manufacturing ecosystem** for H_2 reactors would enable QC to reduce emissions from SMR processes, while supporting the biomass recovery sector (vs. incineration).
- However, **demand for this equipment segment remains very low** compared with that for electrolysers (dynamics to be monitored).

Quebec's Capacity

An underdevelopped manufacturing ecosystem

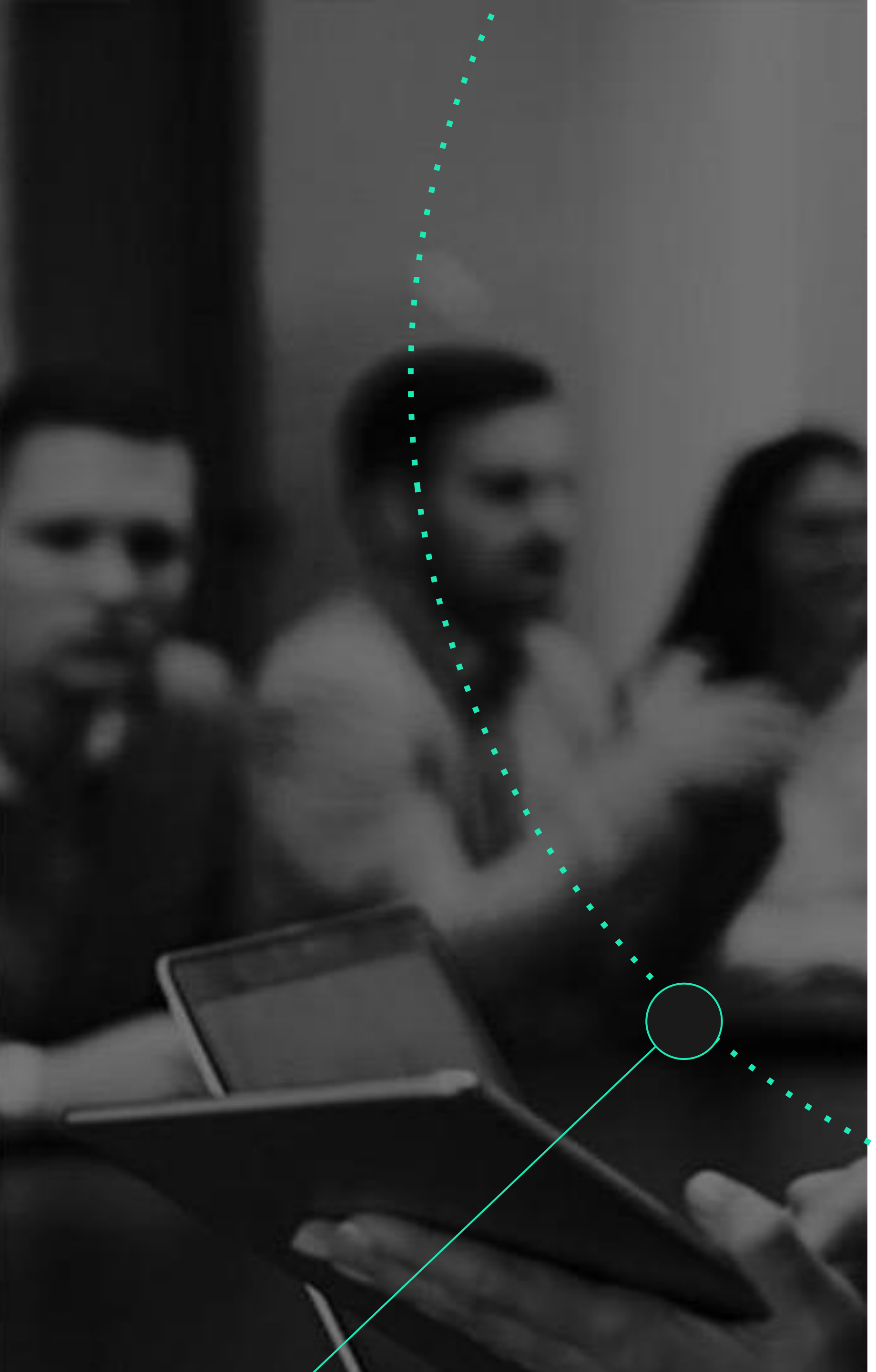
R&D expertise

- Expertise in plasma fermentation and pyrolysis processes from McGill, UQTR, Polytechnique, etc.

Manufacturing ecosystem

- No identified player in QC capable of producing H_2 reactors, but presence of specialized firms with complementary skills (Pyrogenesis: manufacture of plasma torches).

Relative importance of indicators Low ○ ○ ○ ● ● High



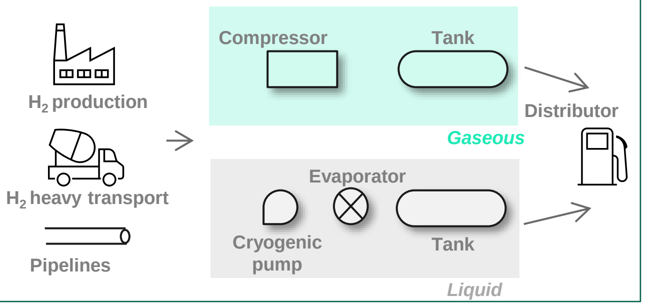
2.D. H_2 Stations

Ecosystem Analysis | Global Portrait of Hydrogen Stations

Hydrogen stations are critical for the adoption of hydrogen propulsion technologies. Despite the growth in the number of stations, their dynamics are less significant compared to those observed for electric charging stations. **Hydrogen stations require various auxiliary equipment**, including piping, storage systems, compressors, liquefiers, hydrogen production equipment, evaporators, cryogenic pumps, and dispensers. Two systems coexist (gaseous and liquid), which can be implemented in two configurations depending on the need (on-site or off-site). Today, there are more than 1,000 hydrogen stations worldwide, with China accounting for a third of these installations. **Gaseous hydrogen stations enable refueling at two distinct pressures: 350 bar or 700 bar**, depending on the type of vehicle.

SCM

Copper
Titanium
Inox (Nickel)
Platinum
Cobalt
Graphite



Technologies *(Current and future)*

Type	TRL	Energy demand*	Advantages	Disadvantages
Gaseous	**9**	**4.21 kWh/kg** **Transition from 10 à 55 MPa*	**350 bars** Capacity **700 bars** Refueling time	**350 bars** FCEV spectrum **700 bars** Less capacity
Liquid	**9**	**8.57 kWh/kg**	High capacity	High costs

R&D perspectives

- > **Liquid storage** : R&D to develop Portable liquid storage: promising storage density but energy-intensive liquefaction & evaporation
- > **Weather:** Researches solutions to address challenges related to extreme weather conditions: H_2 leaks at dispensers amplified by winds
- > **Modularity:** Modular design to allow scalability of technologies
- > **Interoperability:** Standardization to enable interoperability and compatibility between manufacturers

MARKET OUTLOOK

World Vision

$0.95 billion in 2022	CAGR of 26.43% by 2030
On-site or off-ste	On-site stations account **for 56% of market revenues** (limited transport and storage requirements); Mobile stations are an emerging segment
Major segment	Stations of less than 1 tonne per day account for **92% of the market, but there is a trend towards larger stations to improve profitability**
Europe	Growth attributed to increasing **government and industrial investment**
North America	Pearson Airport: **first public hydrogen station;** Partnerships to develop fuelling technologies (CHFCA);
Asia Pacific	South Korea: the government has announced plans to produce **6.2 million hydrogen vehicles and deploy at least 1,200 stations by 2040**

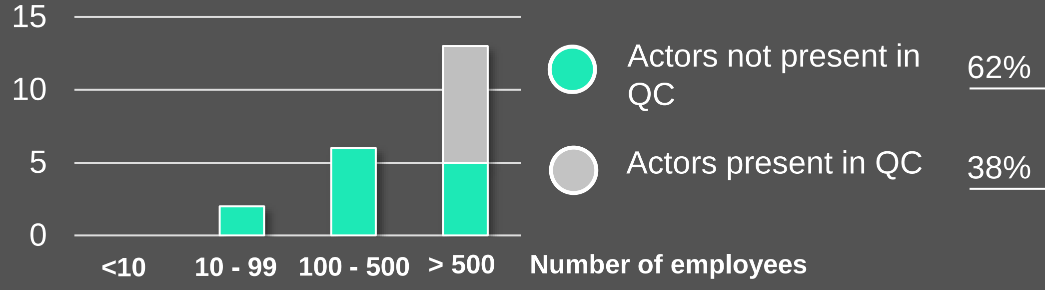
Quebec Vision

Green Hydrogen and Bioenergy Strategy 2022	Quebec positions hydrogen as a promising alternative for decarbonizing **heavy and long-distance mobility**
Low maturity infrastructure	Very little fuelling infrastructure: **growing adoption but high infrastructure costs**
Value chain to be consolidated	Lack of a hydrogen value chain**: no large producers and a majority of on-site producers**
Opportunities	**Expertise in QC** held by Harnois Énergies and emerging projects: Hydrolux - network of H2 stations produced by Vinci and TES - 1/3 of whose output could be used for heavy transport.
Codependant market	Need for station development to go hand in hand with H_2 mobility development

**Including hydrogen compression for gaseous systems from 10 to 55 MPa and liquefaction for liquid systems; Excluding electrolysis*

Projects and Actors Involved | H_2 Stations

Origin and size of the actors



Positioning of manufacturers

Typology of existing actors

1. Typology of actors

- Most players are multinational companies focused on manufacturing H2 stations, with hydrogen as their core business. These companies are expanding their technology portfolios by integrating other equipment into the value chain (e.g., Linde and Nel: electrolyzers).
- **Significant disparity in the number of fuelling stations deployed**: 5 to 300 stations deployed. Some projects are undergoing trials, while others are being implemented on a commercial scale.

2. Positioning in the H_2 value chain

- In the manufacturing chain, they are mostly **assemblers**. Some integrate the **manufacture of sub-components:** (Linde: cryogenic pumps and ionic compressors).
- Other players identified during the analysis specialize in **sub-components only**: compressors (Neuman & Esser), cryogenic pumps (Fluitron), liquefiers (Chart).
- Hyfindr offers **fuelling stations at two pressures (350 and 700 bar)**, covering all existing H_2 propulsion technologies.

3. Typical partnerships

- The majority of large-scale manufacturers are developing **strategic partnerships with players specializing in the manufacture of electrolyzers** to include an H_2 production unit in their stations (Messer & Siemens; Nel & SFC Energy).
- **Development of turnkey solutions**: production integration (Nel & SFC Energy), transport and distribution (Toyota & Messer; First Hydrogen)
- **Some partnerships with end-users to secure demand**: Fuel Element & Nikola; Cummins & Air Products

Major manufacturing projects

Nel Hydrogen
Denmark
Future capacity: 300 stations/year
50 stations deployed

Power Plug
United States
5 stations planned in North America
60 stations deployed

Linde
China
Capacity that will triple
200 stations deployed

Atawey
France
400 stations by 2025
25 stations deployed

Positioning and Quebec Vision | H_2 Stations

The key players in hydrogen stations stand out for their ability to **absorb the high costs of manufacturing** and operating the fuelling infrastructure by building **solid business models**. These are the two major barriers to entry in this segment. In Quebec, although **demand for fueling stations is growing, few players have been identified as capable of setting up substantial manufacturing capacity**, despite a few announced projects.

Observations on the H_2 stations segment

Analysis of key players

Nel Hydrogen
556 employees
Largest industrial capacity
Produces electrolysers

Plug Power
3 353 employees
3 manufacturing sites
Takes care of the manufacture of distributors

Linde
74 207 employees
1 manufacturing site
Produces ionic compressors and cryogenic pumps

Developed partnerships

The manufacturers that are scaling up **are those that are able to secure auxiliary equipment to hydrogen stations.**

nel ▽ HTEC Hydrogen Technology & Energy Corporation

plug ▽ **Manufacture of distributors**

Linde ▽ HYOSUNG

Other observations on the segment

Interdependent markets – Manufacturers hesitant to build hydrogen-powered cars due to lack of refueling infrastructure and vice versa

Specialization trends – Generalist players tend to specialize and abandon certain segments (Purchase by Atawey of the H_2 Stations division of Mcphy)

Issues Identified

1. **Standardization of fueling pressures**	●●●●
2. **Economic competitiveness compared to alternatives**	●●●○
3. **Absence of large hydrogen producers**	●●○○
4. Ability of ecosystem players **to scale**	●○○○

Focus on Quebec's manufacturing capabilities

1 seul acteur balisé est présent au QC: HTEC (dont les stations sont fabriquées par Plug Power). Malgré la présence d'autres acteurs au QC, leurs projets anNocés se font hors-QC (Linde, Air Products). Les entretiens réalisés ont listé First Hydrogen comme **potentiellement intéressé de développer des activités manufacturières** au Québec (véhicules FCEV) en offrant une solution clé en main pour ses clients du secteur de la mobilité lourde (intégration de services d'avitaillement)

Quebec's Strategic Interest

Producing stations serves the decarbonization of transport

Provincial decarbonization targets

- The Quebec government aims to reduce its GHG emissions by 37.5% by 2030 and transportation accounts for **44% of these emissions.**
- Furthermore, the provincial strategy for green H_2 identifies heavy transport as a **medium priority outlet** for H_2.

Quebec's Capacity

Low demand for the moment

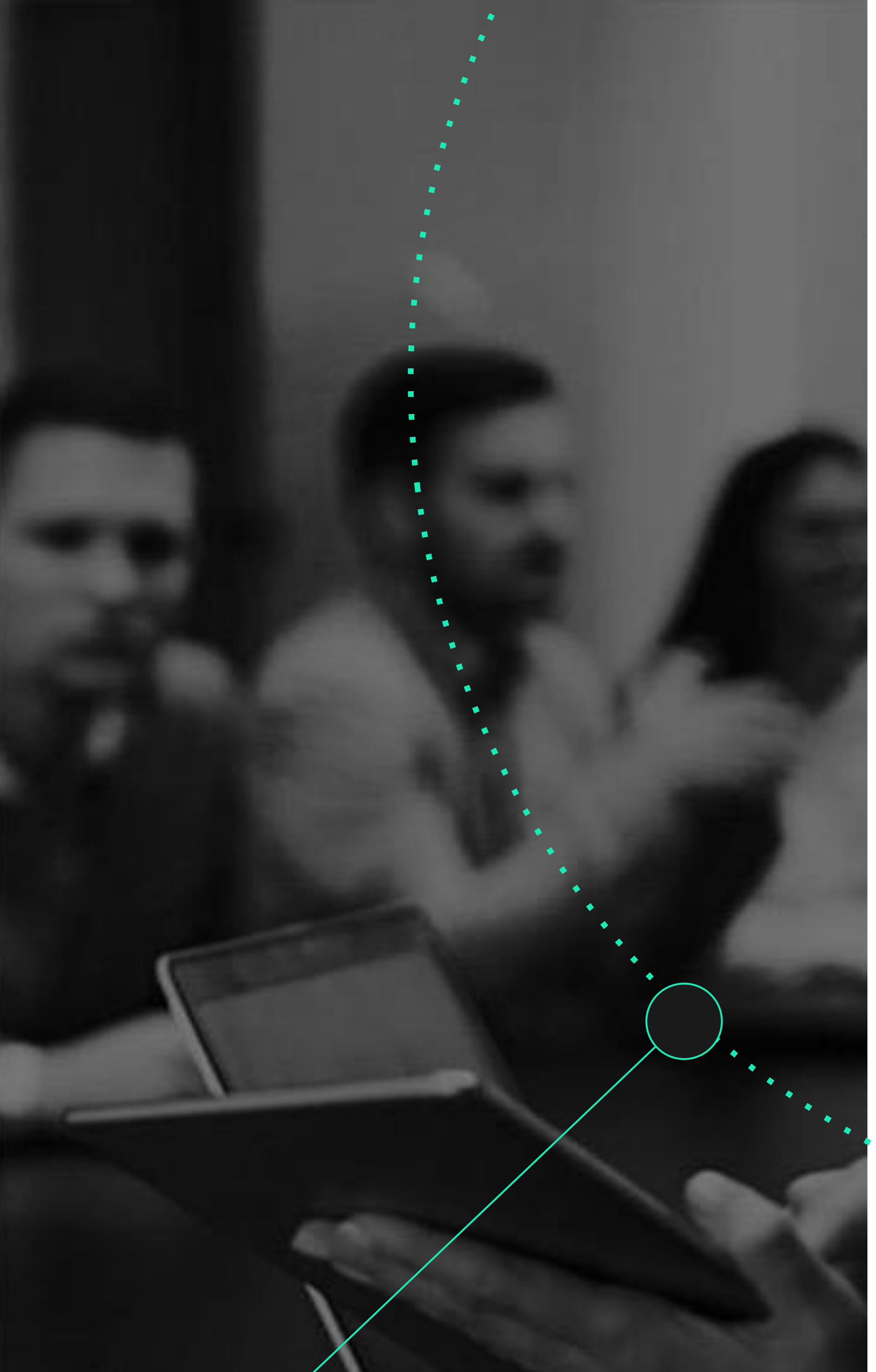
Complementary expertise present at QC

- Ability to meet the needs of manufacturers and station operators: Harnois Énergie is a proven player in the operation of hydrogen stations and the integration of billing processes

Manufacturer

- Few/no QC players identified capable of producing stations on a large scale but emerging dynamics (7 hydrogen stations announced by Hydrolux and produced by Vinci) and low demand for the moment

Relative importance of indicators Low ○ ● ● ● ● High



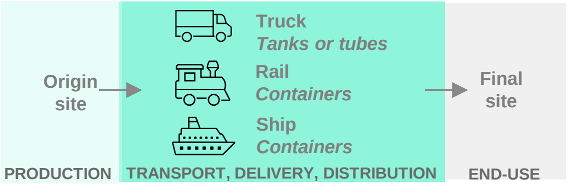
2.E. Heavy-Duty H_2 Mobility *(For the transport of H_2)*

Ecosystem Analysis | Global Portrait of Heavy-Duty H_2 Mobility

There are several methods for transporting and distributing hydrogen: pipelines (long-term supply), trucks, ships, and trains (short- to medium-term supply). The focus of H2 transport is primarily on ships and pipelines, rather than heavy-duty truck transport, which has been widely used for decades (via cryogenic or pressurized transport**). Hydrogen can be transported in three forms: gaseous, liquid, or via carrier molecules**. Carrier molecules are primarily used for export applications by ship and truck (e.g., liquid ammonia, methanol, and LOHC). In Canada, hydrogen transport by pipeline is under close consideration, with Enbridge leading initiatives in the industrial sector. However, this analysis emphasizes **hydrogen transport via H2 heavy-duty mobility**, which is better aligned with Quebec's context of centralized production and short- to medium-term supply needs.

SCM

Inox (Nickel)
Titanium
Copper



Technologies (Current and future)

Method	TRL	State	Barriers and needs	
Truck	9	Gaseous	Storage capacities Pressure limits Certification of new approaches	
		Liquid	Cost reduction and evaporation Capacity increase	
Rail	7	Gaseous	Storage capacities Pressure limits Certification of new approaches	FUTURE
		Liquid	Safety; Cost reduction (weight) Low capacity	
Ship	7	Liquid Carrier molecules	Temperature limits Technology maturity	EMERGING

R&D perspectives

- > **Alternative alloys :** R&D for the development of new **corrosion-resistant alloys**
- > **Sensors :** Next-generation sensors will need to multiply to meet the **growing needs in terms of the quality of hydrogen transported in tanks** ; new sensors will be able to use the following **4 types of technologies** : AF, AI, printed electronics with RFID antennas, and quantum dots for optical sensors

MARKET OUTLOOK

World Vision

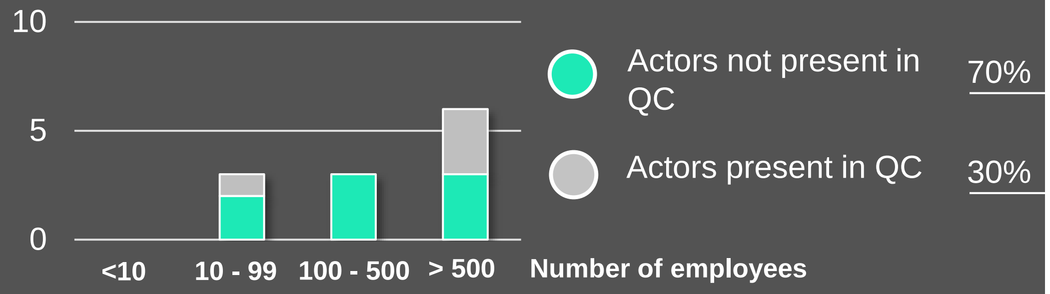
At the heart of the debate	Compromise between **centralized production** and developed hydrogen transport infrastructure & decentralized production with distribution costs (-) but high production costs (+) (Influence on H2 cost)
Most widespread technologies	**Truck transport:** Tank trucks (liquid): most widespread and economical method for long-distance H2 transport (high capacity) Pipe trailers (gas): shorter distances (capacity limited by weight of Portable tanks)
R&D challenges to be mastered on a global scale	**R&D efforts and investments** to develop new technologies such as carrier molecules for high-density transport - e.g. Chiyoda Corporation: SPERA LOHC technology demonstration (210 tons per year)
North America	**US-led simulation and optimization work:** DOE performs H2A Delivery Analysis to optimize H_2 transport technologies for end-use scenarios.

Quebec Vision

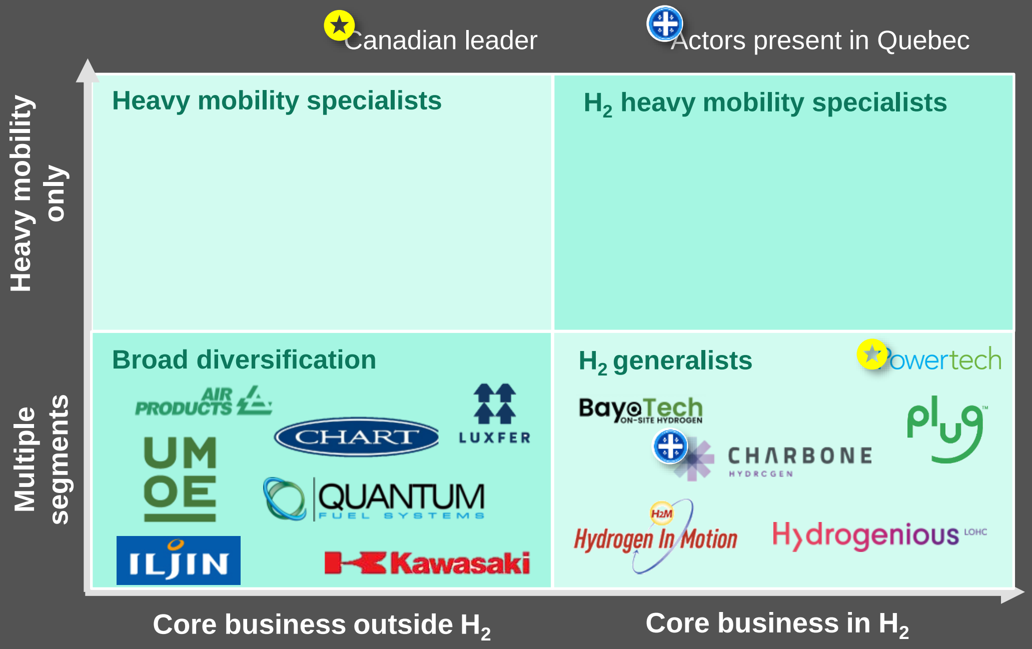
Green Hydrogen and Bioenergy Strategy 2022	Targeted industrial and refueling applications that will drive demand for H2 transportation: **need to get H_2 from the place of production to the place of use;**
Green hydrogen production for local needs	No exports planned: deliveries mostly local (between producers and users); - **Trucks: most suitable segment** - Ships: underdeveloped - Rail: lack of standards and less attractive for large quantities
Achieving decarbonization targets	**Heavy-Duty vehicles used for H2 transport are expected to be electrified**, otherwise an analysis of the associated emissions is required to justify this use.
Co-development necessary	Particularly in terms of **adapting Type 4 tanks to a scale compatible with H2 transport operations.**

Projects and Actors Involved | Heavy-Duty H_2 Mobility

Origin and size of the actors



Positioning of manufacturers



Typology of existing actors

1. Typology of actors

- The majority of players are **diversifying manufacturers** whose core business is not hydrogen, and **H_2 generalists** whose core business is hydrogen. **No heavy mobility specialists have been identified for H_2 transportation.**
- Manufacturers supplying technologies mainly in the **heavy-duty truck segment** for transporting hydrogen (liquid or gaseous).

2. Positioning in the H_2 value chain

- A majority of generalists are positioned on **several links in the hydrogen value chain** (Charbone, Chart, Air Products, Bayotech, etc.).
- **Two main profiles: manufacturers of Portable or stationary tanks** who internalize tank production (Luxfer, Iljin) or **manufacturers of hydrogen stations** (Plug Power, Powertech, etc.).
- Most players are **assemblers of the final solutions** used in this segment (truck/ship/train: outsourced + tanks/tubes/tanks: in-house).
- Hydrogenious has been identified as a **specialist in the transport of hydrogen** by ship and train in the form of LOHC.

3. Typical partnerships

- Partnerships with **heavy-mobility manufacturers** (e.g. BayoTech & Nikola: H_2-powered heavy-duty trucks for hydrogen transport)
- Partnerships between **H_2 generalists and tank manufacturers** to provide complete H_2 transportation solutions (BayoTech & Luxfer; Luxfer & Octopus Hydrogen; Powertech & NPROXX)

Key manufacturers

Bayotech	Chart	Air Products	Powertech
Mexico, United States	*Theodore, AL*	*United States, China, India*	*British-Columbia*
50 trucks purchased for H_2 transport applications by Chevron	**Manufacturing capacity x5 in 18 months** **55 years of experience in H_2 transport**	**Trucks for H_2 transport : internal technology tested in +250 projects**	**Acquisition Lifte H2** **Largest capacity available on the market (1.2 tonnes of compressed H2 gas at 550 bars**

Positioning and Quebec Vision | H_2 Heavy-Duty Mobility

The dynamics of this segment are mainly driven by the formation of **partnerships for the construction of complete hydrogen** transport solutions. In Quebec, the growth in demand stems from the need to meet **local hydrogen requirements**, transporting hydrogen from the point of production to the end point. Quebec has the R&D expertise to further develop tank transport capacities, but demand does not yet justify the deployment of an extensive distribution network, despite the presence of several players.

Observations on the H_2 stations segment

Analysis of key players

BayoTech
101 employees
Development of a hydrogen hub in Missouri BayoGaas (hydrogen production and delivery)

Chart
5 200 employees
Growing through acquisitions: James Russell Engineering Works, GOFA, VRV

Air Products
19 275 employees
H2fM trademarked technology used in 20+ countries

Observations

Manufacturers in this segment are teaming up with partners to secure the building blocks of the final solutions (heavy mobility and/or storage tanks)

BayoTech ON-SITE HYDROGEN ▽
NIKOLA
Trucks

CHART ▽
VRV — *Tanks*
GOFA — *H_2 heavy mobility*

AIR PRODUCTS ▽
Retrofitting heavy trucks with cylinders for H_2 transport

Other observations on the segment

Influence on the price of H_2 - The dynamics of this segment have a strong influence on the price, which must take account of variations in distribution costs depending on the world of transport.

Flexibility - The risk involved in developing a specific technology is offset by the flexibility associated with truck transport (e.g. Chart's plan to also provide H_2 gas transport solutions).

Issues Identified

1. **Immature distribution models and infrastructures**	●●●●
2. **Demand still too low** to justify large-scale manufacturing (centralized production)	●●●○
3. **Co-development of complementary technologies**	●●●○
4. **Challenges regarding the robustness of technologies**	●●◐○

Focus on Quebec's manufacturing capabilities

From a manufacturing point of view, **4 players are present in QC** (Air Products, Charbone, Chart Ind. and Luxfer), but their **manufacturing activities take place outside QC**. Observed demand is mainly local, and H_2 transport distances remain fairly short; the electric trucking sector is well developed in QC and would justify the use of heavy-duty trucks for H_2 transport over short distances.

Quebec's Strategic Interest ●

Towards a decentralized production

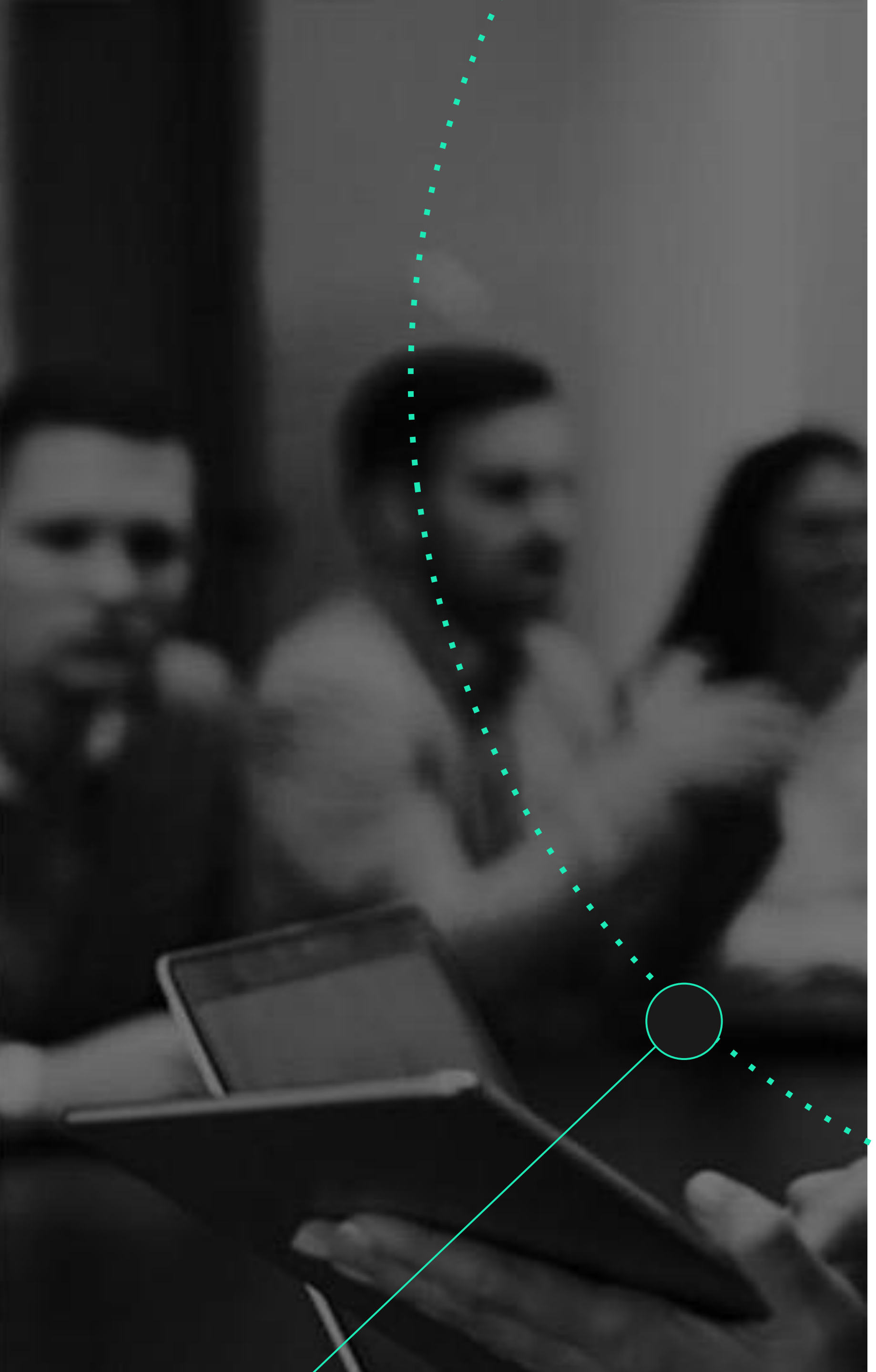
- A **shift from centralized to decentralized production** is observed, with hydrogen generation projects multiplying (TES, Greenfield); need to develop transport technologies to **meet distribution and delivery needs.**
- Growing need for hydrogen supplies for **synthetic fuels, green steel and refueling station applications.**

Quebec's Capacity ●

Meeting R&D challenges and responding to needs

- R&D on valves to control **leakage issues** and to continue developing **tank technologies** that will enable **higher-capacity** H_2 transport (ETS, ULaval, Polytechnique Montréal, McGill).
- **Industrial expertise** held by Air Products, Charbone, Chart Ind., Luxfer and Air Liquide
- **Complementary industrial expertise**: heavy-duty trucking is already a strong presence in QC.

Relative importance of indicators Low ○ ● ● ● ● High



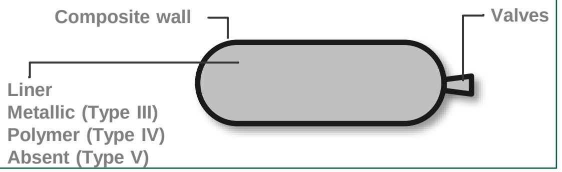
2.F. Portable Tanks

Ecosystem Analysis | Global Portrait of Portable Tanks

Portable tanks are one of the many methods of storing hydrogen. Unlike underground and above-ground tanks used for stationary applications, **portable tanks are designed for road, air, or sea transport.** Their composition varies depending on the application, but they are generally made of carbon fiber or stainless steel. Type IV tanks are the most commonly used due to their lightweight construction and high hydrogen storage density. While some liquid/cryogenic storage applications are under consideration, gaseous storage, as presented in the Technologies section, remains the most prevalent.

SCM

Copper
Titanium
Inox (Nickel)



Technologies (Current and future)

Type	TRL	Cost	Weight	Applications
Type I	*9*	*++*	*-*	*Stationnary*
Type II	*9*	*+*	*=*	*Stationnary*
Type III	**9**	**-**	**+**	**Portable**
Type IV	**9**	**-**	**++**	**Portable**
Type V*	**7**	**++**	**+++**	**Portable**

FUTURE

R&D perspectives

- > **Additive manufacturing** **:** for the repairability of stainless steel systems which are weakened at high pressures
- > **Robustness of safety systems** **:** R&D for a design at the same level as for current internal combustion engine vehicles
- > **Liquid and solid storage** : R&D to develop Portable liquid storage (mature technology but promising storage density but energy-intensive liquefaction & evaporation) and LOHC storage applications

MARKET OUTLOOK

World Vision

$22 billion in 2030 *($2021)*	CAGR of 5.2% by 2030Composite tanks: market share growth directly dependent on the price of carbon fibers (50% of their weight)
Type IV tanks	Most commonly used **Mobility applications:** light weight and storage density
North America	**Larger revenue share by 2030** driven by several R&D initiatives: storage density and cost reduction for embedded applications
Europe	**Fastest CAGR**: government regulations encouraging storage technologies
Asia Pacific	**Steady growth**: ongoing investment in the manufacturing sector

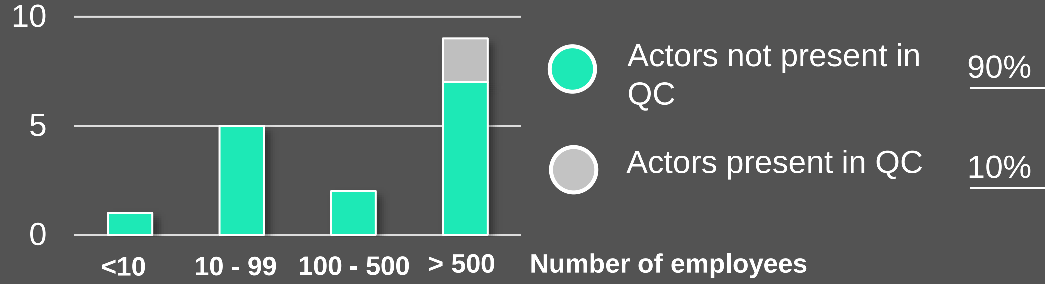
Quebec Vision

Green Hydrogen and Bioenergy Strategy 2022	Quebec positions hydrogen as a promising alternative for decarbonizing **heavy and long-distance mobility**
A fast-growing application sector	Recent study by Propulsion Québec - **Heavy and long-distance transport is a complementary application** to heavy truck electrification
Ongoing projects and growing demand	Harnois Énergies orders **5 H_2 trucks** for operation in 2026 Hydrolux projects **7 H_2 stations and 20 H_2 trucks** on route 117
Expertise in Quebec	**R&D** in Portable tanks: liquefaction, improved storage density, additive manufacturing, metals and composites (CQFA, CMQ, Mcgill, CDCQ)

**Tanks without liner, composite wall only; still under development, the price of composite materials limits commercial applications*

Projects and Actors Involved | Portable Tanks

Origin and size of the actors



Positioning of manufacturers

★ Canadian leader ⊕ Actors present in Quebec

Typology of existing actors

1. Typology of actors

- The 3 main types of player in this segment are **multinationals whose core business is not hydrogen**, **manufacturers of industrial gas tanks** who are diversifying with H_2, and **SMEs with a technological specialization** (innovative, lighter tanks, etc.).
- There are **wide differences in the production capacities of the players**. The players' strike forces are very uneven: from less than 100 tanks sold to over 100,000 tanks a year.

2. Positioning in the H_2 value chain

- The majority of players are **specialists in Portable tanks** and are not developing other hydrogen solutions. Those who diversify offer more complete systems for transport/storage (H_2 trailers, stationary storage applications, etc.).

3. Typical partnerships

- Most of the largest manufacturers (>500 employees) (Faurecia, Plastic Omnium, etc.) are developing **strategic partnerships with H_2 mobility players** (Hyzon, Symbio, etc.).
- Partnerships are also being forged within **supply chains** to source composite materials, carbon fiber, etc. (e.g. Faurecia & Arkema).

Major manufacturing projects

Faurecia	**Plastic Omnium**	**Plastic Omnium**
Allenjoie – In operation	*Michigan - 2026*	*Compiègne – 2025*
100,000 tanks/year Production capacity multiplied by 10	**+100,000 tanks/year** Largest hydrogen tank plant in the United States	**80,000 tanks/year** 700 bar tanks, 200 jobs created on site

Positioning and Quebec Vision | Portable Tanks

The key players in Portable fuel tanks stand out for their **technological innovation** and ability to **form partnerships with hydrogen mobility** players to secure demand. In Quebec, although **demand for tanks is growing, few players have been identified** as capable of installing significant manufacturing capacity.

Observations on the Portable tanks segment

Analysis of key players

Plastic Omnium
28 330 employees
Largest industrial capacity
(180,000 tanks/year)
40% lighter tanks

Faurecia
110 000 employees
50 manufacturing sites
(100,000 tanks/year)
Develops with partnerships

Luxfer Gas Cylinder
1 350 employees
7 manufacturing sites
(70 million tanks in use)

Developped partnerships

Manufacturers moving to scale **work hand in hand with hydrogen mobility players**

Plastic Omnium ▽ Hopium, hyliko

faurecia inspiring mobility ▽ Renault, Hyundai, Stellantis

Luxfer Gas Cylinders ▽ Hyzon, CPKC, octopus hydrogen

Other observations on the segment

New competitors - Some H_2 mobility players are moving back into tank production (e.g. Toyota).

R&D - Nerve of the technological war: weight, costs, volume. R&D is very important and leaves room for new technologies, hence the development of specialist SMEs.

Issues Identified

1. Standardization of H_2 transport **pressures**	●●●●
2. Component **supply issues**	●●◐○
3. Ability of ecosystem players **to scale**	●●○○
4. Difficulty **in anticipating demand to calibrate capacities**	●○○○

Focus on Quebec's manufacturing capabilities

From a manufacturing point of view, **only 2 players** operate in QC: Chart Ind. and Arkema, **but it's not clear whether their QC activities are H_2-related**. The manufacture of these tanks **could be handled by existing specialist SMEs** in the aeronautics sector, which could be identified through the STIQ or RICQ.

Quebec's Strategic Interest

Producing reservoirs helps decarbonize transport

Provincial decarbonization targets

- The Quebec government aims to reduce its GHG emissions by 37.5% by 2030 and transportation accounts for **44% of these emissions.**
- Furthermore, the provincial strategy for green H_2 identifies heavy transport as a **medium priority outlet** for H_2.

Quebec's Capacity

Although R&D is dynamic, few manufacturing players are present

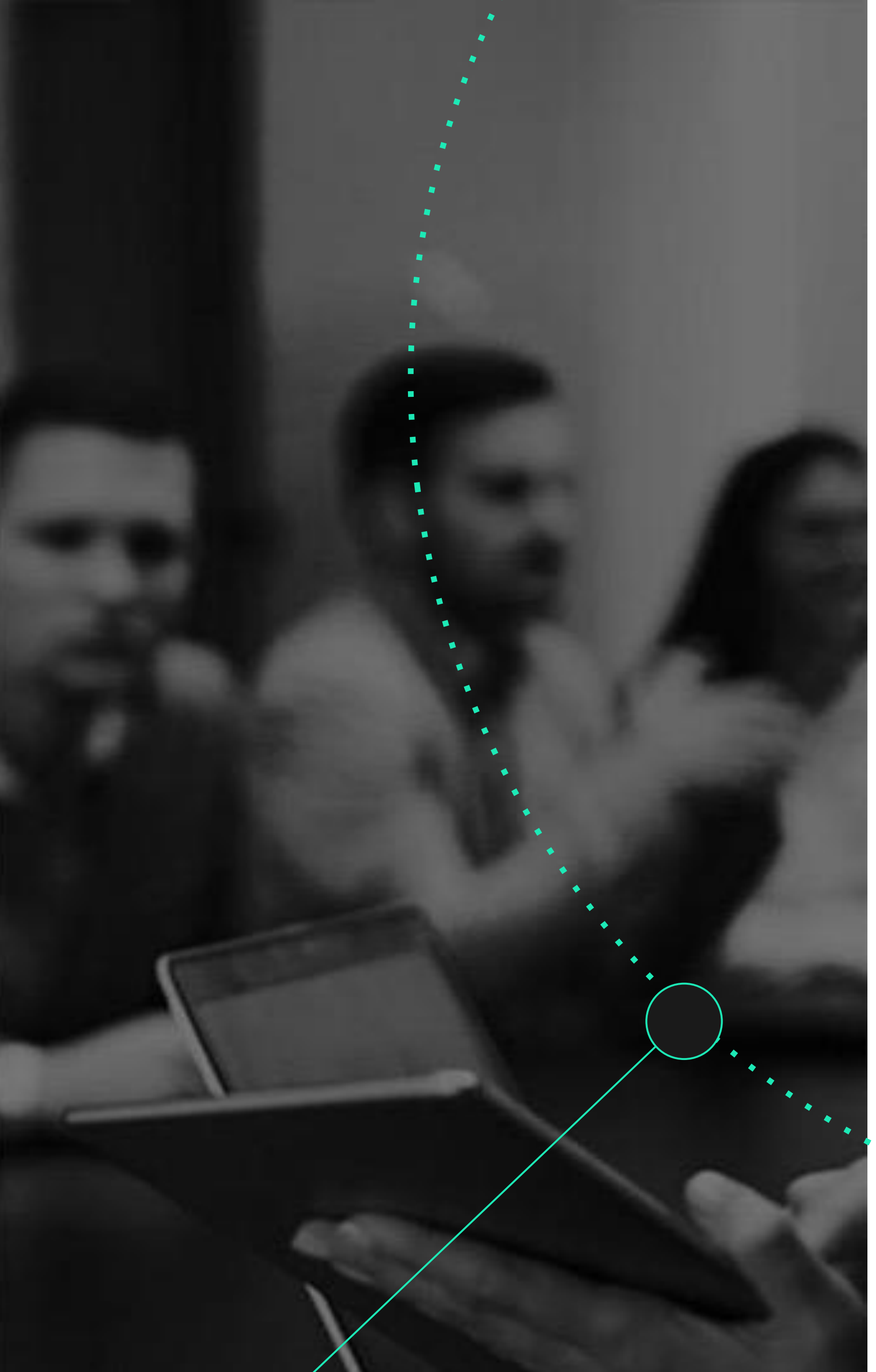
R&D expertise

- **R&D is key in this market segment** where there is still plenty of room for technological innovation. In QC, the CQFA is the one-stop shop where stakeholders are grouped together to work on **additive manufacturing issues.**

Manufacturer

- Existing specialist SMEs could potentially produce this equipment

Relative importance of indicators Low ○ ○ ○ ● ● High



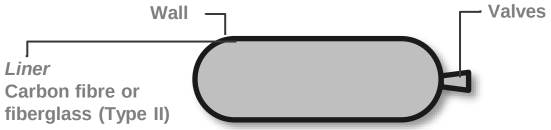
2.G. Stationnary Tanks

Ecosystem Analysis | Global Portrait of Stationnary Tanks

Stationary tanks are one of the many ways of storing hydrogen. Unlike portable tanks, stationary tanks are used for medium- to long-term storage. Their composition varies according to their use, but they are generally made of **steel and aluminum**. **Type I** tanks are used for subsea applications or large-scale industrial storage, while **Type II** tanks are suitable for higher pressures (300 bar) thanks to their filament liner, which gives them greater rigidity. Stationary tanks are used in a number of applications: temporary storage after production, storage for conversion into electricity, storage in refuelling stations and storage for use in industrial processes. Hydrogen can be stored in various forms: liquid, gaseous or solid.

SCM

Titanium
Platinum
Inox (Nickel)



Technologies (Current and future)

Type	TRL	Cost	Maximal pressure	Weight	Applications
Type I	**9**	**++**	**-**	**-**	**Stationnary**
Type II	**9**	**+**	**=**	**=**	**Stationnary**
Type III	*9*	-	++	+	*Portable*
Type IV	*9*	-	++	++	*Portable*
Type V	*7*	++	++	+++	*Portable*

R&D perspectives

> **Additive manufacturing** : for the repairability of stainless steel systems which are weakened at high pressures

> **Robustness of safety systems** : R&D for a design at the same level as for current internal combustion engine vehicles

> **Liquid and solid storage** : R&D to develop Portable liquid storage (mature technology but promising storage density but energy-intensive liquefaction & evaporation) and LOHC storage applications

MARKET OUTLOOK

World Vision

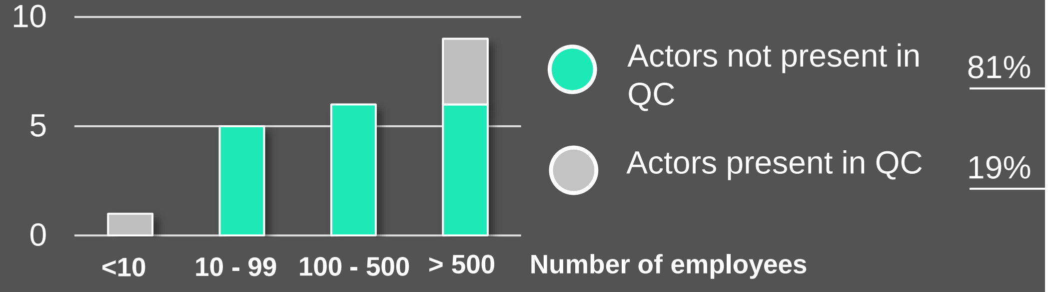
$21.8 billion in 2021	**CAGR of 5.2%** by 2030 Type I and Type II tanks account for more than 50% of the hydrogen tank market share
Stationary tanks	**Greater growth by 2028** Main applications: storage for conversion into electricity (network balance) and storage in H_2 stations
North America	**Several major hydrogen storage projects** with US dominance
Europe	**Rapid growth** : government regulations encouraging storage technologies
Asia Pacific	**Highest CAGR:** Growing demand for clean energy contributes to industrial adoption of stationary storage

Quebec Vision

Green Hydrogen and Bioenergy Strategy 2022	The use of H_2 in industrial processes and synthetic fuels: **applications to be prioritized;** Stationary tanks essential for these applications
An opportunity for electricity storage	Hydrogen is **complementary to intermittent energies** (wind and solar) and constitutes a possible avenue for **stationary electricity storage and grid balancing**
Demand expected to increase	Demand for stationary tanks will be driven by several applications including the use of hydrogen for generators or to power data centers
Expertise present in Quebec	Several players stand out in QC in terms of **stationary tank safety systems** (AS Devices)

Projects and Actors Involved | Stationnary Tanks

Origin and size of the actors



Positioning of manufacturers

Typology of existing actors

1. Typology of actors

- The 3 main types of player in this segment are **multinationals whose core business is hydrogen**, **manufacturers of industrial gas tanks** (Kawasaki, Arkema, Mincatec) who are diversifying into H_2, and **players with technological specialization** (underground storage - Linde, solid storage - Mincatec, etc.).
- The best positioned players in this sector are those with a strong presence in the hydrogen station segment (the main application for these tanks).

2. Positioning in the H_2 value chain

- In the manufacturing chain, they mainly develop solutions for stationary storage **in hydrogen stations, with a minority of solutions for industrial applications.** Some of them also **manufacture tanks** (Chart, Fives Nordon, GKN Hydrogen).

3. Typical partnerships

- Most large manufacturers are developing **strategic partnerships with sub-component manufacturers** (Chart, Tissot Industrie, etc.).
- Partnerships are being forged to **provide turnkey hydrogen fuelling infrastructure solutions** (Fluitron and Ara Partners, Charbone and Resato Hydrogen Technology, Matrix Service and Chart...etc).

Major manufacturing projects*

Chart Industries	**Air Products**	**Linde**	**Plug Power**
United States, Europe, Asia	*United States, China, India*	*China*	*United States*
800 tanks produced	**250 stations deployed**	**200 stations deployed**	**+60 stations deployed**

**The most widespread application for stationary tanks and the one that will experience the greatest growth is the use of these equipments for storage in H_2 stations . The capacity of the major players was then analyzed from this angle.*

Positioning and Quebec Vision | Stationnary Tanks

Key players in stationary tanks stand out for their ability to provide turnkey solutions for refueling applications; this broad spectrum of services gives them a significant competitive advantage over other manufacturers. In Quebec, although **demand for stationary tanks is growing** , **few players have been identified** as capable of installing significant manufacturing capacities.

Observations on the stationnary tanks segment

Analysis of key players

Chart Industries
5 200 employees
Largest industrial capacity
(High liquid storage capacity)

Air Products
19 275 employees
98 manufacturing sites
Grows with partnerships
(Cummins)

Linde
74 207 employees
73 manufacturing sites
Develops with partnerships
(Hyosung Corporation)

Observations

Scaling manufacturers **integrate other complementary equipment segments into the value chain**

CHART
▽
Liquefiers
Compressors
Flow controllers

AIR PRODUCTS
▽
Purification systems
H_2 Stations

Linde
▽
Electrolyzers
H_2 stations

Trends in the segment

Main application – Majority of players are developing solutions for storage in hydrogen stations

R&D – Very important R&D and technologically No-finished product, hence the development of specialist SMEs and work on solid or underground storage

Issues Identified

1. **Robustness of security systems**	●●●●
2. Component **supply issues**	●●◐○
3. **Tailor-made dynamics** for integration into applications	●●○○
4. Difficulty **in anticipating demand to calibrate capacities**	●○○○

Focus on Quebec's manufacturing capabilities

From a manufacturing point of view, **6 analyzed players are present in QC but the majority operate outside QC.**
The interviews conducted highlighted the importance of securing the local supply chain at the stationary reservoir level to meet growing storage needs.

Quebec's Strategic Interest ●

Producing tanks serves the decarbonization of transport

Provincial decarbonization targets

- The manufacture of stationary tanks at QC would allow the consolidation of the supply chain (tanks present throughout the value chain) for future projects (TES, Greenfield Global and stations which will be deployed (Hydrolux)

Quebec's Capacity ●

Although R&D is dynamic, few manufacturing players are present

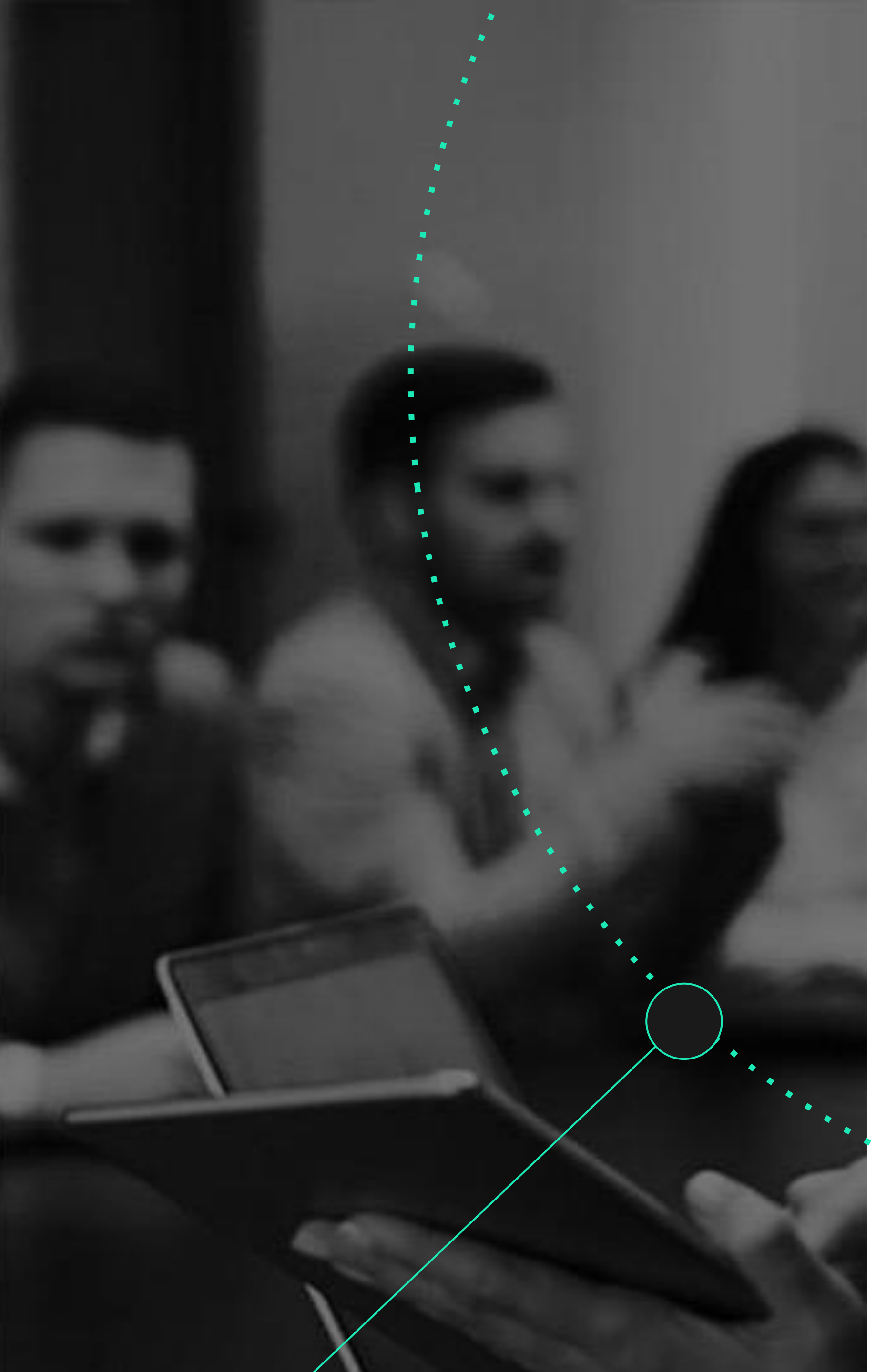
R&D expertise

- **R&D is key in this market segment** where there is still plenty of room for technological innovation. In QC, several players stand out in tank safety systems: a major technological challenge (AS Devices)

Manufacturer

- Some actors present but with production chains outside QC (Europe and United States)

Relative importance of indicators
Low ○ ● ● ● ● High



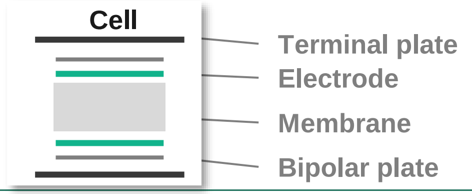
2.H. Fuel Cells

Ecosystem Analysis | Global Portrait of Fuel Cells

Fuel cells combine H2 and O2 to produce electricity, water and heat. Fuel cells can be built to meet a variety of specifications or energy needs, from **a few watts to several megawatts of power**. There are **three main markets** for fuel cell technology: stationary use (backup generators for data centers, hospitals, winter peak management, etc.), transportation (light and heavy vehicles) and **portable applications**, which concern all portable uses (electricity supply in remote areas, sales to individuals, etc.).

SCM

Inox (Nickel)
Platinum
Cobalt
Graphite



Technologies (Current and future)

Techno.	TRL	Advantages	Difficulties
PEMFC	9	*Low temp.* *Quick response*	*Expensive catalyst* *Sensitive to impurity*
AFC	*Mature*	*Few SCM*	*Sensitive to CO_2*
PAFC	Average	*Impurity tolerance*	*Slow response*
MCFC	Low	*High efficiency*	*Corrosion*
SOFC	9	*Electricity/heat complementarity*	*Slow response* *Corrosion components*

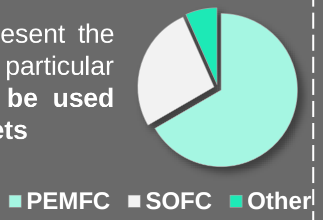
R&D perspectives

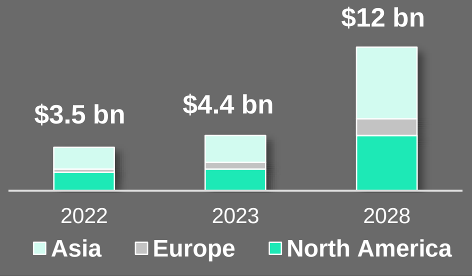
- \> **Efficiency** : improving the efficiency of PACs (currently around 60% for PEMFCs and SOFCs, and 40% for PAFCs)
- \> **SCM** : finding alternative catalysts to Platinum
- \> **Materials** : developing an alternative to PFAS (currently under discussion to be banned in Europe, closely watched in the US and Canada)
- \> **Modeling** : Total Cost of Ownership Simulation

MARKET OUTLOOK

World Vision

$12 billion in 2028	The market is expected to grow from $4.4 billion in 2023 to $12 billion in 2028 with a **CAGR of 21.7%**
Main applications	**Stationary uses** are the most developed and should remain so, driven by demand from **data centers** . The second market developing rapidly is that of **H_2 mobility**
Dominant technology	PEM fuel cells represent the majority of uses, in particular because **they can be used in the 3 PAC markets**
Regional market developments	



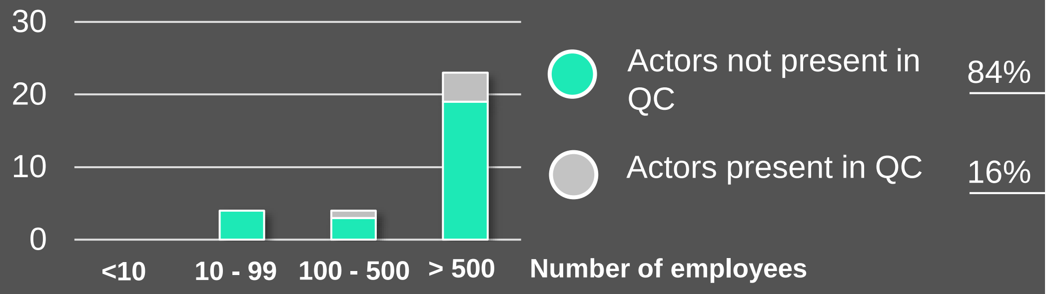


Quebec Vision

Green Hydrogen and Bioenergy Strategy 2022	Quebec positions several fuel cell applications as priorities for hydrogen: seasonal storage, replacement of diesel generators and long-distance class 8 trucking
Propulsion Quebec Study	In its study published in 2023, Propulsion Québec reaffirms **the interest in heavy and long-distance trucks H_2**
Current projects	**Hydrolux project includes 7 H_2 stations** and 20 H_2 **trucks** on route 117 (Hydrolux). First H_2 wishes to develop manufacturing activities in Shawinigan
R&D needs are significant	Several Quebec players have been identified as having expertise that can be transferred to fuel cells: NRCC, INRS, Polytechnique de Montréal

Projects and Actors Involved | Fuel Cells

Origin and size of the actors



Positioning of manufacturers

Typology of existing actors

1. Typology of actors

- The majority of players are **multinationals** (75% have over 500 employees), largely from the **mobility sector**, which are diversifying to develop low-carbon solutions (Volvo, Toyota, Volkswagen, etc.).
- FC specialists are **SMEs developing around a specific technology** (e.g. Sylfen, reversible SOEC technology) or **key players who have managed to expand without being bought out** (Ballard, Doosan).
- In the hydrogen-powered truck sector, this high value-added technology is assembled by a handful of global players (Accelera, Toyota, Hyundai, etc.).

2. Positioning in the H_2 value chain

- Players diversifying into the hydrogen value chain **are mostly involved in electrolyzer production** (Bloom Energy, Bosch, Mitsubishi, etc.) or the **development of more complete mobility solutions** (Toyota, Hyundai, etc.).
- Some players specialize in **fuel cell sub-components**, notably the major chemical companies that produce membranes (Solvay, Arkema) or **auxiliary equipment** - valves, pressure regulators, seals, etc. (e.g. Wesport Fuel Systems).

3. Typical partnerships

- Players are developing their FC production capabilities mainly through **takeovers of specialist companies**: Bell Flight - Response Technologies LLC, Cummins - Hydrogenics, Alstom - Helion Power).
- **FC specialists are also teaming up with mobility players** to develop more comprehensive solutions (e.g. Symbio - Stellantis; Safra - Mercedes).
- **Some mobility players are joining forces** to develop this segment (e.g. Volvo - Daimler; Faurecia - Michelin).

Major manufacturing projects

HTWO *Korea*	**Bloom Energy** *Newark (US)*	**Ballard** *Vancouver*
23,000 FC/year HTWO develops PEMFCs	**1 GW/year** Develops SOFCs up to 10MW	**Capacity of 1.6 GW/year** Desire to multiply this capacity by 6 (PEMFC) by 2030

Positioning and Quebec Vision | Fuel Cells

Historically a niche market, the fuel cell market is expanding rapidly, driven by demand for mobility and backup power systems, **prompting several players to position themselves by acquiring specialized SMEs**. In Canada, Ballard is a key player, present in the **majority of projects requiring fuel cells in Quebec** (First H_2, etc.). This is a segment whose development is largely linked to the objectives set by the DOE, particularly in terms of cost.

Observations on the fuel cells segment

Analysis of key players

HTWO | PEMFC

105 000 employees

Develops its FC sector in close collaboration with Kia and Gore (for membranes)

Bloom Energy | SOFC

2530 employees

Offers SOFC emergency systems for hospitals and data centers

Ballard | PEMFC

1300 employees

Produces the majority of its subcomponents (including membranes)

Developed partnerships

Manufacturers scaling up join forces with mobility players to **build complete hydrogen solutions**

HTWO ▽ KIA, GORE

Bloomenergy ▽ Xcel Energy, INL

BALLARD ▽ SOLARIS, CP, Ford

Other observations on the segment

SCM - Manufacturers have a detailed knowledge of SCM issues, Bloom has committed to providing a report to give visibility on these topics

Highly dynamic sector - Most of the players in this sector are very recent (Kohler, Airbus, etc.) and production targets are very high

Issues Identified

1. **Presence** of **qualified and trained workforce**	●●●●
2. **Difficulty in sourcing critical**	●●●○
3. Lack of **H_2 refueling infrastructure**	●●◐○
4. Risk of **technological overrun**	●○○○

Focus on Quebec's manufacturing capabilities

Of the 3 analyzed players operating in QC, **Noe has a manufacturing chain present in Quebec**. In Canada, **Ballard is a leader in the development of fuel cells** and has expressed an interest in eventually establishing a presence in Quebec **should significant demand warrant it**. In QC, the mobile use of fuel cells is justified for Class 8 trains or trucks.

Quebec's Strategic Interest

Data centers and trucking drive demand

Objectives of the Quebec H_2 strategy

- FCs are used in applications prioritized in the hydrogen strategy - diesel generator replacement, winter peak management and Class 8 heavy-duty trucking.
- Buses do not appear to be a priority application.

Quebec's Capacity

In Quebec, the R&D ecosystem is dynamic

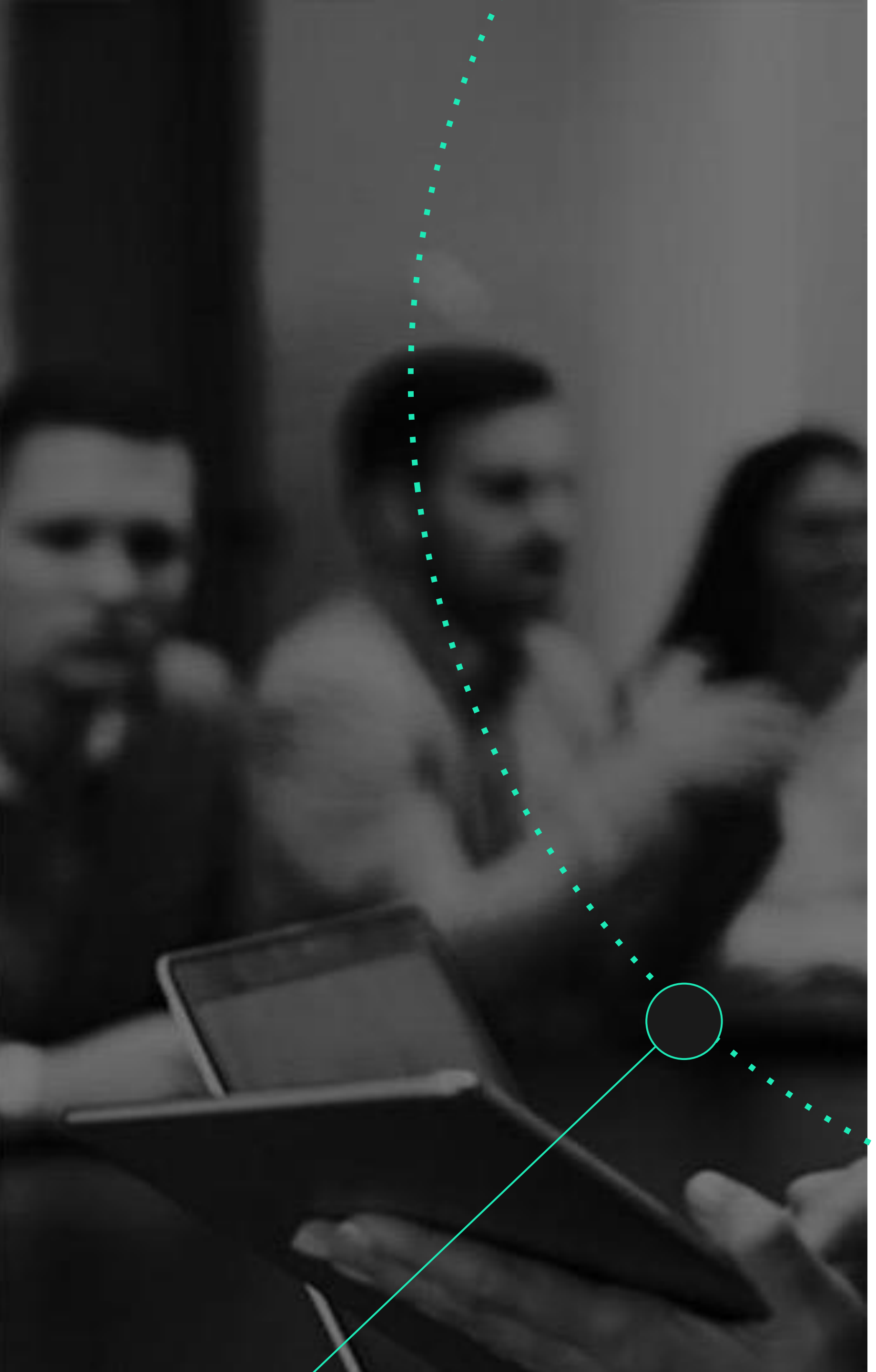
R&D expertise

- NRC, INRS, UQTR and École Polytechnique de Montréal are potential R&D players in the fuel cell segment.

Manufacturing

- Few players present in Quebec who could develop manufacturing activities locally

Relative importance of indicators Low ○ ● ● ● ● High

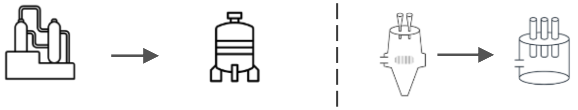


2.I. Industrial Equipment

Ecosystem Analysis | Global Portrait of Industrial Equipment

Hydrogen (H2) is used in many industrial processes, such as refineries and the chemical industry. This study focuses on two emerging applications**: green steel and synthetic fuels**. Synthetic fuels are produced by combining H2 and CO2 and are considered low-emission when the hydrogen is generated using decarbonized electricity. Various types of fuels can be produced through this process, including methanol, methane, ammonia, and more. According to the IEA, these fuels are expected to play a key role in decarbonizing the transport sector. Hydrogen also holds great promise for the decarbonization of iron and steel production. By directly reacting hydrogen with iron ore, iron and water are produced instead of iron and CO2. While this iron reduction process is still in its early stages, **when combined with an electric arc furnace, it has the potential to significantly decarbonize steel production**.

SCM



Cobalt
Copper
Inox (Nickel)

SYNTHETIC FUELS

« Reverse Water-Gas Shift » reactor → **« Fischer-Tropsch » reactor**

GREEN STEEL

Direct reduction reactor → **Electric arc furnace**

Technologies (*Current and future*)

Equipment	Purpose
« Reverse Water-Gas Shift » reactor	Converts CO_2 into CO, necessary for FT synthesis
« Fischer-Tropsch» reactor	Synthesizes the molecule of interest with l'H_2 and CO
Direct reduction reactor	Reduces iron ores in a decarbonized way (-up to 95% CO_2 emissions)
Electric arc furnace	Transforms iron ore into steel using electricity

R&D perspectives

> **Production of Green Steel from H_2:** Reduce production costs (currently 10-50% more expensive than the fossil-based version according to the IEA), ensure furnace safety, address corrosion, and mitigate steel embrittlement caused by hydrogen.

> **Production of Synthetic Fuels:** Improve the efficiency of H_2/CO_2 conversion reactions, explore new reaction pathways to eliminate conversion steps, develop e-biofuels, and enhance the ability to manage intermittent input flows.

MARKET OUTLOOK

World Vision

GREEN STEEL

IEA Analyses	In its 2020 roadmap (the "SDS" scenario), the IEA mentions that more than 8% of global steel production will come from a system using green H_2 as a reducing agent (12Mt H_2/year)
Scaling up	The race is on among steel producers to position themselves quickly on these new technologies with large-scale projects announced in Europe, North America and Japan.

SYNTHETIC FUELS

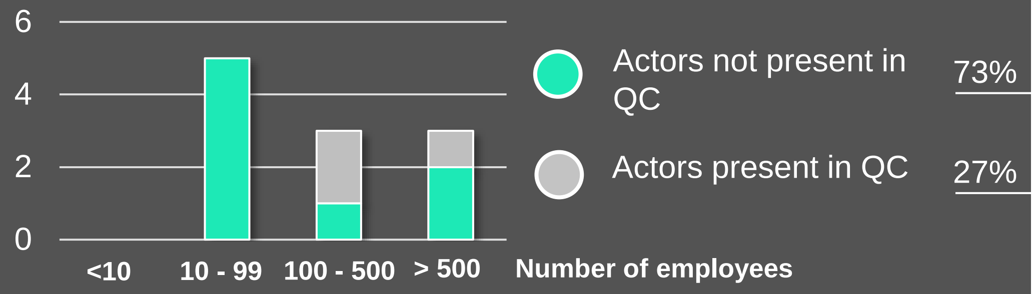
IEA Analyses	In its study published in December 2023, the IEA proposes scenarios for integrating synthetic fuels of **up to 10% of aviation**, maritime and road fuels.
Dominant molecule	According to the announced projects, of the 14Mt of synthetic fuels produced by 2030, more than **90% should be in the form of ammonia** , 4% methane, 1% methane and 5% others.

Quebec vision

Green Hydrogen and Bioenergy Strategy 2022	Quebec has identified the use of H2 in industrial processes and synthetic fuels as the **two applications to be prioritized**
Projects underway to deploy green H_2	H2Green Steel is currently in discussions with QC to develop a \$3 billion to \$6 billion plant. Arcelor Mittal has tested up to 7% H_2 in its Contrecœur reactor, but its plants are **too old** in QC to develop H_2 on a large scale.
Notable projects have been announced in the field of synthetic fuels	**Mauricie - TES Canada**. 150 toe of synthetic methane for injection into the natural gas network **Montreal - SAF+.** 75 Tep of e-kerosene for the aviation industry **Varennes - Enerkem**. 105 Tep of e-methanol **Baie-Comeau - Hy2Gen**. 90 Tep of e-ammonia, for local use. **Montreal - Greenfield.** Production of e-methanol for shipping.

Projects and Actors Involved | Industrial Equipment

Origin and size of the actors



Positioning of manufacturers

Typology of existing actors

1. Typology of actors

- In the race for green steel, the steel industry's major equipment manufacturers are developing and testing H_2 solutions. Few players have positioned themselves in this segment, due to its **high technological complexity** and **capital intensity**. The segment is dominated by **Japanese companies** (Midrex - 80% of DRI reactors, Primetals).
- Synthetic fuels companies are mostly VSEs/SMEs (<100 employees) in development.

2. Positioning in the H_2 value chain

- Players developing solutions for green steel are **always specialists**, focusing on the industrial equipment segment.
- Similarly, all the players positioned in synthetic fuels **are specialists**, with the exception of Sunfire, which also produces electrolysers.

3. Typical partnerships

- Steel industry players are joining forces to develop **complete ecosystems** (e.g. Primetals - Engie - Forvia); and with **major renewable energy players** (e.g. H2Green Steel - Primetal - Iberdrola; LKAB - SSAB - Vattenfall) to produce green H_2.
- Synthetic fuels companies are forming consortia with **renewable energy and green hydrogen producers, project developers and technology suppliers** (electrolysers, etc.) to **complement their expertise** and **share risks** on these initial projects.

Major manufacturing projects

Primetals	Midrex	Enerkem
Sutton, Worcester	*United States*	*Quebec*
+4 green steel production plants supplied (Russia, US)	**+100 DRI modules deployed worldwide** (80% of global DRI)	**+5 major projects** In Spain, Europe, US, Canada

Positioning and Quebec Vision | Industrial Equipment

These two industrial applications **are recent and are developing rapidly** because the markets are so promising. Industrial ecosystems are being set up to launch the first projects, with **technology suppliers at the forefront**. For Quebec, the **challenges of decarbonization are major**, and certain players are well positioned to meet them.

Observations on the industrial equipment segment

Analysis of key players

Primetals

7 000 employees

Involved in the majority of large-scale green hydrogen production projects (France, Sweden)

Midrex

500 employees

Deploys 80% of the world's DRI. Complementarity with parent company Kobe Steel

Enerkem

380 employees

Fast-growing and very mature for its segment

Developed partnerships

Manufacturers are growing by building **partnerships with the ecosystem** to set up the first projects.

PRIMETALS TECHNOLOGIES ▽ Metalloinvest Lebedinsky GOK, MIDREX, ArcelorMittal

MIDREX ▽ PRIMETALS TECHNOLOGIES, H2 green steel, Hy24

Enerkem ▽ T.EN TECHNIP ENERGIES, NOVA Chemicals

Other observations on the segment

Modular solutions - The majority of reactor manufacturers for the production of synthetic fuels are capable of producing a wide variety of different molecules

Maturity - These are two very young segments that are subject to a great deal of publicity, making it difficult to distinguish which projects will actually see the light of day

Issues Identified

1. **Fragility of the business model** of the decarbonized	●●●●
2. **Positioning:** license provider or manufacturer	●●●◐
3. **Difficulty in anticipating demand**	●●●○
4. **Scaling up the ecosystem**	●○○○

Focus on Quebec's manufacturing capabilities

From the manufacturers' point of view, **a number of manufacturers are already operating in Quebec, notably the Midrex processes used at Contrecœur**;

In addition, Enerkem offers its technological solution for **major waste-to-synfuels projects (specifically for methanol).**

Quebec's Strategic Interest ●

These are key priority segments for Quebec

Provincial decarbonization targets

- Green steel is a priority for Quebec - the metallurgical industries account for 29% of CO_2 emissions subject to the SPEDE.
- In addition, synthetic fuels meet the decarbonization needs of the chemical and transportation industries.

Quebec's Capacity ●

Strong demand could attract industrial actors to Quebec

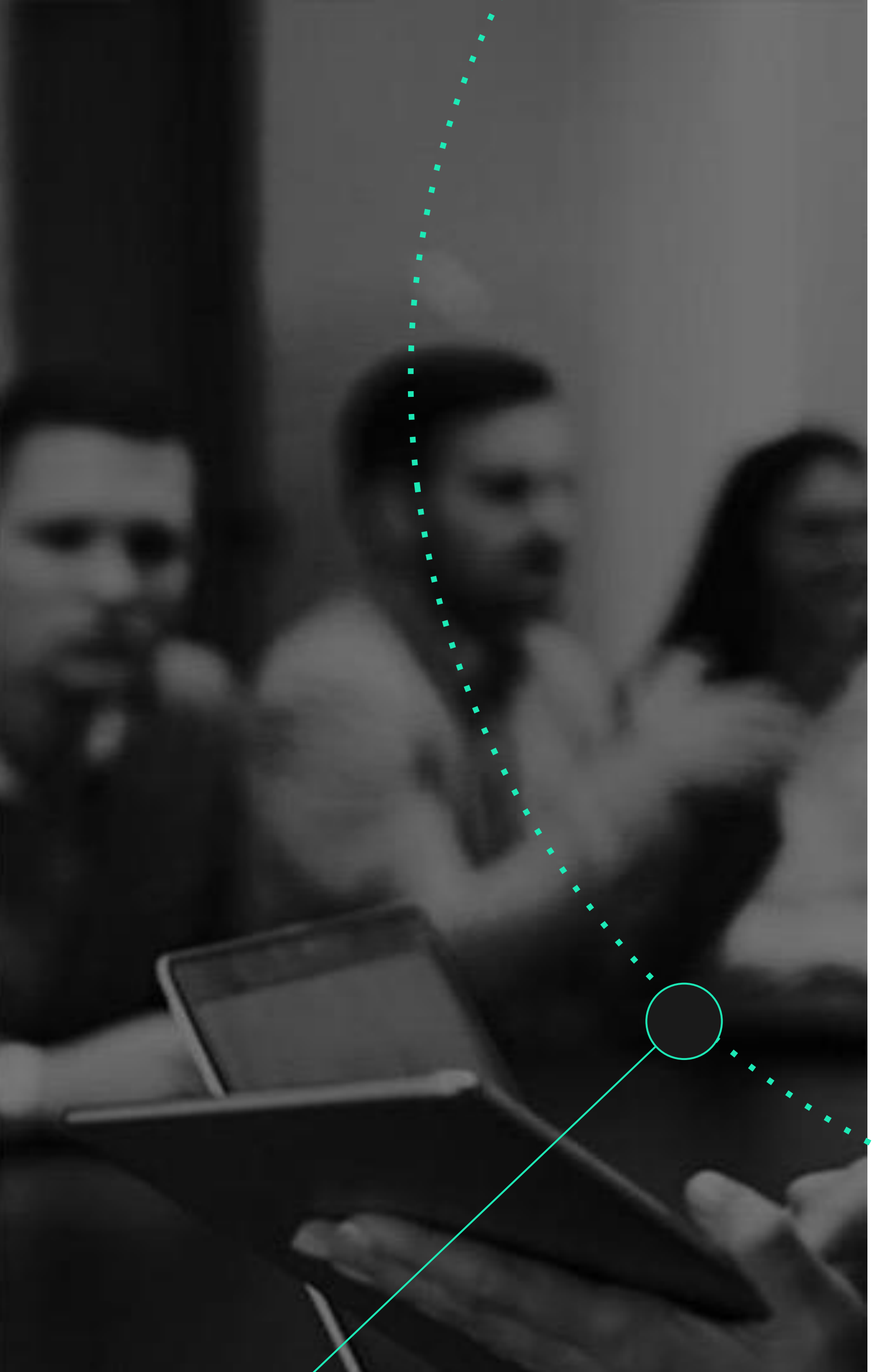
Manufacturing

- The general enthusiasm for steel and synthetic fuels could justify the establishment of a manufacturer in Quebec, especially since Enerkem is already present.

R&D

- Polytechnique Montreal and University of Sherbrooke have expertise in synthetic fuel production processes

Relative importance of indicators Low ○ ○ ○ ● ● High



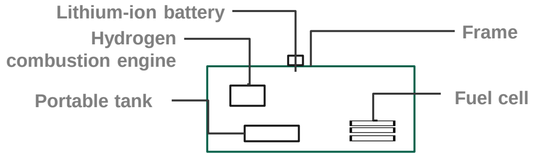
2.J. H_2 Buses and Trucks

Ecosystem Analysis | Global Portrait of H_2 Buses and Trucks

Hydrogen-powered vehicles are typically divided into **two categories: personal vehicles and commercial vehicles, including medium- and heavy-duty vehicles**. Commercial vehicles are being marketed most extensively due to the longer distances they cover and the lower efficiency of conventional vehicles. This segment encompasses several key technologies, such as fuel cells, hydrogen combustion engines, and hydrogen refueling or injection solutions. Closed-loop systems are particularly noteworthy. This analysis focuses on heavy-duty transport, which is gaining significant momentum in Quebec, particularly for hydrogen-powered trucks and buses. The Quebec government recently announced the conclusion of its pilot project for light-duty hydrogen vehicles, with no further investments planned for this type of vehicle.

SCM

Copper
Titanium
Inox (Nickel)
Platinum
Cobalt
Graphite



Technologies (Current and future)

Type	TRL	Need for fast charging	Autonomy needs	Relevance vs EVs
Light vehicles	9	+	+	-
Buses	9	+++	++	++
Trucks	9	+++	+++	+++

R&D perspectives

> **Component stress analysis:** R&D to optimize transfer of liquid or gaseous hydrogen at high flow rates

> **Liquid storage**: R&D to develop portable liquid storage: promising storage density but energy-intensive liquefaction & evaporation

MARKET OUTLOOK

World Vision

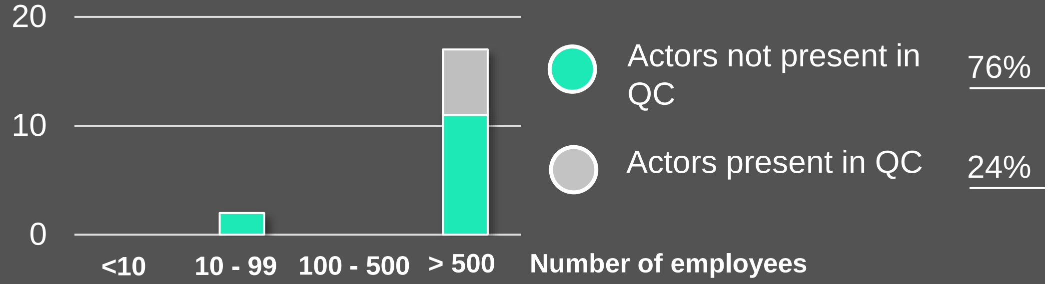
$1.3 billion in 2023	H_2 propulsion vehicle market to grow at a CAGR of **47.9% between 2024 and 2030**
A majority demand	**95% of hydrogen demand by volume will come from commercial vehicles. Medium and heavy-duty vehicles** are expected to have the highest market share by 2050.
North America	In 2022, 8% market share which will continue to increase: partnerships and government support (eg: AZETEC Project & Edmonton Hydrogen Hub)
Japan and South Korea	Different trend: Hydrogen for personal vehicles heavily subsidized and manufacturers lead the market with their proven technologies; High population density
Europe	A leader in terms of vehicle volumes: with more than 850,000 medium and heavy-duty hydrogen vehicles by 2035

Quebec Vision

QC Propulsion Study	Heavy-duty trucks (class 8) represent a strong potential for decarbonization; The study does not mention buses, which are mainly targeted by ambitious electrification objectives at the moment.
H_2 truck segment is dynamic…	Projects/announcements demonstrate the dynamics of the sector in QC: 5 **H_2 trucks** in operation in 2026 (Harnois Énergies) and **7 H_2 stations** and 20 **H_2 trucks** on route 117 (Hydrolux)
…but buses are competing with EVs	There are no announced projects for hydrogen buses in QC despite the presence of manufacturers (PACCAR, Prevost)
A lack of infrastructure	The lack of refueling infrastructure is a barrier to the adoption of hydrogen-powered vehicles; to date, there is only one station in QC, for light vehicles.
A niche manufacturing ecosystem	Two manufacturing projects announced to date: First Hydrogen in Shawinigan (vehicle assembly and hydrogen production) and Prévost in Bellechasse

Projects and Actors Involved | H_2 Buses and Trucks

Origin and size of the actors



Positioning of manufacturers

Typology of existing actors

1. Typology of actors

- Most of the players are **multinationals** specializing in the manufacture of buses and trucks **whose core business is not hydrogen.** They are expanding their technology portfolio to offer hydrogen-powered buses and trucks
- There is a **significant disparity in terms of order backlogs of the players** : from 1 to 100 trucks. Some projects are at a demonstration scale (VDL Groep , Daimler) while others are at a more advanced stage: in marketing (New Flyer)

2. Positioning in the H_2 value chain

- The majority of players are **manufacturers of conventional buses and trucks, few specialists in H_2 buses/trucks have been identified**
- On the manufacturing chain, they are mainly **assemblers.** Some of them integrate **the manufacture of fuel cells** (Hyundai - HTWO), **tanks** (New Flyer) or **combustion engines** (JCB Bamford)
- Hydra Energy has been identified as a specialist in **hydrogen rehabilitation and injection technologies**

3. Typical partnerships

- The majority of large manufacturers are developing **strategic partnerships with players specializing in fuel cells or related systems to secure supply chains** (Symbio , Faurecia, Ballard)
- Another type of partnership is observed between bus and truck manufacturers and **hydrogen suppliers** for refueling vehicles (e.g. PACCAR and Toyota)

Major order backlogs

New Flyer *United States*	**Nikola** *Arizona*	**Hyundai** *South Korea*	**Prevost** *Bellechasse, QC*
108 buses ordered by SamTrans	**50 trucks ordered by BayoTech**	**1000 buses deployed in Switzerland**	**318 conventional buses for the New York MTA assembled in Bellechasse**

Positioning and Quebec Vision | H_2 Buses and Trucks

The key players in this segment stand out for their ability to form **partnerships to secure supply chains for key bus and truck components** (fuel cells, tanks, combustion engines). In Quebec, although **H_2 heavy mobility is showing interesting momentum** and **some players have been identified** as capable of producing this equipment on a large scale, demand remains low.

Observations on the H_2 buses and trucks segment

Analysis of key players

Hyundai
278 735 employees
Largest industrial capacity *(1000 trucks deployed to date)*
Produces fuel cells

New Flyer
8000 employees
5 manufacturing sites
(Order of 108 trucks)
Produces the tanks

Nikola
1 500 employees
1 manufacturing site
(Order for 50 trucks)
Developed through partnership

Developed partnerships

Manufacturers who are scaling up **work in tandem with suppliers of ancillary equipment or produce it themselves**. Others, like Nikola, partner with **station manufacturers** to provide turnkey solutions for their customers.

Other observations on the segment

Complementarity with EVs - In the government's objectives for decarbonizing transport, ambitious quantified targets are presented for EVs. Hydrogen's decarbonization potential is recognized, but clear objectives have yet to be defined.

Issues Identified

1. **Business model under construction**	●●●●
2.. **Lack of refueling infrastructure**	●●●○
3. **Performance and wear** of ancillary equipment	●●○○
4. Ability of ecosystem players **to scale**	●○○○

Focus on Quebec's manufacturing capabilities

From a manufacturing standpoint, there are **3 established players operating in QC**: First Hydrogen in Shawinigan, PACCAR in Sainte-Thérèse and possibly Prevost in Bellechasse (with ambitions to move into hydrogen), even if their growth dynamics are driven by projects outside QC (Los Angeles, London, New York). The interviews conducted identified First Hydrogen as being **interested in developing manufacturing activities in Quebec.**

Quebec's Strategic Interest

Producing trucks and buses serves the decarbonization of transport

Provincial decarbonization targets

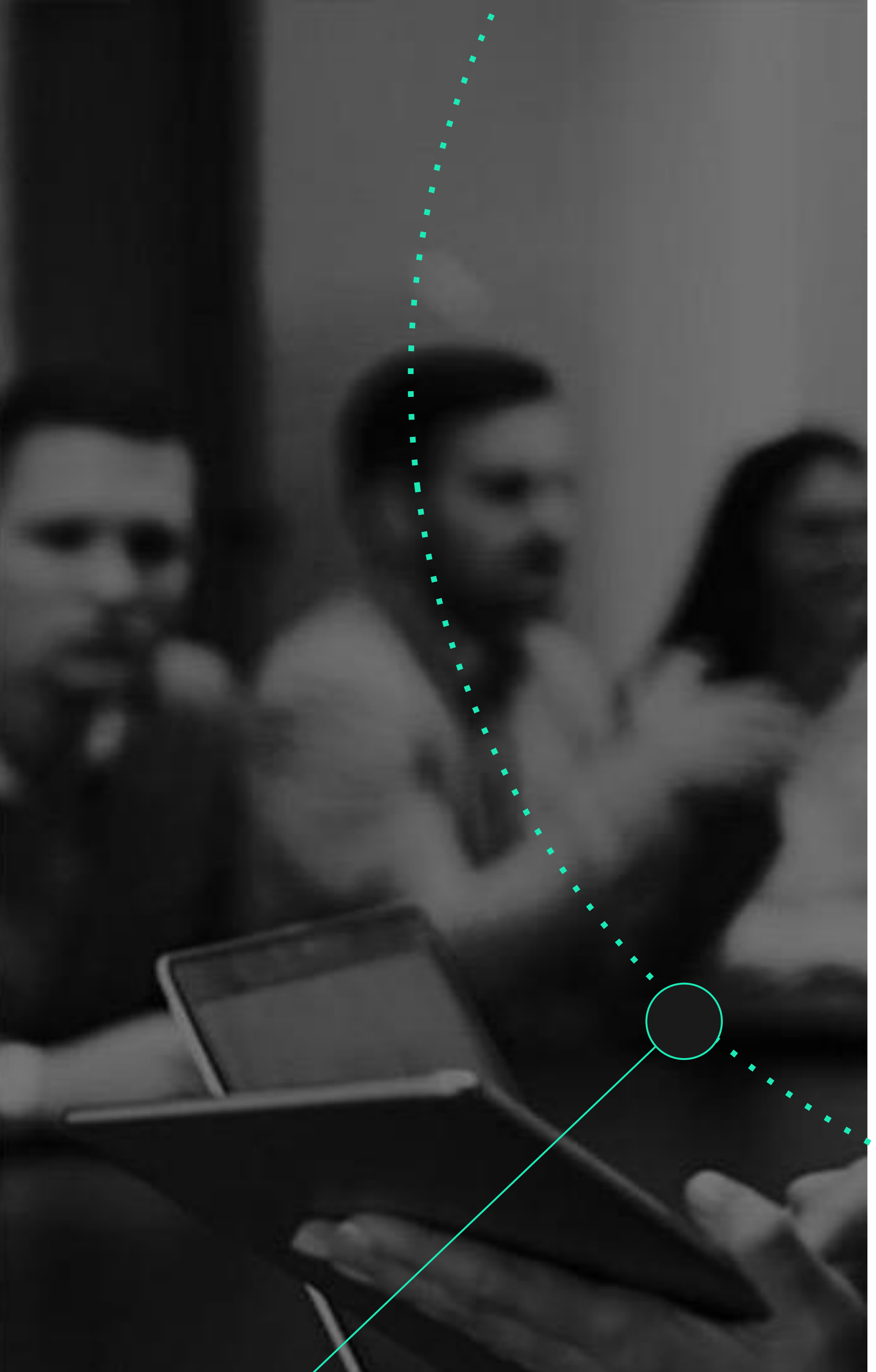
- The Quebec government aims to reduce its GHG emissions by 37.5% by 2030 and transportation accounts for **44% of these emissions**
- Furthermore, the provincial strategy for green H_2 identifies heavy transport as a **medium priority outlet** for H_2

Quebec's Capacity

An emerging dynami

- **H_2 buses and/or trucks?** Projects and feasibility studies focus on the truck segment for H_2 applications ; No H_2 bus projects have been announced in QC; dynamics to follow (Prevost presence)
- **Manufacturing**: Several players capable of producing H2 buses and trucks and emerging momentum, but Class 8s are not currently favored (e.g. First Hydrogen - future assembly plant in Shawinigan).

Relative importance of indicators Low ○ ● ● ● ● High



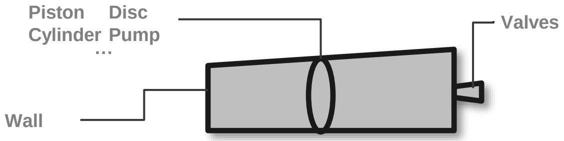
2.K. Compressors

Ecosystem Analysis | Global Portrait of Compressors

Hydrogen compression technologies can be divided into two categories: mechanical and No-mechanical. The mechanical category includes reciprocating, diaphragm, ionic, and liquid compressors. The No-mechanical category includes cryogenic, metal hydride, electrochemical, and adsorption compressors. Today, mechanical compressors are the most widely used. The compressor segment is undergoing significant evolution, as compression remains the most common method for storing and delivering hydrogen, followed by truck delivery, particularly for small stations and low-demand applications. As a result, ongoing efforts are focused on improving compression technologies. Additionally, compressors are required at every stage of the hydrogen value chain.

SCM

Titanium
Inox (Nickel)



Technologies (Current and future)

Type	TRL	Efficiency*	Applications
Alternative	9	45%	High pressure
Diaphragm	9	45%	Low flow rate
Linear	9	>70%	Aerospace
Ionic	9	70%	H_2 stations
Cryogenic	9	25-50%	Liquid
Metal hydride	7	25%	Exothermic
Electrochemical	7	60%	Gaseous
Adsorption	7	-	Solid

FUTURE

R&D perspectives

- > **Tightness of safety systems:** maintenance of valves and pistons to prevent compressor leaks accounts for around 90% of operating costs
- > **Efficiency of metal hydride and electrochemical systems**: R&D needed to reduce energy consumption and improve efficiency

MARKET OUTLOOK

World Vision

$2.3 billion in 2024	**CAGR of 5.28%** to 2029Mechanical compressors: largest market share in terms of revenues in 2022, and a trend that will continue until 2029
Oil and gas	Highest market share by 2022 **Most common application** for hydrogen compressors by 2032
North America	**United States**: the fastest-growing market Growth driven by **growing demand for refining processes**
Europe	Extensive use of hydrogen compressors in **government-backed renewable energy applications**
Asia Pacific	**Market dominance**: favorable government policies for manufacturers in China, Japan and India

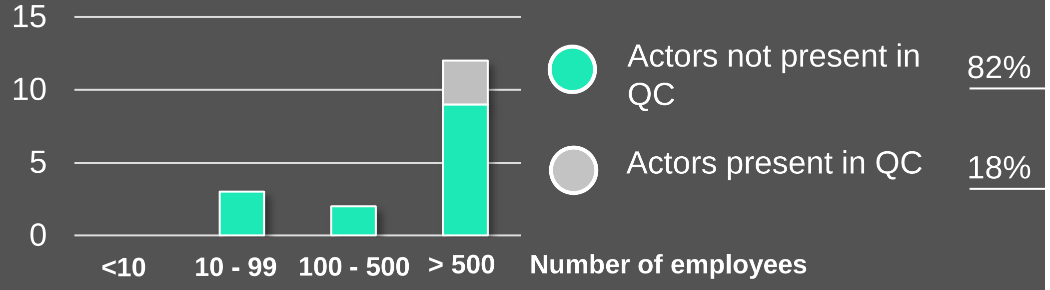
Quebec Vision

Green Hydrogen and Bioenergy Strategy 2022	Québec positions hydrogen as a promising alternative for decarbonizing several sectors **Compressors essential for these applications**
Equipment found throughout the value chain	Compressors are used throughout the value chain Their development in Quebec could respond to recent project announcements and attract new projects
A niche manufacturing ecosystem	To date, no compressor manufacturer in QC has been identified as capable of producing this equipment on a large scale.
Expertise present in QC	**Leading-edge expertise in electrochemical compression demonstrated by NRC in 2003**

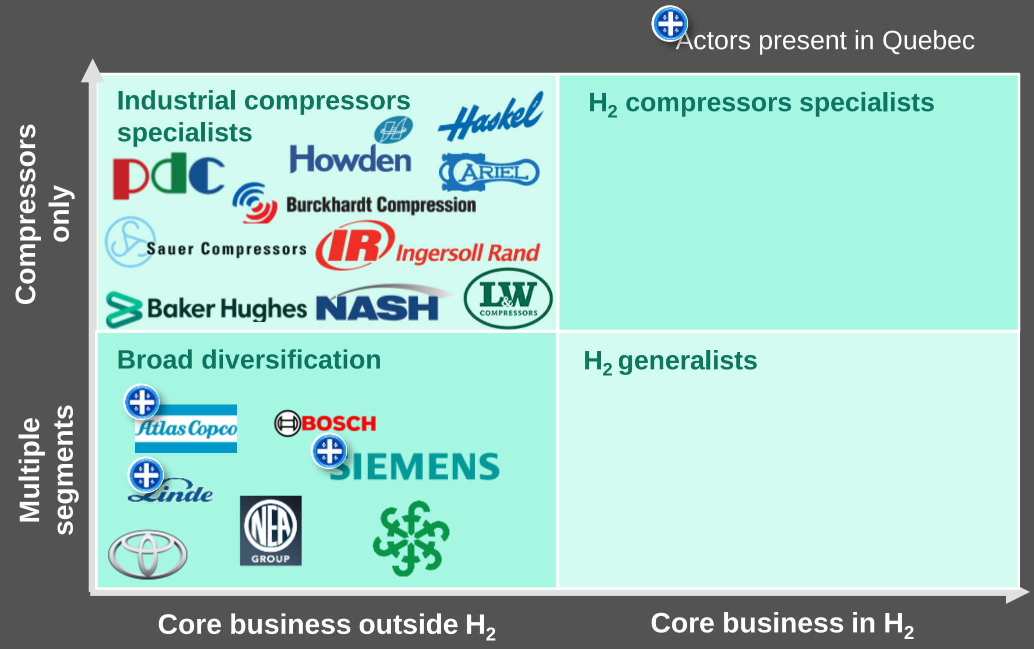
*Compression efficiency evaluated for a compression system from 10 Mpa to 87.5 Mpa and a hydrogen flow rate of 100 kg/h;

Projects and Actors Involved | H_2 Compressors

Origin and size of the actors



Postioning of manufacturers



Typology of existing actors

1. Typology of actors

- The main players in this segment are **manufacturers of industrial compressors whose core business is not hydrogen**, **and a few multinationals** already involved in the hydrogen value chain that are positioning themselves in the compressor segment (Linde, Siemens, Bosch...).
- No player whose core business is hydrogen has been identified; hydrogen compression is technologically complicated: barrier to entry for generalists.

2. Positioning in the H_2 value chain

- Most players are **hydrogen compressor specialists** who do not develop other hydrogen solutions (Baker Hughes, Howden, PDC Machines...).
- The majority of players are compressor **assemblers**, with a few players also producing **sub-components** (Ariel Corporation and Burckhardt: compression cylinders).

3. Typical partnerships

- Most manufacturers are developing **strategic partnerships with end-users** (Howden & Everfuel, Bosch & Maximator Hydrogen, PDC Machines & Hynion).
- Partnerships are also being forged to **develop compressor solutions for specific applications**: Mobility for high-capacity, high-pressure stations (Ariel Corporation & Hoerbiger); Liquefaction (Atlas Copco & Plug Power).

Capacity of major identified manufacturers

Siemens	Baker Hughes	PDC Machines	Howden
India, USA, Germany, Sweden	*Australia, Asia, Europe, United States, Middle East*	*Europe, Americas, Oceania*	*Australia, Europe, Asia, USA, Netherlands, UK, Czech Republic*
2500 H_2 compressors delivered	**2000 H_2 compressors delivered**	**2000 H_2 and other gas compressors delivered**	**1500 H_2 and other gas compressors delivered**

Positioning and Quebec Vision | H_2 Compressors

The key players in this segment distinguish themselves through their highly specialized technological expertise. This is a critical sector characterized by a technologically complex manufacturing process. In Quebec, while the sector is evolving and compressor applications are increasing, **only a few players have been identified as capable of establishing substantial manufacturing capacities**.

Observations on the compressor segment

Analysis of key players

Siemens

92 000 employees

Largest industrial capacity 2 well-referenced product lines (alternatives and turbocompressors)

Baker Hughes

55 000 employees

10 manufacturing sites

Develops with partnerships (Air Products and Terna)

PDC Machines

1 350 employees

3 manufacturing sites

Hydrogen compression expertise since 1992

Developed partnerships

Manufacturers who scale up **work hand in hand with end users.**

SIEMENS ▽ Linde

22 alternative compressors supplied

Baker Hughes ▽ GEK TERNA, AIR PRODUCTS

PDC ▽ Hynion

Other observations on the segment

Sector not very mature – Compressor: critical equipment; Several players are still in the testing phase, creating obstacles in other links in the chain

Risky Technology Choice – Manufacturers take a high risk by specializing in a specific compression technology

Issues Identified

1. **Business model to be consolidated**	●●●●
2. **Durability of components** (valves and piston)	●●●○
3. **Choosing a compression technology** to produce on a large scale	●●○○
4. Ability of ecosystem players **to scale**	●○○○

Focus on Quebec's manufacturing capabilities

From a manufacturing point of view, **only 3 analyzed players are present** in QC: Siemens, Linde and Atlas Copco with activities mainly outside QC.

This segment is not specific to hydrogen and is involved in applications for other gases as well.

Quebec's Strategic Interest ●

A critical equipment in the value chain

Provincial decarbonization targets

- The hydrogen sector is experiencing dynamic development with several projects on the horizon
- Compressors are essential to several applications across the entire value chain from production to use.

Quebec's Capacity ○

Although R&D is dynamic, few manufacturing players are present

Electrochemical compression

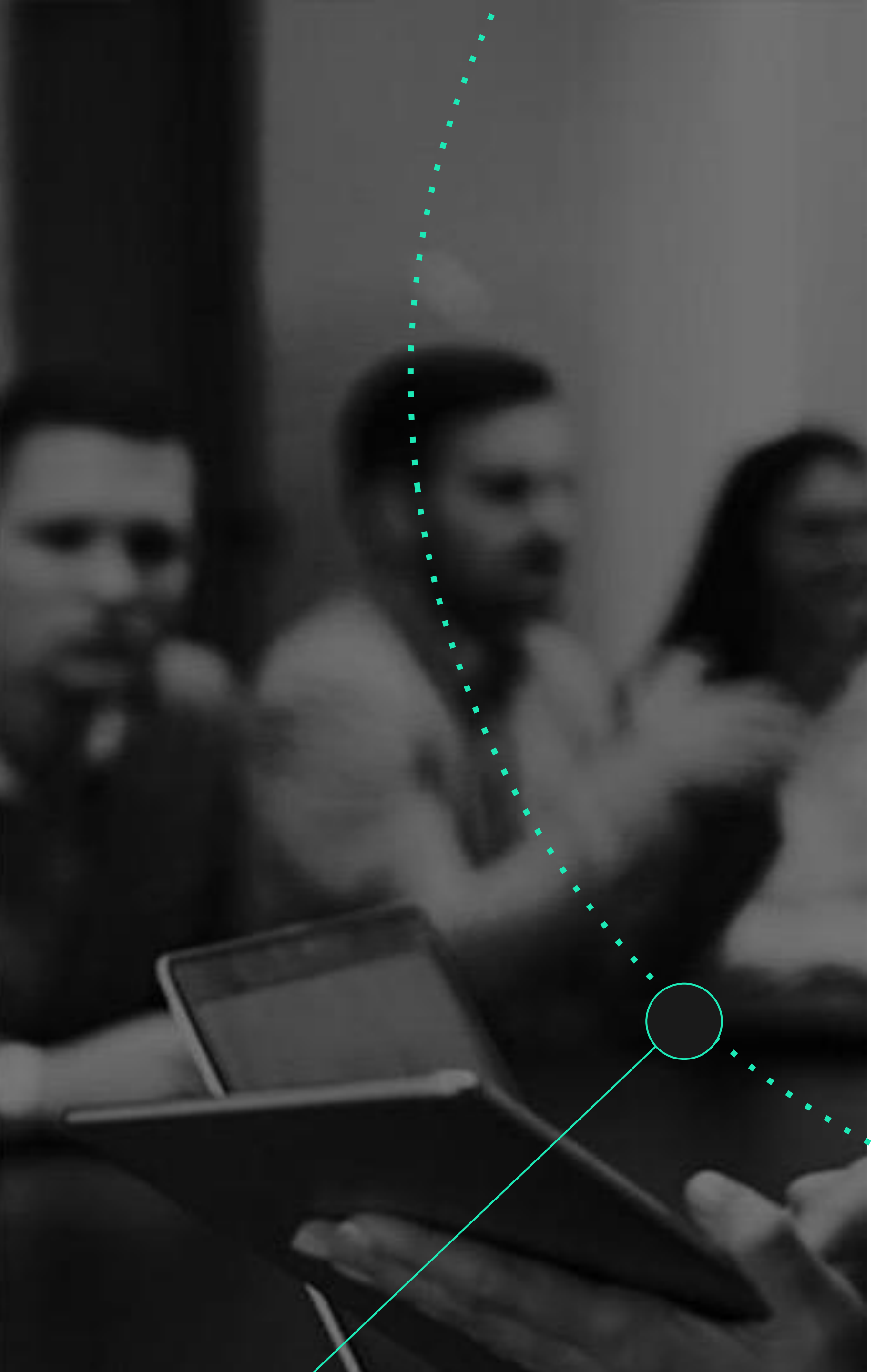
- In QC, the NRC stands out in the demonstration of electrochemical compression technologies; collaborations with manufacturers would allow the move to the commercialization stage

Manufacturer

- Few/no QC players identified capable of producing compressors on a large scale

Relative importance of indicators

Low ○ ○ ○ ● ● High



2.L. Fittings and Valves

Ecosystem Analysis | Global Portrait of Fittings and Valves

The valves and fittings segment **includes various types of equipment: valves, fittings, gaskets, taps, connectors, dampers, flanges, accessories, and more**. While this equipment is typically used in conventional industrial processes, it must be adapted for hydrogen applications due to hydrogen's high volatility and reactivity with materials, requiring improved sealing capabilities. These components are critical at most stages of the value chain to ensure the safety and quality of operations. The major challenges for this equipment include using materials resistant to the corrosive effects of hydrogen and minimizing hydrogen leaks. Currently, there is no global framework for certifying such equipment for hydrogen applications.

SCM

Inox (Nickel)
Titanium

Valves
Fittings
Taps
Connectors
Dampers

Technologies (Current and future)

Equipment	**Use**
Valves	**Control the** hydrogen flow
Connectors	**Connect the pipes**
Taps	**Cut off the** hydrogen flow
Fittings	**Ensure waterproofing**
Dampers	**Preventing the passage of hydrogen** in a conduit

R&D perspectives

- > **Additive Manufacturing : Repairability of stainless steel systems weakened** at high pressures due to corrosion and control of leaks and fugitive emissions
- > **Robustness of security systems :** R&D for a design with the same level of security as for other industrial applications
- > **Resistance to pressure cycles** : Development to improve resistance to pressure cycles, particularly for pipeline applications

MARKET OUTLOOK

World Vision

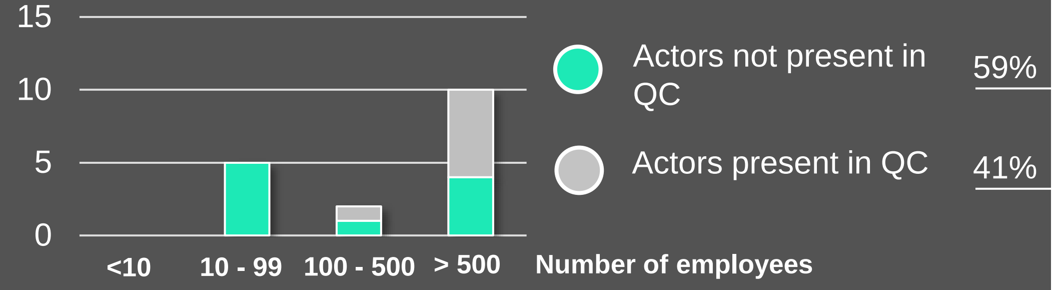
$5.6 billion in 2027	The industrial valves market is growing due to demand from several sectors including hydrogen
Several niche markets	Hydrogen valve manufacturers have difficulty selecting a **specific application segment** The most served application sector is that of **transport**
Special attention to the valves	Investments in the order of hundreds of millions of dollars are planned in valves for hydrogen applications
Europe	Pioneer in standardization; **European Committee for Standardization** : standards in development for hydrogen valves
Emerging certification	**Several** players are acquiring **FE** *"Fugitive Emissions" certification* for methane or hydrogen

Quebec Vision

Regulations to be developed	The development of a QC standard to enable **large-scale manufacturing. The BNQ and the CSA are currently working on developing these standards.**
Equipment present throughout the chain	Valves are used throughout the entire value chain The development of this segment in Quebec could meet the needs created by the new projects announced and **solidify the Quebec supply chain.**
Industrial expertise	Hydrogen valve expertise held by **Velan, Swagelok, KSB and JC Valves**
R&D expertise	Expertise in **additive manufacturing (CQFA)** and **several studies** on corrosion by embrittlement of valves (eg: IBECA, McGill & CMQ),

Projects and Actors Involved | Fittings and Valves

Origin and size of the actors



Postioning of manufacturers

Typology of existing actors

1. Typology of actors

- > The majority of players in this segment are **diversifying manufacturers whose core business is not hydrogen. Their manufacturing capacities for hydrogen-specific fittings and valves** are therefore closely linked to their manufacturing capacities for other gases

2. Positioning in the H_2 value chain

- > The majority of players are **hydrogen valve specialists** who do not develop other hydrogen solutions (KSB, SLB, JC Valves, Mokveld Valves...)
- > When valve manufacturers diversify, they find themselves in the instrumentation segment of the hydrogen value chain (actuators, actuators, etc.)
- > **The majority of hydrogen valve manufacturers focus on valves (77%),** which are in high demand in this segment thanks to the development of several applications where they are indispensable (e.g. stationary or Portable storage)
- > Several players provide operation and maintenance services for valves (KSB, SLB, Parker, etc.)
- > **Solvay has been identified as a specialist in polymers for valves**

3. Typical partnerships

- > Most manufacturers are developing strategic **partnerships with end-users** (Rotork Motorisation & H2Gen; Swagelok & Everfuel).
- > Partnerships are also being forged to **develop new hydrogen technologies** (SLB in partnership with CEA have developed Genvia for the design of a SOEC electrolyzer).

Major manufacturing capabilities

Schlumberger
USA, Norway, Japan, Canada, UK, China
Valves; Operation in 120 countries

Swagelok
+70 countries
Valves and fittings; 20 manufacturing sites; 5 technology centers

Flowserve
+ 50 countries
Fittings; 206 manufacturing and service sites

Ivys (Xebec)
Quebec
Valves; 9 manufacturing sites; 17 service centers

Positioning and Quebec Vision | Fittings and Valves

Scale-up in this segment is hampered by the absence of standardization, which creates a bespoke market dynamic. This segment is easy for players in the hydrogen chain to outsource, thanks to existing capacities that meet their needs. Quebec is in a position to meet manufacturers' current needs **but is limited by relatively low demand compared with the United States, which boasts the highest manufacturing capacity**.

Observations on the fittings and valves segment

Analysis of key players

Schlumberger | Valves
99 000 employees
Develops by creating partnerships to consolidate its H_2 expertise

Swagelok | Fittings and Valves
5 500 employees
Strong presence in QC
H_2 compatible FK fittings

Flowserve | Joints
16 000 employees
Expands through acquisitions to broaden its product portfolio and manufacturing capabilities

Developed partnerships

Manufacturers often grow through **large-scale projects**

Schlumberger
Hydrogen production project by SOEC technology
GENVIA

Swagelok
Everfuel
Supply of fittings HySynergy Project

FLOWSERVE
AUDCO INDIA LIMITED
Acquisition
VELAN
Acquisition stopped

Other observations on the segment

Certifications – Although the regulatory framework remains unclear at the level of this segment, the players are acquiring certifications as a competitive advantage

Acquisitions – Players are also expanding through acquisitions to broaden their H_2 valve product portfolio and increase their manufacturing capabilities (e.g. Flowserve acquires Velan; acquisition stopped by the French government: critical valves for the nuclear sector)

Issues Identified

1. **Durability of components**	●●●●
2. Difficulty **in anticipating demand to calibrate capacities**	●●●◐
3. **Difficulty in selecting a particular segment**	●●●○
4. **Custom manufacturing and lack of standards**	●●◐○

Focus on Quebec manufacturing capabilities

From a manufacturing point of view, **several manufacturers operate in Quebec: Swagelok, Siemens, Solvay, Velan and Ivys**. It is not clear whether their manufacturing activities are concentrated in QC. **Fluroseal** has manufacturing facilities in Montreal. Interviews with manufacturers show the importance of developing a **strong Quebec supply chain** for secondary and auxiliary equipment (including valves).

Quebec's Strategic Interest

Meeting needs and attracting manufacturers

- The development of a **manufacturing ecosystem** for hydrogen valves would make it possible to meet the needs created by the announced projects (TES, Greenfield Global, Hydrolux , etc.)
- Furthermore, the presence of this **supply chain** in QC could attract new manufacturing players seeking good proximity with component suppliers.

Quebec's Capacity

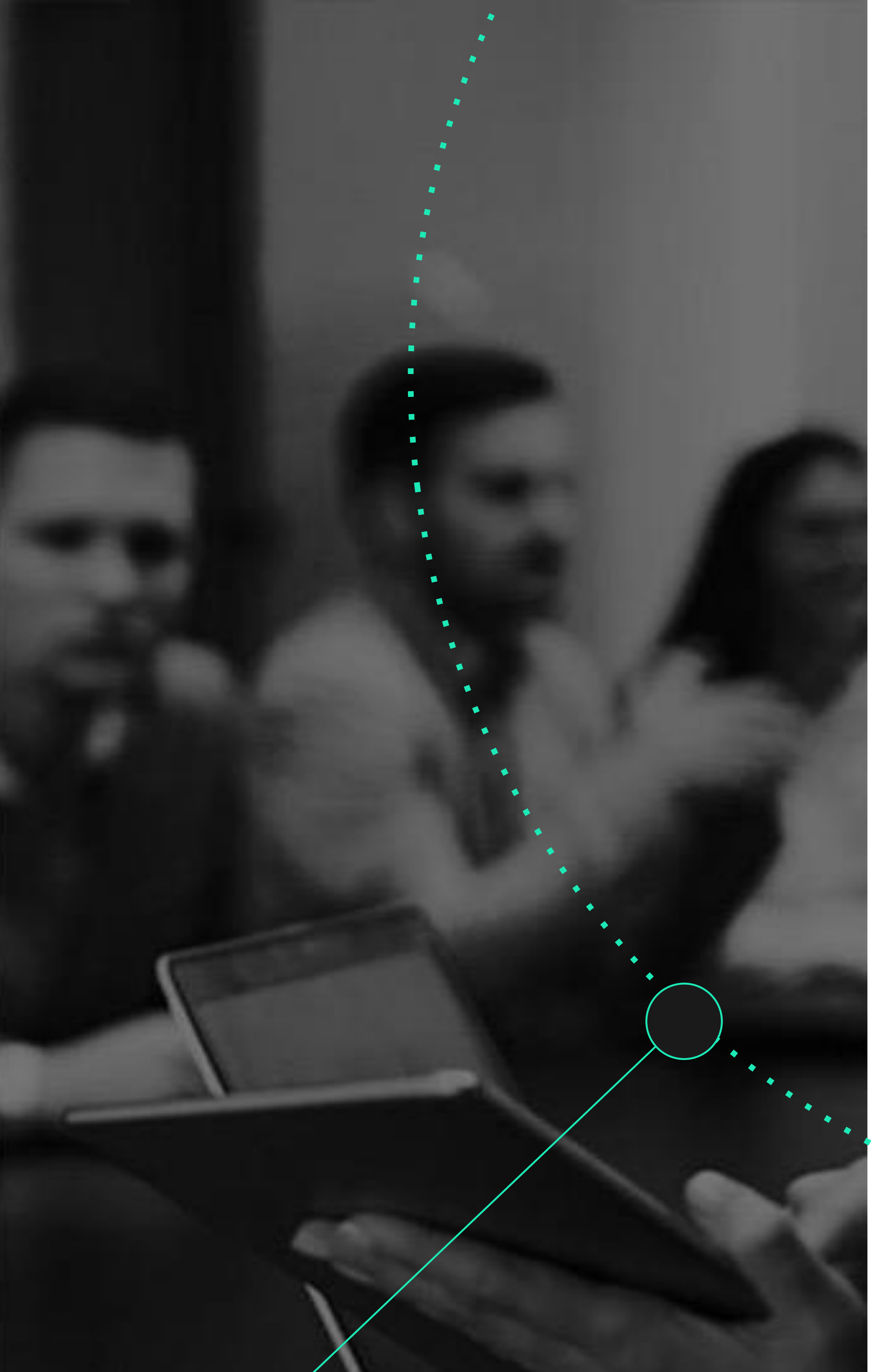
A dynamic manufacturing ecosystem

Industrial and technological expertise

- In QC, **additive manufacturing** can address the challenge of corrosion of valve components
- Several players in QC identified capable of producing valve equipment (JC Valves, Swagelok, Siemens, etc.)
- Alliances between researchers and industrialists would help to further develop the manufacturing ecosystem

Relative importance of indicators

Low ○ ◌ ◍ ● ⬤ High



2.M. Instrumentation

Ecosystem Analysis | Global Portrait of Hydrogen Instrumentation

To detect hydrogen leaks, automate production processes, or ensure gas purity, instrumentation systems are essential for the safe development of the H_2 sector. These systems are used to improve the efficiency of production plants, reduce operating costs, extend plant lifespans, and **guarantee the quality of finished products**. Due to hydrogen's flammability, high diffusion power, and its odorless and invisible flame, industrial processes involving H_2 require heightened vigilance in terms of safety. As such, they rely on reliable and robust equipment specifically adapted to the unique characteristics of hydrogen.

SCM

Platinum
Palladium
Graphene
Tungsten

Sensor **Controler** **Analyzer**

Technologies *(Current and future)*

Equipements	**Uses**	**Sample of techno.**
Sensor	*Detect leaks, excessive pressure or temperature*	*Optical sensor* *Electrochemical sensor*
Controler	*Open/close a remote valve or tap. Flow control*	*Air pilot valve (with H_{2-} compatible steel)*
Analyzer	*Check for quality and impurities*	*Plasma analyzer* *Gas chromatography*

R&D perspectives

- > **Sensor** : reduce cost and size, improve accuracy and reliability, minimum limit of H_2 concentration detectable
- > **Controler** : ability to optimize and fully automate processes
- > **Analyszer** : develop solutions capable of analyzing composition in real time

MARKET OUTLOOK

World Vision

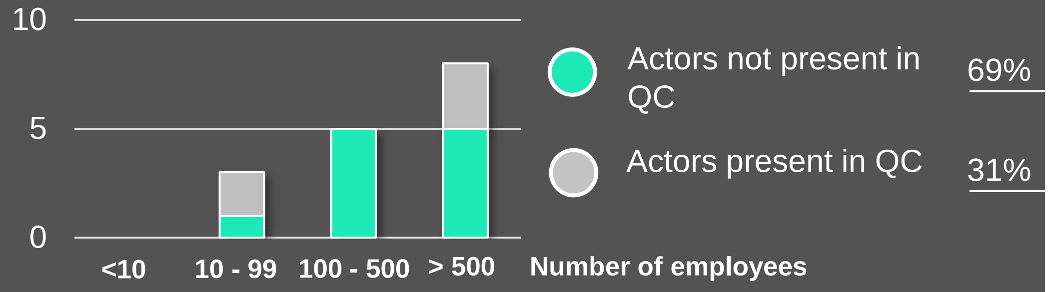
$8,2 Mds in 2028	The market for gas instrumentation (not justH2) is expected to grow from $6.3 billion in 2023 to $12 billion in 2028, at a **CAGR of 5.6%.**
Key growth drivers	The development of more effective safety systems and growing awareness of the environmental impact of gas leaks (the global warming potential of methane and H_2 is very high) are driving this sector forward.
Crucial points to safety	The development of 100% H_2 pipelines, and the use/production of H_2 in confined environments (cars, factories, etc.) makes detection all the more important to avoid industrial incidents that could slow down the sector.
Asia: the main potential market	Growth will be strongest in Asia, driven by the industrialization of these countries and the introduction of international safety standards.

Quebec Vision

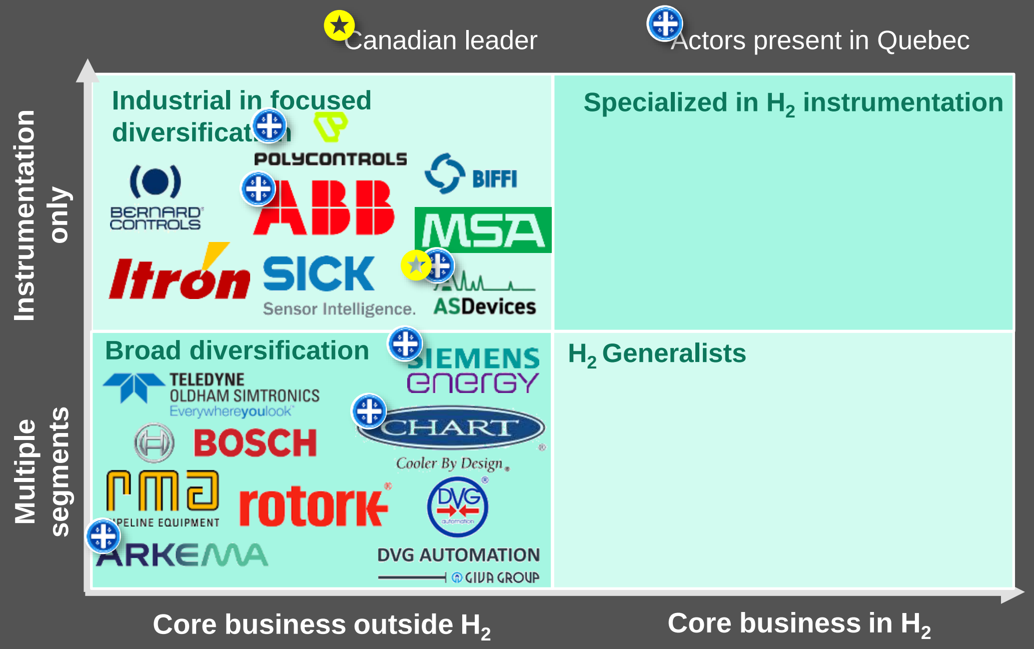
Regulations to be developed	The development of a QC standard would help the deployment of large-scale solutions. **BNQ and CSA are currently working on the development of such standards**.
Equipment present throughout the chain	Instrumentation equipment is used throughout the entire value chain The development of this segment in Quebec could meet the needs created by the new projects announced and **strengthen the Quebec supply chain**.
Industrial expertise	Industrial instrumentation expertise held by Polycontrols, AS Devices and ABB in Quebec
R&D Expertise	Expertise in H_2 leak detection at Polytechnique Montréal, and in sensors at École de Technologie Supérieure and Université de Laval

Projects and Actors Involved | Instrumentation

Origin and size of the actors



Positioning of manufacturers



Typology of existing actors

1. Typology of actors

- The types of players found mainly in this segment are diversifying manufacturers **whose core business is not hydrogen;** these **players' manufacturing capacities for hydrogen-specific instrumentation** are therefore closely linked to their manufacturing capacities for other applications.

2. Positioning in the H_2 value chain

- The majority of players are **hydrogen instrumentation specialists** who do not develop other solutions (Itron, MSA, AS Devices, Bernard Controls...).
- The instrumentation players who diversify are positioned in **valves** (RMA, Rotork Motorisation...) or **other segments of the value chain requiring high quality and safety control** (Hydrogen production: Siemens Energy; Hydrogen transport: Chart).
- The majority of players are **assemblers of instrumentation solutions** (e.g. AS Devices only assembles instrumentation equipment).

3. Typical partnerships

- Most manufacturers are developing **strategic partnerships with green hydrogen producers,** notably for the automation of their H_2 generation processes (Rotork Motorisation & H2Gen; ABB & Hydrogen Optimized)
- Partnerships are also being forged to **develop turnkey solutions** to meet the quality control and safety needs of hydrogen processes (Sick & Endress+Hauer).

Major manufacturing capabilities

ABB	Siemens	Chart
Finland, Sweden	*India, USA, Germany, Sweden*	*Americas, Asia, Europe*
491 manufacturing and service sites	**Presence in +190 countries**	**More than 1,000 flow measurement systems produced per years**

Positioning and Quebec Vision | Instrumentation

The instrumentation market is driven by growing demand for hydrogen **process quality and safety**. Despite the lack of standards, players are making their mark by building solid business models and ensuring proximity to end-users. In QC, several players are present, but demand remains weak and is highly dependent on the speed of development of the hydrogen sector.

Observations on the instrumentation segment

Analysis of key players

ABB
105 000 employees
Developing partnerships for large-scale green hydrogen projects

Siemens Energy
92 000 employees
Offers webinars and studies to share expertise on hydrogen process automation

Chart
5 200 employees
Expands by internalizing the manufacture of instrumentation for its hydrogen liquefaction processes

Developed partnerships

Manufacturers who are scaling up **are those who are partnering on large-scale green hydrogen projects.**

ABB ▽ Hydrogen Optimized

SIEMENS energy ▽ MUBADALA

CHART ▽ 8 RIVERS

Other observations on the segment

Tendency to specialize- The technological specificity of this segment means that players have little tendency to position themselves in other segments of the manufacturing chain.

Priority applications - A trend observed in the prioritization of hydrogen distribution and production applications for instrumentation, which are currently driving demand.

Issues Identified

1. Difficulty **anticipating demand to calibrate capacity**	●●●●
2. **Lack of standards and custom manufacturing**	●●●○
3. **Project race between key players**	●●○○
4. Quality control **mentality to change**	●○○○

Focus on Quebec manufacturing capabilities

Of the 5 benchmarked players operating in QC, **3 have a local manufacturing chain** (Arkema, Polycontrols and Siemens). This segment is often outsourced by manufacturers in the sector. **AS Devices** has made a name for itself in supporting the growth of hydrogen stations by offering mobile hydrogen purity analyzers for refueling stations.

Quebec's Strategic Interest

Demand still too weak to justify the development of a manufacturing ecosystem

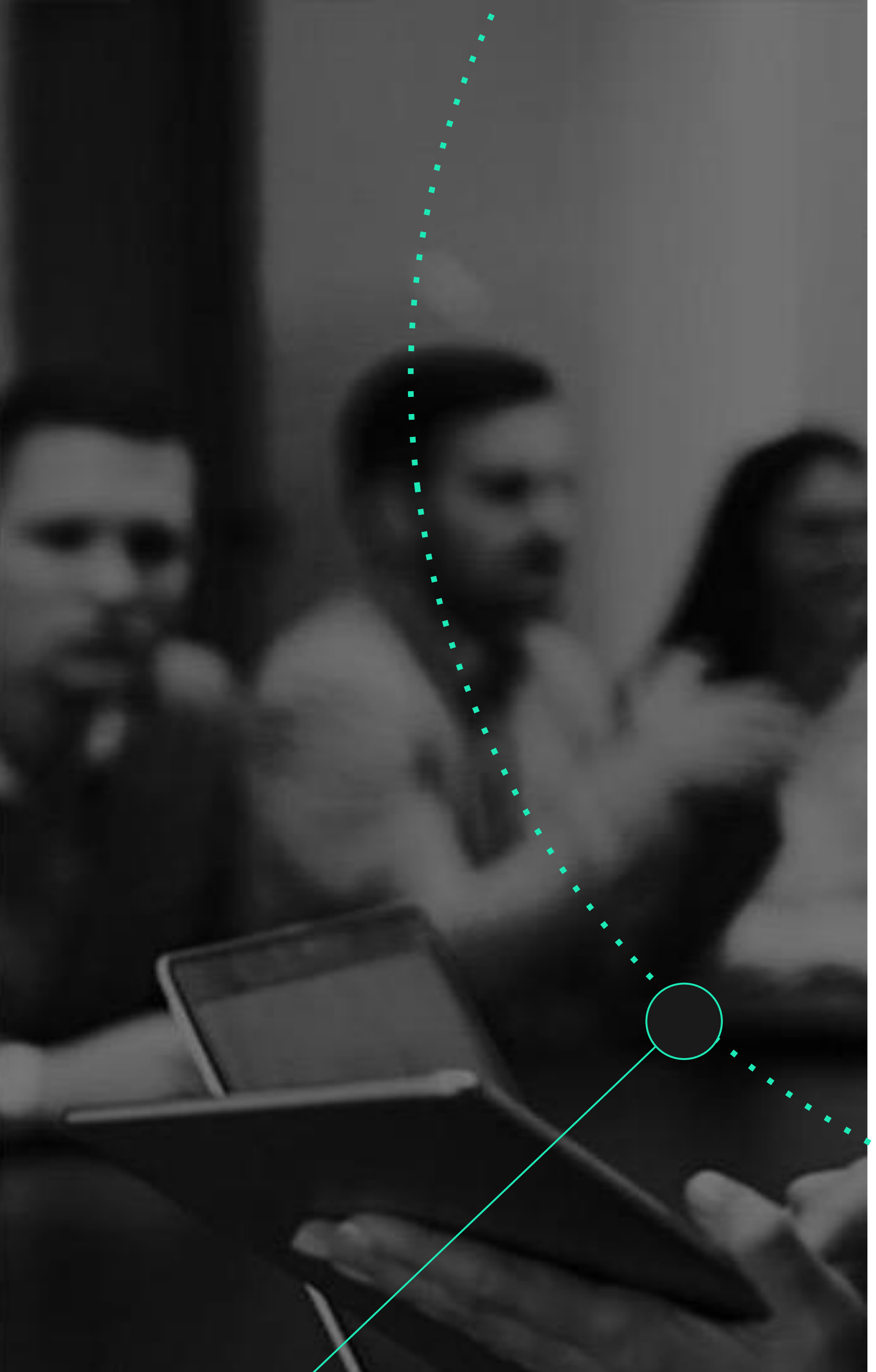
- Manufacturers need good visibility of demand to justify setting up a manufacturing plant.
- Demand remains low in QC, and key players are able to meet local instrumentation needs from their manufacturing facilities outside QC.
- Interest would be justified with greater demand starting to develop as new projects are announced.

Quebec's Capacity

Quebec's ability to meet manufacturers' criteria

1. Need for very strong local demand	**Weak**
2. Presence of existing infrastructures/spaces	**Strong**
3. Subcontractors present	**Weak**
4. Skilled workforce	**Average**

Relative importance of indicators Low ○ ○ ○ ● ● High



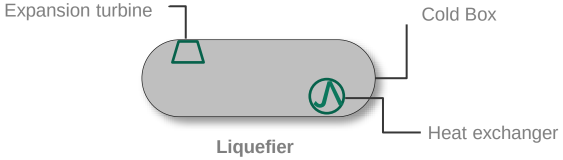
2.N. Liquefiers

Ecosystem Analysis | Global Portrait of Hydrogen Liquefiers

Liquefiers are devices used to compress and cool hydrogen until it condenses into a liquid state. They are part of the equipment involved in the liquefaction process, alongside piston compressors, hydrogen conditioning and purification units, expansion turbines, and storage tanks. Hydrogen in its liquid state offers the advantage of being more compact and easier to handle, with the ability to be stored without pressurization prior to transport or use. These factors **are driving manufacturers to develop liquid hydrogen technologies**, including liquefiers for applications in hydrogen-powered vehicles, hydrogen stations, and the aerospace industry. However, the evaporation of liquid H_2 poses safety challenges, and solutions involving the use of liquid hydrogen are currently being refined to improve cost-effectiveness.

SCM

Inox (Nickel)
Titanium



Technologies (Current and future)

Process	TRL	Barriers and needs
Linde-Hampson	9	*Low efficiency* *Only compatible with small-capacity systems*
Claude	9	*Process modification by adding heat exchangers*
Brayton	8	*Adaptation for higher capacities*
Magnetic refrigeration	7	*Energy-intensive process and performance to be optimized*

FUTUR

R&D perspectives

- > **Auxiliary equipment: D**evelopment needed to improve the tightness of auxiliary equipment such as cryogenic pumps and compressors (high losses, leaks and evaporation)
- > **Efficiency of liquefaction process** : R&D to achieve at least 60% efficiency in the refrigeration cycle
- > **Energy intensive process** : 10 kWh/kg of hydrogen while DOE target is at 6 kWh/kg

MARKET OUTLOOK

World Vision

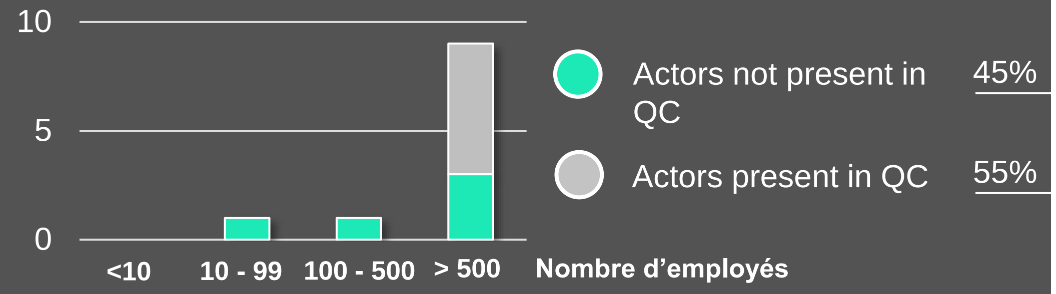
$5 Mds in 2022	The H_2 liquefaction market will reach $10 billion in 2031 with a CAGR of 7.88%.
A dominating application	Growth mainly driven by demand for liquid hydrogen from the transportation sector (fuelling)
North America	Emerging market, some projects announced: Saulsbury in the U.S. for a hydrogen liquefaction plant with a capacity of 30 tonnes/day
Europe	Major liquefaction projects: IDEALHY: optimizing efficiency and reducing costs (budget of 2M euros) Liquid hydrogen: the solution of choice for supplying large-capacity stations
Asia Pacific	Most important contribution to segment growth: several liquid hydrogen projects (China: 250 stations in operation; South Korea: ambition to produce 5.3 million tonnes of hydrogen by 2040).

Quebec Vision

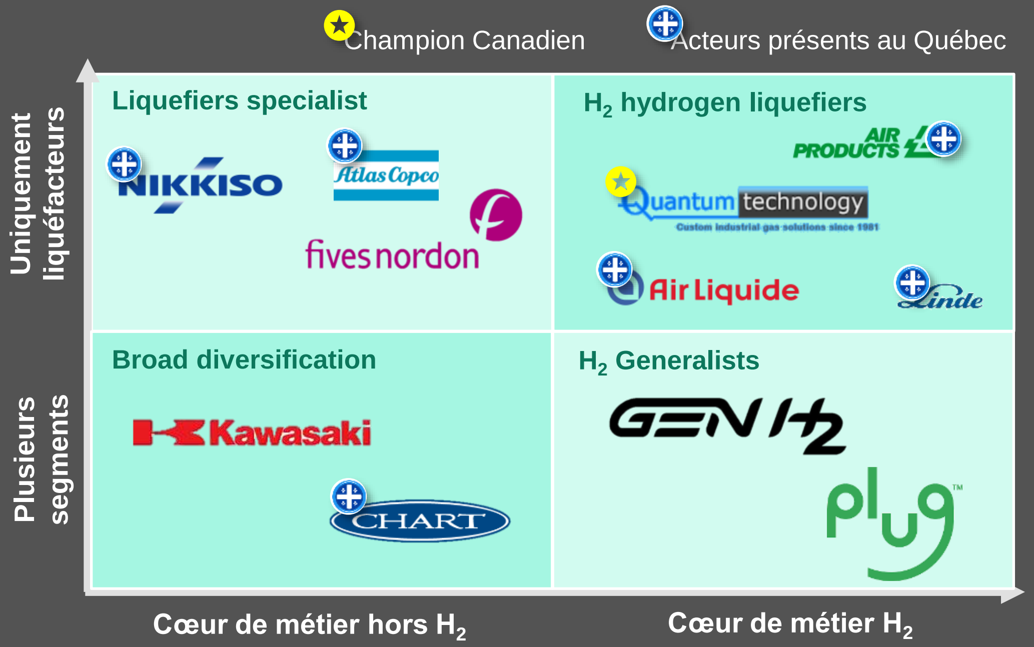
Green Hydrogen and Bioenergy Strategy 2030	Québec positions hydrogen as a promising alternative for decarbonizing the heavy and long-distance mobility sector
Growing demand for liquid H_2	Several projects are already using industrial-scale liquefaction in Quebec (e.g. Olin/Arkema/ Air Liquide in Bécancour), and demand is set to continue growing.
A bottleneck caused by R&D needs	Applications being considered or commercialized at QC are held back by R&D requirements for liquefaction technologies (liquid storage, heavy transport of hydrogen).
Co-development needed	A segment that could grow, provided it develops at the same time as liquid H_2 transport and storage.

Projects and Actors Involved | Hydrogen Liquefiers

Origin and size of the actors



Positioning of manufacturers



Typology of existing actors

1. Typology of actors

- The majority of players are multinationals **specializing in industrial liquefiers** (for H_2 and other gases).
- Most manufacturers **provide solutions based on a modification of Claude's** process that justifies the marketing of their liquefiers (improved efficiency conferred by adding an exchanger to the liquefaction device).
- Players **stand out for their expertise in liquefaction technologies and liquefaction** and cryogenics process operations (Linde, Air Liquide).

2. Positioning in the H_2 value chain

- The majority of players are **hydrogen liquefier specialists** who are also positioned in complementary segments of the liquid hydrogen value chain (e.g. Plug Power is positioned in generation, liquefaction and distribution).
- The majority of players **internalize the manufacture of auxiliary equipment for liquefiers**: **the manufacturing challenges in terms of volatility and fragility are similar** (e.g. Fives Nordon: manufacture of heat exchangers; Linde: manufacture of expansion turbines and others; Atlas Copco: manufacture of compressors)

3. Typical partnerships

- Involvement in development programs for **specific liquid hydrogen applications** (e.g. Fives Nordon & HyCryo; Plug Power, Chart & Fives Nordon).
- Partnerships are also being forged **with end-users to develop low-carbon solutions** (e.g. Plug Power supplies hydrogen to Nikola to fuel its trucks; Linde supplies hydrogen to Dow for its zero-emission project in Saskatchewan).

Major manufacturing capabilities

Linde	Air Liquide	Plug Power	Quantum Technology
Switzerland, Tulsa, Germany	*Nevada, Las Vegas*	*Spokane, Washington, Rochester*	*British Columbia*
140 years of experience in H_2 liquefaction and other gases	**60 years of experience in H_2 liquefaction and other gases**	**10 years' experience in H_2 liquefaction**	**40 years' experience in H_2 liquefaction**

Positioning and Quebec Vision | Hydrogen Liquefiers

Despite the presence of several manufacturers capable of producing liquefiers on a large scale, and the growing demand forliquid H_2 solutions, **the development of this segment is limited by that of liquid transport and storage**, **where R&D needs remain high**. The players positioning themselves in this segment have historically had expertise in liquefaction, which represents a major barrier to entry. Quebec is in a position to meet **the R&D needs** of this segment, but **manufacturing expertise remains less developed than in the rest of Canada.**

Observations on the fittings and valves segment

Analysis of key players

Linde	Air Liquide	Plug Power
74 207 employees	67 100 employees	3 353 employees
Strong expertise in liquefaction *Extensive portfolio of liquefiers (exchangers, turbines)*	*Low-maintenance, high-efficiency liquefiers* *Largest liquefaction plant*	*Complete solutions for liquid hydrogen (generation, liquefaction and distribution)*

Interesting facts

The best-positioned players in this segment are involved **in large-scale liquefaction** projects to demonstrate the efficiency of their equipment.

Linde
Leuna liquefaction plant
Capacity of 10 tonnes per day

Air Liquide
World's largest liquefaction plant in South Korea
Capacity of 90 tonnes per day

PLUG POWER
Liquefaction systems with a capacity of 30 tonnes per day
NIKOLA
TC Energy

Other observations on the segment

Acquisitions – Players are expanding through acquisitions in the liquidH2 market: Linde (acquisition of Praxair); Plug (Joule Processing LLC)

Co-dependence – The development of this segment is highly dependent on that of other liquid hydrogen technologies (storage and transport).

Issues Identified

1. **Consolidation of liquid hydrogen technologies**	●●●●
2. **Demand too low** to justify large-scale manufacturers	●●●◐
3. **Race for projects and competitiveness among manuf.**	●●●○
4. **Custom manufacturing dynamics**	●●◐○

Focus on Quebec manufacturing capabilities

From a manufacturing point of view, **several players are present in QC** (Atlas Copco, Air Liquide, Chart Ind., Linde, Nikkiso, Air Products), but their **manufacturing activities take place outside QC**. Local demand for liquid hydrogen is set to increase, and liquefaction projects will follow this trend, generating **demand for liquefiers**. Interviews highlight the need for R&D in liquid hydrogen technologies.

Quebec's Strategic Interest

Meeting growing needs for liquid hydrogen

- The development of an H_2 liquefier **manufacturing ecosystem** would meet the growing need for H_2 liquid.
- **Collaboration between researchers and industry** would help create a center of expertise and position QC as a pioneer in these technologies. Certain other segments, held back by R&D needs, would benefit greatly (liquid storage and long-distance transport).

Quebec's Capacity

Forging strong links between research and industry

- QC possesses expertise **in liquefaction processes**, **held by research organizations** (NRC, UQTR) and **experienced industrialists** (Air Liquide, Linde, Chart Ind.). Collaboration would enable these technologies to move from the prototype stage to commercialization.
- Several QC players identified as capable of meeting current liquefier demand, despite manufacturing activities outside QC

Importance relative des indicateurs

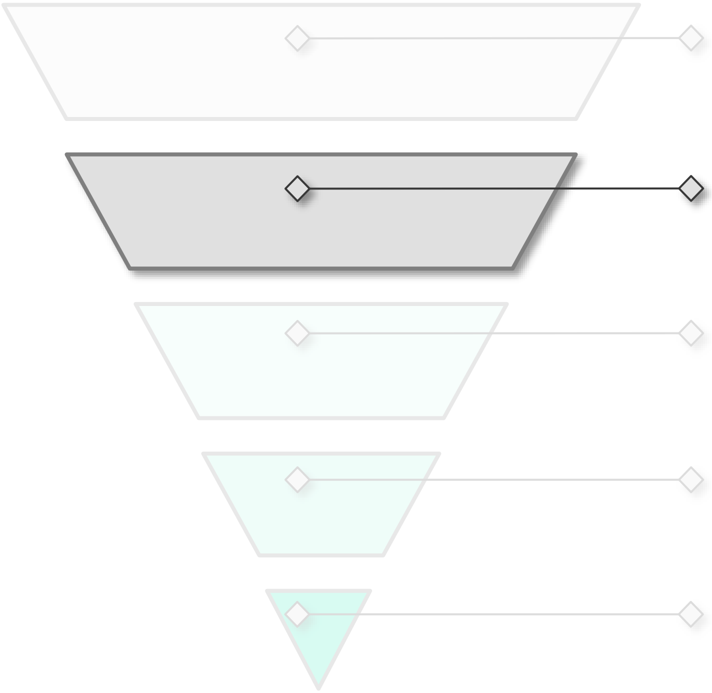
Faible ○ ● ● ● ● *Élevé*

3. Intellectual Property Analysis

Intellectual Property Analysis | Key Challenges and Objectives

Understand the dynamics of intellectual property in the hydrogen (H_2) sector: Who are the most active players in patent filings? In which sectors are these patents concentrated? On which technologies? What are the nationalities of these players? **The objective is to position Canada within this ecosystem and highlight its specific features.**

Overall methodology



1. IN-DEPTH STUDY OF THE MANUFACTURING ECOSYSTEM
- **Analysis of 350 H_2 actors** *(Appendix 1.A.)*
- **Selection of 200 actors** for in-depth analysis
- **Study** of their strategies, ambitions, projects, partnerships, etc.
- **Meeting with 30 industry players** *(Appendix 1.B.)*

2. IN-DEPTH ANALYSIS OF H_2 EQUIPMENTS
- **Segmentation of the value chain into 14 segments** of equipment for detailed analysis
- **In-depth analysis of associated markets,** major projects, critical minerals, R&D dynamics, etc.

3. SELECTION OF 4 STRATEGIC EQUIPMENT SEGMENTS
- Identification of key criteria for prioritizing segments: alignment with H_2 strategy, Quebec capabilities, etc.
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4. ANALYSIS OF SOCIO-ECONOMICAL IMPACTS
- **Selection of 9 indicators** reflecting the socio-economic impact of manufacturing sector development
- **Study of these indicators for the 3 most mature segments**
- **Specific analysis** for the emerging segment

5. CONCLUSION AND RECOMMENDATIONS
- **Definition of 8 major findings** from previous analyses
- **9 recommendations** associated with these findings

Main Challenges

- **Find reliable and relevant data** at a geographic scale fine enough to perform analyses by nationality.
- **Put this information into perspective with the ecosystem analysis** detailed in the previous section.

Scope of Analysis

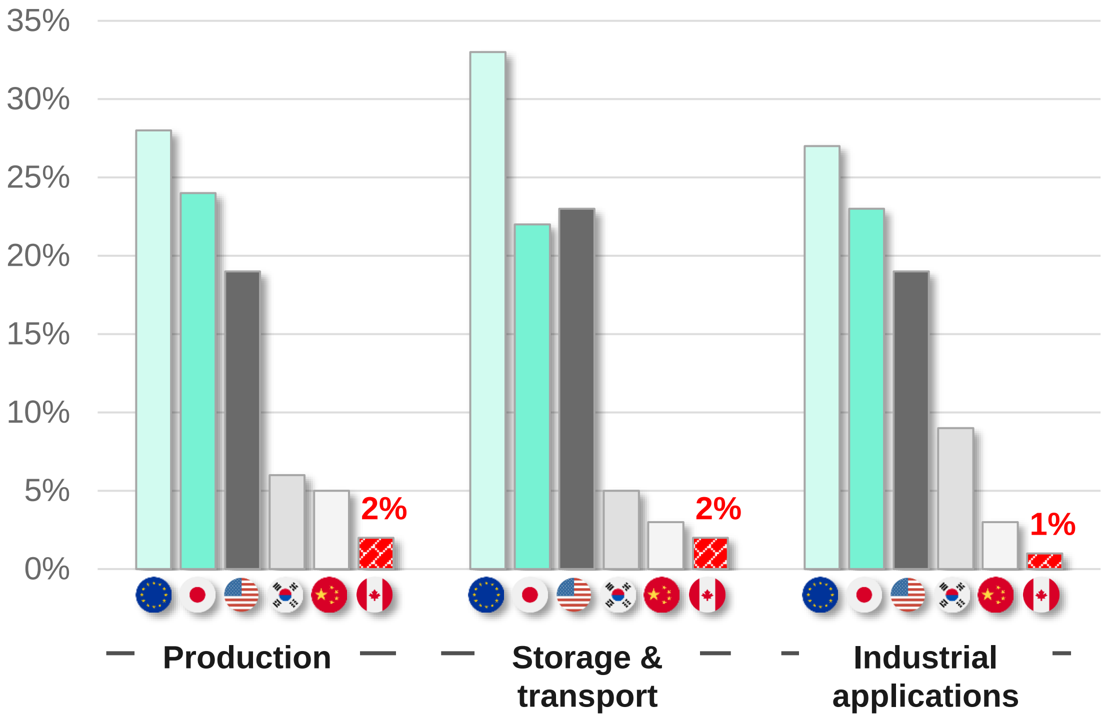
- **The entire H_2 manufacturing sector**, with a particular focus on the **14 prioritized equipment segments**.

Intellectual Property Analysis | Overview

Driven by the anticipated growth in green H_2, **Europe, the USA and Japan have positioned themselves as innovation leaders in this sector**. The ecosystem - still in its infancy - **gives full scope to research and development across the entire value chain**: production, transport, distribution, storage and use.

Geographical breakdown of all patents filed on H_2

*(2011-2020)**

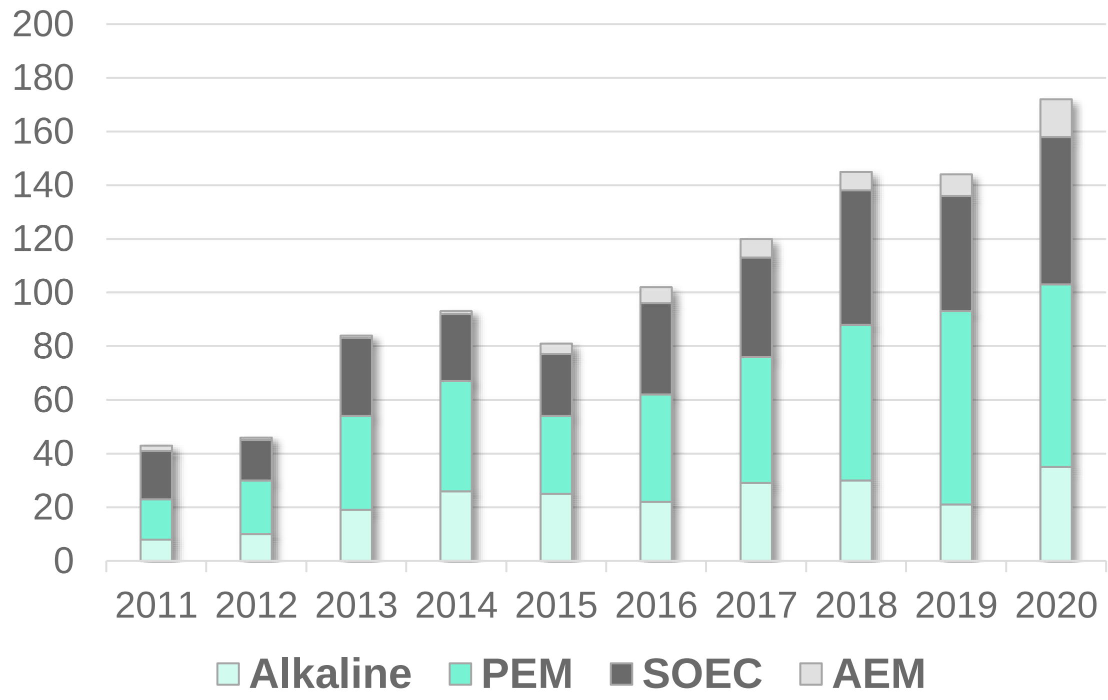


- Over the last decade, **the most dynamic regions have been Europe** (Germany, France and the Netherlands) and **Japan**.
- Although accounting for 20% of patents, the USA is **the only major innovation zone where patent registrations have fallen over the last 10 years**.
- The players developing most of these patents are **chemical and gas manufacturers** (Air Liquide, Linde, BASF, etc.) and **automotive industry players** (Toyota, Hyundai, etc.).
- Of the patents filed over the last 10 years, **almost 80% concern technologies linked to green H2, with the remaining 20% focusing on existing technologies**.
- A few countries outside the top 5 (EU, Japan, USA, Korea and China) **are particularly dynamic**: the UK, Switzerland and **Canada**.

**Source : Hydrogen Patents for a Clean Energy Future, IEA, 2023*

Intellectual Property Analysis | Production by Electrolysis

Breakdown of patents by electrolyser technology
*(2011-2020)**



- It is interesting to note the **different dynamics between countries' manufacturing capacities and their patent filings**. Over the last 10 years, **Japan has been the most prolific country in terms of patent filings, but its manufacturing capacity has not kept pace**. Conversely, **China files few patents, but invests heavily in its local manufacturing chains**.

- Technological trends are also emerging by region:
  - **The USA** has a strong presence in **PEM** technology innovations;
  - **Europe** files the majority of **SOEC electrolyser** patents;
  - **China** is developing few patents, but most are in **alkaline technology**.

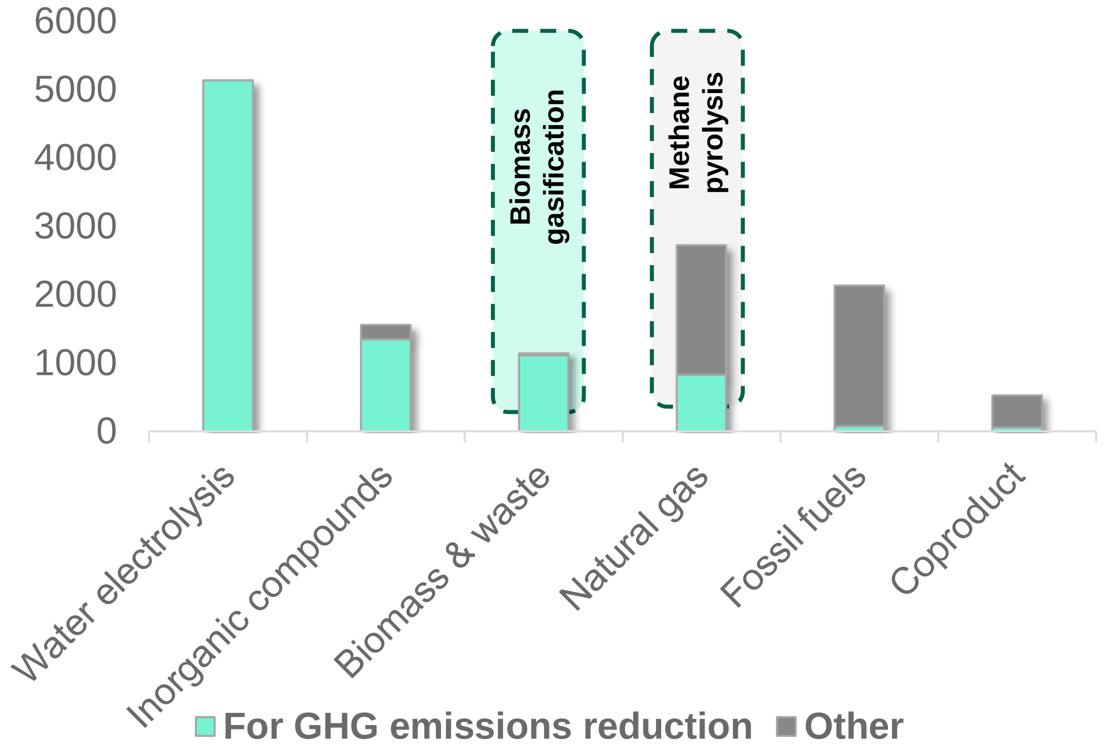
- **No single technology dominates the market**, as shown by the large number of patents filed. Alkaline is the oldest technology, PEM the most innovative, and SOEC and AEM are seeking to scale up.

**Source : Hydrogen Patents for a Clean Energy Future, IEA, 2023*

Canada has developed intellectual property in many of these technologies, with companies springing up in these fields. For example, **Hydrogen Optimized** has developed a **patented alkaline electrolyser technology** for industrial-scale applications (12.5 MW to 50MW), and **Cipher Neutron has filed 5 patents in AEM technologies**.

Intellectual Property Analysis | Other Production Methods

Distribution of patents for H_2 production and their main puropose *(2001-2020)**



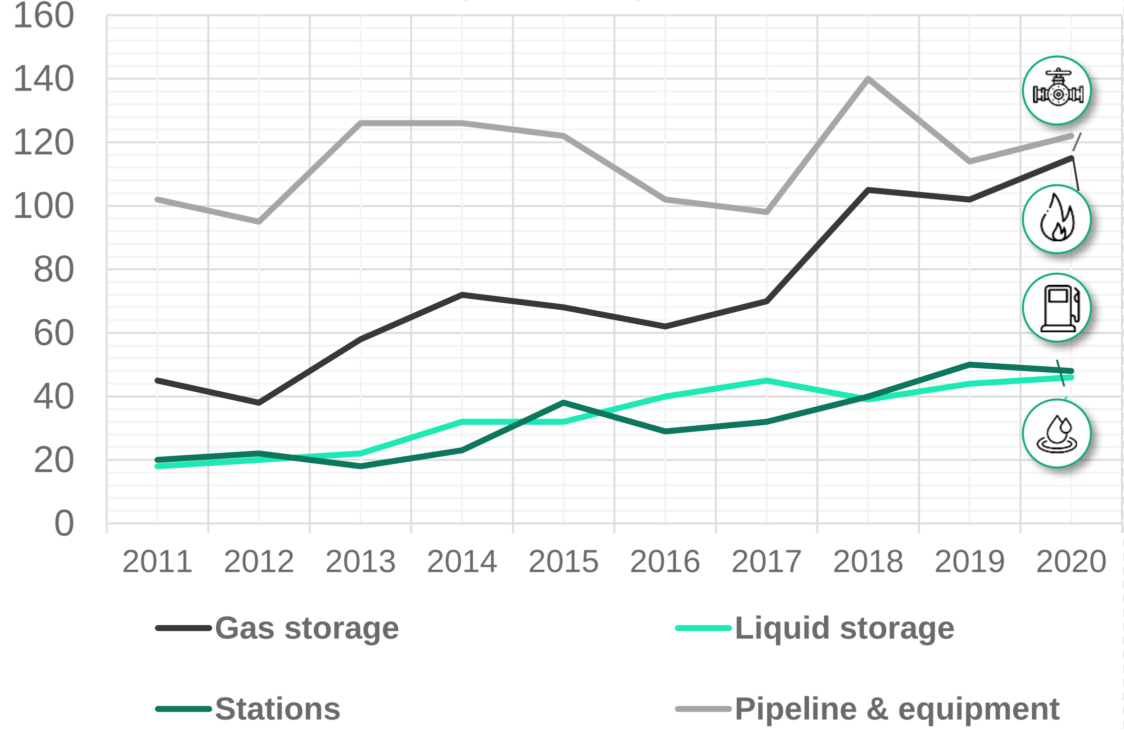
- Patent filings in the field of hydrogen production **from biomass or waste** (by gasification or pyrolysis) rose sharply between 2007 and 2011 **but have since fallen back considerably**.
- **A number of challenges are being addressed** for hydrogen production by **methane pyrolysis**:
  - Operating temperature;
  - Industrial scale-up;
  - Auxiliary reactions that reduce yields;
  - The possibility of producing graphite instead of carbon black at the end of the process;
  - etc.
- **Thyssenkrup, SABIC and Exxonmobil are the players with the most patent applications on methane pyrolysis**.
- Obtaining a patent is a key factor in helping **start-ups** position themselves in **biomass gasification and methane pyrolysis** to scale up and obtain financing.

**Source : Hydrogen Patents for a Clean Energy Future, IEA, 2023*

In Canada, these two sectors are particularly dynamic. Companies such as Pyrogenesis, Aurora Hydrogen, Innova Hydrogen, Plasco Energy, Omni conversion and Nu:ionic **all hold patents of interest in these technologies**.

Intellectual Property Analysis | Transport, Distribution, Storage

Trends in patent registrations for transport, distribution and storage technologies
*(2011-2020)**



- H2 is transported either in gaseous form via pipelines/trailers, or in liquid form in cryogenic containers.
- **An analysis of patents shows that innovations are being made across the entire value chain: transport, storage and distribution of H_2**, and across all technologies - **with a particular focus on Portable tanks** to enable the commercialization of H_2 vehicles.
- For the moment, innovation in stationary storage is mainly focused on current applications: **in the form of compressed gas on industrial sites and for refuelling stations**.
- Nevertheless, in regions where demand for H2 is particularly high (Northern Europe, Texas), **innovation efforts** are underway to **store H_2 underground** on a large scale in salt caverns and **transport large quantities of H_2 via pipelines**.

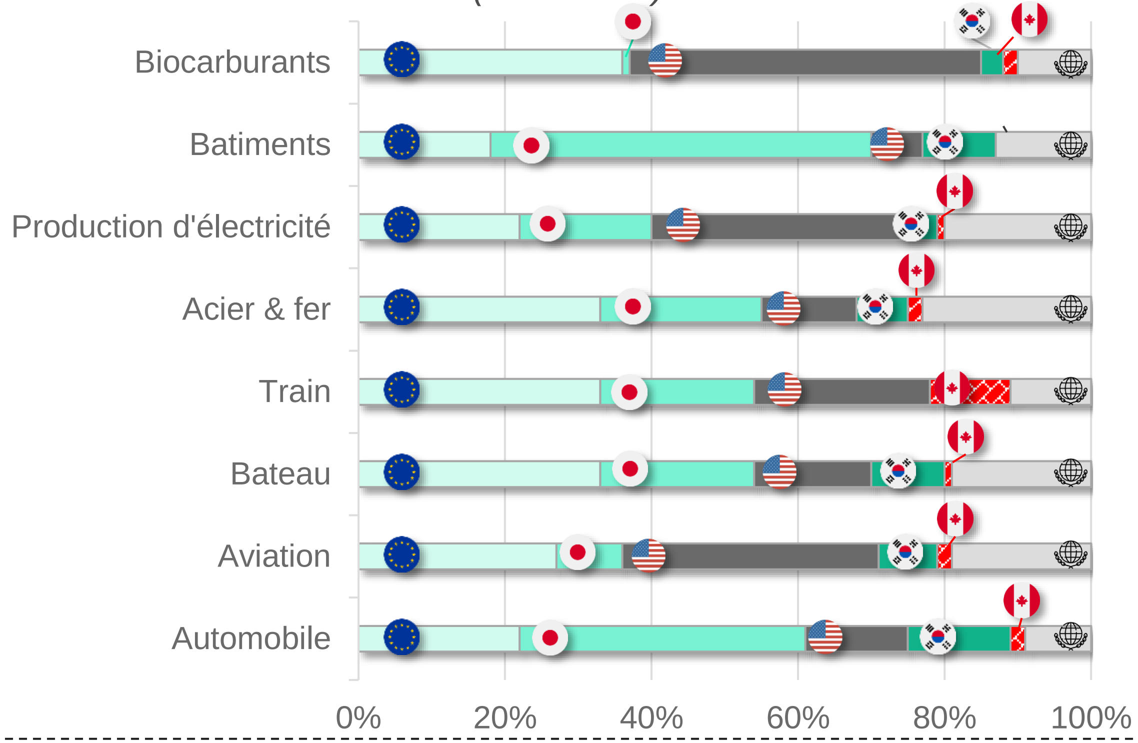
**Source : Hydrogen Patents for a Clean Energy Future, IEA, 2023*

In Canada, **several players are taking innovative positions in these areas**. Vessel Energy, for example, offers micro-channel H_2 **storage solutions that reduce tank weight by a factor of 2**. In addition, Powertech's laboratories in British Columbia are unique in North America, and **highly prized by manufacturers** for testing the components of their H_2 stations.

Intellectual Property Analysis | Industrial Applications

Breakdown of all patents filed for H2 industrial applications

*(2011-2020)**



- **Dominated by Japan** in the majority of fuel cell applications, the **automotive industry** is the most dynamic player in this segment.

- **Innovations in fuel cell technology** are generating synergies with **PEM electrolysers**, notably in the areas of :
  - polymers that separate membranes
  - catalysts
  - cell stacking processes

- Recently (after 2016), **the number of patents filed for the decarbonization of steel by H_2 has increased** significantly, with a **high concentration of intellectual property** in a small number of players - **mostly of European origin**.

- **The majority of advances on FCs concern applications in road transport** (light and heavy) and, to some extent, **light aviation** (drone) and **maritime transport**.

**Source : Hydrogen Patents for a Clean Energy Future, IEA, 2023*

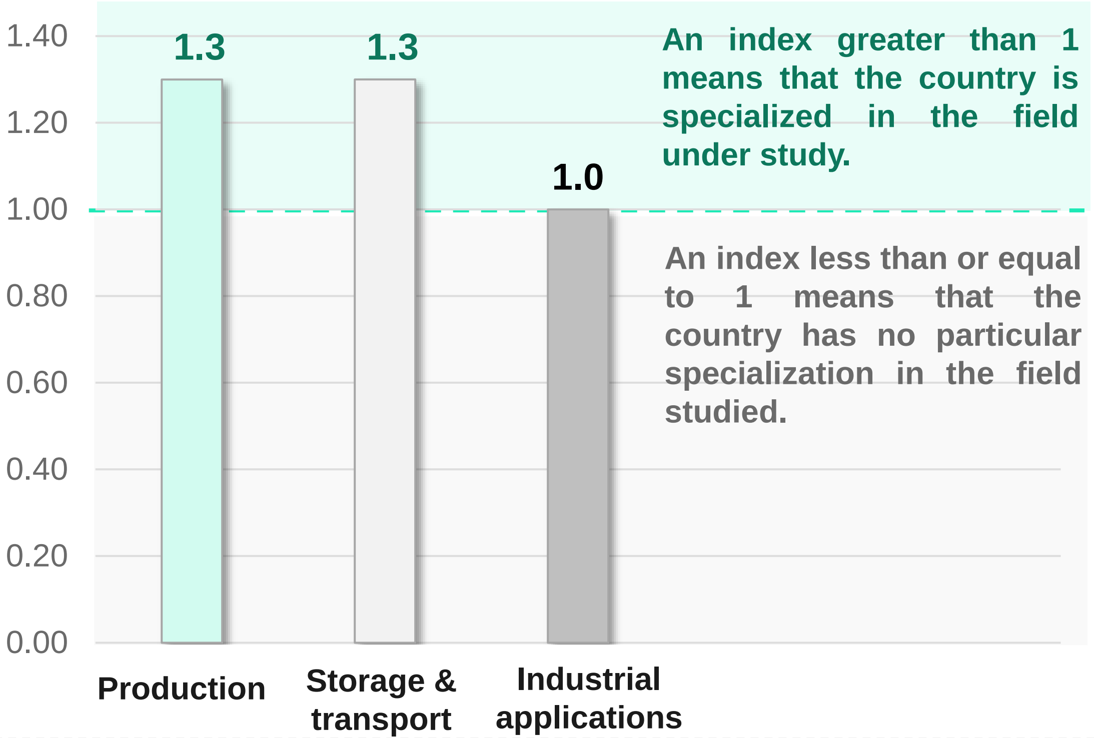
What is not visible in these graphs is that **well-established FC players whose core business is FCs** - such as **Ballard in Canada** - have filed fewer patents in these fields, but nevertheless **own a lot of intellectual property on more generic FCs** (not related to specific automotive applications - which take up a lot of space on these graphs).

Intellectual Property Analysis | Summary of Canada’s Positioning

Although outpaced by the main H2 ecosystem driving nations: Europe, Japan, the USA, China and Korea, Canada has been identified internationally as a **dynamic and emerging patenting hub** in the H_2 sector, on a par with Switzerland and the UK.

Canada’s H_2 technology advantage index

*(2011-2020)**



- **The technological advantage index** is an indicator developed by the OECD to identify a country's **technological specialization**.
- It is calculated as the ratio of the share of patents filed by a country in a particular field to the share of patents filed in all fields. **When it is greater than 1, this indicates technological concentration in the field studied**.
- Analysis of this indicator demonstrates **the important role played by H_2 in innovation in Canada, since it is greater than or equal to 1** at every link in the value chain.
- **The technological advantage index** also illustrates the fact that **Canada specializes in part on the upstream side of the value chain: production and storage, transportation, distribution**.

**Source : Hydrogen Patents for a Clean Energy Future, IEA, 2023*

4. Selection of 4 Strategic Equipment Segments

Strategic Segments Selection | Key Challenges and Objectives

The main objective of this stage is to **select** - from the 14 manufacturing segments presented above - **the 4 most strategic segments for Quebec**. This selection is based on a **detailed study of Quebec's capacity and interest in developing each of these segments**.

Overall methodology

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5. CONCLUSION AND RECOMMENDATIONS

- **Definition of 8 major findings** from previous analyses
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Main Challenges

- **Develop an objective decision-making tool**, based on **criteria reflecting Quebec's capacity and interest** in each equipment segment.
- **Work in collaboration** with local players on these criteria to **add intelligence and take into account the reality of the H_2 sector in Quebec**.

Scope of Analysis

- **The 14 H_2 production equipment** *(presented in p.11)*

Strategic Segments Selection | Methodology

Two criteria were used to select the **4 strategic segments for Quebec**: **Interest** and **Capacity**. Scores associated with each of these two criteria were evaluated. These scores correspond to the weighted average of the scores attributed to each of the established sub-criteria. **The weightings of the sub-criteria and the assignment of scores were developed in a workshop with PRIMA and the MEIE**.

		Sub-criteria scores				
	Sub-crtieria - Weighting	**1**	**2**	**3**	**4**	**5**
Criteria #1 Interest for Quebec	**Strategy on Green Hydrogen and Bioenergies - 50%**	Out of scope		Medium-priority application		High-priority application
	Criticality- 20%	Present in few segments and easy to source		Present in few segments and difficult to source/Present in several segments and easy to source		Present in many segments and difficult to source
	Ease of entry into the segment– 15%	Strong entry barrier		Medium entry barrier		Low entry barrier
	Added value – 15%	Low technological and R&D content		Medium technological and R&D content		High technological and R&D content
Criteria #2 Capacity of Quebec	**Manufacturing capacity – 25%**	No manufacturer		Interested/present manufacturer		At least 1 manufacturer
	R&D capacity – 25%	No R&D organism		Some R&D work and actors		Strong R&D expertise and many actors
	Dépendance on SCM present in Quebec – 25%	Few SCMs and Noe present in Quebec		At least 3 SCMs present in Quebec		5+ SCMs present in Quebec
	Weighted segment maturity* – 25%	Low maturity		Medium maturity		High maturity

*Sub-criterion calculated by weighting manufacturing capacity and R&D capacity: $\frac{5 - maturity}{5}\ x\ R\&D\ capacity + \frac{maturity}{5}\ x\ Manufacturing\ capacity$

Strategic Segments Selection | Prioritization Matrix

By assigning scores to each of the sub-criteria and calculating the **Interest** and **Capacity** scores, an average score is obtained which is used **to rank the segments**. This decision-making tool was used to **select the 4 priority segments** in a workshop with PRIMA and MEIE. The selection is based both on the **analysis of the scores and on discussions with MEIE experts**, giving **depth** to this objective tool.

	Interest				**Interest Score**	**Capacity**					**Capacity Score**	**Total**
Segments	*H_2 Strategy*	*Criticality*	*Ease of entry into segment*	*Added value*		*Manuf. capacity*	*R&D Capacity*	*Dependance on QC SCMs*	*Weighted maturity*			**Average Score**
Electrolyzer	5	3	5	5	**4.6**	3	5	5	*3*	3.8	**4.2**	**4.4**
Industrial equipment	5	3	5	5	**4.6**	5	3	3	*2*	3.8	**3.7**	**4.2**
H_2 reactors	4	3	4	5	**4.0**	3	5	5	*2*	4.2	**4.3**	**4.1**
Fuel cells	4	5	5	5	**4.5**	3	5	3	*4*	3.4	**3.6**	**4.1**
Compressor	4	5	5	5	**4.5**	3	5	2	*3*	3.8	**3.5**	**4.0**
Liquefiers	4	5	4	4	**4.2**	3	5	2	*4*	3.4	**3.4**	**3.8**
Auxiliary equipment	4.5	3	4	3	**3.9**	5	2	1	*4*	4.4	**3.1**	**3.5**
H_2 buses and trucks	4	1	2	2	**2.8**	5	2	5	*4*	4.4	**4.1**	**3.5**
H_2 stations	4	3	4	3.5	**3.7**	3	2	5	*3*	2.6	**3.2**	**3.4**
Heavy H_2 mobility	3	3	3	3	**3.0**	3	5	3	*3*	3.8	**3.7**	**3.4**
Instrumentation	3.5	3	3	2	**3.1**	3	5	3	*4*	3.4	**3.6**	**3.4**
Stationnary tanks	4	4	3	3.5	**3.8**	1	5	3	*3*	2.6	**2.9**	**3.3**
Portable tanks	4	3	3	3.5	**3.6**	1	5	3	*4*	1.8	**2.7**	**3.1**
Fittings and valves	3.5	3	1	2	**2.8**	3	5	2	*5*	3	**3.3**	**3.0**

**Sub-criterion calculated by weighting manufacturing capacity and R&D capacity:* $\frac{5 - maturity}{5}\ x\ R\&D\ capacity + \frac{maturity}{5}\ x\ Manufacturing\ capacity$

Strategic Segments Selection | The 4 Selected Segments

The segments with the highest average score were selected (electrolysers, FC, H_2 reactors), with the exception of industrial equipment, which was eliminated because of its low specificity to the hydrogen sector.

	ELECTROLYSERS	FUEL CELLS	H_2 REACTORS	STATIONNARY TANKS
INTEREST	• **Strong alignment** with The Green hydrogen and bioenergy strategy • Presence of **green** hydrogen would benefit several **complementary sectors** (refineries, steel industry, etc.)	• Several FC applications identified as priorities: **seasonal storage and winter peak management, long-distance trucking (class 8)** • **High technological content transposable to the electrolyser segment**	• **Reducing emissions from conventional H_2 production processes (SMR)** • **Technology of the future**, with growing needs ahead and a market that resonates strongly with QC's strengths	• **Consolidation of the QC supply chain** possible through local tank manufacturing • **High level of specificity in the hydrogen sector** and response to the needs of hydrogen users and producers
CAPACITY	• QC meets many of the needs expressed by manufacturers: **strong local demand, proximity to deep-water transport, presence of infrastructure, skilled workforce and political will to support manufacturers**	• **Strong R&D expertise** held by universities and CCTT targeting efficiency issues and alternatives to PFAS • **Manufacturers present in Canada**, including Ballard, which says it would be interested in setting up in QC if strong demand were to justify it	• **Strong QC expertise and intellectual property** in plasma pyrolysis and biomass/waste gasification technologies • **Strong complementarity with existing plasma torch manufacturing skills**	• **Strong R&D expertise,** with plenty of room for innovation in safety systems and different storage modes • A number of uses for hydrogen storage are set to develop, helping to **secure demand** for this equipment

> With a view to developing strategic markets that **resonate strongly with Quebec's strengths**, and in **strong alignment with the applications prioritized by the Green H_2 and bioenergy strategy,** the stationary reservoir segment has also been selected.

> Applications linked to the latter, such as **winter peak management**, are targeted, and its prioritization would help **secure an important link in the local supply chain** to meet the needs of both hydrogen users and producers.

5. Socio-Economic Analysis of Sector Development

Socio-Economic Analysis | Key Challenges and Objectives

The main objective of this stage is to study the **externalities associated with the development of manufacturing industries in the 4 strategic equipment segments selected**. A **quantitative analysis** of **socio-economic impacts was carried out** for the mature segments (electrolysers, fuel cells and stationary tanks) and a **qualitative approach** for the emerging H_2 reactor segment.

Overall Methodology

1. IN-DEPTH STUDY OF THE MANUFACTURING ECOSYSTEM
- **Analysis of 350 H_2 actors** *(Appendix 1.A.)*
- **Selection of 200 actors** for in-depth analysis
- **Study** of their strategies, ambitions, projects, partnerships, etc.
- **Meeting with 30 industry players** *(Appendix 1.B.)*

2. IN-DEPTH ANALYSIS OF H_2 EQUIPMENTS
- **Segmentation of the value chain into 14 segments** of equipment for detailed analysis
- **In-depth analysis of associated markets,** major projects, critical minerals, R&D dynamics, etc.

3. SELECTION OF 4 STRATEGIC EQUIPMENT SEGMENTS
- Identification of key criteria for prioritizing segments: alignment with H_2 strategy, Quebec capabilities, etc.
- Calculation of a score for each segment, then selection of the 4 most promising segments

4. ANALYSIS OF SOCIO-ECONOMICAL IMPACTS
- **Selection of 9 indicators** reflecting the socio-economic impact of manufacturing sector development
- **Study of these indicators for the 3 most mature segments**
- **Specific analysis** for the emerging segment

5. CONCLUSION AND RECOMMENDATIONS
- **Definition of 8 major findings** from previous analyses
- **9 recommendations** associated with these findings

Main Challenges

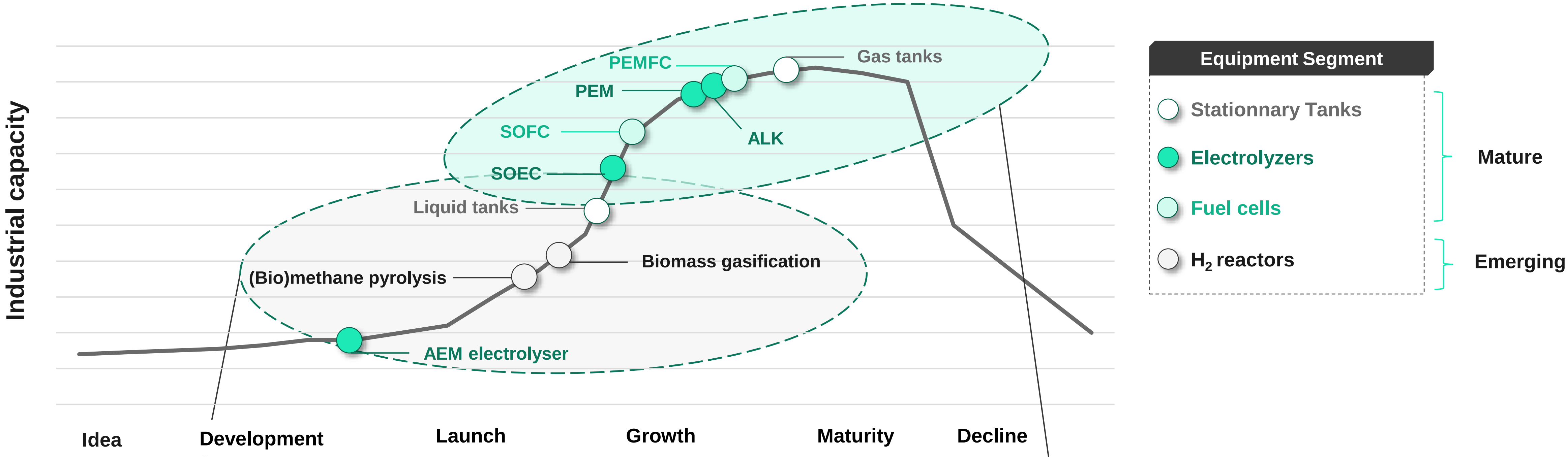
- Select socio-economic indicators that **capture the full range of externalities associated with the development of the sector**
- **Compare data with benchmark studies and feedback from manufacturers** to assess their reliability and limitations

Scope of Analysis

- **The 4 strategic equipment segments**
- **Batteries** (lithium-ion technology)

Methodology | Scope of Analysis by Technological Maturity

The degree of maturity of the technologies associated with the four selected strategic equipment segments does not permit the same level of analysis for socio-economic and environmental indicators. **Externalities in mature segments have been defined using quantitative indicators, while those related to the emerging hydrogen reactor segment have been assessed at a higher, qualitative level**. The chart below ranks the technologies based on their corresponding industrial capacities.



Industrial market in development

- *Lack of manufacturers with significant production capacity*
- *Pilot project developers confused with technology solution developers and manufacturers*
- ***No socio-economic and environmental analysis of the sector's development***
- *This concerns the emerging H_2 reactor segment*

Sufficiently mature industrial capabilities

- ***Enables a socio-economic-environmental analysis of the sector's development***
- *This concerns the 3 mature segments of electrolysers, fuel cells and stationary tanks*

Socio-Economic Analysis of Sector Development| Detailed Description

INDICATORS	RELEVANT QUESTIONS
Financing needs	> What are the **initial investments ($M)** to develop a production plant for a given capacity?
Electricity needs	> For the production of a certain capacity per year, what is the **electrical capacity** required by the plant? > NB: These data come mainly from scientific literature.
Jobs created	> For a typical capacity plant (1GW or 1GWh), **how many jobs are created?**
Average salary	> On average, what is the **annual salary of employees** working for the manufacturer?
Type of jobs	> What is the **breakdown of jobs created**? Engineers, PhD students, technicians, support, sales, etc.?
Revenues Government of Quebec	> How much **revenue would the government generate** for a 1GW plant? > NB: Based on ISQ methodology and taking into account two components - Taxes on products and salaries
Added value	> What is the **added value** of this segment? > NB: This indicator is qualitative: dynamics of integration into the Quebec economy, synergies with the battery industry and neighboring regions, priority in H2 strategy, etc.
GHG Emissions	> What are the **annual GHG emissions** associated with the deployment of a 1GW/GWh plant? > NB: These data are based on LCAs for the entire equipment manufacturing phase.
SCMs	> A criticality index has been calculated (details on p.102). This corresponds to the average stress on the SCMs that make up the technology and that are listed in the provincial strategy. The stress on the SCMs was assessed in a workshop held in collaboration with the MRNF.

Socio-Economic Analysis | Data Collection

In order to carry out the socio-economic impact analysis, two methodologies were used at the data research/collection level: the first, termed **'top-down',** which involves using the most reliable value and validating its order of magnitude by surveying several projects; and the second, termed **'bottom-up'**, which involves surveying as many projects as possible and homogenizing them by calculating an average that excludes outliers.

Methodology #1 : Top-down

Use of the most reliable value in the reference studies, then census of several projects to validate the order of magnitude.

Preferred method when information is available

1. **Literature review** of reliable studies on the subject: IEA, IRENA, energy branch of governments, federation of industrial players around H2 (Ex: France hydrogen, Hydrogen Council, etc.)
2. **Collection of the most reliable/documented data**
3. **Review of** major manufacturing projects then average data by project
4. **Verification of the consistency** between the data from the study and that from the project review

Methodology #2 : Bottom-up

Census of a maximum number of projects, homogenization of the units then average of the values encountered after exclusion of "aberrant" data.

Method used if no reference study is found

1. **Literature review** of a large number of industrial hydrogen projects
2. **Unit homogenization work** (number of units produced vs. total power of the plant, etc.)
3. Study of "outlier" data – location, technology, reliability, etc.
4. Average of reliable data

Socio-Economic Analysis | Data Reliability

The manufacturing sector linked to green H_2 is very sensitive to announcement effects, which creates a **challenge in terms of reliability and the limit of the data collected** . Two reliability scales have therefore been established in order to judge the reliability of the data collected. The **first applies to the primary data** at the collection stage. The **second scale corresponds to the aggregation of these primary data.**

Degree of reliability

	I	**II**	**III**	**IV**
#1. Reliability of "primary data" *From a project, a study or a manufacturer.*	Data from a key reference study and/or discussions with manufacturers	Data from scientific publications and/or project reviews	Data from scientific publications and/or project reviews	Data poorly documented in the literature, from less reliable/unverifiable studies
#2. Reliability of "retained values" for the segment – *Used for further analysis*.*	Value from reliability I data or 5+ reliability II data	Value from 3+ reliability data II	Value from 3- reliability data II	Value derived only from reliability III or lower data

**This second scale is the one used for the rest of the analysis p.92 to p.97*

Socio-Economic Analysis | Overview of the 3 Mature Segments

	Financing needs	Electricity needs	Jobs created	Average salary	Job types	Quebec govt revenues	Added value*	GHG Emissions**	SCMs *(no unit)*
1 **Electrolyzers** *Analysis by indicator*	**142 M$/GW**	**35 MW/GW**	**450 FTE/GW**	**66 000$/yr**	**73%** - *Technician* **15%** - *Engineer* ***11%*** - *Support* **1%** - *Sales*	**90 M$/yr**	-	**108 000 ktCO2eq/GW**	ALK – **3,2** PEM – **3,3** AEM – **3,1** SOEC – **2,9**
2 **FC** *Analysis by indicator*	**162 M$/GW**	**5 MW/GW**	**323 FTE/GW**	**72 615$/yr**	**73%** - *Tech./sup.* **22%** - *Engineer* **4%** - *PhD*	**41 M$/yr**	-	**24 000 ktCO2eq/GW**	PEMFC **3,5**
3 **Stationnary tanks** *Analysis by indicator*	**16 M$/GWh**	**0,16 MW/GWh**	**9 FTE/1000 tanks**	-	-	-	-	**18 224 ktCO2eq/GWh**	Gaseous – **3,3** Liquid – **2,7**
Batteries *Analysis by indicator*	**144 M$/GWh**	**7 MW/GWh**	**154 FTE/GWh**	**63 255$/yr**	**50%** - *Operator* **15-25%** - *Engineer* **10-20%** - *Tech./sup.* **5-15%** - *Support*	-	-	**13 083 ktCO2eq/GWh**	Lithium-ion **3,4**

The indicator around added value is a qualitative indicator that has been integrated into the following section of the **Conclusion and Recommendations report in the findings presented. It takes into account elements such as the dynamics of integration into the Quebec economy, synergies with the battery sector and neighboring regions, priority in the H_2 strategy etc.*

***GHG emissions come from life cycle analyses carried out over the entire manufacturing phase of the equipment (extraction and processing of minerals, assembly, etc.)*

Socio-Economic Indicators Analysis | Electrolyzers

INDICATORS	VALUE	OBSERVATIONS
Financing needs *(M$/GW)*	**142 M$/GW** III* Data from an average calculated from 10 projects (different technologies) and verified by feedback from manufacturers and reference studies	> In ascending order of CAPEX: **ALK < PEM** > Less mature technologies are associated with higher CAPEX > **Labor costs drive manufacturers to automation** > Value **strongly influenced by the technical targets defined by the DOE**
Electricity needs *(MW/GW)*	**35 MW/GW** IV Data from an average calculated from the electrical flows taken into account in several LCAs	> Manufacturing processes less electro-intensive than the use of electrolysers > Significant impact on the **environmental footprint** of manufacturing processes when the **energy mix is No-decarbonized**
Jobs created *(FTE/GW)*	**304 FTE/GW** II Data from an average calculated from 10 projects and verified by reference studies	> **Nolinear relationship** between number of jobs and manufacturing capacity > Mid-size projects (a few dozen MW): **most positive impact in terms of job creation**
Average salary *($/year)*	**$66,000/yr** III Data calculated based on job typology and average salary per job; verified by manufacturers' feedback and benchmark studies	> Value that is likely to increase with the **acquisition of niche expertise** in manufacturing processes linked to electrolysers

*Based on reliability scale #2 presented on p.90

Socio-Economic Indicators Analysis | Electrolysers

INDICATORS	VALUE	OBSERVATIONS
Type of jobs *(%)*	**73%** - *Tech./sup.* **22%** - *Engineer* **5%** - *PhD* II Value from the work of France Hydrogène	> Typology that changes significantly in the **exploitation phase** > **Significant synergy with FCs** in terms of job typology > Adaptation of the **training device** required > **Synergies with the skills required in the battery sector**
Quebec government revenues *(M$/GW)*	**$90M/yr** IV Value calculated following the ISQ methodology	> Taking into account **taxes on products** (QST and GST) **and on salaries** (according to salary level) > The product tax represents approximately 94% of the revenue generated for the Quebec government.
GHG emissions *(tCO2eq/GW)*	**108,000 ktCO2eq/GW** III Data from an average calculated from several LCAs	> Buyers are increasingly looking for ***green* electrolysers** > Data used as input to **assess the carbon footprint of hydrogen production** > If the energy mix is No-decarbonized, this has a significant impact on GHG emissions
SCMs* *(Without unit)*	ALK – **3.2** PEM – **3.3** AEM – **3.1** SOEC – **2.9** II	> PEM technology is the most intensive in terms of SCMs > **Some SCMs in medium to high tension with the battery sector** > Technological advances that enable the **substitution** or **recycling of SCMs**

**Indicator calculated by aggregating the criticality index of each SCMs composing the technology. The "raw" data by SCMs were calculated and verified by the MRNF.*

Socio-Economic Indicators Analysis | Fuel Cells

INDICATORS	VALUE	OBSERVATIONS
Financing needs *(M$/GW)*	**162 M$/GW** II Data from an average calculated from 5 projects (different technologies) and verified by feedback from manufacturers and reference studies	> Value that would evolve downwards with the increase in manufacturing capacities in the coming years; possible thanks to **improvements in manufacturing processes** and the **automation of certain manufacturing phases** > Unlike the battery, the manufacturing cost of a heat pump results from the manufacture of the latter and not from the materials that compose it.
Electricity needs *(MW/GW)*	**5 MW/GW** IV Data from an average calculated from the electrical flows taken into account in several LCAs	> This value makes sense when the energy mix is not decarbonized > It has a **significant impact on the environmental footprint** of a heat pump over its life cycle, in which the manufacturing phase is often taken into account.
Jobs created *(FTE/GW)*	**323 FTE/GW** I Data from an average calculated from 5 projects and verified by reference studies	> The evolution of the PAC manufacturing sector will result in **recruitment peaks** which risk coinciding with those of other segments or sectors (mobility) > Estimating long-term job demand helps better **plan labor needs**
Average salary *($/year)*	**$72,615/yr** III Data calculated based on job typology and average salary per job; verified by manufacturers' feedback and benchmark studies	> Average salary which could increase with the **acquisition of advanced skills** > **Growing demand for jobs** generated by the development of the hydrogen manufacturing sector and that of the battery; value which would increase in the short term: demand stronger than supply

Socio-Economic Indicators Analysis | Fuel Cells

INDICATORS	VALUE		OBSERVATIONS
Type of jobs *(%)*	**73%** - *Tech./sup.* **22%** - *Engineer* **4%** - *PhD student* Value based on a project carried out by Symbio	II	> **Job typology similar to that observed in the electrolyser segment** > **Strong technological similarity in fuel cell assembly processes** and electrolyzer cell assembly processes
Quebec government revenues *(M$/GW)*	**$41M/year** Value calculated following the ISQ methodology	II	> Similar to the electrolyser segment, the **largest share of revenue generated for the government is due to product taxes** (90%).
GHG emissions *(tCO2eq/GW)*	**24,000ktCO2eq/GW** Data from an average calculated from 2 LCAs	III	> Other environmental impacts around PACs must be considered, particularly around PFAS **which** contaminate water and soils. > If the energy mix is No-decarbonized, this has a significant impact on GHG emissions
SCMs* *(No unit)*	PEMFC – **3.5**	II	> Several R&D projects are underway to find **alternative catalysts** to Platinum that would reduce the criticality of SCMs in PEM technology.

**Indicator calculated by aggregating the criticality index of each SCMs composing the technology. The "raw" data by SCMs were calculated and verified by the MRNF.*

Socio-Economic Indicators Analysis | Stationary Tanks

INDICATORS	VALUE	OBSERVATIONS
Financing needs *($/kWh)*	**16 M$/GWh** III Data from an average calculated from 7 projects (different pressure and type)	> **Significant cost difference depending on tank type** : Type IV tanks approximately 300% more expensive than Type I > The opposite trend is observed in terms of weight per volume of stored gas. > Unlike the electrolyzer segment, the **cost of materials has a significant impact on the manufacturing cost of tanks.**
Electricity needs *(kWh/kgH_2)*	**0.16 MW/GWh** IV Data from an average calculated from the electrical flows taken into account in several LCAs	> Tank manufacturing processes are assumed to be electro-intensive in the literature: high temperature **heating requirements of the polymers composing the internal liners before their packaging**
Jobs created *(FTE/tank)*	**9 FTE/1000 tank** IV Data from an average calculated from 2 projects	> Jobs created could be filled in the short term with resources from the aeronautics sector where the **manufacturing processes used are similar, especially at the filament winding level.**
Average salary *($/year)*	- Data impossible to calculate: job typology not available in the literature or from manufacturers	> Labor represents about 9% of the total cost of tank manufacturing > The significant increase in average wages would be a trigger for a move towards automation **of manufacturing processes.**

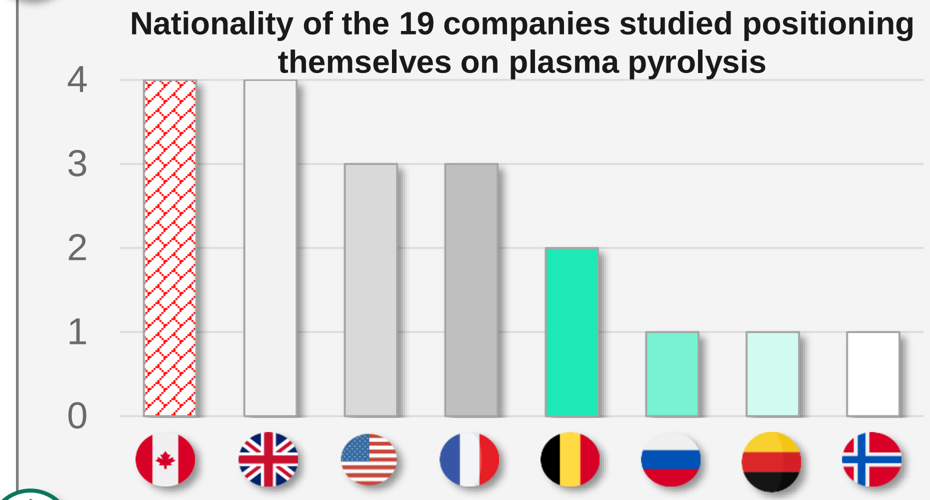
Socio-Economic Indicators Analysis | Stationary Tanks

INDICATORS	VALUE	OBSERVATIONS
Type of jobs *(%)*	**-** Data impossible to calculate: job typology not available in the literature or from manufacturers	> Jobs created require a **good knowledge of the processes involved in tank manufacturing** (e.g. winding carbon fiber filaments to produce the internal liner) and adequate quality control. > **Different job typology depending on the type of tanks** : Type I and II mainly forging, Type III: mainly assembly and wrapping, Type IV: experience in polymer extrusion
Quebec government revenues *(M$/GW)*	- Uncalculable data: value of the required average salary	> Although an estimate of the demand for tanks remains necessary, certain applications targeted by the strategy on green H_2 and bioenergies such as seasonal storage will result in **an increasing demand for this equipment, thus attracting manufacturers in the long term.** > The share related to the tax on products generated by manufacturers could represent the largest share of the revenues generated (like the other segments)
GHG emissions *(ktCO2eq/kgH $_2$)*	**18224 ktCO2eq/GWh** IV Data from an average calculated from several LCAs	> Some tank manufacturing processes take place at high temperatures, therefore requiring **a significant energy input.** > If the energy mix is No-decarbonized, this has a significant impact on GHG emissions
SCMs* *(Without unit)*	Gaseous – **3.3** II Liquid – **2.7** Data calculated and verified with the MRNF	> **SCM in tension with the battery sector** : aluminum, carbon, chrome, iron, nickel, titanium > R&D efforts exist around the substitution of SCMs present in tanks but are mainly focused on safety systems

**Indicator calculated by aggregating the criticality index of each SCMs composing the technology. The "raw" data by SCMs were calculated and verified by the MRNF.*

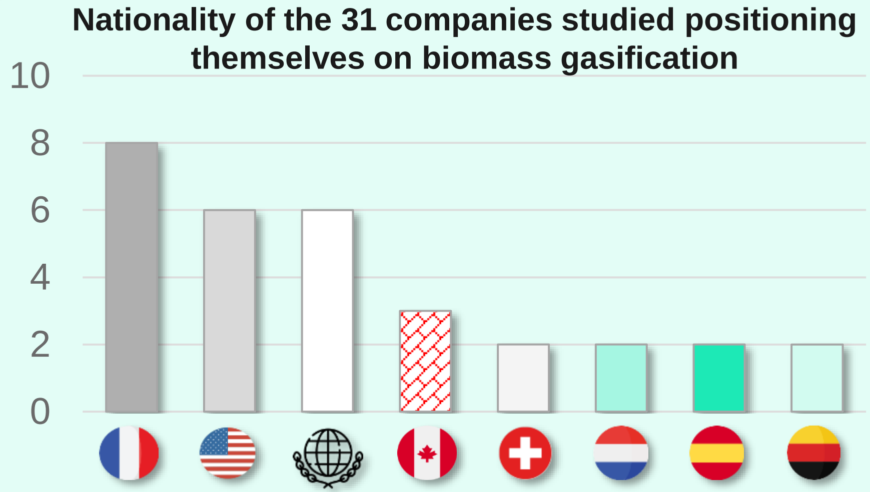
Analysis of H_2 Reactors | Key Players and Their Market Positioning

Plasma pyrolysis


Nationality of the 19 companies studied positioning themselves on plasma pyrolysis

- In plasma pyrolysis, Canada is a particularly dynamic player with 4 out of 19 companies tagged.
- These players are mainly companies that have **developed plasma processes for other applications** (metal separation, waste management, additive manufacturing, etc.; **or start-ups from universities** (6K – University of Alberta; Cambridge Nanosystem – Cambridge, etc.).
- The companies **are particularly young** , most of them having been created between 2008 and 2012; or after 2021. **They are small and medium-sized companies with low TRLs** . Only Monolith has reached industrial scale with its factory expansion in Olive Creek (USA) planned for 2025.

Biomass/waste gasification

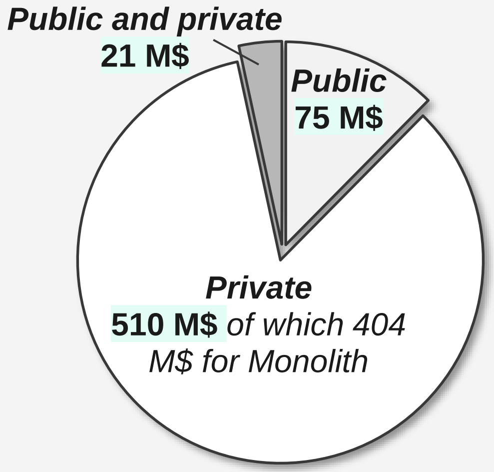

Nationality of the 31 companies studied positioning themselves on biomass gasification

- In biomass gasification, 3 out of the 31 companies tagged are Canadian. **France and the United States stand out** in this segment.
- **The majority of the players are specialists in H2 reactors** , which are developing only in this niche.
- **At least 9 of the 43 development projects for these reactors are in collaboration with research institutes.**
- Of the 31 companies, **3 closed due to lack of a profitable business model, financial inability and/or inability to source inputs.**

Analysis of H_2 reactors | Financing and Partnerships

Plasma pyrolysis

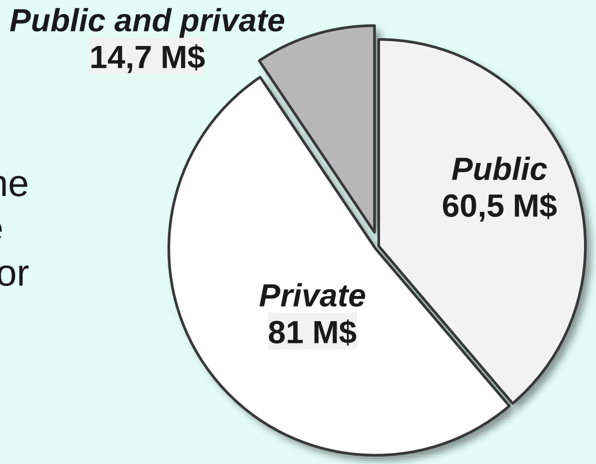
In total, **$606 million of investment** in the methane pyrolysis sector has been earmarked.



- Partnerships are being formed **between technology solution providers** and manufacturers to develop **reactors producing customized carbon outputs** :
  - **Carbon black production for tires** : Monolith and Good Year
  - Studies underway to develop solutions **producing graphite for the battery industry** – Aurora Hydrogen
- Monolith 's funding comes from a fundraising round in 2022. **$1.35 billion in aid was also provided by the Department of Energy**, but is not represented in the chart opposite because it takes the form of a loan.

Biomass/waste gasification

In total, **$156 million of investment** in the biomass/waste gasification sector has been earmarked.



- **Technology solution providers develop strategic partnerships with research and development organizations** (InEnTec – MIT, Materia Nova – the University of Mons, etc.) **to optimize the performance of their technologies** .
- Partnerships **are also being forged in collaboration with potential input suppliers** such as agricultural associations and/or the pulp and paper industry to recover agricultural residues and municipalities to collect municipal waste (Mote – Municipality of Sacramento)

Analysis of H_2 Reactors | Added Value for Quebec's Economy

Plasma pyrolysis

Example of Canadian companies

Players	Province	Distinctive elements
AURORA HYDROGEN	Alberta	Could produce battery-grade graphite
innovahydrogen	Alberta	Named among Canada's 15 most innovative young companies in 2023
NU:IONIC TECHNOLOGIES	New Brunswick	Announced a **2400 kg H_2/d project** by 2025 in New Brunswick
PYROGENESIS	Quebec	Mature company (51-200 employees) with **proven technology in No- H_2**

Interesting interactions of methane pyrolysis in the Quebec economy

- Co -products of **H_2 production have strong synergies with the Quebec economy** : graphite for use in battery and/or electrolyzer production plants (in the event of support from the sector).
- **Less congestion on electrical capacities** : up to **7x less electricity required for** H_2 production than by electrolysers in theory.
- **Synergy with the development of the GNR sector** : When using GNR as an input, **the H_2 produced sequesters CO_2 .**

Biomass/waste gasification

Example of Canadian companies

Players	Province	Distinctive elements
OMNI CONVERSION TECHNOLOGIES	Ontario	Factories already in operation in California
MINNOVA CORP.	Ontario	Pilot plant planned in Manitoba
REN energy	British Columbia	Pilot plant planned in British Columbia
PYROGENESIS	Quebec	**Plasma expertise** is also used to produce synthesis gas from waste

Interesting interactions of gasification in the Quebec economy

- **Forest, agricultural and municipal biomass deposits are significant –** in its strategy on green H_2 and bioenergy for 2030, Quebec identifies 19.2 Mt anhydrous of biomass or 326 PJ in energy equivalent in 2019.
- **80% of the minerals that make up these reactors** are identified as SCMs by the provincial strategy.
- **The processes are versatile** and could take municipal, hospital, etc. waste as input.

Socio-Economic Analysis | Interactions with the Battery Sector

The socio-economic study of the development of the sector made it possible to identify observations that were used to feed the **analysis of high-level interactions between the hydrogen sector and the battery sector** . These interactions are studied under 4 axes: **SCMs, technologies, workforce and policies.**

Technologies

STRONG TECHNOLOGICAL SYNERGIES EXIST BETWEEN THE TWO SECTORS

This technological synergy is mainly observed at the level of batteries and electrolysers which are two **modular technologies** well suited to large-scale manufacturing. The technological progress observed at the level of batteries is more advanced than that of electrolysers with the costs of lithium-ion batteries which are significantly reduced thanks to the scaling up of manufacturing processes. The scaling up at the level of electrolysers is at an earlier stage but the reductions in costs are evolving significantly with several objectives established by the Department of Energy in the United States. **The technological synergies between the two sectors are broken down into 3 elements** :

Similar processes

Batteries and electrolysers are **based on the same electrochemical principles** allowing the hydrogen industry to benefit from the knowledge and expertise generated to reduce scale-up cycles and associated costs.

These two sectors share several components such as electrolytes, membrane materials and manufacturing processes. This explains why some manufacturers such as Toray or BASF offer both solutions.

Promising complementary applications

Current efforts in terms of application of electrolysis are concentrated around processes based on renewable energies such as solar or wind which are **intermittent sources.** not allowing stable production. **The integration of a battery** that allows energy storage upstream makes it possible to generate a stable power source for the electrolysers, highlighting an example of the **complementarity of these two technologies** that can exist. This application scenario is becoming more and more frequent thanks to the reduction in battery costs.

Common research and development issues

Despite the high maturity of the battery sector, some R&D challenges remain to be mastered and several of them are complementary to the challenges targeted for the hydrogen sector:

- **Substitution of SCMs :** need to replace SCMs components of technologies by the discovery of new materials thanks to AI
- **SCMs recycling :** need to find ways to recover the metals that make up the technologies
- **Improving the durability of catalytic materials and membranes**

Socio-Economic Analysis | Interactions with the Battery Sector

SCM

INTERACTIONS EXIST ON SOME SCM BETWEEN THE TWO SECTORS

Zoom in on p.102

The identification of SCM common to the hydrogen and battery technologies makes it possible to estimate the **tension** and **criticality** that is created around them by the development of the two respective sectors. This reflection is in alignment with the **Quebec Plan for the Valorization of Critical and Strategic Minerals**, which aims to make Quebec a leader in the production, processing and recycling of critical and strategic minerals in partnership with regional and indigenous communities. The importance of this Plan is illustrated by the **geopolitical tensions** recently observed such as Chinese restrictions on the export of gallium, germanium and graphite. The installation of this context makes the **mapping of SCMs** increasingly necessary in order to identify **risks related to the supply chain** and **ways to mitigate future bottlenecks.** Our analysis is limited to the identification of SCM in tension and the assessment of their criticality.

Identification of SCMs in tension

The SCMs present in each of the technologies related to the equipment studied (battery, electrolyzers, PAC, stationary tanks and H_2 reactors) were identified and a tension score was determined for each SCMs in the workshop with the MRNF. An increasing tension scale from 1 to 5 was established. The SCMs with a tension of 4 or more are as follows:

Carbon – in tension with the battery sector but possible synergy (graphite from methane pyrolysis)

Cobalt – in tension because available in small quantities, concentration of mines in Congo

Iridium – in tension because produced in small quantities

Lithium – In the long term, 95% of demand in the battery sector (currently more in the order of 80-90%)

Nickel – in lower tension than other SCMs but concentration of mines in Indonesia

These tensions mainly concern electrolysis technologies and lithium-ion batteries.

Assessment of the criticality of SCM under tension

In order to study the tension on the common SCMs between the technology studied and Quebec, a **criticality index** (presented in S102) was calculated. The latter corresponds to the average of the tensions of the SCMs **that make up the technology and that are included in the provincial plan.** By equipment segment, the technologies with the highest criticality indices are as follows:

Lithium-ion batteries: 100%*
ALK electrolysers: 67%
PEM fuel cells: 75%
Gas tanks : 80%
Plasma pyrolysis reactors: 80%

**% of SCMs components of the technology listed in the provincial plan*

Socio-Economic Analysis | Interactions with the Battery Sector

Workforce

SIMILAR JOB TYPES

The study of the socio-economic indicator on the typology of jobs makes it possible to **characterize at a high level the skills that will be required following the development of the** hydrogen sector. Some job typologies are similar to those found in the battery sector. A study on labor needs would make it possible to better plan vocational training, guarantee balanced economic growth and meet the needs of the labor market. Our analysis is limited to the study of high-level job typologies.

Job types and training

A similar job typology between the two sectors : similarities in job typologies between electrolysers and fuel cells and the battery sector; a majority of technician and engineer profiles. In terms of skills, the need is present both for cross-functional skills (safety and regulations) and for specific expertise needs (H_2 system).

A training offer that is in a dynamic of construction : different universities in Quebec train a qualified workforce and the VTÉ innovation zones focus on the development of skills specific to the two sectors.

Policies

COMPLEMENTARY TECHNOLOGIES

Local policies have a significant impact on the **development of industrial sectors and the adoption of the technologies** that are part of them. In Quebec, the **PEV 2030** and the **Green H_2 and Bioenergy Strategy** present the battery and hydrogen technologies respectively as key pillars of decarbonization. These policies position these sectors and the technologies that are part of them as two complementary outlets for a clean energy future.

Policies supporting both sectors

PEV 2030: This plan refers to both the battery sector with applications that target in particular the transport sector and energy storage and the hydrogen sector as a complementary solution to electricity when the latter is not an economically profitable or possible solution to replace fossil fuels.

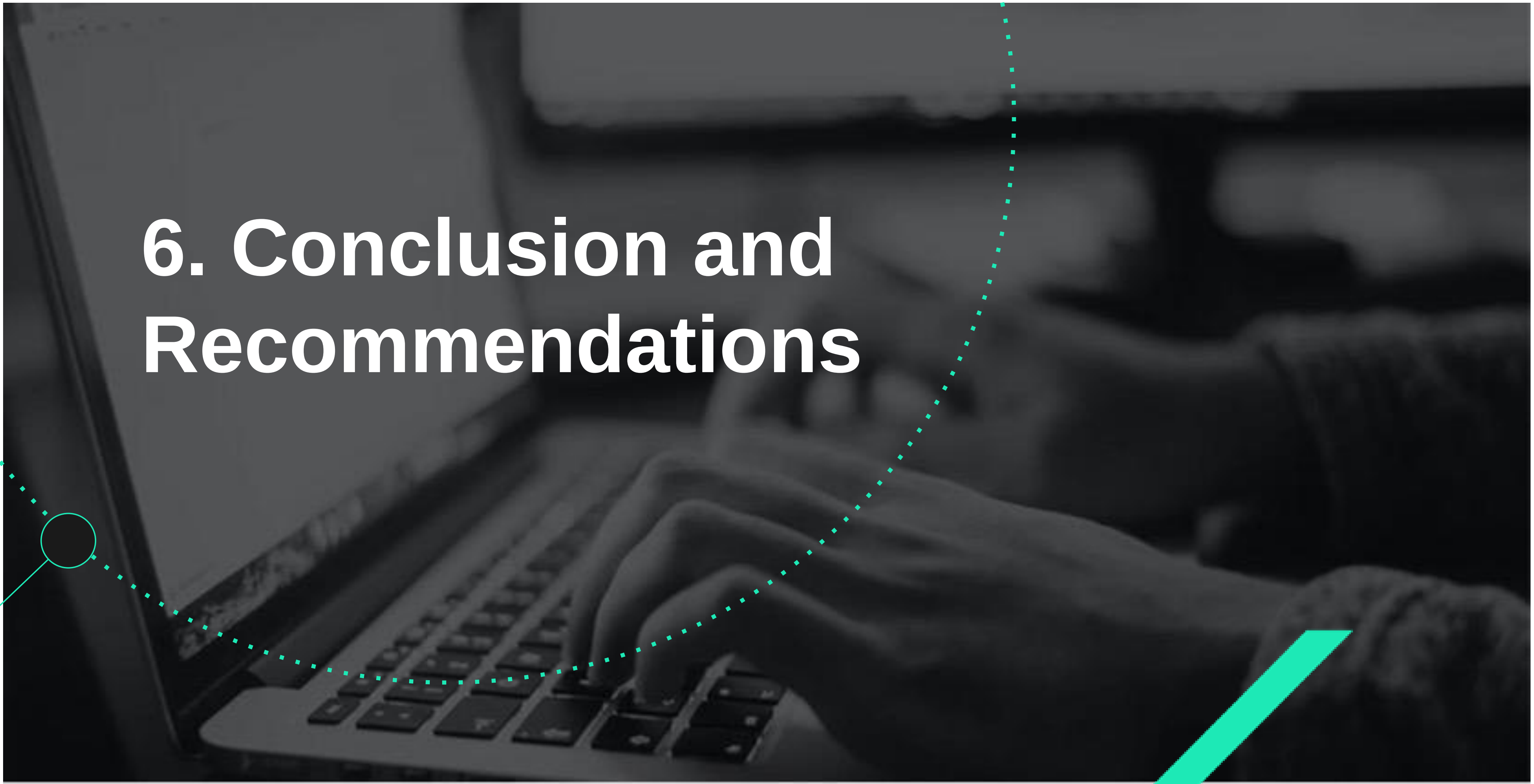
Strategy on green hydrogen and bioenergies : This strategy prioritizes several applications in the hydrogen sector for which the energy demand will be served by Hydro-Québec in complementarity with other sectors including the battery sector.

Socio-Economic Analysis | Focus on SCMs

A **criticality index** was calculated. The latter corresponds to the average of the tensions of the SCMs **that make up the technology** **and** which are **included in the provincial plan. The tension on the SCMs was evaluated in a workshop in collaboration with the MRNF.**

			Battery	Electrolysers				FC	Stationnary tanks		H_2 reactors	
Minerals	**Quebec SCM?**	**Tension**	**Li-ion**	**ALK**	**PEM**	**AEM**	**SOEC**	**PEMFC**	**Gas**	**Liquid**	**Biomass gasification**	**Methane pyrolysis**
Aluminium	Yes	2	1	1	1				1	1	1	1
Silver	No	1			1	1						
Carbon	Yes	4	1	1	1	1			1			
Cerium	Yes	2				1	1					
Chrome	No	-		1	1	1	1	1	1	1		1
Cobalt	Yes	4	1	1		1	1					
Copper	Yes	3	1		1	1	1				1	1
Iron	Yes	-	1	1	1	1	1		1	1		1
Gadolinium	No	-					1	1				
Iridium	Yes	4			1	1						
Lanthanum	Yes	2				1	1					
Manganese	Yes	3	1				1					
Molybdene	No	-		1		1						
Lithium	Yes	4	1									
Nickel	Yes	4	1	1	1	1	1	1	1	1		1
Gold	No	1			1							
Platinum	Yes	3			1	1		1				
Ruthénium	Yes	3			1	1						
Scandium	Yes	1					1					
Silicium	Yes	1	1									
Titanium	Yes	2		1	1	1	1			1		
Yttrium	Yes	3					1					
Zirconium	No	-		1			1					
Quebec SCMs criticality index		-	**3.43**	**3.20**	**3.30**	**3.10**	**2.7**	**3.50**	**3.33**	**2.67**	**2.50**	**3.00**

Criticality (low to high)	0	1	2	3	4	5

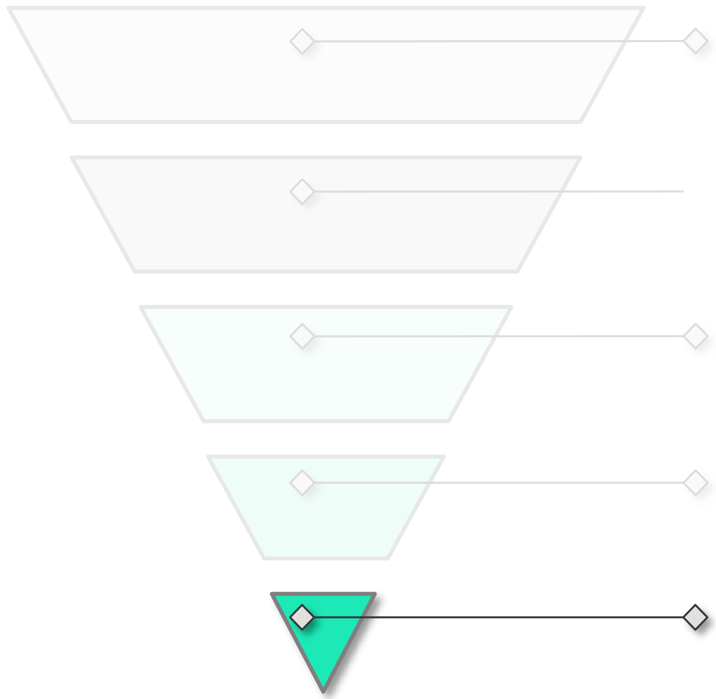


6. Conclusion and Recommendations

Conclusion and Recommendations | Key challenges and objectives

Synthesize the strengths, weaknesses, threats and opportunities for the H_2 manufacturing sector in Quebec. Then, based on the findings of the analysis and meetings with manufacturers, **draw up a set of recommendations** backed up by **well-founded, objective arguments**.

Overall methodology



1. IN-DEPTH STUDY OF THE MANUFACTURING ECOSYSTEM
- **Analysis of 350 H_2 actors** *(Appendix 1.A.)*
- **Selection of 200 actors** for in-depth analysis
- **Study** of their strategies, ambitions, projects, partnerships, etc.
- **Meeting with 30 industry players** *(Appendix 1.B.)*

2. IN-DEPTH ANALYSIS OF H_2 EQUIPMENTS
- **Segmentation of the value chain into 14 segments** of equipment for detailed analysis
- **In-depth analysis of associated markets,** major projects, critical minerals, R&D dynamics, etc.

3. SELECTION OF 4 STRATEGIC EQUIPMENT SEGMENTS
- Identification of key criteria for prioritizing segments: alignment with H_2 strategy, Quebec capabilities, etc.
- Calculation of a score for each segment, then selection of the 4 most promising segments

4. ANALYSIS OF SOCIO-ECONOMICAL IMPACTS
- **Selection of 9 indicators** reflecting the socio-economic impact of manufacturing sector development
- **Study of these indicators for the 3 most mature segments**
- **Specific analysis** for the emerging segment

5. CONCLUSION AND RECOMMENDATIONS
- **Definition of 8 major findings** from previous analyses
- **9 recommendations** associated with these findings

Main Challenges

- **Synthesize a large amount of information** into a coherent set of findings/recommendations
- **Propose recommendations** based on **factual, clear, objective and pragmatic findings**

Scope of Analysis

- **The 4 strategic segments: electrolysers, fuel cells, stationary tanks and H_2 reactors**

Conclusion and Recommendations | Guide to Interpreting the Findings

In the interests of neutrality and objectivity, each recommendation presented below is associated with at least one observation, and is supported by an argument based on an analysis of the ecosystem.

FINDING

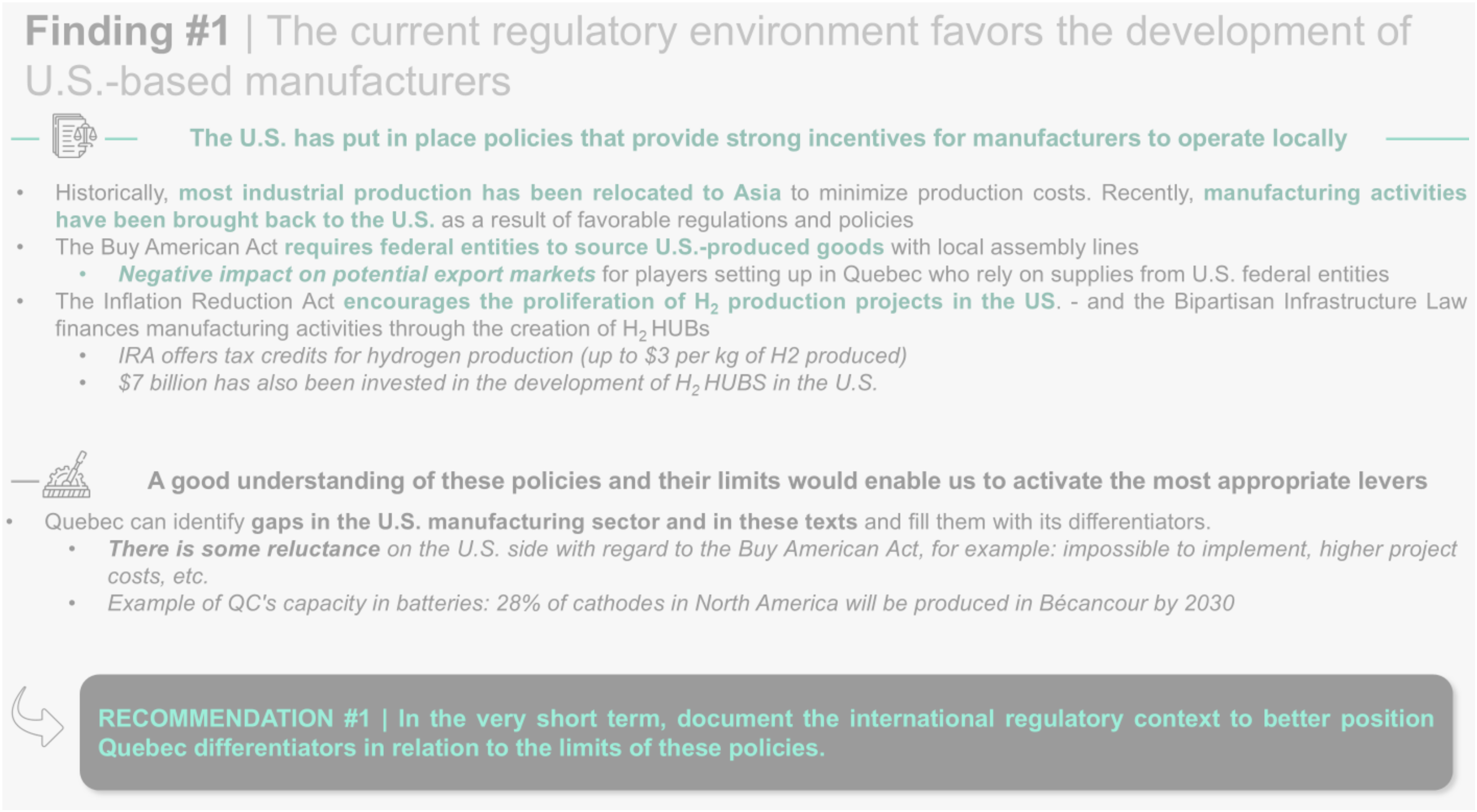
Findings are objective observations that emerge from analysis or interviews with manufacturers

ARGUMENTS

The arguments support and illustrate the findings. They add depth to the analysis

RECOMMENDATION

Based on an observation, the recommendation is issued with the aim of taking advantage of an opportunity or reducing risks



Finding #1 | The current regulatory environment favors the development of U.S.-based manufacturers

The U.S. has put in place policies that provide strong incentives for manufacturers to operate locally

- Historically, **most industrial production has been relocated to Asia** to minimize production costs. Recently, **manufacturing activities have been brought back to the U.S.** as a result of favorable regulations and policies
- The Buy American Act **requires federal entities to source U.S.-produced goods** with local assembly lines
  - ***Negative impact on potential export markets*** for players setting up in Quebec who rely on supplies from U.S. federal entities
- The Inflation Reduction Act **encourages the proliferation of H_2 production projects in the US**. - and the Bipartisan Infrastructure Law finances manufacturing activities through the creation of H_2 HUBs
  - *IRA offers tax credits for hydrogen production (up to $3 per kg of H2 produced)*
  - *$7 billion has also been invested in the development of H_2 HUBS in the U.S.*

A good understanding of these policies and their limits would enable us to activate the most appropriate levers

- Quebec can identify **gaps in the U.S. manufacturing sector and in these texts** and fill them with its differentiators.
  - ***There is some reluctance*** *on the U.S. side with regard to the Buy American Act, for example: impossible to implement, higher project costs, etc.*
  - *Example of QC's capacity in batteries: 28% of cathodes in North America will be produced in Bécancour by 2030*

RECOMMENDATION #1 | In the very short term, document the international regulatory context to better position Quebec differentiators in relation to the limits of these policies.

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Finding #2 | Quebec is unique in its ability to capture value across the entire supply chain

Presence of SCMs in H_2 technologies is an important strategic advantage for Quebec

- Each of the 9 technologies that make up the 4 strategic equipment segments **are made up of at least 50% of SCMs** identified by the provincial strategy - **including 7 technologies with more than 75% of SCMs in common with the Quebec vision**.
- **Manufacturers have identified SCMs as a key issue. The** SCMs market is particularly volatile and sensitive to project announcements.
  - For example, over 60% of the cost of a PEMFC cell is related to platinum

Quebec's workforce is skilled and capable of taking on high-tech phases

- When setting up a manufacturing plant, **an in-depth analysis is carried out to identify which components need to be imported or produced locally**. Quebec has a workforce capable of **handling most manufacturing steps**, especially the more complex ones.

Particular attention is needed to recover value at every stage of production

- When setting up a manufacturing plant, **a detailed analysis of its supply chains** will ensure that Quebec is not positioned solely as a territory where **minerals are extracted and finished technological solutions assembled**, but that **development of intermediate stages** (mineral processing, production of sub-components, etc.) is encouraged as much as possible.

RECOMMENDATION #2 | Scheduling the various links in the supply chain and ensuring that any grey areas are identified when a manufacturer is set up

Finding #3 | Technological choices are key in a developing manufacturing ecosystem

In a context of rapid, ever-changing innovation, betting everything on a single technology would be very risky

- Following the example of the battery industry, **certain technologies that currently dominate the market** (alkaline electrolysers, gas storage, etc.) **could be gradually replaced by technologies that are more efficient/adapted** to market needs. To meet this challenge, some manufacturers are developing adaptable plants capable of making the transition from one technology to another rapidly.

Collaborative innovation as a lever for the development of new technologies

- **Strengthening research/industry links and offering financial support** help to de-risk the innovation process.
    - It could be worthwhile to draw on the support of **industrial research clusters** such as PRIMA, InnovÉÉ, etc., and the VTÉ Hydrogen Innovation Cluster.
- **Facilitate the transition from laboratory to pilot project scale,** particularly for less mature strategic segments (AEM electrolysers, H2 reactors, liquid storage).
    - A number of Investissements Québec's innovation programs can help mature technologies (Innovation Program, Productivité innovation, etc.).

Innovation must be deployed rapidly to take advantage of the current window of opportunity

- With a view to delivering solutions in a timeframe consistent with market needs, **the R&D sector would benefit from the experience and expertise in innovation project management of certain industrial players**

RECOMMENDATION #3 | Foster the development of collaborative innovation between research and industry to develop solutions in the 4 strategic segments linked to green H_2

Finding #4 | The risk of technological mismatches between supply and demand solutions is high

Innovations are very present in the segments studied and in the H_2 sector in general

- The diversity of H_2 solutions developed in laboratories and, more recently, in commercial-scale units, **has created a dynamic for innovation in all directions** - supported by economic competition between companies and regions. This supports a **fragmented economy** in which **technological needs and innovations do not always meet**.

It is necessary to direct and prioritize developments to ensure that solutions find a market within a timeframe aligned with the needs of industry

- Regions have every interest in directing innovation towards new manufacturing techniques, less dependence on certain critical minerals or the use of desirable inputs (brine or contaminated water for electrolysers, for example). However, it is necessary to **define objectives and priorities for each technology in order to rationalize efforts and avoid dispersion**.
  - *Ex : alkaline electrolysers encounter difficulties when the energy source is intermittent. If off-grid projects such as TES Canada are developed in Quebec, should R&D in this technology be prioritized?*
- Too many different technologies can **complicate standardization efforts and end-of-life initiatives**. With too many different forms of components, recycling precious minerals will be a challenge.
  - *R&D prioritization initiatives exist in the USA, with milestones set by the DOE for each technology. Similarly, in Europe, “Strategic Innovation Milestones” anchor a common vision for research.*

RECOMMENDATION #4 | Establish precise, quantified R&D objectives, based on clearly defined guidelines, targets and milestones, which will **support the development of green H_2 equipment in the 4 strategic segments identified.**

Finding #5 | There are a number of technical and economic synergies between the segments and the battery industry

Some manufacturing processes are very similar and require the same components

- **Supporting similar technologies/processes allows several segments to shine with the same investment**
  - ***There are strong complementarities between PEMFC manufacturing processes and PEM electrolysers****, for example. This is due to the reversibility of PEM fuel cells, which can be used in the opposite direction for electrolysis, and thus enables significant synergies between the innovation efforts of the two technologies.*

From the point of view of SCMs and manpower, synergies with the battery industry have also been observed

- **Numerous SCMs are contained in H2 technologies and in the lithium-ion batteries developed in Quebec**: aluminum, carbon, cobalt, copper, iron, manganese and nickel. Complementarities therefore exist in **the recycling chain, in R&D, and in securing significant local demand.**
- **The types of jobs developed** by the plants are also **similar**: technicians, engineers, support, sales, etc. A more in-depth analysis of labor requirements would enable us to identify the bridges between the two sectors.

There's a fine line between synergies and inter-sector competitions

- In cases where labor and SCMs **are in tension, these synergies are transformed into competition** (i.e., an insufficient labor pool for both sectors, and a supply of SCMs too low to support both sectors). It would then be interesting to **quantify precisely these two points to characterize the interactions between the sectors**.

RECOMMENDATION #5 | Give priority to supply chain links that benefit several segments (SCMs, recycling, similar manufacturing processes).

RECOMMENDATION #6 | Define a concrete vision of future demand (SCMs, etc.) and production **to ensure a match between these ecosystems**

Finding #6 | Manufacturers look closely at local authorities' ability and willingness to provide support

Financing helps manufacturers set up shop, but is not the only lever for action

- The following measures actively **support the establishment of manufacturers** in the region:
  - **Simplification of set-up procedures**
  - **Standardization and certification of technologies,** development of standards
  - **Positioning QC as a purchaser of** part of the production process
  - **Establishing contact with the local industrial and academic ecosystem, and helping to develop potential subcontractors**

Quebec would benefit from the development of a common vision on foreign direct investment

- **Standardizing Quebec's** message and “brand image” and **pooling the efforts** to attract **foreign manufacturers** would improve the effectiveness of our actions in this area.

RECOMMENDATION #7 | Standardize and communicate a concerted foreign direct investment attraction plan for potential H_2 manufacturers in identified strategic segments.

Finding #7 | The race is on, and Quebec has strategic assets to position itself

Industrial capacities are already well developed in the most mature strategic segments

- In these markets, **the balance of power currently favors manufacturers**. The majority of international players are large, well-established manufacturers who are diversifying with H2 and looking for the most attractive location.
- These players are primarily looking for **local demand for their equipment, skilled labor, local support and relays, low-cost, decarbonized electricity, SCPs linked to H2 technologies, and so on**.
- Large-scale investment has already been seen in the electrolyser, fuel cell and tank markets, but Noe in Quebec. However, the majority of manufacturers' needs are similar to what the region has to offer - **so Quebec is in a favorable position to host future investments**.

Some strategic emerging markets resonate strongly with Quebec's strengths

- Players who take risks by entering the still-developing markets of **H_2 reactors** or **AEM electrolysers, gain valuable market share and feedback**
- **Expertise in plasma gasification and pyrolysis processes** is held by universities such as McGill, Polytechnique, INRS, UQTR, Concordia and Sherbrooke. Companies such as **Pyrogenesis** in Quebec **and Cypher Neutron** in Ontario are also promising players in these emerging markets.

RECOMMENDATION #8 | Striking a balance by supporting **one technology in mature strategic segments** (FCs, electrolysers and reservoirs) **and one emerging technology** (AEM, plasma pyrolysis, biomass gasification) would **reduce risks and leverage all of Quebec's assets**

Finding #8 | Lack of clear signals from current policies is holding back H_2 manufacturers

The development of a costed industrial policy reduces risk and uncertainty for players

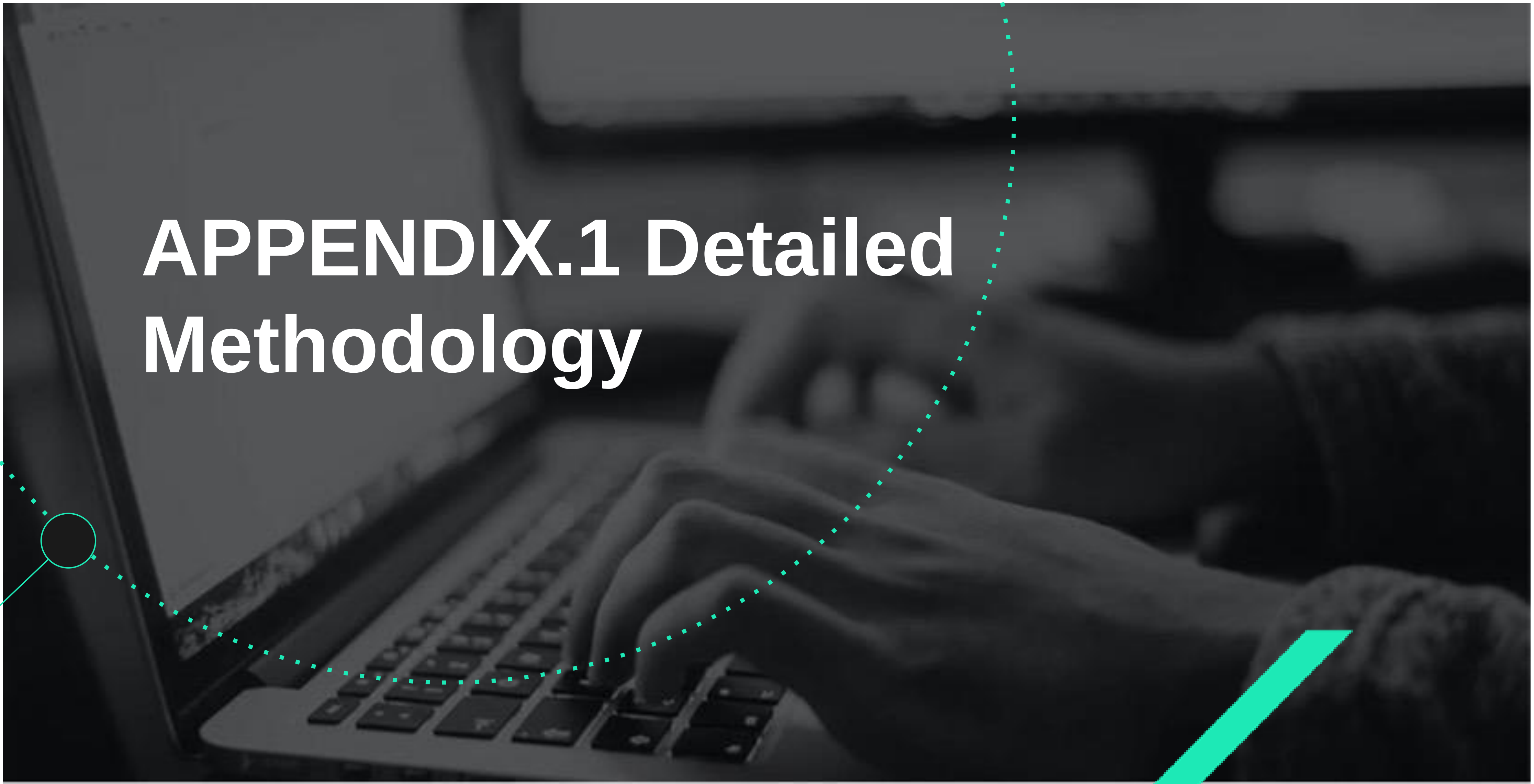
- Le **rationnel principal** dans le choix d’implantation d’un manufacturier réside dans **sa confiance envers la demande locale.** Le déploiement d’une **politique industrielle manufacturière donnerait de la visibilité** et permettrait **de réduire le risque prévisionnel des investisseurs** et **promoteurs.**
- Plusieurs anNoces de projets de grande envergure au Québec (TES, Greenfield, etc.) sont regardées de près par les manufacturiers, mais **la peur des effets d’anNoces dans un écosystème H_2 très volatil freine les investissements**
- Une politique industrielle manufacturière chiffrée **compléterait la vision existante** développée dans Stratégie québécoise sur l’hydrogène vert et les bioénergies qui fixe le cap jusqu’à 2030. Elle pourrait détailler – entre autres - **les orientations R&D, l’implication du milieu universitaire, la part des équipements pour le marché local et pour l’exportation, la demande en SCM,** etc.

Clarifying which technologies to prioritize and which standards to use would facilitate scaling up

- **The H_2 manufacturing universe is difficult to navigate** due to the changing nature of the ecosystem: **regular innovations, standards that vary according to geography, projects, etc**. An industrial manufacturing policy would provide **guidance and a clear vision** for equipment manufacturers.

RECOMMENDATION #9 | Drawing up a costed manufacturing industrial policy (time horizon, objectives, equipment, technologies, SCPs, etc.) for the development of H_2 green equipment in Quebec would help **clarify the uncertainties** raised by the above findings. It could be **linked to a more comprehensive carbon-neutral industrial policy**, as recommended in the report by the Groupe de Consultation pour la Carboneutralité.

APPENDICES



APPENDIX.1 Detailed Methodology

APPENDIX 1.A. | Sources and Types of Information Collected

The analysis is based on a **detailed study of the players making up the manufacturing ecosystem**. To this end, **a complete review of Quebec and international manufacturers was carried out**, identifying a total of over 300 players in the ecosystem.

Ecosystem analysis process

Consolidated list | 312 actors

Elimination criteria | Ex : size of the company, activity sector, etc.

Preliminary list | 156 manufacturers

High-level analysis criteria | Ex : H_2 ambitions, Influence, etc.

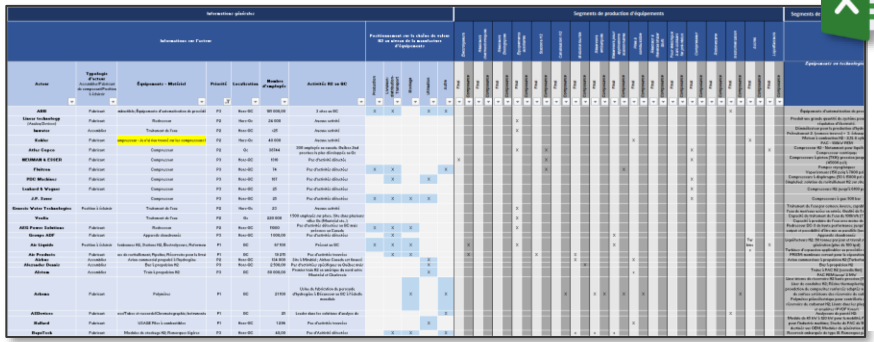
Refined list | 156 manufacturers filtered and analyzed

In-depth ecosystem analysis| Ex : See here

Ecosystem analysis deliverable | 14 equipment segments

Focus on the ecosystem analysis

- **1 | Detailed characterization of the actor**: size, presence in Qc, geography, etc.
- **2 | Identification of the production equipment segment**
- **3 | Analysis of technologies used and intellectual property**
- **4 | Analysis of manufacturing capacity:** number of installations, installed capacity, orders, etc.
- **5 | Strategic/Technological partnerships:** buyouts, joint ventures, implementation in foreign countries, technology supplier partnerships, etc.
- **6 | Other useful information:** ambitions, competitive positioning, key projects, technology applications, etc.



312 actors
High-level

156 manufacturers
In-depth analysis

+800 sources
Used

APPENDIX 1.B. | Interviews with H_2 Industry Players

In parallel with this ecosystem analysis, **individual H_2 players were interviewed** to understand their needs and expectations. In addition, the project steering committee included **several government institutions, and the results were presented several times to a panel of H_2 experts.**

Players interviewed individually

- ArcelorMittal
- Powertech
- SACRÉ DAVEY
- John Cockerill
- FIRST HYDROGEN
- SIEMENS
- Harnois Énergies
- ASDevices
- ABB
- BELL
- BALLARD®
- Swagelok®

Steering committee

- Économie, Innovation et Énergie Québec
- Ressources naturelles et Forêts Québec
- Relations internationales et Francophonie Québec
- Investissement Québec
- PRIMA Les matériaux pour avancer

Experts du milieu

- InnovÉÉ Innovation en Énergie Électrique
- Hydrogène Québec
- Natural Resources Canada / Ressources naturelles Canada CanmetÉNERGIE *Leadership en écoInnovation*
- Investissement Québec
- CHARBONE
- Evolugen
- UQTR Université du Québec à Trois-Rivières
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