

**Master's Thesis**

**Breaking through the Hype Cycle:**

**Has Hydrogen's Time Finally Come in Canada?**

Patrick Fleming

Master's thesis submitted to the University of Ottawa in fulfillment of the requirements for the

Master of Science in Environmental Sustainability

Institute of the Environment, University of Ottawa

Ottawa, Ontario

Supervised by Dr. Ryan Katz-Rosene

Thesis Committee: Dr. Monica Gattinger & Dr. Nicholas Rivers

© Patrick Fleming, Ottawa, Canada, 2023

## Table of Contents

Acknowledgements.....	iii
Abstract.....	iv
List of Figures.....	vi
List of Tables.....	vii
Chapter 1: Introduction.....	1
1. Introducing the Thesis.....	1
2. Hydrogen 101.....	2
3. Background Context.....	3
4. Research Problematique.....	10
5. Literature Review .....	10
Chapter 2: Methodological Approach.....	14
1. Introduction.....	14
2. Research Approach.....	14
3. ESPELT Analysis.....	15
4. Collection of Primary Data.....	17
5. Collection of Secondary Data.....	18
6. Analysis and Techniques.....	19
Chapter 3: The Post-Kyoto Hydrogen Hype Cycle Analysis	
1. Environmental Analysis.....	21
2. Social Analysis.....	27
3. Political Analysis.....	33
4. Economic Analysis.....	47
5. Legal Analysis.....	53
6. Technological Analysis.....	60
Chapter 4: The Post-Paris Hydrogen Hype Cycle Analysis	
1. Environmental Analysis.....	67
2. Social Analysis.....	73
3. Political Analysis.....	80
4. Economic Analysis.....	91
5. Legal Analysis.....	97
6. Technological Analysis.....	104
Chapter 5: Takeoff Point- The Hydrogen Hype Cycle Discussion.....	112
Chapter 6: Conclusion.....	121
References.....	126
Appendix 1: Interview Guide .....	151
Appendix 2: Interview Annex.....	153

### *Acknowledgements*

I would like to express my deepest appreciation to my supervisor Dr. Ryan Katz-Rosene for your patience and guidance. Thank you to my thesis committee members, Dr. Monica Gattinger and Dr. Nicholas Rivers, for your insights into my research topic.

I am grateful to all the interview participants who provided valuable information that added to my research. I learned so much during these interviews, and I genuinely appreciate the time it took to discuss my research topic. I appreciate the contributions and feedback I have received from my interview participants and look forward to following your continued work in the hydrogen space.

I thank my family and friends for their continued support and encouragement throughout my research. All of you have been a part of this journey, and I am genuinely grateful to everyone who helped me complete my Master's thesis research.

## *Abstract*

In the face of climate change, many have argued that developing low-carbon energy technologies must be prioritized. Many countries recognize hydrogen as a low-carbon solution that has the potential to meet increased domestic energy demands while addressing the need to prioritize low-carbon targets. The Canadian government and several provinces have indicated their current intentions to facilitate a growing domestic hydrogen-based economy, however, this is not Canada's first attempt at doing so. Canada previously pursued developing clean hydrogen in the early 2000s, but without success.

This Master's thesis aims to examine Canada's historical and contemporary attempts to establish a sustainable hydrogen market in Canada. Specifically, my research sought to answer whether hydrogen is poised to take off within the current hype cycle or will be stifled, such as in previous attempts. My research aimed to explore this question by examining and comparing historical and contemporary literature relevant to hydrogen development in Canada. My research utilized an ESPELT analysis and involved interviewing multiple experts from across the country to reveal any nuances that underline the barriers and opportunities for determining the viability of Canada's domestic hydrogen market within the contemporary context.

My research uncovered that the likelihood of clean hydrogen taking off in Canada would depend on multiple factors, most of which have been addressed from previous iterations to propel hydrogen into the Canadian energy mix. Namely, these enabling factors include: a) the rise of efficient technologies that enable the production of clean hydrogen; b) supportive legislation that facilitates lowering costs; c) political willingness to reduce harmful emissions;

and d) the urgency to address climate change. Today, hydrogen has emerged once again as a contender to produce low-carbon solutions within hard-to-abate sectors, targeting the emissions from industries which have been traditionally challenging to decarbonize. As Canada narrows its focus on leveraging these advantages to stimulate its domestic hydrogen market, decision-makers understand the value of hydrogen in mitigating climate change and achieving a low-carbon economy in alignment with its international commitments to address climate change. Overall, my research points to a greater likelihood of the current hydrogen hype cycle having the greatest potential to establish a sustainable hydrogen market in Canada due to challenges from previous hype cycles being addressed.

## List of Figures

Figure 1A: Revenue and R&D in Canadian Hydrogen Sector.....	p.7
Figure 1B: Employment in Canadian Hydrogen Sector.....	p.7
Figure 2: Global CO2 Emission from Energy Combustion and Industrial Processes ('95- '05). p.	23
Figure 3: Global CO2 Emission from Energy Combustion and Industrial Processes ('00- '22). p.	68

List of Tables

Table 1: Emergence of Hydrogen ESPELT Analysis.....p.119

## CHAPTER 1: INTRODUCTION

---

### *Introducing the thesis*

The idea of using hydrogen as clean energy fuel is not new in Canada. As the Government of Canada's *Hydrogen Strategy for Canada* (2020) notes, hydrogen fuel was first produced in Canada almost a century ago, and commercial advancements in fuel cell technology were achieved approximately 40 years ago. Moreover, the Government of Canada made a concerted effort in the early 2000s to build a robust hydrogen sector (Theckedath, 2010). Despite this, hydrogen remains a small part of Canada's energy sector today (in 2023), accounting for less than 1% of Canada's overall energy supply (Canada Energy Regulator, 2023). This begs two questions: where did previous efforts to build a sustainable hydrogen economy go wrong? Are current conditions favourable to support a scale-up to a hydrogen-based economy? This thesis examines the historical and contemporary moments in hydrogen's history through an 'ESPELT' analysis (examining the Environmental, Social, Political, Economic, Legal, and Technological contexts underlying the Canadian clean hydrogen sector development). I apply an ESPELT analysis to both what I call the previous hydrogen hype cycle era ("the Post-Kyoto period", from 2000 – 2004) and the contemporary hydrogen hype cycle era ("the Post-Paris period", from 2018 to present). As described by Yap & McLellan (2023), hype cycle models track clean hydrogen development as they progress through successive stages of "peak", "disappointment", and "recovery of expectations" (Yap & McLellan, 2023). These time frames were selected because they represented the points where clean hydrogen garnered the most attention.

I argue, in short, that attention directed toward developing clean hydrogen in Canada will result in a robust clean hydrogen market and firmly establish clean hydrogen as a critical component of Canada's efforts to decarbonize its economy. My thesis research aims to inform contemporary policy discussions about Canada's sustainable energy future by comparing both hydrogen hype cycle eras and determining whether the modern factors that will contribute to establishing a robust hydrogen market in Canada this time around.

### *Hydrogen 101*

Hydrogen is a clean-burning molecule that could become a zero-carbon substitute for fossil fuels in hard-to-abate sectors of the economy (BloombergNEF, 2020). The Government of Canada has seen clean hydrogen as a critical tool to facilitate Canada's shift away from higher-carbon fuel sources in all sectors (Hydrogen Strategy for Canada, 2020). Hydrogen will be used to achieve the Government of Canada's environmental objectives that Canada has committed to, such as reducing GHG emissions by 30% below 2005 levels by 2030 and attaining net-zero emissions by 2050 (BC Hydrogen Strategy, 2021).

Hydrogen is an energy carrier, like electricity, that can store and transport energy from other sources (Karaca AE & Dincer I., 2021). Hydrogen is versatile because it can provide heat, fuel, electricity, energy storage or feedstock (Canadian Climate Institute, 2021). For instance, hydrogen can be used in heating appliances such as furnaces, boilers, water heaters, gas fireplaces, stoves, and laundry dryers (Government of Alberta, 2022). Hydrogen fuel cells can generate power, and producing hydrogen via electrolysis from intermittent renewables can be used as an energy storage medium (Government of Alberta, 2022). Furthermore, hydrogen fuel

cells can power cars, buses, trucks and trains, and hydrogen co-combustion engines can be implicated in heavy-duty applications (Government of Alberta, 2022). When hydrogen is used in a fuel cell, the process only produces water and heat as a by-product, which allows for cleaner power generation (as compared to hydrocarbons, which emit greenhouse gases and air pollutants). Due to its versatility, hydrogen is one of the only solutions for decarbonizing sectors of the economy where direct electrification is impractical, such as heavy-duty transportation and industrial heat applications (BC Hydrogen Strategy, 2021). Therefore, implementing hydrogen in hard-to-abate sectors can help decarbonize the Canadian economy by replacing fossil fuels with new hydrogen-based applications. For these reasons, clean hydrogen continues to be highlighted as a potential decarbonization tool for a low-carbon future.

### *Background Context*

The Canadian awareness of hydrogen's potential to be used as a fuel and energy storage medium was known from the early 19<sup>th</sup> century, with Canadian companies emerging as leaders in the hydrogen space leading into the early 2000s. The first recognition of hydrogen as a fuel source was in 1804 when the first internal combustion engine in history was powered by hydrogen (Rifkin, 2002). Since then, hydrogen has been commercially produced in Canada, with Canada's Electrolyser Corporation Limited representing one of the first enablers of hydrogen in North America (Rifkin, 2002). The Canadian company manufactured and sold the first commercial electrolyzers to U.S. companies in San Francisco in 1920 (Rifkin, 2002). However, Canada's research and development of hydrogen didn't stop there, with numerous hydrogen companies beginning to emerge into the hydrogen space leading into the 1980s. Fast forward to 1989, when Canadian Geoffrey Ballard developed a new fuel cell that used a conducting

polymer as the electrolyte, which was perceived as a significant improvement from existing fuel cell technologies (Rifkin, 2002). Hydrogen's early beginnings were promising, motivating Canadian research and development that led to hydrogen technology's continued growth and resulting in technological breakthroughs.

In the early 2000s, after decades of technological advancements in hydrogen fuel and fuel-cell development, Canada made a concerted effort to build a sustainable hydrogen economy<sup>1</sup> (Liu et al., 2012). However, this effort failed due to hydrogen's lack of cost competitiveness, unavailability of enabling infrastructure, and little public confidence in the technology (Hydrogen Council, 2020). Canada's hydrogen market still represents an insignificant portion of Canada's energy mix today. Although hydrogen accounts for less than 1% of Canadian energy demand today, proponents forecast hydrogen will fulfill 27% of domestic energy demand by 2050 (Mortlock, 2021). According to Canada's Hydrogen Strategy, the Canadian hydrogen market will potentially generate \$50 Billion in domestic revenue; create more than 350,000 jobs; and deliver up to 30% of Canada's end-use energy while abating up to 190 Mt-CO<sub>2</sub>e of GHG emissions through deployment in transportation, heating, and industrial applications (Hydrogen Strategy for Canada, 2020).

For my research, I will define the success of clean hydrogen's establishment by measuring Canada's recent attempts to scale up hydrogen in accordance with these benchmarks. Canada's successful implementation of a robust clean hydrogen market will determine whether

---

<sup>1</sup> I define "sustainable hydrogen economy" as an economy which utilize hydrogen to meet a substantial portion (at least 25%) of domestic energy demand, while sourcing the hydrogen from low-carbon sources

hydrogen will project to meet 25% of Canada's domestic energy demand by 2050, creating 300,000 jobs and \$40 Billion in domestic revenue.

In the early 2000s, the Government of Canada set the stage for the initial emergence of Canada's potential hydrogen market. In 2005, the Government of Canada released a discussion document that focused on establishing a national hydrogen and fuel cell strategy. The discussion paper highlighted the opportunities Canada possessed that would facilitate the adoption of hydrogen within the Canadian landscape and benefit many aspects of Canadian society, including offering Canadians economic, environmental, and social benefits (Government of Canada, 2005). By releasing these policy papers, the Government of Canada revealed its ambition to take advantage of the emerging optimism surrounding clean hydrogen. However, the Government of Canada's research into hydrogen highlighted the limitations of the clean energy carrier.

For instance, in 2006, Natural Resources Canada consulted with other federal departments, and with the Provinces and Territories to reach a general consensus on the principal economic assumptions in a Canada's Energy Outlook 2006 report that provided a reference outlook for Canadian energy supply and demand up to 2020. The Outlook report highlighted the limitations of hydrogen and referenced to lower optimism about hydrogen's application within the transportation sector, citing that the "significant use of hydrogen-fueled vehicles is not envisaged during the outlook period" (Natural Resources Canada, 2006). Furthermore, hydrogen's limitations were detailed in a comprehensive profile of the Canadian hydrogen and fuel sector developed by the Government of Canada, Fuel Cells Canada, and

PricewaterhouseCoopers titled the Canadian Hydrogen and Fuel Cell Profile 2005. The profile revealed numerous pessimistic insights into the growth of the Canadian hydrogen market over the 2003-2004 period. These insights underlined an overall *decrease* in the Canadian hydrogen industry's revenue from \$188 million to \$133 million, a *reduction* of research expenditures of 18%, and a *decrease* in demonstration projects of 18% from 2003 to 2004 (The Canadian Hydrogen and Fuel Cell Association, 2005). In hindsight, while the report recognized the sector's growth from 2001 to 2004, it did cite an eventual downturn in 2005, which led to a *decrease* in optimism surrounding clean hydrogen production in Canada.

The hydrogen hype cycle can be depicted below in graphs derived from data that the Canadian Hydrogen and Fuel Cell Association developed with the Government of Canada throughout the early 2000s into their most recent publication in 2022. These tables display the emergence of the “Hydrogen Economy” and illustrate the boom-and-bust cycles associated with hydrogen development in Canada. Figure (1A) showcases the amount of revenue and the RD&D investments in the Canadian hydrogen sector over the previous two decades. Figure 1B demonstrates the employment levels within the Canadian hydrogen sphere, accounting for a significant rise in employment numbers from 2019 to 2021. The figure also reflects the volatility of work with hydrogen from the early 2000s (1,800 employed), spiking to over 2,000 employed from 2006 to 2011 and then towards 2016 (1,846 employed) (The Canadian Hydrogen and Fuel Cell Association, 2022).

Figure 1A

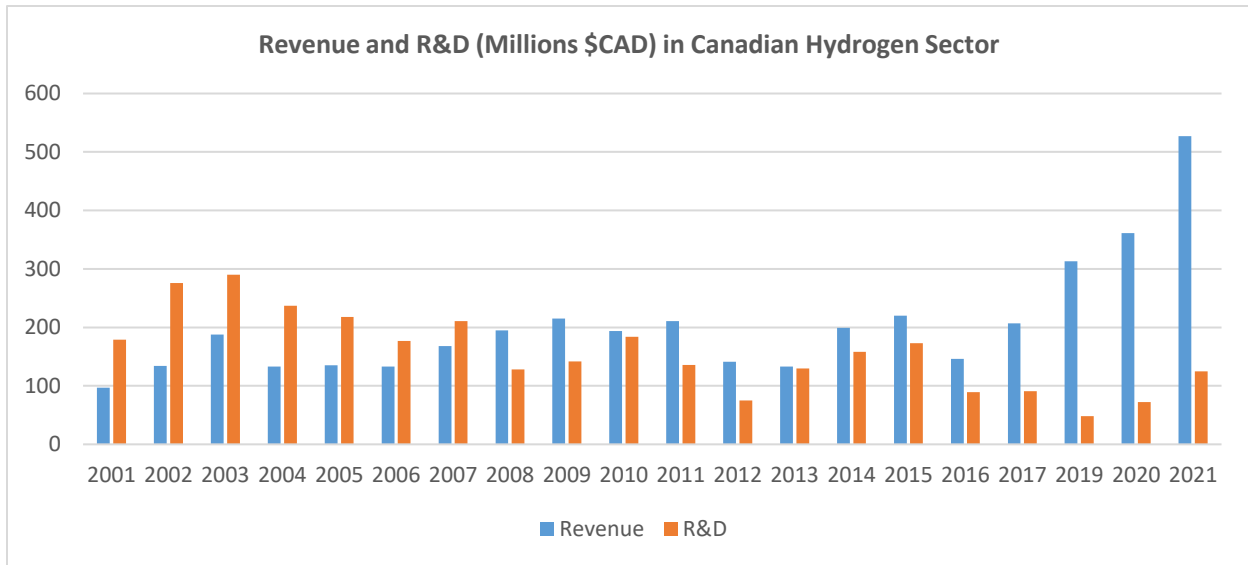


Figure 1A: Revenue and R&D in Canadian Hydrogen Sector). Source: Data from Canadian Hydrogen and Fuel Cell Association, 2022, created by Patrick Fleming.

Figure 1B

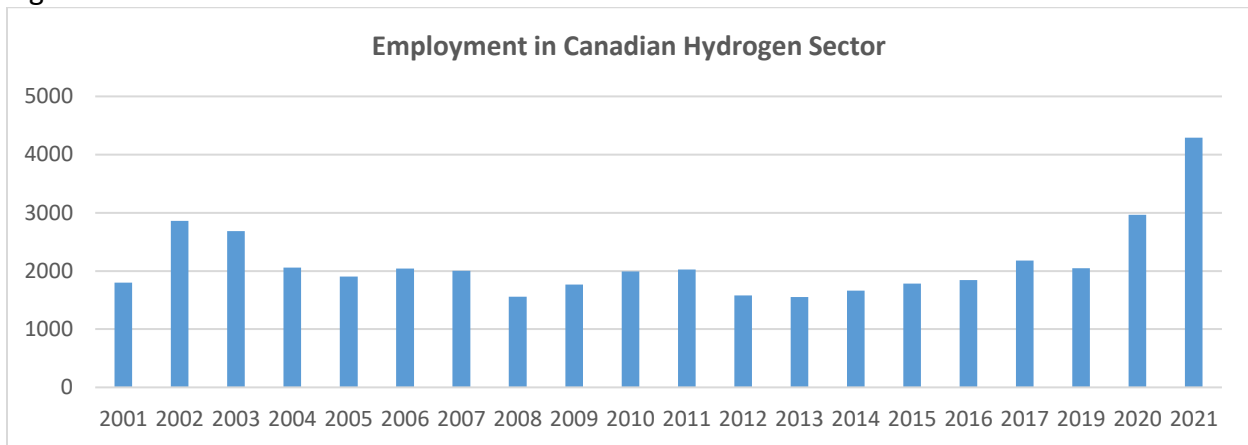


Figure 1B: Employment in Canadian Hydrogen Sector. Source: Data from Canadian Hydrogen and Fuel Cell Association, 2022, created by Patrick Fleming.

Regardless of its disappointing history, there is optimism today regarding the potential establishment of the Canadian hydrogen market in the coming years. This is highlighted by Canada's ambitions to use its abundant natural gas resources for "blue hydrogen"<sup>2</sup> production

<sup>2</sup> Clean hydrogen can be produced from fossil fuels with carbon capture, utilization, and storage (Blue Hydrogen).

and utilize the country's ample access to the electricity required for electrolysis paired with an advanced clean power system to advance pathways for "green hydrogen"<sup>3</sup> production (Canadian Climate Institute, 2021). Additionally, since 2018 the Government of Canada has made critical investments to accelerate hydrogen uptake within the industry to ensure that clean hydrogen suppliers will have demand for their products domestically. This includes a \$1.35 million investment by the Government of Canada to test and demonstrate compatible hydrogen technologies at a C-FER Technologies Edmonton facility (Prairies Economic Development Canada, 2021). Furthermore, the Government of Canada is working towards researching potential partnerships and transportation avenues to expand hydrogen demand to overseas markets by implementing its Canadian Hydrogen Strategy at the federal and provincial levels (Hydrogen Strategy for Canada, 2020).

Nevertheless, vital questions persist surrounding the feasibility of establishing and implementing a robust hydrogen market in Canada. Initial criticisms directed at current hydrogen production focus on its historical shortcomings, including its inability to become cost-competitive with other energy sources (Robitzski, 2018). Critics such as Howarth and Jacobson have pointed to hydrogen production pathways that lean on unproven assumptions of the efficiency of carbon capture technology leading to questions surrounding hydrogen's actual environmental performance (Howarth & Jacobson, 2021). Ultimately, for the hydrogen industry to truly take off, not only will hydrogen have to be clean, but it will have to address some of its past and current limitations to rival other sources of energy (Robitzski, 2018).

---

<sup>3</sup> Clean hydrogen can be produced from low-carbon electricity (Green Hydrogen)

Although Canada does possess a significant opportunity to produce hydrogen at a large scale, Canada can observe its past limitations of hydrogen production to inform policy decisions now and into the future. Examining the past barriers to upscaling hydrogen production within the contemporary renewable energy policy field may enable a better understanding of whether hydrogen has an important place within the energy mix of a low-carbon future in Canada.

Through this contrast of the historical and contemporary barriers to hydrogen production in Canada, new considerations may emerge which could inform the policy decisions surrounding hydrogen today. Additionally, a holistic analysis of the previous attempts and momentum shifts in producing hydrogen may contribute to continuing investments in hydrogen production in Canada.

Through my proposed ESPELT analysis of both historical (from 2000- 2004) and contemporary (from 2018- 2022) periods in Canadian hydrogen development, I will be able to evaluate the salience of the claims made by both hydrogen proponents and critics. For this thesis, I will name the historical period (from 2000-2004) the **“Post-Kyoto Period”** and the contemporary period (from 2018-2022) the **“Post-Paris Period”**. I have decided to name these periods to align with Canada’s previous international environmental commitments, the Kyoto Protocol (adopted in 1997) and the Paris Agreement (adopted in 2015), and their influence on domestic hydrogen development within the context of fighting climate change. By contrasting Canada's previous attempts to establish and develop a sustainable hydrogen market with its current efforts, this analysis will help determine whether Canada's clean hydrogen production will likely address the contemporary environmental concerns of Canada's low-carbon future. It will also determine whether clean hydrogen can become cost-competitive with other energy sources, thereby

contributing to crucial domestic policy discussions about the future of sustainable energy in Canada.

### *Research Problematique*

As the underlying market for renewable resources has shifted and Canada positions itself to invest heavily in hydrogen production, revisiting policy directions about previous attempts at producing a Canadian hydrogen market has become essential to identifying hydrogen's decarbonization potential to meet 2030 and 2050 climate goals. Therefore, with the understanding that Canada will accelerate investments in hydrogen production, I plan to examine the question, "Are Canada's contemporary attempts to establish a hydrogen market likely to be successful, and have hydrogen's past limitations been addressed to show signs that clean hydrogen will take off this time around"?

### *Literature Review*

The global transition to a low-carbon future is an opportunity for Canada to become a leader in sustainable energy. Canada and 185 countries signed the Paris Agreement to reduce greenhouse gas (GHG) emissions and achieve clean growth and prosperity (Government of Canada, 2019). Numerous governments worldwide and other stakeholders from industry, non-profits, and academia have identified clean hydrogen as a critical target fuel to help achieve net-zero goals by 2050. As the Government of Canada seeks to invest in low-carbon fuels, clean hydrogen potentially represents a way to reduce and improve the environmental performance in Canada's energy sector while supporting job growth and economic transition to a low-carbon future (Government of Canada, 2019). For instance, Canada could potentially utilize the

benefits of clean hydrogen production to diversify from hard-to-abate sectors by substituting hydrogen as a renewable transport fuel for domestic applications, including heavy transportation in long haul trucks and industrial processes such as steelmaking. Furthermore, hydrogen fuels (and the new tools developed to produce them) could be marketed and exported to other countries.

Recent interest in hydrogen can be attributed to many factors, including, but not limited to, technological improvements which have contributed to hydrogen's increased viability, versatility, safety, and accessibility (Hydrogen Council, 2020). Canada has had an initial deployment of production and end-use applications. Canada deployed the first industrial-scale hydrogen production in the 1920s, the first fuel cell bus demonstration in the 1990s, and the first fuel cell forklift and light-duty fuel cell electric vehicle in the early 2000s (Government of Canada, 2020). Despite Canada's history of exploring hydrogen's viability, numerous factors have inhibited the adoption of hydrogen in Canada. At the root of the challenge of producing climate-friendly hydrogen is ensuring low levels of lifecycle GHG emissions while balancing higher costs associated with more sustainable forms of hydrogen production. Hydrogen production costs depend heavily on inputs such as natural gas and electricity (BC Hydrogen Strategy, 2021). Although Canada's hydrogen economy has yet to take off, enabling factors to have indicated that this recent emergence may signal hydrogen's arrival as a serious contender within Canada's renewable energy discussion.

The available literature does not concentrate on Canada's efforts to implement its hydrogen strategy through contrasting attempts via historical and contemporary lenses. Instead,

literature focusing on Canada's historical attempts to produce hydrogen is limited to the Government of Canada's released roadmaps, discussion papers and strategies focused on the conditions at their respective publication dates (Theckedath, 2010). Otherwise, literature that discusses contemporary hydrogen research focuses on developing a domestic and international market for hydrogen, ensuring the viability of production pathways in Canada, and enabling technological advancement in the hydrogen space (Hydrogen Strategy for Canada, 2020). Discussions regarding Canadian hydrogen production are centred on utilizing its abundance of feedstock options, such as its natural gas reserves for blue hydrogen production or stimulating green hydrogen production through more investments in renewable energy sources (BloombergNEF, 2020). In addition to the viability of production pathways, the literature points to the numerous conditions that favour hydrogen's potential to decarbonize hard-to-abate industries (Government of Alberta, 2020).

Therefore, there is a need to examine hydrogen's previous hype cycle (the Post-Kyoto period) in the Canadian context to inform the costs and benefits of current policy efforts in the Post-Paris Period to enable the hydrogen industry to take off. Research into the questions of the past that pertain to Canada's efforts to develop policy frameworks that will allow hydrogen emergence may address today's uncertainties related to hydrogen production. After carefully reviewing the current literature on hydrogen production in Canada, this thesis research will thus aim to inform the policy discussion about the appropriate pathways forward for Canadian hydrogen development and analyze the previous policy decisions that impacted the prevention of an established hydrogen market in Canada. The research will follow a categorization into the

current levels of hydrogen production in Canada, historical perspectives of hydrogen production, and the outlook of future hydrogen production within the Canadian context.

## CHAPTER 2: METHODOLOGICAL APPROACH

---

### *Introduction*

This chapter outlines the methodological approach taken to complete this thesis. First, the research approach that directed this research is described. Secondly, primary data collection is discussed, followed by the methods used to collect secondary data. The final two sections are analysis methods and methodological limitations. A concluding summary is provided at the end of the methodology section.

### *Research Approach*

For this research thesis, I collected primary and secondary research on developing clean hydrogen within Canada to increase my data pool for my analysis and discussion sections. The study collected primary and secondary data from an extensive literature review of historical and contemporary documents about hydrogen development in Canada. Additionally, semi-structured interviews with eleven (11) Canadian hydrogen experts were conducted to capture nuances and insights that the literature may not provide. I chose this method of collecting data primarily because it provided the most holistic approach required for answering whether a robust hydrogen market will be established in Canada this time around. It aimed to review past barriers to the Canadian hydrogen market's takeoff and examine contemporary hydrogen production. By collecting data through primary and secondary resources, I would enable a comprehensive review of the chosen time frames, which were the early 2000s hype cycle (Post-Kyoto period) and the 2020s hype cycle (Post-Paris period).

### *ESPELT Analysis*

The initial research was conducted using an altered ESPELT analysis that is a slight variation from a "PESTEL" analysis (which examines the political (P), economic (E), social (S), technological (T), environmental (E), and legal (L) parameters of the current literature surrounding hydrogen production in Canada. An ESPELT analysis works to evaluate the impact of external factors on the implementation of new technology and the contexts for its implementation (Thomas et al. 2021). For this thesis, the ESPELT categories have been arranged to reflect the logical flow of the environmental focus of the thesis research. For instance, the ESPELT follows an order that emphasizes the E- Environmental, S-Social, P- Political, E- Economic, L-Legal, and T-Technological explorations into hydrogen development in Canada. Through an ESPELT analysis, I will be able to examine the contrasts between the Post-Kyoto and Post-Paris hydrogen hype cycles to provide a comprehensive understanding of hydrogen's emergence in Canada.

An ESPELT analysis was chosen as the particular method for examining hydrogen development in Canada as it offers a "useful way of exploring issues that are mainly qualitative in nature and for analyzing problems holistically" (Thomas et al. 2021). An ESPELT analysis uses a multi-dimensional framework for evaluating a nascent technology and evaluating the many factors that lead to its successful implementation within an economy. By employing this method of analyzing hydrogen development in Canada, the thesis will be better equipped to explore the risks, opportunities, and challenges associated with determining hydrogen's emergence within the contemporary context. Exploring each of the different categories within an ESPELT analysis will be able to contribute to the research problem by assessing the credibility of each category

with relevance to hydrogen production through a lens that will indicate the most viable pathway within the Canadian context.

The *environmental* sections of the ESPELT analysis aim to explore the environmental considerations for hydrogen development; this includes the environmental challenges that impact Canada and other countries, and the resulting understanding of hydrogen's potential environmental benefits to address climate change. The *social* sections of the ESPELT analysis aim to explore the historical perceptions of the development of the hydrogen market in Canada, including the perceived limitations and benefits of hydrogen development in Canada and the emerging environmental awareness towards climate change. The *political* sections explore the major Canadian political parties' responses to the emerging climate movements during the two examined hydrogen hype cycles, including the domestic party platforms and international geopolitical considerations. The *economic* section aims to explore the economic barriers associated with the development of hydrogen, including a perspective on the cost competitiveness of clean fuel during the Post-Kyoto Period and the Post-Paris Period. The *legal* section aims to analyze the laws and regulations that have enabled the development of hydrogen in Canada. Finally, the *technological* sections of the ESPELT analysis aims to examine the available technology, applications and production pathways that enabled the development of hydrogen in Canada. The ESPELT categorization guided the type of data collected by narrowing the focus within specific categories that showcased enabling and limiting factors to answer the research questions about whether a robust hydrogen market would be forecasted to take off this time.

### *Collection of Primary Data*

Two primary data sources were collected for this research thesis: a literature review comprised of primary documents and virtual semi-structured interviews (Yin, 2016). The virtual semi-structured interviews were conducted with each participant for approximately 30 to 45 minutes. Yin (2016) describes structured interviews as an *interaction* between an interviewer and a participant and outlines the structured interview process: first, the researcher will use a formal questionnaire that lists every question to be asked; second, the researcher will formally adopt the role of an interviewer, trying to elicit responses from an interviewee; and third, the researcher as the interviewer will try to adopt the same consistent behaviour and demeanour when interviewing different participants (Yin, 2016). The goal is to encourage the participant to have the time and opportunity to reconstruct their own experiences and reality through their perspectives (Yin, 2016).

I conducted eleven interviews (11) virtually over Microsoft Teams and recorded each interview, using the built-in recording feature, which developed a transcript and video recording. Before the interviews, participants were identified through various methods, including recent publications on clean hydrogen held in the uOttawa library database, thinktank webinars presented by the Transition Accelerator or the Canadian Institute for Climate Choices, and social media platforms such as LinkedIn and Twitter. As a result of their expertise in the hydrogen field, experts would be expected to provide valuable input into the historical and contemporary landscape of hydrogen development in Canada. Additionally, they provided insights into potentially answering whether hydrogen is poised to take off this time within current efforts. To provide a holistic understanding of the historical and contemporary

landscape of the hydrogen field in Canada, experts representing academia, the private sector, the non-profit sector, the government, and Indigenous groups were invited to participate in interviews (Appendix II).

After each interview, the transcripts were reviewed and manually corrected using the audio recording. The transcripts were then emailed to the participant for their review. This allowed participants to provide any clarifications for their answers and any feedback on the research. These transcripts were then integrated into the ESPELT and discussion portions of the thesis research.

#### *Collection of Secondary Data*

A qualitative approach was conducted to fully explore my research question, which involved a literature review supporting a comprehensive, two-phase resource-deployment analysis called a "PESTEL analysis" (developed by Thomas et al. 2021). The analysis evaluates external factors' impact on implementing new technology and the contexts for its performance. Ultimately, analyzing within this framework permitted my research to evaluate the parameters for the market development of the chosen commodity, which in this case was hydrogen (Thomas et al. 2021).

This literature review was conducted by researching relevant academic articles, news articles, discussion papers, and reports from online sources. Online sources also included trending news articles on hydrogen production, which mainly questioned the viability of hydrogen as an alternative fuel source. In addition to online news articles available, online discussion papers and reports were included in the literature review. Information from the International Energy

Agency (International Energy Agency A, 2022) and other international organizations provided historical and contemporary data useful for research purposes. Reports from think tanks such as the Smart Prosperity Institute (Allan et al., 2022), the Canadian Institute of Climate Choices (Canadian Climate Institute, 2021), and the David Suzuki Institute (The David Suzuki Foundation, 2000) were included.

I researched within the uOttawa library database to collect relevant contemporary articles, which were more abundant than articles related to hydrogen production within a historical context. In addition to consulting online sources through the uOttawa online library database, I ordered physical copies of government documents available at other universities in Ontario through Interlibrary Loans. This included government marketing material from McMaster University and the University of Guelph, which detailed some promotional material about hydrogen development in Canada almost twenty years ago. Finally, I also research material from Library and Archives Canada, and Government of Canada publications in the Canada Gazette.

### *Analysis and Techniques*

The data analysis was conducted by categorizing the collected literature into the different ESPELT subsections. A number of the analyzed publications had cross-cutting studies of the hydrogen market in Canada, which facilitated the categorization of the data. Additionally, the year of their publication facilitated the separation of the data into the historic and contemporary portions of the ESPELT research. I categorized articles from the 2000-2004 Post-Kyoto Period, and the 2018-2022 Post-Paris Period. Through this categorization of data, I could

analyze and identify critical patterns within the research, which facilitated the development of the discussion portion of the study by showcasing enabling and limiting factors that led to clean hydrogen's failed emergence in the Post-Kyoto period and pointed to the optimism surrounding the contemporary Post-Paris period. The 2005 to 2018 period represented an era in which hydrogen development did not garner significant attention, as indicated by sector profiles that illustrate reduced employment, revenue and research and development in the Canadian hydrogen sector. As a result, this period was not examined within the ESPELT analysis to the same extent as the Post-Kyoto and Post-Paris periods. Once I was ready to conduct the interview portion of my research, the interview questions that I had developed enabled a depth of conversation between myself and the participant, encouraging opinions and insights to be shared for the study.

### *Concluding Summary*

In conclusion, this study provides insight into the Canadian hydrogen market within the historical and contemporary context. The approach included an extensive literature review, coupled with semi-structured interviews, which advanced the intended holistic development of this research thesis. The ESPELT categorization was the overarching guiding framework and facilitated the analysis and discussion portions of the study. Participants were recruited with various perspectives carried over from the specific sectors they represented, such as private industry, government, non-profits, universities, and think tanks.

### **The Post-Kyoto Hydrogen Hype Cycle Introduction**

During the Post-Kyoto Period (2000-2004) evaluated for this thesis research, there were promising moments of hydrogen's emergence into the Canadian energy mix. As highlighted in the analysis below, hydrogen emerged in Canada during the Post-Kyoto period due to multiple factors. These factors included the increased intensity of weather events as a result of climate change, an increased social urgency to address climate change, domestic and international political pressures, awareness of the Canadian hydrogen sector's research and development efforts. However, while these factors impacted and contributed to the post-Kyoto hydrogen hype cycle, clean hydrogen was ultimately not successfully established within the Canadian clean energy mix that it was expected to achieve. As highlighted in the ESPELT analysis, the following factors emphasize these drawbacks and showcase the current opportunities to establish a robust hydrogen market in Canada.

### **The Post-Kyoto Environmental Analysis: Increasing Environmental Factors**

This section of the ESPELT analysis aims to explore the environmental factors that impacted the initial attempts to establish a hydrogen market in Canada during the Post-Kyoto period.

Specifically, the following analysis examines the impacts of climate change on Canadians. That led to Canadians' emerging environmental awareness towards climate change, and its significance on the development of clean technology, specifically clean hydrogen, in Canada.

The analysis aims to highlight the impacts of climate change on Canadians and explores the Government of Canada's approach to mitigating environmental impacts on Canadians by

implementing hydrogen into the clean energy mix. Ultimately, hydrogen garnered some attention during the post-Kyoto period primarily because it represented a potential and competing option for addressing climate change.

### *The Climate Change Shift*

The Intergovernmental Panel on Climate Change (IPCC) describes climate change as a shift in climate variability that persists over an extended period of time (IPCC, 2012). Climate change has accelerated due to the combusting of fossil fuels such as oil, natural gas, and coal, resulting in more of these fossil fuels contributing to a greater concentration of CO<sub>2</sub> in the atmosphere (Rubin, 2002). Burning fossil fuels is the dominant factor determining CO<sub>2</sub> concentrations during the 21<sup>st</sup> century (IPCC, 2018). The concentration of greenhouse gas emissions has risen steadily, resulting in the mean global temperatures rising since the Industrial Revolution (IPCC, 2012). Since 1995, global CO<sub>2</sub> emission from energy combustion and industrial processes have continually risen from 22.4 GT CO<sub>2</sub> in 2000 to 28.7 GT CO<sub>2</sub> in 2005 (Figure 2, IEA, 2023).

In 2000, the concentration of carbon dioxide was nearly 370 parts per million (ppm), representing a 47 percent increase since the beginning of the Industrial Age, when the concentration was near 280 ppm (Buis, 2019). By 2019, the concentration of carbon dioxide in the Earth's atmosphere sat at 412 ppm representing an 11 percent increase since 2000 (Buis, 2019). The IPCC Sixth Assessment Report states that concentrations of cumulative net CO<sub>2</sub> emissions from 1850 to 2019 were 2400±240 GtCO<sub>2</sub> (IPCC, 2023). More than half (58%) occurred between 1850 and 1989, and about 42% occurred between 1990 and 2019 (IPCC, 2023). These higher emissions concentrations have led to drastic changes in climate variability,

some of which were reflected in changing weather patterns during the early 2000s. As a result of the increased fluctuation in temperatures, the climate crisis has accelerated, leading to severe impacts on the global weather systems and increasing extreme weather events worldwide.

Figure 2

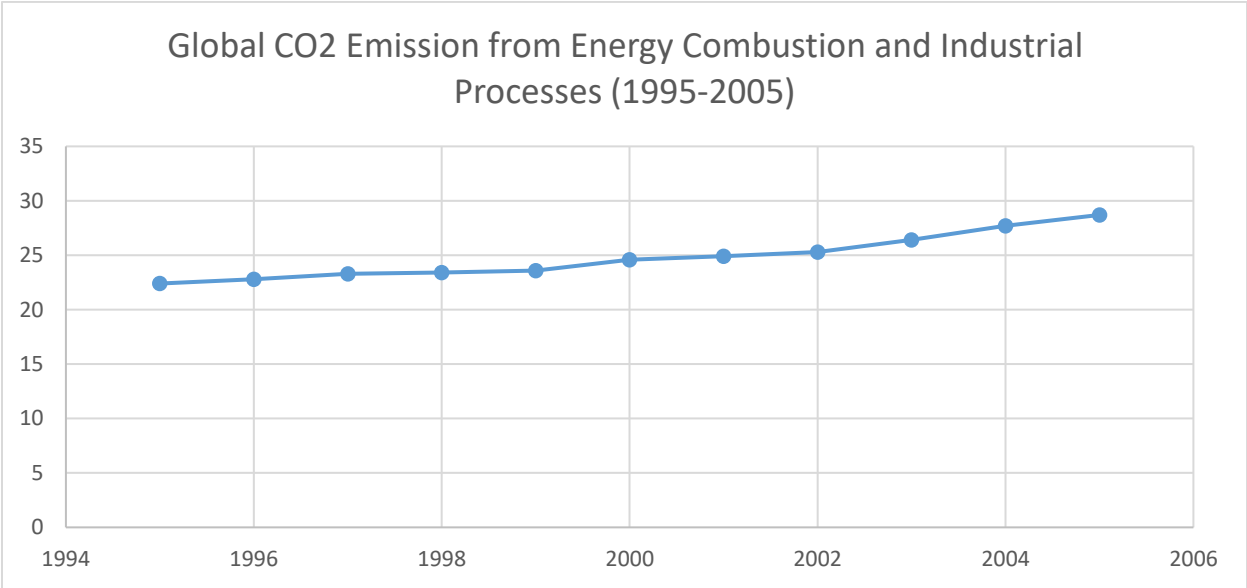


Figure 2: Global CO2 Emissions from Energy Combustion and Industrial Processes (1995-2005). Source: International Energy Agency, 2023

*Climate Change and Extreme Weather Events*

By the early 2000s, changing weather patterns resulting from climate change had produced floods in parts of Europe, Africa, and Asia (UNEP, 2000). These increased extreme weather events were causing considerable damage to urban centres and putting populations at risk. In North America, forest fires in the United States and Canada were becoming more significant as well. For instance, the 2003 Okanagan Mountain Park Forest fire, the most significant wildfire event to that point in British Columbia's history, caused \$200 million in damage and led to the

evacuation of 33,000 people and the destruction of over 230 homes (CBC News, 2013).

Changing weather systems perpetuated by climate change equalled less precipitation in the summers and resulting in Canadian forests becoming more vulnerable to forest fires. These forest fires, and their impacts, have exemplified how vulnerable populations can be susceptible to catastrophic climate disasters, with many of its socio-economic impacts lingering for years afterwards. The rise in global average temperatures materialized by this point in history, directly affecting people's lives and with severe implications for an interconnected global economy.

The IPCC has stated that the average global temperatures should avoid rising above the 2-degree Celsius threshold to limit catastrophic impacts on the human population (IPCC, 2023).

The unpredictability of fluctuating global temperatures highlighted the need for countries to advance the global energy transition to combat climate change (UNEP Annual Report, 2000).

Weather events perpetuated by the massive burning of fossil fuel energy is the first example of human activity on a global scale that now threatens a radical shift in the Earth's environment, and impact global economics, society, and politics due to unpredictable weather leading to natural disasters such as devastating floods and forest fires. This International attention began to focus on mitigating GHG emissions to lessen their environmental impacts by managing the risks posed by climate change leading to catastrophic environmental disasters. An increased focus on finding low-carbon solutions to high-emitting sources.

### *Clean Hydrogen's Environmental Benefits*

Hydrogen and fuel cell technology's environmental benefits to address climate change.

Renewable energy sources such as wind, solar and nuclear have been researched to produce low-emitting energy to address and mitigate greenhouse gas emissions. At the time, hydrogen was recognized as a crucial possible energy carrier that would facilitate the transition to an economy based on a green economy (Rifkin, 2002).

Compared to conventional fuels, hydrogen fuel cell technologies have the potential to result in tremendous environmental improvements, including reductions in greenhouse gas emissions and improvements in local air quality. For example, a fuel cell vehicle operating on hydrogen produced from steam methane reforming of natural gas has almost 55% fewer greenhouse gases over its entire life cycle when compared with a conventional car running on low-sulphur gasoline (Taylor et al., 2002). Hydrogen's potential to tackle GHG emissions was potentially seen as a critical input into the global energy infrastructure that had need to limit global temperature increase by 2 degrees Celsius, otherwise leading to catastrophic consequences for the Earth, including the massive losses in biodiversity over the next one hundred years (Theckedath, 2010).

One long-term rationale for pursuing hydrogen and fuel cell technologies is that they can help "decarbonize" the Canadian energy system so that it produces clean energy and fewer emissions. This would mitigate climate change, reduce air pollution, increase energy security, and contribute to the general public good (Government of Canada, 2005). Hydrogen provides a viable solution where electricity has a problem, in that, if the sun is not shining or fossil fuels

are not available to burn, electricity can't be generated (Rifkin, 2002). For instance, a power system can provide energy, but may not be able to provide flexible capacity to ensure stability and resilience. In terms of flexible capacity hydrogen can solve this issue because it can store energy to ensure a continuous clean power supply, as well as provide an efficient way of balancing economic and environmental considerations to achieve a low-carbon future (Hydrogen Council, 2020). Although batteries offer short-term flexibility, technology such as hydrogen turbines offer a way to provide balance and flexibility to a power system because energy can be stored as hydrogen and therefore be used to generate low-carbon or renewable electricity when demand increases (Hydrogen Council, 2020).

The extreme weather events in the Post-Kyoto Period brought a sense of urgency to addressing climate change. The world had grown to be dependent on fossil fuels for their collective energy consumption, but the extensive utilization of fossil fuels began to show the detrimental effects on the world's climate. Meanwhile, the Government of Canada saw climate change, the depletion of oil resources and the need for sustainable growth as significant elements of the mobilization of hydrogen to address worldwide environmental issues while securing future energy supplies (Government of Canada, 2005). Canada wanted to demonstrate its global stewardship in addressing the world's environmental difficulties (Government of Canada, 2005). However, transitioning from a petroleum-based economy to a hydrogen-based economy is a complex process that demands long-term investment and technological breakthroughs. Ultimately, Canada's ambitions to leverage its oil sands resources overtook its climate ambitions at the time and the hydrogen market in Canada was not fully accepted.

## **The Post-Kyoto Social Analysis: Climate Urgency Rising**

This section of the ESPELT analysis aims to explore the historical social perceptions of the development of the hydrogen market in Canada during the early 2000s. The following section highlights the impact of Canadians' perceptions concerning the emerging climate change crisis and its influence on hydrogen development. The social analysis examines the social perspectives towards hydrogen, including the perceived limitations and benefits of hydrogen development in Canada. Additionally, the analysis examines the knowledge gaps Canadians may have had towards the clean technology and its application within Canadian society. The growing urgency to address climate change by implementing measures to reduce harmful emissions were demonstrated in Canadians' promising curiosities towards hydrogen.

### *Climate Movement and Social Pressure*

The notion that climate change and greenhouse gas pollution was the most significant environmental threats led to a favourable perception of hydrogen and fuel cell technology during the Post-Kyoto Period. It was not until the oil crisis in 1973 that scientists, engineers, and policymakers decided to view hydrogen as an all-purpose form of energy (Rifkin 2002). The arrival of the 1990s climate movement, and subsequent social pressure on politicians and policymakers, drew focus to the growing concerns of climate change. Interest in hydrogen began to pick up again in the 1990s after the publication of alarming studies and reports warning that increased CO<sub>2</sub> emissions from burning fossil fuels were heating the planet and posing a potentially grave threat to the Earth's biosphere (Rifkin 2002).

The Government of Canada had been exploring ways to expand partnerships to promote the clean and efficient use of energy resources that would eventually replace fossil fuels. By researching potential options to replace fossil fuels within the energy mix, Canada, like other industrial nations, could lessen its dependency on fossil fuels while improving its respective environmental performance. Due to scarcity, conventional fossil fuels and uranium prices rose in world markets. These costs were compounded by the rising externalities brought on by CO<sub>2</sub> emissions, which impacted the Earth's climate and the stability of the Earth's ecosystems (Rifkin 2002). Clean hydrogen was identified as a potential way forward to foster economic prosperity with the benefit of achieving a low-carbon future. As Rifkin explains, the basic emphasis for the development of a hydrogen market in industrialized nations, such as Canada's, was due to the continued dependence on foreign sources of fossil fuels such as natural gas and oil, and then by the impending climate crisis (Rifkin, 2002). Therefore, clean hydrogen had the potential to realize the objectives of lessening fossil fuel dependency for Canada and other industrialized countries.

The extreme difficulties associated with transitioning a Canadian economy based on natural resource exploitation towards a low-carbon economy are further underlined by policies that shift with each election. This is highlighted by the Government's Action Plan 2000, which focused on reductions and set targets for industry and consumers, laying the foundation for long-term behavioural, technological, and economic change (Government of Canada, 2000). As environmental concerns emerged, uncertainties remained regarding how to keep Canada's climate policy ambitions uniform throughout elected officials that will eventually influence

policies and keeping government and industry accountable for measuring their environmental ambitions and mitigating their emissions.

### *Public Perception and Adoption*

The Canadian public interest in hydrogen during the 2000s was limited due to little general knowledge of renewable energy. To better understand the public's perception of hydrogen technology development in Canada, Natural Resources Canada, on behalf of the Canadian Transportation Fuel Cell Alliance (CTFCA), contracted with the Strategic Counsel to conduct a nationwide telephone poll of 1500 respondents (The Strategic Counsel, 2007). The study found that many factors influenced the public's perception of the development of hydrogen. The first was that Canadians were focused on the environment and viewed climate change as a significant threat. Potentially impacted by the early social movements concerning the environment, Canadians had been made aware of climate change and the potentially disastrous impacts it would have on the planet. This awareness was coupled with the second notion uncovered by the study: Canadians believed there was an urgency to develop and implement environmentally friendly alternative energy (The Strategic Counsel, 2007). Within their survey study, the Strategic Counsel found more than half of Canadians (51%) indicated that it is extremely urgent to address environmental problems by developing and implementing alternative forms of energy and technologies, compared to the quarter (28%) of respondents in 2004 (Strategic Counsel, 2007). These findings underlined that Canadians knew the speed of creating renewable, non-emitting technology to address climate change.

While open to introducing new energy technologies, Canadians expressed reluctance to fully adopt fossil fuel alternatives. The Strategic Counsel's study highlighted the crucial policy issues related cost barriers associated with emerging renewable energy alternatives like hydrogen. The study found that although more Canadians thought that fuel cells were "something good for the environment," with 76% of respondents agreeing with this statement in 2007 versus 69% of respondents in 2004, the percentage of those who associated fuel cells with "expensive technology" also increased correspondingly with 55% in 2007 versus 49% in 2004 (The Strategic Counsel, 2007). Hydrogen, therefore, was falling victim to a primary barrier of technology adoption, wherein innovators typically would take the lead in stimulating early market demand at risk of potential consumers being slow to adopting the technology (Rifkin, 2002). Altogether, the Strategic Counsel's study presented the necessary indicators that were moving in the right direction to draw the public further toward the tipping point needed for acceptance.

Regardless of the barriers associated with the implementation of hydrogen within the Canada's clean energy mix, Canadians remained curious regarding hydrogen development but viewed hydrogen's performance within mobile power sources as more feasible than stationary applications. The Strategic Counsel's study found that Canadians were favourable to hydrogen but continued to view other environmentally friendly applications, such as hybrid vehicles, as the next step in the evolution of cleaner fuels (The Strategic Counsel, 2007). According to the study, the public was open to developing alternatives to conventional engines and cleaner fuels to make vehicles more environmentally friendly. Respondents were aware of fuel cells, with 41% of responses indicating that they had read or heard something about them in the last six

months, up from 32% in 2004 (The Strategic Counsel, 2007). This insight presented a far more profound understanding of the need for a change in mobile power sources. Canadians had an understanding that vehicle pollution remained a significant problem and that changes to the automotive industry were necessary to address climate change.

Conversely, there was less of an understanding of change in household power. As the study points out, this underlines the challenge of introducing novel and unfamiliar technologies into mainstream public thinking. Canadians had made an emotional commitment and restricted perspective that hydrogen would only be applicable to the conventional vehicle and home energy technologies. This notion would have been challenging to shift considering that hydrogen was not restricted to those applications (The Strategic Counsel, 2007). The findings from the Strategic Counsel all point to one contributing factor for hydrogen's emergence within the Canadian energy landscape; awareness was critical to hydrogen's successful implementation.

#### *Awareness of Hydrogen's Potential*

The awareness of hydrogen's environmental benefits will be a key contributing factor to its emergence within Canada's energy context. At the time, the awareness of these environmental issues may not have been as prominent as they are currently, presenting one of the significant issues concerning the initial emergence of hydrogen during the Post-Kyoto Period. In a separate interview, Grant Strem (Interview I) said that awareness is the fundamental issue regarding clean energy, meaning that the public should become more aware that clean energy

alternatives are more readily available and affordable. He explained that many Canadians don't understand the cost benefits of switching to clean energy. Strem believes that once Canadians realize the benefits that hydrogen affords everyday Canadians, not only will hydrogen emerge within the mainstream energy context, but it will also lead to more public acceptance of hydrogen as beneficial to the pursuit of a low-carbon economy (Strem, 2022). Demonstrations during the Post-Kyoto Period were present, but limited, leading some experts such as Stream to highlight that more demonstrations that effectively showcase hydrogen's potential would benefit hydrogen in the future.

Another critical aspect of awareness that a few experts alluded to is ensuring Canadians realize that hydrogen is a safe energy carrier. In an interview, Greg Caldwell (Interview B) said that hydrogen's reputation as dangerous or as something that explodes quickly could be attributed to the popular lore about the Hindenburg disaster in the early 1900s. He added that people may equate hydrogen with nuclear energy, which he stated was the safest energy ever developed. Yet, he says, people are terrified of hydrogen because hydrogen production companies during the early 2000s did not actively create a safety dialogue that assured people of hydrogen's benefits and safety measures. In his interview, Ali Karaca (Interview E) also alluded to the knowledge gap and the safety concerns that have been traditionally attached to hydrogen. He contends that hydrogen is safe when handled correctly and that perceptions of hydrogen's dangerousness should also be mindful of the dangers of fossil fuels, which are also combustible.

Overall, social considerations for hydrogen development were based on the potential for hydrogen's growth to become the alternative to fossil fuel energy. A deeper understanding of the public's perception of hydrogen uncovered that there was some knowledge of hydrogen's application within the Canadian energy mix. While public awareness of hydrogen grew in the Post-Kyoto Period, the general population was aware of hydrogen's application within individual mobile power. In contrast, hydrogen potential could include industrial power applications and hard-to-abate sectors which are being highlighted within the Post-Paris Period. Additionally, the reluctance to newer technologies was present within the Canadian mindset. However, these perceptions could change as research and development grow, leading to more innovation. Finally, given the oil sands boom in Alberta and other fossil fuel extraction projects in Canada, energy security may not have been top of mind for Canadians.

### **The Post- Kyoto Political Analysis: Economy First, Climate Second**

This section of the ESPELT analysis explores the political history concentrating on the initial attempts to establish a hydrogen economy in Canada during the Post-Kyoto Period. The historical political analysis explores the major Canadian political parties' responses to the emerging climate movement from the 1980s by examining the political platforms announced ahead of elections in the early 2000s. Additionally, this section discusses the throne speeches of the political parties that were able to form a government. Furthermore, media scans and government announcements are showcased to highlight the Government of Canada's emphasis on hydrogen's environmental benefits during the turn of the century. The historical political

analysis gave significant context to the sense of urgency placed on the main political parties in Canada.

### *Climate Movement and Political Pressure*

Prior to the 2000's, hydrogen's potential emergence as a clean technology was contingent on the political pressures from the climate movement beginning in the late 1970s continuing into the early 1990s (IEA, 2019). In the 1990s concerns about climate change spurred more research into hydrogen's potential, with a particular focus on carbon capture and storage, renewable energy, and transport (IEA, 2019). Following the Montreal Protocol in 1987, that resulted in an international agreement to ensure the protection of the earth's ozone layer through the global phase-out of ozone-depleting substances and was widely considered one of the most successful international environmental accords, the global community became aware of their impacts on the world's environment as a result of the discovery of the depleting ozone layer (Government of Canada, 2022). The arrival of the 1990s climate movement influenced Canadian politics during the early 2000s, which began to focus more on growing concerns about climate change. By 1992, 197 countries ratified the UN Framework Convention on Climate Change (UNFCCC) to address the stabilization of greenhouse gases in the atmosphere and establish the annual assembly of nations at the Conference of the Parties (COP). The Kyoto Protocol was adopted in 1997, becoming the first legally binding agreement between countries to tackle climate change. These international commitments to address climate change had spurred Canada to act on reducing emissions and developing renewable energy sources, which ultimately influenced domestic political parties and their proposed political platforms leading into federal elections.

Leading into the early 2000s, the Canadian public became increasingly interested in combatting climate change. Canadians were becoming aware of the impacts of human activity on the environment. For instance, a study conducted by the Strategic Counsel found that Canadians viewed global warming, air quality, greenhouse gas emissions, and pollution from vehicles and industrial activity to be the most significant threats to the environment at this time (The Strategic Counsel, 2007). As Canadians focused on addressing climate change, private companies began positioning themselves to align with these environmental priorities. Soon Canadian energy companies focus on renewable energy became more prominent, such as Ballard Power Systems, one of the first Canadian companies to deploy a low-cost PEM fuel cell in 1983 (Canadian Hydrogen and Fuel Cell Association, 2022). The momentum continued on the environmental awareness front, with perceptions shifting to accept renewable energy to address greenhouse gas emissions. Finally, with domestic perspectives on climate change shifting, Canadian political parties took notice and implemented climate policies into their respective platforms to attract voters.

### *Political Party Platforms*

Canadian political parties positioned themselves by generating policies to address climate change to align with international commitments and domestic priorities. Since the early 1990s, the Canadian political landscape began to shift its policy priorities to meet some of the demands to achieve a reduction in greenhouse gas emissions. Although these Canadian political parties included language concerning climate change, hydrogen and fuel cells were sparingly mentioned specifically, whereas the mention of the development of clean technologies

increased. As detailed below, major political parties began to state their intentions to address climate change by announcing policy directions towards research and development of clean technologies, designing economically viable mechanisms to reduce emissions, and addressing challenges related to biodiversity and environmental degradation.

The first of the major Canadian elections to address aspects of environmental degradation was in the lead-up to the 1997 Federal election. The Liberals centred their environmental policies by stating in their platform the commitment to implement clean technologies to combat climate change to align Canada with other governments worldwide (Liberal Party Platform, 1997). By doing so, Canada would be competitive with other countries researching more innovative, flexible, and economically efficient policy tools that encouraged the reduction of greenhouse gas emissions (Liberal Party Platform 1997). Alternatively, the Reform Party, Bloc Quebecois, and Progressive Conservative Party of Canada- winning 18.69%, 13.52% and 16.04% of the vote in 1997, respectively- did not mention climate change in their election platforms. The New Democratic Party –winning 6.88% of the vote- said the need to strengthen the Canadian Environmental Protection Act was a priority (New Democratic Party Platform, 1997). Finally, the Green Party of Canada advocated within their platform that air quality and energy consumption were interlinked, emphasizing the need to advance “the development of solar, biomass, wind, hydro, *hydrogen* and geothermal technologies with strong and sustained investment in research, development and demonstration" (Green Party Platform, 1997, *emphasis*).

As the 2000 Federal election loomed, the incumbent Liberal Party was contending with the emergence of environmental policies included within rival Canadian political party platforms.

The Liberals also emphasized their intention to invest in innovation and research by doubling federal expenditures, explicitly funding the development of new energy technologies such as hydrogen fuel cells to target emissions in the agricultural industry (Liberal Party Platform, 2000). Meanwhile, Joe Clark's Progressive Conservative Party of Canada focused its platform's environmental section on introducing preferential tax treatment and incentives for renewable energy sources to encourage consumer and industry buy-in of clean fuel sources (Progressive Conservative Party 2000). The Green Party Platform included the most extensive information regarding clean and renewable energy sources, which alluded to the notion that energy such as wind, solar and hydrogen and fuel cells would be the foundation of a sustainable Canadian economy (Green Party Platform, 2000). Additionally, their plan included commitments to encourage renewable energy development by providing incentives such as tax credits and rebates for energy producers and consumers (Green Party Platform, 2000). After the 2000 federal election, the Liberal Party would again hold power.

In 2004, the Liberal Party ran Paul Martin as their next party leader in an election that pitted him against Stephen Harper's Progressive Conservative Party in Ottawa. The Liberal Party ran on a platform that promised \$1 Billion in investment into environmental technologies funded by the party by proceeds from the intended sale of the remaining federal ownership stake in Petro Canada (Liberal Party Platform, 2004). The Conservatives promised to become an environmental world leader by focusing on clean air, water, land, and energy. Additionally, they stated their intention to work with the provinces to develop a national strategy for alternative energy and energy conservation, including increasing the use of renewable energy sources,

research and development into alternative energy and energy efficiency technology (Conservative Party Platform, 2004). Despite the Conservatives promises made on the campaign trail, the Conservatives did not deliver as evidenced by their intention to pull out of the Kyoto Protocol. Ultimately, Stephen Harper's Conservatives would make their political emergence, foreshadowing their influence on Parliament for the next almost decade.

In 2006, following the tenth anniversary of the Kyoto Protocol, the Federal election served as a catalyst for the implementation of more environmental policies in Canadian political party platforms. Alluding to the UNFCCC conference hosted in Montreal in 2005, Paul Martin's Liberals stated in their platform their commitment to assuming Canada's international responsibilities to address global environmental challenges as it assumed the UNFCCC presidency the following year. This commitment included the introduction of the Renewable Fuels Standard that intended to mandate an average of 5% renewable fuel content in all gasoline and diesel fuel sold in Canada (Liberals Party Platform, 2006). The Green Party stated the urgency to find new renewable energy sources to respect Canada's Kyoto engagements, adding the need to reduce our energy consumption to avoid future economic hardships for Canada (Green Party 2006). The Green Party stated that if elected, their government would increase capital cost allowances for green technology such as solar, geothermal, tidal and hydrogen fuel cell development (Green Party Platform, 2006). The Progressive Conservative Party's platform included commitments to address the issue of greenhouse gas emissions by supporting the development of new technologies in partnership with provinces and territories and international industrialized partners (Conservative Party Platform, 2006). Ultimately,

Stephen Harper's Progressive Conservative Party scored the most significant number of seats with 40.3% of the vote. The examination of the political parties platform suggests that climate change and environmental awareness as increasing at this time, and further spurred political parties to include environmental policies in their platforms to attract potential voters that would have prioritized governments that planned to address climate change. Despite political party platforms promises made during elections, these platforms don't always match the reality of the party that assumes power.

### *Speeches from the Throne*

As indicated in the Speeches from the Throne, once in power, political parties began to focus on the impending challenges that climate change would present to Canadians. In 1997, Governor General Romeo LeBlanc delivered a throne speech for the Liberal Party of Canada during the First Session of the 36<sup>th</sup> Legislature, which did not mention clean energy or climate change (Speech from the Throne, 1997). Although climate change was not mentioned in the Throne Speech, the Kyoto Protocol, and its impending impact on the Government of Canada's international commitments to combatting climate change would shift throne speeches to become more inclusive of climate change in the following years.

By the Second Session of the 36<sup>th</sup> Legislature in 1999, then Governor General Adrienne Clarkson delivered a speech for the Liberal Party that conveyed a message to meet Canada's commitment under the Kyoto Protocol to reduce greenhouse gas emissions (Speech from the Throne, 1999). In 2001, during the First Session of the 37<sup>th</sup> Legislature, Governor Adrienne

Clarkson followed up that speech with a speech on behalf of the incumbent Liberal Party, which detailed the government's commitment to clean air, clean water, and the conservation of Canada's natural spaces" (Speech from the Throne, 2001). During the Second Session in 2002, within the context of meeting the Kyoto Protocol commitments, the Liberal Party stated their intentions to continue consultations with Canadians, industry, and provinces to develop an implementation strategy to meet Canada's obligations over the next ten years (Speech from the Throne, 2002). While by the Third Session, the Liberals stated the "intention to increase the resources to support innovative environmental technologies and further encourage their commercialization" (Speech from the Throne, 2002).

By the First Session of the Thirty-Eighth Parliament in 2004, the Liberal government provided more structured language concerning the commercialization of the best new environmental technologies, including the intention to focus on energy efficiency and energy research and development- including a focus on wind-power production in Canada (Speech from the Throne, 2004). This evolution, detailed in the throne speeches ranging from 1997 to 2004, showcases the Government of Canada's response to meet the demand for more decisive political action on climate change. Elected governments would indicate their intentions to fund research and development in renewable technologies to meet these demands at the beginning of each session. That is to say, the elected governments failed to mention hydrogen, instead keeping a broad generalization of "renewable technologies." As indicated by the evolution of party platforms from the late 1990s to the early 2000s, due to the emergence of combatting climate change, Canadian political parties aligned their environmental policies to include researching

clean technologies, which ultimately led to the initial emergence of hydrogen within the Canadian political landscape. This is caveated, in that, Throne Speeches are self-authored by the political parties themselves, and don't necessarily reflect the political realities and policies that end up becoming implemented once a political party is in power.

### *Media Scans*

The Conservative government of the early 2000s was aware of the environmental benefits of clean hydrogen; however, it did not figure predominately into the government's policies compared to the current Canadian government. A search through Library and Archives Canada's database using keywords such as "fuel cells," "clean hydrogen" and "hydrogen economy" yielded few results; however, it did reveal that Prime Minister Stephen Harper did give some limited attention to hydrogen fuel cells. Archived within Library and Archives Canada's database, there is a photo in which Prime Minister Stephen Harper examines a Hydrogen Fuel Cell Engine before he announces that he will provide the Province of British Columbia with \$199.3 million through the Canada Ecotrust for Clean Air and Climate Change in Vancouver (Ransom, 2007). Although Canada was primarily focused on leveraging its fossil fuel resources in Alberta's oil sands, there is evidence that Stephen Harpers' government had explored hydrogen to some extent. As Rubin (2015) explains, Harper planned to leverage the term "energy superpower," first introducing it in a speech to the Economic Club of New York. However, there's little evidence hydrogen figured prominently in Harper's vision of energy "superpowerdom": Two years later, he would utilize the energy superpower theme during the 2008 federal election campaign (Progressive Conservative Party Platform, 2008). The Harper government had invested in campaign ads to emphasize to Canadians that oil sands were

Canada's future (Rubin, 2015). Evidently, Canada's aim was to amplify Alberta's oil sands, while clean hydrogen production did not receive as much media attention in contrast.

Additionally, government announcements presented the political emphasis that may have been placed on hydrogen environmental benefits during the turn of the century. Although there was a spike in media attention toward hydrogen, it was not sustainable. A fascinating insight from the interviews conducted for this thesis was that the initial emergence of hydrogen in the early 2000s may have been a limiting factor in optics. As Klippenstein (Interview F) suggests, the hydrogen sector received too much attention during the early 2000s. He explained that it may have been better for the industry if it emerged slowly rather than the rapid rise it experienced. He uses Ballard Power Systems' stock value as an example of consumers' awareness of hydrogen at the time. He highlights that having a company like Ballard go to \$200.00 a share and then sink back down to approximately \$5 a share created terrible optics for the sector (Klippenstein, 2022). Ultimately, the volatility of Ballard Power's stock prices may have influenced policy at the time, as political parties may have been alarmed about the viability of the hydrogen market in Canada as a result of stockholder confidence in one of Canada's premier hydrogen fuel cell manufacturers.

Media scans reveal that clean hydrogen was not as prominent within the news cycle during the Post-Kyoto Period. Research into media at the time shows that there were a few prominent stories in newspapers that highlighted demonstration projects in the early 2000s. The most notable stories focusing on hydrogen were ahead of the 2010 Winter Olympics in Vancouver. In 2009, BC Transit unveiled a fleet of 20 fuel-cell electric transit buses, which utilized Ballard

Power Systems' fuel cells, further highlighting British Columbia's innovation within the clean hydrogen sector. The 2010 Winter Olympics represented a worldwide view of Canada, specifically British Columbia. As Ali Karaca (Interview E) indicated in my interview with him that companies such as Ballard Power Systems are well-known worldwide and demonstration projects that implemented technologies from these companies such as Ballard further advanced their recognition on the global stage. He added that this served as an example of Canada positioning itself well to show leadership within the global hydrogen landscape (Karaca, 2022). This was one of the most prominent stories of the time.

### *Geopolitical Energy Considerations*

In my research I also found a critical policy issue of nation states' need for national domestic energy production. Alongside environmental considerations hydrogen fuel was increasingly being focused on as a solution to Canada's energy dependency. As early as the 1970s, the United States and other countries began investing in public funds for hydrogen research due to the 1970s global oil crisis. The United States program, however, never exceeded \$24 million, whereas the European Economic Community spent between \$72 million and \$84 million on hydrogen research during the 1970s (Rifkin 2002). As the energy crisis of the time concluded, and the price of oil began to drop, government funding for hydrogen declined. However, the remnants of oil price volatility remained. Nations were beginning to buy into further hydrogen development, which could reduce reliance on fossil fuel imports. Governments, in turn, could become less dependent on oil-producing countries for their energy needs. There was also growing recognition that Canada could benefit from increased export opportunities for

hydrogen fuel and fuel cell technologies (Taylor et al. 2002). Hydrogen's connotation as stable within the energy independence context was because hydrogen could be derived from numerous sources, including renewable energy sources that were readily available domestically.

### *Political Considerations for Hydrogen Development*

Provinces that possess specific advantages may choose to generate hydrogen utilizing feedstocks that can leverage their resources, infrastructure, and capacities. For instance, Alberta, which possesses a large portion of Canada's natural gas resources, has demonstrated their ambitions to generate hydrogen using natural gas as the primary feedstock (Hydrogen Strategy for Canada, 2020). British Columbia was also referenced for its potential to leverage its natural gas resources (Hydrogen Strategy for Canada, 2020). Alternatively, Quebec, which possesses one of Canada's strongest capacities to generate electricity, could facilitate the generation of hydrogen from electrolyzers. As referenced by David Van Den Assam (Interview K), Quebec has the hydro resources and affordable power to continue commercializing electrolysis technologies and leverage their environmental benefits (Van Den Assam, 2022). Some interview participants such as Martin Bush (Interview A) referenced Newfoundland and other eastern provinces' interests in generating electricity from wind power and its potential for feeding into the hydrogen development process (Bush, 2022). Therefore, hydrogen could be a resource that would attract attention from multiple provinces and territories, due to each provinces' competitive advantages in multiple feedstocks. Political parties in each of Canada's provinces and territories would view leveraging their feedstock advantages and enabling the

growth of the Canadian hydrogen market as a method to stimulate their economies while aligning with Canada's commitments to mitigate greenhouse gas emissions.

The federal government has the capacity to encourage provinces and territories to manage their natural resources, however, the choice of leveraging natural resources comes down to the choices of each province's elected governments. The Canadian federal government is elected based on numerous competing factors, however, the political pressures that emerged throughout the years have influenced the Government of Canada's policies toward reducing GHG emissions and developing renewable energy solutions. Additionally, Canadian provincial governments are also influenced by the electorates that they represent, therefore, the provincial government's decisions have a vested interest in appealing to the voters.

The major political considerations of the time concerned Canada's fossil fuel resources and the opportunities to utilize them for economic gains. As Rubin explains, after the 2011 federal election, Harper felt he had a mission to safeguard Canada's economic future. The Progressive Conservatives wanted to create a new vision of Canada's economic outlook by leveraging its natural resources in Alberta, the government was intent on producing 5 million barrels a day (Rubin, 2015). Leveraging these resources would establish Canada as one of the top oil producers in the world and usher in the age of Canada as an energy superpower, passing on this wealth to Canadians. This focus on leveraging Alberta's oil sands also came at a price of government funding towards addressing climate change. For instance, Harper cut funding for environmental studies, particularly anything mentioning climate change (Rubin, 2015). Within the 2012 federal budget came a special \$8-million allocation to fund Canada Revenue Agency

(CRA) audits of basically every major environmental charity group in the country that opposed new pipeline construction, such as the David Suzuki Foundation, Environmental Defence, and Tides Canada (Rubin, 2015). Ultimately, this emphasis on fossil fuels left clean hydrogen without a strong point in the context of Canada's energy superpower ambitions, falling out of favour for more efficient and secure production of oil in Canada.

The political considerations surrounding the emergence of the hydrogen market in the early 2000s largely depended on Canada's recognition of climate change and, consequently, the need for cleaner energy sources. The emerging threat of climate change influenced some party platforms and, in turn, formed policies once governments were instituted. During the early 2000s, however, the political focus deviated from clean hydrogen development. As showcased by the political platforms and throne speeches of Canadian governments that held power during that time, clean energy was prominent. Still, there was little to no mention of hydrogen. Media scans revealed that hydrogen was capturing some attention within mainstream media; however, this attention was not as prominent as today. Finally, the insights from experts interviewed for this thesis indicated that the government's focus may have been more towards leveraging fossil fuel resources than pursuing clean hydrogen's environmental benefits at first glance. Logically, clean hydrogen's emergence can be attributed to climate change awareness, and its attention within the contemporary sense may be scheduled to increase as climate change presses on to capture more of the political engagement of Canadians.

## **The Post- Kyoto Hydrogen Hype Cycle Economic Analysis: Balancing Supply and Demand**

This section of the ESPELT analysis explores the economic history of the initial attempts to establish a hydrogen market in Canada. The historical economic analysis examines the economic barriers associated with the development of hydrogen, including a perspective on the cost competitiveness of clean fuel during the Post- Kyoto Period. The section highlights the Government of Canada's investments in clean hydrogen, particularly enabling technologies such as fuel cells, to allow its application within the transportation sector in Canada. Additionally, this analysis examines the significant barriers to development during this early period, particularly the cost to manufacture, store and transport hydrogen in comparison with other fuels within the Canadian energy mix.

### *Government Incentives to Accelerate the Hydrogen Economy*

At the time, clean hydrogen suffered from the "chicken-and-egg" scenario, a dilemma that underlines the problem of ensuring that costumers are willing to pay for hydrogen technologies, and innovators have hydrogen technology available for purchase. This scenario inhibited hydrogen's adoption based on limited clean hydrogen supply and limited demand. While supply and demand have increased contemporarily, clean hydrogen still suffers from this scenario. Ensuring the development of hydrogen infrastructure while accounting for commercial readiness of clean hydrogen within the transportation sector was an obstacle that experts believe needed to be filled by governments. Hamid Rahmanifard (Interview J), an analyst at the Transition Accelerator, explains that governments have a broader role to play in incentivizing hydrogen production, and end-users should be subsidized and encouraged to

adopt the technology. Rahmanifard (Interview J) builds on this by suggesting that investments in technology development are crucial to reducing the cost of hydrogen as much as possible (Rahmanifard, 2022). As hydrogen garnered more attention during the early 2000s boom, the Government of Canada started to provide funding opportunities to get hydrogen into the Canadian clean energy mix.

The Government of Canada's started its initial investments into clean hydrogen, allowing private companies to make steps towards reducing the costs associated with producing, storing, and transporting hydrogen. In October 2003, the Government of Canada invested over \$215 million over five years through the Hydrogen Economy Initiative to accelerate the Government's ambitions to establish a hydrogen market in Canada. This funding was in addition to the C\$130 that the Government of Canada announced to accelerate the development and commercialization of fuel cell technologies under its Climate Change Plan (Fuel Cells Bulletin, 2003). These investments aimed to increase the early adoption of hydrogen solutions through integrated demonstration projects and increase the capacity of establishing hydrogen infrastructure and reduce the costs of hydrogen technologies.

From 2003 to 2008, these investments enabled significant technological progress that addressed cost, performance, and infrastructure development issues. The cost and performance of fuel cells improved, and public-private partnerships developed demonstration projects such as the BC Hydrogen Highway, which was a planned highway with hydrogen fueling stations from Vancouver to Whistler. Clean Hydrogen development indeed progressed during this period. However, the Hydrogen Economy Initiative was sunsetted at the end of March

2008, leaving a lack of funding available to keep the momentum going. As Theckedath explains in his background paper titled "Where's the Hydrogen Economy?", the 2008 Canadian Fuel Cell Commercialization Roadmap Update, a Government of Canada publication that detailed the progress of Canada's hydrogen and fuel cell industry, highlighted that interest remained strong in fuel cells and hydrogen, however, it concluded that the Government of Canada should aim to have their investments within a mix of technologies (Theckedath, 2010). While the Government of Canada did create funding opportunities to accelerate the hydrogen market in Canada, federal investments dried up at the very moment when hydrogen needed the funds to establish itself in the alternative clean fuel market.

### *Cost Competitiveness*

A critical obstacle that clean hydrogen proponents had to contend with was the cost of manufacturing, storing and transporting hydrogen relative to conventional fuels. As Theckedath (2010) explains, the high cost of hydrogen production, the low availability of hydrogen production systems, and the challenge of providing safe production were all barriers at the time. These factors resulted in generally high costs for end-users, which was a prominent issue for early adopters. Grant Strem (Interview I) also indicated during his interview that the cost of hydrogen was the main contributing factor that limited its emergence 20 years ago. He detailed that fuel cell vehicles were still relatively expensive and materials to manufacture them were incredibly costly, such as platinum (Strem, 2022). These numerous factors contributed to potential end-users looking elsewhere for their energy needs, often looking to more established technologies and fuels with lower price points.

The lack of enabling infrastructure represented another key obstacle clean hydrogen had to address. At the time, Canada's energy economy relied on its fossil fuel resources, resulting in more investments related to transportation and production. The built-out infrastructure facilitated fossil fuel production, storage, and transportation across Canada, allowing for more efficiency and lower costs passed on to consumers. As stated in the Canadian Fuel Cell Commercialization Roadmap Update from 2008, during that time, there were proven distribution systems of pipelines in place to move conventional liquid and gaseous fuels but no existing plan for hydrogen (Government of Canada, 2008). A primary example was the Trans Mountain Pipeline, which operates as the critical link for the Alberta oil sands to connect to the west coast of North America. Primarily transporting crude oil and refined petroleum products from Edmonton to refineries and terminals in British Columbia, it represented Canada's most significant movement of fuels to market. For clean hydrogen to penetrate the energy market at the time, either the construction or retrofitting of pipelines would have to happen to keep up with the competitive advantage that fossil fuels possessed. Currently there are plans to blend hydrogen in order to transport it through pipelines, however, these pipelines are costly because would have to be retrofitted in order to ensure that hydrogen would flow without risk of escaping (Bakx, 2020).

Finally, not only did the hydrogen movement have to contend with the costs of building infrastructure, but it also had to deal with public attitudes toward energy infrastructure. As Klippenstein (Interview F) explains, building infrastructure in Canada often has had a lot of opposition; therefore, even getting past the permitting process would be lengthy and complex (Klippenstein, 2022). At the time, clean hydrogen would have had to market itself in opposition

to fossil fuels based on its low-carbon potential. However, this marketing would have to hedge on Canadians' awareness of climate change and their willingness to pay for the inefficiencies of clean hydrogen in the face of a changing climate. Klippenstein (Interview F) suggested that starting that pipeline-permitting process, which would go across the country similarly to Canada's natural gas network, would have been a good step. Establishing pipeline infrastructure would be the next logical step at the time and remains a persistent barrier in contemporary attempts to develop a clean hydrogen market in Canada if clean hydrogen were to compete in terms of cost with other fuels.

### *Supply and Demand*

Equally important as shoring up the supply of hydrogen and lower costs is ensuring sufficient demand for clean hydrogen. At the time, the transportation sector was beginning its transition to low-carbon options. However, multiple contending options were available. While beneficial for hydrogen's emergence, the demand for cleaner alternatives to fossil fuels was not entirely focused on clean hydrogen and fuel cells. Klippenstein (Interview F) explains that in the early 2000s, the source of hydrogen was not considered, but the focus was primarily concentrated on the technological aspects of hydrogen, such as fuel cells. Klippenstein (Interview F) further explains that there was more immediate attention on batteries (Klippenstein, 2022). Fuel cells had to compete against batteries, which were gaining traction in the world of low-carbon transportation, with the progression of charging infrastructure and electric vehicles beginning to take hold of the market. Therefore, there was less concern from industry players about the inputs going into producing hydrogen (such as the renewable energy needed to produce green hydrogen) and more on fuel cells fighting against batteries' efficacy. Hydrogen fuel cells had the

advantage in terms of their short refueling time, less weight added for energy stored and the lower material footprint than lithium batteries (IEA, 2019).

Efficiency and cost have always haunted clean hydrogen development in Canada. As James Gaede (Interview C) indicated during his interview, the biggest hindrance back then was that clean hydrogen was expensive and inefficient and required substantial investment in infrastructure. Some of these factors remain to be realized within today's context (Gaede, 2023). Compared to today's context, the most significant shift is that hydrogen has come down in cost relative to the early 2000s (Strem, 2022). Layzell (Interview G) indicated a similar notion in his interview for this thesis, adding that the biggest hindrance has always been that clean hydrogen only works at a large scale. In terms of energy system transition and climate change solutions, the principal drivers have always been economic theory, and incremental cost changes have been a significant indicator of clean hydrogen's emergence (Layzell, 2022). There is optimism, however, that with considerable interest and government support, clean hydrogen can emerge within Canada's future low-carbon economy.

During the Post-Kyoto Period, clean hydrogen focused primarily on enabling technology and the relevant costs. Clean hydrogen suffered from limited supply due to the limited infrastructure, which resulted in higher prices relative to other fuel sources that dominated the market. The Canadian public's urgency of climate change and the individual impacts of clean hydrogen fossil fuel-based transportation could simply not shore up sufficient demand to effectively penetrate the market. Even as the urgency of climate change started to enter the Canadian consciousness, the efficiency of batteries and their inputs into electric vehicles out competed clean hydrogen's

applications into technologies such as fuel cells. Although the government attempted to secure more hydrogen availability by encouraging private companies to invest, the funding could not ensure a sustainable, long-term impact that clean hydrogen needed at the time to be regarded as a genuine low-carbon alternative in the emerging clean energy market. Ultimately, the variables were not mature enough to contribute to clean hydrogen's adoption in Canada, resulting in higher costs and limited supply for potential early adopters of hydrogen.

### **The Post-Kyoto Legal Analysis: Environmental Regulations Origins**

This section of the ESPELT analysis explores the legal history of the initial attempts to establish a hydrogen market in Canada during the Post-Kyoto Period. The following analysis examines the legislation and regulations that enabled the development of hydrogen as a clean technology in Canada. This includes some of the first environmental protection acts passed by the Government of Canada. Additionally, the analysis will explore the global environmental agreements and internal legal obligations that Canada had committed to around the turn of the century. Ultimately, hydrogen's potential was tied to the Government of Canada's ambitions to address climate change through its regulations and legislation, especially in the automotive and energy sectors that encouraged the push away from traditional high-emitting fuels. However, due to the nature of Canada's federalism, it was challenging to bring into law or enforce.

In Canada, increasing awareness of global environmental destruction and the subsequent social pressures associated with the environmental movement spurred the Canadian Government to establish legislation that responded to the threats of climate change. One of the first moves the Government of Canada enacted toward environmental legislation came from uniting agencies

focused on the environment. The culmination resulted in the amalgamation of old agencies such as the Meteorological Service of Canada (1871), the Water Survey of Canada (1908), and the Canadian Wildlife Service (1947). Although these ministries were collected, their primary focus remained on aspects of the natural environment rather than the impacts of fossil fuels on a changing global climate. While this represents an initial piece of Canadian environmental legislation, the amalgamation of these agencies leads to more environmental legislation becoming implemented, namely the founding piece of environmental legislation, the Canadian Environmental Protection Act.

#### *The Canadian Environmental Protection Act*

The Canadian Environmental Protection Act represented Canada's first domestic piece of legislation to address the degradation of the environment. The Canadian Environmental Protection Act (CEPA) was passed by amalgamating existing laws and providing new powers to protect human health and the domain from pollution risks (Government of Canada, 1999). The Act aimed to contribute to sustainable development, pollution prevention and protection of the environment in Canada. The Act included provisions requiring the Act to be referred to Parliament for review every five years after it entered into force. Given that the Act came into force on March 31, 2000, it must be directed to Parliament by March 31, 2005, and the review will begin sometime after that.

At the time, Canada lacked a comprehensive regulatory framework specifically mentioning hydrogen. However, the CEPA 1999 noted provisions to control the quality of fuels, including information regarding maximums, minimums, or a range of characteristics to be set that

enabled an approach towards performance-based fuel standards (Hydrogen Strategy for Canada, 2020). Provisions within the CEPA 1999 permitted flexibility in the authority to make regulations that covered different sources of fuels, the place or time of their use and the fuel's effect on the operation of emissions control equipment. There are also provisions for a "national fuels mark," a trademark promoting a national standard for fuels where specific characteristics may be desirable.

The CEPA 1999 incorporates responsibility for regulating emissions from on-road vehicles previously contained in the Motor Vehicle Safety Act and its regulations administered by Transport Canada. In addition, CEPA 1999 allows for regulating emissions from engines used in off-road applications. Examples include spark-ignition (gasoline) engines used in lawnmowers, chainsaws, light industrial machines, outboard motors and off-road recreational vehicles, and compression ignition (diesel) engines used in construction, industrial, farm and forestry machines. The authority for regulating emissions from engines used to power large marine vessels, aircraft and trains is covered under separate federal legislation administered by Transport Canada. The CEPA 1999 indicated one of the foundational pieces of legislation that acknowledged the need to implement pollution prevention measures and cemented Canada's approach to environmental protection. Ultimately, CEPA 1999 did not have a profound impact on hydrogen development in Canada, but still acted as the first piece of legislation concerning environmental protection, paving the way for future environmental legislation to be enacted.

### *The Kyoto Protocol*

Along with domestic legislative commitments, Canada entered into international environmental accords with other countries to combat climate change. For instance, Canada joined the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 following the Rio Earth Summit in 1992. The objective of the UNFCCC was to ensure the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (Kyoto Protocol Implementation Act, 2007). By joining this commitment, Canada indicated the drive to reduce GHG emissions and address climate change through subsequent multilateral environmental agreements.

The most significant of these commitments was the 1997 Kyoto Protocol, which established an international institution for domestic responses to climate change that links emissions target Organization of Petroleum Exporting Countries (OPEC) countries to the global market (Bernstein, 2002). It introduced three primary market mechanisms to transfer "credits" to help countries meet their respective environmental responsibilities (Bernstein, 2002). These three central market mechanisms allowed numerous countries to remain flexible while striving to achieve their GHG emission mitigation strategies. Additionally, while these flexible mechanisms permitted some leeway in how developed countries could meet their targets, the protocol established a normative framework for the strategy pursued (Bernstein, 2002).

The Kyoto Protocol was a significant moment in Canadian climate history, primarily because it was a major setback for Canada's reputation as an international climate leader due to their withdrawal from the international climate commitment. In accordance with Article 27,

paragraph 2 of the Protocol, Canada's withdrawal took effect on December 15, 2012. Following some of the past international climate agreements that Canada had hosted, Canada legally opted to pull out of the Kyoto Protocol, stating that the commitments did not fall within the Canadian vision for addressing climate change. As stated by Canada's Environment Minister at the time (2011), Peter Kent, concerning the world's largest two emitters not entering the protocol, Kent said, "It's now clear that Kyoto is not the path forward to a global solution to climate change. If anything, it's an impediment." (Guardian, 2011).

The Kyoto Protocol was ambitious and would have been a major accelerator of the opportunities for new firms to satisfy the ever-increasing demand for low-GHG technologies, such as hydrogen (Taylor et al., 2002). Developed countries would commit to individual targets to limit or reduce their greenhouse gas emissions. The 36 developed countries (including Canada) had ratified commitments that would cut their total emissions of greenhouse gases on average between 2008 and 2012 levels 5% below 1990 levels. Canada's target is an average of 6% below 1990 levels over the 2008-2012 period. Under the Kyoto Protocol implementation, emerging sectors would be enabled in order for Canada to meet these commitments and was promising for industries that were aiming to implement renewable energy into the domestic energy mix.

The Kyoto Protocol propelled investment opportunities such as wind power facilities in Canada, which could be worth up to \$6.5 billion by 2010 (Taylor et al., 2002). Additionally, sectors that included alternative transportation technology were poised to take off. At the time, major firms such as Shell International and DaimlerChrysler expected hydrogen to emerge as the world's

primary energy medium, with fuel cell vehicles playing a significant part in the hydrogen economy (Taylor et al., 2002).

As a result of this promising outlook firms like Ballard Power Systems were positioned to become more prominent in the Kyoto implementation scenario. Ballard Power Systems is a Vancouver-based firm and world leader in the development of fuel cells in automotive applications. According to firms such as Ballard Power Systems, the ratification of the Kyoto Protocol would have assisted firms in bringing new technologies and improved products to the domestic market, enhanced abilities to become significant exporters of Canadian technology and provided an incentive for them to remain in Canada (Taylor et al., 2002). The development of fuel supply infrastructure for fuel cell vehicles in Canada can be accelerated through initiatives to reduce GHG emissions. This potential was captured with the Canadian Transportation Fuel Cell Alliance, with \$23 million to do just that over the next five years (Taylor et al., 2002).

In Canada, the roles and responsibilities of local, municipal, indigenous, provincial/ territorial, and federal governments differ with respect to their management of non-renewable natural and forestry resources (Natural Resources Canada, 2017). As stated in the 1982 amendments to the 1867 Constitution Act, provinces and territories possess constitutional rights to manage their respective non-renewable natural resources, forestry resources, and electrical energy (Natural Resources Canada, 2017). Therefore, political parties that can form governments within provinces that develop hydrogen will have a say in the feedstocks utilized in the

development of hydrogen depending on what feedstock they may have a competitive advantage in producing.

There are numerous federal and provinces disputes that impact the long-term enactment of legislation that would contribute to hydrogen development in Canada. This illustrates the eternal dilemma of environmental law in Canada. Provincial resistance to federal interference effectively prevented federal authorities from introducing long-term strategies. While laws and regulations were available for clean hydrogen to be leveraged at the time, these laws and regulations are not as strong as they are today. Ultimately, this did not provide an even playing field for hydrogen to emerge.

## **The Post-Kyoto Technological Analysis: Innovation Leadership Requires Advancements**

This section of the ESPELT analysis aims to explore the technological advancements of the initial attempts to establish a hydrogen economy in Canada during the Post-Kyoto Period. The following analysis examines the available technology, applications and production pathways that enabled the development of hydrogen in Canada at the time. This technological review highlighted the prominent enabling technology, the fuel cell, which accelerated the potential for hydrogen's application within the transportation sector. Additionally, the analysis showcased the number of production pathways available during the 2000s, including the industry's most viable and emerging pathways. Ultimately, hydrogen's potential as a clean technology was limited to specific sectors, such as single-use transportation, competing with other clean technologies that impacted hydrogen application and wide-scale adoption in Canada.

### *Clean Technology for a Low-Carbon Future*

The hydrogen fuel cell was, and still is, a significant component of hydrogen's technological capabilities and represents an ideal power source to meet the growing consumer demand for hydrogen. Fuel cells can be thought of as a sort of battery. Still, instead of storing chemical energy, fuel cells convert the chemical energy of a fuel fed into them to generate electricity as long as external fuel and oxidant are supplied (Rifkin 2002). Fuel cells were invented in the early 1800s, but the technology was not applied until the 1960s and '70s (The Pembina Institute, 2000). Since then, Canadian industries and the government have pointed to the fuel cell as the means to reduce greenhouse gas emissions (The Pembina Institute, 2000). At the time, the system that received the most attention from the automotive sector was the Proton Exchange

Membrane (PEM) fuel cell. The PEM fuel cell had several advantages, including an efficient start and shutdown timing, a secure manufacturing process, and a simplified system that increased cost efficiency (Dircks, 1999). The PEM fuel cell had hydrogen protons migrating from the anode through the electrolyte to the cathode. A platinum anode acted as a catalyst to facilitate splitting the hydrogen molecules into positively charged protons and negatively charged electrons. The electrolyte membrane allowed only the protons to pass through to the cathode. The electrons could not pass through this membrane, so they flowed as an electrical current through an external circuit to get to the cathode, thus creating electricity (Natural Resources Canada, 2005). The oxygen supplied at the cathode is then combined with the protons to form water (Natural Resources Canada, 2005).

While conventional wet and dry cell batteries can store energy, this energy is finite. In contrast, in a fuel cell, fuel can be fed continuously into the cell to produce electricity continuously. Therefore, if hydrogen is used as the fuel source, the resulting process could be highly efficient (Taylor et al. 2002). At the time, proponents of the renewable energy/hydrogen complex focused on developing small stationary and portable fuel cells and on the fast-growing market for them as mini plants for use in factories, offices, retail stores, homes and automobiles (Rifkin, 2002). Although fuel cells were highly developed by the early 2000s, the hydrogen feedstock into the fuel cells needed to be produced in large quantities that were economically viable for clean hydrogen to be more established within the overall Canadian energy mix.

### *Hydrogen Production*

In the Post-Kyoto Period, there were numerous ways to produce hydrogen, including deriving hydrogen from natural gas or coal via a steam-reforming process and electrolysis. In 2002, nearly half the hydrogen produced in the world was derived from natural gas via a steam-reforming process, where natural gas reacts with steam in a catalytic converter (Rifkin 2002). Gasified coal could also be used as a feedstock within the steam-reforming process, which would have hydrogen atoms stripped away, resulting in a carbon dioxide by-product (Rifkin 2002). While achieving the lowest cost of producing hydrogen, it remained the highest carbon intensive form of hydrogen production. During the early 2000s, employing this hydrogen production method meant high emissions, which would not be mitigated due to technologies such as carbon capture and storage not being fully developed or too costly to reduce emissions by this point.

Utilizing natural gas via steam reforming is the cheapest method to produce commercial hydrogen and that gives it the cost-competitive edge that it has enjoyed for many decades. Although natural gas seemed to be the relatively cheaper feedstock for hydrogen development, future assumptions concerning natural gas hinged on its availability and price. Natural gas was to be readily available for Canada based on the existing infrastructure and consistent supply from provinces such as British Columbia and Alberta. This abundance leads to lower prices for industrial consumers of hydrogen. However, this process utilizes fossil fuel feedstocks that are eventually emitted as harmful greenhouse gases into the atmosphere. While greenhouse gas emissions remained a concern during the early 2000s, proponents for hydrogen argued that research and development into carbon sequestration could facilitate hydrogen's ascension as a

fuel that could be emissions-free. Proponents say that in the future, CO<sub>2</sub> generated in the conversion process could be isolated and sequestered in under-storage sites, including depleted oil or gas fields.

During the Post-Kyoto Period, producing electricity through renewable methods such as photovoltaic (PV) systems was not cost-competitive with energy produced from fossil fuels. At the time, PV was still two to five times more expensive than conventional electricity generated from fossil fuels; however, it was continually lowering costs, with PV prices dropping to under \$4 per watt for the first time by the late 1990s (Rifkin 2002). Electrolysis' potential to usher in an era of clean hydrogen production was promising; however, by the early 2000s, electrolysis accounted for only 4 percent of the hydrogen produced. This low hydrogen production annually was due to the cost of generating electricity. Considering this, achieving hydrogen's environmental benefits and the public's interest in addressing climate change further spurred the urgency to develop clean energy technology at the time, regardless of cost competitiveness. A Pembina Institute study concluded that hydrogen fuel from natural gas reformed in a large plant could reduce a vehicle's carbon dioxide emissions per 1,000 km travelled by approximately 72% hydrogen derived from a renewable energy source such as hydroelectricity would reduce emissions even more (Taylor et al. 2002). This figure is even less dependent on the production stream of hydrogen used, with carbon capture technology and electrolysis seen as a potential emerging and less emission-intensive way to make hydrogen.

### *Advantages and Barriers*

Hydrogen's potential was emerging during the Post-Kyoto Period, along with other forms of renewable energy, such as solar and wind, which were increasingly being seen as alternative energy sources. However, as solar and wind were inherently distributed technology and therefore faced challenges in storage. Hydrogen had an advantage in this space and could fill this void through its storage capabilities (Bardi 2021). The most important aspect of using a renewable resource to produce hydrogen is that the sun's energy and wind, hydro, and geothermal energies will be convertible into "stored" energy that can be applied in concentrated forms whenever and wherever needed with zero CO<sub>2</sub> emissions (Rifkin 2002).

Although during the Post-Kyoto Period, hydrogen technology had come a long way, however, several technological challenges still needed to be addressed. Considering fuel cell technology of the time, durability was a critical challenge to operating fuel cells within various external conditions while being reliable (Tayler et al., 2002). Another technical challenge facing fuel cell developers, as with any new mass-produced product, is optimizing manufacturing processes to keep costs low and obtain an acceptable level of product quality (Taylor et al., 2002). A final major technical challenge facing fuel cell companies is the further development of materials and tools or decreasing cost and improving the performance of fuel cells (Taylor et al., 2002). The production of hydrogen also faced some critical barriers, including that hydrogen possessed a low energy density; to be used effectively within a wide range of applications, it required the further development of advanced storage technologies (Taylor et al., 2002). Hydrogen must be compressed at high pressures to be stored utilizing the available storage methods of the time, which requires more energy than hydrogen yield when used in a fuel cell (Taylor et al. 2002).

Secure, reliable, and cost-effective distribution networks would need to be established to foster the widespread utilization of hydrogen, thereby requiring further advancement of hydrogen technologies. Lastly, Canada would need to expand the implementation and demonstration of fuel cell technologies and hydrogen infrastructure, as these demonstration and procurement programs would reassure potential adopters in the short term while technological advancements and cost remained barriers at the time (Taylor et al. 2002). Therefore, technological advancement will only make efficient hydrogen production more viable, and increase its advantages as a viable, climate friendly alternative to traditional fossil fuels.

Hydrogen technology was well advanced by the early 2000s but faced significant cost hurdles to become more viable within the clean energy market. As Martin Bush (Interview A) detailed during his interview how fuel cell technology received considerable research, leading to cheaper costs currently, but not back then. Additionally, questions surrounding fuel cell technology and clean hydrogen's efficiency were prevailing questions at the time and remain today to a certain extent. Bush (Interview A) also alludes to the factor of competing with electric vehicles, where the batteries are getting more powerful. While there may be space for fuel cell vehicles to enter the singular clean transportation market, this emergence may not factor in as completely as many would want to see (Bush, 2022).

## CHAPTER 4: THE POST-PARIS HYDROGEN HYPE CYCLE

---

### *Introduction*

During the Post-Paris Period (2018-2022) evaluated for this thesis research, hydrogen has been highlighted as a potential solution to climate change and has emerged as a contending proponent within Canada's contemporary energy mix. As highlighted in the analysis below, hydrogen emerged during this Post-Paris hype cycle as a result of multiple factors, including the increased intensity of climate related weather events, advances in hydrogen's technological development, and expanded social awareness of hydrogen's potential as a critical component to reaching Canada's Net-Zero objectives by 2050.

For the Post-Paris Hydrogen Hype ESPELT analysis, Canada's 2050 net-zero ambitions have been instrumental in hydrogen's emergence as a modern solution to address the lingering emissions from hard-to-abate sectors worldwide and domestically. Since the Government of Canada's announcement to commit to Net Zero by 2050, some provincial and territorial governments have accelerated their plans to achieve a low-carbon economy to align with these federal ambitions. The aspirations to reach Net Zero further highlighted hydrogen's potential to have more significant implications within Canada's clean energy mix (Hydrogen Strategy for Canada, 2020). This had been highlighted in Government reports, particularly the Government of Canada's Hydrogen Strategy, which have evaluated the benefits of producing hydrogen and its potential applications to meet Canada's clean energy demand. As a result of this analysis, it is likely to infer that the development of a robust hydrogen economy is poised to be established within the Post-Paris Period than previous hype cycle iterations.

## **The Post-Paris Environmental Analysis: Environmental Influences**

The environmental crisis has had a significant role in the development of hydrogen. GHG emissions contribute to global warming, which is projected to lead to change in average climate conditions and extreme weather events. The impacts of climate change are expected to worsen as the global average surface temperature becomes warmer (The Canada Gazette, 2020).

Hydrogen has the potential to mitigate GHG emissions, and in turn, contribute to the lessening the impacts of global warming by becoming a fixture in Canada's clean energy mix. This analysis examines the environmental impacts as a result of climate change that has contributed to clean hydrogen's emergence as a potential factor within the modern, clean energy space in Canada and globally.

### *Climate Change*

The International Energy Agency highlights that Global CO<sub>2</sub> emissions rebounded to their highest level in history in 2021, stating that global energy-related carbon dioxide emissions rose by 6% in 2021 to 36.3 billion tonnes (International Energy Agency A, 2022). Since 2000, global CO<sub>2</sub> emission from energy combustion and industrial processes have continually risen from 24.6 GT CO<sub>2</sub> in 2000 to 36.8 GT CO<sub>2</sub> in 2022. The most recent AR6 IPCC report indicates that there has been an increase in GHG concentrations as a direct result of human activity since 1750 due to humanity's continued reliance on burning fossil fuels and land use changes. The IPCC report indicates that global temperatures are currently 1.09°C [0.95°C–1.20°C] higher in 2011–2020 than in 1850–1900 (IPCC, 2023). The increase in temperatures has accelerated climate change leading to numerous detrimental impacts on society and the earth (Figure 3,

IPCC, 2023). Global warming is projected to lead to change in average climate conditions and extreme weather events,

Figure 3

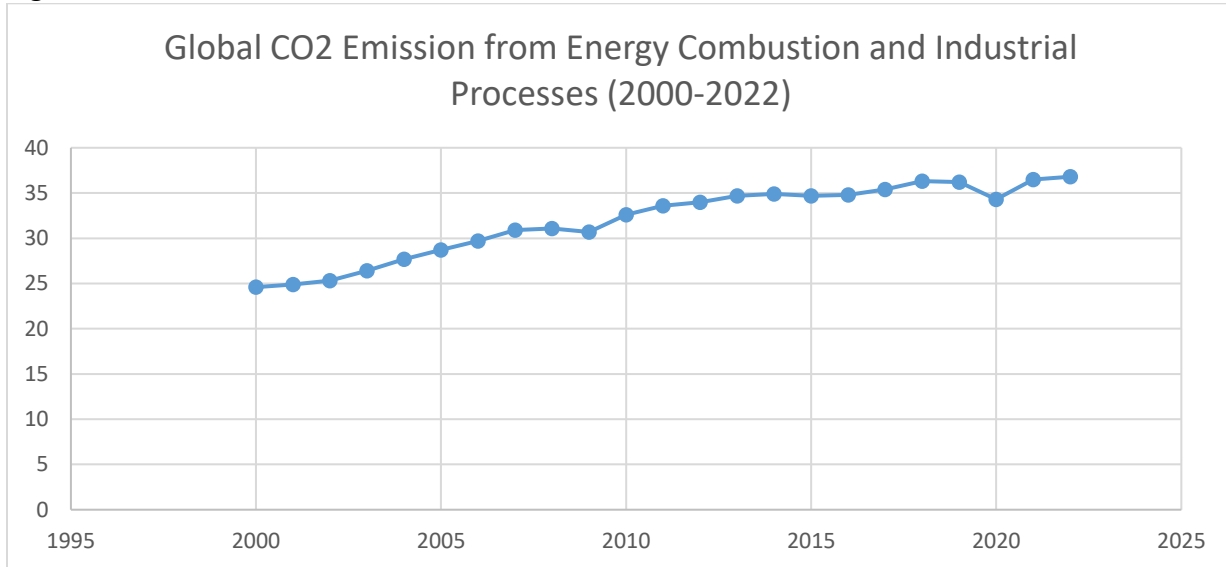


Figure 3: Global CO2 Emissions from Energy Combustion and Industrial Processes (2000-2005). Source: International Energy Agency, 2023

Climate change’s impacts continue to amplify as global temperatures continue to rise. Climate change strains the global economy by straining supply chains, leading to increased costs and food insecurity in some parts of the world. Rising greenhouse gas emissions directly impact human health, including decreased air quality due to the continued release of greenhouse gas emissions. Furthermore, climate change creates economic challenges for climate-exposed sectors, such as agriculture, forestry, fishery, and energy (IPCC, 2023). Greenhouse gas emissions have increased the intensity of extreme weather events, which directly impact urban infrastructure, including transportation, water sanitation and energy systems (United Nations, 2022).

### *Extreme Weather Events*

Climate change's adverse impacts are demonstrated by increasing catastrophic events that have captured the attention of Canadians. Extreme weather events from heatwaves, droughts, flooding, winter storms, hurricanes and wildfires increased in frequency and magnitude (IPCC, 2023). For instance, wildfire outbreaks can be disastrous for local and regional economies and air quality. In Canada, extreme events result in adverse economic, social, and environmental impacts and affect Canadians' livelihoods, health, and well-being. Canada has experienced, first-hand, the effects of climate change with devastating wildfires and floods. British Columbia is experiencing significant climate change impacts with worsening heat waves, droughts, wildfires, storms, and floods. In Alberta, whole towns have been devastated by the effects of climate change. Not long ago, Fort McMurray experienced major wildfires resulting in the largest wildfire evacuation in history (CBC News, 2017). In British Columbia, atmospheric rivers produced relentless rain over much of the province, resulting in devastating flooding in the Sumas Prairie, significantly impacting British Columbia's agricultural sector. (CBC News, 2021)

The realities of climate change have become more prevalent and have increased the attention on addressing climate change through exploring low-carbon options. Increased frequency of catastrophic weather events has emphasized the need for investments in low-carbon technologies such as clean hydrogen. Low-carbon technology is seen as a critical component of achieving environmental commitments due to the environmental benefits associated with its production and use.

### *Hydrogen's Environmental Benefits*

Hydrogen in the Post-Paris Period was underlined in Canada's Hydrogen Strategy, which sets the strategic pathway to position clean hydrogen as a critical part of Canada's net-zero carbon plan by 2050, emphasizing Canada's comparative advantages to be a leader in the hydrogen space (Allan et al., 2022). The release of the Strategy indicates that the Government of Canada has identified the benefits of hydrogen technology due to its ability to be produced cleanly and economically by using fossil fuels when coupled with carbon capture technology and renewable energy sources such as solar and wind. For this reason, clean hydrogen can play a significant role in decarbonizing energy systems. According to the Government of Canada, it makes its adoption promising in Canada's efforts to transition to a low-carbon economy (Hydrogen Strategy for Canada, 2020).

According to the Paris agreement, Canada pledged to minimize GHG emissions by 30% lower than in 2005 by 2030, aiming to reach 511 Mt (Razi, 2021). These reductions are difficult to achieve and are determined to be quite ambitious. Canada's Hydrogen Strategy states that embracing new technologies to give Canadians more choices of zero-emission alternatives will be vital to achieving the low-carbon transition (Canadian Hydrogen Strategy, 2020). However, hydrogen is forecasted to be critical to decarbonizing the last hard-to-abate sectors such as heavy-duty transport and steel manufacturing. BloombergNEF estimates hydrogen could abate up to 37% of the world's energy-related emissions with strong policy support (BloombergNEF, 2020). This will be needed because, in Canada, 82% of emissions came from energy (in 2018). Therefore, implementing hydrogen can help decarbonize the Canadian economy by replacing fossil fuels with new hydrogen-based applications, particularly in sectors that are the most

difficult to decarbonize and where alternatives are limited. Hydrogen can also facilitate the decarbonization of natural gas utilities, which are increasingly setting targets or facing regulations requiring they blend in increasing amounts of renewable gases, including biomethane and hydrogen (Clean Energy Canada, 2020).

Canada in the Post-Paris Period is one of the most economically advanced countries in the world and aims to achieve a net-zero economy by 2050 (Razi, 2021). Low-emission hydrogen shows the potential to contribute to the 2050 GHG reduction challenge, addressing the most demanding third of applications where other options like direct electrification may not be technically or economically favourable. Low-carbon intensity hydrogen best serves applications such as long-range transportation, high-grade heat for industry and buildings, and use as a feedstock in the industrial process (Hydrogen Strategy for Canada, 2020).

In conclusion, hydrogen provides the many environmental benefits Canada and other countries seek in their respective quests to achieve their climate goals by 2030 and net zero by 2050. The development of clean hydrogen in Canada will significantly contribute to reaching its climate goals. As stated, the real potential for hydrogen will be in hard-to-abate sectors, making clean Hydrogen one of the critical pillars to reducing GHG emissions in Canada. Indeed, Canada has a competitive advantage in producing hydrogen utilizing natural gas and carbon capture and storage. However, producing hydrogen via electrolysis is a promising pathway to embracing hydrogen's low-carbon potential. Indeed, the Government of Canada will seek to align itself with other countries advancing towards environmental goals under the international environmental regulations put in place by 2030 and 2050. Hydrogen figures are a significant

component of these goals, and Canada has sought alignment opportunities, as evidenced by its agreements with Germany, the Netherlands, and recently the United States (IEA, 2022).

Ultimately, hydrogen's ability to contribute to the decarbonization of energy systems is the biggest driver for adoption and a pivotal component of Canada's commitment to achieving net-zero emissions by 2050 (Hydrogen Strategy for Canada, 2020). Hydrogen's environmental benefits are a primary reason for its interest within the Post-Paris hydrogen hype cycle.

As the world converged in Paris in 2015, the need to decarbonize parts of many industries was emphasized and represented in many discussions. This analysis examines environmentalism's contributions to clean hydrogen's emergence as a potential factor within the contemporary clean energy space domestically and globally. The environmental crisis has had a significant role in the development of hydrogen. The global efforts to address the challenge of climate change and the need to decarbonize parts of the industrial and transportation sectors have primarily contributed to clean hydrogen's current hype within the Canadian energy landscape. Clean hydrogen offers an opportunity to minimize GHG emissions, meet the projected energy demands of a low-carbon future and avoid the threat of radical climate shifts attributed to a changing climate due to high carbon emissions.

## **The Post-Paris Social Analysis: Climate Change Urgency Arrives**

This section of the contemporary period ESPELT analysis aims to explore the contemporary notion of hydrogen's social acceptance by Canadians. The analysis includes uncovering the levels of clean hydrogen awareness amongst Canadians and examining the support of clean hydrogen within different sectors in Canada. Private companies, government, and non-profit organizations have all been implicated in developing clean hydrogen in Canada. The analysis revealed that the support of project demonstrations, research and development, and public-private partnerships has grown in Canada, indicating increasing social acceptance of clean hydrogen. Within the contemporary sense, Canadians generally perceive hydrogen as a future clean energy source and demonstrate a general understanding of hydrogen as necessary to Canada's overall clean energy matrix.

### *Changing Social Perceptions about Climate Change Urgency*

Using fossil fuel sources in the power generation and transportation sectors has been a primary source of carbon dioxide emissions contributing to global warming (Razi, 2021). Natural gas, crude oil, and coal have been primary power generation sources due to their capacity to produce energy at higher efficiencies (Razi, 2021). The sense of urgency attributed to the climate crisis has narrowed the focus on renewable energy and clean technologies as crucial ingredients to solving climate change. The sense of urgency has led to clean hydrogen has been identified as a critical pillar in the energy transition due to its capacity to address the carbon emissions from hard-to-abate sectors.

The social acceptance of clean hydrogen has increased as a direct result of its potential as a clean technology within the current efforts to transition to a low-carbon economy. Clean hydrogen has garnered considerable recognition that may not have otherwise been realized without the significant push to decarbonize in today's context. The Government of Canada's approach to committing to international climate agreements, specifically net-zero 2050 goals, has accelerated clean hydrogen's perceived role in decarbonization, resulting in sustained pressure on high-emitting private companies to adapt to new policies and regulations implemented by the federal government. The Government of Canada has aligned with numerous industrial sectors to emphasize the importance of developing and adopting clean technologies and alternative energy sources, such as hydrogen (Hydrogen Strategy for Canada, 2020).

This is further evidenced in one of Canada's largest industries; as mining companies face mounting social and economic pressure, many companies have identified clean hydrogen's potential to figure into their operations to lessen their emission impact (Hydrogen Strategy for Canada, 2020). Moving forward, these companies will need to extend these efforts to meet the standards demanded by law if they wish to gain or maintain their social "license" to operate (Hydrogen Strategy for Canada, 2020). Clean hydrogen plays a significant role in mitigating emissions within these companies' operations and could translate into a better perception from the public and more recognition of the companies' efforts within hard-to-abate sectors to implement cleaner processes. For instance, as pointed out by Lozano et al., there remains a strong preference for hydrogen produced from renewable energy in a process known as electrolysis (Lozano et al. 2022). Canada does possess some advantages for this form of

production, particularly in Quebec, due to the province's investments in its electricity grid.

However, Canada's main benefit will be utilizing its natural gas reserves in western provinces such as British Columbia and Alberta.

Using fossil fuels to produce clean hydrogen may alarm Canadians, especially considering many Canadians may not be familiar with the potential for carbon capture technology. However, Lozano et al., 2022 also stated that their analyses indicated some support for hydrogen produced from fossil fuels with carbon capture and storage as long as it was part of the transition to renewable energy sources. Meaning that fossil fuels to produce hydrogen, when coupled with carbon capture technology, could be used as a bridge towards eventually producing hydrogen through electrolysis. Therefore, there may be some instances in which the social acceptance of hydrogen produced by natural gas may be favoured as a bridge feedstock until clean hydrogen production through other feedstocks becomes more efficient. Regardless of the direction that the clean hydrogen industry wants to take concerning utilizing their feedstocks, the Government of Canada has aligned with provinces by focusing on the carbon intensity of hydrogen rather than the inputs associated with its production.

### *Hydrogen's Potential to be Inclusive*

The social acceptance of clean hydrogen will be a key factor in whether the hydrogen economy will emerge within the next few decades. For instance, traditional heavy-emitting industries will also have to get on board with transitioning to clean hydrogen to compete within the green economy. Clean hydrogen has the potential to be inclusive, especially with the Government of Canada's approach to equity, diversity, and inclusivity. In an interview for Amandeep Garcha

(Interview D), a Senior Analyst at Natural Resources Canada highlighted that awareness is a critical component of the federal government's hydrogen strategy. He added that there is an opportunity for the development of clean hydrogen in Canada to be inclusive. He refers to the federal government's activity in ensuring that perspectives are shared, including developing an Indigenous Oversight Committee to ensure Indigenous voices have access to government decision-makers. Ultimately, as Garcha (Interview D) put it in his interview for this thesis, there is a massive opportunity for all Canadians to get involved in developing the hydrogen economy in Canada. Clean hydrogen can play a significant role in including specific populations within Canada.

### *Technology Adoption*

Like any new technical innovation, Hydrogen is building on social acceptance to ensure wide-scale adoption. Considerations for societal acceptance of Hydrogen within Canada will factor in relative associated costs, trust in clean hydrogen's safety, and the source of hydrogen production. Lozano et al. indicate that when people perceive higher risks and limited benefits of new technologies, they are less likely to support them (Lozano et al., 2022). A clear focus on clarifying uncertainties around hydrogen technologies is required and highlighting clean hydrogen's benefits (Lozano et al., 2022). Since awareness levels are strongly associated with technology acceptance and uptake, communication and education campaigns that build knowledge will be critical in fostering changes in attitudes toward hydrogen and an inclination to use Hydrogen (Lozano et al., 2022). The further acceptance of hydrogen will facilitate the emergence of hydrogen's perception as a decarbonization tool and the establishment of the hydrogen economy.

Hydrogen's environmental benefits have sparked the initial interest in hydrogen as a decarbonization solution. Clean hydrogen's contribution to climate protection was positively associated with overall support, and the positive health impacts on air pollution are positively associated with the backing for hydrogen in domestic use (Lozano et al., 2022). The urgency of addressing climate change has enabled the public's perception of interlinking the emergence of climate change issues with viable solutions, such as hydrogen, that can actively work to decrease carbon emissions.

### *The Growing Hydrogen Sector*

The data from the Canadian Hydrogen and Fuel Cell Association (CHFCA) illustrates the growth of the hydrogen industry in Canada and delivers insights into the levels of social acceptance necessary for its wide-scale adoption. The CHFCA, in collaboration with the Government of Canada, developed a series of industry profiles of the Canadian hydrogen and fuel cell sector. These industry profiles were done consistently from 2004 until 2022 and provide an informative glimpse into some of Canada's awareness of hydrogen development. The insight provided by these industry sectors revealed crucial data for this thesis research, including key figures related to employment levels, investment decisions, and the overall indications of hydrogen's growth across Canada.

For instance, in 2015, respondents answered the CHFCA's industry sector survey, which reported 1,785 jobs with over 18 demonstration projects, 98 Strategic alliances, and 222 research partnerships equaling a total research, development, and demonstration expenditures of C\$173 million (CHFCA, 2015). The 2015 CHFCA industry profile also highlighted that hydrogen

and fuel cell activities took place in most provinces within Canada; however, the majority of facilities and actions were in British Columbia (31%) and Ontario (18%), followed by Quebec (14%) and Alberta (5%). The rest of Canada (4%) included Manitoba, Newfoundland and Labrador, Nova Scotia, and Saskatchewan facilities. Finally, the CHFCA's industry sector survey indicated that their primary areas of expertise were research (28%). In comparison, other areas of expertise included fuel cell development or manufacturing and supplying to developers or manufacturers (12% each), professional services (10%), and commercialization.

Examining the 2022 CHFCA industry sector profile revealed the contrast from previous years. In 2022, the CHFCA industry sector profile reported employment of 4,291 full-time jobs with 74% of respondents indicated that they represented a corporation organization, with educational institutions and non-profit organizations representing 9% and 8% of respondents showing that they are governments and other organizations, respectively. The majority of survey respondents (75%) indicated that they plan to increase the number of employees engaged in hydrogen and fuel cell activities in the next two years, while 24% indicated that they plan to keep the same number of employees (CHFCA, 2022). Furthermore, the CHFCA Hydrogen Sector Profile 2022 highlights that the Canadian hydrogen and fuel cell sector has experienced growth between 2016 and 2021, especially within the revenue and employment metrics with survey respondents from the Canadian hydrogen and fuel cell sector reporting total revenues of \$527 million and \$125 million in RD&D expenditures (CHFCA, 2022). These sector profiles provide insight into the social acceptance associated with hydrogen production in Canada, and the showcase the increasing optimism surrounding the Canadian hydrogen sector in the Post-Paris Period.

The analysis in this section supports the notion that the contributing factors of climate change and the increased technological knowledge associated with hydrogen have led to a sense of social acceptance of clean technology amongst Canadians. While not entirely explored in this section of the ESPELT analysis, the support of the hydrogen industry in Canada will have to contend with the price points associated with producing and implementing hydrogen (Lozano et al., 2022). However, the health benefits associated with lower emissions and the more significant impacts of climate change have shifted Canadians' perceptions of clean technology as a general benefit to society. As long as clean hydrogen can address the barriers it will have to contend with in the future, there is more considerable potential for the social acceptance of clean hydrogen as a critical mechanism in the fight against climate change.

## **The Post-Paris Political Analysis: Climate Takes Priority**

This section of the ESPELT analysis aims to explore the contemporary notion of politics surrounding hydrogen production within Canada's clean energy context. The analysis includes uncovering the levels of attention attributed to hydrogen from Canadian political parties, politicians, and other elected entities. This section also explores the Government of Canada's policies that act to facilitate the development of the Canadian hydrogen economy. Within the contemporary sense, hydrogen has received more attention within the Canadian political sphere as climate change issues prevailed as a competing policy issue during the Post-Paris Period.

### *Political Pressure*

Clean Hydrogen's emergence is contingent on the political pressures from the modern-day climate movement. Progressively, climate change is seen as an international issue, with countries coming together to negotiate climate accords to align themselves for a low-carbon future. Climate policies leading into this decade aimed to address climate change with stricter international commitments such as the 2030 and 2050 benchmark years to achieve climate goals. In the Paris Agreement, Canada committed to setting a national greenhouse gas target every five years to address climate change. In accordance with the Intergovernmental Panel on Climate Change's (IPCC) report, world commitments acknowledged the impacts of global warming to be limited to an increase of 1.5°C. This acknowledgment signified that significant efforts were needed from countries to reach climate targets.

In the recognition to do more to meet these targets, Canada submitted an enhanced Nationally Determined Contribution (NDC) in July 2021, raising its emissions reduction target to 40-45% below 2005 levels by 2030 (up from a previous target of 30% below 2005 levels). Canada's NDC submission further underlined Canada's efforts to achieve net-zero emissions by 2050, which was formalized in the Canadian Net-Zero Emissions Accountability Act. The Canadian Net-Zero Emissions Accountability Act is a foundational piece of legislation that will accelerate clean hydrogen's prominence due to mitigate the hardest-to-abate emissions to reach a net-zero economy. Today, the Government of Canada recognizes that clean technology is critical in every pathway to Net Zero and essential to meet the climate commitments it has set out at these international summits.

Canada has specifically endorsed the Glasgow Breakthrough Agenda, encouraging, and strengthening countries' climate action in key sectors. The Glasgow Breakthrough Agenda has special significance for hydrogen's development and deployment by 2030 because it commits Canada to address hard-to-abate sectors such as steel, power, and road transport by including hydrogen and carbon capture utilization and storage (CCUS) within the Government of Canada's strategies. The international climate commitments Canada has committed to are contributing political factors that have influenced the domestic perspectives towards hydrogen's place within the low-carbon future that Canada is committed to pursuing. Hydrogen is not only a possible way to address climate change, but it also has the potential to meet some of the international and domestic pressures elected governments will hope to adhere to as long as voters remain engaged in addressing climate change.

### *Domestic Platforms*

A review of the Canadian political parties' platforms revealed that they had positioned themselves by generating policies to address climate change to align with international commitments and domestic priorities. By examining political party platforms leading up to significant elections from 2011 into the most recent election in 2019, the evolution of climate policies has generally shifted from broader approaches to more specific mentions of clean technologies such as hydrogen.

For instance, in 2011, the Conservative party mentioned within their party platform that they had previously made substantial investments in clean energy research and development, including carbon capture and storage. The Conservatives also highlighted the establishment of the Clean Energy Dialogue between Canada and the United States to enhance collaboration on reducing greenhouse gases and combatting climate change (Conservative Party Platform, 2011). The Harper government promised within their platform that they would make new investments to improve air quality and reduce greenhouse gas emissions and provide additional support for research and development in clean energy and energy efficiency. The Conservatives mentioned their intention to support economically viable clean energy projects that would assist regions and provinces in replacing fossil fuel with renewable fuel sources (Conservative Party Platform, 2011). Clean hydrogen was not mentioned within the Conservatives' platform, but the commitments above underlined the importance placed on investing in clean energy projects of the time.

In 2011, the official opposition, the New Democratic Party of Canada (NDP), mentioned within their platform the need to combat climate change, which included re-introducing legislation to ensure that Canada meets the long-term target of reducing our greenhouse gas emissions. Specifically, the NDP wanted to reduce GHG emissions to 80 percent below that of 1990 by the year 2050 and will establish interim targets for 2015-2045. Additionally, the NDP mentioned their intention to redirect revenues raised through auctioning emission permits equitably across Canada into investments in green technologies, business, household energy conservation, public transit, support for renewable energy development, and transitioning workers to a green economy (NDP Platform, 2011). This campaign promise included working with provinces and territories to reinstate federal financial incentives for clean power, including solar, wind, water, tidal, biomass, and other renewable sources for electricity production. The NDP highlighted the contributing factors that enable clean hydrogens' development today, such as the required legislation for clean growth, developing green technologies, and the growing enabling inputs for low-carbon hydrogens, such as solar and wind power.

In 2019, the Liberals introduced a platform highlighting the need to fight and prepare for climate change. The Liberals underlined new initiatives, including A Net- Zero Emissions Future, A Price on Pollution, and a Real Climate Plan focused on a clean energy transition. For example, the liberal government promised to use dollars earned from the Trans Mountain Expansion Project to fund Canada's clean energy transition, with the potential to earn \$500 million per year from the project. The Liberals' plan also included a strategy to make it easier for Canadians to use and afford zero-emission vehicles, with a plan to install 5,000 charging stations along the Trans-Canada Highway and other major road networks in Canada's urban and rural areas.

Additionally, the Liberal government worked to make clean, affordable power accessible to Canadians, such as the new \$5 Billion Clean Power Fund that will help support the electrification of Canadian industries making Canada home to the cleanest mills, mines, and factories in the world. The Clean Power Fund will also help support northern, remote, and Indigenous communities' transition from reliance on diesel-fueled power to clean, renewable, reliable energy. The mention of the Net-Zero Emissions future within the Liberal Platform, and their election, further advanced clean hydrogen's evolution as a piece of the puzzle for the Liberals to pursue net-zero ambitions. There is no question that all major political parties in Canada must address climate change through their platforms, or risk failing to garner support from voters concerned for the environment.

### *Speeches from the Throne*

The Speeches from the Throne are a key indicator of an incoming or re-elected political party's intentions once they form government. Recently, the Liberals have requested the Governor General to deliver Throne Speeches with detailed plans to pursue a transition to a low-carbon economy. For instance, for the 1<sup>st</sup> Session of the 43<sup>rd</sup> Parliament 2019, the honourable Julie Payette delivered a Throne Speech underlining the importance of setting a target to achieve net-zero emissions by 2050. The Speech also mentioned the need to facilitate Canadians' choice of zero-emission vehicles. This Speech was followed up on the 2<sup>nd</sup> Session in 2020 that and concentrated on building solid commitments to bring forward a plan to exceed Canada's 2030 climate goal and to legislate Canada's goal of net-zero emissions by 2050, as well as support investments in renewable energy and next-generation clean energy and technology solutions.

For the 1<sup>st</sup> Session of the 44<sup>th</sup> Parliament in 2021, the honourable Mary Simon delivered a Throne Speech that presented Canada as a leader in producing the world's cleanest steel, aluminum, building products, cars, and planes. The Governor General mentioned investing in public transit and mandating the sale of zero-emission vehicles to accelerate the pathways toward a net-zero future. Although hydrogen is not explicitly mentioned within the Throne Speeches, the indication that Canada is pursuing clean energy gives a more unambiguous indication of the Government of Canada's pursuit of clean hydrogen to meet climate targets while appeasing its domestic electorate.

### *Media Scans*

The Liberal Government, particularly Prime Minister Justin Trudeau, has increased clean hydrogen's potential as a fixture within Canada's visions for a low-carbon economy. The Liberals have highlighted clean hydrogen as a critical component of Canada's 2030 and 2050 climate goals during its highly publicized visits to hydrogen related facilities across the country. For instance, the Prime Minister visited Stephenville, Newfoundland, and Labrador to announce the Government of Canada's intentions to export Canadian hydrogen to Germany by 2025 (Office of the Prime Minister A, 2022). His remarks indicate the vote of confidence in Canadian innovation and Canada's leadership in clean energy. This prominent political talking point creates assurances about clean hydrogen's role in transitioning to a low-carbon economy while building and maintaining employment for highly skilled Canadians. Additionally, Justin Trudeau visited students and professors at the Hydrogen Research Institute (Office of the Prime Minister A, 2023). The Prime Minister's visit highlights clean hydrogen technology's role in helping to fight climate change and reduce pollution.

News articles that include today's politicians further reflect the importance of showcasing clean hydrogen as part of the climate agenda and further extend to making Canadians aware of the potential for hydrogen. The Government of Canada's cabinet ministers relevant to hydrogen production has also been public about clean hydrogen's prominence as a low-carbon option for Canada. The former Canadian Minister of Natural Resources highlighted hydrogen's importance. He stated that hydrogen would be an opportunity to create thousands of jobs and use Alberta workers' skills and expertise to lead Canada to the forefront of the global hydrogen market (Government of Alberta, 2022). The Government of Canada's approach to publicizing hydrogen focuses mainly on clean hydrogen's environmental benefits and the economic opportunities it would bring Canadians.

#### *Political Considerations for Hydrogen Development*

The political considerations surrounding hydrogen will primarily focus on the inputs into creating it. For instance, Alberta holds the most prominent natural gas resources in the country; however, for their natural gas to be used within hydrogen's development in Canada, carbon capture technology will need to be employed. Meanwhile, Quebec has a robust electricity grid compared to the rest of Canada. British Columbia has been so fundamental to the emergence of the hydrogen fuel cell market that the province is referred to as the "cradle" of the fuel cell industry (Allan et al., 2022). Market powers, and regulations, will ultimately factor into the hydrogen development in these provinces.

The politics surrounding the transition to a low-carbon economy will be an interesting perspective to understand in the coming years. Across the political spectrum, there is an

understanding that clean hydrogen will factor into 2030 and 2050 goals. An exciting insight provided some commentary on the politics of green transition, highlighting each political side's divides. As Klippenstein (2022) (Interview F) suggested in his interview, there is a phenomenon in Canada that has political progressives tending to prefer renewable batteries in direct application to electric vehicles, which creates a scenario where political conservatives are more open to hydrogen. This notion may come into play, especially in Alberta, the Canadian province best equipped to take advantage of its hydrogen position because it already produces enormous amounts of hydrogen in oil refineries and ammonia production (Klippenstein, 2022). Provincial and federal governments have aligned with a desire to build a hydrogen market. The Government of Canada, and provinces, have a common understanding that hydrogen will not be categorized into colour spectrums, but rather that carbon intensity will be a more telling consideration of clean hydrogen's environmental impacts. The recent joint investments in hydrogen production have showcased the mutual understanding between the federal and provincial governments. In 2021, the Government of Canada and Alberta signed an agreement with Air Products Canada to build a \$1.3 billion hydrogen plant in Edmonton (Weber, 2021). Across the country, hydrogen is seen as an economic opportunity that can bode well for governments hoping to be re-elected.

### *International Climate Commitments*

The urgency associated with protecting the environment from the threat of climate change convened at the international climate UNFCCC summit in Paris in 2015. As countries converged and discussed the impact of greenhouse gas emissions on the global environment, an

international agreement was drafted seeking to align countries on the pathway toward a low-carbon future. This international agreement, known as the Paris Agreement, set the objective to limit global warming to 1.5 degrees Celsius by ensuring a transition to reduce harmful emissions within the next few decades, further emphasizing countries' roles in achieving a low-carbon future and mitigating the impacts of climate change on the planet (IEA, 2022). As a result, under the Paris Agreement, Canada committed to reducing GHG emissions by 30% below 2005 levels by 2030 and the commitment to reach net zero by 2050. Canada's commitment to the Paris Agreement further highlighted its alignment with its international partners in the fight against climate change.

The Government of Canada contends that within the near future, Canada's economy will be characterized by the prominence of electric power and low-carbon fuels, with low-carbon fuels expected to provide up to 60% or more of Canada's energy needs (Hydrogen Strategy for Canada, 2020). As the Canadian Hydrogen Strategy outlines, the Government of Canada views hydrogen as essential to decarbonizing hard-to-abate and energy intensive applications such as long-range transportation, high-grade heat production, and as a feedstock in industrial processes (Hydrogen Strategy for Canada, 2020). This vision for a low-carbon future emphasizes hydrogen's potential to decarbonize many hard-to-abate sectors contributing to rising GHG emissions. The opportunity to decarbonize these sectors presents Canada with challenges and opportunities, given its reputation as a major producer, consumer, and exporter of energy (IEA, 2022). However, Canada's approach to these opportunities and challenges will be characterized by the international pressures it currently faces after committing to international commitments such as the Paris Agreement.

Canada is not alone in identifying hydrogen as a critical part of the solution to combat climate change and improve air quality while driving economic growth in a carbon-constrained world. Countries worldwide have developed strategies to inform the optimal supply pathways and end-use applications for hydrogen and define export strategies (Hydrogen Strategy for Canada, 2020). This has resulted in the Government of Canada seeking out synergies domestically between provinces but also between Canada and other countries. For instance, Canada and Germany agreed to enable investment in hydrogen projects through policy harmonization by developing secure hydrogen supply chains and a transatlantic supply corridor to export Hydrogen to Germany by 2025 (Natural Resources Canada, 2022).

Furthermore, Canada and the Government of the Netherlands signed a memorandum of understanding to advance a partnership for collaboration and cooperation in the field of hydrogen energy (Natural Resources Canada, 2022). These partnerships represent the advancements made by the Government of Canada to become a top global supplier of clean hydrogen. These partnerships send clear signals of commitment to create an international policy and regulatory environment to facilitate the development of clean hydrogen to boost the Canadian economy while leveraging its environmental benefits to achieve Canada's climate goals.

Clean hydrogen under the current Canadian government has received significant attention. As the Government of Canada progresses to meet its climate goals slated for 2030 and 2050, clean hydrogen's prominence as a contending factor in the clean energy mix in Canada will only rise. The Government of Canada aims to meet net-zero commitments by allied countries that have

allowed Canada to accelerate its clean hydrogen development and further emphasize the potential for employment, economic prosperity, and the environment.

## **The Post-Paris Hydrogen Hype Cycle Economic Analysis: Boosting Cost Competitiveness**

This section of the ESPELT analysis aims to explore the economics that factor into the emergence of Canada's hydrogen economy in the Post-Paris Period. The Government of Canada has identified opportunities to provide financing that will help to address clean hydrogen's cost competitiveness with fossil fuels in Canada. Managing the costs associated with hydrogen production will enable supply and demand issues to resolve as production increases and demand becomes more robust. Canada's climate advancements and public-private sector partnerships will aim to lower the price of clean hydrogen. Allowing companies to tap into resources that could accelerate the readiness of key technologies and advance infrastructure will be crucial for clean hydrogen's ascendance as a key feature in the low-carbon future.

### *Cost Competitiveness*

Currently, clean hydrogen's cost competitiveness is a restraining factor in developing the hydrogen market in Canada. Within the next few decades, the Government of Canada will implement broad climate measures and environmental incentives through the 2030 Emissions Reduction Plan to reach its emissions reduction target of 40 percent below 2005 levels by 2030 and net-zero emissions by 2050 (Environment and Climate Change Canada, 2022). These actions will accelerate the cost reductions of producing hydrogen within the sector and help to bring clean hydrogen to a cost-competitive level with fossil fuels. According to the Hydrogen Economy Outlook 2020 by BloombergNEF, the global hydrogen economy will require approximately USD 150 billion to make clean hydrogen competitive with current natural gas prices in China, India, Brazil, and Germany (BloombergNEF, 2020). Canada is doing its part by launching the Clean Fuels Fund to invest \$1.5 billion to grow the production of hydrogen and

other clean fuels in Canada. The Clean Fuels Fund would aim to de-risk the capital investment required to build new or expand existing clean fuel production facilities in Canada by providing financial incentives to companies wanting to expand Canada's hydrogen production. (Natural Resources Canada, 2022). Currently, clean hydrogen is too costly to produce, resulting in economic difficulties within the clean fuel market when competing against fossil fuel feedstocks such as natural gas. Still, if government investments remain consistent, there are avenues for clean hydrogen to reach cost parity with its competition.

The production method of clean hydrogen, through either electrolysis or the reforming of natural gas coupled with carbon capture technology, will significantly influence costs. As Greg Caldwell (Interview B), Director of Utility Hydrogen Strategy at ATCO Gas, indicated, one of the contributing factors to the uptake of hydrogen will be the "cost of the input energy" (Caldwell, 2022). "If the prices of those inputs are high, hydrogen is going to be expensive, and you're going to have less willingness within a society to accept hydrogen" (Caldwell, 2022). If the price of clean hydrogen is to come down, energy inputs such as natural gas and renewable energy such as wind and solar will have to come down first. In addition to the cost of inputs for clean hydrogen production, the cost of technology associated with its output will significantly influence its economics. Enabling electrolyzers and carbon capture technology will also need to be affordable. Cost parity between these two methods will be achievable. Forecasts indicate that the global cost of hydrogen from large renewable energy-powered projects will be cost-competitive with low-carbon hydrogen from natural gas via SMR with carbon capture utilization and storage by 2030 (BloombergNEF, 2020). Therefore, the steps taken to approach cost parity

between low-carbon hydrogen production methods show signs of further adoption within the Canadian low-carbon economy.

Advancing the construction of infrastructure will influence clean hydrogen costs. Enabling infrastructure will increase efficiencies to bring clean hydrogen to uptakers and meet demand, thereby factoring in transporting clean hydrogen from the production site to end users. For instance, within the transportation sector, increasing the amount of hydrogen fuel cell charging stations would allow hydrogen fuel cell vehicles to compete within an increasingly electric vehicle-dominated market. However, it is not as easy as creating more fuel cell charging stations but ensuring that these fuelling stations are available for customers. Currently there are six public hydrogen refuelling stations in Canada (Amato, 2023). Clean hydrogen's emergence will benefit from the initial development of infrastructure that can create focus on a concentrated area and ensure the scale-up of production and will meet demand. Ultimately, all along the hydrogen value chain, clean hydrogen will need to take advantage of its versatility of uses as a fuel, heat, and feedstock that is storable, transportable, and low-emission intensive to become attractive to buyers within the clean fuel market.

### *Supply and Demand*

The contemporary approach to ensuring the adoption of a robust hydrogen market in Canada will ultimately come down to supply and demand. When interviewed for this thesis, Matthew Klippenstien (Interview F) explained that the most significant leverage towards scaling up hydrogen production in Canada would be the need to ensure a large offtake of hydrogen in place (Klippenstein, 2022). Without shoring up this demand for hydrogen, producers may be

hesitant to scale up production to be competitive within the market. Greg Caldwell (Interview B) echoed this by stating that without stable off-takers, big hydrogen projects will be limited due to the risk of the investment (Caldwell, 2022). Companies that produce hydrogen will want to avoid stranded assets by ensuring that there is constituent demand for the clean hydrogen they have. Klippenstein (Interview F) put it simply; clean hydrogen is currently facing a "chicken and egg scenario" (Klippenstein, 2022).

Experts such as David Layzell (Interview G), a University of Alberta professor and a leading contributor to the Hydrogen Accelerator, confirmed the modern complexities of supply and demand when producing hydrogen. Layzell (Interview G) underscored the importance of developing hydrogen hubs in Canada when asked about the Transition Accelerator's work, a pan-Canadian organization that advances research toward identifying viable pathways to Canada's 2050 climate targets. As explained by Layzell (Interview G), these hydrogen hubs will act as localized areas where hydrogen is produced near potential up-takers, thereby fast-tracking the supply and demand issues that hydrogen has historically faced. These hubs would be developed in cities such as Edmonton, Calgary, Regina, Vancouver, Prince George, and Winnipeg, forming links called "hydrogen corridors". These hydrogen corridors would be optimal for heavy trucks and trains that utilize hydrogen and ensure fuel availability for end-users due to enabling infrastructure. These hydrogen hubs would undoubtedly advance the scale-up of hydrogen and act as an initial stimulant that could go a long way to advancing clean hydrogen's supply and demand uncertainties and cement hydrogen's place within the clean energy economy in Canada.

## *Export*

Hydrogen's export potential has garnered significant attention at the Federal and Provincial levels, with Canada's Hydrogen Strategy pointing to producing clean hydrogen for export to the United States, Europe, and Asia, which would ensure demand for Canada's clean hydrogen internationally. Export to European countries has gained significant attention as the Government of Canada has pursued agreements with Germany and the Netherlands to develop secure hydrogen supply chains (Natural Resources Canada, 2022). The E.U., one potential market for Canadian hydrogen, would see a projected price difference of U.S. \$1.5/kg for Canadian imports compared to domestically produced green hydrogen (Allan et al., 2022). Provinces like British Columbia have also expressed interest in exporting clean hydrogen to international markets. The BC Hydrogen Strategy has highlighted export markets in China, Japan, South Korea, and California as potential export partners, stating that the forecast for these jurisdictions will account for almost 50% of the total global demand for hydrogen by 2050 with a combined market size of \$305 billion (B.C. Hydrogen Strategy, 2019). However, if these jurisdictions can produce hydrogen, the export market for Hydrogen from Canada may evaporate. During his interview, Martin Bush (Interview A), an author and climate adaptation consultant, alluded that he is dubious that Canada will be a significant Hydrogen exporter (Bush, 2022). He explained that hydrogen export would be challenging due to the efficiency of generating hydrogen on-site compared to the costs and efficiency losses associated with exporting it. Bush's (Interview A) perspective aligns with the indications in Smart Prosperity's report *Canada's Future in a Net-Zero World*; the jurisdictions that can produce hydrogen locally and transport it through a pipeline will be at an advantage (Allan et al., 2022).

Alberta, a key player in establishing Canada's hydrogen economy, has highlighted within its Alberta Hydrogen Roadmap a level of recognition of hydrogen as a significant economic opportunity for the province (Alberta Hydrogen Roadmap, 2021). However, as Klippenstein (Interview F) explained during his interview, a potential drawback for Alberta is the logistics of delivering that hydrogen cheaply and efficiently. Alberta is hundreds of kilometres from the coast, making it rather difficult for the province to take advantage of export opportunities. The export potential, conversion, and transportation costs will disadvantage Alberta's clean hydrogen product in overseas markets (Allan et al., 2022). If Alberta were to export its hydrogen, it would most likely need to be converted to ammonia to ship overseas and then converted back upon arrival (Allan et al, 2022). Klippenstein (Interview F) further explained that export projects could rely on cheap power, especially if hydrogen is shipped in ammonia, leading to further inefficiencies that will translate into higher costs.

The contemporary approach to hydrogen's development will need to address today's barriers by looking to economic opportunities for hydrogen domestically and internationally. The costs associated with hydrogen will significantly impact the cost of inputs for production, the enabling technology to ensure alignment of low-carbon priorities, and the demand from various industries in Canada and abroad. Ultimately, the growth of demand and supply of hydrogen in Canada will indicate whether a robust hydrogen market will take off as governments and private companies collaborate to achieve a low-carbon future.

## **The Post-Paris Hydrogen Hype Cycle Legal Analysis: Canada's Net Zero Objectives**

This section of the ESPELT analysis explores the contemporary legal considerations surrounding the development of Hydrogen in Canada from 2019 to the present. The legal analysis explores the regulatory frameworks that have been implemented, or will soon be implemented, to facilitate the development of a hydrogen economy in Canada. Upon reviewing the available legislation and regulations, it is evident that the Government of Canada has spotlighted hydrogen because of the increased attention directed toward reducing carbon emissions. Interviews with hydrogen experts across Canada underlined the same notions regarding the increased efforts to find low-carbon solutions and the importance of regulations and legislation-aiding hydrogen's implementation into the Canadian energy landscape. As climate change continues to be a competing policy issue, the Government of Canada has shown encouraging signs related to regulations and policies that could accelerate hydrogen's development as a critical pillar in pursuing a low-carbon economy.

### *Regulations*

The Government of Canada has indicated its commitment to addressing climate by announcing its plans to reduce Canada's total GHG emissions by 30% from 2005 levels by 2030 (Environment and Climate Change Canada, 2019). This commitment established mechanisms to facilitate Canada's transition to a low-carbon economy. A key instrument within the context of hydrogen development in Canada was the implementation of the *Renewable Fuel Regulations* in 2010, that mandated that Canadian fuel producers and importers achieve an average renewable content of at least 5% based on the volume of gasoline that they produce or import

and of at least 2% of moderate renewable content found on the importance of diesel fuel (Environment and Climate Change Canada, 2019). Although the *Renewable Fuel Regulations* did not explicitly mention hydrogen, it indirectly impacted hydrogen development in Canada. The *Renewable Fuel Regulations* initiated a renewed focus on other low-carbon options that could be implemented within the Canadian energy mix, which would further lessen Canada's reliance on fossil fuels and spur innovation. These regulations notified fossil fuel producers in Canada that the Federal Government was pursuing a plan that entailed decarbonization by incentivizing low-carbon approaches. The social pressure to address climate change accelerated the Government of Canada to establish environmental legislation focused on reducing GHG emissions and advancing the pathway towards decarbonization to achieve the objectives intended for 2030 and 2050, respectively.

In December 2016, the Government of Canada began to implement the Pan-Canadian Framework on Clean Growth and Climate Change (Canada Gazette, 2020). The Pan-Canadian Framework on Clean Growth and Climate Change was developed as a tool to implement Canada's commitments under the Paris Agreement and support the development of a clean fuels sector in Canada. In the Pan-Canadian Framework on Clean Growth and Climate Change, the Government of Canada evolved the *Renewable Fuel Regulations* into the newly established *Clean Fuel Regulations* (Government of Canada, 2022). The Clean Fuel Regulations, which are currently being implemented, aim to increase incentives to facilitate the development and adoption of clean fuels and technologies (Government of Canada, 2022). Under the *Clean Fuel Regulations*, the Federal Government states that Canadian-produced liquid fossil fuels such as diesel and gasoline would need to reduce their carbon intensity to achieve a decrease of

approximately 15% (below 2016 levels) in the carbon intensity of gasoline and diesel used in Canada by 2030 (Government of Canada, 2022). In addition to implementing the *Clean Fuel Regulations*, the Government of Canada began a series of investments and initiatives, such as investing \$1.5 billion towards a Clean Fuels Fund. The Clean Fuels Fund, aligned with the Clean Fuel Regulations, is slated to increase support for the domestic production and adoption of low-carbon fuels, such as Hydrogen (Government of Canada, 2022). *The Clean Fuel Regulations* showcase an alignment opportunity with provinces and territories' efforts, as several Provincial governments have already established clean fuel standards in Alberta, British Columbia, Manitoba, Saskatchewan, Ontario, and Quebec.

The Clean Fuel Regulations and the establishment of the Clean Fuels Fund are examples of new regulations and policies that would accelerate the development of Hydrogen in Canada.

Canada's hydrogen strategy has highlighted the Clean Fuel Standard as fundamental to driving near-term investment in the sector (Hydrogen Strategy for Canada, 2020). As stated by Garcha (Interview D), from the federal perspective, there are critical steps already being implemented, such as "increasing accessibility to the Government of Canada's resources through a dedicated fund that would be helpful to building the hydrogen economy out" (2022). As well, there is an opportunity, as Smart Prosperity points out, to ensure that Canada's clean fuel standard extends to examine the suitable emissions reductions from the uptake of hydrogen and assess whether they produce suitably low emissions (Allan et al., 2022). Hydrogen producers in Canada can leverage these kinds of government incentives to lower hydrogen costs and increase their cost competitiveness. This can also be said for the Federal Government's announcement of a federal ZEV (Zero-Emission Vehicle) sales mandate for light-duty vehicles.

By instating this mandatory sales target, the Government of Canada aimed to ensure that Canadians have low-emission vehicles available, with 20 percent of all new passenger vehicles sold in Canada to be ZEVs by 2026. At least 60 percent by 2030 to achieve 100 percent by 2025 (Office of the Prime Minister of Canada B, 2022). This further underlines the potential for hydrogen fuel cell vehicles to play a critical role in helping Canada reach net-zero emissions by 2050.

### *Carbon Pricing*

Policies and regulations that encourage the use of hydrogen technologies include low-carbon fuel regulations and carbon pricing (Hydrogen Strategy for Canada, 2020). To further incentivize low-carbon solutions within the Canadian economy, the Federal Government implemented a nationwide carbon price, beginning with a cost of \$20 per tonne of carbon dioxide equivalent emissions (tCO<sub>2</sub>e) in 2019 and rising to \$50 per tonne as of April 1, 2022 (Government of British Columbia, 2022). While many provinces voiced their concerns concerning implementing a federal carbon tax, the Government of Canada allowed for a certain level of flexibility in the mechanisms they wished to achieve these benchmarks. This includes allowing any province or territory to design its pricing system specific to their respective conditions (Government of Canada, 2022). Hydrogen's development will benefit from these new and upcoming regulatory environments and ultimately give Canadians more of a choice of zero-emission alternatives in the quest towards a low-carbon economy.

### *Policy Support*

Within the next few years, it is expected that the Government of Canada will continue to roll out mechanisms to support the hydrogen industry in Canada. Canada is making progress by offering multiple clean energy funding opportunities, such as Natural Resources Canada's Smart Renewables and Electrification Pathways program that has more than \$1.5 billion available for smart renewable energy and electrical grid modernization projects which could implicate hydrogen production (Brown, 2023). Additionally, the Government of Canada is providing a 30 percent tax credit for solar, wind and energy storage projects deployed through March 2034, which could favour in the production of green hydrogen through electrolysis (Brown, 2023).

For instance, the Government of Canada announced in the 2022 Fall Economic Statement that it would advance a tax incentive to keep investments in clean hydrogen production (Government of Canada, 2022, Hydrogen). Encouraging the acceleration of hydrogen through incentives such as these aligns with Canada's vision within the hydrogen strategy. Governments can also support industry in coordinating national and international standards and choose to invest in infrastructure to enable hydrogen incentives, such as tax breaks and subsidies, can also encourage the initial acceleration of Hydrogen (Hydrogen Council, 2020). Although Canada has policies that facilitate the emergence of clean technologies, the hydrogen strategy points to a lack of a comprehensive and long-term policy and regulatory framework that explicitly includes hydrogen (Hydrogen Strategy for Canada, 2020). The Strategy underlines that clean hydrogen projects located in other parts of the world have benefitted from the combination of supporting policies and regulations, with mechanisms that de-risk investments for end-users facilitating the uptake of hydrogen (Hydrogen Strategy for Canada, 2020). This announcement

in the 2022 Fall Economic Statement gives a sense of optimism that the development of the hydrogen economy in Canada will advance with these long-term enabling policies.

### *Canada's Net-Zero Ambitions*

Domestically, Canada's commitment to reach net-zero emissions by 2050 implicates the necessary actions to put Canada's economy on a long-term trajectory to net zero (Clean Energy Canada, 2020). Since the Government of Canada's announcement to commit to net zero by 2050, provincial, and territorial governments have accelerated their plans to achieve a low-carbon economy to align with these federal ambitions. Namely, the federal government proposed Canada's Strengthened Climate Plan, *A Healthy Environment, and a Healthy Economy* (A Healthy Environment and A Healthy Economy, 2020). This will be further emphasized with the *Net-Zero Emissions Accountability Act*, which the Government of Canada introduced to Parliament in November 2020 as part of its commitment to developing a plan to achieve net zero emissions by 2050 (IEA, 2022).

As stated earlier, the Government of Canada has already taken steps to develop a national strategy, with the publishing of Canada's National Hydrogen Strategy, with numerous provinces such as Alberta and British Columbia following with their plans. However, new policies and regulatory measures will also be needed (Hydrogen Strategy for Canada, 2020). The Government of Canada can make it easier for hydrogen proponents to obtain permits for new refuelling stations and implementing internationally consistent regulations to limit entrance into the domestic hydrogen market (Hydrogen Council, 2020). Building hydrogen refuelling stations at strategic locations for long-haul transport would also aid the domestic expansion of

the hydrogen sector (Hydrogen Council, 2020). These policies and incentives will further accelerate Hydrogen in Canada and lay the foundation for the planning of developing hydrogen supply and distribution infrastructure that will enable new hydrogen supply and distribution (Hydrogen Council, 2020).

## **The Post-Paris Technological Analysis: Critical Enabling Technology**

This section of the ESPELT analysis aims to explore the enabling technology currently facilitating the hydrogen economy's emergence in Canada. The Government of Canada's ambitions to meet its 2050 Net-Zero Goals have renewed the focus on the potential of clean hydrogen. In Canada, clean hydrogen will have implications as a feedstock, transportation, heating, and power due to its versatility. Although hydrogen offers some efficiencies, there are some barriers that clean hydrogen will have to address to be deemed viable. The following examination will look into the advancement of the development of hydrogen production and the emission-reducing technologies that have contributed to hydrogen's renewed prominence within Canada's clean energy context.

### *Hydrogen Development Pathways*

There are numerous ways to produce hydrogen within the contemporary context. As indicated in the historic technological analysis, there has been a significant push to colour categorize the hydrogen production pathways to articulate further the benefits of hydrogen's low greenhouse gas emissions. These colour categorizations utilize different technologies for hydrogen production; however, the two pathways that continue to garner the most attention are hydrogen production through electrolysis (green hydrogen) and hydrogen production coupled with carbon capture technology (blue hydrogen). That said, there has been pushback to shift away from the colour categorizing of hydrogen and instead focus on hydrogen emissions and scale up the production of hydrogen as a whole (Klippenstein, CHFCA, 2022). The most prominent technological factor that emerged through the literature and the semi-structured

interviews was the capabilities of carbon capture technology to leverage Canada's fossil fuel resources. This notion opens the door for Canada to utilize its competitive advantage in producing clean hydrogen with natural gas and carbon capture technology instead of inputting high-priced electricity. Hydrogen production has historically been emission-intensive; however, the emergence of carbon capture technology has enabled the potential for hydrogen to be lower emission that fits within the low-carbon vision for Canada and the rest of the world.

For the production of blue hydrogen, as indicated in the historic technological analysis of this thesis research, the traditional production method included using steam methane reforming. As described by the Pembina Institute, the steam methane reforming process (SMR) employs steam to separate hydrogen from natural gas (Taylor et al., 2021). However, today some companies are pursuing a more cost-effective process called auto-thermal reforming (ATR). This process can produce pure hydrogen from natural gas while allowing for higher carbon capture rates at lower costs (Taylor et al., 2021). Compared to SMR, ATR possesses a more straightforward production stream with a high concentration of carbon dioxide, allowing for a higher percentage of captured carbon emissions in the conversion process (Taylor et al., 2021). There have been demonstrated carbon capture rates equally 90%, but they have yet to be applied to the production of Hydrogen via SMR (Taylor et al., 2021). While carbon emissions associated with the ATR process are nearly entirely contained within the process gas stream (Taylor et al., 2021).

However, there are questions surrounding the effectiveness of carbon capture technology and the potential for producing "blue hydrogen" at a scale that enables competitive consumer

prices while remaining environmentally friendly. Today, knowledge gaps persist concerning the production of blue hydrogen, as indicated by David Layzell (Interview G), who acknowledged that Canada possesses the technologies to make low-carbon hydrogen from natural gas with carbon capture and storage; however, the quantities may vary (David Layzell, 2022). Significant work remains to scale up blue hydrogen to address these knowledge gaps that, if filled, may give more confidence to industries looking to utilize clean hydrogen within their operations. Regardless, considering the technological advancements needed to accelerate clean hydrogen production within the Canadian context, Layzell (Interview G) contends that building on carbon capture will be critical in Canada if clean hydrogen can get into 25 to 30% of the Canadian energy system (Layzell, 2022). This is the niche clean hydrogen can fill and the main reason for its recognition as a vital tool in reaching net-zero goals.

Furthermore, the effectiveness of carbon capture technology has been questioned by some scholars. A paper by Howarth and Jacobson (2021) examined the lifecycle greenhouse gas emissions of blue hydrogen, accounting for carbon dioxide and unburned fugitive methane emissions (Howarth & Jacobson, 2021). The report found that there appeared to be "no role for blue hydrogen in a carbon-free future" based on their findings that indicated a slight reduction in carbon dioxide emissions of blue hydrogen in comparison to natural gas are insignificant in consideration of the release of the more significant emissions of fugitive methane (Howarth & Jacobson, 2021). The Howarth and Jacobson paper has been critically analyzed within the hydrogen sector in Canada and internationally, with several experts providing criticisms of the paper's conclusions. For instance, a study by the Pembina Institute titled "The Carbon Intensity of Blue Hydrogen Production" opposes many of Howarth & Jacobson's claims. The Pembina

Institute points to that capture rates of 95% are technically possible and have been proposed at new facilities; however, no plants in current commercial operations demonstrate these maximum capture rates (Taylor et al., 2021).

Indeed, the scale-up of carbon capture and storage technology will prove whether these capture rates are accurate and will require oversight and regulations by federal, provincial, and territorial governments to adhere to the standards needed to meet Canada's net-zero ambitions. The advancement of carbon capture technology will influence Canada's clean hydrogen production, especially if Canada wants to leverage the natural gas resources in provinces such as Alberta and British Columbia. However, as the carbon capture rate is one of the critical determinants of the carbon intensity of blue hydrogen, high capture rates will be necessary to accelerate clean hydrogen development in Canada (Taylor et al., 2021). Ultimately, carbon and capture technology will be critical to Canada's clean hydrogen development and low-carbon future.

### *Fuel Cells and Transportation*

As indicated in the Post-Kyoto ESPELT analysis, fuel cells represented the most significant potential for the implementation of hydrogen within the transportation sector. Fuel cells represented the enabling of hydrogen's environmental benefits as the world advanced towards transitioning to low-carbon economies. In the Post-Paris context, the application of hydrogen has shifted since its initial focus from singular commuter vehicles to leveraging hydrogen's potential to be applied within other areas within the transportation sector. This is primarily due to the emergence of battery-powered electric cars, and with it, the focus on building charging

infrastructure in Canada has accelerated in the last few years. Although electric vehicles have gained a large share of the available clean transportation market, experts interviewed for this thesis research still believe there may be an opportunity for hydrogen to be part of this in the transportation sector. As Paterson (Interview H) indicated in his interview “there’s absolutely room for hydrogen, just as there’s a belief that there will be room for individual trucking companies to run LNG, hybrid vehicles, and all different types of fuel sources” (Paterson, 2022).

The perception of hydrogen's emergence as a mode of singular vehicle transportation may have shifted; however, leading companies such as Hyundai and Toyota have advanced hydrogen fuel cell vehicles in recent years. The advancement of hydrogen fuel cell vehicles further emphasizes that, while electric vehicles may be a thriving clean alternative to fossil fuels within the transportation sector, hydrogen may still have a role to play. Numerous experts agree that within the transportation industry, there will be "a diversified amount of different types of vehicles that will be operating in the space, so absolutely, there's going to be a role for hydrogen" (Paterson, 2022). Therefore, it may likely to have hydrogen fuel cell vehicles within the mix of only clean transportation options in Canada. Additionally, hydrogen has also gained traction within areas of the transportation sector. This includes focusing on utilizing hydrogen fuel cells within heavy-duty industry applications, buses, and potentially airplanes.

As indicated by Cory Paterson (Interview H), the potential for hydrogen within the heavy-duty commercial vehicle transportation sector (Paterson, 2022). Paterson (Interview H) explains, that “hydrogen rather than other types of options such as electric has a competitive advantage in fuelling time” (Paterson, 2022). Furthermore, "the charge rate concerning electric vehicles is

quite a long period to be able to charge to 80% capacity, with the need for a rapid charger- whereas if you look at hydrogen fueling, it's pretty much on par with that of fueling a diesel truck versus fueling a hydrogen truck which is critical because of the hours and service of that the industry operates in (Paterson, 2022). However, Paterson (Interview H) also stated that "vehicles in the sector won't come unless fuelling networks are established to support the vehicles" (Paterson, 2022). Experts interviewed for this thesis research agree with this notion stating that "right now if you're trying to fuel up your hydrogen car, it's going to cost more than diesel and gasoline" (Strem, 2022). Therefore, a key industry accelerator will be access to fuelling stations.

#### *Alternative Applications for Hydrogen*

The potential for hydrogen to be deployed within hard-to-abate sectors is a primary reason for the amount of attention surrounding hydrogen development in Canada. As stated in British Columbia's Hydrogen Strategy, clean hydrogen is forecasted to play a critical role in hard-to-decarbonize areas where direct electrification is impractical (B.C. Hydrogen Strategy, 2019). This includes areas such as heating and power and high-heat industrial processes. The technology enabling hydrogen's implementation will need to be scaled up to ensure that it is cost-effective while leveraging its environmental benefits.

Hydrogen's potential to reduce emissions associated with natural gas represents one way that hydrogen can facilitate Canada's transition to a low-carbon economy. In a process known as blending, hydrogen is injected into the natural gas grid. As stated within British Columbia's Hydrogen Strategy, when natural gas is blended with hydrogen, its emissions from combustion

are reduced, resulting in a low-emission energy source (B.C. Hydrogen Strategy, 2019). "While the volume of hydrogen that can be injected into B.C.'s extensive pipeline distribution network depends on the point of injection and pipeline capacity, studies have shown that hydrogen by volume up to 5%-15% can be tolerated in the pipeline network with minimal disruption to appliances in homes and businesses" (B.C. Hydrogen Strategy, 2019). Ultimately blending hydrogen with natural gas is a method natural gas utilities can employ to attain environmental standards. Many provinces, such as British Columbia, mandate that 15% of natural gas consumption be derived from renewable gas by 2030 (B.C. Hydrogen Strategy, 2019).

While building out the infrastructure is needed to accelerate the use of Hydrogen in Canada's transportation sector, hydrogen has garnered significant attention due to the numerous potential applications within other hard-to-abate industries. In his interview, Martin Bush (Interview A) identifies the transport sector, especially long haul trucks and aircraft, which utilize fuel cell technology, will be a significant source of demand for hydrogen (Bush, 2022). Martin Bush (Interview A) also alluded to steel production being one area where green hydrogen is substantially utilized. Hydrogen is well suited to substantially impact Canada's high-heat industrial processes, such as Canada's steel manufacturing industry. For instance, a clear example would be ArcelorMittal, the world's second-largest steelmaker, which successfully tested the use of green hydrogen to reduce iron ore at one of the company's industrial sites in Contrecoeur, Quebec. Engineers replaced nearly seven percent of the natural gas typically used to reduce iron ore with green Hydrogen (Harapyn, 2022). These sectors can reduce emissions by converting to blends of hydrogen and natural gas or pure hydrogen for heat production (Hydrogen Strategy for Canada, 2020).

In conclusion, the enabling technology such as fuel cells, efficiencies in hydrogen production and carbon capture technology will facilitate the growth of clean hydrogen in Canada's low-carbon economy is crucial. As mentioned in the analysis, producing hydrogen between green and blue pathways is not as important as concentrating on increasing the supply of hydrogen made. That said, because hydrogen emerged as a contributor to Canada's net-zero ambitions, facilitating and implementing carbon capture technology will be essential for hydrogen's viability in Canada. As a result of this analysis and semi-structured interviews, it is clear that hydrogen will have to address the technological challenges of carbon capture technology and efficiency to facilitate the emergence of the hydrogen economy in Canada.

## **CHAPTER 5: TAKEOFF POINT: THE HYDROGEN HYPE CYCLE DISCUSSION**

---

### *Introduction*

This section of the thesis discusses the findings and elaborates on the implications of the ESPELT analysis of the Post-Paris and Post-Kyoto Periods. This section investigates any similarities and contrasting features from both periods that will answer this thesis' research question: Will a robust hydrogen economy emerge in Canada? The following discussion will concentrate on the themes from the literature and the interviews. Following the ESPELT analysis of both periods, reoccurring themes emerged that represented the most significant contributing factors critical to Canada's clean hydrogen development and establishment of a robust hydrogen economy in Canada.

In contrast to the Kyoto period, the long-term shifts in temperatures and weather patterns are becoming more apparent within the Post-Paris Period. It is evident in data collected from the IPCC reports that there are more greenhouse gases present in the earth's atmosphere in the Post-Paris period than in the Post-Kyoto period. The higher concentration level of greenhouse gases increases global temperatures to a greater degree and influences weather patterns. As a result of climate change, environmental disasters within the Post-Paris Period are becoming more severe and frequent and impacting more of the Canadian population. The Post-Paris Period represents an era in which rising global temperatures and increased environmental disasters are being recognized as linked to human-caused climate change, further cementing the need for humans to develop solutions to address climate change.

Despite the forest fires that ravage entire towns, floods that devastate urban and rural communities, and heat waves that sweep through Canada's largest cities becoming more frequent due to long-term temperature shifts, Canada's reliance on conventional fossil fuels has traditionally led to resistance to transitioning to cleaner fuels such as hydrogen. Fossil fuel emissions impact the level of climate change, leading to more profound questions about the continued use. That said, the Post-Paris period represents a moment for hydrogen, as it has been highlighted to facilitate the mitigation of the use of fossil fuels and contribute to meeting global commitments to limit temperature rise to within the 2-degree frame in accordance with the Paris Agreement. The contrast of both Periods in the frequency of drastic environmental disasters underlines whether hydrogen is poised to take off this time is linked to the changing environmental factors that Canada and the rest of the world are facing. Within the Post-Paris Period, the severity of these catastrophes has contributed to hydrogen's evolution as a potential solution to addressing climate change.

Climate change has become a more pressing issue amongst Canadians and has undoubtedly emerged as a significant contributing factor to whether establishing the hydrogen economy is likely. In an interview for this thesis, Amandeep Garcha (Interview D) detailed that climate change is a significant variable much more prevalent now than in the early 2000s (Garcha, 2022). The Government of Canada's promotion of hydrogen development aligns with the public's attention to climate change. Considering hydrogen's environmental benefits would contribute to Canada's ambitions to establish a low-carbon economy within the next few decades, the continued importance of addressing climate change is critical to the emergence of hydrogen. The Government of Canada's approach to the emerging domestic and international

environmental pressures highlights the optimistic perception of clean hydrogen's role in addressing climate change. As a result, societal pressures have placed the urgency associated with replacing fossil fuels with clean and efficient energy to avoid increasing greenhouse gas emissions. It was clear within the ESPELT analysis, both in the literature and the semi-structured interviews, that the societal urgency to address climate change is more present within the Post-Paris period.

A closer look into the Post-Kyoto and Post-Paris periods revealed a contrast in the Canadians' perceived limitations and benefits of hydrogen development in Canada. The ESPELT analysis indicates an increased awareness of hydrogen and its perceived role as a clean alternative to fossil fuels in the Post-Paris period. In contrast to the Post-Kyoto period, the Post-Paris period represents an era with a greater understanding of hydrogen's benefits and broader social acceptance as a solution to the growing urgency to address climate change. During the semi-structured interviews for this thesis, multiple participants signalled that raising awareness about hydrogen in Canada would determine its successful implementation into the Canadian energy mix. As Garcha (Interview D) stated in his interview for this thesis, policy changes dictate awareness, ensuring the Government of Canada continues to work with provinces and municipalities to enable widespread clean hydrogen benefits in Canada (Garcha, 2022). This statement highlights how the Government of Canada, as influenced by the public, is developing strategies such as the Canadian Hydrogen Strategy to cultivate the increased awareness of hydrogen into policies that expand hydrogen's applications and implementation into the Canadian energy mix.

The impact of social awareness of climate change has contributed to the emerging issue within the Canadian political landscape. Examining both periods revealed that climate change was entering the political discourse amongst all the major political parties in Canada. Politically, Canadian parties are inputting more environmental policy into their platforms, with more policies focusing on hydrogen's implementation into the clean energy economy. The Green Party of Canada was the first major political party to identify the value of clean hydrogen within the low-carbon economy. The overall perception within today's context points to clean hydrogen's place as a political tool that could unite both sides of the political spectrum. Clean hydrogen's adaptability to use multiple feedstocks within its production, namely with natural gas and electrolysis, may appease many voters with ties to these industries. Particularly Albertans, who represent a large portion of employees within the fossil fuel sectors in Canada. Therefore, the prominence of clean hydrogen as an avenue to reach net zero goals will have implications in elections, with many political parties aiming to capitalize on the economic benefits of emphasizing clean hydrogen in the lead-up to 2030 and 2050.

Hydrogen's emergence within the Post-Paris context is more promising when analyzing the Post-Kyoto and Post-Paris Periods. Hydrogen has benefitted from the Government of Canada's recognition to set national emissions reduction targets for 2030 and 2050. The commitment to implementing these science-based emissions reduction plans was absent in the Post-Kyoto Period. The Government of Canada's Net-Zero Accountability Act will proceed to expedite a legal framework for clean hydrogen development in Canada. Hydrogen policies within the Post-Paris period will benefit from the Canadian Net-Zero Emission Accountability Act, which enshrines in legislation the Government of Canada's commitment to achieving net-zero

greenhouse gas emissions by 2050 and provides a framework of accountability and transparency to deliver on it (Government of Canada, 2022).

An overarching theme from the economic analysis was the necessity for hydrogen to reach a level of cost-competitiveness with other clean technologies to ensure wide-scale adoption. The cost-competitiveness of hydrogen is essential in the wide-scale adoption of clean technology and the overall implementation of the hydrogen economy in Canada. Historically, hydrogen had to compete monetarily with fossil fuels within the transportation sector to gain traction. Today, hydrogen can capitalize on the volatility of the costs associated with fossil fuels, coupled with the environmental movement to reduce emissions.

The contrast between both periods revealed that the issues of supply and demand still haunt clean hydrogen within the current context. Layzell (Interview G) indicated that the biggest hindrance has always been that clean hydrogen only works at a large scale. In terms of energy system transition and climate change solutions, the principal drivers have always been economic theory, and incremental cost changes have been a significant indicator of clean hydrogen's emergence (Layzell, 2022). However, more government funding has been made available to hydrogen producers and end-users to enable the free market to flow. The emphasis on hydrogen's potential to contribute to Canada's clean energy mix will likely allow the Government of Canada, along with provinces and territories, to invest in infrastructure that would facilitate its scale-up and bring costs down. Some experts indicated that “as people realize how much money they can make by switching to hydrogen, it'll get more self-sustaining, and the obvious advantages will become more apparent as the sector grows (Strem, 2022).

Ultimately, hydrogen's environmental benefits must balance with its economics to become a viable, clean energy technology and contribute to decarbonizing traditional high-emitting sectors to finally achieve the Government of Canada's vision for a low-carbon economy.

It is clear from the literature and the interviews that the government will have a crucial role in establishing the clean hydrogen market. Regulations will be critical to lead the shift towards clean energy production. The 2030 Emissions Reduction Plan will provide a roadmap for how Canada can achieve greenhouse gas emissions reductions of 40-45% below 2005 levels by 2030. The 2030 Emissions Reduction Plan acts as a critical piece of regulations to establish the legally binding process of setting five-year national emissions reduction targets that will contribute to accelerating hydrogen production and application within the Canadian context.

In addition to the Canadian Net-Zero Emission Accountability Act, regulations such as the Clean Fuel Regulations will likely increase incentives for developing and adopting clean fuels and technologies. These regulations are a critical component of clean hydrogen production in Canada because they offer support in developing the clean fuels sector in Canada through a series of investments. This includes Canada's recent acquisition of \$1.5 billion towards a Clean Fuel Fund, which will increase support for the increased production of clean hydrogen. These investments will help implement early opportunities identified in the Hydrogen Strategy for Canada. In tandem with other measures implemented by the Government of Canada, the objective of the Clean Fuel Regulations will be crucial to implementing clean hydrogen to reduce pollution. This will culminate in the Government of Canada's ambitions to address climate change through its regulations and legislation.

In the Post-Kyoto Period, technology such as fuel cells were available that enabled the utilization of hydrogen. In the Post-Paris Period, there were more ways that hydrogen could be applied within other sectors. As stated by the International Energy Agency, hydrogen has the potential to be used within multiple sectors of the Canadian economy, such as aviation, shipping, and steelmaking (IEA, 2019). As Ali Karaca highlighted, hydrogen is a feedstock for many industrial applications, including the Canadian steel industry, where it can replace steelmaking methods that traditionally use fossil fuels and produce it via cleaner methods (Karaca, 2022). This notion of hydrogen's efficiency and environmental benefits has led to higher acceptance of hydrogen and fuel cells within the Canadian energy mix, contributing to its growing recognition as an alternative to current fuels and inputs (IEA, 2019).

As multiple experts interviewed for this thesis indicated, the availability of electrolyzers and the effectiveness of carbon capture technology will be crucial for hydrogen's emergence. In contrast to the Post-Kyoto Period, carbon capture technology has emerged as a viable pathway to decarbonizing hydrogen production. Carbon capture technology's deployment will lead to further adoption of hydrogen to meet Canadian regulations. Experts pointed to Canadian regulations, such as the Clean Fuel Standard, to have an impact on enabling carbon capture and storage (Layzell, 2022). Ultimately, this urgency to find solutions to reduce carbon-intensive fuels resulted in more research and development into renewable energy, including solar, wind, hydro and nuclear. Addressing climate change by researching renewable energy enabled innovators to look again at hydrogen's conversion process and to develop hydrogen fuel and

fuel cell technologies further to ultimately position hydrogen as a solution for tremendous environmental improvement within the energy space (Bardi, 2021).

The following Table 1 represents the main contrasts between both the Post-Kyoto Periods and Post-Paris Periods.

<b>Table 1: Emergence of Hydrogen ESPELT Analysis</b>		
	<b>Post-Kyoto Period (2000-2004)</b>	<b>Post-Paris Period (2018-2022)</b>
<b>E</b>	Less Frequent Environmental Disasters	More Frequent Environmental Disasters
<b>(Environment)</b>	Increase in Global Temperature Rise	Increase in Global Temperatures since the 2000s
<b>S</b>	Less Climate Change Urgency	More Climate Change Urgency
<b>(Social)</b>		
<b>P</b>	Climate Change is less of a political issue	Climate Change is more of a political issue
<b>(Political)</b>	Prominent Investment in Fossil Fuels	More Investment in Renewable Technologies
<b>E</b>	Cost Competitiveness, Supply and Demand	Cost Competitiveness, Supply and Demand Issues
<b>(Economic)</b>	Issues	alleviated by Government support
<b>L</b>	Environmental Regulations are not specific to enabling clean hydrogen and need further development to address GHG emissions	Clean Fuel Standard and other regulations enable clean hydrogen. The Canadian Net-Zero Emissions Accountability Act is positioned to accelerate clean hydrogen development in Canada
<b>(Legal)</b>		
<b>T</b>	Canada leads in innovation, especially in Fuel	Canada has a large innovation base, however, it must tap into carbon capture technology to enable the full potential of the hydrogen economy
<b>(Technological)</b>	Cells	in Canada

Table 1: Emergence of Hydrogen ESPELT Analysis: Created by Patrick Fleming, 2023.

The contrasts and similarities in the Post-Kyoto Period and the Post-Paris Period underline the enabling factors that give promise to the emergence of hydrogen within the contemporary context, including the enabling factors such as the rise of efficient technologies that enable the production of clean hydrogen, supportive legislation that facilitates lowering costs; political willingness to reduce harmful emissions; and the urgency to address climate change.

Experts all indicated a similar notion that hydrogen would be one of the multiple solutions to climate change but not the sole solution. As Paterson indicated, “all striving for the same interest to find policy levers and provide actions to address the issue of climate change and to find a path forward that gets us net zero and gets us to the climate targets we need, but we have recognized that it's not just going to be one lever” (Paterson, 2022). There is optimism, however, that with considerable interest and government support, clean hydrogen can emerge within Canada's future low-carbon economy.

## CHAPTER 6: CONCLUSION

---

This thesis has explored the likelihood of establishing a robust hydrogen market in Canada within the contemporary context. The research for this thesis has revealed that there is optimism towards the establishment of a robust hydrogen economy in Canada. While there is optimism about the emergence of the hydrogen economy, challenges stem from the Post-Kyoto period that persist today. These challenges depend on addressing the uncertainties regarding hydrogen development in Canada, specifically by addressing any pitfalls within each category highlighted in the ESPELT analysis of the Post-Kyoto and Post-Paris literature for this thesis. The commitment to supporting the development of hydrogen across government and industry is poised to address the challenges identified during the Post-Kyoto Period and give rise to clean hydrogen as a contributing component to address climate change within the Post-Paris Period and beyond. As indicated in the Government of Canada's central policy piece on hydrogen, the Hydrogen Strategy for Canada 2020, hydrogen has opportunities to decarbonize critical sectors for Canada to meet its environmental objectives scheduled for 2050.

While optimistic, the experts interviewed for this thesis were cautious when discussing the outlook of clean hydrogen in Canada. Experts urged that pure hydrogen's fixture in the Canadian energy dialogue should not be exaggerated to avoid the issues plaguing hydrogen's initial emergence during the Post-Kyoto Period. Hydrogen has garnered a reputation for the boom and bust hype due to previous hype cycles; therefore, Canadian experts warn that its growth would benefit from consistent policymaking and precise investments into research and development. Experts also alluded to the importance of the awareness of hydrogen's potential

environmental benefits and its contention as a contributing solution to decarbonization in Canada.

The public's perception of climate change, particularly the urgency to address it, introduced efforts to advance policy development that explored renewable energy that could curb GHG emissions in Canada. Awareness of hydrogen was the predominant factor experts perceived as essential to hydrogen's success in the contemporary period. Encouraging hydrogen's awareness would significantly reduce the questions concerning its efficiency as a tool within Canada's clean energy ambitions and enable more hydrogen uptake. The public's understanding of hydrogen's environmental benefits remains critical in enabling hydrogen's implementation within the low-carbon economy. Given the current urgency to address climate change, the Canadian hydrogen economy is possible. However, it will only emerge if its current and historical challenges are addressed through public and private collaborations.

The Canadian public's perception of climate urgency resulted in Canadian political parties' platforms setting clear policy objectives to develop clean energy and utilize its environmental benefits to establish a low-carbon economy. This was in contrast to the platforms showcased from the early 2000s, which revealed that policy was mainly directed towards stimulating the economy rather than environmental considerations. Canadian political parties focusing on developing clean energy to respond to climate change were elected and implemented regulations and incentives to promote clean energy growth. These incentives support clean hydrogen project economics, while the regulations create market demand for those projects. In tandem, incentives and regulations will attract more investment and facilitate the

establishment of a growing hydrogen market in Canada. Canada can further attract investment capital by creating predictable demand for hydrogen by establishing clear, meaningful, and well-designed rules. To that end, regulations should provide a pathway for all jurisdictions in Canada to become net zero in ways that support their unique needs. The *Net-Zero Emissions Accountability Act* will be critical in advancing Canada's hydrogen economy (Hydrogen Council, 2022).

The analysis revealed that clean hydrogen remains too costly to produce, resulting in competitive losses when competing against other forms of energy. As stated earlier in the analysis, the production method of clean hydrogen will impact the associated costs. The production method of clean hydrogen, through either electrolysis or the reforming of natural gas coupled with carbon capture technology, will significantly influence costs. As Greg Caldwell (Interview B), Director of Utility Hydrogen Strategy at ATCO Gas, indicated, one of the contributing factors to the uptake of hydrogen will be the "cost of the input energy" (Caldwell, 2022). "If the prices of those inputs are high, hydrogen is going to be expensive, and you're going to have less willingness within a society to accept hydrogen" (Caldwell, 2022). If the price of clean hydrogen is to come down, energy inputs such as natural gas and renewable energy such as wind and solar will have to come down first. Still, if government investments remain consistent, there are avenues for clean hydrogen to reach cost parity with its competition.

Focusing on Canadian hydrogen development will bring Canada to the forefront of global clean hydrogen production discussion. It is prioritizing the implementation of enabling regulations that will accelerate industry investments in the hydrogen market in Canada. Leveraging its

resources and remaining adaptable to upcoming trends will allow Canada to proceed on the pathway toward contributing to a sustainable future with equal benefits for the economy and the environment. Further advancing the mainstream understanding of hydrogen benefits would increase its prominence as a clean fuel.

Hydrogen's technological advancements have come a long way since the Post-Kyoto Period, leading to efficient production methods, which have shown more efficiency gains and a slight price reduction. Enabling electrolyzers and carbon capture technology will also need to be affordable. Cost parity between these two methods will be achievable. Forecasts indicate the global cost of hydrogen from large renewable energy-powered projects will be cost-competitive with low-carbon hydrogen from natural gas via SMR with carbon capture utilization and storage by 2030 (BloombergNEF, 2020). Therefore, the steps taken to approach cost parity between low-carbon hydrogen production methods show signs of further adoption within the Canadian low-carbon economy.

Canada's development of hydrogen hubs will also significantly impact hydrogen production and uptake. These hydrogen corridors would enable the localization and utilization of hydrogen for many industries, including some of the most hard-to-abate. These hydrogen hubs will advance the scale-up of hydrogen and further stabilize clean hydrogen's supply and demand uncertainties. Furthermore, carbon and capture technology will significantly contribute to Canada's clean hydrogen development and low-carbon future (Layzell, 2022). The successful scale-up of carbon capture technology and the reduced costs of producing environmentally

friendly hydrogen will be the main reason for hydrogen's recognition as a vital tool in reaching net-zero goals.

Clean hydrogen will be vital to the Government of Canada's energy policy toolkit to address climate change. Canada's successful implementation of a robust clean hydrogen market that meets the threshold of 25% of Canada's domestic energy demand by 2050, creating 300,000 jobs and \$40 Billion in domestic revenue, will be determined if the following factors continue to advance at the consistent pace that they currently are. These factors include the continued investments in efficient technologies to enable the production of clean hydrogen, the Government of Canada's continuing to implement supportive legislation that incentivizes clean energy production, consistent political willingness to reduce harmful emissions, and capitalizing on the urgency to address climate change and meet net-zero objectives by 2050. To answer the research question posed in this thesis, is Canada on the cusp of a more successful hydrogen hype cycle in the Post-Paris Period? The signs are promising that Canada can lead the way in hydrogen development, but only if the Government of Canada continues to promote the growth of hydrogen and works in tandem with industries in Canada to achieve a low-carbon future for Canadians.

## References

- Allan, B., Eaton, D., Goldman, J., Islam, A., Augustine, T., Elgie, S., and Meadowcroft, J. (2022). Canada's Future in a Net-Zero World: Securing Canada's Place in the Global Green Economy. Smart Prosperity Institute, Transition Accelerator and Pacific Institute for Climate Solutions. Retrieved from: [https://institute.smartprosperity.ca/sites/default/files/CanadasFutureinNetZeroWorld\\_Report\\_final.pdf](https://institute.smartprosperity.ca/sites/default/files/CanadasFutureinNetZeroWorld_Report_final.pdf)
- Amato, S. (2023). "Cutting-edge opportunity": Alberta seeking private investors to build hydrogen fuelling stations. CTV News. Retrieved from: UCP ministers want hydrogen stations in Alberta | CTV News
- Bakx, K. (2020). Canada needs to build pipelines for oil and gas- but for hydrogen, too, clean energy advocates say. CBC News. Retrieved from: Canada needs to build pipelines for oil and gas — but for hydrogen, too, clean energy advocates say | CBC News
- Bataille, C., Neff, J., & Shaffer, B. (2021). The Role of Hydrogen in Canada's Transition to Net-Zero Emissions. The School of Public Policy Publications, 14(30).
- Bardi, U. (2021). A Concise History of the Concept of "Hydrogen Economy." Retrieved 23 June 2021, from <https://www.resilience.org/stories/2021-05-21/a-concise-history-of-the-concept-of-hydrogen-economy/#:~:text=The%20concept%20of%20%E2%80%9Chydrogen%20economy%E2%80%9C>

80%9D%20has%20a%20distinct%20%E2%80%9C1960s,be%20powered%20with%20clean%20hydrogen

BloombergNEF: Hydrogen Economy Outlook. (2020). Retrieved from: BNEF Long Form Template (Grid) (bloomberglp.com)

Bockris, J. O'M. (1972). A Hydrogen Economy. *Science (American Association for the Advancement of Science)*, 176(4041), 1323–1323.  
<https://doi.org/10.1126/science.176.4041.1323>

Bernstein, S. (2002). International Institutions and the Framing of Domestic Policies: The Kyoto Protocol and Canada's Response to Climate Change

Brown, G. (2023). Favourable Regulations and Incentives- Not a Moratorium- are Necessary for Clean Energy Prosperity. Retrieved from:  
<https://www.theglobeandmail.com/canada/alberta/article-favourable-regulations-and-incentives-not-a-moratorium-are-necessary/>

Canadian Climate Institute. (2021). Transition-opportunity sector profiles: Clean Hydrogen. Retrieved from: <https://climatechoices.ca/wp-content/uploads/2021/10/CICC-Clean-hydrogen-Sector-Profile.pdf>

Canada's Energy Regulator. (2023). Canada's Energy Future 2023- Results. Retrieved from: <https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2023/results/>

Canadian Hydrogen and Fuel Cell Association. (2005). Canadian Hydrogen and Fuel Cell Profile 2005. Retrieved from: <https://www.chfca.ca/wp-content/uploads/2019/10/2005.pdf>

Canadian Hydrogen and Fuel Cell Association. (2016). Canadian hydrogen and fuel cell sector profile. Retrieved from: <https://www.chfca.ca/wp-content/uploads/2022/08/CHFCA-Sector-Profile-2022-Final-2.pdf>

Canadian Hydrogen and Fuel Cell Association. (2018). Canadian hydrogen and fuel cell sector profile. Retrieved from: <https://www.chfca.ca/wp-content/uploads/2019/10/CHFC-Sector-Profile-2018-Final-Report.pdf>

Canadian Hydrogen and Fuel Cell Association. (2022). Canadian hydrogen and fuel cell sector profile. Retrieved from: <https://www.chfca.ca/wp-content/uploads/2022/08/CHFCA-Sector-Profile-2022-Final-2.pdf>

Canadian Hydrogen and Fuel Cell Association (2022). Our History. Retrieved: <https://www.chfca.ca/about/our-history/>

Canadian Hydrogen and Fuel Cell Association 1A. (2022). CHFCA Sector Profile 2022. Revenue, Research and Development in the Canadian Hydrogen Sector [Replicated Data Table]. Retrieved on August 21<sup>st</sup> 2023, from [CHFCA Sector Profile 2022](#)

Canadian Hydrogen and Fuel Cell Association 1B. (2022). CHFCA Sector Profile 2022. Employment in the Hydrogen Sector [Replicated Data Table]. Retrieved on August 21<sup>st</sup> 2023, from [CHFCA Sector Profile 2022](#)

Chemical Industry Digest. (2021). Air Products to Build Hydrogen Complex in Canada. Chemical Industry Digest (Mumbai).

Clean Energy Canada. (2020). A New Hope: How Hydrogen can deliver climate solutions and clean energy competitiveness for Canada. Retrieved:

[https://cleanenergycanada.org/wp-content/uploads/2020/10/CEC\\_Report\\_Hydrogen2020.pdf](https://cleanenergycanada.org/wp-content/uploads/2020/10/CEC_Report_Hydrogen2020.pdf)

Cook, S. (2022). Alberta has lofty hopes for the hydrogen energy market. But there are still a few gaps to be filled. CBC News. Retrieved from:

<https://www.cbc.ca/news/canada/edmonton/alberta-hydrogen-2030-decarbonization-fuel-source-1.6632984>

Cuda, Dincer, I., & Naterer, G. (2012). Hydrogen utilization in various transportation modes with emissions comparisons for Ontario, Canada. *International Journal of Hydrogen Energy*, 37(1), 634–643. <https://doi.org/10.1016/j.ijhydene.2011.09.076>

Dircks, Ken. 1999. "Recent Advances in Fuel Cells for Transportation Applications." International Congress and Exposition, SAE, Warrendale, Pennsylvania USA. March 1999.

Environment and Climate Change Canada. (2019). Federal Renewable Fuels Regulations:

Overview. Retrieved: [https://publications.gc.ca/collections/collection\\_2019/eccc/en14-28/En14-28-1-2019-eng.pdf](https://publications.gc.ca/collections/collection_2019/eccc/en14-28/En14-28-1-2019-eng.pdf)

Environment and Climate Change Canada. (2022). 2030 Emissions Reduction Plan: Canada's Next Steps for Clean Air and a Strong Economy. Retrieved from:  
<https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf>

El-Emam, & Gabriel, K. S. (2021). Synergizing hydrogen and cement industries for Canada's climate plan - case study. *Energy Sources. Part A, Recovery, Utilization, and Environmental Effects*, 43(23), 3151–3165.  
<https://doi.org/10.1080/15567036.2021.1936699>

Environment and Climate Change Canada. (2022). 2030 Emissions Reduction Plan: Canada's Next Steps for Clean Air and a Strong Economy. Retrieved from:  
<https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/erp/Canada-2030-Emissions-Reduction-Plan-eng.pdf>

French, J. (2022). Federal, Alberta governments pour \$461 million into Edmonton hydrogen plant.

Harapyn, L. (2022). What net zero looks like and what it could mean for Canada. *Financial Post*. Retrieved from: <https://financialpost.com/commodities/energy/what-net-zero-looks-like-and-what-it-could-mean-for-canada>

Financial Times. (2022). "This is a milestone": ArcelorMittal successfully tests use of green hydrogen at Quebec Plant. Retrieved from:

<https://financialpost.com/commodities/energy/renewables/this-is-a-milestone-arcelormittal-successfully-tests-use-of-green-hydrogen-at-quebec-plant>

Fuel Cells Bulletin. (2003). Canada commits C\$215m to extend H2 leadership. Retrieved from:

[https://doi.org/10.1016/S1464-2859\(03\)01101-5](https://doi.org/10.1016/S1464-2859(03)01101-5)

Government of Alberta. (2022). Hydrogen Roadmap. Retrieved from:

<https://www.alberta.ca/hydrogen-roadmap.aspx>

Government of Alberta. (2022). Hydrogen Development. Retrieved from:

<https://www.alberta.ca/hydrogen-development.aspx>

Government of British Columbia. (2021). BC Hydrogen Strategy: A Sustainable Pathway of BC's Energy Transition. Retrieved from: [https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/electricity/bc-hydro-review/bc\\_hydrogen\\_strategy\\_final.pdf](https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/electricity/bc-hydro-review/bc_hydrogen_strategy_final.pdf)

Government of British Columbia. (2022). British Columbia's Carbon Tax. Retrieved:

[https://www2.gov.bc.ca/gov/content/environment/climate-change/clean-economy/carbon-](https://www2.gov.bc.ca/gov/content/environment/climate-change/clean-economy/carbon-tax#:~:text=In%20Canada%2C%20the%20federal%20government,at%20least%20%2450%20per%20tCO2e.)

[tax#:~:text=In%20Canada%2C%20the%20federal%20government,at%20least%20%2450%20per%20tCO2e.](https://www2.gov.bc.ca/gov/content/environment/climate-change/clean-economy/carbon-tax#:~:text=In%20Canada%2C%20the%20federal%20government,at%20least%20%2450%20per%20tCO2e.)

Government of Canada (2000). Government of Canada Action Plan 2000 on Climate Change.

Retrieved from: <https://publications.gc.ca/collections/Collection/M22-135-2000E.pdf>

Government of Canada. (2003). Government of Canada Supports Fuel Cell Technologies Ltd. To

Install the First Residential Fuel Cell in Canada. Retrieved from:

<https://www.canada.ca/en/news/archive/2003/11/government-canada-supports-fuel-cell-technologies-ltd-install-first-residential-fuel-cell-canada.html>

Government of Canada. (2005). Towards a National Hydrogen & Fuel Cell Strategy: A Discussion

Document for Canada. Retrieved from: [https://davidsuzuki.org/wp-](https://davidsuzuki.org/wp-content/uploads/2019/03/climate-friendly-hydrogen-fuel-comparison-greenhouse-gas-emissions-fuel-cell-vehicle.pdf)

[content/uploads/2019/03/climate-friendly-hydrogen-fuel-comparison-greenhouse-gas-emissions-fuel-cell-vehicle.pdf](https://davidsuzuki.org/wp-content/uploads/2019/03/climate-friendly-hydrogen-fuel-comparison-greenhouse-gas-emissions-fuel-cell-vehicle.pdf)

Government of Canada. (2008). Canadian Fuel Cell Commercialization Roadmap Update.

Retrieved from: [https://publications.gc.ca/collections/collection\\_2009/ic/lu44-2-2008E.pdf](https://publications.gc.ca/collections/collection_2009/ic/lu44-2-2008E.pdf)

Government of Canada. (2022). Government consulting on clean hydrogen and labour

conditions for clean investment tax credits. Retrieved:

<https://www.canada.ca/en/department-finance/news/2022/12/government-consulting-on-clean-hydrogen-and-labour-conditions-for-clean-investment-tax-credits.html>

Government of Canada. (2022). Carbon Polluting Pricing Systems Across Canada. Retrieved

from: <https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work.html>

Government of Canada- Trade Commissioner Service. (2019). Canada a Global Leader in Hydrogen Production. Retrieved from: [https://www.chfca.ca/wp-content/uploads/2019/09/GOC-HydrogenProduction\\_en\\_WEB.pdf](https://www.chfca.ca/wp-content/uploads/2019/09/GOC-HydrogenProduction_en_WEB.pdf)

Government of Canada (2020). Canada Gazette, Part 1, Volume 154, Number 51. Retrieved from: [Canada Gazette, Part 1, Volume 154, Number 51:](#)

Government of Canada. (2020). A Healthy Environment and A Healthy Economy. Retrieved from: [A healthy environment and a healthy economy - Canada.ca](#)

Government of Canada. (2020b). Hydrogen Strategy for Canada- Seizing the Opportunities for Hydrogen. Retrieved from: [https://www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan\\_Hydrogen-Strategy-Canada-na-en-v3.pdf](https://www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf)

Government of Ontario. (2022). Ontario's Low-Carbon Hydrogen Strategy: A Path Forward. Retrieved from: <https://www.ontario.ca/files/2022-04/energy-ontarios-low-carbon-hydrogen-strategy-en-2022-04-11.pdf>

Government of Canada. (2021). Timeline: Major milestones of Environment and Climate Change Canada. Retrieved: <https://www.canada.ca/en/environment-climate-change/campaigns/50-years-environmental-action/eccc-timeline.html>

Government of Canada. (2022). Ozone Layer Depletion: Montreal Protocol. Retrieved:  
<https://www.canada.ca/en/environment-climate-change/corporate/international-affairs/partnerships-organizations/ozone-layer-depletion-montreal-convention.html>

Government of Canada- Speech from the Throne- First Session of the Thirty Sixth Legislature. (1997). Retrieved from: <https://www.poltext.org/en/part-1-electronic-political-texts/canadian-throne-speeches>

Government of Canada- Speech from the Throne- First Session of the Thirty Sixth Legislature. (1999). Retrieved from: <https://www.poltext.org/en/part-1-electronic-political-texts/canadian-throne-speeches>

Government of Canada- Speech from the Throne- First Session of the Thirty Seventh Legislature. (2001). Retrieved from: <https://www.poltext.org/en/part-1-electronic-political-texts/canadian-throne-speeches>

Government of Canada- Speech from the Throne- First Session of the Thirty Seventh Legislature. (2002). Retrieved from: <https://www.poltext.org/en/part-1-electronic-political-texts/canadian-throne-speeches>

Government of Canada- Speech from the Throne- Second Session of the Thirty Seventh Legislature. (2002). Retrieved from:

Government of Canada- Speech from the Throne- Third Session of the Thirty Seventh Legislature. (2002). Retrieved from:

Government of Canada- Speech from the Throne- First Session of the Thirty Seventh Legislature. (2004). Retrieved from: <https://www.poltext.org/en/part-1-electronic-political-texts/canadian-throne-speeches>

Government of Canada- Speech from the Throne- First Session of the Thirty Eighth Legislature. (2004). Retrieved from: <https://www.poltext.org/en/part-1-electronic-political-texts/canadian-throne-speeches>

Gnanapragasam, Reddy, B. V., & Rosen, M. A. (2010). Feasibility of an energy conversion system in Canada involving large-scale integrated hydrogen production using solid fuels. *International Journal of Hydrogen Energy*, 35(10), 4788–4807.  
<https://doi.org/10.1016/j.ijhydene.2009.10.047>

Ghandehariun, & Kumar, A. (2016). Life cycle assessment of wind-based hydrogen production in Western Canada. *International Journal of Hydrogen Energy*, 41(22), 9696–9704.  
<https://doi.org/10.1016/j.ijhydene.2016.04.077>

Hydrogen strategies for Canada, Scotland. (2021). *Fuel Cells Bulletin*, 2021(1), 15–15.  
[https://doi.org/10.1016/S1464-2859\(21\)00051-1](https://doi.org/10.1016/S1464-2859(21)00051-1)

Hydrogen cars now: Canada's effect on hydrogen & fuel cell history (2017). Chatham: Newstex.  
Retrieved from  
<https://login.proxy.bib.uottawa.ca/login?url=https://www.proquest.com/blogs-podcasts-websites/hydrogen-cars-now-canadas-effect-on-amp-fuel-cell/docview/1876083419/se-2?accountid=14701>

Hydrogen Council, (2020). Path to hydrogen competitiveness: A cost perspective. Retrieved from: [https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness\\_Full-Study-1.pdf](https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf)

Hoffmann. (2012). Tomorrow's energy : hydrogen, fuel cells, and the prospects for a cleaner planet (Rev. and expanded ed.). MIT Press.

Howarth, R. & Jacobson, M. (2021). How Green is Blue Hydrogen? Retrieved from: <https://doi.org/10.1002/ese3.956>

Industry Canada. (2003). Preliminary Findings for Innovation Case Study on Canadian Fuel Cell Technology

Intergovernmental Panel on Climate Change. (2012). Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (Eds.) Available from Cambridge University Press, The Edinburgh Building, Shaftesbury Road, Cambridge CB2 8RU ENGLAND, 582 pp. Available from June 2012

Intergovernmental Panel on Climate Change. (2023). Synthesis Report for the Sixth Assessment Report: Climate Change 2023. Retrieved from: <https://www.ipcc.ch/report/sixth-assessment-report-cycle/>

International Energy Agency. (2005). Prospects for hydrogen and fuel cells (Ser. Energy technology analysis). International Energy Agency. Retrieved March 8, 2022, from

<https://web.archive.org/web/20080307082839/http://www.iea.org/textbase/nppdf/free/2005/hydrogen2005.pdf>

International Energy Agency. (2016). Energy Policies of IEA Countries: Canada 2015 Review.

Retrieved from: <https://www.iea.org/reports/energy-policies-of-iea-countries-canada-2015-review>

International Energy Agency A. (2022). Canada 2022: Energy Policy Review. Retrieved from:

<https://www.iea.org/reports/canada-2022>

International Energy Agency B. (2022). Canada's bold policies and support for innovation can

underpin a successful energy transition, new IEA policy review says. Retrieved from:

<https://www.iea.org/news/canada-s-bold-policies-and-support-for-innovation-can-underpin-a-successful-energy-transition-new-iea-policy-review-says>

International Energy Agency (2023). Global CO<sub>2</sub> emissions from energy combustion and

industrial processes, 1900-2022, IEA, Paris [https://www.iea.org/data-and-](https://www.iea.org/data-and-statistics/charts/global-co2-emissions-from-energy-combustion-and-industrial-processes-1900-2022)

[statistics/charts/global-co2-emissions-from-energy-combustion-and-industrial-](https://www.iea.org/data-and-statistics/charts/global-co2-emissions-from-energy-combustion-and-industrial-processes-1900-2022)

[processes-1900-2022](https://www.iea.org/data-and-statistics/charts/global-co2-emissions-from-energy-combustion-and-industrial-processes-1900-2022), IEA. Licence: CC BY 4.0

Innovation, Science and Economic Development. (2022). Net Zero Accelerator Initiative.

Retrieved from: <https://ised-isde.canada.ca/site/strategic-innovation-fund/en/net-zero-accelerator-initiative>

Klippenstein, M. 2022. Hydrogen 101, etc.: Unabridged slide Deck. Provided by Matthew Klippenstein, Canadian Hydrogen Fuel Cell Association

Karaca AE & Dincer I. An updated review of Canada's hydrogen related research and development activities. *Int J Hydrogen Energy* 2021;46(69): 3415-25. Retrieved from: <https://www.sciencedirect.com/science/article/abs/pii/S0360319921030226>

Koppel, T. (1999). *Powering the future : The Ballard fuel cell and the race to change the world* . Wiley.

Kyoto Protocol Implementation Act. (2007), Revised Statutes of Canada (2007, c. C.30)

Retrieved from: <https://www.lib.sfu.ca/help/cite-write/citation-style-guides/apa/gov-docs-apa#actsstatutes-a704-pp-219-221>

Laverty, G. (2021). Committee launches to increase hydrogen use in Canada. SNL Canada Energy Week.

Lee, Hsu, S.-S., Tso, C.-T., Su, A., & Lee, D.-J. (2009). An economy-wide analysis of hydrogen economy in Taiwan. *Renewable Energy*, 34(8), 1947–1954.  
<https://doi.org/10.1016/j.renene.2008.12.006>

Liu, Almansoori, A., Fowler, M., & Elkamel, A. (2012). Analysis of Ontario's hydrogen economy demands from hydrogen fuel cell vehicles. *International Journal of Hydrogen Energy*, 37(11), 8905–8916. <https://doi.org/10.1016/j.ijhydene.2012.03.029>

Lozano, LL., Bharadwaj, B., De Sales, A., Kambo, A., and Ashworth, P. (2022). Societal acceptance of hydrogen for domestic and export applications in Australia. Retrieved from: <https://doi.org/10.1016/j.ijhydene.2022.06.209>

Martin, P. (2021). Hydrogen: hope, hype, and thermodynamics with Paul Martin. Retrieved from: <https://www.hcgroup.global/hc-insider/hc-insider-podcast/hydrogen-hope-hype-and-thermodynamics-with-paul-martin>

Mortlock. (2021). Canada's Hydrogen Future- Risks and Rewards. Ernest and Young Canada. Retrieved from: [https://www.ey.com/en\\_ca/energy-resources/canadas-hydrogen-future-risks-and-rewards-ey](https://www.ey.com/en_ca/energy-resources/canadas-hydrogen-future-risks-and-rewards-ey)

Natural Resources Canada. (2005). Transforming the future: Moving toward fuel cell-powered fleets in Canadian Urban Transit System. Retrieved from: [https://www.uvic.ca/research/centres/globalstudies/assets/docs/publications/Transit\\_S\\_tudy\\_summary.pdf](https://www.uvic.ca/research/centres/globalstudies/assets/docs/publications/Transit_S_tudy_summary.pdf)

Natural Resources Canada. (2006). Canada's Energy Outlook 2006. Retrieved from: <https://publications.gc.ca/site/eng/292801/publication.html>

Natural Resources Canada. (2009). Summary Report for the Technology and Innovation Research and Development Initiative. Retrieved from: <https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/pdf/eneene/pdf/tirdrdti-eng.pdf>

Natural Resources Canada. (2017). Roles and Responsibilities of Governments in Natural Resources. Retrieved from: <https://www.nrcan.gc.ca/science-data/science-research/earth-sciences/earth-sciences-resources/earth-sciences-federal-programs/roles-responsibilities-governments-natural-resources/8882>

Natural Resources Canada. (2022). Canada and Germany Sign Agreement to Enhance German Energy Security with Clean Canadian Hydrogen. Retrieved from: <https://www.canada.ca/en/natural-resources-canada/news/2022/08/canada-and-germany-sign-agreement-to-enhance-german-energy-security-with-clean-canadian-hydrogen.html>

Office of the Prime Minister of Canada A. (2022). Remarks on the Canada-Germany Hydrogen Alliance. Retrieved from: <https://pm.gc.ca/en/videos/2022/08/23/remarks-canada-germany-hydrogen-alliance>

Office of the Prime Minister of Canada B. (2022). Helping more Canadians drive electric vehicles. Retrieved: <https://pm.gc.ca/en/news/news-releases/2022/04/11/helping-more-canadians-drive-electric-vehicles>

Office of the Prime Minister of Canada. (2023). Prime Minister visits l'Université de Quebec à Trois-Rivieres. Retrieved from [:https://twitter.com/CanadianPM/status/1615905206964715521](https://twitter.com/CanadianPM/status/1615905206964715521)

Olateju, & Kumar, A. (2013). Techno-economic assessment of hydrogen production from underground coal gasification (UCG) in Western Canada with carbon capture and

sequestration (CCS) for upgrading bitumen from oil sands. *Applied Energy*, 111, 428–440. <https://doi.org/10.1016/j.apenergy.2013.05.014>

Pekic, S. (2022). Canada in Push to Position Nova Scotia as Clean Hydrogen Hub. Retrieved from: <https://www.offshore-energy.biz/canada-in-push-to-position-nova-scotia-as-clean-hydrogen-hub/>

Prairies Economic Development Canada. (2021). Federal Investment Advances Alberta's Hydrogen Economy. Retrieved from: <https://www.canada.ca/en/prairies-economic-development/news/2021/11/federal-investment-advances-albertas-hydrogen-economy.html>

Ransom, D. (2007). Prime Minister Stephen Harper examines a Hydrogen Fuel Cell Engine before he announces that he will provide the Province of British Columbia with \$199.3 million through the Canada Ecotrust for Clean Air and Climate Change in Vancouver. Library and Archives Canada.

Razi, & Dincer, I. (2022). Challenges, opportunities, and future directions in hydrogen sector development in Canada. *International Journal of Hydrogen Energy*, 47(15), 9083–9102. <https://doi.org/10.1016/j.ijhydene.2022.01.014>

Ricci M., Bellaby P., and Flynn R. (2008). What do we know about public perceptions and acceptance of hydrogen? A critical review and new case study evidence, *International Journal of Energy*. Retrieved from: <https://doi.org/10.1016/j.ijhydene.2008.07.106>

Robitzski, D. (2018). Cheap Hydrogen Fuel Was A Failed Promise. But Its Time May Have Arrived.

Rifkin, J. (2002). The Hydrogen Economy.

Rifkin, J. (2011). The Third Industrial Revolution: How Lateral Power is transforming Energy, the Economy, and the World.

Ruth, Lawrence A. "Advanced Coal-Fired Power Plants." Journal of Energy Resources Technology. Vol.123. March 2001. P.4

Taylor, A., Row, J. & Winfield, M. (2002). A Fiscal Framework for a Fuel Cell and Hydrogen Economy: A Review of International Fiscal Policy and Program Examples and Precedents. Retrieved from: [https://www.pembina.org/reports/Fiscal\\_Framework\\_H2.pdf](https://www.pembina.org/reports/Fiscal_Framework_H2.pdf)

The David Suzuki Foundation. (2000). Climate-friendly hydrogen fuel: A Comparison of the Life-Cycle Greenhouse Gas Emissions for Selected Fuel Cell Vehicle Hydrogen Production Systems. Retrieved from: <https://david Suzuki.org/wp-content/uploads/2019/03/climate-friendly-hydrogen-fuel-comparison-greenhouse-gas-emissions-fuel-cell-vehicle.pdf>

The Guardian. (2011). Canada pulls out of the Kyoto Protocol. <https://www.theguardian.com/environment/2011/dec/13/canada-pulls-out-kyoto-protocol>

The Hydrogen Council. (2017). How Hydrogen empowers the energy transition. Retrieved from:  
<https://hydrogencouncil.com/wp-content/uploads/2017/06/Hydrogen-Council-Vision-Document.pdf>

The New York Times. (1974). Hydrogen- A Way out of the Energy Crisis? Retrieved from:  
<https://www.nytimes.com/1974/05/12/archives/hydrogena-way-out-of-the-energy-crisis-this-light-plentiful-gas-is.html>

The Pembina Institute. (2000). Climate-friendly hydrogen fuel: A Comparison of the Life-Cycle Greenhouse Gas Emissions for Selected Fuel Cell Vehicle Hydrogen Production Systems. Retrieved from: <https://davidsuzuki.org/wp-content/uploads/2019/03/climate-friendly-hydrogen-fuel-comparison-greenhouse-gas-emissions-fuel-cell-vehicle.pdf>

The Strategic Counsel. (2007). Final Report: Canadian's perceptions of Fuel Cell and Hydrogen Technologies. Retrieved 23 June 2021, from [https://epe.lac-bac.gc.ca/100/200/301/pwgsc-tpsgc/por-ef/natural\\_resources/2007/452-06/report.pdf](https://epe.lac-bac.gc.ca/100/200/301/pwgsc-tpsgc/por-ef/natural_resources/2007/452-06/report.pdf)

Theckedath, D. (2010). Where's the Hydrogen Economy? Industry, Infrastructure and Resources Division- Library of Parliament.

Tchir, J. (2021). Boondoggle or boon? Looking back at Whistler's hydrogen-bus pilot and why it failed. Retrieved: <https://www.theglobeandmail.com/drive/mobility/article-boondoggle-or-boon-looking-back-at-whistlers-hydrogen-bus-pilot-and/>

United Nations (1987). Montreal Protocol on substance that Deplete the Ozone Layer.

Retrieved: <https://treaties.un.org/doc/publication/unts/volume%201522/volume-1522-i-26369-english.pdf>

United Nations (1992). United Nations Framework Convention on Climate Change. Retrieved:

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (unfccc.int)

United Nations (1998). Kyoto Protocol to the United Nations Framework Convention on Climate Change. Retrieved: <https://unfccc.int/resource/docs/convkp/kpeng.pdf>

United Nations Environment Programme. (2020). UNEP Annual Report 2020. Retrieved from:

<https://www.unep.org/resources/annual-report/unep-annual-report-2000>

Yap, J & McLellan, B. (2023). A Historical Analysis of Hydrogen Economy Research, Development and Expectations, 1972 to 2020. Retrieved:

<https://doi.org/10.3390/environments10010011>

Yin, R.K (2016). Qualitative Research from Start to Finish. Guildford Press.

Weber, B. (2021). Canada, Alberta sign deal for \$1.3B hydrogen plant in Edmonton. Retrieved

from: <https://www.cbc.ca/news/canada/edmonton/cda-alta-hydrogen-1.6059241>

## Interviews

Martin Bush. 2022. Interview: The Emergence of Canada's Hydrogen Economy Thesis Research

Greg Caldwell. 2022. Interview: The Emergence of Canada's Hydrogen Economy Thesis  
Research

James Gaede. 2022. Interview: The Emergence of Canada's Hydrogen Economy Thesis Research

Amandeep Garcha. 2022. Interview: The Emergence of Canada's Hydrogen Economy Thesis  
Research

Ali Karaca. 2022. Interview: The Emergence of Canada's Hydrogen Economy Thesis Research

Matthew Klippenstein. 2022. Interview: The Emergence of Canada's Hydrogen Economy Thesis  
Research

David Layzell. 2022. Interview: The Emergence of Canada's Hydrogen Economy Thesis Research

Cory Paterson. 2022. Interview: The Emergence of Canada's Hydrogen Economy Thesis  
Research

Graeme Strem. 2022. Interview: The Emergence of Canada's Hydrogen Economy Thesis  
Research

Hamid Rahmanifard. 2022. Interview: The Emergence of Canada's Hydrogen Economy Thesis  
Research

David Van Den Assam. 2022. Interview: The Emergence of Canada's Hydrogen Economy Thesis  
Research

## Political Party Platforms

Conservative Party Plan (1997). Let the Future Begin: Jean Charest's Plan for Canada's Next Century. Retrieved: [CAN\\_PL\\_1997\\_PC\\_en.pdf \(poltext.org\)](#)

Conservative Party Plan (2000). Change You Can Trust- The Progressive Conservative Plan for Canada's Future. Retrieved: [CAN\\_PL\\_2000\\_PC\\_en.pdf \(poltext.org\)](#)

Conservative Party Plan (2004). Demanding Better. Retrieved: [PlatformDoc \(poltext.org\)](#)

Conservative Party of Canada (2006). Stand Up for Canada. Retrieved: [CAN\\_PL\\_2006\\_PC\\_en.pdf \(poltext.org\)](#)

Conservative Party Platform (2008). The True North Strong and Free: Stephen Harper's plan for Canadians. Retrieved: [CAN\\_PL\\_2008\\_PC\\_en.pdf \(poltext.org\)](#)

Conservative Party Plan (2011). Stephen Harper's Low-Tax Plan for Jobs and Economic Growth. Retrieved: [https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN\\_PL\\_2011\\_PC\\_en.pdf](https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN_PL_2011_PC_en.pdf)

Conservative Party Plan (2015). Protect Our Economy: Our Conservative Plan. Retrieved: [https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN\\_PL\\_2015\\_PC\\_en.pdf](https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN_PL_2015_PC_en.pdf)

Conservative Party Plan (2019). Andrew Scheer's Plan: For You to Get Ahead. Retrieved:

[https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN\\_PL\\_2019\\_PCC\\_EN.pdf](https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN_PL_2019_PCC_EN.pdf)

Green Party Platform (1997). Politics for the Next Century. The Green Party of Canada's 1997 Platform. Retrieved: [CAN\\_PL\\_1997\\_GREEN\\_en.pdf \(poltext.org\)](#)

Green Party Platform (2000). The Green Guide to a Healthy and Sustainable Canada. Retrieved: [CAN\\_PL\\_2000\\_GREEN\\_en.pdf \(poltext.org\)](#)

Green Party Platform (2004). Someday is Now. Retrieved: [10158\\_eng \(poltext.org\)](#)

Green Party Platform (2006). We Can. Retrieved: [Layout 1 \(poltext.org\)](#)

Liberal Party Platform (1997). Securing Our Future Together. Retrieved: [CAN\\_PL\\_1997\\_LIB\\_en.pdf \(poltext.org\)](#)

Liberal Party Platform (2000). Opportunity For All: The Liberal Plan for the Future of Canada. Retrieved: [ENG/FINAL\\_booklet\\_2.1 \(poltext.org\)](#)

Liberal Party Platform (2004). Moving Canada Forward: The Paul Martin Plan for Getting Things Done. Retrieved: [CAN\\_PL\\_2004\\_LIB\\_en.pdf \(poltext.org\)](#)

Liberal Party Platform (2006). Securing Canada's Success. Retrieved: [0861-P05\\_Lib06\\_platform\\_02.qxd \(poltext.org\)](#)

Liberal Party Platform (2008). Richer, Fairer, Greener: An Action Plan for the 21<sup>st</sup> Century. Retrieved: [CAN\\_PL\\_2008\\_LIB\\_en.pdf \(poltext.org\)](#)

Liberal Party Platform (2011). Your Family. Your Future. Your Canada. Retrieved:

[https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN\\_PL\\_2011\\_LIB\\_en.pdf](https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN_PL_2011_LIB_en.pdf)

Liberal Party Platform (2015). A New Plan for A Strong Middle Class. Retrieved:

[https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN\\_PL\\_2015\\_LIB\\_en.pdf](https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN_PL_2015_LIB_en.pdf)

Liberal Party Platform (2019). Forward: A Real Plan for the Middle Class. Retrieved:

[https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN\\_PL\\_2019\\_LIB\\_EN.pdf](https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN_PL_2019_LIB_EN.pdf)

New Democratic Party of Canada Platform (1997). A Framework for Canada's Future. Making Good Jobs the Top Priority. Retrieved: [CAN\\_PL\\_1997\\_NDP\\_en.pdf \(poltext.org\)](#)

New Democratic Party of Canada Platform (2000). The NDP Commitment to Canadians. Retrieved: [Eplatfoct27for pdf \(poltext.org\)](#)

New Democratic Party of Canada Platform (2008). Jack Layton and the New Democrats: A Prime Minister on your Family's side, for a change. Retrieved: [CAN\\_PL\\_2008\\_NDP\\_en.pdf \(poltext.org\)](#)

New Democratic Party of Canada Platform (2011). Giving Your Family A Break: Practical First Steps. Retrieved: [https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN\\_PL\\_2011\\_NDP\\_en.pdf](https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN_PL_2011_NDP_en.pdf)

New Democratic Party of Canada Platform (2015). Building the Country of Our Dreams: Tom Mulcair's Plan To Bring Change To Ottawa. Retrieved:

[https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN\\_PL\\_2015\\_NDP\\_en.pdf](https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN_PL_2015_NDP_en.pdf)

New Democratic Party of Canada Platform (2019). A New Deal for People: New Democrats' Commitments to You. Retrieved:

[https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN\\_PL\\_2019\\_NDP\\_EN.pdf](https://www.poltext.org/sites/poltext.org/files/plateformesV2/Canada/CAN_PL_2019_NDP_EN.pdf)

## Appendix 1: Interview Guide

Could you please describe your experience in the hydrogen sector?

What caused you to seek out a profession that concentrates on developing renewable energy, such as hydrogen?

How do you see Canada's role in the global development of clean hydrogen? Do you believe that this role has shifted since initial attempts to secure a domestic hydrogen supply chain?

How do you see hydrogen's role as a key pillar in the energy transition? How can hydrogen development benefit Canadians?

How do you see hydrogen's versatility playing a helping role in its development as a viable renewable energy option?

How have you seen Hydrogen's viability to become a contending renewable energy option change within your sector?

How do you see hydrogen's potential use in Canada's contemporary mix differing from previous potential applications within the Canadian context?

What do you see as the largest contributing factor to hydrogen's successful implementation within the Canadian energy context this time around?

What are the potential considerations that must be made, from your perspective, in the development of a hydrogen economy? Social, political, economic?

What should policy makers be most aware of when implementing and developing policy regarding hydrogen?

How do you see the private sector's role in hydrogen development? Have you noticed a shift in efforts to scale-up hydrogen as a viable renewable energy source?

What do you see as the biggest hindrance to hydrogen development in today's context? Has this changed from initial attempts at hydrogen development decades ago?

What do you see as the largest knowledge gap within the hydrogen industry? Has this knowledge gap been identified in the past? Are there possible avenues to addressing this knowledge gap within today's context?

What, in your view, are the most critical next steps in the development of hydrogen? Establishing a supply chain, shoring up demand, and/or investments in enabling technology?

How do you see the challenge of hydrogen's cost competitiveness limiting hydrogen development in the contemporary sense? Has this view changed from previous attempts to develop hydrogen? What are potential ways to address this challenge in the near future?

What do you see as "progress" within the development of clean hydrogen. In contrast to initial clean hydrogen development efforts, have you seen progress on this front?

## Appendix 2: Interview Annex

<b>Interview Participant</b>	<b>Sector</b>	<b>Title/ Organization</b>	<b>Abbreviation</b>
Martin Bush	Industry	Independent Consultant	Interview A
Gregory Caldwell	Industry	ATCO Energy	Interview B
James Gaede	Academia	Efficiency Canada	Interview C
Amandeep Garcha	Government	Natural Resources Canada	Interview D
Ali Karaca	Academia	Research Assistant	Interview E
Matthew Klippenstein	Industry	Hydrogen BC	Interview F
David Layzell	Academia	Transition Accelerator	Interview G
Cory Paterson	Industry	BC Trucking Association	Interview H
Grant Strem	Industry	Proton Technologies Canada	Interview I
Hamid Rahmanifard	Industry	Transition Accelerator	Interview J
David Van Den Assam	Industry	Alberta Hydrogen Centre of Excellence	Interview K