Hydrogen and the Carbon Trap: Hydrogen Coalitions and the Feedback Effects of the BC Hydrogen Strategy

by

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ABSTRACT

Hydrogen has become increasingly regarded as a clean alternative for harder-to-abate sectors in Canada. British Columbia was the first province in Canada to release a hydrogen strategy, which discusses ambitions to support low-carbon hydrogen development derived from renewables and fossil fuels. Political science literature has examined the relationship between renewable and fossil dependent interest groups, often stating that there is increasing amounts of resistance against renewable technologies as they develop. Hydrogen presents an opportunity to expand upon this literature, as it can favour the political interest of either renewable or fossil fuel coalitions. Examining the feedback effects of the BC Hydrogen Strategy, this thesis examines policy developments in three cases: hydrogen production, hydrogen in long-haul road transportation, and hydrogen in heavy-industrial applications. Results find that the presence of incumbent interests is not hindering renewable hydrogen developments in BC. Rather, renewable hydrogen may be supporting the political position of incumbents.

DEDICATION

I would like to dedicate this work to my wife, Olivia, who has supported our family while I pursued a higher education. Thank you for everything.

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I would like to thank my supervisor, Associate Professor Heather Millar for guiding me towards my research goals and teaching me about the environmental politics of energy systems. I would also like to thank everyone who committed their time to doing an interview with me. The information and resources you provided are invaluable contributions to this work, and I am forever grateful for your assistance.

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Abbreviations

ARC: Advanced Research Commercialization

BCER: British Columbia Energy Regulator

BCTA: British Columbia Trucking Association

BCUC: British Columbia Utilities Commission

BEV: Battery Electric Vehicle

CCS: Carbon Capture and Storage

CCUS: Carbon Capture Utilization and Storage

CHA: Canadian Hydrogen Association

CI: Carbon Intensity

CICE: Centre for Innovation and Clean Energy

CIIP: CleanBC Industrial Incentive Program

CNG: Compressed Natural Gas

CO2: Carbon Dioxide

CVPP: Commercial Vehicles Pilot Program

Fcell: Fuel cell

FCEV: Fuel Cell Electric Vehicle

GGRR: Greenhouse Gas Reduction Regulation

HDV: Heavy Duty Vehicle

HDVE: Heavy-Duty Vehicle Efficiency

HTEC: Hydrogen Technology & Energy Corporation

LCFS: Low Carbon Fuel Standard

LNG: Liquified Natural Gas

OBPS: Output-Based Pricing System

RNG: Renewable Natural Gas

SMR+CCS: Steam Methane Reformation with Carbon Capture and Storage

UCA: Utilities Commission Act

ZEV: Zero Emission Vehicle

Chapter 1: Introduction

In the last four years, hydrogen has exploded onto the Canadian political scene as a clean fuel alternative to gasoline and diesel (Natural Resources Canada, 2024). In British Columbia, hydrogen has been viewed by the provincial government as a renewable alternative to electricity generation that can provide clean energy to businesses where direct electrification is seen as inefficient (FortisBC, 2024f; Government of BC, 2021). By 2050, hydrogen could reduce 60% of emissions from the transportation sector, 25% from industry and synthetic fuels, and 15% from natural gas (Government of BC, 2021). In 2020, global hydrogen production from natural gas was responsible for roughly the same amount of GHG emission emitted from the aviation sector (HEC Montréal, 2024; IEA, 2021a). Hydrogen production via renewables[1] and low-carbon fossil fuel production[2] are being promoted as clean energy alternatives for harder-to-abate sectors throughout Canada. These sectors include home heating, industry, feedstock production, and long-haul transportation. Since the release of the Canadian Hydrogen Strategy in 2020 (Natural Resources Canada, 2020), seven out of

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[1] Renewable hydrogen is made from water that is electrically charged through renewable energy, such as wind, solar power, or hydroelectricity. Often, this has been defined as "green" hydrogen.

[2] Fossil hydrogen is produced from natural gas and typically comes from steam methane reformation without carbon capture. Low-carbon fossil hydrogen tends to come from natural gas if there is carbon capture and storage technology, or if there is a facility that creates hydrogen through pyrolysis. These types of hydrogen are typically called grey, blue, and turquoise hydrogen respectively. See Chapter 3, page 25 for more details.

the ten provinces in Canada have published their hydrogen strategies to highlight their low-carbon objectives. These provinces are British Columbia, Alberta, Ontario, Québec, Nova Scotia, New Brunswick, and Newfoundland and Labrador. Additionally, Manitoba is also working on a hydrogen strategy (Government of Newfoundland and Labrador, 2024; Natural Resources Canada, 2024).

The energy profile of Canada largely consists of renewable energy, with the majority of energy production coming from hydroelectricity, followed by nuclear power and natural gas. Conversely, end-use demand is primarily satiated by refined petroleum products and natural gas (Government of Canada & Canada Energy Regulator, 2024b). Similarly in British Columbia, most end-use demand is derived from refined petroleum products and natural gas, though electricity production in BC is mainly generated from renewables. Roughly 95% of electricity generation in BC is derived from renewable energy, with 87% being produced directly from hydroelectricity (Government of Canada & Canada Energy Regulator, 2024a). Additionally, BC is recognized by the Canadian government as a global leader in renewable energy production expertise in the 21st century (Environment and Natural Resources Canada, 2023). In terms of direct hydrogen production, 51% of hydrogen-based businesses in Canada reside in British Columbia, and are centered around the development of low-carbon hydrogen and renewable hydrogen (Government of BC, 2021).

The Government of BC has been largely interested in facilitating hydrogen production from both their renewable and natural gas sectors. Within their 2021 BC

Hydrogen Strategy, the government of BC outlines that low-carbon hydrogen[3] from either renewables or fossil fuels can help facilitate a decarbonization trajectory for harder-to-abate sectors; such as heavy-industrial heating and the transportation sector (Government of BC, 2021). Findings from economic analysis suggest that by expanding low-carbon hydrogen supply and demand, the overall cost of hydrogen will go down; allowing for an energy transition that facilitates decarbonization (IEA, 2019). However, these findings lack a consideration about the role of politics in shaping the speed of this transition.

Political science, the study of governance and power, can aid in understanding how the development of renewable and low-carbon fossil hydrogen may interact with existing political structures and policy goals. In turn, this can also aid in coercing policymakers to make collective evidence-based decisions as they aim to decarbonize existing and future political, economic, and physical infrastructures (Mansbridge, 2014). Policy and political science scholars have previously stressed the importance of coalition developments around niche technologies to counteract resistance from incumbent industries and provide political and financial support (Bernstein & Hoffmann, 2019; Breetz et al., 2018; Meckling & Nahm, 2022; Rosenbloom & Meadowcroft, 2022; Rosenbloom & Rinscheid, 2020). Based on these previous findings, as coalitions develop around renewable and low-carbon hydrogen, resistance to the development of

[3] Low-carbon hydrogen, according to the BC Hydrogen Office, means any kind of hydrogen production except for grey hydrogen (Anon, personal communication, November 2023).

renewable hydrogen may occur as incumbent[4] fossil fuel coalitions collectively gather support for low-carbon hydrogen development.

This research seeks to explore the differing political dynamics surrounding the developments of renewable and low-carbon hydrogen in BC, and whether coalition growth around low-carbon hydrogen is undermining renewable-hydrogen development and subsequent decarbonization policies. This thesis argues that hydrogen production to decarbonize harder-to-abate sectors can make overall decarbonization efforts vulnerable to carbon lock-in mechanisms, which can prevent industries from reaching deep decarbonization by allowing fossil incumbents to maintain their political authority. This argument gives a new perspective for sociotechnical transition literature by providing insight on how incumbents can choose to either facilitate change that benefits them, or delay battles that may typically occur during the mid-stages of technological transitions. BC is an excellent candidate for research involving the strength of hydrogen coalitions which also promote the use of low-carbon fossil hydrogen because there is currently potential for the province to support both renewable and low-carbon fossil hydrogen. If there is evidence to support that hydrogen is facilitating lock-in mechanisms, this could have profound implications for the rest of Canada as provincial governments begin integrating hydrogen into their economies.

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[4] "Incumbents" for most of this thesis will refer to those who benefit from maintaining the current end-use fuel demand hydrogen seeks to replace. This includes the producers, distributors, and sellers of natural gas and diesel.

Starting with a literature review, the following chapter discusses existing political science literature on energy transitions, feedback effects, climate delay, and carbon lock-in mechanisms. The literature review argues that hydrogen presents an opportunity to measure the feedback effects of policies that support niche and incumbent interests and that based on current literature, it is likely fossil incumbents might hinder renewable hydrogen developments. Feedback effects will be measured through an illustrative probably probe, in which process tracing is used to perform document analysis (including policy and industry reports and other grey literature) and media analysis. Additionally, eight key-informant interviews were conducted with government officials, hydrogen industry representatives, and experts to get direct insight into the current effects of hydrogen policy and decarbonization efforts in the province. After the literature review, the historical context of hydrogen development in British Columbia will cement the current layout of hydrogen coalitions in the province. This thesis then examines policy developments in three cases: hydrogen production, hydrogen in long-haul road transportation, and hydrogen in heavy-industrial applications.

Chapter 4 outlines the 2021 BC Hydrogen Strategy, and its stated policy objectives to establish a hydrogen production economy in the province. This chapter discusses the status of hydrogen production and the development of regulatory structures assisting with hydrogen market accessibility. Additionally, this chapter discusses supporting institutions and policies. Chapter 5 describes policy objectives described in the BC Hydrogen Strategy that relate to the decarbonization of the transportation sector, followed by a discussion on the provincial Low Carbon Fuel Standard and the CleanBC Go Electric Program. The barriers to the adoption of hydrogen in the heavy-duty trucking sector will then be discussed, followed by the additional levels of policy support aiming to remove these barriers. This chapter will then conclude with an analysis of policy feedback effects and the politics of decarbonizing the sector.

Chapter 6 examines the industrial uses of hydrogen and will once more discuss objectives in the BC Hydrogen Strategy, followed by an analysis of supportive hydrogen industrial development policies such as the CleanBC Program for Industry. This chapter discusses the assistance being provided by the provincial utilities to facilitate growth in the hydrogen market while also bringing down the costs of low-carbon hydrogen use. This chapter will then conclude with the policy feedback effects of using hydrogen for industrial uses, followed by a discussion on the political implications of deep decarbonization efforts.

The thesis concludes with a discussion of the findings that the development of renewable or low-carbon fossil hydrogen leaves openings for political actors to undermine renewable hydrogen development in BC. I find that contrary to expectations from the literature on the politics of mid-transitions, the potential for carbon lock-in is generated not through direct political resistance against renewable hydrogen, but rather a broad acceptance of renewable and low-carbon fossil hydrogen being developed with the same levels of support from both renewable and low-carbon hydrogen coalition members. As a result, typical battles that may be expected in the mid-transition period could be pushed to the late stages, resulting in difficulty establishing deep decarbonization. This provides a contribution to energy transition literature beyond the scope of hydrogen by giving insight on the level of power incumbents have within the existing regime, and how they can use that power to influence the timing of policy decision making to benefit themselves. This research also finds that, economically, developing renewable hydrogen may not be in the best interests of British Columbia for the sake of future decarbonization efforts and financial gains.

Chapter 2: Literature Review

Decarbonization in Canada is a difficult political dilemma largely due to the system of federalism that was put in place with the creation of the Canadian constitution in 1867. Though the current federal Liberal government (2015 -) has attempted to put some decarbonization initiatives into effect, the division of powers within the constitution has made it difficult for Canada to collectively combat climate change. This places much of the responsibility of combating climate change on the shoulders of provinces within Canada, and necessitates significant collaboration between provincial governments to tackle climate change[5] (Bernstein & Hoffmann, 2018; Malcolmson et al., 2016). How a province decarbonizes its electricity and transportation sectors is often constrained by the limitations in generational capacity, available technology, and its availability of natural resources (Natural Resources Canada, 2023a). British Columbia has created an opportunity for itself, in which electricity generation is primarily made up of hydroelectricity, representing 87% of the province's electricity grid. However, according to the Canada Energy Regulator, refined petroleum products take up 39% of end-use demand, and natural gas takes up 29%, whereas electricity end-use demand takes up 16% (Government of Canada & Canada Energy Regulator, 2024a). This provides BC with an opportunity to take advantage of its existing renewable capacity and use this to spur an energy transition that is spearheaded through the use of

[5] Provinces can also receive support from the federal government through financial means

alternative fuels, such as hydrogen among industrial consumers and hard-to-abate sectors (CleanBC, 2021; Government of BC, 2021).

Energy transitions in the context of decarbonization refer to the rise of clean energy solutions, such as renewables, and their eventual replacement of fossil fuel-based energy production (S&P Global, 2020). Transitions towards cleaner energy alternatives typically appear as “S-curves” over time, with the objective being to diffuse the cleaner technology while phasing out the old (Rosenbloom & Meadowcroft, 2022). Technologies are often seen to develop via a specific route. To simplify, first, they are invented. Next, they are innovated; and tested against real-world problems to understand their use in the modern day. Lastly, the new or “niche” technology is diffused and slowly becomes readily available in the market (Alberth, 2008). However, the acceptance of that technology during and after innovation within supporting industries and the public can have a pivotal role in how well that technology diffuses. For instance, as the automobile diffused into the market, infrastructure was created to continue supporting the automobile while also defining how society would function alongside it (Rosenbloom & Meadowcroft, 2022). Since then, the automobiles existence is maintained not only by the industries that manufacture their parts, but also by government ministries and cultural symbolisms (Geels, 2002). Counter to this, it has often been assumed that technological innovation will be inevitable and that niche technologies will as a “matter of fact” replace carbon-intensive energy arrangements as they move along this experience curve (Breetz et al., 2018; Goodall, 2016, Chapter 1).

Political science literature has shown that the diffusion of technology is often reliant upon the politics that aid or hinder a technology’s access to markets. Incumbents who feel threatened by a technology that impedes their markets will often fight against a policy that supports them to protect their business interests. Though niche technologies often do not face resistance in their early stages of development, it is when technology begins to diffuse into the market that incumbents take notice. For instance, after the State of Ohio introduced a new renewable portfolio standard, utilities that relied upon fossil fuels pushed against the standard to avoid incurring costs associated with developing renewables, such as solar, and instead sought after subsidies that supported their aging coal plant infrastructure. This eventually resulted in increased costs for solar energy, and social resistance towards wind energy (Breetz et al., 2018).

Policies can affect the rate at which technology reaches maturity (Breetz et al., 2018). Policy can also have greater impacts on resulting politics; which in turn can shape future policy decision-making (Pierson, 1993). Energy transition experience curves can be analyzed at three distinct phases, the top, the middle, and the bottom. As technology moves along a transition curve, coalition[6] and political support become increasingly important aids to allow technologies to become affordable and competitive within existing markets, and to combat resistance from incumbents, through the creation of policy that supports that technology (Breetz et al., 2018). More specifically for low-carbon transitions, coalitions take an important role in that a single actor cannot possibly have enough resources alone to bring about a transition (Roberts et al., 2018).

[6] In Political Science, a coalition refers to a diverse set of stakeholders who come together and support the same policy interventions (Levin et al., 2012).

Historically, technological transitions, such as the transition from sailing to steamships, or horse-drawn carriages to internal combustion engines, are brought about by a need to meet core societal needs to enable a certain way of doing things, such as the provisioning of power, water, heat, or food. For instance, the development of steamships was largely supported through a fundamental need to have more reliable departure times that were not at the mercy of wind speeds. This increased reliability in departure times also facilitated better communication through the shipments of letters, which also helped facilitate better trade (Geels, 2002). These transitions are often driven by the *regime*, the dominant industries and business models that make up the current rules of a particular system; the *niche,* which is the emerging innovation that seeks to displace elements within the regime; and the *landscape*, which makes up broader developments such as market shocks, cultural shifts, environmental problems, wars, and changes to political administrations which could reinforce or place pressure on existing regimes. As a result, niches are often novelties that can generate change and are embedded within the frameworks of the regime, while the regime is embedded into the landscape. Additionally, processes within the regime and landscape must have interests that also align with the niche to facilitate change (Geels, 2002; Rosenbloom & Meadowcroft, 2022).

Niches that are at the top of the experience curve often require political strategies that make use of subsidies or quotas to facilitate technology adoption. Often, political actors who support the niche technology are few, as it is still relatively new (Breetz et al., 2018). A variety of policy tools are at the disposal of policymakers to begin establishing support for technology within an energy transition. For instance, the cost of a niche technology can be lowered through subsidizing the development, production, or deployment of said technology. Adoption of that technology can also be increased using mandates, the state uptake of that technology, or creating performance standards to encourage technological adoption. To further encourage a low-carbon transition, policies can exert pressure on fossil-dependent systems, either through the same mandates and performance standards that were used before, or through purposefully increasing the cost of fossil fuels via taxes, stringent environmental standards, or reduced subsidies (Breetz et al., 2018). In the middle of the experience curve, though the technology becomes more affordable for consumers, it also becomes more controversial. Incumbents may seek subsidies to support their position or attempt to stall new technologies' capability of accessing the market. Therefore, knowledgeable and strong coalitions that can continue to support the diffusion of renewable technologies are increasingly important (Breetz et al., 2018; Schwartz, 2016). At the bottom of the experience curve, new technologies reach competitive levels with incumbent industries. Some technologies that do not require large societal or industrial changes will likely have an easier time being adopted, but those that do require large changes will still face political hurdles. To "level the playing field", policymakers must find ways to create supporting infrastructure, enforce economic strains on incumbents, and align social interests with green policy objectives to deprive political power of incumbent industries (Breetz et al., 2018). (See Figure 1).

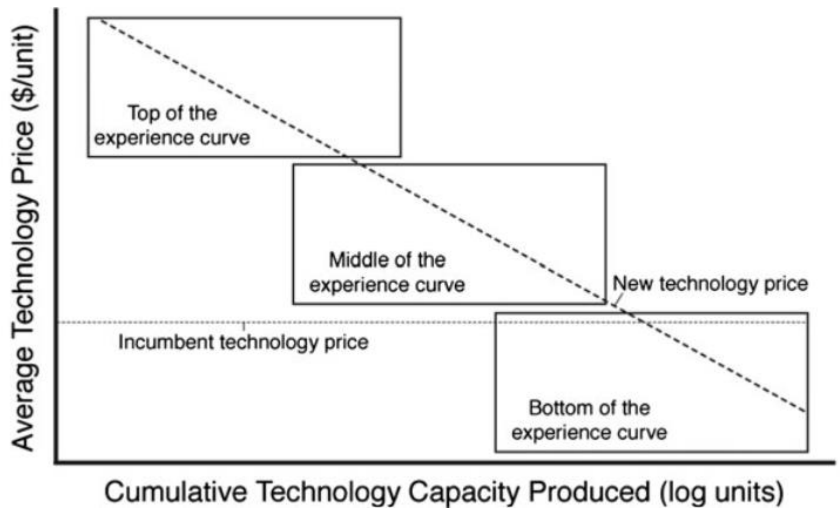

Figure 1: Visualization of the technological experience curve. As technology progresses, it requires more and more support as it reaches the bottom of the experience curve (Breetz et al., 2018, p. 499)

Resistance from incumbents can come in a variety of ways, but throughout the policy process, resistance to new technologies will likely include different forms of discourse that nurture climate delay. Lamb et al (2020) identify four methods of discourse delay incumbents may use, which often involve policymakers or government officials. Types of discourse include: “redirecting responsibility”, providing “non-transformative solutions”, “emphasizing the downsides” of climate policies, or “surrendering” to climate change (Lamb et al., 2020, pp. 3–5). Redirecting responsibility can occur when climate policies are viewed as unfair amongst different jurisdictions. For example, it may be viewed that a carbon price is deemed fit for use within the transportation sector, but decision-makers may state it is unfair to single out the transportation sector with a carbon price. Non-transformative solutions can occur when technological transitions are viewed as inevitable, and therefore long-term solutions that can support technological development through its experience curve are not actualized. Downsides can be emphasized by pointing out short-term societal burdens associated with costs. A clear example of this can be seen in Brampton, Ontario, in which politicians viewed green building practices as unbeneficial for economic growth, despite politicians in Toronto, Ontario showing otherwise in their analysis of the economic benefits of green building practices (Schwartz, 2016). Lastly, surrendering to climate change aims to push a narrative that perpetuates a discourse of "giving up" or "it is too late" to solve the climate crisis. This form of discourse elevates the belief that there is no point in changing the status quo (Lamb et al., 2020).

Attempts to stall the diffusion process of renewables can be countered by policymakers who are prepared to combat incumbents. Meckling and Nahm (2022) identify four strategies governments may use to achieve policy goals and counter opposition. These strategies are *Recruiting Allies*, *Limiting Access*, *Aligning Interests*, and *Quieting Interests*. *Recruiting Allies* may involve either interest-shopping or coalition building. Interest-shopping involves policy decision-makers seeking out forums that support the intended policy goals, and as touched on earlier, coalition building takes interest-shopping a step further by creating a collective group of interest forums that support policymakers with their intended policy objectives. *Limiting Access* can occur by negotiating policy decisions in more secure levels of government bureaucracies, or by having private negotiations with actors who have competing interests. *Aligning Interests* may involve bargaining with competing interest groups, triggering policy feedback to set up future policy decisions, and political signaling to business actors that encourage the development of upcoming policy objectives. Finally, *Quieting Interests* occurs by compensating economic losers as market forces shift (Meckling & Nahm, 2022), though this may take away from divestment strategies (Rosenbloom & Rinscheid, 2020).

Yet the sequencing of diffusing a niche technology is much easier said than done, as everyone who is trying to decarbonize and fix the "carbon problem" is also participating in it (Levin et al., 2012). Some coalitions can support or hinder the development of renewables on either side of the political spectrum (Mildenberger, 2020, Chapter 2), and coalitions that support cleaner energy are often fighting an uphill battle to defeat counter-coalitions (Roberts et al., 2018). In this sense, we exist in a state of "carbon lock-in", in which we have economic dependence on fossil fuel infrastructure and face a challenge to move away from fossil fuels within our economic and social environments (Unruh, 2000). Institutions and industries rely upon carbon-intensive technologies to remain active; economic, social, and political actors seek to maintain or control the existing conditions that support carbon-intensive industries; carbon-intensive social norms perpetuate themselves within society and, as a result, lock in behaviours that support carbon-intensive patterns (Seto et al., 2016); and language is used to perpetuate the status quo by using political discourse to protect incumbents (Buschmann & Oels, 2019). Yet, we also know globally that we must change these carbon-intensive arrangements, or else we will face irreversible damage to ecosystems; both natural and artificial. This makes transitioning away from carbon-intensive arrangements a rather complicated challenge. As time is running out to address necessary changes, policy decisions that fail to create meaningful change cannot necessarily be revisited later.

Those making these policy decisions are integrated directly into the previously mentioned lock-in mechanisms. Addressing climate change requires cross-jurisdictional cooperation between economic sectors and multiple political levels, and it must be addressed with purposeful long-term thinking; thinking that may even extend past the terms of political leaders (Levin et al., 2012).

But there is also another problem, the pace in which transitioning away from fossil-intensive technology, and towards zero-emission technologies, must happen at an exponential rate to meet climate objectives as laid out in the Paris Agreement (UNFCC, 2024). Historically, transitions from one technology to another are slow and arduous processes; yet we need to accelerate the pace of change rapidly (Grubert & Hastings-Simon, 2022; Roberts et al., 2018; Rosenbloom & Meadowcroft, 2022). This means approaching a transition away from fossil technology in a way that meets multiple sectoral and industrial transformations, creating radical change within the systems that are fixed within their fossil-dependent states. In other words, carbon-intensive arrangements must be phased out in a managed way while niche technologies are uplifted through financial and policy support structures (Rosenbloom & Meadowcroft, 2022; Rosenbloom & Rinscheid, 2020). This means changes with not just technology, but the very institutional capacities, supporting infrastructure, cultural norms, and political authorities that shape daily life must be affected by decarbonization strategies to experience deep decarbonization; otherwise, we risk maintaining the political legitimacy of fossil incumbents within the existing regime (Bernstein & Hoffmann, 2018, 2019; Geels, 2005; Rosenbloom & Meadowcroft, 2022).[7] The carbon lock-in mechanisms that maintain the regime can therefore decline via deliberate decline mechanisms, in a manner that is controlled, and steers governments away from fossil-dependent practices. Coalitions who aim to steer governments away from fossil systems can be further supported while carbon-intensive systems are replaced; to ensure continued and knowledgeable support that destabilizes the existing regime. All the while the divestment of financial resources that support fossil fuels can reduce the political legitimacy of incumbents, while also aiding in the managed termination of carbon-intensive technologies and infrastructure. In doing so, behaviours, politics, and technology can be shifted toward a future that entails zero emissions (Rosenbloom & Rinscheid, 2020).

Yet given the pressing matter of time, we must also transition towards cleaner energy with explicit planning, or else we risk reinforcing fossil incumbents' political legitimacy (Grubert & Hastings-Simon, 2022). For instance, in the case of Germany, the federal government ambitiously sought to replace nuclear power with renewable electricity. After reducing their energy capacity by dismantling their nuclear power stations, a switch in government resulted in the country becoming more reliant on coal to substitute their generation capabilities (Buschmann & Oels, 2019). Hence, the importance of managed termination plays a critical role in a period where mistakes can be extremely costly both for economics and time (Levin et al., 2012; Rosenbloom &

[7] See Geels (2005) for a more detailed description on this multi-level perspective model for change.

Rinscheid, 2020). It is as simple as this; if an electricity system is 50% non-carbon emitting, and the other 50% is carbon-emitting, then 50% more generating capacity must be built before the entire carbon-emitting 50% is brought offline. But again, this is easier said than done. This gives time for incumbents, who have a status-quo bias, extra time to resist the build-up of that other 50% to protect their economic interests and survivability. (Grubert & Hastings-Simon, 2022). Therefore, managed termination requires specific actions on the part of policymakers to ensure a managed energy transition, in which fossil fuels can be replaced as alternatives are introduced. (See Figure 2).

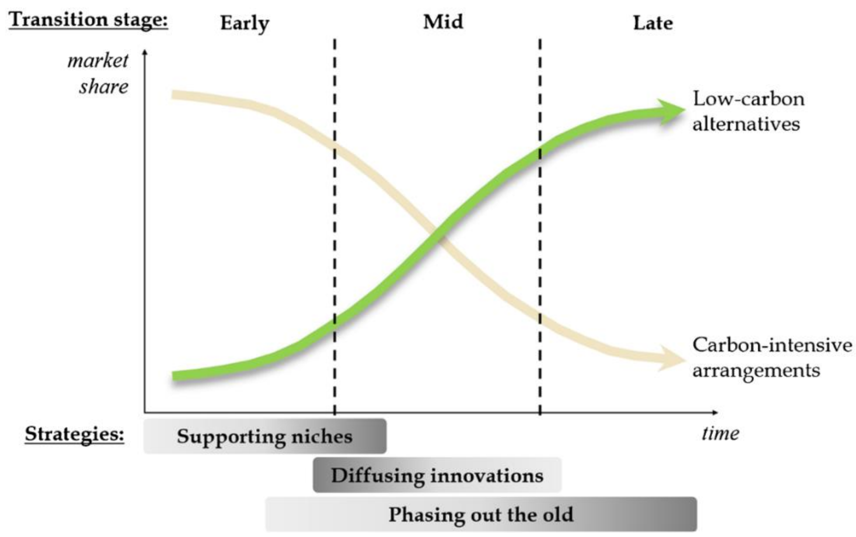

Figure 2: Visual representation of an energy transition, in which fossil-dependent arrangements get replaced by low-carbon alternatives diffusing into the market (Rosenbloom & Meadowcroft, 2022, p. 106).

When transitioning into a decarbonized future, it can be easy for decarbonization trajectories to be undermined by the very systems that technology seeks to replace.

Environmental politics scholars Steven Bernstein and Matthew Hoffmann (2019) call this scenario a *Fractal Carbon Trap* in which the socioeconomic systems that have a goal to decarbonize may be able to improve but are unable to fully decarbonize due to the patterns of carbon lock-in renewing fossil fuels as something reliable for our existing institutions. They argue that we live in a fractal system, in which the lock-in mechanisms work separately in a fractured and independent way; yet support each other in an interdependent manner that encourages fossil-dependent markets, decisions, and behaviours. This places decarbonization pathways into a *double trap,* in which an economic system improves but also constrains itself from being able to reach deep decarbonization (See Figure 3). For instance, framing natural gas as a “bridge” towards reducing emissions from coal may improve emissions within the short term; but still entrenches fossil interest within our economic systems; leaving a political structure that still gives fossil incumbents political legitimacy. Another less obvious example comes from the use of LEDs, in which money saved by consumers who purchase LEDs is then used by banks to generate capital to invest in ecologically devastating industrial activities (Bernstein & Hoffmann, 2019). Where a technology, such as hydrogen, might improve one or more industrial sectors; its use may also entrench fossil interests in other areas within the fractal system. These areas could be energy infrastructure, cultural and social norms, or political institutional capacities. The resulting entrenchment of fossil interests can cause these fractal areas to backslide or remain stuck in a system improvement phase that is constrained by external dependencies on fossil fuels (Bernstein & Hoffmann, 2019; Grubert & Hastings-Simon, 2022; Rosenbloom & Rinscheid, 2020).

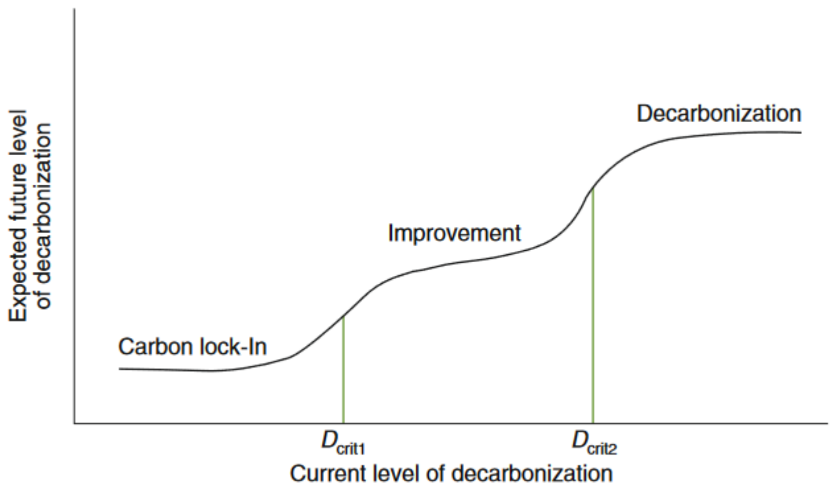

Figure 3: Visual representation of the *double trap*, in which a system may improve by passing one threshold to decarbonize (Dcrit1), but struggle to pass more hurdles (Dcrit2) to reach full decarbonization. (Bernstein & Hoffmann, 2019, p. 923)

In other words, because we live in this fractured system that is prone to carbon lock-in, it can be easy for one solution to cause unintentional consequences in another system. Therefore, despite things seeming better in one particular sector, the interconnectedness of the fractal system prevents that particular sector from fully improving (Bernstein & Hoffmann, 2019). To ensure a transition is accelerated, yet managed in a way that does not encourage backsliding into carbon lock-in tendencies, policy must be generated with a forward reasoning approach. Levin et al. (2012), describe "applied forward reasoning" to policy decisions as the identification of policy interventions that can support intended policy outcomes. Small policy changes can generate significant effects later if path-dependent processes are triggered. This means coalitions must be formed that help shift the norms and values of existing regimes, to facilitate path-dependent trajectories that steer our fractured system towards a collective decarbonization goal (Bernstein & Hoffmann, 2018, 2019; Levin et al., 2012). In other words, we must create policies that create enough support for new technology trajectories to establish resistance against incumbents while also further entrenching the perceived economic and social benefits of that technology (Levin et al., 2012). But we must also do this in a manner that creates longevity for incumbent replacement policies so that the longer process of replacing incumbents is met with less resistance (Jordan & Matt, 2014).

All the energy and technology transition literature thus far has been primarily focused on the experience curve renewables have often had when encountering incumbent markets. Hydrogen opens the door to a different experience curve trajectory, in which fossil incumbents can also benefit from the support being given to hydrogen by political institutions thanks to their vested interests in the production of fossil hydrogen. Renewable and low-carbon fossil hydrogen can both receive benefits from the same funding streams and coalitions within a global economic system that already favours incumbents. Though this may favour the need to accelerate a technological transition by speeding up the diffusion process of hydrogen due to increased coalition support; the presence of fossil incumbents within coalitions might favour low-carbon fossil hydrogen over renewable hydrogen as technology reaches the middle of the curve. In British Columbia, policy is supporting both the development of renewable hydrogen and low-carbon fossil hydrogen (Government of BC, 2021). The province's support of the hydrogen industry is part of its much broader plan to reach net zero emissions by 2050 as outlined within the CleanBC Roadmap to 2030 (CleanBC, 2021). There is also broad coalition support for hydrogen development from both fossil incumbents and renewable hydrogen entrants[8], with the majority of executive members of the BC division of the Canadian Hydrogen Association (CHA) being made up of actors with incumbent fossil fuel interests (CHA, 2024e).

I argue that the BC Hydrogen Strategy represents a critical point in time when BC begins investing its resources in developing a hydrogen economy. Given the presence of fossil incumbent involvement within a strategy that is largely aiming to pivot away from fossil fuel use, this research observes whether positive or negative policy feedback effects are impacting hydrogen diffusion along the experience curve. My research examines whether current policy is generating a new fractal carbon trap in which some systems improve; but the political legitimacy of fossil incumbents remains (Bernstein & Hoffmann, 2019).

Feedback effects, also called self-reinforcing or self-undermining sequences in the social sciences (Jacobs & Weaver, 2015; Mahoney, 2000) and reinforcing patterns in the climate sciences (Bernstein & Hoffmann, 2019), refers to the sequential stages of policy developments from an initial policy decision that either reinforces or undermines the intention of that initial policy. New policies are shaped by the effects of previous policies, which construct the institutional limitations new policies must be subjected to (Jordan & Matt, 2014). For this paper, "feedback effects" will be referred to as self-

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[8] Fossil hydrogen incumbents are the producers of fossil hydrogen, primarily that of natural gas producers. Renewable hydrogen entrants are those who seek to produce and sell "green" hydrogen in a market that is dominated by fossil fuels.

reinforcing or self-undermining effects. Often, how initial policies are reinforced or undermined is largely dependent upon the level of support from political coalitions and the surrounding political context or previous social norms of a region that is attempting to decarbonize (Roberts et al., 2018). Self-reinforcing effects can make it difficult to change the future trajectory of low-carbon developments, either for the better or worse (Bernstein & Hoffmann, 2019; Mahoney, 2000). These occur when an initial policy changes the surrounding politics, which then reinforces support for the initial policy. This can result in the entrenchment of the initial policy over time as more policies develop and subsequently continue to shape surrounding politics. In other words, a policy that generates broader political support can make initial policies difficult to reverse (Roberts et al., 2018). Policymakers can use a few strategies to ensure their initial policy design is self-reinforced by encouraging actors to commit to the intention of the policy. *Programme Wide Adhesion Mechanisms* create program-wide long-term targets that shape the expectations of the regime to allow the protection of policies in short-term political skirmishes (Jordan & Matt, 2014). This takes on a similar form to the Meckling and Nahm (2022) interpretation of *aligning interests* through political signaling. *Instrument-specific Adhesion Mechanisms* can take measures that ensure a target group has the confidence to invest in newer technologies that are deemed beneficial for long-term solutions. To ensure the original policy is not falling off course, it can always be monitored or reviewed to better understand how well the policy is performing (Jordan & Matt, 2014).

Self-undermining feedback effects can create conditions that counteract the initial policy objective, again whether for better or worse. This means that policy is generated after the initial policy, which then serves to undermine that initial policy, creating a non-transformative economic, technological, or political system that looks very similar to the original (Bernstein & Hoffmann, 2019; Jordan & Matt, 2014). Though reinforcing patterns often constrain what options are available to any given government, negative policy consequences can often provoke policymakers to search for alternatives, leading to the undermining of the original policy (Jacobs & Weaver, 2015). Jacobs and Weaver (2014) identify three mechanisms that can signal whether a policy is being self-undermined: feedback through emergent losses, policy losses in mass cognition, and the expansion of alternatives. *Emergent losses*, or the unintentional loss of power, may occur when policies create unintentional outcomes for actors who support the initial policy. Due to the layered and complex process of policy design over time, and the inherent benefit of policy that achieves short-term goals in Western democracies, long-term effects can strip away power from those originally invested in the policy. This is likely to occur when either the original policy required large compromises across actors, the policy was enacted by political actors facing the end of their term, or when a policy involves an ambitious target to change social norms in a causal, rather than incremental way. Policies can also be undermined through *losses in mass cognition*, in which a policy undermines its base level of support. Negativity bias can play a major role here, in which negative information around policy objectives can overshadow the positive information. Framing effects can also play an important role here, in which political elites can shape the attitude of citizens towards a policy by limiting the information presented to them. This, in turn, can allow elites to exploit the negativity bias of voters by portraying a policy as a loss rather than a gain. If initial policies require high costs to be successful, elites who are against the policy can hyper-fixate on those costs, taking advantage of voters' negativity bias even further. The third mechanism of undermining policy, the *expansion of alternatives,* mainly occurs when a policy is already beginning to generate problems, and policymakers begin searching for alternatives. For instance, if there already are high costs associated with a particular policy outcome, alternatives may become more tasteful on the menu to avoid further high costs (Jacobs & Weaver, 2015).

Previously, scholars have researched and explained the importance of key policy developments and support systems that have enabled positive or negative feedback effects that influenced policy outcomes (Jacobs & Weaver, 2015; Mahoney, 2000; Pierson, 1993). Others have used policy feedback to explain differing dynamics of energy transitions which have faced resistance from incumbent fossil fuel industries and their political allies (Bernstein & Hoffmann, 2019; Jordan & Matt, 2014; Millar et al., 2021; Rosenbloom et al., 2019). Roberts et al. (2018) look towards self-reinforcing sequences as a way to reinforce policies that aim to accelerate the low-carbon transition, while also recognizing the importance of coalitions that either hinder or improve support for socio-technical transitions. Furthermore, they recognize the role of the broader context of economic institutions, cultural norms, and current technical solutions that are already locally dependent upon the region attempting to transition. In short, the agency of political actors, the process of policy development, and the structure that a niche technology must go through all can influence the outcome of a low-carbon transition. Previous transitions have met success with climate policy where the policy aimed to improve projects beyond the scope of just climate change, such as developing energy security or creating competing "green" industries. Some have been more successful than others, largely dependent upon their own geographic and technical limitations. But using reinforcing sequences is a daunting task in the realm of low-carbon transitions, in part due to other overarching mechanisms that connect with initial policies beyond just the coalitions, but the larger technical systems, the niche technologies themselves, the ever-changing market dynamics, and niche user agency. Though technological reinforcing sequences are likely to create self-reinforcing effects due to the very purpose of the initial policy being to support their growth, they can still generate self-undermining effects if cost becomes a problem (Roberts et al., 2018).

Most research on reinforcing sequences has studied the unintended effects of policies, rather than the extent to which policies purposefully generate self-reinforcing effects to better establish themselves within the broader context of low-carbon transitions. Though there are few case studies available to measure how effective reinforcing sequences are in completed low-carbon transitions, it may be possible to measure feedback effects through the sequential stages of the technological experience curve as a technology, such as hydrogen, begins to diffuse into the market. Low-carbon transitions often require several sequential policy changes to be successful (Roberts et al., 2018). Additionally, more research is needed to better understand which policies can create deep decarbonization effects, and avoid potential *double-trap* scenarios (Bernstein & Hoffmann, 2019).

BC stands out as a case study in Canada for understanding the potential effects of reinforcing sequences involving hydrogen development. This is because BC is calling for the support of both renewable and low-carbon fossil hydrogen through their hydrogen strategy (Government of BC, 2021). The province also has a long history of hydrogen development in the province,[9] and has been a champion of climate policy developments in Canada (Dale et al., 2020). Additionally, though the energy grid of BC is comprised of mostly hydroelectricity, the province has already developed some path dependencies on the development of liquified natural gas for export opportunities. This pre-existing path dependency could directly compete with decarbonization policies and also allow for a comparison of Canada as a whole (Chen & Gunster, 2016; Government of Canada & Canada Energy Regulator, 2024a). Whereas Canada is striving to decarbonize and embrace hydrogen production, but also relies upon exporting oil and gas (Government of Canada & Canada Energy Regulator, 2024b; Natural Resources Canada, 2020), an analysis of BC could provide some insight into how hydrogen production will interact with the rest of Canada.

This research seeks to explore the differing political dimensions of coalition support around the adoption of renewable and low-carbon fossil hydrogen, and whether provincial and federal support for low-carbon fossil hydrogen causes undermining effects that make renewable hydrogen and supporting technologies vulnerable to climate delay. In turn, this research seeks to understand whether broad levels of hydrogen development can leave decarbonization efforts vulnerable to being undermined through the continued maintenance of incumbent political power, rather than the erosion of it.

[9] This will be discussed in depth in Chapter 3

This research uses the case of the BC Hydrogen Strategy to examine the feedback effects that are self-reinforcing or self-undermining the objectives of the strategy. In doing so, I examine the following research questions:

1. Does the development of the hydrogen industry in BC create entrenched fossil interests?
2. Where does hydrogen development in BC rest on a technological experience curve?
3. How does the current provincial policy around hydrogen development in BC generate self-reinforcing or self-undermining feedback effects?

To address these questions, this research uses process tracing, document analysis (including policy and industry reports and other grey literature), media analysis, and eight key-informant interviews with government officials, hydrogen industry representatives, and experts to observe the current effects of hydrogen policy on decarbonization efforts in the province. I examine three related cases to determine the role of policy feedback effects: 1) hydrogen production in BC, 2) the use of hydrogen in the heavy-duty transportation sector, and 3) hydrogen use in heavy-industrial applications.[10]

Using a process of forward reasoning, in which social scientists can identify and connect contingencies that could shape the future (Levin et al., 2012), this research seeks

[10] The research design for this project was approved by the UNB Research Ethics Board under application number REB 2023-122.

to measure how well the initial BC Hydrogen Strategy is self-reinforcing, or self-undermining, its initial policy intentions. With the establishment of a greater hydrogen coalition after the BC Hydrogen Strategy was released, these coalition members can influence knowledge generation and therefore policy decision-making. This can facilitate either self-undermining or self-reinforcing feedback effects. For instance, if the BC Hydrogen Strategy is generating self-reinforcing support through policies and programs, then it stands to reason that the early stages of hydrogen development and deployment are being met with success. However, if unintended consequences generate self-undermining effects, the rate at which hydrogen begins to diffuse in the middle of the experience curve may face unintended challenges. This could result in a path toward system improvement (carbon-trap), or deep decarbonization. Drawing on a combination of process tracing, document analysis, and key informant interviews, this paper makes an illustrative plausibility probe (Levy, 2008). It does this through a qualitative analysis of the current reinforcing or self-undermining events that are affecting the development of the hydrogen industry in BC and comparing this evidence with existing political science theory on energy transitions. Furthermore, this research examines how the current policy to diffuse hydrogen within the transportation and industrial sectors is performing, followed by an assessment of how the province’s plan to decarbonize BC is performing.

Chapter 3: Hydrogen in Context

Before taking a deeper approach to understanding why British Columbia has taken an interest in hydrogen as an energy source, it is important to understand the context of different types of hydrogen production. Hydrogen can come from a variety of different sources, and there is an entire colour spectrum of hydrogen production that delegates where hydrogen originated from. For this research, hydrogen derived from fossil fuels and renewables are the only areas of concern that need explanation. Hydrogen derived from fossil fuels can come from three types of hydrogen production methods, but for this research, only two of them will be discussed. Hydrogen derived from Steam Methane Reformation with Carbon Capture and Storage (SMR+CCS), also known as “blue” hydrogen, involves natural gas being mixed with steam to create a chemical reaction that produces hydrogen and carbon monoxide. Another reaction turns this carbon monoxide into CO_2, which is then stored underground in a process called carbon capture and sequestration. This means for SMR+CCS to be successful, it requires some form of geological storage (Natural Resources Canada, 2020). Pyrolysis, or “turquoise” hydrogen uses high levels of heat and energy to disassociate methane into hydrogen and turn the carbon molecules into the chemical “carbon black”, which can be used as a manufacturing material in other applications within the automotive sector or cosmetic industry. Because the carbon is sequestered into solid carbon, there is no need for geological storage to be in place to sequester emissions (Natural Resources Canada, 2020; Power Technology, 2022). Renewable, or “green” hydrogen, is rather simple, in that water that is heated through a renewable energy source eventually separates to become its own hydrogen and oxygen atoms. Though the process generates zero emissions, how that process is powered can have varying degrees of carbon intensity (IEA, 2024). Additionally, it is also the costliest both in terms of its actual price and its energy demand (Howarth & Jacobson, 2021; Natural Resources Canada, 2020). Seven times more energy is required to produce hydrogen via electrolysis than is required for steam methane reformation (Xiao, 2024), and globally, the cost of producing blue hydrogen is typically significantly less than green hydrogen; with blue hydrogen ranging from $1 to $2 USD/KG, and green hydrogen costing $3 to $8 USD/KG (IEA, 2021b). Hydrogen derived from fossil fuels that use technology to capture emissions for the rest of this paper will be called "low-carbon fossil hydrogen", while hydrogen derived from renewables will be called "renewable hydrogen" for the rest of this paper.

As hydrogen production requires synthetic production by extracting it from other chemical bonds, it works extremely well for storing energy. In addition to hydrogen technicalities, the development of ammonia to assist with hydrogen transportation purposes is also of great interest to British Columbia. Though hydrogen can be compressed or liquified to enable better transportation as a fuel, ammonia has been seen as a temporary solution for transporting hydrogen and avoiding some challenges that typically come with transporting the lightest element on earth (Serpell et al., 2023). Though liquid hydrogen can be easily converted to gaseous hydrogen, the steps to liquify hydrogen consume a lot of the energy from hydrogen; in addition to the release of hydrogen emissions during liquid transportation (Chatterjee et al., 2021). As hydrogen is the lightest element in the universe, it is capable of escaping even the most air-tight containers and can also cause damage to unprotected metals that are often seen in existing natural gas pipeline infrastructure. This makes it extremely difficult to transport by conventional means you would typically see from natural gas or oil. Ammonia, the chemical compound of “NH_3”, can resolve this issue through its creation. By combining hydrogen with natural gas, ammonia can be formed through a process called the “Haber-Bosch” process. Traditional use of the Haber-Bosch process releases roughly two tons of CO_2 into the atmosphere for every ton of ammonia produced. However, using renewable hydrogen to create “green ammonia” can cut down these emissions, though it is incredibly expensive. It is seventy-three percent cheaper to produce ammonia from fossil fuels than it is from renewably charged ammonia (Jones, 2022). As there is already a level of infrastructure in place to support the transportation of ammonia, this can allow for the easier transport of hydrogen, in which ammonia can then be heated at its end-destination to release the hydrogen, though this does result in some decreases to the hydrogen net energy yield (Serpell et al., 2023).

Historical Context

British Columbia was the first provincial government to release its hydrogen strategy in 2021 as a part of its broader climate policy, CleanBC Roadmap to 2030 (Ministry of Energy Mines and Low Carbon Innovation, 2022a). Hydrogen, within the context of the roadmap, is viewed as a way to decarbonize sectors that may have difficulty being decarbonized through electrification alone, such as the heavy-duty transportation sectors and heavy-industrial heating (Anon, personal communication, November 2023; CleanBC, 2021; Government of BC, 2021). This strategy came one year after the release of the federal government’s Canadian Hydrogen Strategy in 2020, which recognized BC as a top contributor to hydrogen development not just in the context of Canada, but in the rest of the world. The federal government also recognized the potential for both renewable and low-carbon fossil hydrogen, seeing value in the vast amounts of hydroelectric power and fossil fuel reserves in the country. The Canadian Hydrogen Strategy positions low-carbon fossil hydrogen to leverage the existing natural gas reserves in Canada while other technologies were to be used as a replacement once scaled. The federal government also viewed BC as a province that could capitalize on both its vast amounts of hydroelectricity and its natural gas emission storage potential for the use of carbon capture and storage (CCS). Though not explicitly against the production of hydrogen without the use of steam methane reformation and carbon capture and storage (SMR+CCS), the Canadian Hydrogen Strategy recognized the need to decarbonize using low carbon intensity hydrogen and introduced a carbon intensity threshold for hydrogen production. This carbon intensity threshold is measured based on the end-of-life cycle emissions of hydrogen as it moves from its source of production to its intended use purpose. Inspired by the European Commission's hydrogen carbon intensity measuring pilot program called "CerifHy", Canada placed its carbon intensity threshold for hydrogen at 36.4 grams of CO_2 equivalent per megajoule (gCO_2e/MJ) (Natural Resources Canada, 2020). Taking after this threshold, the BC Hydrogen strategy also set its carbon intensity threshold for hydrogen production at 36.4 gCO_2e/MJ, allowing for either SMR+CCS technology that is proven to capture 90% of CO_2 emissions, or other means such as natural gas pyrolysis that can produce under that carbon threshold (Government of BC, 2021).

BC already had an economic advantage within the hydrogen industry because of its previous attempts to stimulate its hydrogen economy. One of the earliest examples of fostering the hydrogen economy in the province was the formation of Ballard Power, which began as a research company in 1979 and established itself as a researcher involved with fuel cell production within British Columbia in 1989 (Ballard Power, 2024). By 2009, because of an established history of fuel cell development in the province, the BC government decided to have a demonstration of fuel cell buses at the 2010 Winter Olympic Games. The demonstration, which took place in Whistler, BC, was met with mixed reactions. Despite the demonstration being promoted as an example of a clean energy fuel, the Suzuki Foundation argued that it was "environmental window dressing" (CBC News, 2010). Additionally, there were issues with the high cost of purchasing the bus fleet. The buses cost roughly $2.1 million each, and maintenance of the vehicles required $25 million in funds from the provincial government for the next four years after the demonstration. Though it was envisioned that green hydrogen derived from a bleach plant in Northern Vancouver would eventually fuel the busses (M. Klippenstein, personal communication, December 2023), a desire to fuel the busses with only renewable hydrogen forced BC to purchase the fuel from Quebec, incurring even higher cost to an already costly fuel (CBC News, 2010; CHFCA, 2021). Despite the high cost, interest in hydrogen buses continued in Europe, and later pilot projects allowed Ballard Power to continue supplying fuel cells to them. As the development of hydrogen fuel cells for buses advanced, so did the technology to support it. In this regard, according to the Canadian Hydrogen Association, the trial of the Whistler buses was the first step in proving hydrogen could fuel heavy vehicles in Canada (CHFCA, 2021).

In 2011, the BC provincial government established the Clean Energy Vehicle Program to create financial incentives for consumers to purchase light-duty ZEVS and assist with the development of supporting ZEV infrastructure while also educating customers on the benefits of ZEV adoption. These incentives included the purchase of light-duty fuel cell vehicles and hydrogen refueling infrastructure, though fuel cell light-duty vehicles were not market-ready during the duration of the program. The program intended that by 2020, 5% of all new light-duty vehicle purchases would be a zero-emitting vehicle. The program ended in 2014 with 14.3 million in total funding distributed, helped stimulate the beginning of the battery electric vehicle (BEV) market, and funded the development and support of five hydrogen fueling stations in the province (CHA, 2024a; Government of BC, 2015). In 2015, the Clean BC Go Electric Hydrogen Station and Fleet Program was launched to further support the development of hydrogen infrastructure in the province (CHA, 2024b; Ministry of Energy Mines and Low Carbon Innovation, 2024b).

Before the creation of the BC Hydrogen strategy, the BC government hired a clean energy private consulting company, “Zen and the Art of Clean Energy Solutions” in the late 2010s to create a consultation paper on the next steps to facilitate a hydrogen economy within the province. The purposes of this paper were to understand how hydrogen could be used to blend with natural gas, to be used in fuel cells, and to be used as a feedstock for certain industrial applications. The 2018 BC Climate Accountability Act introduced an emissions reduction target of 40% below 2007 levels by 2030, and 80% below 2007 levels by 2050 (Kanduth & Dion, 2020). The consultation paper deemed that hydrogen could make significant contributions to the 2050 timeline, in which hydrogen could contribute up to 31% of total emission reductions. They also estimated that 60% of hydrogen usage would be for use within the transportation sector of the province. To prepare the hydrogen industry within BC, the paper outlined that between 2020-2025, the government of BC would have to invest roughly $35.2 million every year, amounting to a total of $176 million. Thirty hydrogen refueling stations would also have to become available by the end of 2025 (Zen and the Art of Clean Energy Solutions, n.d.). Though the targets may have been ambitious, as there are only five stations today (HTEC, 2023d; U.S. Department of Energy, 2024a), the paper likely laid the foundational groundwork to help establish the eventual hydrogen strategy that would come out in 2021. As of now, 18 more hydrogen refueling stations are on the horizon being funded by HTEC (Ministry of Energy Mines and Low Carbon Innovation, 2024f).

The Formation of a pro-Hydrogen Coalition

After the release of the 2021 BC Hydrogen Strategy, the province began establishing how hydrogen would be regulated by government agencies. In 2022, the BC Hydrogen Office was formed to further aid in the establishment of an advanced hydrogen economy as a branch under the Ministry of Energy, Mines and Low Carbon Innovation. The Office was established as a pillar of the StrongerBC Economic plan, which much like the BC Hydrogen Strategy, seeks to support the climate goals outlined within the CleanBC Roadmap to 2030 (Office of the Premier, 2022; StrongerBC, 2022). The office serves as a liaison between the government and matters relating to clean energy projects occurring within the province. More specifically the Hydrogen Office serves as a regional hub for hydrogen development and helps coordinate regulatory, permitting, and environmental requirements (Ministry of Energy Mines and Low Carbon Innovation, 2023e, 2024e; Office of the Premier, 2022).

The Canadian Hydrogen Association (CHA) is a national non-profit organization that comprises industrial and academic leaders who are focused on advancing low-emitting hydrogens and fuel cell technologies (CHFCA, 2016e).[11] Their mission is to accelerate the adoption of hydrogen within Canada and abroad through networking, supporting regulation that supports the diffusion of hydrogen in a safe manner, and educating businesses and the general public on where and how hydrogen can be used to the benefit of society (CHFCA, 2016e). The CHA is actively involved with hydrogen development throughout British Columbia, Alberta, and Ontario, and has also partnered with other regional organizations such as the Atlantic Hydrogen Alliance (CHA, 2024g, 2024f). As of now, 51% of all business within Canada is situated within the province of BC (Anon, personal communication, November 2023; Government of BC, 2021; Natural Resources Canada, 2020). But the broader formation of hydrogen-oriented businesses into a singular coalition has also occurred under the umbrella of the Canadian Hydrogen Association's BC regional branch, also called Hydrogen BC, "HyBC", or "H2BC". This regional branch of the association was established with the support of the Government of BC (CHA, 2024e; Government of BC, 2021).

H2BC is comprised of hydrogen interest groups supporting both fossil hydrogen and renewable hydrogen. The executive members list of H2BC indicates which actors

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[11] Previously known as the Canadian Hydrogen and Fuel Cell Association, the organization rebranded itself as the CHA in April 2024 (Klippenstein, 2024).

are influential in hydrogen development within the province. Executive members include companies such as the formerly mentioned Ballard Power, as well as the public utility BC Hydro and their wholly owned R&D association, PowerTech Labs (CHA, 2024e; Government of BC, 2021). Other executive members include the public gas utility FortisBC Energy Inc., natural gas providers and oil refiners such as Imperial Oil, Irving Oil, Suncor, and Enbridge Inc., and Toyota Canada Inc., one of the leading car sales companies in Canada. The law firm Fasken, who have formed a hydrogen advisory team, are also executive members (CHA, 2024e, 2024c, 2024h). Aside from the executive members, there is also a broad range of industrial, small business, end-users, start-ups, consultants, and academic members.

Two key industrial members of H2BC are Hydrogen Technology & Energy Corporation (HTEC) and Fortescue. These companies are heavily involved in the development of the renewable hydrogen industry within the province. HTEC is a hydrogen infrastructure developer that is taking an all-hands-on-deck approach to transitioning the heavy-duty trucking industry to hydrogen fuel cells (Anon et al., personal communication, February 2024). They currently have the largest network of retail hydrogen fuel stations in Canada, though the majority of these are for small-duty vehicles. The establishment of these hydrogen stations was largely thanks to the company's partnership with PowerTech Labs, which will also help with developing a localized supply of hydrogen for heavy-duty vehicles (Anon, personal communication, February 2024; Anon et al., personal communication, February 2024; Powertech Labs, n.d.; PowerTech Labs, 2024). HTEC has also established the first and only (so far) renewable electrolyzer in the province (CHFCA, 2016c; HTEC, 2023d, 2023f).

Fortescue Future Industries, otherwise known as Fortescue, is an Australian-based company interested in electrolysis production within the province and is particularly interested in decarbonizing hard-to-abate sectors. Though they are interested in establishing large electrolysers and ammonia within the province, they also have small and modular-based hydrogen production solutions (CHA, 2024d; Fortescue, 2024b, 2024a). Small business members and start-up members of H2BC, such as Hydra Energy and Ekona Power have also been making an impact within the developing hydrogen economy. Hydra Energy is a dual-fuel engine retrofit manufacturer that has also taken an interest in outsourcing hydrogen production within the province (Government of BC, 2021; Hydra Energy, 2024a, 2024b). Ekona Power is largely involved in the manufacturing of pyrolysis-based hydrogen, and plans to have their first commercial deployment programs between 2025 and 2026 (Ekona Power, 2024; Government of BC, 2021).

The Hydrogen Strategy in Context

With members such as this influencing decision-making within the province, it is evident that there is a broad mix of hydrogen economic beneficiaries involved with the development of BCs upcoming hydrogen economy. This broad base of coalition support aligns with the goals outlined within the CleanBC Roadmap to 2030 which, though implicitly, indicates that the objective of the province is not necessarily to achieve 100% deep decarbonization of the electricity and transport sectors. Rather, the province has two goals. The first, to reach a state of net-zero emissions by 2050, and the other, to create jobs within a developing clean energy economy (CleanBC, 2021). This is an important distinction to make, as deep decarbonization implies a complete removal of fossil emissions in the province. Net-zero, on the other hand, implies the possibility of maintaining a level of carbon-intensive industry while also enabling net-zero technologies to capture or negate emissions. This goal is evident in the objectives of the BC Hydrogen Strategy, which seeks to facilitate clean energy growth in home heating, the heavy-duty transportation sector, and other heavy-industrial applications, through the use of low-carbon fossil and renewable hydrogen (Government of BC, 2021). This distinction is important when measuring feedback effects for the rest of this research, as policies that aim to facilitate hydrogen growth with the use of low-carbon fossil hydrogen are not necessarily policies that will undermine the hydrogen strategy. What they will indicate, however, is that low-carbon fossil hydrogen beneficiaries are getting a political advantage; even in the case of policies that support growth for both renewable and low-carbon fossil hydrogen. This is because, as previous research has suggested, fossil incumbents already have a political advantage above niche innovations in terms of not just their economic power, but also their power over existing social and technical norms (Bernstein & Hoffmann, 2018, 2019; Breetz et al., 2018; Grubert & Hastings-Simon, 2022; Rosenbloom & Meadowcroft, 2022). Even though renewable and low-fossil hydrogen are both niche technologies, fossil hydrogen already has a status-quo bias from incumbents (Grubert & Hastings-Simon, 2022; Howarth & Jacobson, 2021). Though the hydrogen strategy itself may be reinforced, this reinforcement of the strategy could also prove to undermine one form of hydrogen production over another as hydrogen makes its way down the technological experience curve; depending upon the actual strategies being put in place to reinforce the hydrogen strategy. This research will explore this topic further in the following chapters, starting with hydrogen production.

Chapter 4: Policy Feedback Effects in Hydrogen Production

With regards to hydrogen development in British Columbia, the Government of BC plans on increasing its production of hydrogen while making regulatory changes to its existing controls over the public utilities (BC Hydro and FortisBC) to better facilitate the position of hydrogen in the province. This chapter examines the self-reinforcing or self-undermining effects of current policy developments that aim to support hydrogen production and regulatory measures within the province. To understand these effects, this chapter uses the BC Hydrogen Strategy (2021) as a critical juncture point in policy development because it facilitates future policy decision-making for hydrogen production (Mahoney, 2000). Furthermore, this chapter aims to understand how these self-reinforcing or self-undermining feedback effects position the hydrogen strategy in British Columbia's broader objective to reach net-zero goals.

Beginning with an overview of the hydrogen strategy itself, this chapter will discuss hydrogen production in its current state. This chapter will then discuss the regulatory structures and policy developments that are assisting with economic growth in the emerging hydrogen production sector. This chapter will also discuss how the province might capitalize on its existing natural gas infrastructure which is owned by the gas utility to advance an economic transition away from fossil fuels. To conclude, this chapter will analyze the feedback effects of policy developments and discuss how current policy trends could have future implications in the broader objective of reaching net-zero goals in British Columbia.

Understanding the Objectives of the Hydrogen Strategy

Approximately 51% of businesses relating to hydrogen development are located in BC, with the majority being centered around green hydrogen development (Anon, personal communication, November 2023; Government of BC, 2021). As the province has gained traction with its hydrogen industry, the government has increasingly viewed hydrogen as a way to increase its supply of renewable electricity from 98% to 100% (CleanBC, 2021). BC plans to capitalize on hydrogen to decarbonize hard-to-abate sectors and develop zero-emissions transportation and heavy industrial sectors. The provincial government also plans to use hydrogen to develop lower-carbon natural gas, low-carbon or synthetic fuels, and power generation and storage. There is also potential to export hydrogen to countries such as Japan, South Korea, and China (CleanBC, 2021; Government of BC, 2021). The concept of using hydrogen for harder-to-abate sectors such as the transportation sector is a relatively new phenomenon, as it has historically been used for other industrial purposes such as oil refining and synthetic nitrogen fertilizers (Howarth & Jacobson, 2021; H. Xiao, personal communication, December 2023). Though its use as a clean fuel has been previously recognized, hydrogen was largely viewed as an alternative to an oil-based economy if an oil crisis were to occur (Deffeyes, 2005). In light of climate change post-Paris agreement, hydrogen has been viewed as a means to decarbonize a variety of sectors including home heating, transportation, and other industrial applications (Howarth & Jacobson, 2021; Natural Resources Canada, 2020).

In 2021 the government of BC released its Hydrogen Strategy, a staged, multi-year plan designed to support the development of an emerging hydrogen economy. The strategy sets out plans for the 2020 – 2025 period, 2025 – 2030 period, and the 2030 and beyond period. In the 2020 – 2025 period, the provincial government plans to provide incentives to industry for production, provide policy support to derisk capital investments into hydrogen infrastructure development, provide policy support to utilities who purchase hydrogen, advocate for the production and consumption of hydrogen, and work with industries to establish "hydrogen hubs", a new approach to hydrogen development.

Additionally, the provincial government plans to regulate hydrogen production by establishing a regulatory framework for hydrogen under the BC Oil and Gas Commission (now the BC Energy Regulator); amend the Water Sustainability Act to allow hydrogen production for the use of industrial purposes; allow for hydrogen to be used by natural gas utilities to reduce emissions; ensure hydrogen production aligns with continued reductions in carbon intensity; establish carbon-intensity targets for hydrogen production, provide support only for renewable and low-carbon hydrogen pathways; and establish a hydrogen working group made up of representatives from the hydrogen industry.

Between the 2025 – 2030 period, the province plans to potentially introduce new electricity rates, promote hydrogen production at scale for domestic and international demand, and consider the potential for brownfield sites that can be used for hydrogen production. BC also plans to continue supporting the provincial Low Carbon Fuel Standard to advance hydrogen production and other supporting infrastructures, review sectoral opportunities for contractual hydrogen offtake agreements, and encourage at-scale production of low-carbon hydrogen.

From 2030 and beyond, the province plans to support long-term self-sufficiency measures for hydrogen production and continue to support hydrogen infrastructure (Government of BC, 2021, p. 16). Additionally, the province plans to have a clear regulatory environment for hydrogen production, require reductions in the carbon intensity of hydrogen produced in BC, and explore long-term energy storage policy mechanisms for hydrogen use (Government of BC, 2021, p. 18). As we are currently in the 2020 – 2025 period, this analysis will focus on this period when analyzing self-reinforcing and self-undermining feedback effects. However, there will still be an opportunity to review potential outcomes for other policy periods based on current trends.

The Current Status of Hydrogen Production

From an economic perspective, the hydrogen industry currently suffers from what has been repeatedly called a "chicken and egg problem", in which a lack of hydrogen supply and demand is stifling the economic growth of the sector (J. Adams, personal communication, November 2023; Anon, personal communication, November 2023). Currently, there are plans to develop renewable hydrogen stations in Vancouver and its surrounding areas, and the Prince George area. These areas are what the government of BC and the federal government define as hydrogen hubs, which are networked areas of hydrogen producers and consumers that have connective infrastructure within a localized area. This allows for the creation of both the supply and demand within a concentrated area to be used for highly focused applications, such as the refueling infrastructure for class 8 trucks (Government of BC, 2021; Natural

Resources Canada, 2024; U.S. Department of Energy, 2024b). Hydrogen, much like the distribution of natural gas (with a few caveats), can be transported via tractor-trailer or pipeline and delivered to an industrial facility, home, or refueling station. Because of the lack of hydrogen pipeline infrastructure in BC, hydrogen transmission via pipeline is not in use. Rather, gaseous hydrogen is delivered via truck much like diesel fuel is delivered today. Because of the localized access of hydrogen within hydrogen hubs, easier transportation of hydrogen is available within the early developmental stages (Anon, personal communication, February 2024; Anon et al., personal communication, February 2024; Government of BC, 2021; M. Klippenstein, personal communication, December 2023).

Plans to develop around the Prince George Area, currently being called the "central BC hydrogen hub", are currently underway in the hopes of empowering the forestry sector of BC, which has been struggling in recent years, by taking advantage of an existing chemical bleach plant to produce renewable hydrogen. Industry experts argue that connection with the forestry sector would allow hydrogen production to "expand and play offense on the economic "balance table" and use that as a rural economic development angle" (M. Klippenstein, personal communication, December 2023). Development in this region could also prove beneficial for the expansion of supportive infrastructure for the transportation sector, as the transport industry considers Prince George a hub of the province (Hydra Energy, 2022; Petersen, 2023). So far, industry plans in Prince George include capturing hydrogen produced by the Chemtrade bleach chemical plant in the region, which will be spearheaded by Hydra Energy (Hydra Energy, 2021, 2022; M. Klippenstein, personal communication, December 2023; C.

Paterson, personal communication, December 2023). Chemtrade will also be partnering with Teralta, a company that specializes in delivering hydrogen, to bring hydrogen to the local pulp and paper mill, Canfor, to reduce its natural gas consumption by up to 25% (Kurjata, 2024; Teralta, 2024).

Additionally, Mitsubishi is working with the McLeod Lake Indian Band to develop either a green hydrogen or a blue hydrogen project that is budgeted to cost more than $5 billion to build on the Kerry Lake East Indian Reserve (Williams, 2023). Another company taking interest in the region is the Australian-based mining company named Fortescue, which seeks to produce annually 140,000 tons of hydrogen and 700,000 tons of ammonia capacity in Prince George. Working closely with HTEC, this will be a $2 billion green hydrogen and ammonia 1000MW facility which is proposed to support export opportunities and local hydrogen needs. To put the electricity demand of this facility into perspective, this would be relatively close to the amount of megawatt capacity produced by the Site C dam once it is ready to produce power, which will have 1,100MW of generating power. With these projects in mind, the BC government anticipates that Prince George could serve as a central hydrogen hub for the rest of BC as these projects continue to develop (BC Hydro, 2023; Clarke, 2024; HTEC, 2023i; Petersen, 2023).

The most developed hydrogen hub within BC is located in Vancouver and the surrounding areas of the city (CHFCA, 2016b), such as Burnaby and Kelowna (HTEC, 2023f, 2023g). Currently, five hydrogen refueling stations in the province are centered around this area, all of which are meant for smaller vehicles and are owned by HTEC (Alternative Fuels Data Center: Hydrogen Fueling Station Locations, n.d.; HTEC, n.d.-

b). At the moment, there are no hydrogen refueling stations for class 8 vehicles (HTEC, 2023d; HTEC & Zen and the Art of Clean Energy Solutions, 2022). However, there are plans to set up the first class 8 hydrogen refueling station on Tsawwassen First Nation land. This is being set up near the port of Vancouver, and will simultaneously support the development of the BC export market and hydrogen Heavy Duty Vehicle (HDV) sector (HTEC, 2023e). HTEC is also setting up an electrolysis station in North Vancouver, with a hydrogen capacity of 5,475 (CHFCA, 2016c). HTEC is very active in BC hydrogen hub development and plans to solve the so-called "chicken and egg problem" by doing everything themselves (Anon et al., personal communication, February 2024). By being actively involved with technological transition plans, manufacturing the infrastructure within these hydrogen hubs, and leasing out the trucks to trucking companies, HTEC seeks to simultaneously install the refueling stations for hydrogen-based HDVs while also establishing a market for hydrogen (Anon, personal communication, February 2024; Anon et al., personal communication, February 2024; HTEC, 2023a).

Based on the current types of hydrogen production in the province, it is safe to claim that so far, electrolysis has been outmaneuvering low-carbon fossil hydrogen industries because of the complete lack of low-carbon fossil hydrogen infrastructure developments. This could be, in part, due to geographic reasons. According to the BC Hydrogen Office, the geographic locations of supply and demand, and the difficulties of transporting hydrogen, have been contributing factors to the development of electrolysis stations; despite the cheaper cost associated with hydrogen derived from natural gas. In the Northeast of the province lies great geological storage available for technologies like

SMR+CCS. However, most of the energy demand is located south of the province, and as the only means of transporting hydrogen (so far) has been via truck, the distance between SMR+CCS supply and demand makes electrolysis a more viable option (Anon, personal communication, November 2023; Anon et al., personal communication, February 2024; BCER, 2024b). We can also attest that hydrogen production is at the early stages of development along the technology experience curve, in large part because hydrogen hubs are still being developed, which aim to target niche markets (Government of BC, 2021). In this regard, policies are currently supporting renewable hydrogen by providing financial assistance within a niche market and creating better access to the market for hydrogen to diffuse into, as expected in the literature (Breetz et al., 2018). But, as we shall see, early developments that support electrolysis do not necessitate that the BC hydrogen economy will be fully renewable based.

Hydrogen Production Regulatory Structures

Hydrogen production is currently regulated by the BC Energy Regulator (BCER), formerly known as the BC Oil and Gas Commission before 2023 (Ministry of Energy Mines and Low Carbon Innovation, 2023a). The BCER is a regulatory agency designated to regulate the energy activities in BC. The agency aims to protect public safety and the environment while fostering the BC economy and conserving energy resources within the province (BCER, 2024a). In 2022, The BC Oil and Gas Commission was changed to the BCER under the passing of the 2022 Provincial Energy Statues Amendment Act, which established the BCER’s ability to “regulate the manufacturing of hydrogen, ammonia, methanol as well as carbon dioxide (CO_2)

transportation", as well as projects relating to these types of fuels (M. Dawson et al., 2023). In 2023, expanded powers on carbon storage reservoirs were added to the existing mandates on oil, gas, and geothermal activities (BCER, 2024c). Any hydrogen-related inquiries for industries that are interested in establishing themselves within BC can contact the BC Hydrogen Office, which can then direct them to the BCER. It is through the BCER that inquiring industries can be guided through the permitting process (Anon, personal communication, November 2023). Though future water management regulations under the Water Sustainability Act would be developed by the BCER to allow hydrogen not to be produced from water for industrial purposes; official changes have not been made at this time of writing (Ministry of Environment and Climate Change, 2020). However, consultations have been made to provide anticipated amendments that will allow hydrogen production via electrolysis to be permitted through the Water Sustainability Act (M. Dawson et al., 2023).

Where the BCER regulates the permitting processes of energy and oil production, the distribution and purchasing power of energy is regulated under the British Columbia Utilities Commission (BCUC). Their purpose is to ensure that ratepayers pay reasonable rates and have reliable energy service in the non-competitive energy market that resides within the province. They are also responsible for approving utility capital spending projects and energy supply contracts (BCUC, 2024c; Government of BC, 1996). In 2011, the BC Clean and Renewable Resource Regulation was amended to allow for hydrogen produced as "waste" to be considered a "clean and renewable resource" under the Clean Energy Act (BCUC, 2024b). Though perhaps unclear at the time, this early permittance of waste hydrogen to be considered renewable served as a basis for future policy decisions around hydrogen development. In 2012, under the Clean Energy Act, the Greenhouse Gas Reduction Regulation (GGRR) was introduced as a means to permit utilities (though more specifically FortisBC) to offer incentives for natural gas vehicle purchases and support natural gas infrastructure that could be used to support medium and heavy-duty vehicles (Theclimategroup, n.d.). In 2021 the GGRR was amended to allow public utilities to follow "prescribed undertakings" to reduce greenhouse gas emissions within the Clean Energy Act. "Prescribed undertakings" within the context of hydrogen permit public utilities that produce or purchase hydrogen to distribute either renewable or low-carbon fossil hydrogen to customers to reduce greenhouse gas emissions. This can be done either by providing hydrogen directly to a customer or by using hydrogen to displace carbon-intensive fuels, such as natural gas. Hydrogen that has been permitted to be used under the GGRR includes renewable hydrogen and "waste hydrogen" that is purchased by the public utility (King's Printer, 2024b; Province of British Columbia, 2021).

Though the GGRR laid the foundational allowances for utilities to begin using hydrogen to decarbonize, the actual regulatory mechanisms that fully permitted the purchasing and distribution powers of hydrogen were not yet complete. The BCUC is largely governed by the Utilities Commission Act (UCA)(BCUC, 2024a). In 2022 the BCUC established an inquiry into to better understand whether the provision of hydrogen energy services should fall under the definition of a public utility under the UCA and determined the scope in which hydrogen should be regulated by the BCUC. The report was completed in November 2023, which called for a few areas of hydrogen regulation that should be exempted from regulation under the BCUC. These areas included "providing hydrogen as a transportation fuel; production of hydrogen as a fuel for the production of electricity or as a fuel for transportation or heating; and providing hydrogen delivery by truck." (BCUC, 2023a). According to the report, these exemptions were recommended because the hydrogen market is currently under development within a competitive environment, and interference might hinder market development. However, they still noted that the BCUC should actively monitor the development of hydrogen within BC to ensure recommended exemptions are still appropriate as the market develops (BCUC, 2023b). In 2024, under permissions granted by the UCA, the BCUC exempted hydrogen production facilities that produce hydrogen as electricity, fuel for transportation or heating, or the public or a corporation for compensation, from part 3 of the UCA (which is the regulation of public utilities). But a bit of exemptions also applied to these exemptions. To maintain some level of control over the regulation of hydrogen within the UCA, the BCUC still maintained that they were to supervise hydrogen use by public utilities (section 23). They also maintained the ability to order improved services of hydrogen (section 25) and to enforce utilities to provide the services they offered (section 38). Furthermore, utilities still have to obey the BCUC when it comes to the use of hydrogen (section 42) and provide information to the BCUC when required (section 43) (BCUC, 2024b; King's Printer, 2024a).

Through regulatory allowances under the UCA and GGRR, we can see early examples of hydrogen being provided easier access to the markets during its early stages of development (Breetz et al., 2018). We also see examples of political signaling to hydrogen-based industries through both the implementation of the hydrogen strategy itself and the amendments to the UCA and GGRR; in which permissions for public utilities to use hydrogen for decarbonization purposes have increased (Meckling & Nahm, 2022). This, in turn, signals to industry players that a market is opening for hydrogen not just through political promises, but through policy action. But because BC has both a renewable energy utility and a natural gas utility, policy amendments within the UCA and GGRR stretch out to both the hydroelectric and natural gas utilities. One does not get an economic advantage over the other officially, but pre-existing pipeline infrastructure rests with the gas utility. In a sense, this could be seen as the BC government attempting to begin the phase-out of fossil fuels with hydrogen production in a managed way, utilizing the pre-existing infrastructure of the province to its advantage (Rosenbloom & Meadowcroft, 2022; Rosenbloom & Rinscheid, 2020). But in another sense, though this allows for transformative policy solutions that immediately aid the development of hydrogen within an opening market, it also allows for hydrogen to be used for natural gas blending purposes. This makes these policy solutions non-transformative to the status-quo bias of incumbents; who can still use natural gas to supply hydrogen to the province, as we will see in a later section of this chapter (Lamb et al., 2020; Meckling & Nahm, 2022). This would not be a technical problem if low-carbon fossil hydrogen solutions were fully reliable, tested, and the only thing the provincial government should consider. But incumbent political power within our socioeconomic systems also matters. As the example Germany provides in the literature review chapter, shifts in government can change the priorities of one energy source over another through the use of discourse carbon lock-in mechanisms (Bernstein & Hoffmann, 2019; Buschmann & Oels, 2019).

Supporting Institutions and Policies

But these are not the only policy developments that are supporting the growth of a hydrogen economy. For instance, the province has established the BC Centre for Innovation and Clean Energy (CICE), an independent non-profit organization centered around the build-up of commercializing and accelerating clean energy technology adoption. These technologies include carbon capture utilization and storage (CCUS), low-carbon hydrogen, biofuel and synthetic fuel, renewable natural gas, and battery technology (CleanBC, 2021). More specifically, the CICE supports technologies that are at a technology readiness level between 4 and 9, to simultaneously decarbonize the province while also creating new market opportunities (CICE, 2024b). Technology readiness levels at 1, for instance, would be basic foundational discoveries on how a technology could perform in the real world. A technology readiness level of 9, on the other hand, would represent a technology that is proven through actual deployment and on the verge of being ready within existing markets (Government of Canada, 2021). A hydrogen electrolyzer, for example, would be at a technology readiness scale of 8, as it is not currently vastly available in the BC market but it has been proven to work (Anon, personal communication, November 2023; Government of Canada, 2021). Funding for low-carbon hydrogen includes low-carbon fossil and renewable hydrogen production pathways, hydrogen infrastructure development, fuel cell development, solutions for decarbonizing hard-to-abate sectors, and more. For the low-carbon hydrogen fund, the CICE at this time of writing has received $40.5M and has invested $4.9M (CICE, 2024a).

In 2023, the CICE collaborated with Deloitte, (S&T)2 Consultants, and the B.C. Ministry of Energy, Mines and Low Carbon Innovation to create and release the "Carbon Intensity of Hydrogen Production Methods" report. The report found that processes of steam methane reforming for hydrogen production were typically much more carbon-intensive in their upstream and downstream emissions, though in all aspects of methane reforming transportation of hydrogen via truck was much more carbon-intensive. Methane pyrolysis and renewable electrolysis were seen as good alternatives for carbon intensity within the province, though some processes of methane reforming if delivered via pipeline could still be less carbon intensive than pyrolysis applications. The results of this report showed that hydrogen production today would emit a carbon intensity (CI) (from production to end use) ranging from 11.9 to 40.1 gCO2e/MJ. By 2030, it is estimated that the CI of hydrogen production could be reduced from its highest point of 40.1 gCO2e/MJ to 39.1 gCO2e/MJ (CICE et al., 2023). Though this does not align with the carbon threshold outlined within the BC Hydrogen strategy, which is set at 36.4 gCO2e/MJ (Government of BC, 2021), by 2050 it is suggested that with advancements in technology for hydrogen production, and with advancements in other policy outcomes that reduce the carbon footprint of downstream emissions, the carbon intensity of hydrogen could be significantly reduced to 12.2 gCO2e/MJ for methane reforming, 8.2 gCO2e/MJ for pyrolysis production, and 11.9 gCO_2e/MJ for electrolysis (CICE et al., 2023).

The public utility in the province, BC Hydro, has also been active in supporting green hydrogen development in the province. For instance, in 2021, BC Hydro introduced the Clean Industry and Innovation Rate as a discounted rate for new industrial customers to get industries connected to their energy grid. This also was established to encourage electrolysis hydrogen producers to connect to the grid of BC Hydro for a lower cost. For the first five years, industrial customers would receive a 20% discount rate. Afterwards, they would receive a 13% discount rate in their 6th year, and a 7% discount rate in their 7th year. This rate also applies to industry that seeks to remove GHG emissions from the atmosphere. However, because it has been fully subscribed, the government is no longer encouraging hydrogen producers to apply to the application for this rate (Anon, personal communication, November 2023; BC Hydro, 2024; Government of BC, 2021). BC Hydro is also hoping to attract more hydrogen producers (specifically green hydrogen producers) and carbon capture industries, along with synthetic fuel production and data centers, by providing incentives and connecting new customers within appropriate timelines. The utility is offering a total of $60 million for industries that choose to fuel switch to electricity or green hydrogen, $25 million incentive and funding money for new customers, and $20 million to incentivize and support hydrogen production (BC Hydro, 2021b). The BC government plans to enhance this plan by introducing an internal carbon price which will enable investments into "green hydrogen production and commercial vehicle incentives and infrastructure" (CleanBC, 2021, p. 30).

The federal government has also released financial support structures to encourage the growth of low-carbon hydrogen production projects in Canada. In 2022, the federal government announced the Clean Hydrogen Investment Tax Credit, a hydrogen production-based tax credit that refunds investments based on the life cycle emissions of the intensity of hydrogen being produced. The credit was enacted in March of 2023 and is expected to provide $17.7 billion in tax incentive support by the phase-out date of the program in 2035. Project costs are covered by either 15% or 40%, depending upon the life cycle emissions of the hydrogen that is produced (Canada Revenue Agency, 2024b; Natural Resources Canada, 2024). Other levels of funding support for hydrogen include the Clean Technology Manufacturing Investment Tax Credit, the Investment Tax Credit for CCUS, and the Clean Electricity Investment Tax Credit. The Clean Technology Manufacturing tax credit, available as of January 2024, offers up to 30% credit for the manufacturing of electrolysers (Canada Revenue Agency, 2024c; Natural Resources Canada, 2024). The CCUS tax credit, available as of January 2022, offers a 37.5% to 60% tax credit for necessary equipment to support CCS or CCUS (Canada Revenue Agency, 2024a; Natural Resources Canada, 2024). Lastly, though not directly supporting hydrogen development, the Clean Electricity tax credit, which has been available since March of 2023, offers tax credits of up to 30% of the cost of renewable electricity systems, which can then be used to support renewable hydrogen production (Natural Resources Canada, 2024).

Once again, we see from other policy developments, both provincial and federal, that hydrogen production is receiving the necessary early financial support that is required for early niche technology developments. We also see the renewable utility of the province, BC Hydro, attempting to attract renewable hydrogen developers to the province, facilitating a broader coalition of business interests that supports renewable hydrogen (Breetz et al., 2018). However, in the case of provincial and federal financial support structures, there is the inclusion of policy that supports both renewable and fossil-dependent developments. While this could be seen as an example of cross-jurisdictional cooperation (Levin et al., 2012), it could also be viewed as a means of supporting both incumbent and niche political power positions. Despite the establishment of growing coalition support through incentive structures offered by BC Hydro, this is still not the development of a coalition that aims to destabilize the existing regime. All the while, these financial support structures do not facilitate a future in which financial resources for incumbents are limited to erode their political legitimacy (Rosenbloom & Meadowcroft, 2022; Rosenbloom & Rinscheid, 2020). Rather, as has been established in feedback literature focused on the development of new technologies, coalitions that are competing against incumbent counter-coalitions are often fighting an uphill battle (Roberts et al., 2018). Therefore, despite there being a growing coalition of both renewable and fossil-based hydrogen industries, the broader levels of support structures for both types of hydrogen production may be providing more opportunities for backsliding into carbon lock-in mechanisms (Bernstein & Hoffmann, 2019). This may especially be true if recommendations from the carbon intensity report provided by the CICE are fully adopted, as the results favour pyrolysis for long-term targets; further cementing the legitimacy of continued fossil fuel infrastructure and therefore fossil dependent political power.

Future Implications for the Gas Utility

Yet how the natural gas utility aims to take advantage of current policy trends also matters. FortisBC has been actively preparing to transition to renewable natural gas (RNG) for roughly 15 years, to decarbonize from the conventional natural gas they currently supply within the grid (Anon, personal communication, February 2024).

Through permissions granted by the BCUC, FortisBC customers will soon automatically have a portion of their gas come from RNGs, starting in July of 2024 (FortisBC, 2024d). Depending upon the blend density of RNGs, homeowners can expect marginal cost increases. For example, a 5% RNG blend with natural gas would increase the monthly average energy cost by $2.34, while a 100% RNG blend would cost customers an extra $46.89 a month (FortisBC, 2024b). Similar to how FortisBC is using RNGs, the utility plans to do the same with hydrogen in the future, in that hydrogen becomes a blend with natural gas and diffused into a mass market for home heating (Anon, personal communication, February 2024; Government of BC, 2021).

FortisBC has been interested in using hydrogen since 2017, or at least since the Canadian federal government released its hydrogen strategy in 2020, (Anon, personal communication, February 2024), and has invested $500,000 into research at the University of British Columbia Okanagan Campus to study how to blend hydrogen into their natural gas grid (FortisBC, 2020). In this way, incorporating hydrogen into the natural gas grid can be seen as a transition fuel to aid in bringing down the cost of hydrogen by displacing said cost among a vast consumer base through home and industrial heating. According to FortisBC, much like RNGs, hydrogen can be profitable only as a mass-market consumer fuel. Therefore, rolling out hydrogen would work very similarly to RNG, in that it is blended with natural gas and delivered to customers in a manner where the customer does not "see" any of the hydrogen. Costs are then spread out amongst a large consumer base, which allows for the utility to cover the higher cost of renewable and low-carbon fossil hydrogen. To the customer, there is no noticeable change to their use of natural gas aside from a slight cost increase because it is blended into what they are using for their electricity regardless, allowing for the use of hydrogen to scale over time. In this way, hydrogen can be integrated into the grid, customers reduce their emissions, and depending upon the source of hydrogen production, upstream emissions can be “reduced later” as it is regulated and decarbonized (Anon, personal communication, February 2024; FortisBC, 2024c). Therefore, despite hydrogen via electrolysis having a clear advantage for the current market in BC, the ability of the gas utility to prop up low-carbon fossil hydrogen for the use of heating purposes will allow for alternative forms of hydrogen to enter the market in the future. This will be further exemplified in later chapters that discuss the use of hydrogen within the transportation sector and industrial sectors.

Though FortisBC has yet to create larger market access for hydrogen development, early stages of planning indicate that generating marketable access to hydrogen will bring down the cost. This is another way we can identify that hydrogen is in its early stages of development, in that the utility is trying to create more market access through the use of the existing natural gas grid (Anon, personal communication, February 2024; Breetz et al., 2018). It could also be seen as a way to align the interest of incumbents during the early stages of development by political signaling that there will be a change to the current structure of natural gas distribution (Meckling & Nahm, 2022). If hydrogen does become marketed in the same way as RNG, this also follows a managed transition; in which phase-out happens incrementally to not jeopardize economic integrity (Grubert & Hastings-Simon, 2022; Rosenbloom & Rinscheid, 2020). But these policy developments, if they do come into effect, do not necessitate a full divestment of financial resources that support incumbent industries; which is necessary not just for shifts in technological use, but shifts in political legitimacy and social norms (Rosenbloom & Rinscheid, 2020). As FortisBC is agnostic on the hydrogen that runs through its pipeline infrastructure, any allowances for low-carbon hydrogen are an allowance for fossil industries to continue because low-carbon fossil hydrogen is not simply a use of natural gas to manufacture hydrogen. In the case of SMR+CCS, it is still a by-product of continued natural gas production. This allows the industrial status quo to be maintained, while the continued supply of natural gas allows for social norms to perpetuate themselves in industries such as the transportation sector (Seto et al., 2016); which we will see in the following chapter.

The Hydrogen Strategy and Feedback Effects of Hydrogen Production

Based upon the current state of hydrogen infrastructure development in BC, hydrogen development via electrolysis and low-carbon alternatives is at the early stages of development on the technological experience curve, beyond just the technology readiness scale. This is because, though the process of electrolysis can be traced back to the early 1800s (Britannica, 2024), the supporting infrastructure for both technologies is still in development. Hydrogen is receiving financial support from BC Hydro, the BC government through the Canadian Hydrogen Association, program funding through the CICE, and federal funding for infrastructure development via Natural Resources Canada (BC Hydro, 2021b; CHFCA, 2016a; CICE, 2024a; CleanBC Go Electric, 2024c; Ministry of Energy Mines and Low Carbon Innovation, 2024i; Natural Resources Canada, 2019). We also see limited consumer adoption of hydrogen at this stage, with hydrogen being attuned to specific and niche markets within hydrogen hubs

(Government of BC, 2021). Policies have been created to allow utilities a path forward to bring down hydrogen costs, either through the slow advancement of developing hydrogen hubs or branching off from these hubs to bring hydrogen into a broader market via home and industrial heating (Anon, personal communication, February 2024; Anon et al., personal communication, February 2024). We also see from the previous chapter the early stages of coalition support through the Canadian Hydrogen Association, which is bridging renewable and fossil fuel members across the energy sector (CHA, 2024e). This presents a layering of institutions that support the development of hydrogen within the current energy ecosystem (Breetz et al., 2018).

The CleanBC roadmap to 2030 sets out the goal to achieve net-zero targets, which the roadmap defines as any amount of GHG emissions that are released into the atmosphere are equivalently removed from the atmosphere. This would result in roughly 35 to 40 Megatons of CO2 equivalent per year, or 40% reductions in emissions compared to 2007 levels. By 2050, BC plans to reach 80% emission reductions (CleanBC, 2021; Ministry of Environment and Climate Change, 2023b). A central pillar of the CleanBC roadmap is using hydroelectric power as a replacement for fossil fuels, and increasing the electricity needs of the province from 98% renewable energy to 100% renewable energy (CleanBC, 2021). To re-emphasize from the previous chapter, BC is not a province seeking to eliminate carbon emissions. Rather, BC has formulated policies to eventually reach a net-zero goal across multiple economic sectors. Therefore, this is not a province seeking to decarbonize in a traditional sense, in which a complete phase-out of fossil fuels necessarily occurs. Through this lens, low-carbon fossil hydrogen still aligns within the confines of the greater CleanBC strategy. Also to reiterate from the previous chapter, this means that support for low-carbon fossil hydrogen is not necessarily a self-undermining feedback response for the strategy. Rather, it is self-reinforcing but implies that the same level of support for both renewable and fossil hydrogen gives fossil hydrogen a political edge thanks to existing status-quo biases (Grubert & Hastings-Simon, 2022; Levin et al., 2012; Seto et al., 2016).

With the introduction of the Greenhouse Gas Reduction Regulation in 2012, the BC government created a policy that would later be used to assist with hydrogen policy objectives laid out in the BC Hydrogen Strategy. Later amendments to both the GGRR and Utilities Commission Act have further cemented the abilities of BC Hydro and FortisBC to use hydrogen to decarbonize industries. Additional monetary incentives provided by the provincial and federal governments have generated "spoils" for beneficiaries to mobilize around; which can then be used thanks to previous policy amendments signaling that these spoils should be taken advantage of (Pierson, 1993). For policy sequences that directly reinforce the intentions of the BC Hydrogen Strategy, this mixture of policy design also supports the 2020 – 2025 period of hydrogen production and regulation. Self-reinforcing feedback should see shifts in politics and policy outcomes, which then reinforce the initial policy decision (Pierson, 1993; Roberts et al., 2018). With the creation of the CICE and additional support coming from the federal government and BC Hydro, hydrogen hubs are being established within the province, and incentives are being provided to industry that seeks to produce hydrogen. This also serves to derisk capital investments into hydrogen infrastructure and development. All of these events represent reinforcing sequences that encourage both program wide adhesion mechanisms and instrument adhesion mechanisms (Jordan & Matt, 2014), that serve to encourage the existing regime to invest in programs and technology; while also supporting sunk investments into hydrogen production capabilities.

These sequential events in policy decision-making also serve to reinforce the regulatory objectives outlined within the hydrogen strategy. A regulatory framework has been established under the BCER to better manage the locations of hydrogen, ammonia, and geothermal carbon capture and storage projects, which is further managed by the BC Hydrogen Office. Though the Water Sustainability Act has not been completely amended to allow for water offtake for hydrogen production, it does appear that inquiries are being made into understanding how this regulation should be managed. Even though changes have not officially happened to the act yet, this could be a matter of time within the next year. Additionally, natural gas use for utilities has been permitted through amendments via the GGRR and the UCA. Carbon intensity targets have also been established by the CICE, indicating that carbon emission reductions that follow the carbon threshold laid out within the Hydrogen Strategy are likely still distant from 2030 targets; though there is a possibility for the carbon intensity threshold to be met if the provinces go the route of full electrolysis production. The CICE report also indicated that hydrogen production via all routes aligns with continued reductions in carbon intensity, so long as other downstream emissions also improve. Renewable and low-carbon fossil hydrogen have also been the only forms of hydrogen production that have been supported through all incentive and policy advancements; indicating that the BC government is not choosing to support fossil hydrogen without some form of carbon capture. Though there was the establishment of the BC Hydrogen Office in 2022, it is difficult to ascertain whether this is a working group of hydrogen-based representatives from the industry, as was defined within the Hydrogen strategy. However, the availability of the Canadian Hydrogen Association branch within BC certainly fills this role.

Given that most of the objectives outlined within the strategy are being met, the BC Hydrogen strategy is showing that it is being reinforced through additional policy creation. Amendments made within the GGRR and the UCA are likely difficult to reverse, entrenching the decision-making capabilities of using hydrogen for utilities within the province; indicating a clear use of program wide adhesion mechanisms to solidify a future that uses hydrogen in some form or another (Jordan & Matt, 2014). Roberts et al. (2018) indicate that policies that are designed to facilitate technological change do tend to be successful in establishing reinforcing sequences, so long as high costs do not become an issue. So far this does appear to be the case, but there is an exception with the carbon-intensive targets that were indicated by the CICE. Allowing utilities to use hydrogen from sources other than electrolysis may cause BC to miss their carbon intensity threshold targets for 2030; as only electrolysis can meet this threshold. Though the market has been opened for hydrogen production and is actively being clustered with hydrogen hubs that are planning on using hydrogen produced from electrolysis, this does not mean that the energy demand required for these stations could not be used to undermine developments on the electrolysis front. The market can still shift to support low-carbon fossil hydrogen, and given the right political actor to take a position of power in future provincial elections, they could certainly over-emphasize the downsides of electrolysis to better establish low-carbon fossil hydrogen in the province (Buschmann & Oels, 2019; Lamb et al., 2020). For instance, Millar et al (2021) found that a cap-and-trade policy in the province of Ontario largely failed due to issue framing that over-emphasized the downsides of the cost associated with the trading scheme from up-and-coming PC politicians, who indicated that the program created high electricity prices. This was despite the provincial Liberal government showing clear evidence that the cap-and-trade system would be beneficial for the environment; indicating the power of political strategies that frame loss or emphasize the economic downsides of climate policy (Lamb et al., 2020; Millar et al., 2021). If hydrogen production via electrolysis was framed in the same way, then it would oddly not be an undermining effect to the BC hydrogen strategy in the sense that the hydrogen strategy is rather open to low-carbon hydrogen production. This presents a problem with the strategy itself, in that it opens itself up to undermine its own hydrogen carbon intensity targets.

This inherently opens the production of hydrogen to fall into the *double trap* that Bernstein and Hoffmann (2019) define in their article on the fractal carbon trap, in which the province can fall short of functional decarbonization and instead improve only some aspects of its carbon-intensive energy infrastructure (Bernstein & Hoffmann, 2019). Certainly, the provincial government has to be wary when working within its broad base of coalition support in the future; as it is very much the intention of fossil incumbents to protect their assets (Grubert & Hastings-Simon, 2022; Stokes, 2020). It is difficult to judge self-reinforcing or self-undermining sequences in the future phases of development within the hydrogen strategy. However given that the strategy outlines that between the 2025 – 2030 period, the province will simply encourage the at-scale production of low-carbon hydrogen (Government of BC, 2021), the strategy shows a lack of forward reasoning that is important for policy developments that aim to support decarbonization efforts (Levin et al., 2012). In turn, these allowances within the hydrogen strategy could create self-undermining effects in other sectors, such as the heavy-duty trucking sector and heavy industrial sectors, which require deep decarbonization to meet late hydrogen carbon intensity threshold targets.

Chapter 5: Policy Feedback Effects of Hydrogen in Long Haul Transportation

Just as the diffusion of the automobile was increased out of a necessity to remove horse manure from the urban landscape (Carlisle, 2016),[12] petrol aims to be replaced out of a necessity to clean our environment; of course, let us ignore the irony that manure from livestock can be used as an RNG to replace natural gas (U.S. Department of Energy, n.d.). But as we try and move away from diesel in hard-to-abate sectors like the trucking industry, the reality is we are trying to move away from a status quo that is intrinsically interconnected with our surrounding socio-technical and economic systems (Bernstein & Hoffmann, 2019). We are faced with the difficulties of needing to decarbonize a sector quickly, but carefully, to prevent economic loss that could critically undermine future economic decisions (Grubert & Hastings-Simon, 2022). Because of status quo biases that rest within all layers of our socio-technical structures (Bernstein & Hoffmann, 2019), it can be assumed that heavy-duty vehicle (HDV) industry players will likely favour what they already know if given the choice unless there are proper incentives and learning mechanisms to push the industry in the right direction. In this manner, policy should be designed with a forward-reasoning lens that anticipates the difficulties that decarbonization policies face by being undermined by incumbent

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[12] The need to remove manure lined up with a desire to begin improving health and hygiene. Though additionally, the automobile allowed for an increase in population mobility with the expansion of cities. Further niche applications that supported the diffusion of the automobile include taxis, the attraction of races, visiting parks to show off wealth, and touring the country-side (Geels, 2005).

industry players that support the continued use of diesel fuel (Bernstein & Hoffmann, 2019; Grubert & Hastings-Simon, 2022; Levin et al., 2012; M. Paterson et al., 2022).

"Trucking" is the largest method of transporting goods in Canada, with 12.9% of trucking companies calling BC their home (Transport Canada, 2019). Typically, trucking operations can be separated between a "shipper" and a "carrier". The shipper typically does not own any vehicles to move their goods and is largely in charge of packaging, labeling, and monitoring the progress of delivery. Shippers tend to hire carriers, who own vehicles, to transport their goods from point A to point B. Private carriers, who typically do not hire other carriers to move their goods, are also present within the industry and are typically comprised of larger retail giants (Texas International Freight, 2024; Transport Canada, 2019; XPDEL, 2023). Commercial vehicles come in a variety of different sizes and can range from class 2B, which is your utility vans and larger pick-up trucks, all the way to class 8, which comprises all of your extremely heavy-duty vehicles such as semi-trucks or cement trucks (Transport Canada, 2023).

In BC, the transportation sector accounted for the single largest source of emissions generated by the province in 2021, accounting for 41% of total emissions coming out of the province. HDVs accounted for 20% of these transport emissions, making them the 3rd heaviest transportation polluter in the province (CleanBC, 2024a). To reduce these emissions from carriers, the government of BC has taken an increased interest in using zero-emission vehicles (ZEVs) to decarbonize the HDV industry. These plans have included battery electric vehicles (BEVs) and hydrogen fuel cell electric vehicles (FCEVs) (Ministry of Energy Mines and Low Carbon Innovation, 2024k).

Within the provincial Hydrogen Strategy, the BC government has outlined plans to support the transition from diesel fuel to hydrogen within the transportation sector (Government of BC, 2021).

This chapter discusses the current policy developments that support the Hydrogen Strategy and describes whether these policies are supporting or hindering the growth of hydrogen in the HDV market. Additionally, I analyze the transport decarbonization policies in BC from the perspective of energy transition literature. To conclude, this chapter draws on empirical evidence to assess the presence of self-reinforcing or self-undermining policy feedback effects and discusses future implications of the role of hydrogen as it is introduced as an alternative ZEV in the market of British Columbia.

Objectives within the BC Hydrogen strategy

The 2021 BC Hydrogen Strategy aims to support the adoption of hydrogen in the HDV transportation sector through its three transitional periods which it calls the "2020 – 2025" period, the "2025 – 2030" period, and the "2030 and beyond" period. Through the 2020 – 2025 period, the government plans to enable pilot projects to test the feasibility of fuel cells in an assortment of commercial vehicles, such as medium and heavy-duty vehicles, marine, rail, and aviation. The provincial government also plans to leverage the "Part 3 agreement program" (discussed below) to assist with the development of hydrogen refueling infrastructure. The provincial government also plans to provide monetary and non-monetary incentives to companies that are constructing fueling infrastructure and purchasing ZEVs. Additionally, the provincial government will allow for the generation of credits when medium and heavy-duty vehicles are purchased under the ZEV Act. The government also plans to explore ZEV compliance targets for medium and heavy-duty vehicles (Government of BC, 2021, p. 24).

Within the 2025 – 2030 period, the BC government plans to review pilot projects that have been underway within the province and include sales targets for medium and heavy-duty vehicles within the Zero-emission Vehicles Act. From 2030 and beyond, the government will continue to support the use of hydrogen within the commercial transportation sector (Government of BC, 2021). Much like the previous chapter, the following section will conduct an analysis within the scope of the 2020 – 2025 period, though with a caveat on the inclusion of a mandatory sales target that is discussed within the 2025 – 2030 period; and a short backgrounder on some policy elements that have led up to the current state of hydrogen development.

The Establishment of a Low Carbon Fuel Standard

After the state of California pioneered a Low Carbon Fuel Standard (LCFS) in 2007, BC released its own LCFS in 2010 and created one of the most stringent LCFSs in North America at the time, which aimed to reduce emissions from fossil fuels by 10% by 2020 (Axsen et al., 2020; Ministry of Energy Mines and Low Carbon Innovation, 2022b). The BC LCFS is comprised of the provincial Greenhouse Gas Reduction Act, now known as the Low Carbon Fuels Act (Ministry of Energy Mines and Low Carbon Innovation, 2024h), and the Renewable and Low Carbon Fuel Requirements Regulation. The LCFS allows for fuels such as natural gas, electricity, propane, and “prescribed fuels” such as hydrogen to be used in the province (King’s Printer, 2024c, 2024e). Since its release, the LCFS has reduced the annual greenhouse gas emissions from the transportation sector by an average of 6% per year up to 2020 (Juan Ding, 2022). After the release of the CleanBC Roadmap, emission reduction stringencies for the LCFS have increased to require a 30% decrease in gasoline and diesel relative to 2010 levels (Ministry of Energy Mines and Low Carbon Innovation, 2022b).

The LCFS is a “market transformation” policy, meaning it intends to reward the diffusion of low-carbon fuels (Ministry of Energy Mines and Low Carbon Innovation, 2024h). This is done through what is called “Part 3 agreements”, which are agreements between fuel suppliers (those who supply diesel, gasoline, or other fuels) and the BC government. These agreements are also used to fund projects that aid in reducing greenhouse gas emissions (CleanBC, 2024b). Fuel suppliers that adhere to the Greenhouse Gas Reduction Act within the LCFS are eligible for credits that can assist them with either complying with emission reduction targets in the future or can be used to support other part 3 fuel suppliers with their compliance targets (Gill, 2023; Ministry of Energy Mines and Low Carbon Innovation, 2018). Debits are incurred if fuel suppliers sell fuels that are over the carbon intensity limit within the province. Understanding the difficulty of reducing the carbon intensity of carbon-intensive fuels, the government of BC has been consulting on whether to allow carbon-capture technology to comply with obtaining carbon credits under the LCFS, though this has yet to be finalized (CleanBC, 2021; Juan Ding, 2022). Creating the credit system as it stands has encouraged the development of several emission reduction efforts in the province; including the construction of hydrogen refueling stations through Hydrogen Technology

& Energy Corporation (HTEC) (Gill, 2023; Ministry of Energy Mines and Low Carbon Innovation, 2018).

The implementation of the LCFS is a solid example of a policy that uses forward reasoning in its approach to decarbonization and the advancement of upcoming technologies that aim to replace the status quo. It encourages the energy transition to alternative fuels for transportation purposes in the province, such as hydrogen, by creating a quantity mandate that targets emission reductions. It also sets forth an expected standard that fossil fuel producers must adhere to, or else face economic losses (Breetz et al., 2018). It also represents the establishment of a policy that is "sticky" and is extremely difficult to reverse if a political actor came into power that sought to backtrack on policy developments that support decarbonization. This is because it not only puts limitations on emissions but provides benefits for other industries who seek to establish a niche market using the credit system, or through necessitating fuel switching to meet compliance targets. This, in turn, entrenches support over time that seeks to enter a market that is typically largely contested by incumbent fossil fuel coalition members. (Jordan & Matt, 2014; Levin et al., 2012; Roberts et al., 2018). This makes the LCFS a *prerequisite* for path dependency/reinforcing sequencing, as it opens the door for other policies that seek to build upon the LCFS and encourages a market that is run through alternative fuels such as hydrogen which in turn can generate even stronger levels of coalition support. It also quiets the interest of fossil incumbent forces who would otherwise object to further policies by providing credits if they reach specific emission reduction targets (Levin et al., 2012; Meckling & Nahm, 2022). In time, this allows for a potential shift in the dominant rules and institutions that make up the regime,[13] while also encouraging the adoption of niche developments, such as those that would aim to decarbonize the heavy-duty transportation industry (Rosenbloom & Meadowcroft, 2022).

Addressing zero-emission HDV barriers through the CleanBC Go Electric Program

In addition to the LCFS, the government of BC released the "Clean Energy Vehicle Program" in 2011, which was established to create financial incentives for the purchases of light-duty ZEVs and assist with the development of supporting ZEV refueling infrastructure. The Clean Energy Vehicle Program had a couple of different funding streams within it. The "Clean Energy Vehicles for BC" program, which funded up to $5000 in rebates for the purchase of zero-emission vehicles, and the "Clean Energy Vehicle Infrastructure Deployment Program", which provided infrastructure funding for electric and hydrogen refueling stations. The Clean Energy Vehicles Program ended in 2014 and had disbursed $14.3 million in total funding, which helped stimulate the beginning of the BEV market and funded the development and establishment of four hydrogen fueling stations in the province (CHFCA, 2016d; Government of BC, 2015). In 2015, The Clean Energy Vehicles for BC program was renewed in 2015 under the new name "CleanBC Go Electric Vehicle Rate" program (CleanBC Go Electric, 2023a), which would later be expanded upon to include a variety of other "CleanBC Go Electric" programs such as the 2015 CleanBC Go Electric Hydrogen Station and Fleet

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[13] Such as policies, cultural practices, and market preferences.

Program (CHA, 2024b; Ministry of Energy Mines and Low Carbon Innovation, 2024b). Though it is unclear if this program directly replaced the Hydrogen Station and Fleet Program, shortly after the release of the Hydrogen Strategy, the provincial government released a rebate program called the Hydrogen Fueling Infrastructure Program, which is managed through the Canadian Hydrogen Association (CleanBC Go Electric, 2024c; Ministry of Energy Mines and Low Carbon Innovation, 2024j, 2024i). Though details are limited to direct inquiry about the program, the program has been used to help fund fueling stations such as the recent refueling station in Kelowna BC (HTEC, 2023g).

Infrastructure development remains a barrier to zero-emission HDV adoption in the province, despite financial developments being made by the province to address it. There is currently no refueling infrastructure for hydrogen HDVs in BC, but there are plans to develop the first class 8 vehicle hydrogen refueling station on Tsawwassen First Nation land near the port of Vancouver (HTEC, 2023e; C. Paterson, personal communication, December 2023). Battery electric HDVs do have an advantage over hydrogen in this regard, as there are currently 118 commercial charging and fueling stations within the province (Government of BC & CleanBC, 2024). BEVs have had a longer track of support structures through the CleanBC Go Electric program, which has likely contributed to these advancements (CleanBC Go Electric, 2024c; Ministry of Energy Mines and Low Carbon Innovation, 2024j). However, the infrastructure component of adopting both BEVs and FCEVs is still a major concern within the transportation industry and is preventing confidence among carriers in adopting zero-emission HDVs (BCTA, 2024c), as will be touched on later in this chapter. One strategy to mitigate the lack of infrastructure available on the road is for carriers to have hydrogen refueling stations on-site at their terminals, but these stations are very expensive to develop (J. Adams, personal communication, November 2023).

The Hydrogen Fueling Infrastructure Program is just one expansion in the CleanBC Go Electric program out of a much broader range of developments after the release of the BC Hydrogen Strategy and the Roadmap to 2030. For instance, the 2021 Commercial Vehicles Pilot Program (CVPP) was created to help BC-based businesses and organizations transition into ZEVs. Those who are selected for the program can receive up to 33% in direct funding support for the cost of eligible vehicles and fueling infrastructure projects (CleanBC Go Electric, 2024a; Government of BC & CleanBC, 2024). In addition to the CVPP, the Go Electric program has also established the Advanced Research Commercialization (ARC) program, which supports the development of companies working within the ZEV sector by attracting external investment opportunities and promoting employment opportunities within the industry. The program also supports the demonstration of these ZEV projects and aids in advancing their commercialization. To support these developments, the ARC program provides direct funding for pre-commercialized research and development projects (CleanBC Go Electric, 2023b; Ministry of Energy Mines and Low Carbon Innovation, 2023b). Within the ARC program is also the Commercial Vehicle Innovation Challenge, which has so far received $30 million in funding and is available to support ZEV technology that is within the technology readiness scale of 4 to 9[14] (CleanBC Go

[14] See Chapter 4, page 51.

Electric, 2023c). The CVPP and ARC programs are being used to fund projects such as the Hydrogen Ports project in Vancouver, which is led by Hydrogen Technology & Energy Corporation (HTEC). The Ports project is the first large-scale project in the province to use hydrogen and fuel cells in the transportation sector. Receiving $4 million from these programs, and seeks to demonstrate the feasibility of hydrogen fuel cells in six class 8 trucks (Ballard Power, 2023; HTEC, 2023e).[15]

Projects such as the Hydrogen Ports Project are important not only to test the feasibility of fuel cells in HDVs but to also enable a transition into an HDV market that is otherwise extremely costly. The price of a single Fcell HDV will cost a buyer roughly 1 or 1.3 million CAD dollars, with roughly between 550 – 800km in range prior to needing to be refueled, with refueling times that are relatively comparable to diesel. In comparison, the average price of a new diesel truck that can offer you an 800km range will cost you around $220,000 (J. Adams, personal communication, November 2023; Anon et al., personal communication, February 2024; BCTA, 2024c; C. Paterson, personal communication, December 2023). BEVs, for an added comparison, are typically sold for around $600,000, but come with significantly less range capacity, between 200 - 550km. Furthermore, BEVs can take a considerable amount of time to recharge, ranging from two to three hours. (eCascadia, 2024; Kenworth, 2024; Nikola, 2024; C. Paterson, personal communication, December 2023).

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[15] These trucks are comprised of four fuel cell yard trucks and two fuel cell drayage trucks.

At first glance, these charging times may not pose an immediate problem. However, considering that a lot of trucks in Canada are double-shifted, meaning that they are often running 22 to 24 hours a day with a rotation of drivers using the same truck, these charging times can cause serious delays (J. Adams, personal communication, November 2023; C. Paterson, personal communication, December 2023). Thus, hydrogen fuel cell HDVs appear to be a better option for long-haul uses and have the added benefit of being twice as energy efficient as diesel engines (Xiao, 2024). Unfortunately, because fuel cell HDVs are in their pilot stages, a purchaser of one of these vehicles is often placed on a waiting list by a seller or leasing company, such as HTEC, and can expect to wait a couple of years before receiving it (J. Adams, personal communication, November 2023; C. Paterson, personal communication, December 2023).

To provide direct support for the adoption of zero-emission HDVs, the CleanBC Go Electric program has been expanded to include a special use vehicle incentive program for delivery trucks and passenger vehicles, which includes medium and heavy-duty vehicles (CleanBC, 2021). The rebate for heavy-duty vehicles was released in July 2022 and has allowed Class 2B to Class 8 trucks to receive between $10,000 to $150,000 in rebates with the purchase of a new zero-emission HDV in the province. However, to qualify for the full rebate, non-fleet applicants[16] must lease a vehicle for up to 36 months, whereas a fleet must have a lease for up to 24 months to receive the full

[16] Non-fleet applicants are individual operators; those who run independently and own a single vehicle.

rebate (CleanBC Go Electric, 2024b; C. Paterson, personal communication, December 2023). Some consideration has been made to include hybrid HDVs into the rebate program, but so far this has not been the case (Anon, personal communication, November 2023). Direct funding for hydrogen-based HDVs is also being provided through the CleanBC Go Electric Hydrogen Fleet program, managed through the CHA. Under this program, a maximum of 33% of the total cost of a vehicle, up to a value of $8,000, can be provided to fuel cell vehicles purchased and registered within the province (Ministry of Energy Mines and Low Carbon Innovation, 2024b).

The advancement of the Clean Energy Vehicle Program into the broader CleanBC Go Electric program represents a form of “layering” in policy decision-making. Actors who seek to encourage the growth of niche technologies support them without making changes to the existing energy system that would necessarily limit the technological capacity of incumbents (Breetz et al., 2018). These advancements also represent a broader scope of ambitions to create policies that “stick”, in which *Instrument-specific* Adhesion Mechanisms are used to encourage a targeted group, such as those interested in advancing the hydrogen sector, to invest their money in the province (Jordan & Matt, 2014; Levin et al., 2012). This allows for further recruitment of allies in coalition developments without generating anti-coalitions; especially in the case of later hydrogen developments which see coalitions developing around both low-carbon fossil and renewable hydrogen interest groups (CHA, 2024e; Meckling & Nahm, 2022). This makes the early developments of the CleanBC Go Electric program another *prerequisite* for reinforcing sequencing events that come after the establishment of the BC Hydrogen Strategy. Coalition support that was originally invested in ZEVs can entrench itself within the existing regime over time, which in turn can generate growth in interested actors by advancing the CleanBC Go Electric program to include support for additional sectors; such as the HDV sector (Levin et al., 2012). Once again, like the LCFS, this shifts the regime to allow ZEVs to enter the market with more success through early financial support structures for refueling infrastructure, research and development, and HDV adoption (Rosenbloom & Meadowcroft, 2022). Similar policy decisions to advance the adoption of ZEVs occurred in Norway, which now has one of the most successful electric vehicle markets in the world. With incentive programs for ZEV adoption beginning in the early 2000s, combined competition from manufacturers helped reduce the cost. Battery technology also improved, and public infrastructure had investments to improve electric vehicle recharging station availability. The existence of a ZEV coalition then supported ZEV advancements in other sectors, such as passenger ferries (Bernstein & Hoffmann, 2019).

An Additional Barrier: The High Cost of Fuel

The current price of hydrogen can run as high as $12.75 or $14.50/kg (Anon, personal communication, February 2024; HTEC, 2023b; Xiao, 2024). A standard rule of thumb in the industry to compare hydrogen with the price of diesel is to divide the current price of hydrogen by 4.5, and you will get your standard comparable price to diesel fuel per liter (J. Adams, personal communication, November 2023). This makes the diesel equivalent currently at $3.2 – 2.83/L, which is vastly different from the price of diesel in BC at the time of writing, which rests at the average of $1.8/L (YCharts, 2024). Though the price of hydrogen is expected to go down in the future as the industry scales up, it must come down significantly to become competitive with diesel fuel. Alternatively, policies could aim to increase the price of diesel fuel through carbon pricing and artificially make hydrogen cost competitive. However, carbon pricing can have mixed responses from consumers depending on the policy enabling fuel price increases (Axsen et al., 2020). The BC Hydrogen strategy predicts that by 2030, hydrogen will need to cost $3/kg to become cost-competitive, a stark difference from the current cost of hydrogen as mentioned above (Anon et al., personal communication, February 2024; Government of BC, 2021). To bring down these high costs, FortisBC views the expansion of home heating and industrial heating to also expand hydrogen pipeline infrastructure that could fuel hydrogen refueling stations.[17]

Additional Levels of Policy Support

In addition to the LCFS and the CleanBC Go Electric fund, there have been a few other support structures that have advanced the technological transition from diesel-powered HDVs to hydrogen HDVs. For instance, the Innovation Clean Energy Fund was established in 2008, and has been used to support the provincial clean energy sector by supporting research and development, energy efficiency programs, and pre-

[17] Weight limits are also seen as an additional barrier to adoption, as most fuel cells for HDVs are manufactured in the United States; which has different weight restrictions for road freight than Canada (BCTA, 2024c; Xiao, 2024). Additionally, certifications that train mechanics to operate on fuel cells pose another barrier (Anon et al., personal communication, February 2024). This research acknowledges these barriers, but for the overall research question of this chapter, it is not important to address them further.

commercial clean energy projects that aim to reduce greenhouse gas emissions (Ministry of Energy Mines and Low Carbon Innovation, 2024d). So far, the program has supported greenhouse gas reductions in the electricity, transportation, and oil and gas sectors by preventing financial barriers to reducing emissions (Ministry of Energy Mines and Low Carbon Innovation, 2024d). Recently, the Innovation Clean Energy Fund provided $16.5 million to the Pilot Hydrogen Truck Project. This project involves trucks being procured by HTEC, who will then lease these trucks to specific companies to test how they operate for 12 to 14 months. In exchange, carriers such as Arrow Transportation Systems will provide their data on how the trucks are operating during the test through the telematics that the trucks are equipped with (J. Adams, personal communication, November 2023; Arrow Transportation Systems Inc, 2023; HTEC, 2023h; C. Paterson, personal communication, December 2023). Once the study is completed by 2026, HTEC expects the results of this project to show how hydrogen-based transportation can be a viable alternative to conventional diesel fuel trucks by 2026 (Pawson, 2023). HTEC will then draft and release a public report to help carriers transition their vehicles (C. Paterson, personal communication, December 2023).

In addition to financial support for the outright cost of hydrogen HDVs, the provincial government has also been providing funding for vehicle efficiency improvements through the Heavy-Duty Vehicle Efficiency (HDVE) program, managed by the British Columbia Trucking Association (BCTA). The BCTA is an interest group that was formed to “advance the interest of British Columbia Motor Carriers” (BCTA, 2024a). Established in 2019, the HDVE program provides rebates for fuel efficiency improvements carriers make on their vehicles. Having a total of $3.5 million in funding, to become eligible a carrier must have at least one of its members take the CleanBC Heavy-duty Vehicle Efficiency Program Course, a free half-day course that describes the benefits of using fuel-saving technologies and practices. In addition to this, carriers must have purchased their efficiency improvements within BC. After taking the course, a carrier can receive a rebate of up to $20,000 per vehicle, and $150,000 per fleet that receives efficiency improvements (BCTA, 2024b; Today's Trucking, 2023).[18] One example of fuel-saving equipment that is making a lot of traction in the BC HDV sector is the dual fuel engine being provided by Hydra Energy. Hydra has created retrofits that attach to the diesel engines of HDVs which allow diesel engines to be fitted into a diesel and hydrogen hybrid engine (Hydra Energy, 2024a). At zero direct cost to the fleet operator, Hydra will install the retrofit into an operator's engines in exchange for an exclusive five-year purchasing agreement of hydrogen outsourced by Hydra Energy. This hydrogen would be coming from Prince George, where Chemtrade, a chemical bleaching plant, currently emits hydrogen as an emission when creating sodium chlorate (Chemtrade, 2020; Hydra Energy, 2021, 2022). Refueling stations are also currently being developed by Hydra along a corridor between Edmonton and the coast of BC, in which hydrogen from Prince George will be supplied (Hydra Energy, 2022, 2023, 2024b).

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[18] There are currently 74,618 HDVs operating on BC roads according to the Insurance Corporation of British Columbia (BCTA, 2024c). If half of these vehicles (37,309 HDVs) sought out the minimum rebate of $20,000, a total of around $746 million would be required to assist with vehicle efficiency improvements; a stark difference to the current amount of funds the HDVE program has received.

Though it has yet to be fully implemented, the provincial government has also been planning to develop a Clean Transportation Action Plan (CleanBC, 2021). The plan is meant to act as a single point of reference that helps facilitate a comprehensive approach to meeting both short-term (2030) and long-term (2050) goals to decarbonize all aspects of the transportation sector, including HDVs, light-duty vehicles, bicycling, rail, marine, and more (CleanBC, 2023). Provincial plans to reduce emissions go beyond just transitioning technologies from diesel engines but reducing the travel distance of goods movement, encouraging vehicle efficiency through programs such as the HDVE program, and fuel switching (Ministry of Energy Mines and Low Carbon Innovation, 2024c). A request for input was put out in 2023 for the transportation action plan, and some feedback suggested that significant investments in general infrastructure would have to be made to reach decarbonization targets (CleanBC, 2023). Though it was meant to be released at the end of 2023, the action plan has yet to be released (Government of BC & CleanBC, 2023; Ministry of Environment and Climate Change, 2024f).

Policies that support the development of hydrogen infrastructure have also been developed by the federal government. For instance, though the federal "Green Freight Program" does not directly apply to infrastructure, it provides incentives for carriers to switch to fuels offered by upcoming zero-emission infrastructure through two streams of funding for GHG reduction initiatives. Within the first stream that was launched in 2022, grants for retrofits on trucks and trailer equipment provided up to 50% of the cost per device, with a total maximum payout of $250,000 per applicant. The second stream of funding has yet to be launched but intends to cover up to 50% of project costs, with $5 million per project that is centered around “fuel switching, engine repowers, and purchase of low carbon alternative fuel” (Natural Resources Canada, 2023b). Proposals to apply for funding were closed in November 2023, and it is unclear if funding has been released (Natural Resources Canada, 2018). Additionally, the federal government offers funding through the Zero Emission Vehicle Infrastructure Program, which provides 50% of the total project cost for the owners and operators of ZEV infrastructure, up to a maximum of $10 million per project. Though this program is currently closed for applications, it intends to open up once more in the spring of 2024 (Natural Resources Canada, 2019).

Funding to cover the cost of zero-emission HDVs is also being provided through Transport Canada under the Incentives for Medium- and Heavy-Duty Zero-Emission Vehicles Program (Ministry of Energy Mines and Low Carbon Innovation, 2023c). The federal program was launched in 2022 and provides monetary incentives of up to $200,000 for zero-emission HDVs. Currently, the program has a broad amount of support for BEVs, but there is a limited amount of fuel cell HDVs that are considered eligible. Furthermore, to receive the full rebate, fuel cell HDVs must be leased for a total of 48 months (Transport Canada, 2022a, 2022c). This monetary incentive can be combined with the provincial special use vehicle incentive program that is under the CleanBC Go Electric program to further cover the cost of zero-emission HDVs (J. Adams, personal communication, November 2023; C. Paterson, personal communication, December 2023; Transport Canada, 2022b).

Combining the efforts of both the provincial and federal governments, HDVs are evidently receiving a significant amount of financial support structures that are typically required in the early stages of niche technological developments. Pilot programs testing the feasibility of fuel switching to hydrogen engines can receive a vast amount of support; which further aids in developing a pathway in which diesel engines are replaced with fuel cells (Breetz et al., 2018). If pilot programs are successful, this may also establish increasing returns that generate reinforcing feedback to the program itself; in which the social acceptance of fuel cells is increased, and therefore the intended target population (carriers) view hydrogen more positively (Levin et al., 2012).

In addition to funding for pilot programs, funding for vehicle efficiency improvements may also aid in the transition of fuel cell HDVs, in which a combination of retrofits and knowledge building through the CleanBC Heavy-duty Vehicle Efficiency Program Course can help support developments on the production side while also granting familiarity to carriers with the fuel. This, in turn, could help avoid any negative bias that future policy decisions may develop which could undermine hydrogen developments in the sector. This, as we will see in the next section, may be critical to future advancements of hydrogen in the HDV sector. Whereas previous policy decisions so far have allowed for shifts in the current regime and therefore opened the market to niche developments, the high expenses for hydrogen fuel and vehicle adoption may cause carriers to not fully accept hydrogen as an alternative fuel; and look for alternatives instead (Jacobs & Weaver, 2015; Rosenbloom & Meadowcroft, 2022).

The Zev Mandate

As the government of BC supports initiatives to develop hydrogen use in HDVs, it also seeks to include a medium and heavy-duty vehicle sales mandate within its current ZEV sales mandate for personal vehicles. In 2022, the federal government released its 2030 Emissions Reduction Plan, in which it stated Canada would aim to have 35% of medium and heavy-duty vehicle sales be ZEVs by 2030, and 100% of them be ZEVs by 2040 (Environment and Climate Change Canada, 2022). Currently, the ZEV sales mandate targeting personal vehicles in BC requires specific percentages of ZEV sales per year to be sold within the province. These sales targets are 10% of total vehicle sales by 2025, 30% by 2030, and 100% by 2035 (Ministry of Energy Mines and Low Carbon Innovation, 2023d, 2024k).[19] Additionally, credits can be earned by retailers who sell ZEVs that are also registered in the province. This is to encourage ZEVs that are sold in the province to stay within the province. One credit is earned per vehicle sale, and can be used very similarly to the LCFS, in that they can be used to aid retailers reach ZEV sales mandate compliance targets (King's Printer, 2024d; Ministry of Energy Mines and Low Carbon Innovation, 2023d). The ZEV sales mandate for HDVs in BC has been proposed to act in a very similar way to the California blanket HDV sales mandate, in which 7% of HDV sales will be ZEV by 2025, 30% by 2030, 40% by 2035, and 100% by 2036 and beyond. Hybrids, like the modular engine designed by Hydra, are excluded from these sales targets (Buysse & Sharpe, 2020; CleanBC, 2021; Government of BC, 2023; Ministry of Energy Mines and Low Carbon Innovation, 2024k). Pembina Institute has also issued a consultation paper, which recommends that the medium and heavy-duty vehicle portion of the act also have a credit system, which can help retailers

[19] The target to reach 100% vehicle sales was recently changed from 2040 to 2035.

meet their targets or be traded to assist others reach their targets as well. However, the authors also propose that credits should have a limited lifetime of 5 years at max, to prevent credits from being used during more stringent periods when mandates get stricter (Bhardwaj et al., 2023).

However, a recent white paper released by the BCTA suggests that releasing a blanket mandate like the one introduced in California may create barriers to decarbonizing the HDV sector, rather than remove them. In 2023, the BCTA surveyed 991 motor carriers, with the average company respondent being in the business for around 37.5 years. Results showed that 62% of carriers do not believe transitioning into the ZEV market will reduce their operating costs. Additionally, there was a general belief that zero-emission HDVs would not be market-ready for the next 10.2 years, and they would wait an additional 1.8 years after they are market-ready before purchasing one. The top barriers that these carriers viewed as issues to adopting ZEVs were the available range capacity, the initial purchasing price, the lack of refueling infrastructure, and general unknowns about the vehicles. This is significant, as the primary considerations for carriers when purchasing a new vehicle are the decreases in operating cost, the availability of a more reliable vehicle, the potential to increase range capabilities, and maximizing payload capacity (BCTA, 2024c).

A critical consideration for the future of the ZEV mandate is the capacity for carriers in the province to purchase zero-emission HDVs, and their ability to make a return profit through their business operations. The majority of the provincial HDV transportation companies are small, with 94% of companies running on 10 or fewer trucks, meaning their operating capacity is limited (C. Paterson, personal communication, December 2023). The sector is also challenging from a profit margins perspective, with any company being lucky to make 5% in their return profit off the total cost (J. Adams, personal communication, November 2023). Therefore, though there are significant investments being made by the province and federal government to support transitioning into the higher-cost hydrogen HDVs, the price point is still a major concern for carriers within the province (J. Adams, personal communication, November 2023; BCTA, 2024c; C. Paterson, personal communication, December 2023).

This makes alternatives to both battery electric and hydrogen HDVs rather appealing to carriers. BC has an aging fleet, with the average age of vehicles in the province operating since 2010/2011, with roughly 50% of vehicles being older than 2010. The average operating range of vehicles lasts roughly 11.7 years in the province, so carriers are ready now to upgrade their vehicles sooner rather than later. In the same survey released by the BCTA, 15% of HDV operators within the province suggested they would purchase a new diesel vehicle before the suggested medium and heavy-duty vehicle mandates are put into place. Furthermore, roughly 68.3% of respondents said they would run their existing fleets for even longer than usual to mitigate the risk associated with adopting new technologies. When responding to which ZEVs these business operators would purchase, 48.7% stated they would purchase a hybrid,[20] 43.4%

[20] Hybrids include the previously mentioned diesel-hydrogen co-combustion, and CNG/LNG-electric or diesel-electric vehicles. Though the purchasing of a hybrid vehicle may be beneficial as it provides an additional market for hydrogen, it still holds potential to lock-in diesel fuel if hybrids are used for a prolonged period.

stated they would purchase a compressed natural gas (CNG) or liquid natural gas (LNG), and only 3.5% and 4.4% would purchase a BEV or fuel cell truck respectively (BCTA, 2024c). As a result, the BCTA predicts that roughly 78.2% to 87.9% of HDVs will still run off diesel in 2040 due to infrastructure limitations and vehicle lifecycle turnaround times (BCTA, 2024c; C. Paterson, personal communication, December 2023).

CNG and LNG commercial vehicles are currently promoted by FortisBC as low-carbon alternatives to diesel fuel. Not only does refueling with CNGs and LNGs cost 50% less than refueling with diesel fuel but it is also promoted as a way to avoid higher carbon taxes and as a potential way to earn carbon credits by reducing a carrier's fuel emissions (FortisBC, 2024e). Significant changes to existing infrastructure also do not have to occur, as CNG can be transferred to refueling stations through existing pipelines, and LNG can be transferred to refueling stations by trucks; much like hydrogen is currently transported (FortisBC, 2024a). Furthermore, the cost of CNG and LNG vehicles can range from $50,000 to $75,000 more than your standard diesel truck (Canadian Gas Association, 2016, p.; Tracey Road Equipment, 2024). Given that 92.1% of respondents to the BCTA survey said they would purchase either a hybrid or a CNG or LNG vehicle as their choice of "zero-emission vehicle" this shows a large bias for the status-quo that resonates within a significant portion of the trucking industry. When considering the life-cycle period of HDVs lasting an average of 11.7 years in the province, the availability of alternatives may hinder future net-zero emission goals. Even the BCTA recommends, given these results, that the provincial government should create more support for CNG and LNG refueling stations and hybrids (BCTA, 2024c).

The Looming Market of Alternatives

So far, policy developments that aim to establish shifts in the regime and niche markets have been largely successful in terms of setting up pre-requisites for future policy developments. However, perhaps there has been a lack of policy that controls the *landscape*, in which broader developments, such as shifts in political administration or cultural shifts, can exert pressure on a system (Rosenbloom & Meadowcroft, 2022). Though the use of hydrogen in the HDV sector has been largely supported through necessary financial structures that support both its adoption in vehicles and supportive refueling infrastructure; it is also a technology that is entering a market that has a broad base of support for the status-quo. This could be, in part, because of how the BC government has previously framed LNG as a clean alternative to coal. Coal is one of the most exported materials of BC. Viewing LNG to be a clean alternative, the BC government has cited that it can be exported to other countries, create jobs, and reduce emissions to help meet BC climate targets. Additionally, the BC government has previously encouraged the transportation sector to switch to CNG (Janzwood & Millar, 2022). Though the government of BC aims to encourage ZEV uptake through the use of a ZEV mandate, policy itself cannot fully determine experience curves (BCTA, 2024c; Breetz et al., 2018). It is a predicament that scholars are already very aware of in energy transition literature. We need to accelerate the pace of change in sectors that require deep decarbonization, and yet acting too quickly can prove detrimental to the transition; in which the unintended consequences of policy decisions can be used to the advantage of incumbents (Buschmann & Oels, 2019; Grubert & Hastings-Simon, 2022; Levin et al., 2012; Millar et al., 2021).

In the case of hydrogen, though its use intends to decarbonize the industry through low-carbon modes of production, it could also serve to lock in systems that support incumbent fossil fuel use in the transportation industry, and the petroleum industry itself. Though the diffusion of hydrogen and hydrogen HDVs will bring down the cost in time, they are entering a market that is controlled by shippers. Roughly 10% of the cost of purchasing something accounts for the cost of transporting that item to the retailer. This is not necessarily the cost of "trucking" in general, as lots of shipments get carried via other sectors like rail, maritime, or air. However, in Canada, roughly 92% of everything a consumer purchases has been touched in part by a truck, and in BC, 90% of goods are touched by a truck. (BCTA, 2024c; C. Paterson, personal communication, December 2023). Additionally, all prices are passed on to the consumer (J. Adams, personal communication, November 2023; C. Paterson, personal communication, December 2023). Though a shipper might agree to a contract with a carrier and take on the higher cost associated with both the fuel and trucks in the mid stages of technological diffusion to decarbonize their upstream emissions (Breetz et al., 2018; C. Paterson, personal communication, December 2023), they are doing so at the risk to their business interest in a competitive market (J. Adams, personal communication, November 2023). Additionally, this makes hydrogen HDVs susceptible to creating policy reversal within the ZEV mandate by incumbent political actors who favour the status quo by over-emphasizing the downsides of policy (Lamb et al., 2020; Millar et al., 2021). We already see this with the federal carbon tax, in which despite the carbon tax having marginal effects on the cost of grocery prices in Canada, political actors who favour the status quo have blamed the carbon tax for exceedingly high grocery prices (T. Dawson, 2023; Wherry, 2023).

This means hydrogen in the transportation sector generates conditions in which incumbents are highly favoured over the one alternative that has more of a guarantee of coming from renewable energy: BEVs. If a carrier decides to switch from diesel to CNG or LNG, this directly favours incumbent fossil fuel interest. If a carrier decides to go with hydrogen, then depending upon the type of hydrogen production, this could still serve the interest of fossil incumbents.[21] If a carrier decides to invest in the hybrid option provided by Hydra, this still favours incumbents because diesel is still a preferred option. This shows a vulnerability hard-to-abate sectors have in decarbonization efforts, in that the alternatives that present themselves can still have the capability of supporting incumbent interests. Thus, hard-to-abate sectors such as long-haul trucking are extremely susceptible to not being able to overcome the system improvement phase of energy transitions to reach deep decarbonization (Bernstein & Hoffmann, 2019). It also reveals how carbon lock-in mechanisms work in the HDV sector. The industry relies upon carbon-intensive technologies, social norms perpetuate themselves to support carbon-intensive technology, and therefore the politics is vulnerable to remaining unchanged; despite policy that is designed to change power within the regime (Rosenbloom & Meadowcroft, 2022; Seto et al., 2016).

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[21] See Chapter 4

Feedback Effects of the Hydrogen Strategy in the Transportation Sector

Given that hydrogen HDVs are still developing in their pilot stages, it is evident that they are at the top of the technological experience curve.[22] Breetz et al. (2018) also note that there are specific policy developments that can signify the early stages of technological development and diffusion. These strategies include decreasing incumbent technology costs, either through R&D funding or subsidies, and/or policies that encourage the uptake of emerging tech, such as mandates performance standards, or procurement rules (Breetz et al., 2018). We can see this being done through the objectives outlined in the BC Hydrogen strategy. Through the establishment of the LCFS in 2010, the province created a policy that's "stickiness" has been incredibly difficult to reverse the longer it has been in place (Jordan & Matt, 2014; Levin et al., 2012; Roberts et al., 2018). The same can be said about the CleanBC Go Electric program, in which early and strong policy support established the province's ability to shape future policy outcomes and, therefore, shape the regime as niche technologies enter the market (Rosenbloom & Meadowcroft, 2022). This has allowed the periodic plans outlined within the Hydrogen Strategy to be more easily addressed, thanks to broad support structures being set in place before its release in 2021. Through the 2020 – 2025 period, pilot projects have been enabled through financial support driven by the CleanBC Go Electric Commercial Vehicles Pilot Program, Advanced Research

[22] Though it could be argued that companies, such as Ballard Power, have been developing fuel cells for quite some time (Ballard Power, 2024), the development of fuel cells that are specifically designed for HDVs are only now being debuted and tested (HTEC, 2023e, 2023h).

Commercialization Program, and the Innovation Clean Energy Fund. Monetary incentives for infrastructure development are also being provided through the CleanBC Go Electric program. It is difficult to tell whether the Part 3 agreement program has been "leveraged" to support hydrogen refueling projects. However, a recent announcement by HTEC called the "H2 Gateway" project aims to construct a total of 20 hydrogen fueling stations, 14 of which are for HDVs (HTEC, 2023c). It is also too early to confirm whether a credit system will be applied to the HDV portion of the ZEV act, but the act does currently have a credit system enabled for passenger vehicles which could be built upon by 2025. The presence of consultation papers addressing the upcoming ZEV Act for medium and heavy-duty vehicles also suggests that the BC government is currently in the process of considering compliance targets in the future. It is therefore reasonable to attest that the hydrogen strategy is successfully self-reinforcing its policy objectives, given the wide array of program wide adhesion mechanisms that are shaping the expectations of the regime. These adhesion mechanisms are also generating the necessary financial support that niche developments require during the early stages of their development (Breetz et al., 2018; Jordan & Matt, 2014).

These policy developments represent a forward-reasoning approach that entails the use of controlled deliberate decline mechanisms, in which niche technologies are developing at a pace that allows for the deliberate intentions of making hydrogen an alternative to the status quo. Coalition members, such as Hydra Energy, aim to steer the industry away from diesel fuel by developing an industry that allows for a bridge towards FCEVs in the transportation sector (Rosenbloom & Rinscheid, 2020). But as we know from the previous chapter, hydrogen is not necessarily a clean alternative; and even if low-carbon fossil hydrogen is successful, it cannot erode the political legitimacy of incumbents. A ZEV mandate also makes sense as a strategy to slowly eradicate the availability of carbon-intensive vehicles while generating additional supply to negate the losses of older vehicles (Grubert & Hastings-Simon, 2022). But unlike a ZEV mandate for passenger vehicles, a ZEV mandate for commercial vehicles is different because it is intrinsically linked to the income of businesses that supply the province with material goods. It is a competitive market, in which small profit margins make or break contracts with shippers. This adds an additional element to an industry that is already locked into its practices associated with carbon lock-in, in which transitioning to alternative technologies can make the survivability of their business vulnerable. Early financial support structures are meant to negate these risks, and aid in transitioning niche technologies, but given that financial support structures hardly cover the full cost of a single truck, it is difficult to make the transition (J. Adams, personal communication, November 2023; C. Paterson, personal communication, December 2023).

This is not to say that a ZEV mandate should not be in place, but rather the development of hydrogen as a ZEV creates issues that would otherwise not be there. Despite the progress associated with the hydrogen strategy being relatively strong and forward-looking, the high costs of hydrogen serve as a looming consideration that could undo progress. It is not just the development of policy that supports niche technologies that matter. Rather, it is also the agency of political actors and the structure that policy must go through which influences the low-carbon transition (Roberts et al., 2018). The high cost of hydrogen HDVs serves as a self-undermining effect because it opens a pathway to alternatives that look more appealing, such as CNG, LNG, and Retrofit designs. Therefore, the creation of policies that aim to facilitate niche development and change the existing regime ignores the fact that the existing transportation landscape has been encouraged to support the growth of LNG and CNG (Janzwood & Millar, 2022; Rosenbloom & Meadowcroft, 2022). This can serve to generate self-undermining feedback effects through emergent losses; in which the original intention of the medium and heavy-duty ZEV mandate creates unintentional loss frames that undermine its legitimacy. These loss frames are created through policy losses in the mass cognition of the base (carriers) it is meant to support. Additionally, though the intention of allowing hydrogen to be used as a ZEV option is meant to be transformative, the specific mode of producing hydrogen fuel could create a non-transformative political system in which incumbents maintain their political positions of power (Jacobs & Weaver, 2015). In this sense, though the Hydrogen Strategy is receiving significant self-reinforcing sequences through the introduction of supportive policies, coalition members who are invested in low-carbon fossil hydrogen do not have much to argue against. Their political legitimacy has the potential to be maintained at all stages of the technological experience curve; despite the decarbonization intentions of the government. In turn, this could make decarbonization efforts during the late stages of the energy transition more complicated, given that the objective of late-stage developments is to phase out carbon-intensive industries and further erode incumbent political legitimacy (Bernstein & Hoffmann, 2019; Breetz et al., 2018; Rosenbloom & Meadowcroft, 2022).

Chapter 6: Policy Feedback Effects of Hydrogen in Industry

Hydrogen thus far has revealed itself to be a fuel that can entrench the interest of fossil incumbents, either economically, socially, or politically. Conversely, renewable hydrogen also holds the potential to establish itself within the province, which could be used to decarbonize harder-to-abate sectors. This may explain why there is so much support for hydrogen from both fossil and renewable interested parties amongst coalition actors (CHA, 2024e). But there is another sector that hydrogen aims to support which can serve to further entrench fossil incumbents; no matter the form of hydrogen production that makes itself available: heavy industrial applications. The upstream and downstream emissions from the oil and gas sector accounted for 21% of the total greenhouse gas emissions in the province between 1990 and 2020. Additionally, the manufacturing and heavy industrial sectors, such as smelting, cement, and chemical plants, accounted for 16% of total greenhouse gas emissions in the same period (Government of Canada & Canada Energy Regulator, 2024a). However, according to the government of BC, electrification is not an efficient means to decarbonize these sectors. Hydrogen, in this regard, is viewed as a "renewable" alternative to electrification that also holds the potential to support economic development (Anon, personal communication, November 2023; CleanBC, 2021; FortisBC, 2024f; Government of BC, 2021; M. Klippenstein, personal communication, December 2023).

The industrial manufacturing sector of BC generates the highest energy demand in the province, taking up a total of 47% of end-use demand (Government of Canada & Canada Energy Regulator, 2024a). To reduce these emissions, the BC government plans to implement policies that will assist in reducing emissions from the industrial sector between 38% - 43% below 2007 levels by 2030, and reduce emissions from the oil and gas sector between 33% – 38% below 2007 levels by 2030 (Ministry of Environment and Climate Change, 2023a). Hydrogen yields the potential to reduce emissions from the industrial and synthetic fuels sector by 25% in 2050, and also provide 15% reductions in the natural gas sector by 2050 (Government of BC, 2021). This chapter argues that hydrogen as a decarbonization device for heavy industry can cause complications when deep decarbonization matters the most. This chapter will begin with a brief discussion of the industrial strategy within the BC Hydrogen Strategy. It will then discuss the CleanBC Program for Industry and its underlying policies, finding that investments in low-carbon fossil hydrogen could undermine renewable hydrogen as it begins to tax the provincial energy grid. Afterward, this chapter will discuss strategies that are being developed by the provincial public utilities and finds that diffusing hydrogen through a mass market could further establish the political dominance of incumbents. This chapter will also revisit the provincial Low Carbon Fuel Standard and finds that low-carbon fossil hydrogen could be used to further legitimize the use of natural gas. To conclude, this chapter discusses its overall findings, the reinforcing effects of the Hydrogen Strategies industrial policies, and the prospects of deep decarbonization during the late stages of hydrogen diffusion.

The BC Hydrogen Strategy and the Industrial Sector

Once more, the BC Hydrogen Strategy approaches decarbonizing heavy industries through 3 different periods; the 2020 – 2025 period, the 2025 – 2030 period, and the 2030 and beyond periods. How current policy is shaping support for hydrogen within the industrial sector will be the focus of this chapter, with insight into how feedback effects are either reinforcing or undermining the plans discussed within the industrial section of the BC Hydrogen Strategy. During the 2020 – 2025 period, the government of BC aims to evaluate the use of hydrogen within heavy industry. Each industry requires separate evaluation, as each industry requires separate energy needs (CleanBC, 2021). Industries to be evaluated are pulp and paper mills, cement plants, petroleum refineries, and aluminum smelters. There is currently very limited information on the industrial applications for hydrogen in the cement and aluminum industries in BC, so most of this chapter will discuss the use of hydrogen in pulp and paper mills and petroleum refineries. The province also plans to support pilot projects for hydrogen used in synthetic fuel production and explore carbon-intensity targets under the Low Carbon Fuel Standard (LCFS). Within the 2025 – 2030 period, the government plans to review the success of pilot projects within BC industries and continue to support the use of hydrogen in the industrial sector. The government will also continue to support the production of synthetic fuels, with the aim that hydrogen will contribute to the production of 650 million liters of renewable or low-carbon fuel per year, allowing for a reduction in carbon fuel intensity by 20% in 2030. Within the 2030 – beyond period, the government plans to support the use of low-carbon hydrogen within their industrial sector where appropriate (Government of BC, 2021).

Supporting Policy: The CleanBC Program for Industry

The CleanBC Program for Industry is comprised of a CleanBC Industrial Incentive Program (CIIP), a provincial Output-Based Pricing System (OBPS), which will replace the CIIP in 2024, and a CleanBC Industry fund (CleanBC, 2021; Ministry of Environment and Climate Change, 2024a). The CIIP has been in place since 2019 and was initially created to reduce emissions and improve industrial competitiveness for industrial operations by directing a portion of industrial carbon taxes into incentives to clean their operations. Cleaner operations would result in less carbon tax being paid, while also receiving the return benefit of the carbon tax through the CIIP if their industrial performance measures were equal or better to "world leading low-carbon emission benchmarks", which would vary depending upon the specific industrial application (Ministry of Environment and Climate Change, 2024b, 2024d). The CIIP remained in place until April 2024, when it was replaced with the new provincial OBPS. The OBPS is mandatory for industries that emit over 10,000 tons of CO2 equivalents per year and is meant to aid in achieving provincial net-zero targets by incentivizing industrial operators to reduce their emissions. If an operator reduces their emissions by a certain threshold, then they can earn credits for their emission reductions. However, if an operator does not go under their emissions threshold, they will be faced with compliance obligations. Compliance obligations can be met by either using earned credits under the OBPS, BC offset units which are earned through carbon-offset projects, (Ministry of Environment and Climate Change, 2024g), or paying direct payments to the province (Ministry of Environment and Climate Change, 2024e). Within the OBPS, as opposed to the CIIP, operators can be exempted from paying carbon tax, but the stringency measures in carbon threshold reductions are also more severe. The inclusion of carbon offsets also allows industries more flexibility to reach their threshold targets (Ministry of Environment and Climate Change, 2024e). With pressure from the OBPS to reduce carbon emissions, industries are encouraged to adopt negative emission technologies, such as carbon capture and storage or direct CO2 air capture (CleanBC, 2021).

The CleanBC Industry fund serves to eventually support emission reduction projects through four funding streams. These funding streams are "Emissions Performance", projects which are meant to reduce emissions in an industrial operation; "Innovation Accelerator", which is meant to fund pilot projects for clean technologies; "Feasibility Studies", which will provide funding for preliminary studies to test the potential for projects that could eventually apply to the other funding streams; and "Industrial Electrification", a partnership with BC Hydro that will provide funds to aid industry that needs assistance connecting or upgrading their connection to BC Hydro's grid (Ministry of Environment and Climate Change, 2024a, 2024c).

Under the funding stream for Innovation Accelerator, there are currently two hydrogen-based projects that have received funding so far. The first is a hydrogen blending project with Nanaimo Forest Products, the parent company of Harmac Pacific, which is a pulp mill operating on Vancouver Island (Nanaimo, 2024). This project, in partnership with HTEC and FortisBC, seeks to demonstrate how blended hydrogen derived from electrolysis can be used to reduce emissions from combustion fuels. Another project is a commercial demonstration of hydrogen derived from pyrolysis[23] through a partnership of FortisBC and Hazer Group; an Australian-based company interested in advancing pyrolysis development (Hazer Group, 2023b). This project seeks

[23] See Chapter 3 for information on pyrolysis or "turquoise" hydrogen.

to test the decomposition of methane into hydrogen and graphite (Strategy, 2024). FortisBC is actively involved with accelerating the use of pyrolysis within the province in partnership with Hazer Group, as they are currently in the business and development phase of another project known as the "Hazer-BC" project. The planned project would produce around 400,000 gigajoules of hydrogen per year, and though originally meant to be in an undisclosed location that is owned by the Albertan-based company, Suncor Energy, the project has been delayed since Suncor backed out of the original agreement (Anon, personal communication, February 2024; Dokso, 2023a). The project would see Hazer Group technology producing low-carbon fossil hydrogen from a stream of natural gas being provided by FortisBC, who would then redistribute that hydrogen to consumers (Hazer Group, 2023a).

Within the Feasibility Studies stream of funding, two other projects involving low-carbon fossil hydrogen production have received funding; both of which involve CCS. These projects are led by NorthRiver Midstream Inc., a gas gathering and processing business located in northeast BC and northwest Alberta (North River Midstream, 2020). The feasibility studies, located in the District of Taylor, BC, and Fort Nelson, BC, seek to understand the feasibility of technologies required to produce hydrogen and capture emissions, hydrogen transportation, storage, and commercial utilization (Strategy, 2024). Though not specific to hydrogen, there are also funding streams for projects with a demonstrated interest in CCUS. For instance, Petronas Energy, one of the largest LNG operators in the world has received funding through the Innovation Accelerator funding stream to demonstrate carbon capture and storage on two natural gas-fired engines in Northeast BC (Strategy, 2024). Petronas Energy has also taken great interest in developing hydrogen produced from blue and green operations in Canada and Asia (Dokso, 2023b; Morgan, 2021; Petronas Canada, 2018). ARC Resources Ltd, the third largest gas producer in Canada, also has a demonstrated interest in hydrogen production since their partnership with Ekona Power; a hydrogen producer that uses pyrolysis to produce their hydrogen (ARC Resources, 2022b, 2024; Ekona Power, 2024). ARC Resources has already fully electrified its natural gas plants, in part thanks to funding provided by the CleanBC Industry Fund (ARC Resources, 2022a), and has also received funding for installing carbon capture and storage equipment (Strategy, 2024).

Though it is too early to tell how much industry has already connected to BC Hydro's grid through support from the Industrial Electrification funding stream, there has been an incredible increase in demand to electrify industry within the province. Currently, there is 7000MW of proposed industrial electrification demand in the province; relatively six times the amount of power the new Site C dam can produce (Ministry of Energy Mines and Low Carbon Innovation, 2024f, 2024f). As seen in Chapter 4, the renewable hydrogen project being commissioned by Fortesque will require almost the same amount of generating power that the Site C dam will be producing once it has finished construction (BC Hydro, 2023; Petersen, 2023). This begs the question, where will this energy supply come from? BC Hydro is committing $36 billion towards community and regional infrastructure projects in the next ten years, $10 billion of which will be used for new electrification projects and emission reduction efforts (Ministry of Energy Mines and Low Carbon Innovation, 2024f). According to the 2021 BC Hydro Integrated Resource Plan, the provincial grid currently has an overabundance of energy available; but additional resources will be required within the next 10 years. By 2029, “new energy” needs to occur in the fiscal year of 2029, while capacity needs to be improved in fiscal year 2032. In a 2023 update to the plan, BC Hydro cites hydrogen via electrolysis as being primarily to blame for forecast loads increasing in fiscal year 2040 (BC Hydro, 2021a). This implies that the growth of renewable hydrogen on the electricity grid is predicted to have a big impact on electricity demand.

Through the CleanBC Program Industry, the advancement of the OBPS from the CIIP creates conditions that encourage decarbonization projects in heavy industrial applications. It encourages the development and use of carbon capture technologies to achieve emission reduction targets, which can generate progress in low-carbon fossil hydrogen production (Breetz et al., 2018). The addition of a credit system also serves to align the interest of incumbents by signaling a new operating standard to fossil-dependent industries, while also quieting their interest through earned credits that can be traded to further comply with emission reductions (Meckling & Nahm, 2022). Hydrogen can be used to also decrease overall emissions from certain industrial applications, though most funding streams are supporting low-carbon fossil hydrogen technologies. As established in the hydrogen production chapter, though low-carbon fossil hydrogen projects can be used to abate carbon emissions from industry; it does not erode the political legitimacy of fossil fuel incumbents. Interest in hydrogen from Petronas Energy and ARC Resources shows a growing interest in fossil incumbents interested in “dipping their hand” into the hydrogen market when it is more readily diffused. This reveals an accelerated interest in actors seeking to maintain the status quo by using hydrogen to support their industry that produces carbon-intensive fuel; which could further encourage lock-in mechanisms (Seto et al., 2016). Therefore, investments in low-carbon fossil hydrogen by the provincial government could serve to entrench fossil interests further. The additional discrepancy of extremely high electricity demands from renewable hydrogen could further serve this end. Though the grid could potentially handle increasing demands to electrify industry; the presence of renewable hydrogen is having an impact on the expected energy demands on the provincial electricity grid. If electricity demand places undue burdens on the provincial grid, political actors could use the downsides of the high energy demands of renewable hydrogen to promote the use of the fossil alternatives, namely SMR+CCS or pyrolysis, ultimately facilitating carbon lock-in through political discourse that aims to thwart climate objectives (Buschmann & Oels, 2019; Lamb et al., 2020).

BC Hydro and FortisBC

Though the grid may experience demand from a lot of incoming industrial projects, BC Hydro is not deterred from incoming industry consumers. The utility is encouraging growth in industrial electrification, renewable hydrogen, and carbon capture and storage (BC Hydro, 2021b). Although carbon capture and storage projects can be used to begin low-carbon fossil hydrogen production; they do have an additional benefit for decarbonization efforts. Carbon capture technology is not inherently a bad thing, and in fact, can assist with decarbonizing the province by reducing overall carbon emissions. Though it can legitimize the continued production of fossil fuels (Kemfert et al., 2022), it can also capture emissions from biomass energy production and pulp and paper industries (CleanBC, 2021). In addition to promoting the use of carbon capture and renewable hydrogen production, BC Hydro seeks to promote fuel switching in the heavy-industrial sector. Recognizing the cost of switching over from fossil to renewable heating, the utility plans to encourage electricity adoption through a financial incentive program. BC Hydro has committed $60 million to incentivize fuel switching, $25 million to incentivize funding for new customers connecting to their grid, and $20 million to incentivize support for hydrogen production (BC Hydro, 2021b). BC Hydro has also introduced the Clean Industry and Innovation Rate, which was designed to encourage industrial customers to connect to the grid at a lower cost. This rate was also applicable to the hydrogen industry, though because it has been “fully subscribed”, the government is no longer encouraging hydrogen producers to apply to the application. For the first five years, industrial customers would receive a 20% discount rate. Afterward, they would receive a 13% discount rate in their 6th year, and a 7% discount rate in their 7th year (Anon, personal communication, November 2023; BC Hydro, 2024; Government of BC, 2021).

Hydrogen is generally seen as a renewable fuel that can support the electrification of current and upcoming industries in BC. The distribution of hydrogen supply to industrial customers may also be viewed as a method to support BC Hydro as it prepares to provide renewable energy to growing industrial sectors (FortisBC, 2024f; Ministry of Energy Mines and Low Carbon Innovation, 2024f). Given the high energy and monetary cost of producing renewable hydrogen (Anon, personal communication, February 2024; BC Hydro, 2021b; HTEC, 2023b; Xiao, 2024), pipeline infrastructure could be viewed as a way to decrease cost and easily supply industries with direct hydrogen production. Thanks to amendments to the Greenhouse Gas Reduction Regulation and the Utilities Commission Act,[24] FortisBC and BC Hydro can now purchase and distribute hydrogen to customers. This hydrogen can come from either renewable hydrogen or waste hydrogen (Province of British Columbia, 2021). More specifically, FortisBC is allowed to sell hydrogen to replace "at least in part" the use of natural gas. The gas utility plans to decarbonize heavy-industrial applications by creating networks of pipes alongside natural gas pipelines to transport hydrogen directly to the purchaser (Anon, personal communication, February 2024). Specifically designed pipelines would be necessary for using hydrogen for heavy industry, as hydrogen erodes commonly used pipelines (Xiao, 2024), though there is also the potential to reuse older pipelines by simply inserting a new pipe along the same vein (M. Klippenstein, personal communication, December 2023). By co-locating a hydrogen pipe and a natural gas pipe, large industrial producers could have a steady flow of hydrogen available to them but also have a stable baseload of natural gas available as a backup "in case" hydrogen comes offline. This would provide security for industrial customers who require a constant feedstock of energy, and who also want to clean their upstream emissions. Through this route, hydrogen hubs can be further developed via pipelines that carry hydrogen for industrial consumers. As pipelines are manufactured and connected to heavy-industrial consumers, "branching" pipelines can also lay out a refueling network for heavy-duty trucks. It will be some time before hydrogen is used in this manner, as

[24] See Chapter 4.

FortisBC is primarily focused on developing its renewable natural gas capacity (Anon, personal communication, February 2024; FortisBC, 2024c).

The use of financial incentives supports the diffusion of hydrogen from an early economic perspective. Additionally, the use of existing pipeline infrastructure to further deliver hydrogen aids in fortifying coalition support; as the gas utility is being used in alignment with decarbonization goals. These strategies serve to aid the diffusion of hydrogen as it diffuses and expands outwards from the niche markets centered around hydrogen hubs (Breetz et al., 2018; U.S. Department of Energy, 2024b). But as we have already established in this chapter, renewable hydrogen is vulnerable to political actors aiming to maintain the status quo and invest in low-carbon fossil hydrogen as an alternative. In addition to this, we have also established in Chapter 4 that low-carbon fossil hydrogen can serve to reinforce the political legitimacy of incumbents. Already, it is generally understood throughout government and civil servants, that meeting the energy demands of hydrogen from only in-province renewable energy generation would be extremely difficult because of limitations on the grid (BC Hydro, 2021a; M. Klippenstein, personal communication, December 2023).

With these key points in mind, the use of hydrogen to "decarbonize" heavy industries could reinforce the legitimacy of fossil incumbents even further in two ways. First, if low-carbon fossil hydrogen is viewed to be more cost-effective than renewable hydrogen; it could become more readily used for decarbonization efforts, which means an increased use of natural gas to produce that hydrogen (Howarth & Jacobson, 2021). Second is the direct decarbonization of fossil fuel production itself. We cannot forget that natural gas is often used to support other important products that many of us use or take advantage of daily; such as synthetic fertilizers, plastics, and some pharmaceuticals (CAPP, 2024). But this does not excuse creating new pipeline infrastructure to decarbonize the industry while we are also using the same fuels to support other sectors, such as the transportation sector. From 2000 to 2019, natural gas was mostly used for further oil and gas extraction purposes. In the same time frame, oil was mostly used for transportation purposes or industrial purposes (IEA, 2022, pp. 213 & 237). With this in mind, we need deep decarbonization and divestments from the oil and gas sector to meet our climate objectives. Yet the province of BC aims to continue using hydrogen, which could come as a by-product of natural gas production. But even if it comes from renewable hydrogen, it is still being used to decarbonize a sector that is mostly used as a source of fuel for the industries hydrogen also seeks to replace: industry and transportation. In this cyclical arrangement; hydrogen further legitimizes political incumbents in our energy systems, no matter how noble of an intention the use of hydrogen is, and undermines efforts to destabilize fossil incumbent's political and economic authority (Bernstein & Hoffmann, 2019; Rosenbloom & Rinscheid, 2020).

The Low Carbon Fuel Standard Revisited: Increasing Natural Gas Production

The LCFS, as described in the transportation chapter, allows for fuels such as natural gas, electricity, propane, and "prescribed fuels" such as hydrogen to be used in the province as an alternative to carbon-intensive fuels; such as gasoline and diesel (King's Printer, 2024c, 2024e). Emission reduction stringencies for the LCFS have increased to a 30% decrease in gasoline and diesel relative to 2010 levels since the release of the CleanBC Roadmap to 2030. This is an increase from the emission reduction target that was in place before the change, which initially targeted a 20% reduction in the carbon intensity of fuels by 2030. The penalty for not reaching these targets has also increased from $200 per tonne to $600 per tonne. These amendments intend to encourage a continued investment into low-carbon fuels, and steer away from fossil fuel use (Ministry of Energy Mines and Low Carbon Innovation, 2022b). Low-carbon fuels are supported in two ways within the same credit system. In one sense, fuel suppliers that adhere to the LCFS are eligible for credits to help them comply with emission reductions or assist other fuel suppliers with their emission reductions. In another sense, debits that are created can be used to fund clean energy projects (CleanBC, 2021; Gill, 2023; Juan Ding, 2022; Ministry of Energy Mines and Low Carbon Innovation, 2018).

Hydrogen could serve to circumvent the goal of LCFS to reduce emissions from natural gas because of the credit system. Credits are based on compliance measures, and organizations must have a balance of zero or more compliance units at the end of an annual reporting period to receive their credits (Gill, 2023; Ministry of Energy Mines and Low Carbon Innovation, 2024g). Where fossil incumbents are being encouraged to adopt carbon capture technologies, this serves as a way to comply with the carbon intensity of their fuel, as carbon intensity is based on the entire lifecycle of the fuel (Ministry of Energy Mines and Low Carbon Innovation, 2024a). Combining this with low-carbon hydrogen production; or more specifically steam methane reformation (see Chapter 3), allows natural gas producers to have even more carbon credits as they market two "low carbon" fuels (Ministry of Energy Mines and Low Carbon Innovation, 2024g). With more credits, natural gas industries can more easily comply with compliance targets, which allows more natural gas to be produced; which in turn can continue to be used for oil and gas extraction purposes (IEA, 2022). This, in effect, is an example of the fractal carbon trap. The natural gas system improves, but through improving the natural gas system, more natural gas can be produced, which could facilitate further end uses of the natural gas. This locks a system, which was already subjected to carbon lock-in, further into the socio-economic system of BC (Bernstein & Hoffmann, 2019). Pyrolysis does not escape this criticism either, as its necessary supply of natural gas locks in natural gas production in an economic system that is trying to decarbonize.

Feedback Effects in Industry

Incumbents, as technology develops at the top of the experience curve, have a dominant voice in policy decision-making (Breetz et al., 2018). Policies that aim to support the industrial use of hydrogen support both renewable and low-carbon fossil hydrogen and are mostly being used to serve low-carbon fossil hydrogen technologies. Additionally, costly technologies are vulnerable to being undermined by self-undermining feedback effects if cost becomes viewed as a problem (Roberts et al., 2018). The dominant voice of fossil incumbents could serve to undermine renewable hydrogen development and encourage carbon lock-in through political discourse that emphasizes the electricity and monetary cost as a downside (Buschmann & Oels, 2019; Lamb et al., 2020). Beyond this, hydrogen serves to also entrench natural gas production in the province, and though low-carbon fossil hydrogen could facilitate deeper entrenchment; renewable hydrogen in BC could do the same.

This demonstrates how reinforcing sequences can undermine decarbonization efforts if the policy that is being reinforced also serves the interests of incumbent industries. Within the 2020 – 2025 period, pilot projects for synthetic fuel production are being supported through projects such as the hydrogen blending project, with partners Nanaimo Forest Products, HTEC, and FortisBC. Additionally, these projects are serving as a way for the government to evaluate the use of hydrogen in heavy industries. Carbon intensity targets have also been explored in the LCFS, as the LCFS was updated soon after the release of the CleanBC Roadmap to 2030. Though initially, these policies serve to reinforce the BC Hydrogen Strategy through adhesion mechanisms that encourage investments into programs and technologies (Jordan & Matt, 2014), these very policies could also serve to undermine long-term decarbonization targets. By using hydrogen to decarbonize oil and gas, the government of BC is creating policies that are non-transformative to the current regime of political interests. Taken a step further, if the provincial government continues to invest in low-carbon fossil hydrogen, then they are further legitimizing the continuation of natural gas production. If this is more cost-effective in a future where there could be energy insecurity with upcoming industrial projects, political actors can undermine decarbonization efforts further by framing messages that prompt losses in mass cognition among the mass public, because the alternative is much more appealing in a cost reduction perspective (Jacobs & Weaver, 2015).

To even greater effect, the interest in both renewable and low-carbon fossil hydrogen production from major fossil fuel producers such as Petronas Energy should trigger alarm bells for anyone concerned about deep decarbonization at the late stages of the technological experience curve. Technologies that require large societal or industrial changes will face political hurdles as they become cost competitive. Though low-carbon fossil hydrogen does not necessarily require drastic changes to the regime, renewable hydrogen requires completely new industrial projects to become available. To facilitate deep decarbonization and “level the playing field”, policymakers usually must find ways to enforce economic strain on incumbents and align social interests with green policy objectives to deprive political power from incumbent industries (Breetz et al., 2018). This can be done through deliberate decline mechanisms, either by continuing knowledgeable coalition support that destabilizes the regime, divesting financial resources that entrench the political legitimacy of incumbents, or terminating carbon-intensive technology (Rosenbloom & Rinscheid, 2020). However, as hydrogen in BC facilitates coalition support that encourages the development of both renewable and low-carbon fossil hydrogen, fossil incumbents who would typically resist a niche technologies development (Breetz et al., 2018) serve to instead be the knowledgeable support system. This could make managed termination of carbon-intensive industries at the bottom of the experience curve far more difficult; as the political legitimacy of incumbents has not been eroded (Rosenbloom & Rinscheid, 2020). The niche that is meant to change the regime becomes vulnerable to surrounding landscapes as the regime is actively pursuing the maintenance of the status quo (Rosenbloom & Meadowcroft, 2022). In time, this facilitates a much broader *double-trap,* in which the technology that is seeking to change the regime makes a marginal difference to deep decarbonization efforts, establishing only some levels of decarbonization (Bernstein & Hoffmann, 2019).

Chapter 7: Discussion and Conclusion

This research finds that hydrogen development in BC is being thoroughly supported but is at risk of being undermined by political incumbents. The study finds that by and large, the BC Hydrogen Strategy has generated self-reinforcing feedback effects. Currently, in the early stages of hydrogen development, renewable hydrogen has an edge in terms of its production capabilities due to there being several established renewable hydrogen facilities that are currently under consideration. But this serves as a red herring to the overall political dynamics that are occurring with hydrogen development in the province. Though the Hydrogen Strategy itself is not being undermined, its very design allows for alternatives that can make decarbonization efforts difficult in the upcoming years.

Summary of Findings

This study finds that the development of hydrogen production industry in British Columbia has required legislative amendments, as well as financial incentives to encourage hydrogen adoption in the province. The BC government has also implemented regulation changes to better facilitate growth in production and allow hydrogen to become more accessible in the provincial energy market. This has been achieved through robust reforms to the Utilities Commission Act and the Greenhouse Gas Reduction Regulation, and financial support being provided by the BC Centre for Innovation and Clean Energy, BC Hydro, and programs provided by the federal government. However, the study also finds that as these support structures generate spoils (Pierson, 1993) for both renewable and low-carbon fossil hydrogen these structures are likely to only support the growth of upcoming niches instead of also facilitating a shift in the current political influences that exist within the regime (Rosenbloom & Meadowcroft, 2022). The BC Hydrogen Strategy could facilitate support for hydrogen in the mid-transition period but at the cost of maintaining the political legitimacy of incumbents. This, in turn, could place the mid-transitional period of hydrogen production in a fractal carbon trap, in which systems improve; but the legitimacy of incumbents remains intact, preventing future strategies that aim to destabilize the legitimacy of low-carbon fossil hydrogen (Bernstein & Hoffmann, 2019; Rosenbloom & Rinscheid, 2020).

Evidence suggests that the diffusion of hydrogen in the transportation sector is being met with success, according to measures developed by Breetz et al (2018). Pilot projects and supporting refueling infrastructure projects are being funded through programs such as the CleanBC Go Electric Commercial Vehicles Pilot Program, the Advanced Research Commercialization Program, and the Innovation Clean Energy Fund. These spoils (Pierson, 1993) allow original equipment manufacturers interested in entering the hydrogen HDV market to better position themselves; and facilitate some levels of financial support that are necessary at the early stages of the experience curve (Breetz et al., 2018). Additionally, the prerequisite of the Low Carbon Fuel Standard and the CleanBC Go Electric programs set up foundational support for investing in low-carbon fuels that aim to replace natural gas (Lamb et al., 2020). The advancement of hybrid designs also facilitates growth in the production value chain, while also granting familiarity to hydrogen for carriers hoping to transition to a cleaner alternative. The ZEV Mandate also aims to build upon the ZEV Act by legislating growth in the zero-emission

HDV sector. However, hydrogen presents an issue for clean vehicle adoption largely because of the price of fuel and the price of hydrogen HDVs. As shown in the BCTA survey, plenty of carriers prefer CNG, LNG, and hybrids over battery electric and hydrogen fuel cells. Though pilot projects aim to generate knowledge about the feasibility of hydrogen HDVs which can be shared with carriers, technologies that are reinforced through policy developments often face challenges when high costs become associated with that technology (Roberts et al., 2018). The availability of alternatives from hydrogen and battery electric vehicles then looks more favorable. Additionally, if hydrogen HDVs are adopted, high expenses that are transferred to consumers could make the ZEV mandate vulnerable to policy backsliding, in which political allies to incumbents frame the enforcement of zero-emission vehicles as a policy that is generating economic grief in the province (Jacobs & Weaver, 2015; Lamb et al., 2020). In all respects, unless production does head in the direction of being exclusive to renewables, the adoption of hydrogen HDVs continues to serve the interest of incumbent fossil fuel actors.

Lastly, hydrogen diffusion into the industrial market is very much in the preliminary stages; but also holds some promise. In the context of decarbonization, however, outcomes are not looking good. Potentially high strains on the energy grid through renewable hydrogen, compounded with a large portion of pilot project funding going towards low-carbon fossil hydrogen projects, create an economic atmosphere that greatly favors the production of low-carbon fossil hydrogen. Additionally, it appears that despite there being interest from the government of BC to evaluate the use of hydrogen in cement, steel, pulp and paper, and oil production; there seems to be a greater interest in facilitating hydrogen development around oil and gas.[25] Though it seems in some retrospect there is financial support allowing for niche developments to decarbonize heavy-industry that could support hydrogen diffusion (Breetz et al., 2018), this support seems to mostly supply the interest of fossil incumbents. Low-carbon fossil hydrogen also presents an opportunity for fossil incumbents to generate additional credits under the LCFS, which could allow for more production of natural gas than intended as the province aims to decarbonize.

Policy and Theoretical Implications for Deep Decarbonization

We see early financial support and policy development that opens hydrogen to the market and allows for the development of coalitions that can further support and facilitate the growth of the provincial hydrogen economy. For instance, policymakers' amendments to the Utilities Commission Act and the Greenhouse Gas Reduction Regulation allow provincial utilities to purchase and sell hydrogen in the market without many regulatory barriers. Additionally, government incentives to attract hydrogen producers through resources distributed by BC Hydro have further established hydrogen producers who can take advantage of the development of hydrogen distribution systems. Furthermore, government-funded incentives to promote vehicle adoption and pilot projects encourage growth in hydrogen demand in some instances. Government policies have fostered a growing industrial demand for hydrogen by facilitating a need to develop

[25] Admittedly, this could be due to a lack of project time that limits the scope of analysis. However, this does generate concern over the effects hydrogen will have on deep decarbonization.

infrastructure that supports upcoming demand. These developments, as established by Breetz et al. (2018), demonstrate the significant extent of climate policy and support that is incredibly necessary for the development of technology that seeks to replace incumbent fossil fuel interests. The BC Hydrogen Strategy has also contributed to the growth of a coalition that is cross-jurisdictionally aligned, which establishes a growing and diverse hydrogen economy (Levin et al., 2012; Meckling & Nahm, 2022).

However, because the Hydrogen Strategy seeks to establish hydrogen as a low-carbon fuel that replaces carbon-intensive infrastructure, and also seeks to support carbon-intensive industries, the programs and policies that support the strategy also serve to undermine its very objectives. Some aspects of previous policy developments, such as the CleanBC Go Electric Program, aim to facilitate growth in the niche market of ZEVs while also growing coalition support for ZEVs in the hopes of changing the political authority in the current regime. Developing knowledgeable coalition support facilitates ZEV access to the market that is also backed by knowledgeable support groups to defend against resistance that would normally come from incumbents (Breetz et al., 2018; Lamb et al., 2020; Meckling & Nahm, 2022). However, the introduction of hydrogen changes this power dynamic. This study finds that the BC Hydrogen Strategy is largely focused on accelerating the niche industry of hydrogen (including both renewable and low-carbon fossil hydrogen), while not being concerned about the dominant regime and potential factors within the landscape (Rosenbloom & Meadowcroft, 2022).

Typically, strategies to facilitate the growth of a niche market require political and financial support to varying degrees, as we have seen with the growth of hydrogen so far. In addition to this, niche technologies can also be encouraged by placing pressure on existing fossil-dependent systems. This can be done through performance standards that encourage technological adoption, or by purposefully increasing the cost of carbon-intensive fuel by increasing their cost, creating stringent environmental standards, or reducing subsidies granted to them (Breetz et al., 2018). But in the case of hydrogen, many of these strategies cannot work when low-carbon fossil hydrogen enters the picture. Performance standards encourage the adoption of low-carbon hydrogen, entrenching political legitimacy. Subsidies cannot be reduced, as subsidies are going directly to fossil incumbents to support hydrogen development in the market. Environmental standards simply increase the demand for hydrogen production through the presence of credit systems. Though the cost of carbon-intensive fuel can be increased, this has a negative effect on the already costly fuel that is trying to be diffused to facilitate a “renewable” future.

Though this could facilitate a mid-transitional period in which hydrogen diffuses into the market without much political resistance, this could also create issues with deep decarbonization. Typically, in the mid-transition period, incumbents who resist niche technologies can be combated with the development of knowledgeable coalitions, by limiting incumbent access to private negotiations, political signaling to business actors of upcoming policy objectives, triggering feedback mechanisms to establish future policy decisions that can allow for deliberate decline mechanisms, and compensating incumbents as the market shifts (Meckling & Nahm, 2022). These strategies to resist incumbents are still seen to be at play when incumbents are also on the side of a niche technology. But rather than limiting access to incumbents, hydrogen invites them to the dinner table. This presents problems for deliberate decline mechanisms that are necessary for the late stages of niche technology developments, in which typically the "playing field" must be leveled within incumbent fossil fuels by enforcing economic strains on incumbents and aligning policy with "green" objectives to fully decarbonize (Breetz et al., 2018). Yet coalitions that aim to steer governments away from fossil systems no longer have the capacity to do so when the niche market they have been fighting for also encourages natural gas production. With low-carbon hydrogen encouraging natural gas production, which is also used to fuel alternative modes of transportation and oil refining, carbon-intensive systems can no longer be replaced. Therefore, the existing regime cannot be destabilized. Though technologies may have shifted, the power that rests within the regime has not, and therefore managed termination is no longer an option (Grubert & Hastings-Simon, 2022; Rosenbloom & Meadowcroft, 2022; Rosenbloom & Rinscheid, 2020).

The establishment of both renewable and low-carbon fossil hydrogen, therefore, represents a compelling example of the fractal carbon trap (Bernstein & Hoffmann, 2019). Whereas BC is attempting to decarbonize by encouraging the growth of clean energy, low-carbon rather than zero-carbon fuels are set up to "win", positioning industries in a system improvement phase. As investments are encouraging sunk cost into renewable and fossil infrastructure while everything is still in its pilot stage, the government of BC is risking mass investments into a technology that has arguably not been fully tested to work. If renewable hydrogen proves too costly, low-carbon fossil hydrogen gains an advantage. If low-carbon fossil hydrogen proves inefficient, then renewable hydrogen gains an edge but at a greater financial cost; opening political discourse that can thwart climate objectives by emphasizing the downsides of these costs (Buschmann & Oels, 2019; Jacobs & Weaver, 2015; Lamb et al., 2020; Roberts et al., 2018). It is a political and economic system that is trying to decarbonize, while also potentially relying on fossil incumbents to ease the transition into a “renewable” hydrogen future. With so many opportunities for renewable hydrogen development to be undermined by political incumbents, this is a clear example of how our “transportation and energy infrastructure, cultural practices, technological options, political coalitions and institutional capacities reinforce the natural use of fossil energy” (Bernstein & Hoffmann, 2019).

The Reality of Renewable Hydrogen

Just as carbon capture and storage is not “inherently bad”, neither is renewable hydrogen “inherently good”. Rather, it is how governments aim to use renewable hydrogen that can make it an issue for deep decarbonization efforts. There are still economic risks if renewable hydrogen is used for every industrial sector and business. Already, in other regions in Canada and Europe, feasibility studies have been conducted to test the economic viability of hydrogen. For example, a working paper discussing the home heating applications of hydrogen in Germany found that heat pumps would be far more cost-efficient than renewable or low-carbon fossil hydrogen; even with the inclusion of a cost-sensitivity analysis (Baldino et al., 2021). Additionally, a similar white paper released for the UK found similar results, concluding that even in the case where renewable prices were 50% higher and natural gas prices were 50% lower, heat pumps would still be the most cost-effective option (Baldino et al., 2020). Renewable hydrogen has also been seen to be very cost-intensive for the trucking industry in the province of Québec. By 2026, Québec will need to begin expanding its power needs; but still intends to invest in renewable hydrogen to invest in harder-to-abate sectors. A state of energy study out of Québec identified that if all HDVs were to switch to hydrogen, Québec would have to produce an additional 35-terawatt hours of electricity to fuel them. This demand is equivalent to how much Québec currently exports (HEC Montréal, 2024). Additionally, in 2023 a techno-economic assessment of net-zero technologies on the highway corridor between Quebec City and Windsor was conducted to test the economic feasibility of infrastructure and HDV adoption for alternative fuels to diesel. The study found that by 2050, fuel cell HDVs running off electrolysis were the only technology that did not create a positive net-present value, and actually resulted in a loss of -$2,224 million (Cyr et al., 2023).

The aim of this study is not to scare away developments in renewable hydrogen. Rather, I wish to highlight the reality of how economically vulnerable renewable hydrogen can make a provincial energy grid, and how this vulnerability can result in increased support for low-carbon fossil hydrogen as an alternative. Therefore, if renewable hydrogen is introduced to the grid, it should be used for "no-regret" sectors to be economically viable. "No-regret" sectors would be hard-to-abate sectors in which there is absolutely no other option aside from hydrogen can be used to power necessary industrial processes (J. Whitmore, personal communication, February 14, 2024). An energy policy paper in the country of Germany, for instance, indicated that policymakers must assess which applications hydrogen is essential for decarbonization purposes, and limit supply for those specific applications. Additionally, the paper indicated that unless infrastructure to support renewable hydrogen was increased to make renewable hydrogen cost competitive to low-carbon fossil hydrogen, renewable hydrogen would require long-term subsidies (George et al., 2022). Therefore, for the sake of economic sustainability, renewable hydrogen should be considered only on a case-by-case basis.

Concluding Thoughts

Technological transitions within the context of decarbonization face a beast that other transitions have had more luxury with, the beast of time. Though there are additional issues to consider,[26] we face what was previously described by Rittel & Webber (1973), and later Levin et al. (2012), as a "wicked", or "super wicked" problem for policy development. Time is running out to decarbonize, therefore mistakes in policy development cannot necessarily be reversed. Policies that are being developed within our fossil-dependent social and economic systems require broad and encompassing levels of cooperation among interest groups to become successful (Levin et al., 2012). We require careful, yet purposeful levels of progress with our decarbonization goals to avoid backstepping into mechanisms that lock in carbon-intensive industries. We must also destabilize incumbent industries without suffering the consequences of an economic downturn (Bernstein & Hoffmann, 2019; Grubert & Hastings-Simon, 2022). This is complicated further because decarbonization requires an acceleration of technology adoption that can aid in decarbonizing carbon-intensive sectors. As a result, we run the risk of generating policy that could introduce new challenges to decarbonize our

[26] Such as the cost to users and the problems we face with equity as we fund this transition.

interconnected, fossil fuel-dependent systems at an accelerated pace (Breetz et al., 2018; Fouquet, 2016; Grubert & Hastings-Simon, 2022; Rosenbloom & Meadowcroft, 2022).

Hydrogen expands upon these issues two-fold. Hydrogen risks supporting the industry we need to separate ourselves from, not just from a fossil hydrogen standpoint, but also from a renewable hydrogen standpoint. It allows for political elites who are deeply interested in maintaining the status quo to either encourage hydrogen development or support the very industries we seek to divert from. It also allows political actors to destabilize the legitimacy of renewable hydrogen because of how costly it is to our energy systems and wallets. We must be actively conscious in our climate policy decision-making, not only focusing on creating policy that "sticks" and entrenches itself as an enabler for decarbonization goals; but also using forward reasoning in our policy approaches. In this way, we can generate policy that encourages a technological transition without entrenching the interest of political incumbents (Grubert & Hastings-Simon, 2022; Levin et al., 2012; M. Paterson et al., 2022; Rosenbloom & Rinscheid, 2020).

This paper finds that investing in renewable and low-carbon hydrogen is unlikely to generate enough political change to destabilize the existing dominance of the fossil fuel industry. Rather, that if BC and Canada is to move forward with renewable hydrogen production, it must develop it for "no-regret" sectors to avoid entrenching the political resilience of fossil incumbents. This is exemplified by the potential for renewable hydrogen to create extremely high costs for both our energy grids and provincial economies. This, in turn, could make renewable hydrogen vulnerable to framing messages that prompt losses in mass cognition among the mass public, giving an edge to political elites whose loyalty rests with incumbent industries (Jacobs & Weaver, 2015; Lamb et al., 2020; Millar et al., 2021). Additionally, if renewable hydrogen is not undermined during the mid-transitional period, opportunities may be created during the late stages of the energy transition to support incumbents. This is because battles in the mid-stages of the transition have not occurred, and as a result, are pushed to the late stages. This makes strategies to facilitate deep decarbonization much more difficult, as the legitimacy of incumbents has not been eroded with time. This research also opens opportunities for additional research questions, such as the political impacts of other alternative fuels such as renewable natural gas; the political implications of hydrogen derived from nuclear energy; and the political challenges of establishing renewable hydrogen in provinces and countries that seek to establish a hydrogen economy without the use of fossil fuels. In closing, because of the potential political and economic strains hydrogen may have, it is likely in the best interest of British Columbia and the rest of Canada to begin limiting the scope in which hydrogen is used to decarbonize industries, investing further into renewable energy and battery technologies, and creating better efficiency standards in our energy grids. Only then can we manage to erode the political legitimacy of fossil incumbents while maintaining a trajectory towards necessary deep decarbonization efforts.

Bibliography

Adams, J. (2023, November). *Arrow Transportation Interview* [Personal communication].

Alberth, S. (2008). Forecasting technology costs via the experience curve—Myth or magic? *Technological Forecasting and Social Change*, *75*(7), 952–983. https://doi.org/10.1016/j.techfore.2007.09.003

Anon. (2023, November). *BC Hydrogen Office Interview* [Personal communication].

Anon. (2024, February). *Fortis Interview* [Personal communication].

Anon, Déchaux, T., & Turner, A. (2024, February). *HTEC Interview* [Personal communication].

ARC Resources. (2022a). *Innovation*. ARC Resources. https://www.arcresources.com/what-we-do/innovation/

ARC Resources. (2022b). *Who We Are*. ARC Resources. https://www.arcresources.com/who-we-are/

ARC Resources. (2024). *ARC partners with Ekona Power to pilot hydrogen technology*. ARC Resources. https://www.arcresources.com/newsroom/arc-resources-partners-with-ekona-power-to-pilot-hydrogen-technology/

Arrow Transportation Systems Inc. (2023, November 20). *Arrow and Metro Vancouver Forge Innovative Collaboration for Sustainable Material Transportation with Hydrogen Fuel Cell Technology*. Newsfile. https://www.newsfilecorp.com/release/188147/Arrow-and-Metro-Vancouver-Forge-Innovative-Collaboration-for-Sustainable-Material-Transportation-with-Hydrogen-Fuel-Cell-Technology

Axsen, J., Plötz, P., & Michael, W. (2020). Crafting strong, integrated policy mixes for deep CO2 mitigation in road transport. *Nature Climate Change*, *10*(9), 809–818. https://doi.org/10.1038/s41558-020-0877-y

Baldino, C., O'Malley, J., Searle, S., & Adam, C. (2021). Hydrogen for Heating? Decarbonization Options for Households in Germany in 2050. *The International Council on Clean Transportation*.

Baldino, C., O'Malley, J., Searle, S., Zhou, Y., & Christensen, A. (2020). Hydrogen for heating? Decarbonization options for households in the United Kingdom in 2050. *The International Council on Clean Transportation*.

Ballard Power. (2023, October). *Hydrogen-powered trucking in the Port of Vancouver*. https://blog.ballard.com/truck/fueling-port-of-vancouver-hydrogen-fuel-cells

Ballard Power. (2024). *Our History—Power to Change the World | Ballard Power*. https://www.ballard.com/about-ballard/our-history

BC Hydro. (2021a). *2021 Integrated Resource Plan*.

BC Hydro. (2021b, September). *BC Hydro's Electrification Plan: A clean future powered by water*.

BC Hydro. (2023). *Project Overview | Site C*. https://www.sitecproject.com/overview

BC Hydro. (2024). *Industrial electrification rates*. https://www.bchydro.com/accounts-billing/rates-energy-use/electricity-rates/electrification-rates.html

BCER. (2024a). *About*. https://www.bc-er.ca/about/
BCER. (2024b). *Carbon Capture and Storage*. https://www.bc-er.ca/stories/carbon-capture-and-storage/
BCER. (2024c). *Hydrogen*. https://www.bc-er.ca/what-we-regulate/hydrogen/
BCTA. (2024a). *About | BC Trucking Association*. https://www.bctrucking.com/about
BCTA. (2024b). *CleanBC HDVE Program | BC Trucking Association*. https://www.bctrucking.com/cleanbc-hdve-program
BCTA. (2024c, February). *Pathway to Achieving BC's Heavy-Duty Trucking 2030 Climate Targets*.
BCUC. (2023a, November). *BCUC Issues Final Report on the Regulation of Hydrogen Energy Services*. BCUC.
BCUC. (2023b, November 23). *British Columbia Utilities Commission Inquiry into the Regulation of Hydrogen Energy Services Final Report*.
BCUC. (2024a). *Legislation—BCUC*. https://www.bcuc.com/Resources/Legislation
BCUC. (2024b). *The Role of Government—BCUC*. https://www.bcuc.com/AboutUs/Government?sortOrder=category_desc
BCUC. (2024c). *Who We Are—BCUC*. https://www.bcuc.com/AboutUs/WhoWeAre
Bernstein, S., & Hoffmann, M. (2018). The politics of decarbonization and the catalytic impact of subnational climate experiments. *Policy Sciences, 51*(2), 189–211. https://doi.org/10.1007/s11077-018-9314-8
Bernstein, S., & Hoffmann, M. (2019). Climate politics, metaphors and the fractal carbon trap. *Nature Climate Change*, *9*(12), 919–925. https://doi.org/10.1038/s41558-019-0618-2
Bhardwaj, C., McBain, S., & Thorn, A. (2023, June 27). *British Columbia's Medium-and Heavy-Duty ZeroEmission Vehicles 2023 Consultation Paper: Pembina Institute comments and recommendations*. Pembina Institute.
Breetz, H., Mildenberger, M., & Stokes, L. (2018). The political logics of clean energy transitions. *Business and Politics*, *20*(4), 492–522. https://doi.org/10.1017/bap.2018.14
Britannica. (2024). *William Nicholson | Inventor, Chemist & Scientist | Britannica*. https://www.britannica.com/biography/William-Nicholson-English-chemist-and-inventor
Buschmann, P., & Oels, A. (2019). The overlooked role of discourse in breaking carbon lock-in: The case of the German energy transition. *WIREs Climate Change*, *10*(3), e574. https://doi.org/10.1002/wcc.574
Buysse, C., & Sharpe, B. (2020). *California's Advanced Clean Trucks regulation: Sales requirements for zero-emission heavy-duty trucks*.
Canada Revenue Agency. (2024a, June 21). *Carbon Capture, Utilization, and Storage (CCUS) Investment Tax Credit (ITC)*. https://www.canada.ca/en/revenue-agency/services/tax/businesses/topics/corporations/business-tax-credits/clean-economy-itc/carbon-capture-itc.html
Canada Revenue Agency. (2024b, June 21). *Clean Hydrogen Investment Tax Credit (ITC)*. https://www.canada.ca/en/revenue-agency/services/tax/businesses/topics/corporations/business-tax-credits/clean-economy-itc/clean-hydrogen-itc.html

Canada Revenue Agency. (2024c, June 21). *Clean Technology Manufacturing (CTM) Investment Tax Credit (ITC)*. https://www.canada.ca/en/revenue-agency/services/tax/businesses/topics/corporations/business-tax-credits/clean-economy-itc/clean-technology-manufacturing-itc.html

Canadian Gas Association. (2016). *Natural Gas—A Clean and Affordable Transportation Fuel Issue 6*. Canadian Gas Association.

CAPP. (2024). *Petroleum and Real Life | CAPP*. CAPP | A Unified Voice for Canada's Upstream Oil and Gas Industry. https://www.capp.ca/en/oil-natural-gas-you/petroleum-and-real-life/

Carlisle, S. (2016, April 28). We traded carriages for cars – let's embrace the next disruption. *The Globe and Mail*. https://www.theglobeandmail.com/report-on-business/rob-commentary/we-traded-carriages-for-cars-lets-embrace-the-next-disruption/article29782316/

CBC News. (2010, January 8). *Hydrogen-powered buses at Olympics under scrutiny | CBC News*. CBC. https://www.cbc.ca/news/hydrogen-powered-buses-at-olympics-under-scrutiny-1.900837

CHA. (2024a). 2011: Clean Energy Vehicle Program introduced in BC. *Canadian Hydrogen Association*. https://canadah2.ca/history/2011-clean-energy-vehicle-program-introduced-in-bc/

CHA. (2024b). 2015: Hydrogen Fuelling Infrastructure Program is Launched in BC. *Canadian Hydrogen Association*. https://canadah2.ca/history/2015-hydrogen-fuelling-infrastructure-program-is-launched-in-bc/

CHA. (2024c). Fasken. *Canadian Hydrogen Association*. https://canadah2.ca/member/fasken-martineau-dumoulin-llp/

CHA. (2024d). Fortescue Future Industries (FFI). *Canadian Hydrogen Association*. https://canadah2.ca/member/fortescue-future-industries-ffi/

CHA. (2024e). Hydrogen British Columbia. *Canadian Hydrogen Association*. https://canadah2.ca/hydrogen-british-columbia/

CHA. (2024f). Partnerships. *Canadian Hydrogen Association*. https://canadah2.ca/partnerships/

CHA. (2024g). Provincial Affiliates. *Canadian Hydrogen Association*. https://canadah2.ca/affiliates/

CHA. (2024h). Toyota Canada Inc. *Canadian Hydrogen Association*. https://canadah2.ca/member/toyota-canada-inc/

Chatterjee, S., Parsapur, R. K., & Huang, K.-W. (2021). Limitations of Ammonia as a Hydrogen Energy Carrier for the Transportation Sector. *ACS Energy Letters*, *6*(12), 4390–4394. https://doi.org/10.1021/acsenergylett.1c02189

Chemtrade. (2020). *Hydrogen Gas Saftey Data Sheet*. CHEMTRADE.

Chen, S., & Gunster, S. (2016). "Ethereal Carbon": Legitimizing liquefied natural gas in British Columbia. *Environmental Communication*, *10*(3), 305–321. https://doi.org/10.1080/17524032.2015.1133435

CHFCA. (2016a). Funding. *CHFCA*. https://www.chfca.ca/funding/

CHFCA. (2016b). Hydrogen Hubs Map in Canada. *CHFCA*. https://www.chfca.ca/hydrogen-hubs-map-in-canada/

CHFCA. (2016c). Hydrogen Production Map. *CHFCA*. https://www.chfca.ca/canadian-hydrogen-production-database/
CHFCA. (2016d). Our History. *CHFCA*. https://www.chfca.ca/about/our-history/
CHFCA. (2016e). Who We Are. *CHFCA*. https://www.chfca.ca/about/who-we-are/
CHFCA. (2021, January 4). Legacies of the 2010 Olympic Games in Whistler are powering more than nostalgia. *CHFCA*. https://www.chfca.ca/2021/01/04/legacies-of-the-2010-olympic-games-in-whistler-are-powering-more-than-nostalgia/
CICE. (2024a). *Funding Low Carbon Hydrogen Solutions | CICE*. B.C. Centre for Innovation and Clean Energy. https://cice.ca/low-carbon-hydrogen/
CICE. (2024b). *Who We Are*. B.C. Centre for Innovation and Clean Energy. https://cice.ca/who-we-are/
CICE, Deloitte, Government of British Columbia, & S&T2. (2023, March). *Carbon Intensity of Hydrogen Production Methods: Supporting the BC Hydrogen Strategy*. CICE.
Clarke, T. (2024, January 20). *Prince George perfectly positioned as site of hydrogen plant, Fortescue exec says*. Prince George Citizen. https://www.princegeorgecitizen.com/local-news/prince-george-perfectly-positioned-as-site-of-hydrogen-plant-fortescue-exec-says-8137988
CleanBC. (2021). *Roadmap to 2030*. Government of British Columbia.
CleanBC. (2023). *Provincial Clean Transportation Action Plan*. UBCM.
CleanBC. (2024a). *Transportation—CleanBC*. https://cleanbc.gov.bc.ca/about-climate-change/drivers/transportation/
CleanBC. (2024b, March 25). *Part 3 agreements—CleanBC*. https://cleanbc.gov.bc.ca/definitions/part-3-agreements/
CleanBC Go Electric. (2023a). About the Program. *CleanBC Go Electric Passenger Vehicle Rebate Program*. https://newcardealersgoelectric.ca/about-the-program/
CleanBC Go Electric. (2023b). ARC Program. *ARC BC*. https://arcbc.ca/arc-program/
CleanBC Go Electric. (2023c). CVIC Program. *ARC BC*. https://arcbc.ca/cvic-program/
CleanBC Go Electric. (2024a). About. *CVP BC*. https://cvpbc.ca/about/
CleanBC Go Electric. (2024b). *Electric Vehicle Rebate | CleanBC Go Electric Rebates*. https://www.goelectricotherrebates.ca/rebate
CleanBC Go Electric. (2024c). *Rebates for public chargers—Go Electric BC*. https://goelectricbc.gov.bc.ca/rebates-and-programs/for-businesses-and-organizations/rebates-for-public-chargers/
Cyr, M., Whitmore, J., Pineau, D. P.-O., Craglia, D. M., Langlois-Bertand, D. S., Lynch, J., Ribberink, H., & Yip, D. A. (2023). DECARBONIZING LONG-HAUL TRUCKING IN EASTERN CANADA: PART 2 | A techno-economic assessment of net zero technologies on the A20-H401 Corridor between Québec City and Windsor. *Gouvernement Du Québec*.
Dale, A., Robinson, J., King, L., Burch, S., Newell, R., Shaw, A., & Jost, F. (2020). Meeting the climate change challenge: Local government climate action in British Columbia, Canada. *Climate Policy*, *20*(7), 866–880. https://doi.org/10.1080/14693062.2019.1651244

Dawson, M., Zajc, E., Aubin, D., Al Madhoun, W., Keeler, R., Desandoli, L., & Yates, B. (2023). *BC Hydrogen Regulatory Mapping Study*. Government of British Columbia.

Dawson, T. (2023, September 21). What we know about how much the carbon tax is to blame for spiking food costs in Canada. *National Post*. https://nationalpost.com/news/canada/carbon-tax-groceries-food-prices

Deffeyes, K. S. (2005). Hydrogen. In *Beyond Oil: The View From Hubebert's Peak* (1st ed.). Hill and Wang A division of Farrar, Straus and Giroux 19 Union Swuare West, New York.

Dokso, A. (2023a, July 11). *Hazer Group Advances Hydrogen Project in Canada—Green Hydrogen News*. https://energynews.biz/hazer-group-advances-hydrogen-project-in-canada/

Dokso, A. (2023b, September 4). *Petronas Leads Southeast Asia in Green Hydrogen Production—Green Hydrogen News*. https://energynews.biz/petronas-leads-southeast-asia-in-green-hydrogen-production/

eCascadia. (2024). *eCascadia | Freightliner Trucks*. https://www.freightliner.com/trucks/ecascadia/

Ekona Power. (2024). *Technology | Ekona Power*. https://ekonapower.com/technology/

Environment and Climate Change Canada. (2022). *2030 Emissions Reduction Plan: Canada's Next Steps for Clean Air and a Strong Economy*. Government of Canada.

Environment and Natural Resources Canada. (2023, August 10). *British Columbia: Clean electricity snapshot* [Backgrounders]. https://www.canada.ca/en/services/environment/weather/climatechange/climate-action/powering-future-clean-energy/overview-british-columbia.html

Fortescue. (2024a). *British Columbia, Canada*. Fortescue. https://fortescue.com/what-we-do/our-projects/british-columbia

Fortescue. (2024b). *Fortescue Hydrogen Systems*. Fortescue. https://fortescue.com/what-we-do/fortescue-hydrogen-systems

FortisBC. (2024a). *CNG vs. LNG: How to choose your fuel type | FortisBC*. Www.Fortisbc.Com. https://www.fortisbc.com/services/low-carbon-transportation/benefits-of-natural-gas-fuelled-vehicles/cng-vs.-lng--how-to-choose-your-natural-gas-fuel-type

FortisBC. (2024b). *How Much Does Renewable Natural Gas Cost | FortisBC*. Www.Fortisbc.Com. https://www.fortisbc.com/services/sustainable-energy-options/renewable-natural-gas/how-much-does-renewable-natural-gas-cost

FortisBC. (2024c). *Hydrogen gas | FortisBC*. Www.Fortisbc.Com. https://www.fortisbc.com/services/sustainable-energy-options/hydrogen-gas

FortisBC. (2024d). *Providing renewable and low-carbon energy*. Www.Fortisbc.Com. https://www.fortisbc.com/about-us/climate-leadership/providing-renewable-and-low-carbon-energy

FortisBC. (2024e). *Reference guide for dealerships | FortisBC*. Www.Fortisbc.Com. https://www.fortisbc.com/services/low-carbon-transportation/reference-guide-for-dealerships

FortisBC. (2024f, January 19). *B.C. government and industry partners working to develop hydrogen as a low-carbon energy option for families and businesses*. Www.Fortisbc.Com. https://www.fortisbc.com/news-events/media-centre-details/2024/01/19/b.c.-government-and-industry-partners-working-to-develop-hydrogen-as-a-low-carbon-energy-option-for-families-and-businesses

Fouquet, R. (2016). Historical energy transitions: Speed, prices and system transformation. *Energy Research & Social Science*, *22*, 7–12. https://doi.org/10.1016/j.erss.2016.08.014

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, *31*(8), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels, F. W. (2005). The dynamics of transitions in socio-technical systems: A multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). *Technology Analysis & Strategic Management*, *17*(4), 445–476. https://doi.org/10.1080/09537320500357319

George, J. F., Müller, V. P., Winkler, J., & Ragwitz, M. (2022). Is blue hydrogen a bridging technology? - The limits of a CO2 price and the role of state-induced price components for green hydrogen production in Germany. *Energy Policy*, *167*, 113072. https://doi.org/10.1016/j.enpol.2022.113072

Gill, B. (2023, June). *Low Carbon Fuel Standard Electricity Supply*. BC Ministry of Energy, Mines and Low Carbon Innovation.

Goodall, C. (2016). *The Switch: How Solar, Storage and New Tech Means Cheap Power for All*. https://web-p-ebscohost-com.proxy.hil.unb.ca/ehost/ebookviewer/ebook/bmxlYmtfXzEzNjg3ODNfX0FO0?sid=8a374b8e-e8c1-40cf-bc6f-5684306a5d45@redis&vid=0&format=EK&lpid=navpoint-5&rid=0

Government of BC. (1996). *Utilities Commission Act*. https://www.bclaws.gov.bc.ca/civix/document/id/rs/rs/96473_01#section022

Government of BC. (2015, July 9). *British Columbia's Clean Energy Vehicle Program Phase 1 Review*. Government of British Columbia.

Government of BC. (2021). *BC Hydrogen Strategy*. Government of British Columbia.

Government of BC. (2023). *B.C. Medium- and Heavy-Duty Zero-Emission Vehicles: 2023 Consultation Paper*. Government of British Columbia.

Government of BC, & CleanBC. (2023, February). *Clean Transportation Action Plan Request for Input*. Government of British Columbia.

Government of BC, & CleanBC. (2024). *Zero-Emission Vehicle Update 2023*.

Government of Canada. (2021, April 6). *Technology Readiness Level (TRL) Assessment Tool*. https://ised-isde.canada.ca/site/clean-growth-hub/en/technology-readiness-level-trl-assessment-tool

Government of Canada, & Canada Energy Regulator. (2024a, February 22). *CER – Provincial and Territorial Energy Profiles – British Columbia*. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-british-columbia.html

Government of Canada, & Canada Energy Regulator. (2024b, May 27). *CER – Provincial and Territorial Energy Profiles – Canada*. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-canada.html

Government of Newfoundland and Labrador. (2024, May). *Hydrogen Development Action Plan: Newfoundland and Labrador 2024*. Government of Newfoundland and Labrador.

Grubert, E., & Hastings-Simon, S. (2022). Designing the mid-transition: A review of medium-term challenges for coordinated decarbonization in the United States. *WIREs Climate Change*, *13*(3), e768. https://doi.org/10.1002/wcc.768

Hazer Group. (2023a). *Canadian Project Update*. Hazer Group.

Hazer Group. (2023b, May 24). *Hazergroup.com.au | Commercialising the Hazer Process*. https://hazergroup.com.au/

HEC Montréal. (2024). *L'État de l'énergie au Québec 2024*. Gouvernement du Québec.

Howarth, R. W., & Jacobson, M. Z. (2021). How green is blue hydrogen? *Energy Science & Engineering*, *9*(10), 1676–1687. https://doi.org/10.1002/ese3.956

HTEC. (2023a). Business Units. *HTEC*. https://www.htec.ca/business-units/

HTEC. (2023b). FAQs. *HTEC*. https://www.htec.ca/faqs/

HTEC. (2023c). H2 Gateway. *HTEC*. https://www.htec.ca/h2gateway/

HTEC. (2023d). Stations and Distribution. *HTEC*. https://www.htec.ca/stations-and-distribution/

HTEC. (2023e, June 6). Hydrogen Will Fuel Clean Transportation at B.C. Ports. *HTEC*. https://www.htec.ca/hydrogen-will-fuel-clean-transportation-at-b-c-ports/

HTEC. (2023f, June 16). HTEC Hosts Ground-Breaking Ceremony for its Low-Carbon Hydrogen Production Facility in Burnaby. *HTEC*. https://www.htec.ca/htec-hosts-ground-breaking-ceremony-for-its-low-carbon-hydrogen-production-facility-in-burnaby/

HTEC. (2023g, June 29). HTEC Opens a Hydrogen Refueling Station in Kelowna. *HTEC*. https://www.htec.ca/htec-opens-a-hydrogen-refueling-station-in-kelowna/

HTEC. (2023h, November 16). Province Creating New Opportunities in Hydrogen Economy, Commercial Trucking. *HTEC*. https://www.htec.ca/province-creating-new-opportunities-in-hydrogen-economy-commercial-trucking/

HTEC. (2023i, November 29). Fortescue and HTEC to Work Towards Building Canada's First Multi-Use Export and Domestic Green Hydrogen Supply Chain. *HTEC*. https://www.htec.ca/fortescue-and-htec-to-work-towards-building-canadas-first-multi-use-export-and-domestic-green-hydrogen-supply-chain/

HTEC, & Zen and the Art of Clean Energy Solutions. (2022, June). *Hydrogen Station Permitting Guidebook for BC*. Government of British Columbia.

Hydra Energy. (2021, February 23). *Hydra Energy Partners with Chemtrade to Provide Commercial Truck Fleets With Green Hydrogen Below the Cost of Diesel*. https://www.newswire.ca/news-releases/hydra-energy-partners-with-chemtrade-to-provide-commercial-truck-fleets-with-green-hydrogen-below-the-cost-of-diesel-877220173.html

Hydra Energy. (2022, September 20). *Hydra Energy Breaks Ground on World's Largest Hydrogen Refuelling Station for Heavy-Duty Trucks*. Hydra Energy. https://www.hydraenergy.com/news/groundbreaking

Hydra Energy. (2023, March 22). *Hydra Energy Signs 8 New Heavy-Duty Truck Fleet Offtakers for World's Largest Hydrogen Refuelling Station*. Hydra Energy. https://www.hydraenergy.com/news/pgfleets

Hydra Energy. (2024a). *About Us*. Hydra Energy. https://www.hydraenergy.com/about

Hydra Energy. (2024b). *FAQs*. Hydra Energy. https://www.hydraenergy.com/faq

IEA. (2019, June 14). *The Future of Hydrogen – Analysis*. IEA. https://www.iea.org/reports/the-future-of-hydrogen

IEA. (2021a). *Executive summary – Global Hydrogen Review 2021 – Analysis*. IEA. https://www.iea.org/reports/global-hydrogen-review-2021/executive-summary

IEA. (2021b). *Global Hydrogen REVIEW 2021*.

IEA. (2024). *Executive summary – Towards hydrogen definitions based on their emissions intensity – Analysis*. IEA. https://www.iea.org/reports/towards-hydrogen-definitions-based-on-their-emissions-intensity/executive-summary

IEA, I. E. A. (2022). *Canada 2022: Energy Policy Review*. https://www.iea.org/countries/canada

Jacobs, A. M., & Weaver, R. K. (2015). When Policies Undo Themselves: Self-Undermining Feedback as a Source of Policy Change. *Governance*, *28*(4), 441–457. https://doi.org/10.1111/gove.12101

Janzwood, A., & Millar, H. (2022). Bridge fuel feuds: The competing interpretive politics of natural gas in Canada. *Energy Research & Social Science*, *88*, 102526. https://doi.org/10.1016/j.erss.2022.102526

Jones, N. (2022, January 20). *From Fertilizer to Fuel: Can 'Green' Ammonia Be a Climate Fix?* Yale E360. https://e360.yale.edu/features/from-fertilizer-to-fuel-can-green-ammonia-be-a-climate-fix

Jordan, A., & Matt, E. (2014). Designing policies that intentionally stick: Policy feedback in a changing climate. *Policy Sciences*, *47*(3), 227–247. https://doi.org/10.1007/s11077-014-9201-x

Juan Ding, A. (2022, June 29). *Building on Success: B.C.'s Low Carbon Fuel Standard*. Canadian Climate Institute. https://climateinstitute.ca/british-columbias-low-carbon-fuel-standard/

Kanduth, A., & Dion, J. (2020). *Climate Legislation in British Columbia*. Canadian Climate Institute. https://climateinstitute.ca/publications/climate-legislation-in-british-columbia/

Kemfert, C., Präger, F., Braunger, I., Hoffart, F. M., & Brauers, H. (2022). The expansion of natural gas infrastructure puts energy transitions at risk. *Nature Energy*, *7*(7), 582–587. https://doi.org/10.1038/s41560-022-01060-3

Kenworth. (2024). *Kenworth Trucks*. Kenworth Trucks. https://www.kenworth.com/trucks/t680e/

King's Printer. (2024a). *Utilities Commission Act*. https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/96473_01#section22

King's Printer. (2024b, May 15). *Clean Energy Act*. https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/10022_01

King's Printer. (2024c, July 2). *Low Carbon Fuels Act*. https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/22021

King's Printer. (2024d, July 2). *Zero-Emission Vehicles Act*. https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/19029#section12
King's Printer. (2024e, July 9). *Low Carbon Fuels (General) Regulation*. https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/282_2023#section2
Klippenstein, M. (2023, December). *Canadian Hydrogen Association Interview* [Personal communication].
Klippenstein, M. (2024, April). *Matthew Klippenstein on LinkedIn: Rebranding from CHFCA to CHA has given me so much empathy for women who….* https://www.linkedin.com/posts/matthewklippenstein_rebranding-from-chfca-to-cha-has-given-me-activity-7188570668068737025-fDHz
Kurjata, A. (2024, January 17). Canfor to reduce reliance on natural gas with hydrogen power project in Prince George, B.C. *CBC News*. https://www.cbc.ca/news/canada/british-columbia/canfor-teralta-hydrogen-prince-george-1.7085837
Lamb, W. F., Mattioli, G., Levi, S., Roberts, J. T., Capstick, S., Creutzig, F., Minx, J. C., Müller-Hansen, F., Culhane, T., & Steinberger, J. K. (2020). Discourses of climate delay. *Global Sustainability*, *3*. https://doi.org/10.1017/sus.2020.13
Levin, K., Cashore, B., Bernstein, S., & Auld, G. (2012). Overcoming the tragedy of super wicked problems: Constraining our future selves to ameliorate global climate change. *Policy Sciences*, *45*(2), 123–152. https://doi.org/10.1007/s11077-012-9151-0
Levy, J. S. (2008). Case Studies: Types, Designs, and Logics of Inference. *Conflict Management and Peace Science*, *25*(1), 1–18. https://doi.org/10.1080/07388940701860318
Mahoney, J. (2000). Path dependence in historical sociology. *Theory & Society*, *29*(4), 507. https://doi.org/10.1023/A:1007113830879
Malcolmson, P., Myers, R., Baier, G., & Bateman, T. (2016). *The Canadian Regime: An Introduction to Parliamentary Government in Canada, Sixth Edition: Vol. Sixth edition*. University of Toronto Press. https://login.proxy.hil.unb.ca/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=nlebk&AN=1569204&site=ehost-live&scope=site
Mansbridge, J. (2014). What Is Political Science For? *Perspectives on Politics*, *12*(1), 8–17. https://doi.org/10.1017/S153759271300368X
Meckling, J., & Nahm, J. (2022). Strategic State Capacity: How States Counter Opposition to Climate Policy. *Comparative Political Studies*, *55*(3), 493–523. https://doi.org/10.1177/00104140211024308
Mildenberger, M. (2020). *Carbon Captured: How Business and Labor Control Climate Politics*. The MIT Press. https://doi.org/10.7551/mitpress/12393.001.0001
Millar, H., Bourgeois, E., Bernstein, S., & Hoffmann, M. (2021). Self-reinforcing and self-undermining feedbacks in subnational climate policy implementation. *Environmental Politics*, *30*(5), 791–810. https://doi.org/10.1080/09644016.2020.1825302

Ministry of Energy Mines and Low Carbon Innovation. (2018). *Renewable and Low Carbon Fuel Requirements Regulation*. Government of British Columbia.

Ministry of Energy Mines and Low Carbon Innovation. (2022a, October 27). *B.C. making changes to advance hydrogen industry | BC Gov News*. https://news.gov.bc.ca/releases/2022EMLI0055-001598

Ministry of Energy Mines and Low Carbon Innovation. (2022b, December 20). *New carbon-reduction requirements lower emissions on the road | BC Gov News*. https://news.gov.bc.ca/releases/2022EMLI0066-001925

Ministry of Energy Mines and Low Carbon Innovation. (2023a, February 17). *B.C. modernizes oil, gas, energy regulator board | BC Gov News*. https://news.gov.bc.ca/releases/2023EMLI0007-000209

Ministry of Energy Mines and Low Carbon Innovation. (2023b, March 16). *Go Electric Advanced Research and Commercialization Program—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/clean-energy-vehicle-program/new-page-24468

Ministry of Energy Mines and Low Carbon Innovation. (2023c, August 29). *Combining rebates for medium- and heavy-duty EVs—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/clean-energy-vehicle-program/combining-commercial-rebates

Ministry of Energy Mines and Low Carbon Innovation. (2023d, October 24). *B.C. making it easier to buy zero-emission vehicles | BC Gov News*. https://news.gov.bc.ca/releases/2023EMLI0043-001640

Ministry of Energy Mines and Low Carbon Innovation. (2023e, October 31). *BC Hydrogen Office—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/renewable-energy/hydrogen-office

Ministry of Energy Mines and Low Carbon Innovation. (2024a). *Low Carbon Fuel—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/renewable-low-carbon-fuels/fuel-lifecycle-assessment

Ministry of Energy Mines and Low Carbon Innovation. (2024b, April 10). *Go Electric Fleet Charging Program—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/clean-energy-vehicle-program/go-electric-fleet-support-program

Ministry of Energy Mines and Low Carbon Innovation. (2024c, June 14). *Clean Transportation Action Plan—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/clean-transportation-action-plan

Ministry of Energy Mines and Low Carbon Innovation. (2024d, June 14). *Innovative Clean Energy (ICE) Fund—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/innovative-clean-energy-solutions/innovative-clean-energy-ice-fund

Ministry of Energy Mines and Low Carbon Innovation. (2024e, June 24). *Clean Energy and Major Projects Office—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/renewable-energy/clean-energy-and-major-projects-office

Ministry of Energy Mines and Low Carbon Innovation. (2024f, June 27). *Powering Our Future: BC's Clean Energy Strategy*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/powering-our-future

Ministry of Energy Mines and Low Carbon Innovation. (2024g, July 2). *Credit Market—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/renewable-low-carbon-fuels/credits-market

Ministry of Energy Mines and Low Carbon Innovation. (2024h, July 5). *Renewable & Low Carbon Fuel—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/renewable-low-carbon-fuels

Ministry of Energy Mines and Low Carbon Innovation. (2024i, July 9). *Go Electric Hydrogen Fuelling Infrastructure—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/clean-energy-vehicle-program/dcfc-program/hydrogen-fuelling

Ministry of Energy Mines and Low Carbon Innovation. (2024j, July 9). *Go Electric Public Charger Program—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/clean-energy-vehicle-program/dcfc-program/hydrogen-fuelling-52518

Ministry of Energy Mines and Low Carbon Innovation. (2024k, July 10). *Zero-Emission Vehicles Act—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/clean-transportation-policies-programs/zero-emission-vehicles-act

Ministry of Environment and Climate Change. (2020, September 3). *Water Sustainability Act—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/laws-rules/water-sustainability-act

Ministry of Environment and Climate Change. (2023a, March 13). *Sectoral emissions targets—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action/sectoral-targets

Ministry of Environment and Climate Change. (2023b, December 21). *Climate action and accountability—Province of British Columbia*. Province of British Columbia.

https://www2.gov.bc.ca/gov/content/environment/climate-change/planning-and-action#targets
Ministry of Environment and Climate Change. (2024a). *Cleaner Industry*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/environment/climate-change/industry
Ministry of Environment and Climate Change. (2024b, April 24). *About the CleanBC Industrial Incentive Program—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/cleanbc-industrial-incentive-program/about-ciip
Ministry of Environment and Climate Change. (2024c, May 13). *Apply for funding—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/cleanbc-industry-fund/apply-for-funding
Ministry of Environment and Climate Change. (2024d, May 14). *CleanBC Industrial Incentive Program Resources—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/cleanbc-industrial-incentive-program/ciip-resources#benchmarks
Ministry of Environment and Climate Change. (2024e, June 5). *B.C. Output-Based Pricing System—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/bc-output-based-pricing-system
Ministry of Environment and Climate Change. (2024f, June 5). *Clean Transportation*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/environment/climate-change/clean-transportation
Ministry of Environment and Climate Change. (2024g, June 27). *Selling carbon offsets to the Province—Province of British Columbia*. Province of British Columbia. https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/selling-offsets
Morgan, G. (2021, August 16). *Petronas eyes $1.3B project in Alberta to export hydrogen to Asia*. Financialpost. https://financialpost.com/commodities/energy/petronas-eyes-1-3b-petrochemical-project-in-alberta-to-export-hydrogen-to-asia
Nanaimo. (2024). *Nanaimo Forest Products Ltd.* https://members.nanaimochamber.bc.ca/list/member/nanaimo-forest-products-ltd-1834
Natural Resources Canada. (2018, April 4). *Green Freight Program*. Natural Resources Canada. https://natural-resources.canada.ca/energy-efficiency/transportation-alternative-fuels/greening-freight-programs/green-freight-program/20893
Natural Resources Canada. (2019, April 16). *Zero Emission Vehicle Infrastructure Program*. Natural Resources Canada. https://natural-resources.canada.ca/energy-efficiency/transportation-alternative-fuels/zero-emission-vehicle-infrastructure-program/21876

Natural Resources Canada. (2020, October 20). *The Hydrogen Strategy*. Natural Resources Canada. https://natural-resources.canada.ca/climate-change/canadas-green-future/the-hydrogen-strategy/23080

Natural Resources Canada. (2023a, August 3). *Powering Canada Forward: Building a Clean, Affordable, and Reliable Electricity System for Every Region of Canada*. Natural Resources Canada. https://natural-resources.canada.ca/our-natural-resources/energy-sources-distribution/electricity-infrastructure/powering-canada-forward-building-clean-affordable-and-reliable-electricity-system-for/25259

Natural Resources Canada. (2023b, August 8). *Green Freight Program Applicant's Guide: Stream 2*. Natural Resources Canada. https://natural-resources.canada.ca/energy-efficiency/transportation-alternative-fuels/greening-freight-programs/green-freight-program/green-freight-program-applicants-guide-stream-2/25263

Natural Resources Canada. (2024, February 13). *Hydrogen Strategy for Canada: Progress Report*. Natural Resources Canada. https://natural-resources.canada.ca/climate-change/canadas-green-future/the-hydrogen-strategy/hydrogen-strategy-for-canada-progress-report/25678

Nikola. (2024). *Nikola Battery-Electric Vehicle*. Nikola Corporation. https://www.nikolamotor.com/the-nikola-tre-bev-reinventing-short-haul-transportation

North River Midstream. (2020). *Our Assets – NorthRiver Midstream*. https://www.nrm.ca/what-we-do/our-assets/

Office of the Premier. (2022, March 31). *B.C. moves to streamline hydrogen projects to ensure clean energy future | BC Gov News*. https://news.gov.bc.ca/releases/2022PREM0018-000464

Paterson, C. (2023, December). *BCTA Interview* [Personal communication].

Paterson, M., Tobin, P., & VanDeveer, S. D. (2022). Climate Governance Antagonisms: Policy Stability and Repoliticization. *Global Environmental Politics*, *22*(2), 1–11. https://doi.org/10.1162/glep_a_00647

Pawson, C. (2023, November 16). B.C. to spend $16.5M to get 6 hydrogen-powered transport trucks on the road. *CBC News*. https://www.cbc.ca/news/canada/british-columbia/hydrogen-fuelled-transport-trucks-bc-pilot-project-emissions-reduction-1.7030632

Petersen, H. (2023, September 14). *Australian billionaire proposes green hydrogen hub in Prince George*. Prince George Citizen. https://www.princegeorgecitizen.com/local-news/australian-billionaire-proposes-green-hydrogen-hub-in-prince-george-7544865

Petronas Canada. (2018). *PETRONAS Canada*. https://www.petronascanada.com/

Pierson, P. (1993). When Effect Becomes Cause: Policy Feedback and Political Change Review Articles. *World Politics*, *45*(4), 595–628.

Power Technology. (2022, April 4). Commercial-scale methane pyrolysis: The key to carbon-negative hydrogen. *Power Technology*. https://www.power-technology.com/sponsored/commercial-scale-methane-pyrolysis-the-key-to-carbon-negative-hydrogen/

Powertech Labs. (n.d.). *Powertech chosen by HTEC to provide hydrogen refueling equipment for installation in British Columbia, Canada. – Powertech Labs*. Retrieved May 15, 2024, from https://powertechlabs.com/powertech-chosen-by-htec-to-provide-hydrogen-refueling-equipment-for-installation-in-british-columbia-canada/

PowerTech Labs. (2024). *Hydrogen Fueling Stations – Powertech Labs*. https://powertechlabs.com/hydrogen-fueling-stations/

Province of British Columbia. (2021). *Greenhouse Gas Reduction (Clean Energy) Regulation*. https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/102_2012#section6

Roberts, C., Geels, F. W., Lockwood, M., Newell, P., Schmitz, H., Turnheim, B., & Jordan, A. (2018). The politics of accelerating low-carbon transitions: Towards a new research agenda. *Energy Research & Social Science*, *44*, 304–311. https://doi.org/10.1016/j.erss.2018.06.001

Rosenbloom, D., & Meadowcroft, J. (2022). Accelerating Pathways to Net Zero: Governance Strategies from Transition Studies and the Transition Accelerator. *Current Climate Change Reports*, *8*(4), 104–114. https://doi.org/10.1007/s40641-022-00185-7

Rosenbloom, D., Meadowcroft, J., & Cashore, B. (2019). Stability and climate policy? Harnessing insights on path dependence, policy feedback, and transition pathways. *Energy Research & Social Science*, *50*, 168–178. https://doi.org/10.1016/j.erss.2018.12.009

Rosenbloom, D., & Rinscheid, A. (2020). Deliberate decline: An emerging frontier for the study and practice of decarbonization. *WIREs Climate Change*, *11*(6), e669. https://doi.org/10.1002/wcc.669

Schwartz, E. (2016). Developing Green Cities: Explaining Variation in Canadian Green Building Policies. *Canadian Journal of Political Science / Revue Canadienne de Science Politique*, *49*(4), 621–641.

Serpell, O., Hsain, Z., Chu, W.-Y. “Amy,” & Johnsen, W. (2023, March 17). Ammonia’s Role in a Net-Zero Hydrogen Economy. *Kleinman Center for Energy Policy*. https://kleinmanenergy.upenn.edu/research/publications/ammonias-role-in-a-net-zero-hydrogen-economy/

Seto, K. C., Davis, S. J., Mitchell, R. B., Stokes, E. C., Unruh, G., & Ürge-Vorsatz, D. (2016). Carbon Lock-In: Types, Causes, and Policy Implications. *Annual Review of Environment and Resources*, *41*(Volume 41, 2016), 425–452. https://doi.org/10.1146/annurev-environ-110615-085934

S&P Global. (2020, February 24). *S&P Global*. S&P Global. https://www.spglobal.com/en/research-insights/market-insights/what-is-energy-transition

Stokes, L. C. (2020). *Short Circuiting Policy: Interest Groups and the Battle Over Clean Energy and Climate Policy in the American States*. Oxford University Press.

Strategy, M. of E. and C. C. (2024, June 11). *Funded projects—Province of British Columbia*. Province of British Columbia.

https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/cleanbc-industry-fund/funded-projects
StrongerBC. (2022). *BC's Economic Plan 2022, A plan for today, a vision for tomorrow.* Government of British Columbia.
Teralta. (2024). *Industries We Serve*. Teralta. https://teralta.com/industries-we-serve/
Texas International Freight. (2024). *What Is The Difference Between The Shipper And The Carrier? - Texas International Freight*. https://www.txintlfreight.com/faq-article/difference-shipper-carrier/
Theclimategroup. (n.d.). *British Columbia Appendix*. Theclimategroup.
Today's Trucking. (2023, September 13). *BCTA launches fifth year of HDVE program*. Truck News. https://www.trucknews.com/sustainability/bcta-launches-fifth-year-of-hdve-program/1003178108/
Tracey Road Equipment. (2024). *Natural Gas Truck vs. Diesel | What's Right For You? - Tracey Road Equipment*. https://www.traceyroad.com/natural-gas-truck-vs-diesel-whats-right-for-you/
Transport Canada. (2019). *Transportation in Canada Overview Report 2019*. The Government of Canada.
Transport Canada. (2022a, August 30). *Incentives for Medium- and Heavy-Duty Zero-Emission Vehicles*. AEBA 18643916; AEBA. https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/incentives-medium-heavy-duty-zero-emission-vehicles
Transport Canada. (2022b, August 30). *Medium- and heavy-duty zero-emission vehicles*. AEBA 18643916; AEBA. https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/medium-heavy-duty-zero-emission-vehicles
Transport Canada. (2022c, October 12). *Eligible vehicles*. AEAD 18643927; AEAD. https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/medium-heavy-duty-zero-emission-vehicles/eligible-vehicles
Transport Canada. (2023, October 6). *Program overview*. AEAD 18643852; AEAD. https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/medium-heavy-duty-zero-emission-vehicles/program-overview
UNFCC. (2024). *The Paris Agreement | UNFCCC*. https://unfccc.int/process-and-meetings/the-paris-agreement
Unruh, G. C. (2000). Understanding carbon lock-in. *Energy Policy*, *28*(12), 817–830. https://doi.org/10.1016/S0301-4215(00)00070-7
U.S. Department of Energy. (n.d.). *Alternative Fuels Data Center: Renewable Natural Gas Production*. Retrieved May 31, 2024, from https://afdc.energy.gov/fuels/natural-gas-renewable
U.S. Department of Energy. (2024a). *Alternative Fuels Data Center: Hydrogen Fueling Station Locations*. https://afdc.energy.gov/fuels/hydrogen_locations.html#/find/nearest?fuel=HY&location=british%20columbia
U.S. Department of Energy. (2024b). *Regional Clean Hydrogen Hubs Selections for Award Negotiations*. Energy.Gov. https://www.energy.gov/oced/regional-clean-hydrogen-hubs-selections-award-negotiations

Wherry, A. (2023, October 7). Is the carbon tax an easy scapegoat for high food prices? *CBC News*. https://www.cbc.ca/news/politics/carbon-tax-food-prices-wherry-analysis-1.6989547

Whitmore, J. (2024, February 14). *Interview with Energy Scholar* [Personal communication].

Williams, A. (2023, May 26). *McLeod Lake Indian Band, Mitsubishi Power working on $5B hydrogen project*. Prince George Citizen. https://www.princegeorgecitizen.com/local-news/mcleod-lake-indian-band-mitsubishi-power-working-on-5b-hydrogen-project-7053305

Xiao, H. (2023, December). *Pembina Institute Interview* [Personal communication].

Xiao, H. (2024, April). *Fueling the Transition Low-carbon fuel choices for road freight*. Pembina Institute.

XPDEL. (2023, August 18). *Differences Between a Carrier and a Shipper | 3PL | XPDEL*. https://xpdel.com/blog/differences-between-a-carrier-and-a-shipper-and-how-they-impact-your-business/

YCharts. (2024, May 16). *Vancouver, BC Average Retail Price for Diesel Fuel at Self Service Filling Stations Monthly Insights: Canada Consumer Price Index | YCharts*. https://ycharts.com/indicators/vancouver_bc_average_retail_price_for_diesel_fuel_at_self_service_filling_stations

Zen and the Art of Clean Energy Solutions. (n.d.). *British Columbia Hydrogen Study Executive Summary*.

Interview Questions and Interviewees

Interview Questions

1. Describe your work as it relates to hydrogen development.

2. What are the major accomplishments in the development of hydrogen in BC? What were the initial reasons for these developments? Are there differences in the reasoning behind the development of grey/blue/green hydrogen?

3. What are some of the key economic challenges in establishing hydrogen industry in the province? Are the challenges different for different types of hydrogen?

4. Have there been any concerns raised by stakeholders regarding the development and implementation of hydrogen? Are there different concerns for different types of hydrogen?

5. What are some of the key regulatory or social challenges in establishing hydrogen industry in the province? Are the challenges different for different types of hydrogen?

6. What has been the public response (if any) to hydrogen development in the province?

7. Has the province adapted policy in response to stakeholder concerns? If so, how?

8. Are there any questions I have not asked or talked about that you think I should have?

List of Interviewees

Anon. BC Hydrogen Office.

Anon. FortisBC.

Anon, AT Turner, Tracy Déchaux. Hydrogen Technology & Energy Corporation.

Jacob Adams. Arrow Transportation Systems

Johanne Whitmore. HEC Montréal.

Matthew Klippenstein. Canadian Hydrogen Association.

Xiao Hongyu. Pembina Institute.

Curriculum Vitae

Candidate's full name: Orland Albert Edward Clark

Universities attended: University of New Brunswick, 2016 – 2020, Bachelor of Arts.

Conference Presentations: Atlantic Provinces Political Studies Association, 2023.

Canadian Political Science Association, 2024.