Alberta's Hydrogen Roadmap: Efficacy and Efficiency of the Province's Vision for Supporting Low-Carbon Hydrogen

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ABSTRACT

Abstract

Alberta's Hydrogen Roadmap sets a vision for how the province will grow a hydrogen economy to diversify its energy sector, benefit the economy and contribute to emissions reductions. This paper examines the efficiency and efficacy of Alberta's proposed policy actions to support low carbon production and makes recommendation for how to further advance this strategy. It finds that Alberta's Roadmap as industrial policy may be warranted and also finds that Alberta's Roadmap is a solid start to building its hydrogen economy. It sets forth strong policy actions to reduce emissions in existing production, grow demand by implementing hydrogen in carbon-intensive sectors, and support technology and innovation.

A weak carbon price combined with the current high cost of low carbon hydrogen production make it unlikely that the hydrogen industry would develop and produce a maximum benefit in an appropriate timeframe for reaching net zero goals if left to the market. Unless the gap between the cost of emissions and the cost of emissions reduction is closed or significantly decreased, no financial incentive exists for companies to act. Government policy tailored to each of these market issues could support the development of hydrogen to produce economic and environmental benefits. However, without such tailored policy, industrial policy could simultaneously address several of these failures.

In addition to Alberta's proposed policy actions, this paper offers four recommendations to further support low carbon hydrogen production and deeper decarbonization:

1. Increase the stringency and emissions coverage of carbon pricing to signal firms to reduce emissions and improve the economic feasibility of low/zero carbon technologies.
2. Fund innovation to improve low carbon hydrogen feasibility and reduce investment risks/uncertainty.
3. Provide transparency and establish stricter eligibility requirements for fossil fuel subsidies.
4. Prioritize adopting a hydrogen emissions classification system that establishes an emissions threshold aligned with global standards.
5. Establish a regulatory framework to avoid overlap and confusion between regulatory bodies and existing legislation.

EXECUTIVE SUMMARY

Alberta's Hydrogen Roadmap (Roadmap) sets a vision for how the province will grow a hydrogen economy to diversify its energy sector, benefit the economy and contribute to emissions reductions. This paper examines the efficiency and efficacy of Alberta's proposed policy actions to support low carbon production and makes recommendations to further advance this strategy. It finds that Alberta's Roadmap as industrial policy may be warranted, given recently expanded industrial policy uses to encourage a more environmentally sustainable economy and the existence of several market failures discouraging investment and hydrogen adoption. It also finds that Alberta's Roadmap is a solid start to building its hydrogen economy. It sets forth strong policy actions to reduce emissions in existing production, grow demand by implementing hydrogen in carbon-intensive sectors, and support technology and innovation.

A weak carbon price combined with the current high cost of low carbon hydrogen production make it unlikely that the hydrogen industry would develop and produce a maximum benefit in an appropriate timeframe for reaching net zero goals if left to the market. Unless the gap between the cost of emissions and cost of emissions reduction is closed or significantly decreased, no financial incentive exists for companies to act. Government policy tailored to each of these market issues could support the development and scale-up of hydrogen to produce economic and environmental benefits. However, industrial policy could simultaneously address several of these failures without such tailored policy.

The Roadmap successfully capitalizes on Alberta's natural resources (natural gas) and outlines strong policy actions for reducing emissions, including cleaning up existing

hydrogen production, a focus on hydrogen implementation in hard to abate sectors, and funding for carbon capture, utilization and storage (CCUS) projects.

This paper offers four recommendations to further support Alberta's low carbon hydrogen production and realization of deeper decarbonization:

6. Increase the stringency and emissions coverage of carbon pricing to signal firms to reduce emissions and improve the economic feasibility of low and zero carbon technologies.
7. Fund innovation to improve low carbon hydrogen feasibility, reduce investment risks and cost uncertainty.
8. Provide transparency and establish stricter eligibility requirements for fossil fuel subsidies.
9. Prioritize adopting a hydrogen emissions classification system that establishes a threshold for emissions aligned with global standards.
10. Establish a regulatory framework to avoid overlap and confusion between regulatory bodies and existing legislation.

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1.0 INTRODUCTION

As the world's energy systems shift towards clean and lower-carbon technologies, Alberta's energy industry faces significant challenges due to its heavy reliance on supplying hydrocarbons for combustion. However, Alberta, Canada's largest producer of hydrogen, 11and home to commercial-scale carbon capture, utilization, and storage (CCUS) projects, has an opportunity to get in front of the emerging global hydrogen economy while advancing sustainability. *Alberta's Hydrogen Roadmap* seeks to do that.

This capstone will address whether the Roadmap's policies efficiently and effectively support low carbon hydrogen production that contributes to decarbonization efforts. It seeks to evaluate economic efficiency from the standpoint that Alberta's proposed policies support hydrogen's most valuable uses. The Roadmap establishes "incremental" and "transformative" 2030 scenarios with policies that have not yet been fully implemented. For this reason, the capstone conducts a prospective analysis.

2.0 BACKGROUND

2.1 Global Climate Action

As a source of about three-quarters of greenhouse gas (GHG) emissions, the global energy sector is critical to mitigating climate change. Transformation of the world's energy systems to use renewable energy and low-carbon technology is required to avoid anthropogenic, or human-caused, climate change consequences such as rising sea levels, extreme weather, droughts and floods. The International Energy Agency (IEA) estimates that the use of fossil fuels needs to fall from almost four-fifths of today's total energy supply to slightly over one-fifth by 2050 to keep global temperatures to no more than 1.5°C – as called for in the 2015 Paris Agreement (International Energy Agency (IEA) 3, 2021). Attaining this goal would mean a global reduction in emissions to “net zero,” a target that cuts GHGs produced by human activity as close to zero as possible by reducing emissions and implementing methods of absorbing carbon dioxide (CO2) from the atmosphere.

Although global pledges and actions toward climate policy fall short of what is required to reach net zero by 2050, there is growing momentum worldwide toward stringent climate policy and action (OECD, 2021). More than 70 countries have set net-zero emissions targets. Each is taking a combination of policy actions to meet net zero goals by 2050 (United Nations, N.D.) These actions include implementing carbon pricing systems, phasing out coal, and exploring and investing in low carbon and renewable technologies. Global energy companies have also undertaken climate and energy transition initiatives. Shell, BP, Canadian Natural Resources, Cenovus Energy, Imperial Oil, MEG Energy and Suncor Energy have also committed to reaching net zero by 2050 (Reuters, 2021).

Hydrogen can support the Paris Agreement's goal to reduce emissions and expedite clean energy transitions. Hydrogen is an energy carrier that can be used to store, transport, and supply energy produced from other sources with a range of uses, from transportation to heating to power generation (Department of Energy, N.D.). Unlike fossil fuels, hydrogen produces no direct emissions and therefore has the potential to help decarbonize the world’s energy systems, particularly in emissions-intensive industries where other low or zero emission energy sources, such as electrification, are not economically feasible (Bataille, Nef, and Shaffer, 2021). National hydrogen policies have emerged in recent years, and global deployment of hydrogen has increased as the global community looks to reduce emissions and investors have an increasing appetite for low carbon technologies.

As Canada’s largest hydrogen producer, Alberta is well positioned to build on this industry in preparation for a lower emission future. Alberta's energy industry faces significant challenges related to sustainable development because of its heavy reliance on supplying hydrocarbons for combustion. However, experts and organizations working to accelerate Canada's energy transition argue that Alberta has the potential to repurpose resources from its hydrocarbon industries to be compatible with climate change. In the face of the energy transition, Alberta can decarbonize existing hydrogen production by implementing CCUS to produce low carbon hydrogen and further emissions reduction could be realized by integrating low carbon hydrogen into sectors, such as transportation, heating and industrial processes.

2.2 Decreasing Demand for Alberta Oil and Natural Gas

The global energy transition will likely mean less demand for oil and gas. As global oil and gas demand decreases, Alberta will find competing with lower-cost oil and gas produced outside of Canada challenging. A report by the International Institute for Sustainable Development (IISD) finds an average decrease of CAD 4.4 billion each year to 2050 in Alberta's oil and gas sector due to a combination of market forces, increasingly stringent international climate policies, and geopolitics (Cosbey, Sawyer and Stiebert, 2021). Amidst the shift away from fossil fuels, Alberta is looking to hydrogen, which produces no direct carbon emissions, to help the province during the energy transition to potentially benefit the economy, create jobs and utilize Alberta’s natural gas reserves (in combination with CCUS) to lower emissions.

Policy developments in the United States, the destination for 98% of Canada's exported crude oil, could have the most significant and immediate impact on demand for Canadian exports. Stricter climate change regulations and demand-side measures will lower demand for Canadian oil (Cosbey et al, 2021). Resulting lower oil exports and prices could negatively impact resource revenues. The same IISD report models a potential 43% drop in royalties to the Alberta government (Cosbey et al, 2021). Given that the province relies on these revenues for public services, public planning should ensure that public funding remains stable through the energy transition.

Additionally, decreasing demand for Alberta oil and gas presents an immediate challenge. It will be difficult for a capital-intensive sector to adapt to sudden changes in world demand without oil and gas investments becoming stranded. The Financial Stability Board recognizes the risk of climate change-related stranded assets to the global financial system as a very real issue and has created a reporting system to track such risks (Altenburg and Rodrick, 2017). Additionally, some energy companies are pulling out of Alberta's oil sands completely due to pressure from investors to divest from carbon-intensive sectors (Hurst, 2022). Hence, while oil and gas is still in demand, climate policies and market mechanisms will likely decrease demand, make oil and gas investments less profitable, and drive the transition towards a low-carbon economy.

2.3 Hydrogen to Mitigate Climate Change

Globally, governments and industry are increasingly looking to hydrogen to help address climate change. Hydrogen can contribute to decarbonization in several ways. Hydrogen use today is predominately in the industrial sector. In Alberta, just over half of hydrogen production is used for heavy oil upgrading and 38% is used for the chemical sector

(Government of Alberta, n.d.c). Incorporating low carbon hydrogen into existing industrial uses and expanding hydrogen use into other emissions-intensive sectors can significantly reduce emissions. For example, in buildings, hydrogen can be blended with natural gas to provide heat through existing infrastructure. Another example of hydrogen use for decarbonization is in transportation. Hydrogen fuel cells can be used in the transportation sector as an alternative to more carbon-intensive fuels, like gasoline and diesel, and there is further potential for hydrogen in shipping and aviation where low carbon fuel options are limited (IEA, 2021).

The IEA suggests that hydrogen is presently experiencing exceptional political and business momentum with growing global policies and projects under development (IEA, 2021). As of 2021, over 14 countries have developed national hydrogen strategies, and more than 20 other countries have announced they are actively developing strategies.[1] Canada, and several provinces within Canada, including Alberta, have developed strategies of their own.

Alberta already has a significant experience in hydrogen production. As one of the largest hydrogen producers globally, Alberta produces around 2.4 million tonnes of hydrogen each year. Most of this is used for heavy oil upgrading or turned into ammonia and used as a fertilizer (Government of Alberta, n.d.b). To contribute to emissions reductions, existing hydrogen applications can implement cleaner hydrogen production methods, and hydrogen can be used in new applications such as transportation, power generation, and heating

[1] Countries that have adopted hydrogen strategies include: Canada, Chile, France, Germany, the Netherlands, Norway, Portugal, Russia, Spain and the European Union (France had already adopted a Plan for Deploying Hydrogen for the Energy Transition in 2018), Czech Republic, Colombia, Hungary and the United Kingdom) In addition, Poland and Italy have released strategies for public consultation (https://www.iea.org/reports/hydrogen)

instead of carbon-intensive inputs (IEA 2, 2021). In addition to helping meet climate targets, hydrogen has the potential to be profitable. The Energy Futures Lab estimates that by 2050, the potential market for Canadian hydrogen could reach CAD 47 billion per year domestically and CAD 102.7 billion per year, including U.S. and overseas markets (Energy Futures Lab, 2021).

ALBERTA'S HYDROGEN ROADMAP

3.1 Overview

The movement toward low carbon energy sources in Canada and around the world presents Alberta with a dual challenge: remain competitive and reduce emissions. In 2020, Alberta's Recovery Plan and Natural Gas Vision and Strategy established a goal to help address this challenge, incorporating hydrogen into the province's energy system portfolio. In 2021, the Alberta hydrogen Roadmap actualized this goal. Alberta's oil and gas, power generation, and other heavy industries add approximately CAD 100 billion annually to the Canadian economy, and they also account for about 70% of the province's GHG emissions (Government of Alberta, 2021). Alberta's Hydrogen Roadmap seeks to reduce emissions in these sectors and drive economic development by incorporating clean hydrogen into the provinces' energy portfolio (Government of Alberta 2019).

In 2019, Alberta's GHG emissions were 275.8 million tonnes (Mt) of carbon dioxide equivalent (CO2e). The largest emitting sectors are oil and gas production at 51% of emissions, electricity generation at 11%, and transportation at 12% (Canadian Centre for Energy Information, 2019). The Roadmap is a policy framework for how Alberta can grow a clean hydrogen market through building new hydrogen demand outside its current predominate use in industrial processes and seeking export opportunities, reduce its emissions by up to 14 Mt per year (a 5% reduction from 2019 levels), and establish the province as a leader in the global hydrogen economy by 2030 (Government of Alberta, 2021).

3.2 A Note on the *Alberta Hydrogen Roadmap's* "Clean" Hydrogen

The Roadmap's "clean" hydrogen terminology warrants some additional context and understanding. The Roadmap refers to clean hydrogen as its focus for growth and development. However, its primary focus is on "blue" hydrogen produced through steam methane reforming (SMR) technology using carbon capture and storage (CCS), a low carbon hydrogen. While it is a cleaner version than "grey" hydrogen, which is produced without CCS technology, blue hydrogen is not the cleanest form of hydrogen. Rather "green" hydrogen produced through electrolysis using renewable energy is the cleanest hydrogen, producing no carbon emissions (Van Hulst, 2019). The types and emission intensity of hydrogen are discussed in further detail later in section IV.

3.3 Policy Pillars:

The Roadmap outlines potential "incremental" (business as usual) and "transformative" (government intervention) outcomes for the adoption of a hydrogen economy. It identifies the industrial sector, residential and commercial heating, power generation, transportation, and exports as markets for hydrogen opportunities. Seven policy pillars are intended to support Alberta's hydrogen ambition (directly from *Alberta's Hydrogen Roadmap*):

1. **"Build new market demand.** Establishing hydrogen demand is required to build out supply and commercialization pathways.

2. **Enable Carbon Capture, Utilization and Storage (CCUS).** For Alberta to deploy clean hydrogen into the economy, CCUS infrastructure must be widely available.
3. **De-risk investment.** Long-term investment certainty and funding are required as hydrogen is an emerging opportunity with challenging economics.
4. **Activate technology and innovation.** Demonstration projects, research, and innovation are needed to prove and scale up emerging clean hydrogen technologies. Training and development with Alberta's world-class universities and technical schools are important to support a labour force capable of working within the hydrogen economy.
5. **Ensure regulatory efficiency, codes, and standards to drive safety.** As the clean hydrogen economy is emerging, a regulatory regime including codes and standards must be inclusive of hydrogen and enshrine a safety-first mindset across the value chain.
6. **Lead the way and build alliances.** Public-private partnerships and government-to-government relationships, including with Indigenous partners, are essential to advance the hydrogen economy, send coordinated signals to investors, and build public education and acceptance.
7. **Pursue hydrogen exports.** The international community is looking to lock in hydrogen supply agreements now. Alberta must move aggressively to establish market access and close intra-Alberta and hydrogen export gaps in supply chain logistics." (Government of Alberta 2021, pp. 6-7).

4.0 HYDROGEN

Hydrogen is an energy source that can help to tackle various critical energy challenges. Similar to solar and wind power, it can cast high emission levels upstream when produced with fossil fuels. When made using renewables, nuclear or fossil fuels combined with CCUS, it can help decarbonize a range of sectors where it is difficult to reduce emissions (IEA, 2019).

4.1 Production Methods and Types

Hydrogen has several production methods, which result in a classification of hydrogen based on the CO_2 emitted. This paper and Alberta's Hydrogen Roadmap discuss three main types.

Grey Hydrogen. Grey hydrogen has the most carbon-intensive production process, nearly comparable to coal-fired electricity, at approximately 90 grams of CO_2 equivalent per megajoule (g CO_2e/MJ) (Canada Energy Regulator, 2020). Grey hydrogen makes up most of Alberta's current production. The production method uses steam methane reformation (SMR), which brings together natural gas or methane with hot steam that causes a chemical reaction resulting in hydrogen and CO_2 (National Grid, 2022).

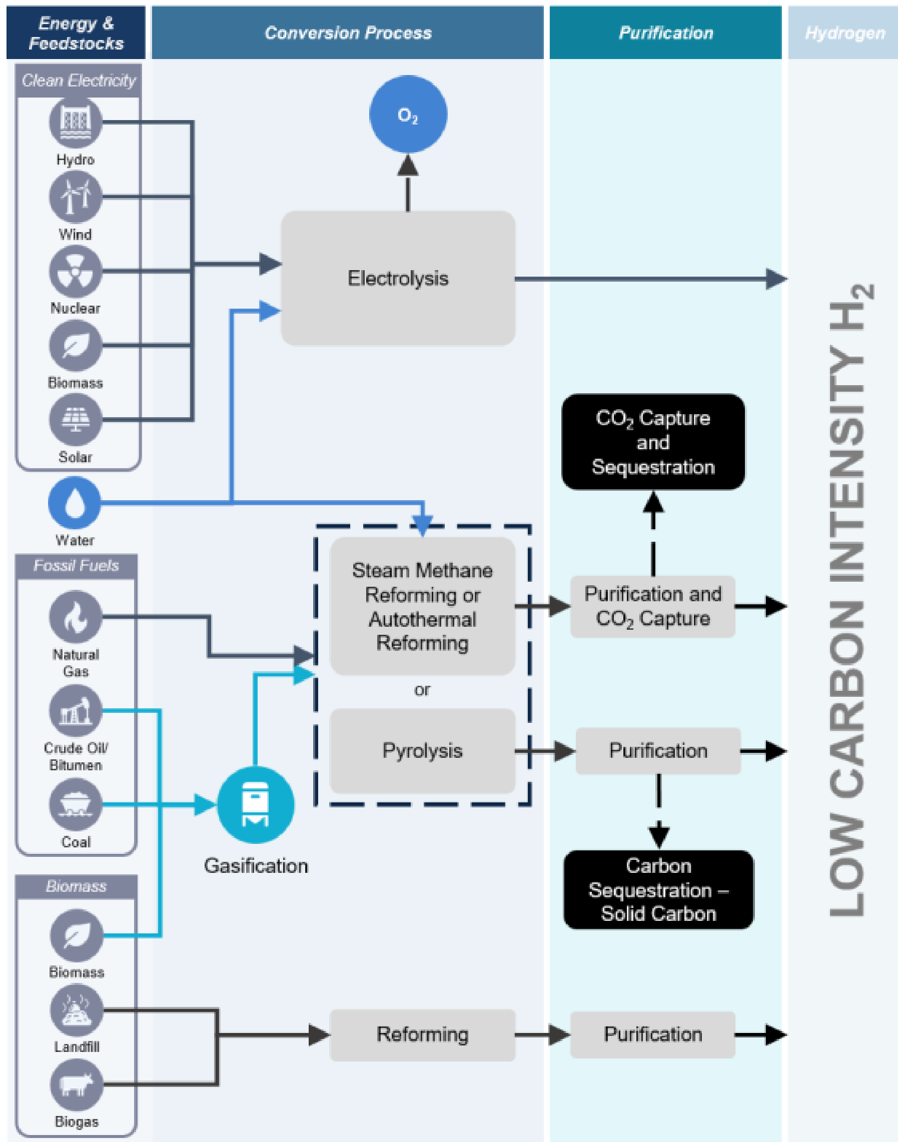
Blue Hydrogen. Blue Hydrogen is the primary focus of the Roadmap. Blue hydrogen is a cleaner option most produced using SMR and CCUS technology which captures and stores the CO_2 emissions. Its emissions reductions are estimated at 22g CO_2e/MJ (Canada Energy Regulator, 2020). The Roadmap discusses a second blue hydrogen production method called autothermal reforming (ATR). This method uses natural gas, steam, and oxygen to produce a high-purity stream of carbon dioxide, which enables over a 90% carbon capture rate (Government of Alberta, 2021). The Roadmap discusses this method briefly, but no clear actions are detailed to support it.

Green Hydrogen. Uses renewable energy to produce hydrogen through electrolysis. This process uses an electric current, powered by renewable energy, to split water into hydrogen and oxygen, emitting zero CO_2 (National Grid, 2022). Alberta could produce green hydrogen as it has some of Canada's best solar and wind potential (Wilson, 2020). However, it is significantly more expensive and not anticipated to become comparable to the cost of blue hydrogen until 2030 (Bloomberg, 2021).

Additional work is underway to more accurately classify hydrogen production's carbon intensity.[2] Due to the range of carbon emitted within each colour, governments and industries globally are working towards a classification system to identify hydrogen based on emissions intensity. Figure 1 illustrates Canada's main hydrogen production pathways.

[2] The Environment and Climate Change Canada discussed this objective in its current hydrogen communication working group and the Alberta Hydrogen Roadmap states that "as Canadian and other global low-carbon hydrogen thresholds are established, Alberta will collaborate with other governments and international partners to support the development of science-based carbon intensity thresholds for hydrogen production. Government of Alberta, "Alberta Hydrogen Roadmap," 27.

Figure 1. Canada's Main Hydrogen Production Pathways



Source: (Natural Resources Canada, 2020).

4.3 Hydrogen applications for emissions reduction

Hydrogen can replace fossil fuels to heat, cool, and power buildings; provide electricity; and be used in industry and transportation. It is particularly valuable in sectors that are difficult to decarbonize. For example, while electrification is central to meeting net zero targets, it is often too costly and challenging in specific sectors. Where this is the case, such as in fertilizer production, iron and steel, aviation and shipping, and long-haul road and heavy freight rail transportation, clean hydrogen can be used instead (Bataille et al, 2021).

However, in many instances, hydrogen is less efficient than its alternatives in many applications, particularly when it is converted to other energy forms. For example, the IEA notes an efficiency loss of approximately 70% of the initial energy source when electricity is converted into hydrogen, shipped, stored, and then converted back to electricity using a fuel cell (IEA, 2019). This is an extreme example, however, the process of hydrogen production and conversion always produces energy losses. Hydrogen has just under a third of the energy of natural gas. That means for every cubic foot (CF) of natural gas, it takes about 3.3 CF of hydrogen to deliver the same energy content (ISTJ Investor, 2020). However, its potential to decarbonize hard-to-abate sectors, and contribute to emissions reduction generally, particularly when produced using renewables, makes hydrogen a promising option amidst the energy transition.

4.4 Alberta's Hydrogen Advantages

Alberta's geology and experience producing hydrogen give it several strengths for building a hydrogen economy.

1) **Resources:** Natural gas reserves, some of Canada's best wind and solar potential, and salt mines for long-term hydrogen storage for later use (Wilson, 2020).
2) **CCUS:** Alberta is home to commercial-scale carbon capture, utilization, and storage.
3) **Experience:** Alberta is a global leader in (mostly grey) hydrogen production with roughly 5,400 tonnes produced daily from natural gas (Government of Alberta, 2021).

5.0 THE CASE FOR INDUSTRIAL POLICY

An important consideration in evaluating the Roadmap is the extent to which industrial policy is warranted. Even with Alberta's over 50 years of experience producing hydrogen and hydrogen's potential to reduce emissions, a hydrogen market will not necessarily develop in an appropriate timeframe (given fast-approaching climate change targets) on its own.

5.1 What is Industrial Policy?

Defined very simply, industrial policy refers to government's intervention in a specific sector with the intent to change its development to benefit the economy. More specifically, it consists of government actions to change the structure of an economy to encourage desirable development, such as economic growth and prosperity (Altenburg and Rodrik, 2017). This concept is important as this paper evaluates the Roadmap in light of it being a vision of industrial policy for Alberta.

Industrial policy takes the form of various policy measures. Industrial policy tools can include protective tariffs, trade restrictions, subsidies or tax credits, publicly funded research and development (R&D), or government procurement of goods and services (Siripurapu, 2021). More recently, however, countries have expanded their goals with the use of industrial policy. In addition to government actions to accelerate structural change to enable economic growth and wealth, industrial policy and inequality, support labour-intensive industries or encourage a more environmentally sustainable economy (Altenburg and Dani Rodrik, 2017).

Industrial policy has drawn skepticism over the years because of its "chequered history" (Rodrik, 2014). While it has been successful for new industries in many East Asian countries, it has primarily been considered costly and of little value in advanced and developing countries. Rodrik argues that industrial policy's negative reputation is misrepresentative of its contributions to technological development. Despite several expensive failures, government support in the form of industrial policy has been central to crucial US industries such as Silicon Valley. Additionally, recent research has argued that key iPhone technologies—the touchscreen, the GPS, voice activation (Siri)—have advanced from public resources (Rodrik, 2014). Another very recent example of this is the Biden administration's restriction on selling semiconductors and chip-making equipment to China in attempts to limit its access to vital technologies (Swanson, 2022).

5.2 Industrial Policy: Critics and Proponents

In addition to costly failures, economists cite two main factors against industrial policy. The first common argument against industrial policy is that governments do not have the information needed to decide which firms or industries to support and that these decisions are better determined by the free market (Siripurapu, 2021). In other words, government cannot pick winners. The concern is that governments may support an industry that fails and wastes public funds and resources. The second argument against industrial policy is that government support for an industry is at risk of political manipulation. Industrial policy becomes determined by political rather than economic motives and leads to "crony capitalism," where success depends on close business-government relationships.[3]

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[3] Rodrik, "Green industrial policy." Rodrik references US company Solyndra—a solar cell manufacturer that folded after having received more than half a billion dollars in loan guarantees from the US government as a recent example where rent-seeking and political manipulation contributed to its failure, and Siripurapu, "Is Industrial Policy Making a Comeback?"

On the other side of the argument, industrial policy advocates argue that government has both the ability and the responsibility to structure the economy to benefit the region or nation, when markets do not efficiently do so on their own (Siripurapu, 2021). In other words, amidst market failures, or even uncertainties, or social suboptimal outcomes, government support in the form of industrial policy is warranted. Supporters also argue that government should fund R&D for specific industries because the social benefits go well beyond what companies will invest on their own (Siripurapu, 2021).

Rodrik offers an alternative view for employing effective industrial policy that supports economic growth and minimizes the risks concerning its critics (wasted public funds and political manipulation). He argues that rather than policy outcomes, the analysis of industrial policy should be placed on “getting the process right.” (Rodrik, 2004). According to Rodrik, the view of industrial policy as a discovery process involving government and industry collaboration to identify and understand costs and opportunities renders traditional arguments against industrial policy less compelling. While governments may not have perfect information to pick winners, neither does the private sector and these information issues create a valuable role for government. Similarly, when industrial policy is thought of as a collaborative discovery process, the concept of keeping private firms isolated from government to minimize political manipulation break down because the process is a combined effort. While government needs to remain autonomous from industry interests, it cannot be isolated because it needs the private sector to help identify obstacles and work together on solutions to address them (Rodrick, 2004).

This alternative view of industrial policy provides insight into whether Alberta should support its own hydrogen industry. It suggests that given the global energy transition and increasing interest in hydrogen, combined with the urgent need to reduce emissions and mitigate climate change, Alberta might be warranted in its decision to develop its hydrogen industry. Additionally, Alberta needs to think critically about and plan for reduced demand for its oil and gas products and define how this future looks while considering its existing resources and expertise. From this perspective, hydrogen support may be in the region's economic and environmental interest. However, as Rodrik suggests, Alberta should focus on “getting the process right” (Rodrik, 2004). It needs to strike a healthy balance between working collaboratively with private firms and their own economic concerns, which lean toward securing the market for natural gas, with deeper decarbonization options, which would include support for hydrogen produced using renewables, if Alberta is to make significant contributions to emissions reductions.

5.3 Green Industrial Policy

Where industrial policy is the government's intervention in a specific sector with the intent to promote development to benefit the economy, green industrial policy is "any government measure aimed to accelerate the structural transformation towards a low-carbon, resource-efficient economy in ways that also enable productivity enhancements in the economy" (Altenburg and Rodrik, 2017).

At first glance, Alberta’s clean hydrogen, produced most commonly using natural gas in combination with CCUS, may not be recognized as a green industry primarily because its objective seems less about decarbonization or growing green hydrogen production as much as it is about supporting blue hydrogen produced using natural gas. However, a closer look reveals similarities. The United Nations Industrial Development Organization describes green industries as “economies striving for a more sustainable pathway of growth, by undertaking green public investments and implementing public policy initiatives that encourage environmentally responsible private investments” (The United Nations Industrial Development Organization, n.d.). Rodrik and Altenburg also consider environmental and energy policies “that deliberately push structural change into the desired direction…part of green industrial policy.” Their definition also includes policies that add to the national, and in the case of Alberta, regional, benefits of the energy transition through higher incomes and job creation, an objective and benefit outlined in the Roadmap (Altenburg and Rodrik, 2017).

Where the Roadmap does not specifically focus on green public investments, it does aim to diversify and benefit Alberta’s economy primarily through the production of blue hydrogen which will contribute to (at least some) emissions reductions, even if it is only by up to 14 Mt per year (a 5% reduction from 2019 levels) (Alberta Energy, 2021). Therefore, hydrogen production likely faces similar challenges and shares similar market failures as many green technologies.

5.4 Appropriate Justification for Industrial Policy and Rodrick’s Three Considerations

Rodrik and Altenburg argue that the rationale for industrial policy rests on the idea that market prices are not always the best guide to allocating investments amidst market failures and/or incomplete understanding of market failures and state that this is truer for climate change and green technologies (Altenburg and Rodrik, 2017). Market failures usually justify government intervention via policy measures to encourage efficiency. A further section will examine hydrogen's challenges and market failures.

Rodrik's Three Considerations

Green industrial policy is different from industrial policy in that there is an urgency to achieve structural change within a short time period to prevent the harmful effects brought on by climate change (Altenburg and Rodrik, 2017). There is also enhanced uncertainty about technologies, policy, and environmental changes. New technologies become especially unpredictable when climate change targets are proposed over decades and when there are no successful examples of a green economy for countries to emulate (Altenburg and Rodrik, 2017). Political factors, like the appetite for increasing carbon taxes, bring additional uncertainty, particularly with change in administration. Finally, environmental change is difficult to predict and does not follow a linear pattern. As uncertainty is more profound in green industrial policy, governments have a critical role in reducing uncertainty (Altenburg and Rodrik, 2017).

Rodrik outlines three considerations that drive a wedge between private and social returns to investment in green technologies, meaning that firms are not able to reap the benefits from their investments that provide social benefits. As mentioned above, similarities can be drawn between green technologies and the production of blue hydrogen (both contribute to emissions reductions); therefore, these three sets of considerations can be applied in the Roadmap's context.

The first consideration is that the development of new technologies generates positive spillovers that the original investors do not fully capture (Rodrik, 2014). A technological spillover is a type of market failure where firms benefit from information created by others at no financial cost (Grossman and E. Helpman, 1992). As hydrogen is a relatively new technology, particularly when used with CCUS and applied to different end uses, it likely has similar spillover effects. Positive spillovers on their own may not justify industrial policy. The standard economic policy prescription for addressing positive externalities is a subsidy to correct the specific market failure. However, climate change and Rodrik's further considerations may warrant public support for green industries.

A second reason green technologies may need to be publicly subsidized is when pricing does not fully internalize its externality (Rodrik, 2014). In other words, green industrial policy may be a viable solution when climate mitigation policy is inefficient. A later section will further examine the stringency of Canada's carbon price in greater detail.

The last consideration Rodrik offers on green industrial policy is about implementation and competitive motive. Though there are strong incentives to free-ride on decarbonization efforts, as it represents a universal public good, Rodrik acknowledges that government support for green industries is extensive, which he attributes to competitive motives (Rodrik, 2014). Competitive motive further complicates effective green industrial policy depending on countries' national objectives or agenda. For example, countries supporting their green industries for competitive reasons, for instance, creating green jobs, can positively contribute to global climate mitigation, but other actions, such as trade restrictions on foreign green industries can impede global climate mitigation efforts (Rodrik, 2014). Though Alberta's Hydrogen Strategy is very focused on its domestic economic growth, according to Rodrick, that doesn't necessarily mean it should be dismissed as bad "green" policy. Instead, it should be evaluated on its ability to promote the development of green technology and contribute to decarbonization. Rodrik suggests that given the above considerations industrial policy critics should look more favourably towards industrial policy in support of green technologies (Rodrik, 2014).

6.0 HYDROGEN CHALLENGES AND MARKET FAILURES

While Alberta is well-positioned to become a leader in hydrogen, it does not mean that a hydrogen market will develop on its own, even if societal benefits outweigh the overall societal costs (Rodrik, 2014). This section will address why a hydrogen market may not develop on its own by reviewing and discussing hydrogen's challenges and market failures.

6.1 Challenges

Low carbon and clean hydrogen production's major challenge is cost. Currently, hydrogen production using fossil fuels is the least expensive option in most parts of the world. A 2021 report from the IEA estimates that the levelized cost of hydrogen production from natural gas ranges from USD 0.5 to USD 1.7 per kilogram (kg). Using CCUS technologies to capture the CO_2 emissions from hydrogen production increases this cost to around USD 1 to USD 2 per kg. Using renewable electricity to produce hydrogen is the most expensive production method, costing an estimated USD 3 to USD 8 per kg (IEA, 2021). For end-use applications, this means higher costs. For example, testing has shown that hydrogen can be blended into existing natural gas infrastructure for heating. Blending up to 20% would require no major infrastructure changes and would contribute up to 7% emissions reductions -- a small amount compared to what is needed for decarbonizing global heating demand (IEA, 2021). Moreover, due to the cost gap between natural gas and hydrogen, customers would face higher prices, and hydrogen blending beyond 20% would require infrastructure retrofits and modifications to in home appliances, raising costs further (Mahajan, Tan, Venkatesh, Kileti, Clayton, 2022). Across the European Union, one study estimates that the end-user natural gas price increase for households due to blending is 0.6% for a 5% blend, 4.7% for a 10% percent blend, and 11.2% with a 20% (Bard, Gerhardt, Selzam, Beil, Wiemer, Buddensiek, 2022). Estimates for industrial consumers are just above double these estimates for each respective blending level (Hastings-Simon, 2021).

Outside of the cost challenge to end users, hydrogen's application in new markets might face skepticism commonly faced by unproven new technologies; primarily the challenge to secure funding for demonstration (Hastings-Simon, 2021).

6.2 Market failures

6.2.1 Fundamentals of environmental and technology economics

Market failures often hinder low carbon and clean technologies. Market failure, in economics, is the failure of a market to deliver efficient outcomes resulting in decreased welfare. In theory, an efficient market distributes goods and services in the most optimal way. This means that goods and services are produced at the lowest cost and consumed by those with the highest willingness-to-pay (Mulder, Perey and Moraga, 2019). However, market failures can exist that prevent the efficient allocation of goods and services. For environmental or climate change concerns, market failures are potentially damaging economic activities, known as externalities, where the negative impacts affect individuals or groups other than those responsible for producing the externality (Jaffe, Newell, Stavins, 2005). Governments often intervene to correct the inefficient allocation of goods and services. For climate change, policies try to correct the imbalance by incentivizing a firm to reduce the externalities, balancing the marginal social cost of reducing emissions with the marginal social benefit of mitigating climate change (Jaffe et al, 2005). In other words, government policies aim to correct market failures that do not account for the social costs harmful to the environment and correct failures that do not reflect the social benefit that often results in underinvestment (Altenburg and Rodrik, 2017).

In environmental economics, when technology becomes involved, the balance between the marginal cost of pollution control and its marginal social benefit are changed (Jaffe et al, 2005). Clean or green technologies have the potential to decrease the cost of pollution control, or specific to the interest of this paper, decrease the cost of emissions reductions.

6.2.2 Underpricing of pollution/Carbon price stringency.

There is a clear market failure in hydrogen production when carbon emissions are mispriced (Mulder et al, 2019). This is generally considered a market failure in producing goods and services where the production of the goods and services generates a negative externality in the form of GHG emissions. It occurs when all production costs are not internalized in prices, resulting in activity levels that are too high from a social cost perspective. In this instance, the negative environmental externalities of oil and natural gas production and consumption, GHG emissions, are not reflected in the price. Introducing more stringent carbon pricing to address the marginal social costs of climate change would solve this market failure (Mulder et al, 2019). As adequate carbon pricing measures are introduced, carbon-intensive energy producers are incentivized to reduce emissions through any cost-effective means possible, including adopting new technology or fuels such as hydrogen. Blue hydrogen can reduce the negative externalities from carbon emissions and local pollutants from existing grey hydrogen production and other industry applications.

Carbon pricing is considered the first-best policy tool for reducing GHG emissions (Bailey, Shaffer, Winter, 2021). However, the stringency of these prices is vital to its effectiveness. Carbon pricing needs to internalize the external environmental damages of burning fossil fuels to maximize social welfare. The social cost of carbon (SCC) is a cash value estimate of the damages of producing one additional ton of CO2 emissions or the value of reducing emissions by one tonne. The measure enables policymakers to evaluate carbon pricing stringency (Carleton and Greenstone, 2021). Given its importance for emissions reduction, the stringency of carbon prices is a significant driving factor for developing a hydrogen market.

Canada's *Greenhouse Gas Pollution Pricing Act* (GGPPA) currently prices carbon at CAD 50 per tonne of CO2 equivalent GHG. Provinces and territories that fail to meet the equivalent through their carbon pricing schemes are subject to a federal backstop. However, experts estimate this is far below the current scientific SCC estimate of CAD 125 per tonne of CO2.[4] The 2020 climate plan *A Healthy Environment and a Healthy Economy* is helping to close this gap. It proposes more stringent pricing, increasing annually by CAD 15 per tonne of CO_2 to reach CAD 170 by 2030 (Environment and Climate Change Canada, 2020).

[4] The SCC is an evolving calculation. Carleton and Greenstone's estimate is $125 for 2020.

However, an independent report published by the Canadian Institute for Climate Choices (CICC) identifies several trends across Canada that undermine the effectiveness of Canada's carbon price (Sawyer, Stiebert, Gignac, Campney, and Beugin, 2021). Of these, and particularly relevant to Alberta, is that not all policies impose the same cost on industry. Alberta implemented its large emitter program with its *Technology Innovation and Emissions Reduction* (TIER) Regulation for large industrial emitters in 2020. The regulation requires facilities emitting more than 100,000 tonnes of CO2 per year to reduce GHG emissions through an emissions trading system. Large industrial emitters regulated under TIER must reduce emissions to meet specific benchmarks or submit Alberta Emission Offsets generated from qualifying emissions reductions outside of regulated facilities, submit emissions performance credits, or pay the federal GGPPA equivalent of CAD 50 per tonne, into the TIER fund (Government of Alberta , n.d.d). Yet not all industrial emissions are covered by this pricing incentive. In fact, In Alberta, only 60% of Alberta's industrial emissions are covered by the price incentive (Sawyer et al, 2021).[5] Additionally, Alberta committed to fossil fuel production to help recover from the pandemic, increasing subsidies and using the TIER fund to boost fossil fuel production, including through subsidies for CCUS (McKenzie, Beedell and Corkal, 2022). Though CCUS is an emissions reduction technology, facilities in Canada use the captured CO2 in

[5] See Sawyer et al, 2021, Figure 9, p. 31. "Emissions covered by the price incentive include all emissions in a province or territory that have an opportunity cost. In other words, an emitter can avoid paying the price of carbon by reducing these emissions—or even generate revenue from selling credits, if they are able to reduce these emissions even more. A price incentive transmitted broadly creates incentives for more emitters to reduce more of their emissions. All else being equal, broader coverage increases policy effectiveness and cost effectiveness." (D. Sawyer, S. Stiebert, R. Gignac, A. Campney, and D. Beugin, 2021), p. 28.

other processes, such as enhanced oil recovery (EOR), which involves injecting the CO2 into declining oil fields to recover additional oil.

The CICC calculates the Average Cost Incentive, or cost on emissions owed, as total direct carbon pricing revenues divided by the total covered emissions in each province or territory (Sawyer et al, 2021). The average cost incentive informs on the strength of the signal or incentive for firms to reduce their emissions. Relevant to hydrogen, this could include new capital investment decisions and retrofits to existing facilities, such as installing CCUS technology (Sawyer et al, 2021). The calculation indicates that the average cost incentive varies considerably across Canada from CAD 4 per tonne to CAD 36 per tonne, with Alberta on the low end at CAD 10 per tonne for all covered emissions (Sawyer et al, 2021). The low average price indicates that long-term signals to invest in low-carbon technology may also be low. When emitters expect increasing carbon prices, they are more likely to invest in emission reduction technologies (Sawyer et al, 2021).

While the federal government improved its carbon pricing effectiveness, strengthening the long-term pricing signal with a clear increasing carbon price of CAD 170 per tonne by 2030, some gaps still exist. For instance, Canada's carbon pricing benchmark could be further improved by establishing a minimum performance standard that would set expectations for how provincial and territorial carbon pricing systems apply to large industrial emitters (Gignac and Sawyer, 2021). Furthermore, the act fails to enforce targets and outline consequences for failing to achieve emission reduction targets beyond providing an explanation and further plans for moving forward (Climate Action Network, 2020). In Alberta, TIER does not reflect carbon pricing beyond 2022. With only 60% of

Alberta's emissions covered by the pricing incentive, TIER could benefit from inclusive emissions coverage to incent further emissions reductions.

Regardless of carbon pricing's importance, it is not stringent enough and drives change at a slower pace than what is needed to support the development of green industries to mitigate climate change and adapt to the energy transition because of other market failures (Bentley, Eaton and Islam, 2022). The same is true for the low carbon hydrogen industry. For instance, a more stringent carbon price will not prevent the knowledge spillovers shared with other firms at no cost and prevent the firms employing the new technologies from capturing the benefits and, therefore, impede hydrogen production. Knowledge spillovers and hydrogen's other market failures are discussed in further detail below.

6.2.3 Knowledge Spillovers.

Knowledge spillovers are a primary source of market failure for new technologies and innovation (Martin and Verhoeven, 2022). They create a positive externality when firms employing new technologies and innovation are unable to prevent other firms from reaping the benefits of its earned knowledge. Consequently, they cannot capture all the associated benefits of these technologies and innovations (Jaffe, 2005). In other words, one company's knowledge spills over to other companies, and that can discourage investment in expensive innovations that provide societal benefits. This market failure exists with green hydrogen as it is a new technology and low carbon hydrogen production using CCS technology, which is incredibly complex, both where knowledge-sharing is important for growing the technology (Dion, 2021). Alberta recognizes this and has committed $1.24 billion through 2025 to two commercial-scale carbon capture projects, the Quest Project and the Alberta Carbon Trunk Line (ACTL).

6.2.4 Reliance on policy or the hold-up problem.

Another market failure affecting hydrogen is hold-up. This market failure occurs when firms are uncertain about ex-post revenues they would receive after making an investment, resulting in too little investment. Another example of this issue is reliance on policy. Research from the Energy Futures Lab (EFL) identifies reliance on policy as a market failure for "Future Fit Hydrocarbon (FFH) industries," which describe existing hydrocarbon industries where there is potential to repurpose assets, such as resources and infrastructure, in a direction that is compatible with a net-zero emissions future (EFL, 2021). Despite this definition, this market failure is still a problem for low carbon hydrogen. In this example of the hold-up issue, demand in FFH industries is dependent on government policies, like the carbon price, which have been unstable in the past. It is challenging to predict the future stringency of these policies, particularly when Alberta has not forecasted pricing beyond 2022, and there are efficiency concerns with pricing incentives, discouraging investment (EFL, 2021). Tools that lock in financial certainty of climate policy could help reduce uncertainty related to investment risks and cost in low carbon technologies (Bailey et al, 2021). If this market failure exists, policy that is guaranteed, like the federal backstop carbon price, at least to the extent that Canada is looking to "future proof" the carbon price against potential future governmental decisions to revoke or lower it, which could include legislative measures, can provide investors with more certainty about future revenues (Rabson, 2022).

6.2.5 Information Barriers and Asymmetric Information.

Clean technologies and FFH industries, like hydrogen, also often face information barriers. These industries involve new technologies, processes, and business models that investors do not completely understand. This lack of understanding can result in reluctance to invest in new technologies and difficulty gauging their potential value (EFL, 2021).

With asymmetric information, an individual or firm in a market situation has relevant information that the other does not. In this situation, buyers or consumers cannot fully assess the characteristics (quality) of a good or service, which can result in a lower willingness to pay (Mulder et al, 2019). In the case of hydrogen, buyers concerned with reducing their emissions will want to ensure they have complete information on the type, or quality, of clean hydrogen they purchase. This information could include production methods, whether with natural gas and CCUS or through electrolysis, and an understanding of the life-cycle emissions of hydrogen-- the carbon footprint associated with each step of production, such as transportation, conversion, etc. (Rapier, 2020). In the presence of this market failure, coordination or regulation is required (Mulder et al, 2019). An example would be the coordination or adoption of an international emissions classification system.

This same market failure can also affect investors. The Roadmap focuses on “clean” hydrogen. A closer read reveals that this is primarily blue hydrogen, yet the emissions intensity varies dramatically in what is classified as clean hydrogen. This is a potential issue for producers and investors who need clear information on emissions intensity (as it affects costs and potential revenue). Without precise classification on emissions intensity, investors and producers cannot be clear on potential projects aligning with Alberta’s definition of clean, and likely more significant for revenue, potential national and international standards of clean (HM Government, 2021).

Given these known market failures, policy tailored to each market failure could support the development and scale-up of hydrogen to produce economic and environmental benefits. However, without such tailored policy, industrial policy could simultaneously address several of these failures.

7.0 ALBERTA AND PROVINCIAL ECONOMIC CONCERNS

7.1 Should Alberta Have a Hydrogen Strategy?

Economic diversification and growth is a key driver of Alberta's Hydrogen Roadmap. Given that demand for oil and gas will likely decline significantly in coming years due to climate change policy, the Roadmap aims to develop a hydrogen production industry proactively. As discussed earlier in this paper, industrial policy describes government's intervention in a specific sector to change the structure of an economy to encourage desirable development such as economic growth and prosperity, and in more recent years, to promote a more environmentally sustainable economy. However, as discussed, industrial policy critics and supporters have several arguments against and for its use.

There is justification for government support of industry when there are significant market failures with limited information about those market failures. Another rationale for industrial policy might be in instances where governments seek to achieve several desired goals or objectives. For example, steam-assisted gravity drainage technology, an in situ oil recovery process that made a large part of the Canadian oil sands accessible, is an example of industrial policy that Alberta used to achieve disruptive innovation and economic development. The government actively funded R&D through the Alberta Oil Sands Technology and Research Authority which led to the innovative in situ recovery method and Alberta's in situ oil sands industry. Similarly, Alberta's current dual challenges of diversification in the energy sector and decarbonization could justify industrial policy Hastings-Simon, 2019). Given Alberta's prominence in the energy sector, it is actively seeking ways to avoid significant economic impacts due to the global energy transition. At the same time, the Province is trying to reduce emissions. Government support for hydrogen, since it is hindered by several market failures, may be a means to address the dual goals to diversify and reduce emissions with less potential political downside than addressing the goals individually with policy.

If Alberta's goals are to diversify its energy sector, reduce emissions and remain competitive in energy, hydrogen production is an industry that may provide a promising avenue for these goals. However, Alberta should have a strategy to address its market failures to allow the hydrogen production industry to develop.

To address industrial policy critics, Alberta needs to be clear and transparent in its policies. Supporting blue hydrogen production, according to Rodrik's recommendations, should be done in collaboration with natural gas firms. However, Alberta needs to be careful not to lock itself solely into blue hydrogen production, which is something that natural gas firms will be pressing.

Another reason that Alberta should have a strategy is that while oil and gas prices have recovered from the pandemic price crash, jobs may not recover to the same extent. Across Canada, oil and gas employment has decreased by 1.0%, and the oil and gas labour force ("those 15 years of age and over who were employed or unemployed, and available to the labour market, specifically within the following industry sub-sectors: exploration and production (including oil sands), oil and gas services and pipeline transmission") decreased by 2.9% from August 2021 to 2022 (PetroLMI, 2022). Meanwhile, jobs in other industries, such as transportation, construction and professional, scientific and technical services have recovered (Statistics Canada, n.d.).

Apart from job losses due to the Covid-19 pandemic, Alberta relies heavily on revenue from oil companies, which poses significant risks to public spending in the face of an energy transition (IEA, 2020).

A weak carbon price combined with the current high cost of low carbon hydrogen production make it unlikely that the hydrogen industry would develop and produce a maximum benefit in an appropriate timeframe for reaching net zero goals, if left to the market. Unless the gap between the cost of emissions and cost of emissions reduction is closed or significantly decreased, no financial incentive exists for companies to act.

Government needs to be involved in addressing the barriers to adoption (Jaffe et al, 2005). At the same time, governments need to be aware of the possibility of technology lock-in, where technology-specific policies risk suppressing the development of other technologies, particularly those that can contribute to emissions reductions (Jaffe et al., 2005). For hydrogen, this might include policies directed specifically towards blue hydrogen production, which could negatively impact the development of green, which has a greater potential to reduce emissions.

7.2 Technology-neutral and Technology-specific policy measures

Technology-neutral instruments. Carbon pricing, or emissions reduction targets/emissions restrictions, are technology-neutral measures that simultaneously decrease demand for carbon-intensive products and industries and increase demand for low carbon and renewable energy sources. Technology-neutral measures can help create hydrogen demand that would signal to investors that hydrogen is a strong/good investment and minimize risk for investors. Other technology-neutral instruments, such as subsidies for low carbon technologies and tax rebates can address capital intensiveness for industries that require large capital investments in facilities, equipment, and infrastructure, which can incentivize private sector investment.

Technology-specific Instruments. Common technology-specific measures include support for hydrogen R&D and hydrogen subsidies. Investment in R&D improves operational efficiencies and contributes to cost reductions. Hydrogen subsidies can address the negative externality produced through burning fossil fuels by increasing demand for low carbon hydrogen and are more politically favourable than raising taxes. An economic argument in favour of tech-specific instruments would be industrial policy reasons to support a specific industry that involves a specific technology that would allow a region to meet multiple goals, such as economic diversification and emissions reduction. On the other hand, the main economic argument against tech-specific policy, including subsidies, is that it has the risk of being too costly than a tech-generic subsidy. If, for example, hydrogen (even blue hydrogen) is a particularly costly form of low-carbon energy, it would be more efficient to have a sufficient carbon price incentivize lower-cost forms of low or zero carbon energy enter the market. Generally, Government support for a new technology can allow it to reach sufficient scale for commercial deployment. Over the last decade solar power costs have decreased by 90%, but this was not the case until subsidies allowed growth and enabled the appropriate economies of scale for prices to decrease (Bridle, 2021).

Environment Canada has recently acknowledged that methane produced by the oil and gas industry has been historically underestimated, so maintaining oil and gas production levels, even with producing blue hydrogen with CCUS could lead to hydrogen subsidies increasing overall greenhouse gas emissions (Environment and Climate Change Canada, 2022; Bridle, 2021). The International Institute for Sustainable Development (IISD) also cautions that hydrogen subsidies can be counterproductive to environmental initiatives. At a macro level, the IISD outlines several potential downsides to subsidizing hydrogen technologies and projects. A significant risk from a climate change perspective is that hydrogen subsidies risk having the opposite effect on the environment (Bridle, 2021). This is likely more true for Alberta due to its intent to capitalize on its natural gas resources, producing blue hydrogen with carbon capture. While CCUS technology can capture a significant portion of emissions, it may also indirectly benefit the fossil fuel industry. Hastings-Simon suggests that while CCUS is a proposed solution to decarbonization efforts, its commercialization could create a new market for oil and gas companies to use the captured CO2 to increase oil production through EOR which has a host of negative environmental impacts including groundwater contamination, and significant air emissions from thermal operations and releases more carbon (Hastings-Simon, 2021; Millemann, Haynes, Boggs, Hildebrand, 1982; Enterprise, 2022).

As the global community looks to decarbonize, another risk common to the fossil fuel industry is that subsidies for fossil fuel production are wasted on potentially stranded assets

(Bridle, 2021). However, blue hydrogen also faces this risk in a global environment increasingly looking to invest in and grow green technologies. Depending on natural gas prices, the levelized cost of hydrogen produced using natural gas (grey hydrogen) ranges from USD 0.5 to USD 1.7 per kg. This cost increases to around USD 1 to USD 2 per kg when CCUS technology is used to capture the CO2 emissions from production (blue hydrogen). Using renewable electricity (green hydrogen) is the most expensive at USD 3 to USD 8 per kg (IEA, 2021). The IEA's *Net Zero Emissions by 2050 Scenario* estimates that the cost of renewable hydrogen could fall to USD 1.3 per kg by 2030, comparable to blue hydrogen. Costs could fall further in the 2050 scenario, making green hydrogen comparable with grey hydrogen (IEA 3, 2021). Continued government support for green and renewable technology could reduce costs further. Combined, the estimated price decrease for green hydrogen and potential additional government support could mean that by 2030, subsidies for blue hydrogen may become stranded as green hydrogen becomes cost competitive (Bridle, 2021).

However, given the short timeframe to reduce emissions to net zero by 2050 as per the *Canadian Net-Zero Emissions Accountability Act* S.C. 2021, c. 22, a combination of technology-neutral and technology-specific measures could help to advance Alberta's hydrogen ambition in the hard-to-abate sectors for which hydrogen could make a significant impact.

8.0 EVALUATING THE ROADMAP

In light of this paper's discussion of industrial policy and the existence of market failures, the hydrogen industry may warrant government intervention to achieve the Province's goals. However, the Roadmap does not necessarily take the right form.

The Roadmap sets out seven policy pillars with near-term and long-term objectives. The pillars are: build new market demand, enable CCUS, de-risk investment in the hydrogen economy, incentivize technology and innovation, ensure regulatory efficiency, build alliances, and pursue hydrogen exports. Within the framework of these pillars, the near-term objectives focus on creating policy foundations, research and innovation, reducing existing hydrogen production emissions and deploying low carbon hydrogen for end-use. The long-term objectives and policy actions focus on hydrogen growth and commercialization.

The Roadmap accurately identifies Alberta's hydrogen opportunities and leverages its advantages, namely Alberta's abundant source of natural gas and its existing infrastructure. However, this can also limit emissions reduction potential by placing its efforts on developing blue hydrogen production which is too natural gas-focused. Blue hydrogen may not be internationally attractive and could potentially involve stranded assets. Additionally, technology-specific policy could ultimately lead to more costly decarbonization.

For Alberta to reach its full emissions reduction potential, the Roadmap should be part of a comprehensive climate plan that supports renewable, or green hydrogen, and other emissions reductions initiatives rather than be confined to Alberta's overall *Natural Gas Vision and Strategy*. It should also align with federal emissions reduction objectives (Severson-Baker, Lothian, and Gorski, 2021). As mentioned earlier, this close partnership with the natural gas sector potentially risks succumbing to criticism of industrial policy that argues government support for an industry is at risk of political manipulation.

The Roadmap also identifies some sectors in which hydrogen makes sense from a cost and efficiency standpoint. A report from Pembina Institute shows that “investments in hydrogen will have the best chance of success if they are prioritized in sectors where it is likely to have a competitive advantage over other low carbon fuels on cost and environmental benefits” (Severson-Baker et al, 2021). These hard-to-decarbonize sectors include fertilizer production, the steel industry, transportation including air travel, shipping, long-haul transportation and heavy freight rail, and where clean hydrogen can replace existing hydrogen used in the chemical sector. Hydrogen makes sense in these sectors where electrification, a key emissions reduction strategy, is not feasible (Bataille et al, 2021). The Roadmap identifies transportation and industrial processes as market for the growth of low carbon hydrogen.

The Roadmap outlines specific policy actions that it is implementing or intends to implement to support hydrogen production that includes:

- Removing barriers for blending hydrogen into natural gas distribution systems by amending the *Gas Utilities Act* and *Gas Distribution Act*;
- Advancing CCUS hubs and exploring ways to lower CCUS costs;
- Using the Alberta Petrochemicals Incentive Program (APIP) to support clean hydrogen production projects; and
- Launching the Clean Hydrogen Centre of Excellence to support hydrogen technology and innovation

Removing hydrogen blending barriers. To build new market demand, Alberta is undertaking action to understand and implement hydrogen blending into the utility market and advancing pure hydrogen communities that have homes heated entirely by hydrogen. While hydrogen blending requires little to no infrastructure changes, pure hydrogen communities are more difficult to implement, requiring changes to infrastructure and home appliances. Both scenarios require amendments to the *Gas Utilities Act* and *Gas Distribution Act.*

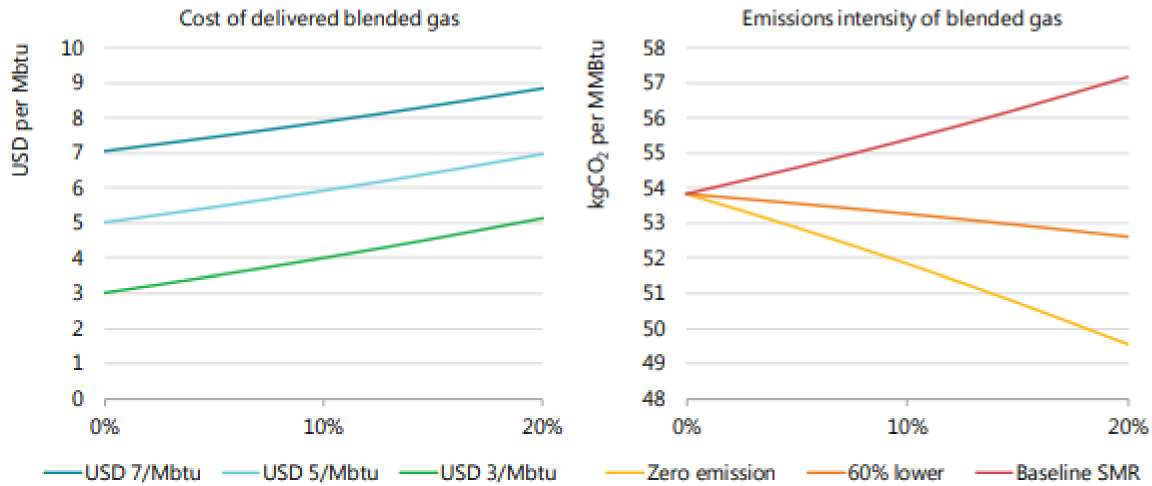
The IEA states that advancing low-carbon hydrogen in clean energy transitions necessitates "a step change in demand creation" (IEA, 2021 p. 6). As a first policy pillar, Alberta addresses the need to create new market demand and actions to pursue this. Although Alberta is Canada's largest hydrogen producer, no regulatory framework specific to hydrogen exists. Hydrogen produced from natural gas, is currently governed by relevant existing legislation, including the *Oil and Gas Conservation Act (RSA 2000, c O-6)*, *Environmental Protection and Enhancement Act* (RSA 2000, c E-12) and *Water Act (*RSA 2000, c W-3).

The Alberta Utilities Commission (AUC) regulates Alberta's utilities sector, electricity, and natural gas markets. Legislation under the AUC currently constrains the Roadmap's implementation as the *Gas Utilities Act and Gas Distribution Act* do not account for hydrogen blending. Nor does the *Gas Utilities Act* consider hydrogen within its definition of gas, preventing utilities from blending hydrogen into the natural gas system.

Section 1 (e) "gas" means all-natural gas both before and after it has been subjected to any treatment or process by absorption, purification, scrubbing or otherwise, and includes all fluid hydrocarbons not defined by clause (i) as oil;"

However, in March 2022, the government of Alberta issued an order-in-council directing the AUC to open an inquiry on matters relating to hydrogen blending, indicating possible future regulatory action to accommodate hydrogen (Alberta Utilities Commission, 2022). Given the required regulatory changes, this may not be the most efficient or effective means to increase demand given the short timeframe outlined in the Roadmap and the timeframe for reducing global emissions. However, if Alberta implements changes quickly, capitalizing on existing natural gas infrastructure to blend low-carbon hydrogen into natural gas can help to boost the market and drive down costs. The IEA estimates that a five percent blend of hydrogen (costing USD 4/kg) into natural gas (costing USD 5 per million British thermal units (MBtu) would initially increase delivered gas costs by about eight percent, which would subsequently decrease due to larger-scale production and efficiencies. Additionally, just a five percent volume blend could reduce the carbon intensity of delivered gas by two percent (IEA, 2019). Figure 2 from the IEA, illustrates the cost and emissions intensity of hydrogen blending.

Figure 2. Cost and Emissions Intensity of Blending Hydrogen into the Gas Network at Different Blend Shares



Notes: Cost of delivered blended gas with assumed USD 4/kgH₂, emissions intensity of "baseline SMR" = 91.0 kgCO₂/GJ H₂, "60% lower" = 36.4 kgCO₂/GJ H₂ and "zero emission" = 0 kgCO₂/GJ H₂. Blend shares on a volumetric basis.

Source: IEA, 2019.

Enabling CCUS. Alberta is incentivizing CCUS hubs, which are an area of pore space, managed by a company who collect and distribute captured CO2 from various emissions sources as a service to industrial clients (Government of Alberta, n.d.). Prior to the Roadmap's release, the government signalled its intent to incentivize the development of centralized carbon storage hubs identifying CCUS as an integral part of the province's environmental and economic future, and announcing its plan to issue carbon sequestration rights. The Roadmap explicitly states the intent to use CCUS to produce low carbon hydrogen and identifies the need to improve the CCUS regulatory framework, but does not discuss how Alberta will approach this (Alberta Energy, 2021). Alberta's CCUS regulatory framework includes several acts and regulations. The *Carbon Capture and Storage Funding Act* (SA 2009, c C-2.5), *Carbon Capture and Storage Funding Regulation, and*

Carbon Sequestration Tenure Regulation, promote the safe and effective use of CCUS technology to curb emissions associated with hydrogen production.

However, the largest barrier to widespread CCUS adoption is insufficient economic incentives (Bankes, Poschwatta and Shier, 2008). While Alberta's CCUS regulatory framework provides up to CAD 2 billion in funding under the *Carbon Capture and Storage Funding Act* (SA 2009, c C-2.5) to "encourage and expedite the design, construction and operation of CCUS in Alberta," amidst weak carbon pricing, it may fall short of what is needed to ensure infrastructure is widely available for Alberta to deploy low carbon hydrogen into the economy as called for in the Roadmap (Alberta Energy, 2021). Likewise, the federal government recently announced funding for carbon capture technology. However, the funding falls well short of the increased investment tax credit that would cover approximately 85% of CCUS costs that Canada's oil and gas industry had been lobbying for (Bulowski, 2022).

CCUS's inclusion as a policy pillar recognizes and seeks to address the need for policy coordination as blue hydrogen production and investment rely on developing and deploying carbon capture technology. While some have argued that CCUS might be counterproductive to encouraging renewable or clean hydrogen production, it positively contributes to emissions reductions (McKenzie et al, 2022).

Support for Capital Costs. APIP provides up to 12% of capital costs to eligible new petrochemical or fertilizer facilities or existing operations expansions to support growth in the petrochemicals sector while leveraging the province's natural gas reserves. Within the program, projects using eligible feedstock for hydrogen production are also eligible.[6] Outside of APIP, additional measures enabling access to capital are not identified. Additionally, the APIP program is only specific to hydrogen produced using natural gas, providing no incentive for green hydrogen, and it provides no long-term guarantees effective for incentivizing investment (Alberta Energy, 2020). On the other hand, the Roadmap itself contributes to this policy pillar by creating a stable framework that can help to lock policies in, protecting them from political cycles and increasing investment security (Altenburg and Rodrik, 2017).

Activating technology and innovation. The Roadmap identifies the need for demonstration projects and research to enable and scale up technologies. To support and advance innovation, Alberta has established the Hydrogen Centre for Excellence and provided CAD 50 million in funding to support the policy pillars outlined in the Roadmap (Alberta Innovates, n.d.). Emissions Reduction Alberta is also funding several funding pilot and projects to explore new applications and clean hydrogen production methods (Alberta Energy, 2021). With exception of the Hydrogen Centre for Excellence's *Advancing Hydrogen - Competition 1*, government funds allocated to advancing hydrogen R&D are vague (Alberta Innovate, n.d.).

The IEA identifies the need to accelerate technology innovation efforts to support faster adoption of low carbon hydrogen for a sustainable energy system by 2050 (IEA, 2021). Emissions Reduction Alberta (ERA) is funding pilot and early demonstration projects to explore emerging clean hydrogen production methods in partnership with industry and

[6] osler.com/en/resources/regulations/2020/alberta-s-petrochemicals-incentive-program

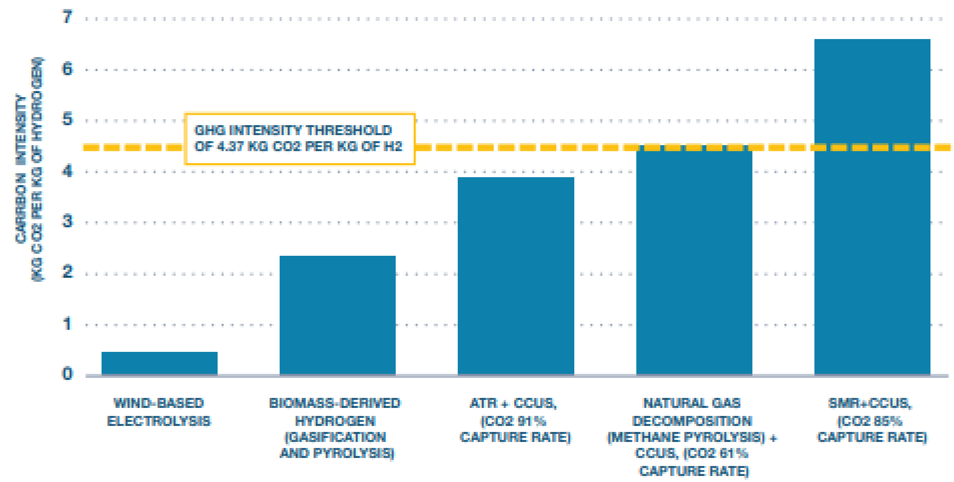
government. However, dedicated innovation support from government and research innovation agencies is not specified (Alberta Energy, 2021). While the Roadmap acknowledges the importance of research and development in coordination with universities and technical schools, specific support measures are not given. For clean energy in particular, post-secondary and government research has significantly contributed to bringing clean energy to market (EFL, 2021). Additionally, public institutions have successfully directed and executed industrial policy energy research. An Albertan example of this success is the Government of Alberta's role in developing oil sands technologies through funding of CAD 1.4 billion (in 2019 dollars) in Alberta Oil Sands Technology and Research Authority (Hastings-Simon, 2021).

Carbon intensity thresholds. The Roadmap acknowledges the need to establish a method for measuring carbon intensity, establishing carbon threshold standards and its willingness to work across government in this process. The Environment and Climate Change Canada is considering a carbon intensity threshold for hydrogen aligned with the carbon intensity threshold set by CertifHy, a European-based Guarantee of Origin program for clean hydrogen. However, should Alberta continue to focus predominantly on blue hydrogen production using SMR, the emissions intensity will exceed the carbon intensity threshold set by CertifHy.[7] This will have negative implications for its objective to lock in export markets should importing countries prefer CertifHy's threshold. Figure 3 taken from the Roadmap, illustrates the various carbon intensity of production methods in Alberta as they

[7] CertifHy's threshold is 4.37 kg CO2 per kg of hydrogen and Alberta's SMR production with CCUS measures approximately 6.6 kg CO2 per kg. (Alberta Energy, 2021).

compare to CertifHy's threshold (as set by CertifHy and also recommended by Canada) (Alberta Energy, 2021).

Figure 3. Carbon Intensity of Hydrogen Production in Alberta



Comparison of carbon intensity by production technology in Alberta (2020). The carbon intensity data is sourced from the University of Alberta Report (2021) (unpublished) and includes upstream and hydrogen production emissions.

Source: Alberta Energy, 2021.

Policy measures outside the Roadmap

In addition to the policy actions outlined in the Roadmap, Alberta has several policy measures that support low carbon hydrogen production. An important policy measure that Alberta has in place is the Roadmap itself. The Roadmap sets a direction and establishes actions for moving forward in support of a hydrogen economy where Alberta produces, consumes and exports hydrogen. It creates the first step to building stakeholder confidence about the potential market for low-carbon hydrogen (IEA, 2021). Its alignment with Canada's Hydrogen Strategy is a positive enabling policy that can help accelerate a hydrogen economy. However, the targets, in terms of emissions reduction, and the term "clean hydrogen," are too vague. As discussed earlier in the paper, this may present some challenges.

The TIER regulation is an existing policy measure that is not included as a policy action in the Roadmap*,* but does contribute to emissions reductions and therefore has the potential to incentivize companies to produce and use low carbon hydrogen. TIER is Alberta's emissions pricing system for regulating industrial emitters. In TIER, facilities that exceed their emissions benchmark can buy carbon credits, while facilities that fall below their benchmark are issued credits that can be sold on the TIER carbon market (Government of Alberta , n.d.d). Carbon pricing, like TIER can incentivize industrial emitters to pursue cleaner technologies, like low carbon hydrogen and the Roadmap states that Alberta has invested up to CAD750 million in TIER over three years for innovative projects that reduce emissions and create investment opportunities (Alberta Energy, 2021).

Despite using TIER revenue to help fund emissions reduction technologies, TIER provides relief through its cost containment program for especially high-emitting facilities that undermine emissions reductions incentive and prolongs the life of high-emitting facilities (Mckenzie et al, 2022). The program provides financial relief for facilities whose compliance costs are over 3% of sales or more than 10% of their profits (Government of Alberta , n.d.d).

9.0 RECOMMENDATIONS

Based on the Roadmap's proposed support for low carbon hydrogen production, Alberta is perhaps overstepping in its support, specifically focused on blue hydrogen production.

Hydrogen faces numerous market failures, and I have hypothesized some suspected market failures based on market failures encountered by green and new technologies generally. Given that market failures are present, the first-best policy would be to address these directly. Below are recommendations for near-term action that Alberta should take to realize its ambition to enable a low carbon hydrogen economy, advancing environmental outcomes and creating economic value.

1. **Increasingly stringent carbon pricing with broader emissions coverage.**

A strong carbon pricing system signals should encourage technology and innovation that supports emissions reductions. The federal government's climate plan, *A Healthy Environment and a Healthy Economy*, proposes to increase the carbon price by CAD 15 per year, starting in 2023, and increasing to CAD 170 per tonne in 2030 (Environment and Climate Change Canada, 2021). A carbon price that internalizes the negative externalities (CO2) produced by burning fossil fuels incentivizes fossil fuel divestment and improves the economic feasibility of low and zero carbon technologies. The *Canadian Net Zero Accountability Act* codifies emissions reduction targets into law. However, the current price is well below what experts estimate should be CAD 125 per tonne of CO2 (Carleston and Greenstone, 2021).

Canada and Alberta should address significant gaps in their current carbon pricing systems. With only 60% of Alberta's emissions covered by the pricing incentive, more transparency and inclusive emissions coverage are needed. Additionally, Alberta's TIER system should commit to a carbon price schedule of its own beyond 2022, accompanied by decreasing emissions benchmarks for large emitters. While TIER is up for review this year to ensure alignment with federal standards, businesses need policy certainty with some advance notice, even when periodic review is part of TIER. Increasing the certainty of more stringent future carbon prices would provide a solid signal to reduce emissions (Dion, 2021).

2. **Funding Innovation to improve low carbon hydrogen feasibility, reduce investment risks and cost uncertainty.**

Carbon pricing is a significant incentive to encourage low carbon hydrogen to displace fossil fuels. Low carbon hydrogen is more expensive than current unabated fossil-based hydrogen production and more costly than fossil fuels in areas where hydrogen can replace them, such as heating and transportation. As discussed above, pricing should be more stringent, but carbon pricing may not be enough and there are market failures that warrant correction to enable hydrogen to develop its cost effective low or zero-carbon option.

While some provinces have implemented mandates to help de-risk investments and improve the economic feasibility of blue and green hydrogen, such as British Columbia's mandate to promote fuel cell vehicles and fueling stations, addressing each market failure is more effective, and it eliminates policy-induced technology lock-in (Government of British Columbia, n.d.; IEA, 2021).

As knowledge spillovers can discourage firms from investing in technology and innovation that bring social benefits critical for accelerating technology uptake, government policy should address this. Alberta can help correct this by funding innovation. Alberta recently open the Hydrogen Centre of Excellence, a funding program, testing and service facility, and forum for facilitating partnerships to de-risk hydrogen technology development (Alberta Innovates, n.d.). The Roadmap also outlines several pilot and early demonstration projects funded by Emissions Reduction Alberta, including a hydrogen blending project with Canadian Utilities, a prototype project testing the hydrogen ability to fuel Alberta's heavy freight transportation sector, and a new clean hydrogen production method that produces no CO2 (Alberta Energy, 2021).

Funding for CCUS innovation is another critical technology for blue hydrogen, and Alberta has committed $1.24 billion through 2025 to two commercial-scale carbon capture projects, the Quest Project and the ACTL. Support for research, development and demonstration can help provide investment certainty through valuable learnings from which other firms can benefit and show more-reluctant firms the current state the technologies' maturity (Dion, 2021). This is a positive step towards addressing knowledge spillovers and de-risking investment. Further action that could contribute towards deeper decarbonization would make financial support contingent on the capacity to contribute to the *Paris Agreement* 1.5 degrees Celsius scenario and the *Canadian Net-Zero Emissions Accountability Act S.C. 2021, c. 22,* regardless of the specific technology. Support mechanisms for projects according to their capacity to contribute to net zero would make investments in the lowest carbon-producing technologies more attractive (World Business Council for Sustainable Development (WBCSD), 2021).

3. **Provide transparency and establish stricter eligibility requirements for fossil fuel subsidies**.

Politically, this might be a hard pill to swallow in Alberta, but it might be appropriate to remove existing subsidies, or tighten eligibility requirements based on emissions reductions, to the fossil fuel industry. Just as subsidies for green technology incent behaviour that benefits the environment, removing, or tightening the eligibility requirements for subsidies to the oil and gas sector can help realize environmental benefits (Sawyer et al, 2021).

A recent report from the IISD states that Alberta's subsidies totalled CAD 1.32 billion in 2020/21 and 658.7 million in 2021/22. Alberta committed to fossil fuel production to help recover from the pandemic, increasing subsidies and using the TIER fund to boost fossil fuel production, including through subsidies for CCUS (McKenzie et al, 2022). Though CCUS is an emissions reduction technology, facilities in Canada use the captured CO2 in other processes, such as EOR, which involves injecting the CO2 into declining oil fields to recover additional oil, which is counterintuitive to reducing emissions because it prolongs the life of the oil industry. The Quest and ACTL projects inject the equivalent emissions of 600,000 cars per year for EOR (CER, 2021). To support more profound emissions reductions, subsidies for projects utilizing CCUS should ensure that the captured CO2 is stored permanently (McKenzie et al, 2022).

The larger issue here might be the lack of publicly available data on fossil fuel subsidies. In many instances, subsidies are incorporated into larger budget lines or funding programs, making it difficult to determine precise data. The IISD estimates described above are conservative, and it estimates that Alberta's fossil fuel subsidies are likely much higher.[8] Greater transparency would allow for a steady and targeted phase-out that identifies and continues to support measures for low carbon technologies like carbon capture, only with stricter parameters around the lifecycle of emissions reduction. While not a market failure,

[8] Janetta McKenzie, Estan Beedell and Vanessa Corkal, "Blocking Ambition: Fossil fuel subsidies in Alberta, British Columbia, Saskatchewan, and Newfoundland and Labrador." Iv. the IISD also notes that its 2021 data included only reflects part of the 2021/22 fiscal year, as full expenditures were not released at the time of the calculation.

subsidies for the oil and gas industry intensify the negative externality because it encourages greater use. The federal government has committed to phasing out subsidies for fossil fuel industries; however, provinces are not bound by this commitment because of Canada's jurisdictional division of powers. Alberta could support deeper decarbonization and the development of clean technology by providing greater transparency, establishing stricter eligibility requirements for fossil fuel subsidies, and diversifying the emissions reduction technologies supported through the TIER fund.

4. **Prioritize adopting a hydrogen emissions classification system that establishes a threshold for emissions and is aligned with global standards.**

International agreement on a life cycle-based CO2 equivalent GHG method to calculate the carbon intensity of hydrogen production is fundamental to ensuring hydrogen production is truly low-carbon (WBCSD, 2021). This is a critical component for the Roadmap. As discussed earlier in this paper, the Roadmap references clean hydrogen and includes blue hydrogen produced using natural gas in combination with CCUS within its definition of clean. This term can be misleading and warrants further clarification. Much like a paint store that carries a large range of different shades of blue and green paint, each colour of hydrogen has a range of emissions intensity associated with its life cycle. Blue hydrogen is a cleaner version than grey hydrogen, produced from natural gas that generates significant carbon emissions, and the cleanest hydrogen is green, made with renewables and without carbon emissions. Further supporting the need for a classification system is that blue hydrogen production methods capture different emissions percentages. For example, ATR produces a high-purity stream of CO_2 and captures over 90 per cent of the emissions produced (Alberta Energy, 2021).

A hydrogen emissions classification system will also play a central role in developing a global hydrogen market. The IEA recognizes international agreement on a methodology for calculating hydrogen's carbon footprint as the foundation from which a global certificate market could develop (IEA, 2021). Developing or participating in current emissions standards being developed, like CertifHy, will require national and international collaboration and efforts to further reduce hydrogen emissions. The Roadmap acknowledges the need to establish a method for measuring carbon intensity, establishing carbon threshold standards and its willingness to work across government in this process as it develops. However, this should be prioritized. Alberta, focusing on growing blue hydrogen using SMR technology in combination with CCUS and a carbon capture rate of 85% does not meet the emissions threshold set by CertifHy[9] and could risk being less preferred by importing countries and companies who prefer a cleaner carbon threshold.

5. **Establish a regulatory framework.**

The Roadmap addresses regulations that stand as barriers to hydrogen specific to blending, but further legislative considerations are needed. Incorporating hydrogen into the province's energy systems portfolio indicates that Alberta is thinking critically and planning for reduced demand for its oil and gas. The government should design a regulatory framework specific to hydrogen to avoid overlap and confusion between

[9] CertifHy's threshold is 4.37 kg CO_2 per kg of hydrogen and Alberta's SMR production with CCUS measures approximately 6.6 kg CO_2 per kg.

regulatory bodies and existing legislation (Olthafer, Nicole Bakker, Bryan Li and Jacob Roth, 2021). However, as efforts to reduce emissions are accelerating, some near-term changes would produce positive changes towards a net zero emissions future. These changes are acknowledged in the Roadmap, and consist of addressing existing regulations to hydrogen blending.

10. CONCLUSION

Alberta's Hydrogen Roadmap sets out the provinces vision for a hydrogen economy that will diversify its energy portfolio, create jobs and contribute to emissions reductions. This paper makes recommendations for how Alberta can further advance this effort. It finds that the Roadmap does a number of things well.

It accurately identifies Alberta's hydrogen opportunities and leverages its advantages, namely Alberta's abundant source of natural gas and its existing infrastructure. The Roadmap also identifies some sectors in which hydrogen makes sense from a cost and efficiency standpoint. It also sets out policy actions to create further hydrogen demand and address the regulatory barriers to hydrogen blending in existing natural gas infrastructure.

To further advance its hydrogen strategy and contribute to deeper emissions reductions, a hydrogen strategy should increase the stringency and coverage of carbon pricing. While Alberta relies on improvements to the federal carbon pricing system, improvements could be made to TIER that would incentivize emitters to lower emissions and increase investment in low carbon technologies. A well-rounded strategy should also include funding for research and development to support new technologies and reduce investment risks.

To support hydrogen for decarbonization, the province should increase the transparency in existing subsidies for the fossil fuel industry and adopt a hydrogen emissions classification system that ensures the emission intensity of hydrogen is really low carbon and is attractive to a global market. Finally, all of this should be supported by a regulatory framework to reduce confusion between regulatory bodies and existing legislation.

These measures would strongly incentivize low carbon hydrogen production while also making investment in the technology for deeper decarbonization less risky and attract global hydrogen customers seeking clean hydrogen.

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