On an Ontario farm, anaerobic digestion tanks turn waste into sustainable energy and fertilizer.

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UNPACKING THE BARRIERS TO FIRST-OF-KIND CLEAN FUEL PROJECTS IN CANADA

By Jared Forman

EXECUTIVE SUMMARY

Government interventions to support clean growth projects will be most effective and efficient if focused on overcoming market and policy failures. Clean growth projects using nascent technologies, including first-of-kind clean fuel projects, often face a multitude of barriers to attracting private capital. Firms and investors are well-placed to manage common market risks. But when market or policy failures hinder project development, governments have an opportunity to intervene with well-designed policies.

Clean fuels are likely to play an integral role in meeting Canada's climate goals and building a strong low-carbon economic future. Clean fuels could be the lowest-cost or only viable decarbonization pathway for many hard-to-abate sectors, while playing a significant role in other economic sectors. Clean fuels are also a potential source of high-paying and secure jobs, new export opportunities, and significant foreign direct investment.

Canada is well-positioned to be a leader in clean fuels development and production. Canada has an opportunity to be a leader in clean fuels. It's positioned between multiple large consumer markets, home to a highly skilled workforce familiar with the energy sector, and has a relatively clean electricity grid, among other advantages.

However, many first-of-kind clean fuel projects are likely to be uneconomic today. Financial modelling of five first-of-kind clean fuel project archetypes concluded that four of them will be unprofitable in the vast majority of the model simulations at present. Additional financial support will be necessary to ensure they are bankable.

March 2023

Some of the barriers that imperil the financial viability of first-of-kind clean fuel projects are standard market risks. Market risks are not unique to first-of-kind projects, nor to clean fuel projects. These risks don't necessarily represent policy problems. Consequently, firms and investors are well-placed to manage them on their own.

Yet, first-of-kind clean fuel projects also face other barriers—market and policy failures—that could prompt government intervention. Market failures represent circumstances where markets alone do not provide incentives to deliver outcomes with overall benefits to society. Similarly, problems with existing policies can create barriers and perverse incentives. In these cases, public policy can provide net benefits—if designed well.

Biogas capture wells in an open meadow section of Montreal's Frederic-Back Park.

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INTRODUCTION

The Canadian Climate Institute's 2021 report, *Sink or Swim: Transforming Canada's economy for a global low-carbon future* (Samson et al. 2021) outlined significant challenges for Canada's clean growth future. Particularly, it showed that (1) Canada's export goods are vulnerable to global market change; and (2) there are employment risks in smaller, rural, and remote communities dependent on transition-vulnerable sectors. It also identified some of the greatest opportunities for Canada in terms of capturing a share of global markets that will grow through transition and economic empowerment of Indigenous communities.

One of those transition-opportunity markets where Canada can grow its market share is clean fuels, specifically hydrogen and its derivative products as well as advanced biofuels.

Clean fuels are promising exportable goods and key products needed for the global energy transition. It is a sector where Canada has a resource and human capital advantage, and Canadian technology companies are already showing significant promise in the sector's development (Arnold et al. 2022). Crucially, they also represent opportunities for communities vulnerable to wealth and employment loss through the global energy transition—which are disproportionately Indigenous, rural, and remote—to generate new sources of secure, skilled jobs.

However, clean fuel projects can face barriers that make them unattractive to private investors. Some barriers relate to the fact that few at scale clean fuel facilities are currently in operation, meaning most clean fuel projects being proposed today are "first-of-kind." That entails lower private returns, at least in the short-term, despite the high potential of significant long-term public benefits (Beck et al. 2023). In these cases, investors have minimal incentive to provide funding. Government intervention is necessary to resolve these market and policy failures. Other barriers may also jeopardize the financial viability of first-of-kind clean fuel projects, but they represent standard market risk. As a consequence, policy intervention is not warranted. In fact, public funding of these projects would increase rather than mitigate market inefficiencies.

Consequently, this scoping paper seeks to identify the various barriers that may hold back the development of first-of-kind clean fuel projects. First, it will provide some context, explaining the potential and role of clean fuels for Canada in the coming decades. Second, using financial modelling and expert feedback, it will identify the key barriers that often hinder the development of clean fuel projects, differentiating market risks and market and policy failures. Lastly, it will conclude with a brief discussion of the approach Canada should take to address market and policy failures to support clean fuel projects as part of building a stronger and more inclusive clean growth future.

A renewable energy plant in Armstrong BC.

2 CONTEXT: CLEAN FUEL PROJECTS IN CANADA

While electrification will likely be the primary driver of Canada's—and the world's—energy transition (Dion et al. 2022), clean fuels can still play a key role. In particular, clean fuels will likely be necessary to decarbonize aviation, international shipping, and many heavy industries, while providing much needed long-term power storage and power system rebalancing (Energy Transitions Commission 2021; IEA 2022a; Dion et al. 2021). Clean fuels could be the only viable decarbonization method or the least-cost option in these sectors (de Pee et al. 2018; Energy Transitions Commission 2018). Many products are referred to as clean fuels, but crucially, only those that drive emissions reductions to meet domestic and global long term climate goals should be classified as such (see Box 1).

BOX 1

What are clean fuels?

Clean fuels refer to delivered energy sources, excluding electricity, that produce considerably fewer greenhouse gas emissions than their traditional counterparts, on a lifecycle basis (Natural Resources Canada 2022a). For the purposes of this paper, we have divided clean fuels into two categories: advanced or second generation biofuels, and low-carbon hydrogen and its derivatives.

Biofuels are produced from biomass materials such as food crops, plant residues, and algaes. First generation biofuels are derived from food crops such as corn and rapeseed oil. Over 90 per cent of biofuels produced today are first-generation (IEA 2022a). However, their use contributes to global food insecurity as arable land and crops are diverted to produce them (Tenenbaum 2008; Canada's Ecofiscal Commission 2016; Wright 2014). Conversely, second generation or advanced biofuels are derived from non-food materials such as woody biomass, agricultural residues, and other forms of solid waste—ideally sourced from non-arable, marginal, or degraded land (Lee and Lavoie 2013; Mohr and Raman 2013). Importantly, ambiguity over advanced biofuel lifecycle emissions could mean that some advanced biofuels will be inconsistent with Canada's climate goals and a sustainable energy transition. Particularly, high-carbon feedstocks and land-use change could adversely affect the emissions profile of advanced biofuel projects, making them ineligible to be referred to as clean fuels (Staples 2018; Jeswani et al. 2020).

Hydrogen production is typically divided into colour-coded categories. Grey hydrogen is an emissions-intensive production process that uses fossil gas as a feedstock. Blue hydrogen also produces hydrogen from fossil gas, but uses carbon capture, utilization, and storage (CCUS) to reduce its emissions footprint. Conversely, green hydrogen uses renewable energy as a feedstock to make low-carbon hydrogen through electrolysis. All forms of hydrogen can also be used to produce derivative products like ammonia.

While blue hydrogen is typically included under the term "clean hydrogen" along with green hydrogen, there are two important caveats to this classification. First, any proposed project must have a carbon capture rate exceeding 90 per cent, the typical threshold to be considered "low-carbon" or "clean." Second, upstream methane leakage rates from fossil gas feedstock, known as fugitive emissions, should not exceed 0.5 per cent (Bauer et al. 2022). If projects are unable to meet these thresholds and project revenues are large enough to cover the relatively low operational expenses, blue hydrogen/ammonia projects are likely to operate for the entirety of their useful life, roughly 30 years, and "lock-in" emissions throughout that time period (Forman and Arnold 2023). Blue hydrogen and ammonia projects could also prolong the useful life of fossil gas infrastructure, contributing to even more emissions lock-in (Collins 2022). Consequently, for the purposes of this paper, only blue hydrogen/ammonia produced by facilities that meet these thresholds will be considered "clean."

Blue hydrogen is often referred to as a transition or "bridge" fuel since it is likely to drive emissions reductions in multiple sectors, but still uses fossil fuels as a feedstock and can produce significant greenhouse gas emissions (DiChristopher 2021). The International Renewable Energy Agency (IRENA) projects that about a third of hydrogen produced in 2050 in its 1.5 degrees Celsius scenario will be blue hydrogen, with a larger role in the short and medium term (IRENA 2022a).

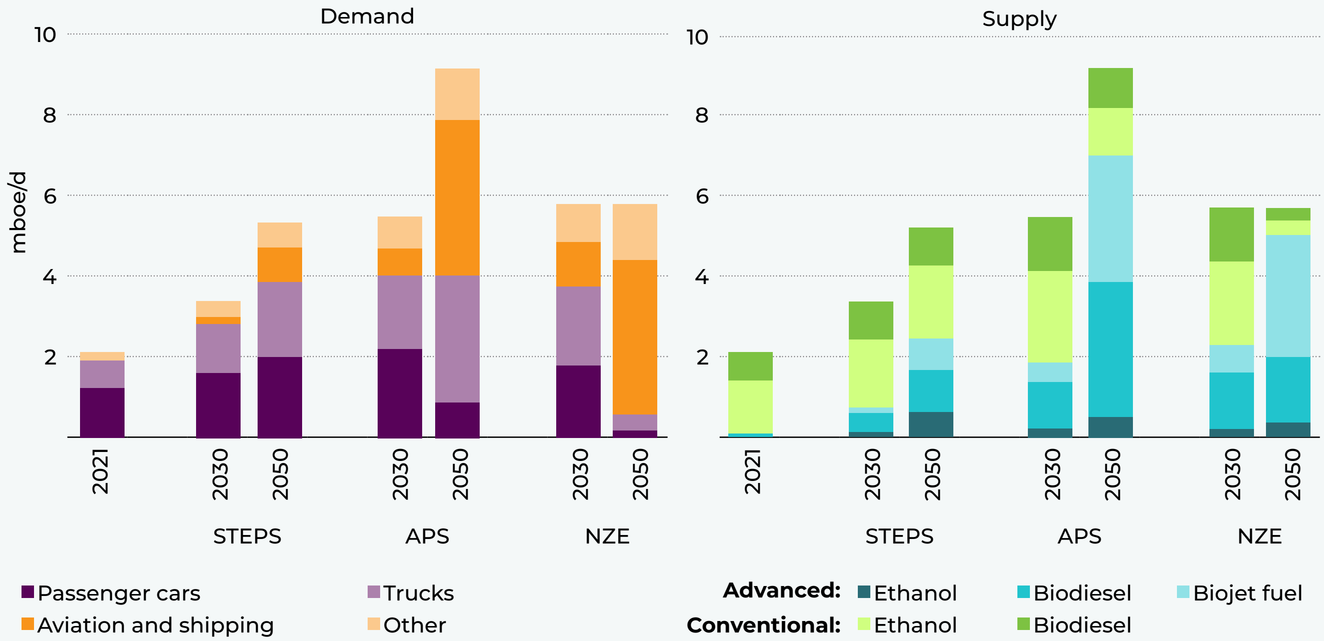
Finally, the end-uses of clean fuels are diverse. In some cases, clean fuels may not be used as a fuel. For instance, hydrogen converted into ammonia could be used as a fertilizer. Hydrogen can also be used as a feedstock in the chemicals industry or in other industrial processes.

Largely because of its projected utility, global demand for clean fuels will likely be robust. In 2021, approximately 120 megatonnes (Mt) of hydrogen was produced, 95 per cent of which was made from unabated, carbon-intensive fossil gas and coal (IRENA 2021). Models project that by 2030, 154 Mt of blue and green hydrogen will need to be produced globally each year to be aligned with a 1.5°C global pathway. By 2050, that rises to 614 Mt (IRENA 2022b). For biofuels, supply is projected to increase from 2.2 million barrels of oil equivalent per day (mboe/d) in 2021 to 5.7 mboe/d in 2030 in the International Energy Agency's (IEA) net zero-aligned scenario. A similar production level of biofuels is projected to be needed in 2050 (IEA 2022a). Together, low-carbon hydrogen and advanced biofuels investment is expected to grow from $23 billion today to $306 billion by 2030 under the IEA's net zero scenario (IEA 2022a).

Figure 1:

Liquid biofuel demand and supply by scenario (IEA 2022a)

Displayed are the conventional and advanced liquid biofuel demand and supply under the IEA's stated policies (STEPS), announced pledges (APS), and net zero emissions by 2050 (NZE) scenarios



In Canada, every net zero scenario shows a growing role for clean fuels (Dion et al. 2021). A federal government report projects that hydrogen demand could range from 8.3 Mt to 20 Mt per year by 2050, representing a maximum of 31 per cent of delivered energy at the mid-century mark in its "transformative scenario" (Natural Resources Canada 2020). Among independent analyses, some see a more modest role for hydrogen (Office of the Auditor General of Canada 2022; Institut de l'énergie Trottier 2021; Dion et al. 2021) while others broadly align with the government's modelled scenarios (Layzell et al. 2020).

Advanced biofuels are currently a "wild card" technology, but they still could play a significant role in Canada's energy transition—particularly to produce sustainable aviation and marine fuels (Net-Zero Advisory Body 2023). In more optimistic scenarios, demand for advanced biofuels could be as high as 2,672 petajoules (PJ), up from 739 PJ in 2019 (Dion et al. 2021; Canada Energy Regulator 2022a). That represents up to 44 per cent of final energy demand in 2050. Conservative scenarios show that advanced biofuels will make up around seven per cent of final energy demand in 2050 (Dion et al. 2021).

That's an opportunity for Canada—both in terms of emissions reductions and in developing a strong low-carbon economic future.

Hydrogen could drive between 18 and 61 Mt of emissions reductions by 2050; biofuels could reduce emissions by up to 64 Mt by mid-century (Dion et al. 2021).

Simultaneously, by 2050, hydrogen could generate between $9 billion and $22 billion (2015 dollars) in investments each year with advanced biofuels generating up to $28 billion (2015 dollars) in annual investments (Dion et al. 2021). That could translate to thousands of well-paying jobs—many of which will be in rural and remote regions disproportionately home to Indigenous Peoples and low-income Canadians. Considering that over 880,000 people in Canada work in transition-vulnerable sectors, strategic investments in low-carbon industries, like clean fuels, will be essential for Canadians to survive and thrive in a low-carbon economy (Samson et al. 2021).

Additionally, clean fuels are a major export opportunity for Canada. In a best-case model, Canadian low-carbon hydrogen is projected to yield $56 billion per year in revenues by 2050 serving the American, Japanese, South Korean, and German markets (Layzell et al. 2020). And as the recently signed enhanced memorandum of understanding (MOU) between Canada and Germany illustrates, there is already a strong interest in Canadian-produced hydrogen and hydrogen derivatives (Natural Resources Canada 2022b).

Canada is also well-positioned to capture the opportunities that clean fuels present. Geographically, Canada is strategically positioned between the European and East Asian markets and also neighbours the United States (Nova Scotia Offshore Energy Research Association [OERA] 2020; HTEC [formerly Zen] 2019). Canada has a significant human capital advantage as well. It consistently ranks as one of the most educated countries in the world with a sizable workforce familiar with the energy sector (Organisation for Economic Co-operation and Development [OECD] 2014; Natural Resources Canada 2020). The federal carbon pricing regime and federal Clean Fuel Regulations (CFR) set up clean fuels to be more cost-competitive with the high-carbon fuels they intend to replace (Energy Transitions Commission 2021). Canada is the lowest cost producer of green hydrogen and second lowest cost producer of blue hydrogen after Russia, according to one study (Asia Pacific Energy Research Centre 2018). And Canada's relatively clean electricity grid makes it an attractive destination for green hydrogen producers (Layzell et al. 2020).

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3 THE CHALLENGE: WHAT ARE THE INVESTMENT BARRIERS FOR FIRST-OF-KIND CLEAN FUEL PROJECTS?

Although there are many opportunities in clean fuels, obstacles still stand in the way of their development in Canada. Some of these barriers represent real costs that should be weighed against benefits. Others might be overcome with smart policies, offering net benefits to Canada.

The nature of these obstacles vary across regions and projects. While the Maritimes, for example, offers considerable export potential, significant infrastructure gaps and a lack of domestic supply mean that the region might not be able to export clean fuels for up to a decade (OERA 2020). Additionally, since hydrogen will likely have to be converted to ammonia to be shipped (at least over long distances) and then back into hydrogen for end-use—a process which results in high efficiency losses and costs—exported ammonia might only be viable as ammonia fertilizer or for industrial use rather than as a hydrogen fuel or feedstock (Parkes 2022).

Other obstacles apply more generally. Despite the fact that Canada is a highly educated country, severe skilled labour shortages in the clean technology sector are expected to persist into the future (Arnold et al. 2022; Guldimann and Powell 2022). Electricity demand is also expected to rapidly rise over the next few decades so meeting the feedstock needs of some clean fuel projects will be challenging (Lee et al. 2022). Finally, Canada may have difficulty competing with the United States whose Inflation Reduction Act offers considerable financial support for their clean fuels industry (Gordon et al. 2022).

This section explores these barriers using financial modelling and expert feedback to evaluate what is preventing the industry's pioneers, the first-of-kind projects, from being built in Canada.

3.1. First-of-kind clean fuel project modelling

As the name suggests, first-of-kind projects are the first at scale, commercially viable projects of their kind and typically employ technologies that are, while still nascent, at the end stages of the technology readiness level (TRL) scale (i.e., at least TRL 7, prototype development) (Mankins 1995). They've been proven to work as demonstration projects, but they have yet to be shown as profitable at scale.

We analysed five archetypal first-of-kind clean fuel projects in Canada using cash-flow financial modelling with Monte Carlo simulations to explore risk. The aim of the modelling was to determine the net present value and internal rate of return of each project to assess financial viability (see Annex 1 for more on modelling methodology and archetype selection criteria).

The five first-of-kind clean fuel projects archetypes are as follows:

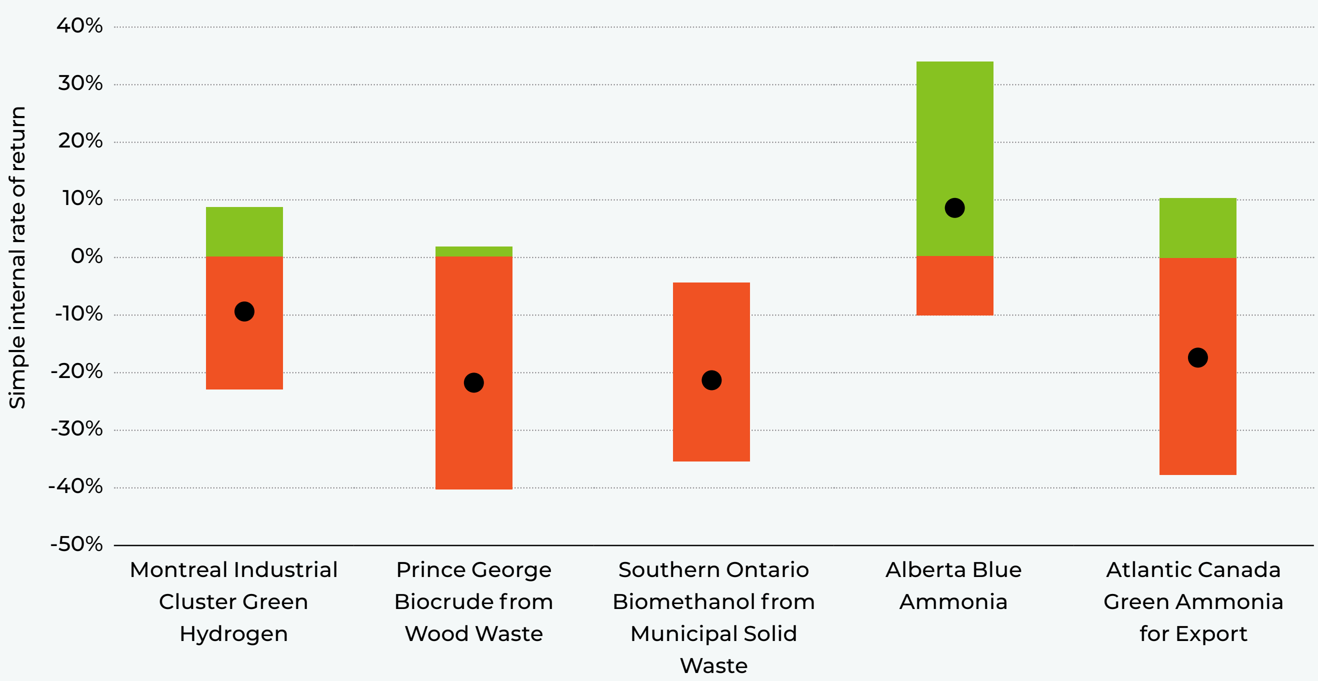
1. Green ammonia for export in rural Atlantic Canada;
2. Green hydrogen produced in a Montreal-area industrial cluster;
3. Blue ammonia produced in Alberta;
4. Biocrude made from wood waste in Prince George, British Columbia; and
5. Biomethanol derived from municipal solid waste sourced and refined in southern Ontario.

Our cash-flow modelling indicates that four of the five archetypal projects are likely to be uneconomic without additional public financial support (see Figure 2). The only financially viable archetype modelled (i.e., has a positive internal rate of return and net present value) is the blue ammonia project based in Alberta which generates a positive net present value in greater than two-thirds of all simulations. Of the four uneconomic projects modelled, all of them have a negative net present value in greater than 70 per cent of Monte Carlo simulations.

Figure 2:

Simple internal rate of return results of the five first-of-kind clean fuel project archetypes

The bars represent the 10th to 90th percentile internal rate of return of each project; the black circle indicates the 50th percentile of Monte Carlo simulations conducted for each archetype



As the cash-flow financial modelling demonstrates, the vast majority of clean fuel projects will likely require government support to be developed.

The challenges for clean fuel projects vary depending on the fuel in question, the feedstock used, the location of the project, the current policy landscape in a given jurisdiction, along with a host of other factors. Our modelling, along with input from practitioners and experts in the sector, highlights the wide breadth of barriers that are hindering these clean fuel projects from being economic and ultimately, from being built. This section will begin with an explanation of some of the market-based costs and risks associated with clean fuel projects that project proponents may face before delving into the barriers that are rooted in market failure which require government intervention to address.

Moreover, it's essential to acknowledge that while some barriers were identified as having a greater impact and were emphasized more than others in our modelling and engagement sessions respectively, each project is unique and faces its unique set of challenges and difficulties. Additionally, the impacts of some barriers on the financial viability of clean fuel projects are difficult to accurately quantify, predict, and/or anticipate.

3.2. Market-based costs and risks

Some barriers are not unique to first-of-kind projects, nor to clean fuel projects. They represent market risks faced by investors and project proponents more generally. These risks don't necessarily represent policy problems. Firms and investors are well-placed to manage market risks without government intervention.

3.2.1. Future market prices

Our cash-flow modelling indicates that future market prices for clean fuels have the largest impact on the financial viability of all five of the archetypes that were evaluated, illustrating that they represent a key uncertainty for clean fuel project proponents.

Clean fuel future market prices will largely be determined by global energy prices and the demand trajectory of fossil fuel products. This standard price volatility is no cause for government intervention.

Still, future market prices are heavily influenced by the policy landscape in a given jurisdiction. Consequently, some degree of market price uncertainty is ultimately a result of policy choices which governments should take action to reduce (See Section 3.3.1.).

3.2.2. Feedstock cost, supply, and quality challenges

Feedstock price, availability, and quality are critical to the success of clean fuel projects and play a key role in determining where and at what cost these projects can be built. Again, risks or high costs related to these factors are generally not a reason for governments to intervene.

For green hydrogen and ammonia projects, a reliance on dedicated

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renewable electricity sources (e.g., solar and wind) for electricity can raise significant capacity concerns. The intermittency of these energy sources prevents facilities from continuous operation, thereby reducing output. That makes the facilities less likely to recoup its capital costs and eventually generate profit.

These projects can connect to the electrical grid, but the grid power might not be entirely low-carbon. While Canada has a relatively clean electrical grid, that is not the case in much of Atlantic Canada where green hydrogen and ammonia projects have received considerable attention as the aforementioned MOU between Canada and Germany demonstrates (Natural Resources Canada 2022b). In Nova Scotia, over 50 per cent of electricity generated was from coal in 2019; almost 30 per cent of New Brunswick's electricity came from fossil gas and coal in that same year (Canada Energy Regulator 2022b; Canada Energy Regulator 2022c). Atlantic Canada also faces higher levels of energy poverty than the rest of Canada with one in three households considered to be energy poor compared to under 20 per cent of households in the rest of the country (Riva et al. 2021). Connecting an ammonia project to the grid could reduce local supply and raise prices, exacerbating the problem. Moreover, the variability of grid power costs introduces considerable uncertainty that can turn investors away.

There is also a high likelihood that regions such as the Middle East and North Africa are able to operate renewables at a lower cost than those modelled in our archetypes. That likely gives projects in those areas a financial edge—especially considering their proximity to the European market (Apostoleris et al. 2021; IEA 2022b).

Additionally, blue and green hydrogen and ammonia projects face highly variable feedstock costs as fossil gas prices are prone to significant price fluctuations and renewables are likely to produce similar price volatility challenges (Fleury 2022; Ballester and Furio 2015; Hirschhorn and Brijs 2022). That can also jeopardize the bankability of these projects.

Biofuels typically face challenges with feedstock availability and quality. For instance, the low energy density of wood waste makes it a less efficient feedstock. In many biofuel processes, the conversion of biomass to biofuels also requires a homogenous feedstock with very specific characteristics such as moisture content, size, and chemical composition. Mixing feedstocks or heterogeneity often inhibits

Much of Nova Scotia's electricity comes from coal powered plants like this one in Trenton.

the process and/or drives up costs. For the biomethanol archetype we modelled, there is a limit to the availability of municipal solid waste from any given municipality. Acquiring waste from multiple municipalities gets around this issue, but that increases transport costs and introduces additional permitting challenges (see Section 3.3.6.). The difficulties in acquiring a sufficient quantity of high-quality feedstock for biofuels projects means that they are likely to only be economic when built in close proximity to homogenous feedstock sources, further constraining their development.

The IEA has warned that the biofuels industry is facing a “feedstock crunch” over the next five years that could drive up costs. In particular, they emphasize that demand for biofuels made from wastes and residues are rapidly approaching current supply limits (IEA 2022c).

These feedstock challenges make it difficult to increase the scale of a project which affects the financial viability of clean fuel projects, an issue consistently raised by the experts we consulted. Increasing project scale can result in lower capital-expenditure-per-unit, but feedstock constraints means that clean fuel projects, like our southern Ontario biomethanol archetype which is only 1.5 times larger than the first waste-to-biofuel facility in Canada, are likely to be too small to be cost-competitive.

3.2.3. Skills and labour shortage

As we learned from industry experts, clean fuel project proponents face considerable headwinds in acquiring the talent and skilled labour necessary to operate their facilities.

As clean fuel projects face significant geographical constraints because they must be in close proximity to feedstock, they are more likely to be built in rural and remote areas which can raise concerns about the availability of skilled labour. In order to attract skilled labour, project proponents will likely have to offer higher wages, competitive benefits, affordable housing, and other amenities—furthering driving up the cost of a given project.

Clean fuel project proponents also face a tight and competitive labour market that raises costs. In the short run, job vacancies remain high with Canada's unemployment-to-job vacancy ratio reaching a record low in 2022 (Statistics Canada 2022). Specifically for skilled tradespeople who are essential to operating clean fuel projects, the labour shortage is poised to be even more severe. More than 700,000 workers in the skilled trades are expected to retire by 2028 and Canada is projected to be facing a shortfall of 60,000 registered apprentices by 2025 (Powell and Richardson 2021).

Overall, Canada faces significant and rising demand for green jobs and potential shortages with one study showing that Canada could add up to 400,000 new jobs that demand "enhanced," green skills by 2050 and the net zero jobs deficit could already reach 27,000 by 2025 (Guldimann and Powell 2022).

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3.3. Market and policy failures

Other barriers for first-of-kind projects do suggest a role for governments. Market failures represent well-established circumstances where markets alone do not provide incentives to deliver outcomes with overall benefits to society. Similarly, problems with existing policies can create barriers and perverse incentives. In these cases, public policy can provide net benefits—if designed well.

3.3.1. Policy-based market price uncertainty

Market prices for clean fuels are not entirely affected by market conditions. Policy choices also have a large impact on the future price that clean fuels are able to demand.

For instance, expert feedback indicated that Canadian biofuel projects might only be economic in British Columbia because of the price premium[1] created by the B.C. Low-Carbon Fuel Standard (BC-LCFS).

Moreover, estimating the price premium that can be garnered for some biofuels can be tricky given that the scope of the BC-LCFS and federal CFR does not extend beyond gas and diesel presently (Government of British Columbia 2023a; Government of Canada 2022). Upgrading biofuels to ethanol or other specialty chemicals could generate a greater price premium. However, that introduces additional costs and, potentially, additional greenhouse gas emissions.

Canada's output-based carbon pricing system (and its provincial equivalents) generates a price premium, but uncertainty over the future carbon pricing creates market price uncertainty as well (See Section 3.3.2.).

[1] In respect to clean fuels, a price premium refers to the additional cost that customers are willing to pay for clean fuels to avoid the extra costs incurred from carbon pricing or clean fuel regulations.

Blue ammonia also faces market price uncertainty given that green hydrogen is expected to be cost-competitive with blue hydrogen by 2028 and climate mitigation policies such as carbon pricing and methane regulations could mean that blue ammonia will have to be sold at a discount, or the opposite of the price premium that green hydrogen can fetch (Collins 2022). Ultimately, blue hydrogen and ammonia facilities could end up as stranded assets as they might not be able to compete with green hydrogen and ammonia.

3.3.2. Policy uncertainty

Policy uncertainty manifests in multiple forms, including uncertainty over financial incentives received, and whether announced and implemented policies will be maintained over the long run, including when there is a change in government. Together, that raises the risk associated with first-of-kind clean fuel projects that harms their economic viability.

While Canada is still developing new investment tax credits and financing facilities to support clean fuel projects, other countries, including the United States, have already provided project proponents and prospective investors with certainty through considerable financial incentives. Canada's 2022 Fall Economic Statement offered two investment tax credits that could be utilized by clean fuel project proponents—one for clean technologies and one for clean hydrogen. It also outlined the contours of the Canada Growth Fund which will be used to provide financing and policy certainty for low-carbon projects (Finance Canada 2022a). However, since these proposed measures from the federal government are still under development, they lack the details and certainty for investors to be confident that they will ensure the financial viability of a given project; projects cannot be deemed bankable based on as-yet-determined financial support. While the $1.5 billion Clean Fuels Fund established in 2021 is now operational, additional financial incentives will likely be necessary (Natural Resources Canada 2022c).

In contrast, the U.S. Inflation Reduction Act offers a subsidy in the form of a production tax credit of up to $3 per kilogram of clean hydrogen, extends the second generation biofuels income tax credit through 2024, and introduces a new clean fuel production tax credit in 2025 worth up to USD$1 per gallon. The Inflation Reduction Act also provides some subsidies up front, meaning that entities do not have to wait to file their taxes to receive the funds (The White House 2023). USD$28 billion in private finance was mobilized in just the first two months after the Inflation Reduction Act passed, and the Act was cited by Ernst & Young for ranking the United States as the most attractive country to invest in renewables (Marcacci 2022; de Giovanni and Warren 2022).

"While Canada is still developing new investment tax credits and financing facilities to support clean fuel projects, other countries, including the United States, have already provided project proponents and prospective investors with certainty through considerable financial incentives.

Biofuel project proponents face additional uncertainty as it is unclear if they are able to capture the full value of credits offered through the BC-LCFS and the federal CFR. Since producers are only eligible for credits under the BC-LCFS or CFR if they are producing a gasoline or diesel fuel, that would exclude biomethanol and biocrude, the two biofuels modelled in our archetypal projects. The fuels would have to be upgraded to directly receive credits through either regulation which, again, would lead to additional costs. Without upgrading their fuels, project proponents would have to negotiate with the fuel refiner to receive some of the value of the credits they generate.

Additionally, the CFR regulates the final supplier of fuels, not upstream producers. This again raises the issue of credit passthrough wherein project proponents may only get a fraction of the credit value. Passthrough in both circumstances is based on market conditions and can therefore be significantly less than 100 per cent.

Programs that provide additional credits based on expected capital expenditure, such as the Part 3 agreements offered by the B.C. government, can help address the inability to capture the full value of credits offered by clean fuel regulations but this program only exists in B.C. presently (Government of British Columbia 2022a).

Furthermore, uncertainty over the future price of compliance credits under the BC-LCFS, federal CFR, and the federal carbon pricing system harms the bankability of clean fuel projects. Carbon credit oversupply precipitated by the federal government's CCUS investment tax credit and lax provincial industrial pricing systems that grant a large quantity of free emissions could reduce the price of credits, thereby diminishing a revenue stream of clean fuel projects (Sawyer et al. 2021; J. Clark et al. 2022). Clean fuel regulations are faced with a similar prospect of credit oversupply. Regular negotiations between provinces and the federal government over industrial carbon pricing equivalency agreements also drives uncertainty (J. Clark et al. 2022).

However, as practitioners indicated, they are also concerned that existing policies could be rolled back or amended in a way that reduces the financial incentives they receive. For example, Canada has committed to a rising carbon price that will reach $170 per tonne of CO_2 equivalent in 2030. However, for this price to be bankable for investors, they must believe that the schedule price is both politically durable and that the governing carbon pricing system in Canada will value credits generated by the project at something close to this price. The aforementioned risk of credit oversupply threatens to drive the value of credits below that of the carbon price. And on durability, the Conservative Party of Canada has proposed to repeal the federal carbon tax. Although they do intend to maintain the existing output-based pricing system—which applies to industrial emitters—at $50 per tonne, it is still far short of the Liberal government's intention to raise the carbon price to $170 per tonne by 2030 (Bulowski 2022).

Contracts for difference are one method that has been proposed to mitigate this uncertainty, but they have yet to be implemented in Canada (J. Clark et al. 2022).

3.3.3. Infrastructure deficiencies

A deficit of public infrastructure such as roads, electricity transmission lines, and grid capacity necessary to build clean fuel projects also drives up costs and increases uncertainty. Individual investors have no incentive to bear the cost of building this infrastructure, but rather, they have an incentive to delay their projects until it is in place. Therefore, governments have to step in and address the shortfalls.

Canada's physical infrastructure consistently lags its global counterparts, making it a less attractive place to invest. In the World Bank's Logistics Performance Index, Canada ranks 20th—behind Germany, Japan, the United States, the United Kingdom, and others—largely because of its poor 21st place ranking in physical infrastructure (World Bank 2018). Rural and remote communities where many of these projects will be located, have even greater infrastructure deficiencies that have already deterred investment. For instance, a critical mineral mine in the Northwest Territories has been beset by delays because of a lack of a winter road (Williams 2021). Urban communities are not immune either. Windsor, Ontario lost out on a $2.5 billion chemical plant because of insufficient electricity supply (Canadian Broadcasting Corporation 2022). Infrastructure gaps are even more pronounced in rural, remote, and Northern communities disproportionately home to Indigenous communities (D. Clark et al. 2022).

Infrastructure gaps were shown to be the most pertinent for the blue and green ammonia archetypes we modelled. For the Alberta blue ammonia project, transporting the ammonia to market by rail or pipeline and accessing the Alberta Carbon Trunk Line were identified as the largest sources of financial uncertainty. For the Atlantic Canada green ammonia archetype to be profitable, it would need a deepwater port with the capacity and facilities necessary to export ammonia to foreign markets along with sufficient road access and existing electricity transmission infrastructure.

3.3.4. Spillovers from innovation and technological change

Many of the archetypes that were modelled use technologies that are still nascent, expensive, and unproven at scale—driving up costs and uncertainty and making them less attractive to potential investors. Yet overcoming the barriers offers benefits that individual project proponents can't capture. As new technologies become more trusted and less expensive through learning-by-doing, other firms applying these technologies benefit, as does society overall.

For instance, autothermal reforming, which is the production method used in our blue ammonia archetype, allows the facility to meet the 90 per cent captured threshold to be considered clean (Bauer et al. 2022). However, autothermal reforming is likely to be far more expensive to operate than its alternative, steam methane reforming, especially when a steam methane reforming-based blue ammonia project is operating with a lower-carbon capture rate (Oni et al. 2022). Even though there are more efficient and cost-effective autothermal reforming processes, like membrane-assisted autothermal reforming, they have yet to be proven at scale (Cloete et al. 2021). That makes it difficult for a true low-carbon blue ammonia project, like the one we modelled, to be competitive with other forms of blue ammonia, grey ammonia, or even green ammonia in some instances.

Green hydrogen and ammonia projects also face technology cost challenges. While the prices of the electrolyzers needed to produce green hydrogen are falling, their high cost still means that green hydrogen is not expected to be cost-competitive with blue and grey hydrogen until 2028 in Canada (IRENA 2022a).

Similar issues plague biofuel projects. Gasification, which is the production method modelled in our biomethanol archetype, is complicated and many developers have had difficulty meeting production targets while facing higher than expected costs. It is also unproven at scale (Mishra and Upadhyay 2021). That reduces investor confidence and the financial viability of the project. This problem is currently afflicting Enerkem, a Canadian company using gasification to create biocrude from municipal solid waste. They are facing headwinds raising enough capital to advance their 30 proposed projects because many banks and even ESG funds are reluctant to provide them with commercial loans because of a lack of production data on the technology they're using (Duarte 2022).

Conversely, economies of scale could dramatically reduce the cost of the technologies used in clean fuel production. A recent analysis suggests that this is likely to occur with electrolyzers used to produce green hydrogen (Way et al. 2021). But generally speaking, the degree to which that occurs remains uncertain and unknown and therefore, does not change the calculus for prospective investors. The inverse is also possible. Increased capital and operational expenditures could arise from unforeseen technological challenges.

Again, while these technological risks are a private cost borne by project proponents, there are substantial public benefits that are not captured by the private firms building clean fuel projects. First-of-kind project proponents are not compensated for taking on the added costs and risks associated with learning-by-doing and scaling up nascent technologies that have high decarbonization and economic potential that's to the benefit of Canada and the world. This makes technological risks and costs a market failure that suggests government intervention to rectify.

"First-of-kind project proponents are not compensated for taking on the added costs and risks associated with learning-by-doing and scaling up nascent technologies.

3.3.5. Policy-influenced labour market challenges

Government policy also affects the skills and labour gap in the clean technology sector.

As numerous analysts explain, the short term labour shortage might be a consequence of the pandemic, but in the medium to long term, tight labour market conditions could persist given Canada's aging population, skills mismatches, and underutilization of skilled immigrants (Carmichael 2022; Janzen et al. 2022).

Changes in immigration policy to attract immigrants with skills needed for a low-carbon future and skills training programs for workers already in Canada are likely to be necessary to close the gap. In particular, regional up-skilling and training programs for workers in carbon-intensive industries with transferable skills and labourers from rural, remote, and Indigenous communities are valuable tools for addressing labour shortages (Harding and Forman 2022).

3.3.6. Permitting delays

The sluggishness and difficulties of permitting remains one of the primary impediments to getting clean fuel projects off the ground.

Feedback from biofuels and low-carbon hydrogen experts and project proponents all emphasized the challenge of engaging in often repetitive permitting and approval processes with multiple levels of government and energy regulators. And while jurisdictions, such as British Columbia, have provided significant financial incentives for clean fuel projects through the BC-LCFS, the lack of government capacity to process development applications has hindered the clean fuels growth that the BC-LCFS is intended to create.

This common sentiment from the experts we engaged is buttressed by the World Economic Forum's Global Competitiveness Index. It found that inefficient government bureaucracy was the most "problematic factor for doing business" in Canada in its 2017-2018 report, and Canada ranked 36th in the world for "burden of government regulation" in the 2019 edition, behind many global peers (World Economic Forum 2017; World Economic Forum 2019). Moreover, the Independent Contractors and Businesses Association of B.C. found that it takes 250 days on average to get a general construction permit approved in Canada. That's three times longer than in the United States and ranks 34th out of 35 OECD countries (Gardner 2020).

Locating facilities in more populated areas, such as in the southern Ontario biomethanol archetype we modelled, faces even greater permitting hurdles which might lead project proponents to pursue a rural facility. However, that raises transportation costs, hurting the financial viability of potential projects.

Permitting delays to build the associated physical infrastructure necessary for clean fuel projects to function also impedes the development of these projects.

3.3.7. The social benefits of Indigenous cooperation and partnership

Building equitable and mutually beneficial partnerships with Indigenous Peoples is essential to the economic success of any clean fuels project and for the success of Canada's low-carbon transition. However, many firms opt to forgo relationship building efforts with Indigenous communities because it is resource-intensive, and firms are not able to fully internalize the society-wide benefits of Indigenous reconciliation. Moreover, past and present policy failures rooted in colonialism have prevented Indigenous Peoples from meaningfully participating in the Canadian economy and society. Governments therefore have a role in enabling strong partnerships between Indigenous Peoples and project proponents.

Building strong relationships with Indigenous partners comes with benefits for Indigenous Peoples and project proponents alike. Indigenous Peoples offer a unique knowledge base, grounded in lived experiences and cultural wisdom, that can improve the sustainability of clean fuel projects which is critical for reducing environmental impacts of projects and ensuring that firms meet ESG standards. Establishing impact

> Building equitable and mutually beneficial partnerships with Indigenous Peoples is essential to the economic success of any clean fuels project.

benefit agreements co-developed with Indigenous communities—or ideally wealth-maximizing equity partnerships—provides mutual benefits, advances reconciliation, and increases community buy-in from the project's construction through to its operational phase. Proponents finance projects in Indigenous communities which can be a source of long-term wealth and employment, and the communities in turn work at the facilities and share their knowledge which propels projects to success (Ross 2022; Podlasly 2022).

The public benefits of Indigenous partnerships with the private sector are even more vast. Beyond advancing reconciliation and growing the wealth and prosperity of Indigenous communities, these partnerships produce positive externalities as they provide a model from which future project proponents can learn and apply best practices. As project proponents do not capture those benefits, there's a market failure that should prompt government intervention to redress.

Conversely, failing to respect Indigenous rights and sovereignty, on top of being morally wrong, creates reputational harm and legal risks for project proponents. As the Truth and Reconciliation Commission urges in Call to Action 92, Canadian corporations should "adopt [the United Nations Declaration on the Rights of Indigenous Peoples] as a reconciliation framework and to apply its principles, norms, and standards to corporate policy and core operational activities" (The Truth and Reconciliation Commission of Canada 2015). While this is not obligatory at present, changing societal norms regarding Indigenous inclusivity mean that transgressing firms are increasingly being punished. For instance, shares for the Vancouver-based mining company, Tahoe Resources, fell from $27 a share to $5 because of its failure to disclose Indigenous opposition to its mining operations in Guatemala (Imai and Colgrove 2021).

Meanwhile, Bills C-15 and C-69 place new legal obligations on firms that expand their duty to consult and set new criteria for them to meet in federal environmental impact assessments (Ugochukwu 2019).

While strong partnerships between Indigenous Peoples and project proponents creates public benefits, neglect on the part of private companies does the opposite. It harms efforts to pursue reconciliation and makes it more challenging to build the projects that are necessary to meet Canada's climate goals and create a competitive low-carbon economy—a market and policy failure that public policy can mitigate.

Consequently, governments have a clear role to play. First, they could create accredited training programs, co-developed with Indigenous governments and incorporating Indigenous knowledge in a two-eyed

> Establishing impact benefit agreements co-developed with Indigenous communities—or ideally wealth-maximizing equity partnerships—provides mutual benefits, advances reconciliation, and increases community buy-in from the project's construction through to its operational phase.

seeing approach, to support Indigenous Peoples in building careers as skilled labourers in the clean fuels sector. That would help to ensure that clean fuel projects employ Indigenous Peoples from the communities in which they operate, closing the employment gap with settlers and securing employment seven generations ahead.

Second, limited capacity can act as a hindrance to Indigenous involvement in clean growth projects. Therefore, building strong relationships between non-Indigenous project proponents and Indigenous communities requires investments in capacity building which can be enabled by governments (Gray 2016). Capacity building programs like those offered by the B.C. government through the First Nations Clean Energy Business Fund offer a good model to follow (Government of British Columbia 2023b).

Lastly, some First Nations have expressed interest in leading clean fuel projects. For example, the Siksika Nation is working with Reconciliation Energy Transition Inc. to build a sustainable aviation fuel facility to supply Calgary International Airport (Tuttle 2022). However, direct Indigenous ownership of projects, along with equity partnerships, is a challenge for Indigenous communities to pursue without government action because of the legacy and ongoing impacts of colonialism. In particular, the *Indian Act* continues to restrict Indigenous Peoples from owning land and conducting commerce meaning that Indigenous governments are unable to use their assets as collateral. As a result, Indigenous Peoples are classified as "high-risk" borrowers who are unable to secure loans at standard commercial interest rates (Von der Porten and Podlasly 2021). Given that equity partnerships and direct Indigenous ownership provides the greatest benefits for Indigenous communities by maximizing long-term wealth, but also entails greater financial risk, governments have a clear role to play in mitigating this policy failure (Garcha 2022). Governments can address these concerns by providing loan guarantees, as is currently done through the Alberta Indigenous Opportunities Corporation and the Ontario Aboriginal Loan Guarantee Program, and/or with a revolving loan fund (Calla 2021; Gale and Hyder 2023).

Piles of wood chips to be made into wood-pellet fuel—a byproduct of the lumber industry and a renewable resource.

An Alberta canola field in bloom.

CONCLUSION: ADDRESSING THE BARRIERS TO FIRST-OF-KIND CLEAN FUEL PROJECTS

There are likely to be many clean fuel projects that would yield net benefits for Canada, but that are not attractive to private investors because of a variety of barriers. However, given limited public funds and resources, Canadian governments should focus support on projects that are not profitable to private investors because of market and policy failures.

As the barriers facing first-of-kind clean fuel projects are unique, so too are the policy solutions. In some instances, financial incentives or public investment might be an effective solution. That could take the form of contracts for difference or investment tax credits to overcome policy uncertainty. Making it easier for Indigenous partners to gain equity stakes through loan guarantees is another example. For other projects, structural regulatory and labour market changes could be essential to getting shovels in the ground. Permitting reform was raised as a key step to moving clean fuel projects forward in our engagement sessions with experts pointing to the B.C. Oil and Gas Commission which is undergoing a change in name and mandate to turn it into a one-stop shop for permitting, regulatory processes, and compliance (Government of British Columbia 2022b).

Each clean fuel project is different so a variety of financial instruments and policy changes will be needed to ensure that clean growth projects are able to mobilize the private capital they need to get off the ground.

However, governments at all levels need to contend with two challenges that are often pulling them in different directions when developing policy to support not only clean fuel projects, but clean growth projects more broadly. **First, one piece of feedback we received, which cuts across all types and varieties of clean fuel projects, is the need to act fast.**

As the federal government acknowledged last year, the measures announced in the Fall Economic Statement were just a "down payment" (Finance Canada 2022b). With the United States already implementing the Inflation Reduction Act, the European Union preparing their own clean

> With the United States already implementing the Inflation Reduction Act, the European Union preparing their own clean growth industrial strategy, and China making massive investments in renewables, Canada needs to build a more permissive policy environment quickly.

growth industrial strategy, and China making massive investments in renewables, Canada needs to build a more permissive policy environment quickly (Liboreiro 2023; Yin 2023).

Simultaneously, Canada has to be careful and deliberate about how it supports clean growth projects. Canada will likely have to pursue a more targeted approach than its southern neighbour because of its smaller size and more limited fiscal capacity (Beck 2022). But beyond that, it will be essential to develop criteria to ensure that support is only being given to projects that would not have gone forward without public intervention and that provide clear benefits to Canada.

Ultimately, governments at all levels need to formulate a smart, targeted made-in-Canada approach for building a low-carbon future that leverages its competitive advantages—including in the production of low-carbon hydrogen and advanced biofuels—into future economic prosperity.

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ANNEX 1:
METHODOLOGY AND ARCHETYPE SELECTION CRITERIA

The scope of the cash flow modelling completed by Seton Stiebert, Dr. Francis Li, and Dr. Chris Bataille was to identify five archetypal low-emission fuel projects that are representative of the clean fuel projects that are likely to be pursued in Canada in the foreseeable future.

The selection of archetypal projects was based on the following criteria:

Criteria	Evaluation Considerations
Consistency with achieving net zero emissions by 2050	Demand for the product is expected to be maintained or grow in a net zero global economy. The project helps accelerate capital and technology deployment that is consistent with a net zero pathway for the sector, recognizing that different technologies will be necessary to reach net zero. Projects should be consistent with long-term sustainability and specifically consistent with a long-term (2050) transition to net zero greenhouse gases covering both direct project emissions (Scope 1), indirect emissions (Scope 2) and upstream and downstream full lifecycle emissions (Scope 3).
Interest by companies active in Canada	The potential project leverages long-term strategies and financing plans of existing companies in Canada. The project must also be competitive with other low greenhouse gas emission alternatives. Focus is placed on promising first-of-kind projects in Canada production options that can scale and meet different end-use demands for energy that are likely to have markets and be cost competitive with alternatives.
Recognizes technological readiness and availability	Best near-term options for low greenhouse gas emission production. Has a technological readiness of at least Technology Readiness Level 7 (prototype development), but hasn't been widely commercialized globally or built in Canada.
Leverages competitive advantages regionally within Canada, i.e., "Why here?"	Looks at regional competitive advantage (i.e., input supply chain, low operating costs, labour and skill availability, energy costs, existing markets) to identify appropriate locations, as well as potential for exports.
Recognizes both climate change risks, community vulnerability and diversity, and geographic diversity	Considers locations and production capacities, including both regional diversity and vulnerabilities to climate change, while also addressing vulnerability of communities to the transition (e.g., loss of jobs). This includes potential impacts to First Nations/Indigenous Peoples.

Twelve project archetypes were evaluated against the criteria in the table above and were provided to the Canadian Climate Institute for feedback and discussion. Interviews were also conducted with stakeholders to review the list and selection considerations. The rationale for the selection of the five archetypes, based on the criteria, can be found below:

	Project description	Brief summary of the rationale for the selection
1	Green hydrogen project for industry cluster east of Montreal	High existing hydrogen demand for numerous high value industry products. Active and demonstrated interest in similar projects in this location. Regional representation for Québec and heavy industry.
2	Biorefinery to convert logging wood waste to biocrude in Prince George, British Columbia	High availability of waste or unused logging residue biomass in the immediate area surrounding Prince George. Active and demonstrated interest in similar projects. Rural representation of vulnerable communities historically dependent on forestry for pulp, for which demand is declining. Co-processing of biocrude at existing refineries reduces overall capital investment and operating costs.
3	Biomethanol produced from municipal solid waste in southern Ontario	High availability of low-cost waste biomass. Active Canadian technology companies building first-of-kind global plants. High value product with multiple markets (transport, industry).
4	Blue ammonia project located in Alberta	Inexpensive methane supply and existing plant and CCUS infrastructure.
5	Green hydrogen converted to ammonia for export sited in Atlantic Canada	Low cost and very large electricity supply from Labrador is possible. Existing and underutilized deepwater port in Stephensville, Newfoundland. Available fleet of ammonia carrying vessels for transport to Europe.

A project finance model was developed to estimate the net present value of each archetypal project based on cash flows of operational expenditures (OPEX), capital expenditures (CAPEX), and revenues. The financial model was built in Microsoft Excel and is a spreadsheet model that tracks cash flow over the construction and operational lifetime of the project, considering appropriate financing and discount rates.

The net present value (NPV) of all costs and revenues are calculated in order to estimate the profitability or unprofitability of the project and the expected simple internal rate of return of the project. The simple internal rate of return is calculated as:

$$\text{Simple Internal Rate of Return} = \frac{\text{Positive Cashflow}}{\text{Negative Cashflow}} - 1 = \text{NPV}\left(\frac{\text{Revenue}}{\text{CAPEX + OPEX}}\right) - 1$$

Physical unit production costs are also calculated to compare with expected market prices. Minimum, central, and maximum values or ranges are entered for important project variables. A sensitivity analysis of the major variables is conducted to understand how each variable affects the project economics. Monte Carlo simulations were also run using a range of reported values (minimum, central, and maximum) to generate a histogram of outcomes.

To inquire about additional details of the financial modelling, please contact Jared Forman at jforman@climateinstitute.ca.

ACKNOWLEDGMENTS

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The author and contributing staff also wish to acknowledge the input we received from a broad range of stakeholders whose feedback helped to shape this paper.

Production Support
Design and Layout: Laurie Barnett, Graphic Designer

Translation: Edgar Co-operative

Recommended Citation: Forman, Jared. 2023. *Unpacking the barriers to first-of-kind clean fuel projects in Canada*. Canadian Climate Institute.

REFERENCES

APERC [Asia Pacific Energy Research Centre]. 2018. *Perspectives on Hydrogen in the APEC Region*. June. https://aperc.or.jp/file/2018/9/12/Perspectives+on+Hydrogen+in+the+APEC+Region.pdf

Apostoleris, Harry, Amal Al Ghaferi, and Matteo Chiesa. 2021. "What is going on with Middle Eastern solar prices, and what does it mean for the rest of us?" *Progress in Photovoltaics*. https://onlinelibrary.wiley.com/doi/full/10.1002/pip.3414

Arnold, Jonathan, Rachel Samson, Sachi Gibson, Antonio Ding, and Melissa Felder. 2022. *Net Zero Opportunities: A province-by-province comparison*. Canadian Climate Institute. https://climateinstitute.ca/wp-content/uploads/2022/05/Provincial-summary-EN.pdf

Ballester, Cristina, and Dolores Furió. 2015. "Effects of renewables on the stylized facts of electricity prices." *Renewable and Sustainable Energy Reviews 52*(December). https://www.sciencedirect.com/science/article/abs/pii/S1364032115008151

Bauer, Christian, Karin Treyer, Cristina Antonini, Joule Bergerson, Matteo Gazzani, Emre Gencer, Jon Gibbins, Marco Mazzotti, Sean T. McCoy, Russell McKenna, Robert Pietzcker, Arvind P. Ravikumar, Matteo C. Romano, Falko Ueckerdt, Jaap Ventek, and Mijndert van der Spek. 2022. "On the climate impacts of blue hydrogen production." *Sustainable Energy & Fuels 1*. https://pubs.rsc.org/en/content/articlelanding/2022/se/d1se01508g

Beck, Marisa. 2022. "Responding to the Inflation Reduction Act: What are Canada's options?" *Canadian Climate Institute* [blog]. November 2. https://climateinstitute.ca/inflation-reduction-act-what-are-canadas-options/

Beck, Marisa, Don Drummond, and Stewart Elgie. 2023. "Optimizing Canada's policy toolbox for clean growth." *Policy Options*. February 21. https://policyoptions.irpp.org/magazines/february-2023/clean-growth-toolbox/

Bulowski, Natasha. 2022. "Conservatives ditch carbon pricing plan." *Canada's National Observer*. February 10. https://www.nationalobserver.com/2022/02/10/news/conservatives-ditch-carbon-pricing-plan-after-erin-otooles-ouster

Calla, Jason. 2021. *Improving Access to Capital for Indigenous Groups to Purchase Equity Stakes in Major Resource Projects: Reviewing existing approaches to inform a National Benefits-Sharing Framework*. FNMPC [First Nations Major Projects Coalition]. https://14x5f4.p3cdn1.secureserver.net/wp-content/uploads/2021/04/FNMPC_Reviewing_Access_final.pdf

Canada's Ecofiscal Commission. 2016. *Course Correction: It's Time to Rethink Canadian Biofuel Policies*. October. https://ecofiscal.ca/wp-content/uploads/2016/10/Ecofiscal-Commission-Course-Correction-Biofuels-Report-October-2016.pdf

Canada Energy Regulator. 2022a. *Provincial and Territorial Energy Profiles – Canada*. July 28. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-canada.html#:~:text=More%20than%20half%20of%20the,and%20petroleum%20(Figure%202).

Canada Energy Regulator. 2022b. *Provincial and Territorial Energy Profiles – Nova Scotia*. July 28. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-nova-scotia.html

Canada Energy Regulator. 2022c. *Provincial and Territorial Energy Profiles – New Brunswick*. July 28. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-new-brunswick.html

Canadian Broadcasting Corporation. 2022. "Windsor loses out on $2.5-billion plant from LG Chem due to lack of energy supply." May 11. https://www.cbc.ca/news/canada/windsor/windsor-plant-lg-1.6448304

Carmichael, Kevin. 2022. "Help Wanted: Acute labour shortages about to become chronic source of economic pain." *Financial Post*. October 31. https://financialpost.com/fp-work/help-wanted/acute-labour-shortages-chronic-kevin-carmichael

Clark, Dylan, Dena Coffman, Ryan Ness, Isabelle Bujold, and Dale Beugin. 2022. *Due North: Facing the costs of climate change for Northern infrastructure*. Canadian Climate Institute. https://climateinstitute.ca/wp-content/uploads/2022/06/Due-North.pdf

Clark, Jason, Blake Shaffer, Michael Bernstein, Jake Wadland, and Dale Beugin. 2022. *Closing the Carbon-Pricing Certainty Gap*. Clean Prosperity and Canadian Climate Institute. https://climateinstitute.ca/wp-content/uploads/2022/10/Closing_the_Carbon-Pricing_Certainty_Gap.pdf

Cloete, Schalk, Mohammed Nazeer Khan, Shareq Mohd Nazir, and Shahriar Amini. 2021. "Cost-effective clean ammonia production using membrane-assisted autothermal reforming." *Chemical Engineering Journal 404*(January). https://www.sciencedirect.com/science/article/pii/S1385894720326784

Collins, Leigh. 2022. "Why multi-million-dollar blue hydrogen investments might fast end up as 'stranded assets.'" *Recharge*. January 17. https://www.rechargenews.com/energy-transition/why-multi-million-dollar-blue-hydrogen-investments-might-fast-end-up-as-stranded-assets/2-1-1146527

de Giovanni, Arnaud, and Ben Warren. 2022. *Renewable Energy Country Attractiveness Index: Can decentralized energy get good enough, fast enough?* Ernst & Young. https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/power-and-utilities/ey-recai-60-v2.pdf

de Pee, Arnout, Dickon Pinner, Occo Roelofsen, Ken Somers, Eveline Speelman, and Maaike Witteveen. 2018. *Decarbonization of industrial sectors: the next frontier*. McKinsey & Company. https://www.mckinsey.com/~/media/mckinsey/business%20functions/sustainability/our%20 insights/how%20industry%20can%20move%20toward%20a%20low%20carbon%20future/decarbonization-of-industrial-sectors-the-next-frontier.pdf

DiChristopher, Tom. 2021. "Blue hydrogen serves as low-carbon bridge to green hydrogen future, experts say." *S&P Global Market Intelligence*. August 27. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/blue-hydrogen-serves-as-low-carbon-bridge-to-green-hydrogen-future-experts-say-66321776

Dion, Jason, Anna Kanduth, Jeremy Moorhouse, and Dale Beugin. 2021. *Canada's Net Zero Future: Finding our way in the global transition*. Canadian Climate Institute (formerly Canadian Institute for Climate Choices). https://climatechoices.ca/wp-content/uploads/2021/02/Canadas-Net-Zero-Future_FINAL-2.pdf

Dion, Jason, Caroline Lee, Anna Kanduth, Christiana Guertin, and Dale Beugin. 2022. *The Big Switch: Powering Canada's net zero future*. Canadian Climate Institute. https://climateinstitute.ca/wp-content/uploads/2022/05/The-Big-Switch-May-4-2022.pdf

Duarte, Esteban. 2022. "BlackRock-Backed Biofuel Firm Says Timid Lenders Slow New Tech." *Bloomberg*. September 15. https://www.bloomberg.com/news/articles/2022-09-15/blackrock-backed-biofuel-firm-says-timid-lenders-slow-new-tech#xj4y7vzkg

Energy Transitions Commission. 2018. *Mission Possible: Reaching net-zero carbon emissions from harder-to-abate sectors*. November. https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC_MissionPossible_FullReport.pdf

Energy Transitions Commission. 2021. *Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy*. April. https://www.energy-transitions.org/wp-content/uploads/2021/04/ETC-Global-Hydrogen-Report.pdf

Finance Canada. 2022a. *Fall Economic Statement 2022*. November 3. https://www.budget.canada.ca/fes-eea/2022/report-rapport/FES-EEA-2022-en.pdf

Finance Canada. 2022b. *Remarks by the Deputy Prime Minister for the 2022 Fall Economic Statement*. November 3. https://www.canada.ca/en/department-finance/news/2022/11/remarks-by-the-deputy-prime-minister-for-the-2022-fall-economic-statement.html

Fleury, Katy. 2022. "U.S. natural gas price saw record volatility in the first quarter of 2022." *United States Energy Information Administration*. August 24. https://www.eia.gov/todayinenergy/detail.php?id=53579

Forman, Jared, and Jonathan Arnold. 2023. "Locking out carbon lock-in (Part I)." *Canadian Climate Institute* [blog]. January 4. https://climateinstitute.ca/locking-out-carbon-lock-in-part-1/

Gale, Sharleen, and Goldy Hyder. 2023. "Meeting Canada's clean energy targets must include Indigenous partnerships." *Toronto Star*. February 25. https://www.thestar.com/business/opinion/2023/02/25/meeting-canadas-clean-energy-targets-must-include-indigenous-partnerships.html

Garcha, Neeta. 2022. "Why Indigenous-led projects could be key to combating Canada's energy dilemma." *Global News*. September 21. https://globalnews.ca/news/9142106/indigenous-projects-canada-energy-landlocked/

Gardner, Chris. 2020. "Slow permit processes undermine Canada's competitiveness." *theORCA*. February 25. https://theorca.ca/visiting-pod/slow-permit-processes-undermine-canadas-competitiveness/

Gordon, Deborah, Eugene Boakye, and Dana C. Jackson. 2022. "Clean fuel incentives in the Inflation Reduction Act of 2022." *RSM*. August 15. https://rsmus.com/insights/tax-alerts/2022/clean-fuel-incentives-in-the-inflation-reduction-act-of-2022.html

Guldimann, Colin, and Naomi Powell. 2022. *Green Collar Jobs: The skills revolution Canada needs to reach Net Zero*. Royal Bank of Canada. https://thoughtleadership.rbc.com/green-collar-jobs-the-skills-revolution-canada-needs-to-reach-net-zero/

Government of British Columbia. 2022a. *Part 3 Agreements*. https://www2.gov.bc.ca/gov/content/industry/electricity-alternative-energy/transportation-energies/renewable-low-carbon-fuels/part-3-agreements

Government of British Columbia. 2022b. *B.C. making changes to advance hydrogen industry*. https://news.gov.bc.ca/releases/2022EMLI0055-001598

Government of British Columbia. 2023a. *Greenhouse Gas Reduction (Renewable and Low Carbon Requirements) Act*. February 8. https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/08016_01#part3

Government of British Columbia. 2023b. *First Nations Clean Energy Business Fund*. https://www2.gov.bc.ca/gov/content/environment/natural-resource-stewardship/consulting-with-first-nations/first-nations-clean-energy-business-fund

Government of Canada. 2022. *Clean Fuel Regulations: SOR/2022-140*. June 21. https://www.canadagazette.gc.ca/rp-pr/p2/2022/2022-07-06/html/sor-dors140-eng.html

Gray, Bryn. 2016. *Building Relationships and Advancing Reconciliation through Meaningful Consultation*. Crown-Indigenous Relations and Northern Affairs Canada. https://www.rcaanc-cirnac.gc.ca/eng/1498765671013/1609421492929?wbdisable=true

Harding, Simon, and Jared Forman. 2022. "Net Zero Workforce: The role of skills training in Canada's climate transition." *Canadian Climate Institute* [blog]. June 2. https://climateinstitute.ca/net-zero-workforce/

Hirschhorn, Philip, and Tom Brijs. 2022. "Will Electricity Be Free? Not When You Really Need It." *Boston Consulting Group*. April 4. https://www.bcg.com/en-ca/publications/2022/free-electricity-unlikely-when-needed

HTEC (formerly Zen). 2019. *British Columbia Hydrogen Study*. https://www2.gov.bc.ca/assets/gov/government/ministries-organizations/zen-bcbn-hydrogen-study-final-v6.pdf

IEA (International Energy Agency). 2022a. *World Energy Outlook 2022*. November. https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf

IEA (International Energy Agency). 2022b. *Renewables 2022*. November. https://iea.blob.core.windows.net/assets/ada7af90-e280-46c4-a577-df2e4fb44254/Renewables2022.pdf

IEA (International Energy Agency). 2022c. "Is the biofuel industry approaching a feedstock crunch?" December. https://www.iea.org/reports/is-the-biofuel-industry-approaching-a-feedstock-crunch

Imai, Shin, and Sarah Colgrove. 2021. "Investors are increasingly shunning mining companies that violate human rights." *The Conversation*. February 22. https://theconversation.com/investors-are-increasingly-shunning-mining-companies-that-violate-human-rights-154702

Institut de l'énergie Trottier. 2021. *Canadian Energy Outlook*. https://iet.polymtl.ca/wp-content/uploads/delightful-downloads/CEO2021_20211112.pdf

IRENA (International Renewable Energy Agency). 2021. *Green Hydrogen Supply: A Guide to Policy Making*. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/May/IRENA_Green_Hydrogen_Supply_2021.pdf

IRENA (International Renewable Energy Agency). 2022a. *Geopolitics of the Energy Transformation: The Hydrogen Factor*. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jan/IRENA_Geopolitics_Hydrogen_2022.pdf?rev=1cfe49eee979409686f101ce24ffd71a

IRENA (International Renewable Energy Agency). 2022b. *World Energy Transitions: Outlook 2022 1.5   Pathway*. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Mar/IRENA_World_Energy_Transitions_Outlook_2022.pdf?rev=353818def8b34effa24658f475799464

Janzen, Nathan, Claire Fan, and Naomi Powell. 2022. "Proof Point: Canada's labour shortages will outlive a recession." *Royal Bank of Canada* [blog]. July 20. https://thoughtleadership.rbc.com/proof-point-canadas-labour-shortages-will-outlive-a-recession/

Jeswani, Harish K., Andrew Chilvers, and Adisa Azapagic. 2020. "Environmental sustainability of biofuels: a review." *Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences 476(2231)*(November). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7735313/

Layzell, David B., Cameron Young, Jessica Yof, Jonathan Leary, and Song Sit. 2020. *Towards Net-Zero Energy Systems in Canada: A Key Role for Hydrogen*. The Transition Accelerator. https://transitionaccelerator.ca/wp-content/uploads/2020/09/Net-zero-energy-systems_role-for-hydrogen_200909-Final-print-1.pdf

Lee, Caroline, Jason Dion, and Christiana Guertin. 2022. *Bigger, Cleaner, Smarter: Pathways for aligning Canadian electricity systems with net zero*. Canadian Climate Institute. https://climateinstitute.ca/wp-content/uploads/2022/05/Bigger-Cleaner-Smarter-May-4-2022.pdf

Lee, Roland Arthur, and Jean-Michel Lavoie. 2013. "From first- to third-generation biofuels: Challenges of producing a commodity from a biomass of increasing complexity." *Animal Frontiers 3(2)*(April). https://academic.oup.com/af/article/3/2/6/4638639

Liboreiro, Jorge. 2023. "EU presents new industrial plan to counter American green subsidies and prevent talent drain." *euronews*. February 1. https://www.euronews.com/my-europe/2023/02/01/eu-presents-new-industrial-plan-to-counter-american-green-subsidies

Mankins, John C. 1995. "Technology Readiness Levels." *National Aeronautics and Space Administration*. https://aiaa.kavi.com/apps/group_public/download.php/2212/TRLs_MankinsPaper_1995.pdf

Marcacci, Silvio. 2022. "$28 Billion In New Clean Energy Manufacturing Investments Announced Since Inflation Reduction Act Passed." *Forbes*. October 12. https://www.forbes.com/sites/energyinnovation/2022/10/12/roughly-28-billion-in-new-clean-energy-manufacturing-investments-announced-since-inflation-reduction-act-passed/?sh=619e17366159

Mishra, Somya, and Rajesh Kumar Upadhyay. 2021. "Review on biomass gasification: Gasifiers, gasifying mediums, and operational parameters." *Materials Science for Energy Technologies 4*. https://www.sciencedirect.com/science/article/pii/S2589299121000367

Mohr, Alison, and Sujatha Raman. 2013. "Lessons from first generation biofuels and implications for the sustainability appraisal of second generation biofuels." *Energy Policy 63*(December). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4048104/

Natural Resources Canada. 2020. *Hydrogen Strategy for Canada: Seizing Opportunities for Hydrogen, A Call to Action*. December. https://natural-resources.canada.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

Natural Resources Canada. 2022a. *Clean fuels – fueling the future*. June 15. https://natural-resources.canada.ca/our-natural-resources/energy-sources-distribution/clean-fuels-fueling-the-future/23735

Natural Resources Canada. 2022b. *Canada and Germany Sign Agreement to Enhance German Energy Security with Clean Canadian Hydrogen*. August 23. https://www.canada.ca/en/natural-resources-canada/news/2022/08/canada-and-germany-sign-agreement-to-enhance-german-energy-security-with-clean-canadian-hydrogen.html

Natural Resources Canada. 2022c. *Clean Fuels Fund*. August 25. https://natural-resources.canada.ca/climate-change/canadas-green-future/clean-fuels-fund/23734

Net-Zero Advisory Body. 2023. *Compete and Succeed in a Net Zero Future*. January. https://nzab2050.ca/publications/news_feed/net-zero-advisory-body-s-annual-report

OECD (Organisation for Economic Co-operation and Development). 2014. *Country Note, Education at a Glance 2014: Canada*. https://www.oecd.org/education/Canada-EAG2014-Country-Note.pdf

OERA (Nova Scotia Offshore Energy Research Association). 2020. *A Feasibility Study of Hydrogen Production, Storage, Distribution, and Use in the Maritimes*. October. https://oera.ca/sites/default/files/2020-11/A%20Feasibility%20Study%20of%20Hydrogen%20Production%20Storage%20Distribution%20and%20Use%20in%20the%20Maritimes.pdf

Office of the Auditor General of Canada. 2022. *Report 3—Hydrogen's Potential to Reduce Greenhouse Gas Emissions*. April. https://www.oag-bvg.gc.ca/internet/English/parl_cesd_202204_03_e_44023.html

Oni, A.R., K. Anaya, T. Giwa, G. Di Lullo, and A. Kumar. 2022. "Comparative assessment of blue hydrogen from steam methane reforming, autothermal reforming, and natural gas decomposition technologies for natural gas-producing regions." *Energy Conversion and Management 254*(February). https://www.sciencedirect.com/science/article/pii/S0196890422000413

Parkes, Rachel. 2022. "'Liquefied hydrogen will have no role anywhere in energy and transport': Liebreich." *Hydrogeninsight*. November 29. https://www.hydrogeninsight.com/transport/liquefied-hydrogen-will-have-no-role-anywhere-in-energy-and-transport-liebreich/2-1-1362458

Podlasly, Mark. 2022. "What happens if Indigenous people say no to mining the minerals needed to run EVs?" *Corporate Knights*. February 1. https://www.corporateknights.com/climate-and-carbon/ev-battery-mining-indigenous/

Powell, Naomi, and Ben Richardson. 2022. *Powering Up: Preparing Canada's skilled trades for a post-pandemic economy*. Royal Bank of Canada. https://thoughtleadership.rbc.com/powering-up-preparing-canadas-skilled-trades-for-a-post-pandemic-economy/

Riva, Mylene, Sophie Kingunza Makasi, Philippe Dufresne, Kimberley O'Sullivan, and Megan Toth. 2021. "Energy poverty in Canada: Prevalence, social and spatial distribution, and implications for research and policy." *Energy Research & Social Science 81*(November). https://www.sciencedirect.com/science/article/abs/pii/S2214629621003303?via%3Dihub

Ross, Ian. 2022. "Indigenous Leaders: The successes and pitfalls of industry partnerships." *Northern Ontario Business*. April 6. https://www.northernontariobusiness.com/indigenous-leaders/indigenous-leaders-the-successes-and-pitfalls-of-industry-partnerships-5225059

Samson, Rachel, Jonathan Arnold, Weseem Ahmed, and Dale Beugin. 2021. *Sink or Swim: Transforming Canada's Economy for a Global Low-Carbon Future*. Canadian Climate Institute (formerly Canadian Institute for Climate Choices). https://climatechoices.ca/wp-content/uploads/2021/10/CICC-Sink-or-Swim-English-Final-High-Res.pdf

Sawyer, Dave, Seton Stiebert, Renaud Gignac, Alicia Campney, and Dale Beugin. 2021. *The State of Carbon Pricing in Canada: Key Findings and Recommendations*. Canadian Climate Institute (formerly Canadian Institute for Climate Choices). https://climatechoices.ca/wp-content/uploads/2021/06/State-of-carbon-pricing-report-English-FINAL.pdf

Staples, Mark D. 2018. "Life cycle analysis for advanced biofuels." Presented at the IEA Bioenergy Task 39 Meeting, Beijing. https://task39.sites.olt.ubc.ca/files/2018/04/Mark-STAPLES_IEA_T39_04-08-2018.pdf

Statistics Canada. 2022. *Labour Shortage Trends in Canada*. November 18. https://www.statcan.gc.ca/en/subjects-start/labour_/labour-shortage-trends-canada

Tenenbaum, David J. 2008. "Food vs. Fuel: Diversion of Crops Could Cause More Hunger." *Environmental Health Perspectives 116(6)*(June). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2430252/

The White House. 2023. *Building a Clean Energy Economy: A Guidebook to the Inflation Reduction Act's Investments in Clean Energy and Climate Action*. January. https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf

Truth and Reconciliation Commission of Canada. 2015. *Honouring the Truth, Reconciling for the Future: Summary of the Final Report of the Truth and Reconciliation Commission of Canada*. https://ehprnh2mwo3.exactdn.com/wp-content/uploads/2021/01/Executive_Summary_English_Web.pdf

Tuttle, Robert. 2022. "Indigenous Group Plans $451 Million Biofuel Refinery in Canada." *Bloomberg*. November 14. https://www.bloomberg.com/news/articles/2022-11-14/indigenous-group-plans-451-million-biofuel-refinery-in-canada#xj4y7vzkg

Ugochukwu, Basil. 2019. "Canadian Corporations, Environmental Solutions and the Implementation of UNDRIP." *Centre for International Governance Innovation* [blog]. July 4. https://www.cigionline.org/articles/canadian-corporations-environmental-solutions-and-implementation-undrip/

von der Porten, Suzanne, and Mark Podlasly. 2021. *ESG-Indigenous Case Study: Cascade Power Plant Project Alberta, Canada*. FNMPC [First Nations Major Projects Coalition]. https://14x5f4.p3cdn1.secureserver.net/wp-content/uploads/2021/04/FNMPC_ESG_Case.pdf

Way, Rupert, Matthew Ives, Penny Mealy, and J. Doyne Farmer. 2021. *Empirically grounded technology forecasts and the energy transition*. Institute for New Economic Thinking at the Oxford Martin School. https://www.inet.ox.ac.uk/files/energy_transition_paper-INET-working-paper.pdf

World Bank. 2018. *Global Rankings 2018* [Data Table]. https://lpi.worldbank.org/international/global?sort=asc&order=Infrastructure#datatable

World Economic Forum. 2017. *The Global Competitiveness Report 2017–2018*. https://www3.weforum.org/docs/GCR2017-2018/05FullReport/TheGlobalCompetitivenessReport2017%E2%80%932018.pdf

World Economic Forum. 2019. *The Global Competitiveness Report 2019*. https://www3.weforum.org/docs/WEF_TheGlobalCompetitivenessReport2019.pdf

Wright, Brian. 2014. "Global Biofuels: Key to the Puzzle of Grain Market Behavior." *Journal of Economic Perspectives 28(1)*(Winter). https://www.aeaweb.org/articles?id=10.1257/jep.28.1.73

Yin, Ivy. 2023. "China to maintain renewables growth pace in 2023 despite uncertainty." *S&P Global Commodity Insights*. February 1. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/020123-china-to-maintain-renewables-growth-pace-in-2023-despite-uncertainty