CANADA'S FUTURE IN A NET-ZERO WORLD

SECURING CANADA'S PLACE IN THE GLOBAL GREEN ECONOMY

MARCH 2022

Smart Prosperity Institute

The Transition Accelerator

PICS
PACIFIC INSTITUTE FOR CLIMATE SOLUTIONS

About Smart Prosperity Institute

Smart Prosperity Institute is a national research network and policy think tank based at the University of Ottawa. We deliver world-class research and work with public and private partners – all to advance practical policies and market solutions for a stronger, cleaner economy.
institute.smartprosperity.ca

About Transition Accelerator

The Transition Accelerator exists to support Canada's transition to a net-zero future while solving societal challenges. The Transition Accelerator works with innovative groups to create visions of what a socially and economically desirable net zero future will look like and build out transition pathways that will enable Canada to get there. The Accelerator's role is that of an enabler, facilitator, and force multiplier that forms coalitions to take steps down these pathways and get change moving on the ground.
transitionaccelerator.ca

About the Pacific Institute for Climate Solutions

The Pacific Institute for Climate Solutions (PICS) develops impactful, evidence-based climate change solutions through collaborative partnerships which connect private and public sector solution seekers with experts from BC's four leading research universities. PICS is hosted and led by the University of Victoria, in collaboration with the University of British Columbia, Simon Fraser University, and the University of Northern British Columbia.
pics.uvic.ca

Acknowledgements

This report was written by Bentley Allan, Derek Eaton, Jonas Goldman, Anik Islam, Teslin Augustine, Stewart Elgie, and James Meadowcroft. David Victor co-designed the chips study with the authors. David Victor and Greg Nemet provided helpful comments on the whole report. Lorne Johnson and Sybil Seitzinger provided strategic direction for the research. Jess Harris, Robyn Meyer, Trudi Zundel, and Kiana Klassen provided invaluable editorial input. Responsibility for the content lies with Smart Prosperity Institute, the Pacific Institute for Climate Solutions, and the Transition Accelerator, and should not be assigned to any reviewers, interviewees, or other external party.

Suggested Citation

Allan, B., Eaton, D., Goldman, J., Islam, A., Augustine, T., Elgie, S., and Meadowcroft, J. (2022). *Canada's Future in a Net-Zero World: Securing Canada's Place in the Global Green Economy.* Smart Prosperity Institute, Transition Accelerator and Pacific Institute for Climate Solutions.

March 2022

This project is a partnership between Smart Prosperity Institute, the Pacific Institute for Climate Solutions, and the Transition Accelerator. This report was supported by the Ivey Foundation and the Pacific Institute for Climate Solutions.

EXECUTIVE SUMMARY

A global energy transition is now underway. This transition is disrupting and reconfiguring all the world's major industries. Automotive, aerospace, oil and gas, mining, forestry, steel, agriculture, and chemicals – all essential pillars of the Canadian economy – will be transformed over the coming decades.

Canada's major trading partners and competitors are working to position themselves in the decarbonized industries of the future. The US, the UK, the European Union, South Korea, Australia, China, and Indonesia have all adopted green industrial strategies to support these efforts.

While Canada has made important investments in the energy transition, these usually take the form of one-off grants to individual firms which are already commercial and often headquartered overseas. Investments are spread thin and fragmented across departments and provinces. **Canada needs to take a more strategic approach to identifying opportunities and building industry before global value chains form.**

To begin this work and start a much-needed conversation, the Pacific Institute for Climate Solutions, Smart Prosperity Institute, and the Transition Accelerator conducted a study of Canada's prospects in a net-zero world.

The first step of such an analysis is to think strategically about Canada's position in a net-zero world. As a small open economy, Canada cannot break into mature global value chains that are dominated by big players without a clear strategy. Even in emerging industries, it is very difficult to maintain competitive advantages in technologies and products that are candidates for mass global production. This means Canada must identify niche areas where resource and innovation advantages promise a secure long-term position.

It is critical to use such a strategic lens to position Canada in the 2050 energy system. The future energy system is clouded with uncertainties, but we can identify the technological solutions that we know the world needs, those that are probably needed, and those whose role is unknown. To better understand Canada's potential to provide these solutions, we conducted a survey of leading experts in climate solutions and market analysis. The survey asked participants to distribute "chips" across sectors and technologies. This produced a ranking of technological areas in which Canada could seek to develop a secure competitive advantage. We then subjected each technology on the list to a rigorous analysis according to five criteria:

- The role of the technology in the net-zero economy
- The maturity of the technology
- National resources that deliver long-term competitive advantages
- Innovation capacities that build upstream intellectual property and specialized skills
- Market potential in North American and global markets

Each opportunity was assessed on these criteria, and then subjected to an uncertainty analysis which accounted for geopolitical and economic factors.

In *Canada's Future in a Net-Zero World,* we identify and outline seven priority opportunity areas:

- Medium and heavy-duty vehicles
- Alternative proteins
- Green aluminum
- Mass timber
- Green chemistry
- Hydrogen
- Carbon capture, utilization, and storage

To fully realize these opportunities, three enabling systems are needed: a clean grid, net-zero minerals, and robust carbon accounting.

The strength of this list is that it focuses on Canada's existing strengths in automotive manufacturing and parts, agriculture, heavy industry, forestry, chemicals, and fuels. In addition, this report identifies specific ways in which these industries can be transformed from current emissions profiles to green industry while building Canada's economy.

Importantly, we acknowledge that this list could be wrong. We may have downplayed good opportunities or ignored key uncertainties. Furthermore, the global and domestic situation is dynamic, as doors close and new opportunities emerge.

However, even if one disagrees with our list, the key contribution of our report is to lay out a four-part framework for a strategic approach:

1. Establish a vision of Canada's place in a net-zero world.
2. Identify priority opportunities and build a focused portfolio of investments across sectors.
3. Develop sectoral strategies or roadmaps that show the sequences and policies that are needed to drive industrial development and transition.
4. Collaborate across public-private and federal-provincial lines to advance the roadmaps – evaluating, realigning, and adjusting as we go.

Perhaps the most transformative shift we propose is to deliberately move from a risk averse approach to one that is experimental and strategic. A risk averse strategy will lead us to miss significant opportunities and fail to position Canada in a rapidly forming net-zero world.

Industry and government need to work together to develop a portfolio of priority initiatives that establish Canada's position in the net-zero future. These initiatives must be treated as experiments and all stakeholders must be willing to learn and change course as the global situation evolves.

Canada's Future in a Net-Zero World concludes by outlining principles for how Canada might forge ambitious public-private collaborations to build an industrial strategy. First, there is an important role for the government, which must articulate public purpose, set targets, leverage finance, and coordinate a whole supply-chain approach. Second, governments must work with intermediary organizations that can facilitate good information flows between governments and businesses, provide independent expertise, and serve as sites of learning and experimentation.

By implementing the framework in this report – developing and implementing roadmaps for the high-opportunity sectors that have been identified and forging ahead with an approach that is strategic and experimental – Canada can build a prosperous, inclusive, and sustainable position in the net-zero future.

TABLE OF CONTENTS

ABBREVIATIONS

AOSTRA	Alberta Oil Sands Technology and Research Authority
CCUS	Carbon capture, utilization, and storage
CO_2	Carbon dioxide
CO_2e	Carbon-dioxide-equivalent
DAC	Direct air capture
EOR	Enhanced oil recovery
ERA	Emissions Reduction Alberta
ESG	Environmental, social, and governance
EV	Electric vehicles
GDP	Gross Domestic Product
GRI	US Gas Research Institute
IEA	International Energy Agency
IP	Intellectual property
R&D	Research and development
RD&D	Research, development, and demonstration
SAF	Sustainable aviation fuels
SMR	Small Modular Reactor
TRL	Technology readiness level
TWh	Terrawatt hours
ZEV	Zero-emissions vehicle

1. INTRODUCTION

A global transition to a net-zero, low-carbon economy is underway. To ensure future prosperity, Canada needs to strategically position its industries in the value chains of the 21st century green economy.[1,2]

The federal government and many provinces have taken significant actions to accelerate Canada's industrial transition to a low-carbon economy. However, Canada's major trading partners and competitors are taking a more strategic approach to position their economies in rapidly-forming low carbon value chains. The EU has advanced battery and hydrogen strategies.[3] Australia has a technology roadmap that aims to gain market share in many of the same net-zero industries that Canada operates in.[4] The UK has deployed industrial strategies for offshore wind and carbon capture and storage.[5] History has shown that industrial policy can be a powerful tool for transforming industries and initiating climate action,[6] providing a way for Canada to keep up and secure its place in a global net-zero, low-carbon economy.

Canada must act quickly and decisively to promote clean competitiveness for two key reasons. First, a more coordinated approach will enable Canada to seize emerging economic opportunities for Canadian industry before global value chains form. Second, direct government support for clean growth will help meet climate mitigation objectives. Canada has a strong pricing system in the Pan-Canadian Framework, but it needs to be complemented by efforts to build green industry. If Canada simply raises prices on fossil fuels without lowering the costs of alternatives and building up industrial partners that are politically invested in the transition, there is a considerable risk that rising prices will produce a political backlash that undermines support for the carbon price.[7] A more strategic approach to industrial transition can reduce the costs of new technologies, create jobs for transitioning workers, and build political support for decarbonization over the long run.

Existing funds and policies correctly aim to support clean competitiveness, but:

- investments are **spread thin** across sectors;
- investments are often **one-off** grants to individual firms; and
- priorities are **fragmented** across departments, federal and provincial governments, and private actors.

In this report, we argue for a strategic approach that:

- focuses on the **top economic opportunities;**
- creates **long-term** strategies that integrate multiple policy tools; and
- aligns public and private actions by **co-developing roadmaps** in key sectors.

Our approach directly addresses a key recommendation of the Expert Panel on Sustainable Finance: "Map Canada's long-term path to a low-emission, climate-smart economy, sector by sector, with an associated capital plan."[8] To begin this work, we conducted a study on limited resources to start a conversation about how Canada should develop a strategic approach to industrial transition. Our goal was to create a conceptual and analytical framework and then ask where Canada's best opportunities lie in the global net-zero economy.

As a whole, this report aims to catalyze discussion around four key questions that cover the why, the what, and the how of Canadian green industrial strategy:

- Why should Canada adopt a more strategic approach to an industrial transition to a net-zero economy?
- What strategy should Canada use to position itself in the global economy?
- What technologies and sectors offer the best growth opportunities for Canada in a global economy transitioning towards net-zero emissions?
- How can Canada implement a green industrial strategy? What kind of strategic actions and coordination are required to realize those opportunities?

A central premise of this report is that Canada's economic strategy needs to focus on a smart and limited portfolio of clean competitiveness opportunities.[9] Given a number of apparently good opportunities, it is necessary to make difficult choices and prioritize. Our approach seeks to overcome this challenge by identifying specific sectors and clusters by applying five criteria. First, we look at the state of technology and build a vision of the net-zero energy system in 2050 (full details on this can be found in a companion report[10]). Second, we emphasize opportunity areas that have the potential for export-growth led by Canadian firms. Canada needs to bring domestic manufacturers to scale so that it can build innovation around globally competitive, locally grown industries. Third, our approach tries to privilege long-run economic value by identifying areas where Canada can capture upstream and high-value-added components of supply chains. Fourth, we aim to identify opportunities that leverage Canada's existing strength as a resource economy. Canada can only achieve the scale required for global competitiveness by transitioning its large emissions-intensive industries into green ones. Fifth, we sought to determine areas where Canada could build an innovation advantage on its highly educated workforce and strong knowledge base. Canada cannot rely on extraction alone and must seek to secure higher-value-added sectors.

Applying these criteria, we identify seven priority opportunity areas: medium and heavy-duty vehicles, alternative proteins, aluminum, mass timber, green chemistry, hydrogen, and carbon capture, utilization, and storage (CCUS). This list could be wrong. We may have missed opportunities with significant potential for Canada. More importantly, the global and domestic context continues to evolve as doors close and new opportunities emerge. Even if one disagrees with our choices, this report offers a four-part framework for strategic action that emphasizes the importance of identifying the top opportunities for Canada in the global transition and translating these into roadmaps.

Four-part Framework for Strategic Action

Establish a **vision** of Canada's place in the global green economy of the 21st century.

Identify top opportunities and build a balanced portfolio of priority investment areas.

Develop sectoral strategies or roadmaps that chart the actions necessary to drive industrial development and transition.

Collaborate across public-private and federal-provincial lines to advance the strategies.

Perhaps the biggest shift we propose is to move away from the current approach to clean growth, which is too risk averse and invests primarily in sure bets. Instead, Canada needs an industrial strategy that systematically looks to the future, embracing experimentation and risk diversification.

The rest of the report is structured as follows. Section 2 of this report summarizes Canada's current initiatives and lays out the background that motivates our approach. Section 3 presents a framework for identifying potential areas of future clean competitiveness, thinking through the challenges facing a small, open economy that is dependent on the resource sector. Section 4 presents seven priority opportunities that emerge from an initial application of our framework. Section 5 provides guidance on how roadmaps should be developed and placed within a green industrial strategy in order to cultivate these opportunities.

2. CANADA'S STRATEGIC LANDSCAPE

Canada has made a number of important investments in sustainable prosperity and industrial transition, but these investments have been spread out across opportunity areas and have not been coordinated into a clear strategy. Canada can build on previous work by adopting a green industrial strategy that leverages the country's strengths and seeks to take up a position in the global green economy.

2.1 Current Initiatives

Canada has taken some steps towards a strategic approach to secure its future economic prosperity. For example, the federal government convened Economic Strategy Tables, which focus on advanced manufacturing, agri-food, clean technology, digital industries, health/biosciences, and resources of the future.[11] These Economic Strategy Tables were subsequently complemented in 2020 with the establishment of the Industry Strategy Council, to counter the impact of COVID-19 and improve Canada's competitiveness. The Council is based on four pillars: 1) becoming a digital and data-driven economy; 2) becoming the Environmental, Social and Governance (ESG) leader in resources, clean energy, and clean technology; 3) building innovative and high-value manufacturing where Canada can lead globally; and 4) leveraging Canada's agri-food advantage to feed the planet.[12]

In a set of related initiatives, Canada has promoted a sectoral approach to economic strategy in collaboration with different stakeholders. Some of the strategic initiatives to support emissions reductions and clean growth across different sectors include:

- **Small Modular Reactor (SMR) Roadmap,** which aims to understand SMR's value, identify key issues around usage, potential risks, and challenges, and suggest policies that could influence the feasibility of SMRs in Canada[13];

- **Hydrogen Strategy,** which sets the framework to position hydrogen as a key part of Canada's path to net-zero carbon emissions by 2050 and make Canada a global leader in hydrogen technologies[14]; and
- **Net-Zero Carbon Concrete Roadmap,** which plans to provide the Canadian cement and concrete industry with the technologies, tools and policies needed to achieve net-zero carbon concrete by 2050 and position the industry as a competitive global leader in low-carbon cement and concrete.[15]

Taken together, the Economic Strategy Tables and the experiments with sectoral roadmaps provide a foundation for more action. However, these experiments need to be focused, scaled, and integrated into a broader green industrial strategy. Furthermore, these approaches can benefit from international best practices on green industrial strategy (more on that in section 5).

To be effective, these initiatives must focus on developing a portfolio of clean competitiveness opportunities for public and private investment. The identification of these prospects is part of an economic strategy process that leads also to the development of roadmaps for policies and investment programs.

The success of such a strategy will depend on the effective deployment of capital. Canada has a wealth of funds and financing initiatives that can be aligned to achieve scale and focus. At the federal level, the Strategic Innovation Fund, the Canadian Infrastructure Bank, the Business Development Bank of Canada, Sustainable Development Technology Canada, the Industrial Research Assistance Program, the Zero Emissions Transit Fund, among others, provide the funding basis of a strong innovation ecosystem.[16] However, to maximize their potential, these funds need to be focused strategically. First Nations development funds can play a key role here. Many First Nations have made strategic investments in the energy transition and other governments should work to support Indigenous economic development by orienting their initiatives in support of First Nations' sovereignty and priorities. The Provinces also have their own agencies and funds. In BC, for example, there is the Innovation Clean Energy Fund, the Advanced Research Commercialization Fund, the Center for Clean Energy Innovation, and InBC Investment Corp. These provincial initiatives also need to be focused and aligned with Federal funds. Private finance is also setting up more environmental, social, and governance funding mechanisms. Nonetheless, our research revealed that the main problem was not available capital, but rather the inability to form deals due to lack of options and a lack of policy certainty. Without clear investment roadmaps, finance will continue to sit on the sidelines.

Previous investments from existing government funds have tended to be one-off commitments and divorced from a public strategy that would allow other elements of the relevant clusters and finance to crowd in. For example, Budget 2021 announced that the government will be investing C$8 billion over five years through the Strategic Innovation Fund's Net Zero Accelerator to expedite decarbonization projects with large scale emitters and scale-up cleantech.[17] The federal government provided C$200 million from the Net Zero Accelerator (out of C$420 million) to Algoma Steel Inc., a flat-rolled steel producer in Sault Ste. Marie, Ontario.[18] The purpose of this funding is to aid transition from the coal requiring basic oxygen furnaces to electric arc furnace technology. While this investment will reduce emissions, it does not address the carbon intensity of the primary material required by electric arc furnaces, which might not result in the industry wide emissions reductions that are required to support the net-zero transition from 'hard to abate' emissions industry. The investment leaves Algoma Steel Inc. far behind other experiments in low-carbon steel. Without complementary actions up and down the steel value chain, the investment may end up creating competitiveness problems if it raises Algoma's costs without radically reducing emissions. The Algoma Steel Inc. funding is emblematic of the risks that arise in the absence of a strategic, whole cluster approach to clean growth strategy.

Without a strategic approach to clean growth, Canada runs the risk of uncoordinated capital spending that not only misses industry-wide emissions reductions targets but also reduces competitiveness in the low-carbon economic transition. As a small economy, Canada must concentrate its scarce resources so that it can develop clusters of expertise and bring industries to global scale. This is even more important in Canada given the need to promote opportunities across various regions due to its large geography and small, dispersed population.

2.2 A Strategy for Canada

Canada must build a strategy for industrial transition that reflects its strengths and position in the global economy. In the context of the global economy, Canada is a **small, open economy**. Small means that it cannot directly compete with larger countries that have more capital and capacity to scale. Open means that Canada is dependent on exports, and that lower-cost competitors can and will enter domestic markets.[19]

Canada's future competitiveness will be shaped by when and how it moves into the value chains for 21st century low-carbon technologies. Canada cannot expect to dominate or own these global supply chains so it must play a role in their emergence, but other countries are moving quickly. The Green Deal for Europe includes strategic initiatives on hydrogen, batteries, buildings, agriculture, public transportation, and the circular economy. The Bipartisan Infrastructure Law in the US devotes US$80 billion to a range of key requirements of the energy transition such as Hydrogen, CCUS, electric vehicle (EV) procurement/infrastructure, smart grid buildout, net-zero mineral supply chains, and clean energy demonstration and commercialization.[20] South Korea has announced a "green new deal" that outlays US$60 billion on domestic hydrogen market, green infrastructure, and advanced technological research.[21] Australia has advanced a Technology Investment Roadmap with strong initiatives for CCUS, hydrogen, and other low-emissions technology.[22] Canada must move quickly before global value chains in these crucial areas scale to be beyond reach.

Canada's economy is export driven, so its economic strategy should encourage sectors that will have a competitive advantage in the production of goods for the global market in a low-carbon world. A greater pool of dedicated investment finance, as well as an initial niche domestic market more open to cleantech procurement, will not only help cleantech firms grow but also help keep these industries in Canada as they scale up.

With this backdrop, our approach begins by looking at the global state of technology. Full details on this can be found in a background paper.[23] We also build on recent reports that grapple with Canada's uncertainty about which technologies will provide emissions reductions.[24] However, our approach is distinct from these earlier efforts because we foreground Canada's position as a small, open economy in a rapidly transitioning world. An economic strategy also needs to assess which technologies will be produced here in Canada, and which will be imported. To do that we need to evaluate Canada's strengths and weaknesses.

Canada has core competitive advantages in clean energy and natural resources, a strong business environment, and an educated labour force, all of which have contributed to its high degree of global competitiveness.[25] Canada has a large clean energy supply with 81% of electricity generated from non-emitting sources.[26] It also has the 3rd largest endowment of natural resources in the world behind China and Saudi Arabia.[27] The business environment is buoyed by Canada's macroeconomic stability, ease in starting a business, rule of law, obtaining credit, and the ability to resolve insolvencies.[28] Moreover, Canada's quality education system and merit-based immigration system ensures that the country is able to attract top talent.[29]

To secure its position, Canada must first transform its historic strength in heavy-emitting resource industry into green industries while building up new sectors and opportunities. While Canada's economy is primarily dominated by services, a significant footprint of GDP is still held by legacy natural resources industry, with energy, mining, and forestry comprising 16.9% of GDP in 2019.[30] Expertise in oil and gas, mining, forestry, and chemicals can all be harnessed to turn Canada into a leader in the 21st century global green economy.

To do industrial transition well, Canada cannot simply rely on traditional extraction to drive the generation of value-added activities. Innovation must be built into and around traditional industries. Industrial transition requires a different model of innovation than the one that currently captures the public imagination. As Dan Breznitz has argued, discussions of innovation are often framed in terms of replicating the Silicon Valley experience.[31] This suggests an emphasis on developing new, disruptive technologies that create entirely new markets, scaling exponentially. However, this approach has limitations and cannot be pursued by everyone, everywhere. Instead, other forms of innovation are important, such as the transformation of existing industries and what Breznitz calls second-generation innovation. Second-generation innovation focuses on continuously improving existing product and technological expertise.[32] An economic strategy based on second-generation innovation, along metrics of reliability and sustainability, would help future-proof legacy industries by building on and innovating existing industrial capacity.

However, Canada cannot create an innovative industrial transition with one-off investments. It must build clusters of excellence that bring together firms, universities, and governments into creative spaces. These clusters must bring together supply-push with demand-pull policies to accelerate change.[33]

Canadian economic strategy and policy should better encourage our domestic market to be a 'pull' on the development of nascent cleantech sectors, with policy designed to stimulate demand. At the same time, Canada must compensate for our smaller pool of investment capital by using public investment more effectively to 'push' cleantech development towards desired directions. The Canadian state must wield public capital in a way that better crowds-in and risks-shares with private capital with the objective of a sector-by-sector transition to net-zero.

Public research and development (R&D) expenditures function as a critical push factor to developing nascent enabling technologies. Canada should look to bolster the relevant research capacity in sectors that have been identified as priorities for the transition to a net-zero economy. This needs to be matched by private R&D, which is currently often weak. For instance, Canada has the highest rate of public agricultural R&D spending among the three largest agricultural exporters (including the Netherlands) but lags considerably in business expenditures on R&D.[34,35] The effectiveness of economic policy – in agriculture and industry – depends in part on better synergies between the private and public sectors to achieve a common agenda.

Proactive government leadership is needed. Propelling industry into the future will require a coordinated effort by business and government to ensure the necessary investments, not just in R&D. Government leadership should aim to establish a shared understanding of sectoral priorities, including in terms of goods and services, that will contribute to a net-zero global economy. Partnerships are necessary to provide and enable access to resources necessary for the development of those goods and services. This is increasingly being recognized by business leaders and others in Canada.[36]

History has demonstrated the importance of all these points. Governments, in Canada and elsewhere, have been crucial in the invention, improvement, and diffusion of many of the key general use technologies required by our current economy.[37] This is particularly true for transformative technologies that catalyze broad structural change. Technologies such as electrification, computers, the internet, and renewable energy have all involved a significant public sector role in their creation and uptake. Now, this role needs to be more strategic than ever before.

3. IDENTIFYING STRATEGIC OPPORTUNITIES

How do we identify Canada's top economic opportunities in the global economy of the 21st century? To answer this question, we outline an investment strategy and our assessment framework. As mentioned in the introduction, we do not presume to be providing the final word on these questions, but rather seek to start a conversation about what a global strategy for Canada looks like, how to conceptualize industrial and transition, and how to assess economic opportunities.[38]

Canada needs to identify areas where it has long-term competitive advantages or where industry will be relatively protected from intense global competition.

3.1 A Global Strategy: Opportunities for a Small Open Economy

Canada must act now to secure its place in emerging global value chains. However, early entrants can end up taking the first loss or gaining early positions only to be overtaken by bigger latecomers. Canada needs to identify areas where it has long-term competitive advantages or where industry will be relatively protected from intense global competition.

The open economy strategy presented in Table 1 offers one possible starting point for thinking about what these areas might be.[39] It explores two features of economic opportunity areas. The first feature is the level of maturity of the technology in the area, which at its simplest can be divided into two groups: emerging technologies and mature technologies. Emerging technologies

Table 1: An Open Economy Strategy

Maturity of technology	Mass global production	Contextual applications
Emerging	Do you have the expertise or cost advantages to gain a secure long-term position?	Can you develop lasting upstream capacities or intellectual property (IP) in the technologies needed?
Mature	Can you do better than reap the benefits of deploying foreign technology?	Are there competitive existing firms to invest in or can you break into global value chains?

are those in the demonstration and early commercialization phases. Mature technologies have complex global value chains in place and are entering the diffusion stage.[40]

The second feature concerns the type of production. First, there are technologies and products that can be mass-produced for global markets. This means the products can be standardized and will see the kind of aggressive cost declines as they scale that solar and wind did. Technologies that are amenable to mass global production may seem like good investments[41]; however, the potential for major cost reductions is a good proxy for how intense global competition is likely to be.[42] Second, there are products with contextual applications, where lower economies of scale are expected due to the nature of the technology or due to the need to customize and tailor specific national markets. (These are just two simple distinctions that could be made, and either aspect could be subdivided further.)

Table 1 presents these economic features as a matrix, and places a high burden on mature, mass production technologies. Each quadrant contains a key question which is meant to serve as a starting place for conceptualizing an open economy strategy, rather than a reductive formula.

From the categorization in Table 1, we can infer: it is much more difficult, as a small open economy, to maintain competitive advantage in technologies and products that are candidates for mass global production. An early lead in emerging technologies of this sort may be sustained, provided there are ways to limit competitors and protect the innovative advantage. This might, for example, be based on a high degree of tacit knowledge associated with protectable intellectual property.

Overall, investments in contextual applications might be better areas to concentrate for open economies. However, there are important lessons here, too. First, in emerging areas where uncertainty is high, it makes sense to concentrate on upstream capacities such as knowledge and R&D capacity. Those upstream capacities will allow the economy to continually draw on expertise to adapt to changes in technologies and markets downstream. Mature contextual areas, such as CCUS, are good places to invest if you have established firms. Otherwise, it may be difficult to break into global value chains that are already formed.

3.2 Building Innovation Clusters

An open economy strategy helps to focus investments. However, it does not identify where to focus those investments or present a theory of industrial transition. Instead of supporting specific firms with one-off grants, Canada should build innovation clusters. Building innovation clusters is essential to building competitive industries in the global economy. Innovation clusters bring together universities, firms, investors, and governments to learn together over time. They are the foundation of the transformative and second-generation innovation strategies we are arguing for. Taking this approach to building green industry would build on Canada's supercluster approach by institutionalizing it and increasing its scale.

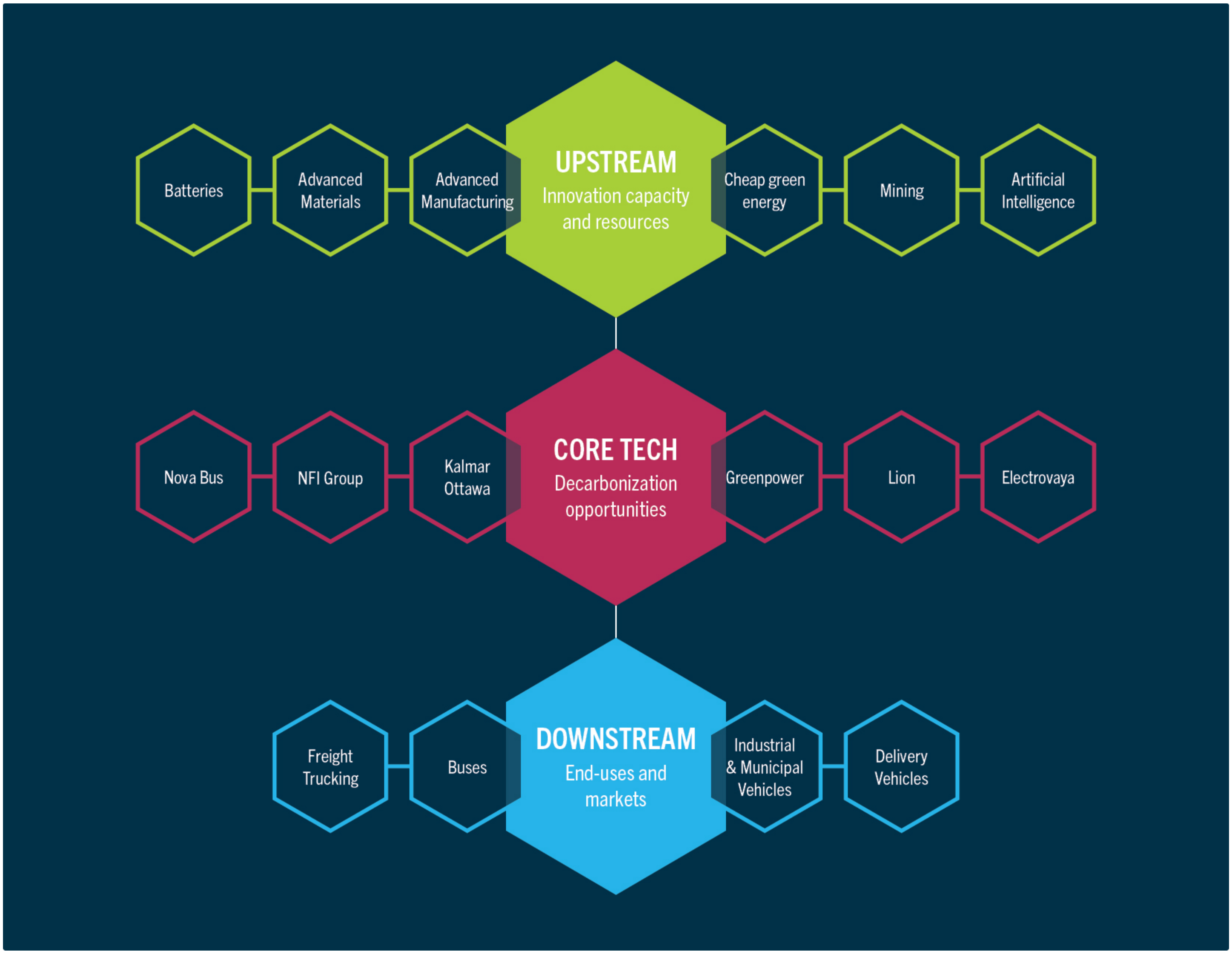
In our approach, innovation clusters are centered on a core technology or service, where core technologies directly contribute to decarbonization. A cluster approach situates a core technology in the entire value chain, or vertical: from upstream research, resource inputs, and supporting technologies to downstream end-uses and markets.

The structure and boundaries of a cluster are necessarily open, as the emergence of new technologies and services will change the functional arrangement necessary to deliver a competitive core technology.

Recent decarbonization strategies highlight the importance of taking a sectoral approach.[43] A sectoral approach divides the challenge of decarbonization into emissions sectors. While our analysis started with a sectoral approach, when engaged with the practical problems of political economy, a more systemic, value chain approach becomes necessary.

Creating new industries and transitioning old ones is challenging. A full theory of industrial transition is beyond the scope of this report, but it is important to consider the following: All the elements of a value chain need to be brought together under the right social, political, and economic conditions. Usually, value chain coordination is left to the market, but as we outline below, the government has a key role to play in ensuring these supply chains come online within the timeframe needed to serve the public good.

Figure 1. The cluster for medium and heavy duty vehicles



To build industry around a core technology, it is necessary to combine push factors and pull factors.[44] Supply-push factors ensure that necessary inputs and technologies are available and affordable. Supply-push policies center on investment in research, development, and demonstration (RD&D) but could also include subsidies and incentives to bring resource inputs to market. Demand-pull factors include procurement, tax incentives, and pricing mechanisms that bring the end-use market online.[45]

We focus our clusters on core technologies because they can be the center of market development strategies that bring an entire value chain online. This would then allow decisions to be made about how to arrange all the complex parts of a net-zero economy into a cohesive, strategic framework.

For example, many stakeholders and commentators tout the economic value of developing minerals for the net-zero supply chain.[46] However, those minerals alone do not provide a decarbonization technology. Without an end-use or target market, these questions cannot be answered definitively. Instead of making minerals a cluster, minerals become an upstream piece of a cluster focused on medium- and heavy-duty electric vehicles.

This is the advantage of the cluster approach – by centering on a core technology with a large end-use market, we bring focus to the whole value chain. In this manner, upstream opportunities can be supported by the demand-pull necessary to bring the value chain online.

3.3 Assessment Framework

The open economy strategy and cluster approach suggest the importance of building industries around globally competitive core technologies. However, this leaves a central question unanswered: **How do we identify the domestic expertise and market positions that could provide global competitiveness for Canada?**

To do this, we designed an assessment framework for the possible technologies spanning multiple sectors, or clusters. This first involved assessing the technology and the role it is likely to play in a net-zero future, including the maturity of the technology and the associated abatement potential.

Then we analyzed three features of the cluster, looking upstream to resources and inputs and downstream to markets. The first feature is **national advantage**, which assesses whether Canada is likely to develop and maintain long-term cost advantages. These may be due to the availability of relevant natural resources (natural capital), upstream inputs, or specialized labour skills (human capital), particularly in a regional and global context.

The second feature is **competitive advantage through innovation**. This criterion assesses whether Canada could build an advantage in the production of a technology and product, due to the nature of innovation in the relevant associated sector or industry. For instance, in sectors such as specialized machinery suppliers, leading companies protect their technological lead through a combination of specialized skills and intellectual property rights (including patents, trademarks, and trade secrets). Such an industry may be better placed to maintain its lead over foreign competitors than one where innovations are primarily embodied in purchased inputs from innovative suppliers. Agricultural crop production is one example: innovations come in the form of seed, chemicals, and equipment, and therefore those upstream stages play a key role in generating a secure stream of profits.

The third feature is **market potential**. This involves estimating the export potential of a particular technology, either within the North American market or overseas markets. It is also relevant to gauge the size of the domestic market, as the ability to serve this, and reduce or avoid imports, may also provide considerable potential. We sought to identify core technologies and services that would have large market potential to provide a pull on upstream elements.

This assessment framework is complemented and informed by an **expert consensus survey**. The goal of this survey was to collect quantitative and qualitative information from experts in decarbonization. We spoke with individuals from Canadian business, finance, government, First Nations, and civil society. The goal of these surveys was to distill the knowledge held by experts on Canada's options within the energy transition.

The quantitative exercise was a "chips study" or resource allocation game. Participants were asked to allocate 1000 chips to technological opportunity areas across sectors such as renewable power for export (electric power sector) or medium- and heavy-duty vehicles (transportation sector). This generated quantitative data which we incorporated into our analysis. The experts were also interviewed about their choices, and we recorded this qualitative data and followed up on their suggestions.

A key aspect of the analysis is the identification of important **uncertainties** affecting the likely prospects of the various technologies. None of criteria in the framework can be assessed with complete certainty. It is therefore helpful to make key areas of uncertainty clear, particularly as it will be important to address these in future roadmap exercises.[47] This could involve, for example, the development of approaches to stress-testing identified technological prospects.

We focus our clusters on core technologies because they can be the center of market development strategies that bring an entire value chain online.

4. PROSPECTS FOR CANADA

In this report, we highlight seven top cluster opportunities and three enabling conditions. Taken together, these seven clusters provide a strong portfolio of opportunities that balance opportunities for 2030 and 2050, include some low-risk and some high-risk, high-reward opportunities, and provide opportunities for all regions of Canada. The opportunities highlighted in this report also center on potential large markets and so can provide the demand-pull necessary to help industries upstream of them to achieve competitiveness. They draw on Canada's strengths in resources, while presenting the possibility of adding value to those legacy industries. They also take advantage of Canada's entrepreneurial advantage and seek to build on its strengths in cleantech.

The seven top priority cluster opportunities are:

- Manufacturing medium- and heavy-duty zero-emission vehicles
- Alternative proteins for the agricultural sector
- Aluminum refining
- Mass structural timber for buildings
- Green chemistry for biofuels, plastics, net-zero fertilizer
- Green and/or blue hydrogen production
- Carbon capture, utilization, and storage and direct air capture

Taken together, these top priorities cover all of Canada's largest economic sectors: primary energy, automotive, agriculture, heavy industry, chemicals, and forestry. They combine to form the basis of an industrial transition strategy that seeds change across the economy.

High Priority Opportunities for Clean Growth

- Manufacturing medium and heavy-duty zero-emission vehicles
- Green chemistry for biofuels, plastics, net-zero fertilizer
- Carbon capture, utilization, and storage, and direct air capture
- Alternative proteins for the agricultural sector
- Green and blue hydrogen production
- Mass structural timber for buildings
- Aluminum refining

Table 2 presents two kinds of findings. First, we conducted an expert survey that asked respondents to allocate 1000 chips across opportunity areas. The table reports the median score across all respondents. Second, we assessed each opportunity according to three criteria: national advantage, innovation capacity, and market potential (see Table 2 for details). After exploring the seven top clusters and three enabling conditions, Table 2 offers eight additional opportunities that are not expanded upon in this report but may be interesting areas for future consideration.

Top Opportunities in the Energy Transition

Medium- and Heavy-Duty Zero-Emissions Vehicles

Canada has world-leading firms in electric and fuel-cell school buses, municipal vehicles, forklifts, and other important niches, as well as upstream capacity in mining and battery metals. There is an urgent need to bring this industry to scale and build innovation clusters around it. Canada must convert its existing light duty automotive sector and its 500,000 jobs to electric vehicles manufacturing.[48] This is a clear government priority, but Canada does not have the domestic manufacturing and design firms necessary to expand its global market share in this area. Building up the nascent medium- and heavy-duty automotive sectors presents a unique opportunity to create an innovative, made-in-Canada industry that is globally competitive.

National Advantage

Globally, approximately 80% of electric vehicles sold are produced in their local regions.[49] Accordingly, Canada's proximity to the United States is a significant national advantage for medium and heavy-duty vehicle manufacturers in Canada. In addition, the weight of battery packs for electric vehicles (EVs) favours their production as close as possible to their end-markets due to the increasing prominence of border carbon adjustments or market pressures for sustainability. Transportation of heavy objects via long-distance maritime shipping will increasingly come with a significant carbon penalty, which will be a determining factor in deciding where things are manufactured.

Carbon cost of shipping aside, another factor influencing the low carbon cost of vehicle manufacturing in Canada is its low emissions electricity grid. If manufacturers locate their operations in Canada, industrial firm power can be sourced from Canada's low emissions electricity grid, thereby reducing the emissions intensity of battery packs and fuel cells compared to other jurisdictions. EVs have a larger manufacturing emissions footprint than fossil fuel alternatives because of their battery packs.[50]

Canada also extracts and processes key minerals required for battery and hydrogen fuel cell manufacturing, and an opportunity to develop greater capacity. Therefore, the combination of a secure supply of key inputs, a a low emissions footprint, and proximity to the US make Canada a promising location to produce medium- to heavy-duty Zero-Emissions Vehicles (ZEVs) for the North American market.

Table 2: Canada's Top Opportunities in a Net-Zero World

Top Opportunites	Value Proposition	Expert Score (Chips Study)	National Advantage (Resources)	Innovation Capacity (Research Clusters & Existing Firms)	Market Potential	Overall Rating (Priority, Probable, Possible)
Medium- and Heavy-Duty Zero-Emission Vehicles	Manufacturing vehicles in niche markets such as school buses, garbage trucks, and forklifts. Creates market pull for mining, battery metals, and hydrogen.	69	3 – Clean grid reduces manufacturing emissions footprint.	3 – Leading firms in Medium-duty and leading researchers in battery metals.	North Am: Large. Global: Unknown.	**Priority**
Alternative Proteins	Process, package, and market plant-based proteins. Develop IP in emerging tech for cell culture and fermentation. Creates market pull and focus for agriculture.	21.6	3 – Builds on strengths in primary agricultural production.	2 – Large ag-science R&D research infrastructure; domestic processing industry to build on.	North Am/Global: Large, fast growing global market.	**Priority**
Aluminum	Aluminum refining to utilize intermittent renewables is advanced sufficiently (likely 20 years) to enable refining near the source of bauxite extraction.	Green Steel, Aluminum, & Cement – 58.4	3 – Significant aluminum refining footprint.	2 – Existing efforts by firms to develop new IP.	North Am: Large.	**Priority**
Mass Timber	Structural wood for building, including development of underlying technology.	15.4	3 – Extensive forest resources.	3 – World-class wood science research capacity, several commercial firms.	North Am: Large. Global: Limited.	**Priority**
Green Chemistry	Build upstream innovation capacity in biofuels, plastics, net-zero fertilizer, and battery processing.	Biofuels – 42.5; Plastics & Chemicals 31.2	3 – Sizable biomass production.	3 – Comparative advantage in green chemistry IP & commercialization.	North Am/Global: Large.	**Priority**
Carbon Capture, Utilization, and Storage	Integrated services for CCUS project planning and development. Develop innovative negative emissions technologies, such as Direct Air Capture (DAC).	30.5	3 – Single point sources for carbon capture; downstream advantages in storage and blue hydrogen production.	2 – Existing R&D clusters; fossil fuel industry support.	North Am: Small, US has expertise. Global: Large.	**Priority**
Hydrogen	Green and/or blue hydrogen producing capacity. Development of downstream technologies such as hydrogen fuel cells.	80.6	3 – Sizeable hydro-electric capacity, gas resources, and CO_2 storage.	3 – Leading fuel cell research cluster. 1 – Electrolyzers.	North Am: Large. Global: Small in the long-run (favours local production).	**Priority**
Enabling Conditions						
Net-Zero Minerals	Mining and processing of critical minerals for net-zero supply chains.	50.7	3 – Key deposits.	3 – Existing firms.	North Am/Global: Large.	**Probable**
Strong Carbon Accounting	Necessary for the operation of effective carbon markets.	33.1	1 – Expertise must be redeployed.	1 – Expertise must be redeployed.	North Am/Global: Small.	**Possible**
Clean Grid	Expand existing clean grid.	32.5	3 – Clean power.	3 - Mature grid intertie.	North Am: Small.	**Probable**
Important Opportunities						
Net-zero mining operations	Environmental mining equipment to a growing minerals sector.	42.1	3 – Mining sector can provide demand-pull.	3 – Existing cleantech mining firms.	North Am/Global: Large.	**Probable**
Battery Metals	Develop upstream capacity in the production of battery metals.	36	2 – Mining resources could be developed.	3 – IP advantage in upstream components.	North Am/Global: Large.	**Probable**
Energy Management Tech for Buildings	Manufacture smart thermostats and other tech for buildings.	35.1	1 – No significant national advantages.	3 - Existing cluster of companies.	North Am/Global: Small.	**Possible**
Marine Shipping	Manufacture net-zero vessels and components.	25	2 – Leading fuel cell capacity upstream.	2 – Existing Ocean supercluster.	North Am: Large. Global: Small.	**Possible**
Aviation	Manufacture short-haul aircraft and develop sustainable aviation fuel.	23.7	2 – Existing industrial capacity.	2 – Research capacity and existing firms.	North Am/Global: Small.	**Possible**
Vertical Agriculture	Niche market for vertical agricultural systems.	21.9	1 – Large ag science focused on outdoor.	2 – Several domestic firms in space.	North Am/Global: Small.	**Possible**
Low Emissions Fertilizers	Low or zero emissions fertilizers from sustainable inputs.	22	2 – Feedstocks and industrial capacity.	1 – No advanced projects.	North Am/Global: Large.	**Probable**

For National Advantage (resources) a 3 means Canada has high existing capacity, 2 that Canada has potential and an existing model or demonstration, and 1 that there is untapped potential only.

For Innovation Capacity, a score of 3 means that Canada has a mature cluster of 5 or more firms in the sector, 2 that Canada has strong research capacity in universities and other institutions plus some promising startups, and 1 that there is research capacity only.

Finally, we considered whether the market potential for the product was small or large, both regionally and globally. Top priority opportunities scored well on all three dimensions.

Competitive Advantage in Innovation

In 2019, Canada accounted for approximately 2.3% of the global heavy truck production and 7% of light commercial vehicle production.[51] While this number includes all vehicle production and not just ZEV production, Canada has the conditions for a strong domestic market in medium- and heavy-duty ZEVs and a robust number of firms that could form the nucleus for a larger producing sector. Quebec-based **Lion,** for example, designs, builds, and assembles all components including chassis, battery packs, and the bodies for its electric school buses, midi/minibus for special needs, urban transit, and urban trucks.[52] What differentiates Lion from its competitors is its ZEV-centered diverse product offering particularly in the e-school bus and e-garbage truck segment.[53] Winnipeg-based **NFI Group** (erstwhile New Flyer), which manufactures EV transit buses and motor coaches and has production facilities in Winnipeg as well as five locations in the United States, is another key Canadian player.

As mentioned earlier, Canada also manufactures key components that are an integral part of the supply chains for a lithium-ion battery operated ZEV, and hydrogen-based road freight sector. Ontario-based **Electrovaya** is a pure-play lithium-ion battery manufacturer with 100+ patents in lithium-ion battery manufacturing and manufactures batteries for e-buses, e-forklifts, and e-delivery trucks.[54] Additionally, as of 2018 Canada had the largest number of hydrogen and hydrogen fuel cell research facilities globally and had deployed the most number of demonstration projects for Hydrogen and Hydrogen fuel cells anywhere.[55] Canadian companies such as BC-based **Loop Energy** and **Ballard Power Systems**, specialize in the manufacture of hydrogen fuel cells for medium and heavy-duty vehicles.[56,57] Overall, Canada's advantage in the R&D of vehicular hydrogen fuel cell technology gives it an innovation advantage in the production of decarbonized medium and heavy-duty vehicles.

Market Potential

Canada holds a small share (0.1%) of global electric heavy-duty vehicle production yet ranks sixth in the world in the sector.[58] The US is the final destination for more than 95% of Canada's medium and heavy-duty vehicle exports.[59] These markets are still nascent and will grow quickly over the coming years.[60] While Canada has an opening to establish itself within supply chains for the production of full vehicles or parts (such as hydrogen fuel cells), the sector is nearing the diffusion phase, leaving a very narrow window for Canada to act in order to place itself within the sector before supply chains are fully established. China, the US, Germany, and France are some of the other important players in this space.

Uncertainties

- Canada's ability to capitalize on its mineral-rich status to focus on the minerals necessary to manufacture lithium-ion batteries is unknown. Currently, most of the minerals mined for battery manufacturing are exported to China, where the minerals are processed so that they are ready for use by battery manufacturers.
- Canada has a narrowing window of opportunity to respond to the needs of the industry with a comprehensive and long-term industrial strategy. Other countries, prominent among which are China and Germany, are moving fast and developing the needed capacity to supply the world.

Alternative Proteins

Canada has an opportunity to make alternative proteins the focal point of an agricultural processing and manufacturing industry. As Canada is already a world leader in the production of lentils and peas, it should seek to move down the value chain. Bringing an industry like alternative proteins up to scale would provide a pull for agricultural decarbonization techniques while displacing future growth in meat consumption and its respective carbon footprint.

National Advantage

Canada's advantage in the alternative proteins space stems from its agricultural expertise in cultivating the inputs for a growing alternative proteins industry.[61] Canada is the largest producer and exporter of lentils, and dried peas,[62] and is a significant producer of dry beans, chickpeas, and grains, all of which are components of plant based alt-proteins.[63] Canada also produces significant starches and sugars which could be the inputs for emerging markets in fermentation based and cell culture based alternative protein industries respectively.

However, as in other industries, Canada has not turned this strength in primary production into a world-leading secondary industry. Canada has the 8th highest number of pure play companies involved in alternative protein production (19 according to the Good Food Institute).[64] It trails the US and the UK, which together have a clear lead in this space and are home to the headquarters of 42% of pure play plant-based proteins firms.[65] Yet, there is an opportunity here because Canada has major firms and innovation clusters that are positioned to support a global push.

Competitive Advantage in Innovation

There is momentum towards re-configuring Canada's agricultural economy to capture more of the added-value components of the emerging alternative protein market. Canadian firm **Maple Leaf Foods** has invested US$310 million into a new plant-based meat processing facility. Canada's leading global role in pea cultivation has also attracted investment from firms such **Roquette** and **Merrit** to open fractionation plants whereby pea-protein is extracted for use in alt-proteins.[66] **Roquette** already has invested C$400 million domestically in pea-processing and will soon open the world's largest fractionation plant near Portage la Prairie.[67]

The global industry for cell-cultured and microbial meats is less established than plant-based alternatives.[68] Canada has players in the underlying technologies behind these more nascent technological sectors, with **Cell Ag Tech** and **Future Fields** specializing in technologies related to cell culture, and Halifax-based **Smallfoods** focused on developing fermentation based protein processes.[69] Domestic centres of potential research capacity within the fermentation and cell based alternative proteins spaces include Guelph, Waterloo, and Concordia's Genome Foundry. That said, Canada is currently behind jurisdictions like Israel, Singapore, the Netherlands, and Silicon Valley in developing suitable firms, research capacity, and government-industry-academia linkages.[70] Building sufficient academic capacity in the alt-proteins spaces is especially important as the industry follows talent, and the development of a strong research base is one of the ways Canada could stop the hemorrhaging of promising startups to the US.[71]

Canada is also putting forward resources to move into the plant-based alt-protein market, with Canada's **Protein Industries Supercluster** making C$153 million available to firms that can increase the values of "key Canadian crops" such as wheat, pulses, and canola.[72] Funding streams available through the **Protein Industries Supercluster** could be used to scale up Canadian plant-based protein firms located elsewhere, as well as to develop domestic firms. However, the supercluster is currently closed to firms in the fermentation and cell culture-based markets, a critical gap in industrial policy that should be corrected either with their inclusion or the development of a new supercluster.

Market Potential

Global meat production is expected to rise by between one-half and one-third by 2050 from 2018 levels (341.6 million tonnes). Current meat and dairy consumption requires the use of 77% of all agricultural land currently cultivated though only providing 37% of land-based protein.[73] **Meeting the rising global demand for protein from animal husbandry alone is impossible given the lack of available lands for the spatial expansion of agriculture.** Furthermore, limits on future growth in agricultural GHG emissions could be achieved by increasing consumption of proteins based on lower trophic levels, made up to a greater extent from plants, microbes, and cells cultivated in the medium. This creates an opening for Canada to supply demand with alternative proteins (i.e., grains, legumes, and alternative dairy products). Market trends already indicate an increased shift to alternative proteins with a market valued at about US$11.5 billion globally expected to grow at a rate of CAGR 11.2% to a market cap of US$27.05 billion by 2027.[74] In just the US, the grocery market for alternative proteins was US$5 billion as of 2020.[75]

Especially relevant to Canada is the emerging potential from fermentation based dairy technologies to outcompete traditional dairy operations due to growing demand, increasing climatic impacts, and efficiency improvements in the underlying technology. Existing demand for milk products from Asia has already stretched the limits of current dairy production capacity.[76] Shrinking demand for dairy milk, counterbalanced by rising demand for products in which milk is a processed component (like cheese, yoghurt, or whey protein) creates a greater opening for value-added uses of "alternative milk" proteins.[77] Meanwhile, climate change will continue to impact the dairy industry both by influencing milk production in dairy cattle[78] and the availability of feed.[79] As the underlying technologies improve, experts believe that "it becomes far less efficient to keep an entire animal alive to produce milk, when a genetically modified bacteria or yeast can produce the same proteins much more efficiently."[80]

Opportunities for synergies exist between traditional aspects of Canada's agricultural economy, and the alternative protein sector, if more of the production and processing of alternative protein value chains can be located domestically. Pea starch, currently a waste product from the fractionation of peas for protein which lacks a suitable end market,[81] makes a suitable carbohydrate input for fermentation-based protein technologies.[82] Other carbohydrates such as agricultural waste could also be utilized as feedstock for fermentation based protein, and Canada's sugar beet cultivation which currently is heavily subsidized could find a viable end market in providing sugars for cell culture operations.[83] All this requires that Canada's agri-food sector invest more in machinery. However, between 1998 and 2016 investment in new machinery and equipment by Canadian food manufacturing businesses fell from 2.3% to 1.2% of sales.[84]

One way the market for alternative proteins could expand would be for emissions pricing to incorporate the environmental impact of meat and pulses into protein prices. Other or complementary policies would likely be needed to ensure food security is not compromised for various consumer groups.

Table 3: Global emissions from protein production

Protein	Mean CO_2e/kg of Protein from Global Production[85]
Beef	500
Pork	76
Poultry	56
Grains	27
Legumes	4

Development of Canada's alternative protein sector could be configured to provide co-benefits of agriculture-based carbon sequestration. Existing research has demonstrated that current soil carbon sequestration practices could potentially offset the emissions involved in the cultivation of some agricultural commodities used in alternative proteins, specifically wheat.[86] Current generation soil sequestration techniques, if implemented, likely have the potential to offset much of the sector's own emissions; however, their sequestration potential beyond the offset of cultivation-based emissions is minimal.[87]

Uncertainties

- Potential to combine different kinds of alternative protein production methods (i.e., products derived from plant and fermentation processes, or cell cultured products with some plant-based ingredients).
- Potential for rapid shifts in public perceptions on the ethics of the current animal operations, especially surrounding factory farms. Potential comparisons include the rapid shift in consumer views around cigarettes. This is counterbalanced by unknown openness of consumer markets to cell cultured meat.
- The domestic agri-food sector's ability to overcome underinvestment in new new-machinery and equipment.

Aluminum

Green steel, cement, and aluminum are crucial considerations in making the energy transition – they are heavy emitters tied to good jobs in strategic industries. Our expert survey ranked them as the third top priority. Our analysis concluded that green steel and cement are essential to Canada's decarbonization goals but there is a limited opportunity for Canada to generate exports or a world-leading industry in those areas. Instead, Canada has the potential to lead in the low-carbon aluminum supply chain.

National Advantage

Aluminum production from primary materials is divided into two main steps: the refinement of bauxite ore into alumina, and the smelting of aluminum from alumina. **Canada's potential advantage is in the smelting of alumina into aluminum, an energy intensive process that can be decarbonized over the short-run using abundant domestic hydro-electric power.** Canada also has potential to capture intellectual property from the development of underlying aluminum processing technologies.

Emissions reductions in the production of aluminum have over the past two decades primarily come from the deployment of efficiency measures and technologies in production facilities. China produces over half of the world's primary aluminum, and it has achieved the greatest average energy efficiency of production compared to other jurisdictions due to an aggressive national strategy of deploying best available technologies relative to other producers.[88] There are, however, limits to what efficiency measures can achieve without sourcing the primary energy used from non-emitting sources. China may smelt over half of the globe's primary aluminum, but it does so primarily through coal fired electricity. Looking globally, 71.5% of the energy demand of the aluminum industry is met through a combination of natural gas and coal.[89] **Canada's clean grid presents an opportunity to capture global market share**.

Canada's competitive advantage in aluminum smelting will likely last at most around 20 years.[90] Currently aluminum smelting requires clean firm power, and with existing technologies it makes economic sense to transport refined alumina from locations with significant bauxite deposits, such as Australia, Guinea, or China, to locations such as Canada with abundant hydro-electric capacity. Over time, advances in grid scale storage, and better temperature management of aluminum smelters will make intermittent renewables compatible with industrial aluminum smelting at which point smelting close to the point of extraction will be economically preferred.[91]

Competitive Advantage in Innovation

Canada's competitive advantage comes from its existing industrial capacity in aluminum smelting with 10 aluminum smelters (all located in Quebec).[92] **Alcoa** and **Rio-Tinto** have a joint venture located in Montreal called **Elysis** to manufacture inert anodes that don't produce emissions as part of aluminum smelting.[93] It is likely that Rio-Tinto may seek to transfer this technology to other sites, but it seems unlikely that this would be done in markets that undermine any advantage of their Canadian production capacity.

Market Potential

Aluminum production is projected to grow to 170% of 2010 production by 2030.[94] In 2019, Canada produced 4.5% of primary aluminum for the global market.[95] Aluminum production has also increasingly been suggested as partial replacement for single use plastics demand, due to its theoretical infinite recyclability.[96] However, tradeoffs exist when substituting primary aluminum for other materials in some product end uses, such as a greater emissions footprint of primary aluminum cans compared to PET plastic bottles.[97] Improvements in the circularity of aluminum materials flows can address some of these tradeoffs but may reduce the market demand for additional smelting capacity.

Production of aluminum from mined materials is 10 times more energy intensive than from recycled scrap.[98] Under the IEA's sustainable development scenario, 40% of aluminum would need to be collected from scrap by 2030.[99] While Canada is well positioned to produce more primary aluminum, the country may face challenges scaling up a scrap recycling industry. Growing East and Southeast Asian markets have larger materials flows to mine for aluminum feedstock. Efforts to develop greater aluminum recycling capacity in Canada could link with Canada's ambitions to become a greater recycling hub for lithium-ion batteries, possibly within a circular economy policy framework.

Uncertainties

- Canada's potential to increase aluminum exports is dependent on end-market adoption of carbon pricing policies, such as border carbon adjustments.
- Canada's relative advantage in meeting global demands for low-carbon aluminum will be curtailed at the point where technologies which allow intermittent renewables to be utilized in industrial processes are commercially viable for aluminum refineries.

Mass Timber

Mass timber can add value to the forestry industry in Canada while displacing carbon intensive materials like cement and steel. Opportunities in manufactured wood are an immediate priority, but there is also an opportunity to develop a prefabrication industry for modular building design.

National Advantage

Canada has the third most extensive forested area on Earth, meaning a significant supply of timber stock is available to meet growing demand for mass timber. In 2018, Canada was the greatest exporter of sawn wood, capturing 19.3% of global exports.[100] The size of Canada's forestry and wood processing sectors creates an industrial base that could be retooled to meet a growing demand for mass timber.

Demands on forests are multifold, however, and growth in the timber industry must be managed against benefits that come from the maintenance of forest ecosystems in a cohesive state such as carbon sequestration, and biodiversity. One study looking at representative forest types across Canada found that if land areas can be maintained in an undisturbed state for a 200-year period, they will sequester more carbon than if they are logged periodically over the same time span.[101]

Leaving old growth with a mean age of 280 years undisturbed could sequester 4.1 MT of CO_2e a year.[102] Correspondingly, only in forest stands in which non-disturbance over a 200-year period cannot be maintained, does managing forests for timber yields make sense from an emissions reduction standpoint. Unfortunately, Canada is likely to see a decline in suitable forested areas that will be able to remain in an undisturbed state for 200 years due to the increasing domestic prevalence of insect infections and fires under climate change. Average annual acreage of forest disturbed by forest fire between 2009-2019 increased by 40% compared to between 1991 and 2000.[103] Similarly, annual acreage disturbed by insects increased by 800% between 2009-2019 when compared to the previous decade.[104] Naturally disturbed stands have the potential to provide a supply of biomass for the structural timber industry without increasing net-emissions from changes in land usage. Insect degraded stands present significant potential, as dead wood stands caused by mountain pine beetle have already been utilized to create a mass timber product known as cross laminated timber.[105]

Canada will have to develop a forest industry that can make better use of wood waste and secondary growth to take advantage of this opportunity.

Competitive Advantage in Innovation

There are 15 firms in North America producing mass timber, among them several Canadian firms such as **Structurlam**, **Nordic Structure**, and **Structure Craft**.[106] In support of this is a dedicated Canadian research infrastructure on the underlying technologies behind added value timber products. Canada has a ready-made network that can be tapped to further advance Canadian innovation capacity in this sector. Research networks and partnerships have already brought together universities, forest product innovations, the National Research Council of Canada, and the Canadian Wood Council to drive innovation in the area.[107]

Market Potential

Interest in mass timber has grown due to lower cradle-to-grave emissions than alternative building materials, and the potential for mass timber buildings to store carbon over long product lifecycles. Compared to other materials, such as concrete or steel, mass timber has a lower carbon footprint from production. Additionally, claims have been made regarding the potential of structural wood to further reduce materials emissions through embodied carbon storage in the product itself. However, embodied carbon storage claims should be tempered by robust lifecycle analysis. In going from the forest to components of its wood being embedded in a product, a tree can lose up to 70% of its carbon.[108]

Interest in mass timber is also attributable to reforms in buildings codes. As of 2021, the International Building Code has been updated to allow construction of mass timber buildings up to 18 stories tall where its standards are accepted.[109] It is projected that by 2034, over 24,000 mass timber buildings could be constructed in North America.[110] This would require 12.9 billion board feet, 28% of current North American supply in 2020,[111] and the conversion of 77 million acres of forest into timber usage.[112]

Table 4: Emissions from selected building materials

Wood Alternative	Current Material
Canadian Produced Mass Timber (production emissions) 211-300kg of CO_2e per tonne of material[113]	**One tonne of steel produces on average:** >1.1t CO_2e from domestic Canadian production[114] >2.4t CO_2e global average[115] **One tonne of cement produces:** >.8-.9 t of CO_2e[116]

Uncertainties

- Potential for the utilization of fire degraded wood is less certain than that disturbed by insects, and depends on the nature of fire disturbance, time since disturbance, and ecological benefits from leaving dead wood in place (e.g., nutrients, soil materials).[117]
- Ability to access degraded wood stands in remote locations and the ecological impact of current means present industry challenges.[118]

Green Chemistry

Canada has an opportunity to develop a world leading upstream industry in green chemistry. This cluster could support downstream markets in biofuels (especially aviation fuel), plastics, sustainable chemicals, fertilizers, and battery metals.

National Advantage

Given the uncertainties in biofuels, plastics, and sustainable chemicals, it makes sense to invest upstream in innovation capacity that can generate technologies through the net-zero transition.

Biofuels did well in the chips study with a mean of 42.5, ranking it sixth in the survey. However, respondents could not agree on what form of biofuels would be best. Support for biofuels from wood (19.51) and biofuels from agriculture (17.03) was roughly equal. And biofuels from waste was a very strong write-in candidate (5.95). Rather than focus on one of these pathways, it makes sense to focus on innovation, knowledge, and experience that might apply to all three depending on how technologies and markets form.[119]

As we pointed out in section 3, there is a danger that upstream investments alone would be unable to bring an industry online. Downstream markets are necessary to help upstream capacities develop and achieve the necessary scale. So, the green chemistry cluster would need to be connected to downstream market opportunities in an ongoing way.

Our expert survey noted the potential to produce biofuels and biomaterials from forest and agriculture waste. Assuming a woody biomass to sustainable aviation fuel conversion rate of 1 tonne to 50 gallons,[120] annual forest residues from Canadian timber operations in managed stands alone could meet the 2019 fuel needs of Canadian air carriers.[121] Canada's biomass capacity is thus sufficient to decarbonize fuel for its own aviation sector, while leaving a surplus for export.

However, biofuels might create greater emissions than fossil fuel equivalents from both direct and indirect emissions.[122] For example, cultivation of canola for biodiesel requires significant fertilizer application, and can also be responsible for substantial indirect emissions from the displacement of food crops.[123] More research is required to determine if Canada's current canola to bio-energy supply chain has a suitably low carbon footprint. Corn-stover (corn husk) is another agricultural waste product that has the potential to be used for producing low-emissions intensity biofuel. Woody forest biomass can also serve as raw material, but only if collected from forest residues, salvage logs, or sawmills residues.[124] Harvesting more traditional timber resources or "round wood" to displace Canadian domestic energy end-uses would not meet 2050 emissions targets.[125] Similarly, forest stands that have been degraded by natural disturbance could also provide a potential reservoir of suitable woody biomass for biofuels. Approximately 4.1 million hectares of forest are degraded each year in Canada from fire and pest infestation.[126]

Competitive Advantage in Innovation

Canada closes more venture capital deals per capita than the US in the biochemical and biofuel sectors, and has a comparative advantage to the US in green chemistry technologies.[127] A greater percentage of Canadian "cleantech" patents are also in biofuels and biochemical technologies than the US.[128] Part of this comparative advantage comes from existing research capacity such as **Green Centre Canada,** an accelerator headquartered in Kingston, Ontario, with hubs in all non-territorial regions of Canada. Having supported over 100 green chemistry and materials companies,[129] Green Centre Canada credits its success to the provision of facilities to early firms as opposed to just mentoring.[130] Providing access to lab equipment valued at C$5-10 million, Green Centre Canada helps firms with a Technology Readiness Level (TRL) of 3-4 engage in extensive product development they would not otherwise be able to accomplish. Though hemorrhaging of green chemistry firms to the US remains a challenge, the facilities offered by Green Centre Canada have been able to reverse this trend at times and attract some US firms north.[131]

Canada also has an opportunity to move into the production of sustainable aviation biofuels as no potential competitors have emerged with significant production capacity to meet expected needs. In 2018, aviation biofuel production of ~15 million litres accounted for less than 0.1% of total aviation fuel consumption.[132] Canada, therefore, starts at the same place in terms of an existing industrial footprint in the sector as potential competitors, but with a comparative advantage in green chemistry. Canada also likely has an advantage in the production of aviation biofuels due to a readily available surplus of suitable biomass inputs.

Market Potential

It is projected that by 2050, the biosphere can sustainably support between 70 and 100 exajoules of biomass cultivation. Given a projected global net-zero energy demand of ~550 exajoules, the number of sectors that can rely solely on bio-energy is limited.[133] Air travel is likely one of the few sectors for which the use of bio-energy will be prioritized owing to a lack of other near-term options to totally decarbonize the sector.[134] Globally, demand for passenger aviation is projected to grow by 31% in 2030 and 146% in 2050,[135] from 2019's 8,686 billion passenger kilometres.[136] Current aviation technical specifications allow biofuels produced from 4 of the 5 major biofuel production pathways to be blended up to 50% with kerosene for use in commercial aviation.[137] Global demand for Sustainable Aviation Fuels (SAF) is thus projected to rapidly grow at a rate of CAGR 72.4% from US$66 million in 2020 to US$15.3 Billion in 2030.[138] Under the sustainable development scenario outlined by the IEA, global consumption of SAF will need to grow from its current level to 5% of all aviation fuels in 2025, and 10% in 2030.[139] As Canada determines how it wants its bioenergy economy to develop, the aviation sector should be kept foremost in mind as an end-market, and associated supply chain to integrate into the sector.

Hydrogen

Canada is a world leader in low-carbon blue hydrogen with carbon, capture, utilization, and storage (CCUS). It has unmatched research capacity in fuel-cell technology. Canada must take advantage of these opportunities. However, there is a short window of opportunity for exports before cheap renewables and electrolyzers give production in other countries an advantage.

National Advantage

With the second greatest potential for hydroelectric capacity globally, and significant natural gas deposits in Alberta as well as BC, Canada is well placed to produce green and blue hydrogen.**[140]** Canada's energy resources will, however, only translate into export potential if domestic production in prospective markets is insufficient or more expensive.

Canada will be able to export hydrogen to the United States, but conversion and transportation costs will put it at a disadvantage in overseas markets. Hydrogen will most likely need to be converted to ammonia to ship overseas, and then converted back again upon arrival. This adds additional costs,[141] so jurisdictions that are able to produce hydrogen locally and transport it through a pipeline will be at an advantage.[142] The EU, one potential market for Canadian hydrogen,[143] would see a projected price difference of US$1.5/kg for Canadian imports compared to domestically produced green hydrogen.[144] If greater grid integration is constructed, water-poor Southern Europe could sell energy resources to water-rich Northern Europe, with total surface water resources in Europe being more than sufficient to meet the bloc's 2050 target of 2251 terrawatt hours (TWh) of hydrogen consumption.[145] China, another potential market, while lacking sufficient solar and wind to meet increasing electrification needs and increased hydrogen penetration, could import electricity from renewable-rich Mongolia and Russia to produce sufficient hydrogen domestically.[146]

Greater grid integration could even see Canada's largest trading partner, the US, produce significant concentrations of hydrogen at a much lower cost than through importation from Canada. Electricity is less costly to transport than hydrogen as a finished product, provided the suitable transmission infrastructure is built. For US customers, if sufficient trans-border transmission capacity were constructed, it would be far cheaper to purchase Canadian electricity to generate hydrogen in the US, than to purchase and ship Canadian hydrogen.

Competitive Advantage in Innovation

Canada has world-leading research capacity in the development of hydrogen technologies. British Columbia has been so fundamental to the emergence of the hydrogen fuel cell market that the province has been referred to as the "cradle" of the fuel cell industry.[147]

Canada is, however, unlikely to develop a competitive advantage in the manufacture of electrolyzers. Electrolyzers are a mass produced, mature technology in the terms of the open economy strategy. Cost reductions in electrolyzer production are likely to come from economies of scale in supply chains and learning from experience.[148] Given the entrenchment of alkaline electrolyzer manufacturing capacity in China,[149] and PEM as well as Solid Oxide in the EU, UK, and US, it is likely that Canada has missed the boat in developing production capacity and research capacity for current electrolyzer technologies.[150] There is room for a possible play in the production of more nascent electrolyzer technologies such as Anion Exchange membranes,[151] or specialized electrolyzers such as Dartmouth's Planetary Hydrogen which produces an alkaline byproduct to address ocean acidification.[152] Superiority of improved versions of novel electrolyzer technologies in end-use cases must be demonstrated before they are considered as promising sectors for industrial policy.

Market Potential

Reports suggest that by the end of the decade, renewable green hydrogen from electrolysis will be more cost competitive than blue hydrogen from natural gas (steam methane reformation) with CCUS.[153] The limited availability of green electricity for hydrogen will likely restrict green hydrogen production for some time after that. However, blue hydrogen has a limited window of opportunity and Canada must act now to take advantage. Blue hydrogen also faces challenges in a net-zero world. Blue hydrogen production is not a carbon neutral technology without offsets. One study commissioned by the BC government showed process emissions of current CCS technologies demonstrating 56-90% capture effectiveness producing 2 kg CO_2e per kilogram of hydrogen.[154] Accounting for current upstream methane leakage from the oil and gas sector, the same study projects that blue hydrogen would have a carbon footprint of 2.7tCO_2e per tonne of hydrogen.[155] Green hydrogen is likely to become the preferred option in meeting global hydrogen needs once electrolyzer prices come down.[156] Demand for blue hydrogen, meanwhile, will come from chokepoints in the production of green hydrogen. Total availability of electricity is likely to be a significant bottleneck in the rollout of green hydrogen.[157] In a scenario where 24% of 2050 global final energy usage (99 exajoules) is met through hydrogen, an estimated 3,000 TWh more of energy would be required.[158]

It is critical, therefore, that public support to develop capacity in hydrogen is not limited to one specific technology (blue versus green). Technologies should be allowed to prove themselves based on how well they can supply market needs. Canada should look to support the development of its hydrogen economy by building the pipeline infrastructure required to transport hydrogen to end users, and by helping Canadian consumers transition to hydrogen compatible infrastructure. One policy that would allow Canada's hydrogen economy to grow rapidly is mandating that new equipment purchases by industrial users such as direct-reduced iron furnaces and natural gas turbines also be compatible with hydrogen inputs. Building new hydrogen refueling stations at strategic locations for use by long haul transport would also aid the domestic expansion of the hydrogen sector. To ensure suitable emissions reductions from the uptake of hydrogen, Canada's clean fuel standard should be extended to hydrogen. Audits of hydrogen providers should then be conducted regularly to assess whether they produce a suitably low emissions hydrogen product when all scope 3 emissions are counted.

Uncertainties

- The strength of carbon pricing enforcement will be crucial to hydrogen demand domestically, especially the extent to which large industrial emitters are exempted from legislation.
- Geopolitical considerations may get in the way of greater grid regionalism for resource poor large energy consumers like Japan, South Korea, Vietnam, and Taiwan.[159]
- Uptake of hydrogen globally will be highly determined by the policy environment implemented in end-markets regarding carbon pricing. At a production price of US$1/kg, it is estimated that a US$100 carbon price could allow hydrogen to become the preferred molecule for critical industrial sectors such as ammonia, aluminum, cement, and steel.[160] Canada's domestic carbon price level is also an important factor.

Carbon Capture, Utilization, & Storage

Canada has expertise in carbon capture, utilization and storage (CCUS) deployment with hydrogen production, emerging utilization firms, and a nascent direct air capture industry. Each of these opportunities is ready to scale up, but policies and investments are needed to bring downstream markets online.

National Advantage

Canada has advantages in single point sources of carbon capture, downstream advantages with geological formations for storage (but not enhanced oil recovery [EOR]) and requires CCUS for commercial blue hydrogen production. The single point concentrated emissions come from oil and gas projects, which account for 26% of national emissions.[161] Canada also has seven large sedimentary basins for permanent geological sequestration of captured CO_2 and approximately 1 in 6 of all tonnes of anthropogenic CO_2 that have been sequestered globally have been injected in Canada.[162]

Additionally, as Canada drives a hydrogen agenda, CCUS integration with coal or natural gas production would help the sector benefit from economies of scale. According to Canada's Hydrogen Strategy, domestic production of hydrogen from natural gas alone could increase in a 2050 net-zero energy system by a maximum of eight times current levels.[163] The CCUS requirement for this magnitude of hydrogen production would be approximately 203 million metric tonnes CO_2 per year, which is far greater than the operational capacity of 4 million metric tonnes CO_2 per year.[164]

The country also has advantages in carbon utilization and sequestration through EOR. For example, the Weyburn oil field in Saskatchewan has sequestered over 35 million tonnes of CO_2 over the last 20 years through EOR processes.[165] EOR, however, is a mature industry and does not typically result in "zero carbon emissions" oil, hence there is likely little or no national advantage in this segment.[166]

Competitive Advantage in Innovation

Canada can potentially build CCUS project planning and development services based on existing expertise in the oil and gas industry and has R&D and scaleup clusters advancing innovation. Different CCUS processes such as capture, transport, utilization and/or storage need to be integrated.[167] This feature complements Canada's existing oil and gas engineering and operational expertise. Canadian project engineering, execution, and operational knowledge have the potential to be mobilized as valuable services.[168] As a result, Canada should focus on providing integrated services in CCUS planning and development. Canada already has a research cluster for carbontech R&D. There are also several testbed and pilot demonstration facilities which focus on: oxy fuel use, pre- and post-combustion techniques to simulate CO_2 capture from industrial flue gas; and monitoring short to long-term behaviour of sequestered CO_2 in geological formations and aquifers to address life cycle concerns regarding permanence.[169] Notably, there are no established Canadian firms with high technology readiness levels in carbon capture.

However, direct air capture (DAC) is an emerging technology where Canada has the potential to perform well. As DAC technologies extract CO_2 directly from the atmosphere, they stand out from CCUS as a separate carbon dioxide removal industry. Currently, there are 15 DAC plants globally capturing more than 9,000 tonnes of CO_2 per year. In the long run, carbon removal is expected to play a key role in the transition to a net-zero energy system. For example, in the IEA's Sustainable Development Scenario, DAC is expected to capture more than 10 million metric tonnes CO_2/year by 2030.[170] However, due to the relatively low concentration of CO_2 in ambient air, DAC requires large installations and faces challenges in terms of high capital costs. Analysis shows that total DAC costs typically range anywhere from US$100/tonne to US$1,000/tonne.[171]

Canada has a few innovative companies in the DAC space. **Carbon Engineering** has intellectual expertise in direct air capture and air to fuel conversion. **Svante** has expertise in nano-sized absorbent materials, which allows quick separation of CO_2 from post-combustion flue gas from industrial processes. **Entropy** specializes in modularization of carbon capture by improving capture and process efficiencies.

To advance Canada's global competitive advantage, the government and various stakeholders need to come together to support domestic firms and advance the technology.

Market Potential

As the global carbon capture market size is projected to increase over the next 30 years, Canada can provide integrated services for CCUS projects. Out of the 27 operational commercial CCUS facilities globally capturing around 40 million metric tonnes of CO_2 per year, 12 are in the US and 4 are in Canada.[172] IEA projections suggest that in 2050, CO_2 capture will be around 4 gigatonnes per year – a 100-fold increase from current levels. Market projections show that the global CCUS market size is expected to roughly double from US$1.6 billion in 2020 to US$3.5 billion by 2025, at a CAGR of 17% during the forecast period.[173] The main factors influencing CCUS market growth are: 1) increasing usage of carbon capture and storage systems in heavy industries where emissions are hard to abate; 2) establishing investment tax credits and other financial incentives in other countries, similar to those which have driven US adoption of CCUS; 3) developing hubs and clusters which bring about significant economies of scale; and 4) introducing blue hydrogen requirements, as it is currently (but will not remain) the lowest cost novel option for producing commercial quantities of hydrogen. Therefore, Canada should focus on developing integrated services in these markets.

Uncertainties

- One study suggests that 80% of new CCUS projects fail to become commercially viable, with high capital costs and the credibility of project revenues cited as key factors.[174] There are proven technologies in the space, but financial innovations and smart policy supports are needed to scale them up.
- Canada's export market is not in the physical CCUS equipment. Countries such as China have a competitive advantage in this segment. Rather, it is in integrated planning and development services, which different countries will need to develop and commercialize their own CCUS projects. These export markets will be affected by the development and stance taken by the fossil fuel market segment.
- With the integrated services approach, there are uncertainties related with talent recruitment and possible merger and acquisitions by larger oil and gas multinational companies.
- DAC has only reached demonstration levels. Until it reaches commercial scale, its potential to help achieve net-zero emissions remains uncertain.

Canada should focus on providing integrated services in CCUS planning and development.

Enabling Conditions

In addition to these top opportunities, we highlight three industries that provide essential enabling conditions for net-zero and clean growth goals.

Clean Grid

From a strategic perspective, Canada's clean grid underpins its economic competitiveness in a global low-carbon economy and Canada needs to continue investing in its grid to remain globally competitive. A relatively clean grid means that Canadian products have a lower carbon footprint. With a global market increasingly factoring in the carbon footprint of its imports, Canadian-made products have a significant head start. However, without continued investment, the clean grid advantage will not necessarily hold in the coming decades.[175] Canada must increase electricity supply by between 60% and 250% by 2050 to electrify transportation, buildings, and other industries.[176] Integrating renewables will require load shifting, greater grid integration and energy storage. Canada needs expanded generation assets, bulk storage, energy management and load shifting, and transmission infrastructure, and these investment needs must be complemented by a national integration strategy. This will also help develop other high potential sectors such as medium- and heavy-duty ZEVs, and hydrogen, which will be of strategic importance in a global low-carbon economy.

Net-Zero Minerals

Canada needs to further grow its net-zero minerals supply chain to respond to a range of factors that could hold back the energy transition, threaten global security, or provide economic growth. From a demand perspective, a projected annual increase in demand of 450% by 2050 for certain battery minerals requires global supplies to grow accordingly.[177] Simultaneously, geopolitical trends provide an opportunity for Canada build the minerals supply chain for Western markets.[178] Canada has an IP advantage in the upstream components of the battery supply chain (everything before the manufacture of the battery cells themselves). Canada has significant extracting and refining capacity for battery minerals harvested in nickel deposits. Nickel deposits are generally co-located with significant intermixed cobalt, creating potential to expand Canadian primary production of these other key energy elements.[179] Canada needs to take a more active role in expanding its minerals sector overall and shoring up its weaknesses where prudent. Growth in Canada's net-zero mineral supply chain should not just be limited to the extraction of primary material but also the reintegration of recycled metals from battery waste back into production.

Carbon Accounting Standards

Carbon pricing and offsets can only work for clean growth with effective carbon accounting standards. Existing provincial carbon markets (Nova Scotia and Quebec) create a pool of human capital that could train others and expand a services sector focused on the vetting and sale of carbon offsets.[180] Additionally, the now-inactive Ontario carbon market has left significant human capital that could be tapped to improve the quality and scope of Canadian carbon offset services.[181] Canada also has a significant academic research capacity in the accounting of domestic natural carbon sinks that could be tapped to help bolster a carbon services industry.[182] Building greater capacity in carbon accounting could also have spillover benefits on issues of trade. Canada's exports go out to a global market increasingly regulating carbon but through a range of policy systems. Developing greater domestic carbon accounting capacity will be critical as Canada considers developing its own policy of border carbon adjustments (or an alternative to serve the same objective), as this country's largest trading partners, the US, EU, and China all have conflicting carbon regulatory systems.[183]

Further Opportunities

We also identify seven further opportunities: net-zero mining operations, battery metals, energy management technologies for buildings, marine shipping, aviation, vertical agriculture, and low emissions fertilizers. There are some important opportunities in these clusters and further analysis may identify low-cost experiments that should be tried to catalyze action. It is important to note that our list could be wrong. The main point we wish to emphasize, therefore, is the need to work systematically and strategically to explore the opportunity space through public-private collaborations.

Growth in Canada's net-zero mineral supply chain should not just be limited to the extraction of primary material but also the reintegration of recycled metals from battery waste back into production.

5. SEIZING OPPORTUNITIES

FROM DESTINATION TO ROADMAPS

Federal, provincial, and First Nations governments can work with experts and the private sector to pursue these opportunities by **co-developing roadmaps** that lay out targets, sequences, policies, and investments to bring the industries to scale. To do this effectively, Canada needs true collaboration across these communities to agree on and implement a strategy.

5.1 What is the role of governments in industrial transition?

Governments have three essential roles in driving industrial transition.

1. Identify priorities and set clear targets.

Given their scarce resources and small global scale, governments of small, open economies must promote the strategic focus needed for economic prosperity. This means identifying priority areas based on their potential contribution to the long-term welfare of society. Governments must articulate public purpose and set the agenda.

Governments must take an active role in setting priorities because they represent the intergenerational interests of all Canadians. If roadmapping processes are driven only by industries, they will privilege status quo interests. If roadmapping processes are driven by the financial sector, they may privilege short-term profitability, which may not allow Canada to build the industries it needs or construct coherent clusters in a short timeframe.

Clear targets are necessary to establish the sequences and timetables that stimulate entrepreneurship and create investor confidence. A common concern in our expert survey was that investors and businesses need to know when market demand will be online so they can create bankable projects. For example, the UK's industrial strategy establishes clear targets (e.g., create two CCUS clusters aiming to capture $10MtCO_2$/yr by 2030).[184] Leadership backed by credible targets is needed to catalyze action.

2. Use public finance to facilitate experimentation and learning.

The importance of public money in the energy transition is widely recognized but its real purpose is misunderstood. Governments are needed to solve market failures in research, innovation, and environmental externalities, and to provide the incentive to act early. However, many are concerned that this amounts to "picking winners."

Smart industrial strategy is not about picking winners; it is about building a sector's capacity for innovation and action over time. A publicly-funded strategy for research, development, deployment, and demand-pull allows public and private actors to learn collectively. Public finance is needed to ensure that the entire solution space is explored, and that potentially viable technologies and industries are not left behind because the market did not incentivize them properly.

In addition, the concern about picking winners is misplaced because Canada has a long history of using public funds and public-private institutions to bolster oil and gas, forestry, mining, and other sectors (see Box 1). Doling out one-off subsidies and grants to leading firms is an outmoded strategy that is likely to generate significant waste. Instead, the government needs a coherent strategy supported by smart, adaptable institutions.[185]

3. Engage and coordinate up and down the verticals.

As we have mentioned throughout the report, a central piece of industrial strategy is ensuring that all the elements of the cluster or vertical move together. The upstream components of the value chain must be developed at the same time as end-use markets are brought online. The government has an important coordination role to play here to ensure good relationships and communication up and down the supply chain.[186]

A key task is to align the supply of inputs, the production of core technologies, and the scaling of end-use markets. Governments establish end-use markets through carbon pricing, domestic market coordination, smart regulation, and strategic procurement. The government also must look outward. The government must deploy Global Affairs Canada and Export Development Canada to help integrate Canadian firms in global value chains. Specific industries will need to be positioned vis-a-vis carbon border adjustments or other international regimes.[187]

Finally, governments should directly support firm collaboration up and down the value chain by creating spaces for communication and collaboration. Governments can use these spaces to advance "high-road" supply chains with good jobs and high ESG standards. Research shows that companies often rely on outsourcing because it is easy, not because they have engaged in an exhaustive analysis of costs and benefits.[188] Simple network building and information exchange can help to build high-road supply chains. Governments can get companies to exchange information with one another by convening the whole value chain and by awarding contracts and incentives to national collaborations.

> ***To begin the necessary work of setting targets, coordinating supply chains, and making smart investments, governments can co-develop clean competitiveness roadmaps in key sectors.***

5.2 What are Clean Competitiveness Roadmaps?

A clean competitiveness roadmap is a strategic collaboration between experts, industry, finance, and governments at various levels. Its power lies in the connections, commitments, and coordination that emerge from true collaboration across parts of society. This kind of roadmap is as much about the process behind as it is the content it contains.

Roadmapping processes in these clusters would build on the current initiatives highlighted above. The ongoing experiments in roadmapping and pathway development are exciting, but there is a need to bring these efforts together, align them, and facilitate learning across the experiments.

A clean competitiveness roadmap for a vertical or a cluster is distinct from a net-zero industry pathway. A net-zero pathway identifies all the emissions produced by a cluster and seeks to source net-zero alternatives or offsets. In contrast, a clean competitiveness roadmap seeks to build the industries needed for net-zero targets at home and abroad. Such a roadmap is not focused solely on emissions. Rather, its goal is to produce long-term economic value for the cluster and the country.

When designing the process, there are a variety of methodologies pioneered by consultancies and non-profits to build on. The key is to enable strategic collaboration under uncertainty, incorporate technical knowledge and expertise, and foster creativity.

An industry roadmap exercise focused on economic opportunity in the energy transition rather than net-zero needs to consist of a number of activities:

Look to 2050: The first step is a global analysis that positions the vertical or the cluster in the 2050 energy system. What technologies will the world need to reach net-zero? Which net-zero technologies will have large global markets? What features of the industry will help make it competitive? This analysis needs to respect the profound uncertainties inherent in such an exercise and lay out multiple possibilities. With a clear picture of the 2050 landscapes, strategic action can begin.

Co-design pathways to 2050: Build a shared roadmap that advances the upstream, midstream, and downstream elements of the cluster to 2050. The sequence of events is crucial to ensure that all the elements of the cluster move in step from upstream services, technologies, and resource inputs; to manufacturing and production of core technologies; to end-use and market development.

Advance to 2050: Finally, the partners need to co-design and co-deploy the policy and investment interventions that can deliver the 2050 vision. Here, governments need to take responsibility for a coherent mix of policies and instruments tailored to the cluster. These can be divided into four types: "push" instruments that drive research and technology generation; "grow" mechanisms that channel financing to emerging ideas; "pull" policies that develop market demand; and "strengthen" tools that broadly enable innovation and learning in the cluster.[189]

Nonetheless, even well-laid plans will be undone by events, so the group must experiment, learn, and adjust over time.[190]

5.3 What institutions are needed to support roadmap development and implementation?

The success of the roadmaps will depend on fostering strong collaborations between the public and the private sectors. When organizations on both sides can learn together, roadmapping processes can be co-developed and co-deployed with purpose and skill.

Successful industrial policy is built on good information flows between the public and the private sectors.[191] Governments need good quality information from the private sector to make smart investments in the energy transition. At the same time, the government must be careful not to become captured by special interests. If the private sector is the only source of information and analysis, governments risk making investments that do not serve the long-term interests of society.

The Economic Strategy tables, the Superclusters and ongoing roadmapping initiatives are valuable precisely because they work to create the kinds of information flows needed to support strategic action. However, Canada needs a set of nimble, yet permanent institutions that will facilitate good information flows and provide a place for strategy, independent expertise, and learning. Moreover, rather than convening large groups of incumbent firms, our roadmap approach is premised upon bringing together willing coalitions of actors invested in the transition from across the whole supply chain.

Different countries use different kinds of institutions to serve these functions. In Japan and Korea, the government convenes deliberation councils. These liaise between large conglomerates and powerful bureaucracies to drive strategic investment. In its industrial strategy for wind energy, the UK created a permanent industry council and built up expertise in the crown corporations that led investment rounds. In the US, the Department of Energy has deep domain expertise and the often-derided revolving door between the government and corporations fosters information sharing. Canada can learn both positive and negative lessons from examples abroad in designing institutions to support clean growth that will suit its political economy and goals.

One instructive model for Canada can be found in the European Commission's hydrogen strategy and battery alliance. The European context is a useful analogue for Canada's federal structure. Canada and Europe share some similar multi-level governance challenges and the need to coordinate many agencies with overlapping jurisdictions.

To develop their green industrial policy, the European Commission and the member states work closely with a public-private partnership called InnoEnergy.[192] InnoEnergy is staffed by engineers, scientists, management experts, innovation specialists, and people with extensive business experience. It has the deep domain expertise necessary to create strategies in complex technical areas, and the business know-how to guide and support firms – both big and small. It also facilitates interaction between politics and business, and it serves as the locus of strategy, expertise, and learning.

The European Commission leadership works with InnoEnergy to get member states, other European agencies, and firms to create a shared vision. They then raise investment capital for the projects from a variety of sources. As an example, for the battery strategy, they pooled finance from Volkswagen, the European Infrastructure Bank, national funds, and investors.

As a public-private partnership, InnoEnergy has the agility and independence to work across jurisdictions and issue areas to coordinate action on clean growth. It demonstrates that a public-private partnership can be an indispensable piece of an industrial.

Public-private partnerships have played an important role in successful technology innovation strategies in the US and Canada. In Canada, public-private partnerships were crucial in translating academic knowledge into the technologies that built the oil sands industry (Box 1). In the US, the Gas Research Institute (GRI) was a research, development, and demonstration organization that was instrumental in creating the technologies behind the fracking boom.[193] These examples show that governments have successfully used public-private partnerships to develop fossil fuels, and now it is time to redeploy them in service of the energy transition.

Box 1. Alberta and the Oil Sands: Canada's Long History of Supporting Innovation and Industry.

In rediscovering the government's abilities to support the growth of nascent sectors into economic engines, it is important to know that Canada does have a long history of using public finance to drive innovation and industrial development. Indeed, Canada's oil sands industry was made possible by industrial policies. Public capital can take greater risks on capital-intensive infrastructure projects that lack market precedent from the use of novel technology; this longer-horizon view of economic potential can be credited in large part for the successful development of the oil sands.

Technologies that have made Alberta's oil sands economically viable emerged from mission-oriented innovation policy focused on opening non-traditional deposits. These efforts were organized under the Alberta Oil Sands Technology and Research Authority (AOSTRA). AOSTRA was created under the Lougheed government with the specific purpose of making economically extractable in-situ oil sands deposits. AOSTRA was a crown corporation that co-financed research and development and demonstration projects with industry partners. The resulting projects – public-private partnerships in their own right – were essential to developing steam-assisted gravity drainage process and a variety of other technologies related to tar sands extraction.[194]

Without Alberta's ability to look past the short-term horizon of immediate investment returns of the private sector capital, it is unlikely that the oil sands would have been developed as quickly or to the same extent as has been experienced. While liberalization of the sector under the Klein government did help facilitate industry expansion, public intervention was essential to kickstart the industry due to the lack of market precedent of what was at the time a novel technology with a large physical capital footprint. Alberta's oil sands demonstrate the role of industrial policy to support nascent sectors until they can demonstrate sufficient viability to attract private capital.

Today, Alberta is again looking to utilize industrial policy to both transition the legacy oil industry toward compatibility with a lower-emissions intensity global market, as well as fund alternatives for Alberta's economy. Emission's Reduction Alberta (ERA) in its most recent round of funding for novel technology deployments provided ~C$40 million to projects that directly reduced emissions from the oil and gas industry, fossil fuel processes, or helped create by-products from fossil fuel projects compatible with a decarbonizing economy.[195] Funding provided by ERA helped crowd in ~C$642 million in funding to transition the oil & gas sector and adjacent industries.[196]

ERA is funded by revenues from Alberta's Technology Innovation and Emissions Reduction – Alberta's emissions pricing system. Having a permanent, industry-funded source of innovation funds puts Alberta in a strong position to drive clean growth.

However, ERA hosts a more diversified portfolio of technology investment than what has historically been the oil-sands-centric industrial policy of Alberta's past. The same funding stream for novel technology deployment also spent ~C$28 million into non-fossil fuel related sectors, helping crowd in C$367 million of private finance.[197]

CONCLUSIONS

In conclusion, our analysis of Canadian opportunities and international case studies indicate that governments, First Nations, firms, and civil society organizations should:

1. Focus strategic efforts in high priority areas

We identified seven high priority clusters: medium- and heavy-duty zero emissions vehicles, alternative proteins, mass timber, green aluminum, green chemistry, hydrogen, and carbon, capture, utilization, and storage.

We do not claim to have provided the final word on these sectors, but governments should seek to identify priority areas by considering Canada's position as a small open economy in a rapidly changing global economy and develop a framework to identify opportunities and create strategic focus.

2. Engage in collaborative roadmap exercises

Governments, firms, and civil society organizations should support and participate in externally driven roadmapping exercises.

- Governments need to set clear goals and targets, provide public finance, and use their capacity to catalyze action up and down the clusters.
- The federal government should seek to align these efforts by convening a high-level cross-departmental clean growth strategy table.
- Firms should work in small, committed groups to create technologically, politically, and socially specific roadmaps that chart a clear path to 2030 and 2050 goals.
- Civil society should provide its expertise to these exercises.

Settler organizations and governments should look to First Nations for leadership. They must find ways to support the full sovereignty of the Nations, consistent with the UN Declaration on the Rights of Indigenous Peoples, as they transition to clean energy and improve the livelihoods of their peoples.

3. Take a cluster approach, focusing on the highest value-added areas

Roadmapping exercises should align and drive all the elements of decarbonization technology clusters, looking upstream to resources and innovation capacity, and downstream to end-uses and markets. Roadmaps must align supply-push and demand-pull policies as well as outline finance and policy needs.

As a small open economy, Canada should not try to replicate all parts of the value-chain. Rather, it should seek to build competitive niches (in, for example, battery metals processing) where Canada can build world-class sub-clusters in high value-added areas. Other areas of the value chain can be imported or subsidized to provide the demand-pull needed to bring high value-add niches online.

4. Use roadmaps to focus existing funding streams and inspire new strategic investments

We have pointed out the tendency of governments to fund one-off projects that benefit single firms. Roadmaps have the potential to identify strategic investments that bolster the development of true innovation clusters.

The Strategic Innovation Fund, the Canadian Infrastructure Bank, and other funds and agencies should collaborate with roadmapping exercises to develop high-quality projects that meet public sector criteria while increasing the scope and ambition of transition investments.

5. Build intermediary organizations that can support green industrial strategy

Canada needs to build public-private partnerships like InnoEnergy to serve as effective intermediaries. Partnerships or other third-party entities can facilitate good information flows between governments and businesses, provide independent expertise, and serve as a site for learning and experimentation.

As a small open economy, Canada should not try to replicate all parts of the value-chain. Rather, it should seek to build competitive niches where Canada can build world-class sub-clusters in high value-added areas.

ENDNOTES

1 See Nye, Josh, Naomi Powell, and Cynthia Leach. 2021. "Trading Places: Canada's Place in a Changing Global Economy." RBC Thought Leadership. https://thoughtleadership.rbc.com/trading-places-canadas-place-in-a-changing-global-economy/.

2 International Energy Agency (2021). *Net Zero by 2050: A Roadmap for the Global Energy Sector.* https://www.iea.org/reports/net-zero-by-2050

3 European Commission (2019). European Battery Alliance. https://ec.europa.eu/growth/industry/strategy/industrial-alliances/european-battery-alliance_en

4 Department of Industry (2020). Technology Investment Roadmap: First Low Emissions Technology Statement 2020. https://www.industry.gov.au/data-and-publications/technology-investment-roadmap-first-low-emissions-technology-statement-2020

5 Department for Business, Energy & Industrial Strategy. 2013. Offshore Wind Industrial Strategy. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/243987/bis-13-1092-offshore-wind-industrial-strategy.pdf

6 Chang, H. J., Andreoni, A., & Kuan, M. L (2013). International industrial policy experiences and the lessons for the UK. Future of Manufacturing Project: Evidence Paper 4; Lewis, J. (2013). Green Innovation in China: China's Wind Power Industry and the Global Transition to a Low-Carbon Economy. New York: Columbia University Press.

7 Meckling, J., Kelsey, N., Biber, E., and Zysman, J. (2015). "Winning Coalitions for Climate Policy." *Science* 349 (6253): 1170–71.

8 Expert Panel on Sustainable Finance (2019). Final Report. http://publications.gc.ca/collections/collection_2019/eccc/En4-350-2-2019-eng.pdf

9 The need for a strategic approach is clear when we consider that it is estimated that $2 trillion is required to decarbonize Canada's existing sectors by 2050; see Royal Bank of Canada. 2021. "The $2 Trillion Transition: Canada's Road to Net Zero." RBC Thought Leadership. https://thoughtleadership.rbc.com/the-2-trillion-transition/

10 Victor, D. G. and Allan, B. (2022). Deep Decarbonization from a Global Perspective: Finding Canada's Future in a Net-Zero World. Smart Prosperity Institute Discussion Paper.

11 ISED (2018). *Report from Canada's Economic Strategy Tables: The Innovation and Competitiveness Imperative - Economic Strategy Tables.* https://www.ic.gc.ca/eic/site/098.nsf/eng/h_00020.html. For more background see the recommendations of the Advisory Council on Economic Growth, which suggested high-potential sectors have to be selected based on their economic prospects. Government of Canada (2017). *Ideas into Action: A Review of Progress Made on the Recommendations of the Advisory Council on Economic Growth.* https://www.budget.gc.ca/aceg-ccce/pdf/ideas-into-action-eng.pdf

12 ISED (2020). *Restart, recover, and reimagine prosperity for all Canadians—Innovation for a better Canada*. https://www.ic.gc.ca/eic/site/062.nsf/eng/00118.html

13 Canadian Small Modular Reactor Roadmap Steering Committee (2018). *A Call to Action: A Canadian Roadmap for Small Modular Reactor*. https://smrroadmap.ca/wp-content/uploads/2018/11/SMRroadmap_EN_nov6_Web-1.pdf?x64773

14 Natural Resources Canada (2020). *Hydrogen Strategy for Canada* https://www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen%20Strategy%20for%20Canada%20Dec%2015%202200%20clean_low_accessible.pdf

15 Government of Canada (2021a). *Joint statement: Canada's Cement Industry and the Government of Canada announce a partnership to establish Canada as a global leader in low-carbon cement and to achieve net-zero carbon concrete*. Innovation, Science and Economic Development Canada. https://www.ic.gc.ca/eic/site/icgc.nsf/eng/07730.html

16 Government of Canada. (2021b). *Budget 2021: A Recovery Plan for Jobs, Growth, and Resilience*. https://www.budget.gc.ca/2021/home-accueil-en.html

17 Government of Canada. (2021b). *Budget 2021: A Recovery Plan for Jobs, Growth, and Resilience*. https://www.budget.gc.ca/2021/home-accueil-en.html

18 Algoma Steel Inc. (2021). *Government of Canada Endorses Algoma Steel's Transformation Plan for Green Steel Commitment of up to $420 Million*. https://www.algoma.com/government-of-canada-endorses-algoma-steels-transformation-plan-for-green-steel-commitment-of-up-to-420-million/

19 The small and open nature of the Canadian economy has been an ongoing theme in discussions around economic strategy for many decades. See for example Harris, R.G. (2015). *Trade, Industrial Policy, and International Competition*, Second Edition. McGill-Queen's University Press. And especially David Wolfe's introduction. Wolfe, D. (2015). "Introduction to the Carleton Library Series Edition" of Richard G. Harris, *Trade, Industrial Policy, and International Competition*, Second Edition. McGill-Queen's University Press. https://49thshelf.com/Books/T/Trade-Industrial-Policy-and-International-Competition-Second-Edition3.

20 Armstrong, C., Hettinger, L., Coulter, H., Elliot, N., Busby, J., Goldsmith R., Barret, D, Barkovic, L., Pollner, L., Nicholas, K., Richardson, J., Colligan, M. (2021). Infrastructure Investment and Jobs Act Summary. Holland & Knight. Hklaw.com/en/insights/publications/2021/08/infrastructure-investment-and-jobs-act-summary

21 Kim, S.-Y., Thurbon, E., Tan, H. Mathews, J. (2020). South Korea's Green New Deal shows the world what a smart economic recovery looks like. https://theconversation.com/south-koreas-green-new-deal-shows-the-world-what-a-smart-economic-recovery-looks-like-145032

22 Department of Industry (2020). Technology Investment Roadmap: First Low Emissions Technology Statement 2020. https://www.industry.gov.au/data-and-publications/technology-investment-roadmap-first-low-emissions-technology-statement-2020

23 Victor, D. G. and Allan, B. (2022). Deep Decarbonization from a Global Perspective: Finding Canada's Future in a Net-Zero World. Smart Prosperity Institute Discussion Paper.

24 Transition Accelerator (2021). Pathways to net zero: A decision support tool. https://transitionaccelerator.ca/wp-content/uploads/2021/01/2021-01-24-Pathways-to-Net-Zero-v9-4.pdf

25 World Economic Forum (2019). *The Global Competitiveness Report 2019*. http://www3.weforum.org/docs/WEF_TheGlobalCompetitivenessReport2019.pdf; Cornell University, INSEAD, & WIPO. (2020). *Global Innovation Index 2020 | Who Will Finance Innovation?* https://www.globalinnovationindex.org/gii-2020-report#

26 Natural Resources Canada. (2018). *CANADA'S ENERGY TRANSITION Getting to Our Energy Future Together*. https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/CoucilReport_july4_EN_Web.pdf

27 World Atlas (2018). *Countries With the Most Natural Resources*. https://www.worldatlas.com/articles/countries-with-the-most-natural-resources.html

28 World Bank (2020). *Doing Business Doing Business 2020*. https://documents1.worldbank.org/curated/en/688761571934946384/pdf/Doing-Business-2020-Comparing-Business-Regulation-in-190-Economies.pdff

29 Deloitte (2019). *Canada's competitiveness scorecard | Measuring our success on the global stage*. https://www2.deloitte.com/content/dam/Deloitte/ca/Documents/finance/ca-bcc-deloitte-scorecard-interactive-pdf-aoda-en-updated-final.pdf

30 Natural Resources Canada (2020). *10 Key Facts on Canada's Natural Resources.* https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/emmc/pdf/10_key_facts_on%20Natural%20Resources%20Canads_2020_E.pdf

31 Breznitz, D. (2021). *Innovation in Real Places: Strategies for Prosperity in an Unforgiving World* (1st ed.). Oxford University Press. https://doi.org/10.1093/oso/9780197508114.001.0001

32 Breznitz, D. (2021). *Innovation in Real Places: Strategies for Prosperity in an Unforgiving World* (1st ed.). Oxford University Press. https://doi.org/10.1093/oso/9780197508114.001.0001

33 Brownlee, M., Elgie, S., and Scott, W. (2018). "Canada's next Edge: Why Clean Innovation Is Critical to Canada's Economy and How We Get It Right." Discussion Paper. Smart Prosperity Institute, https://institute.smartprosperity.ca/library/publications/canada-s-next-edge-why-clean-innovation-critical-canada-s-economy-and-how-we; Nemet, G. F. (2019). *How solar energy became cheap: A model for low-carbon innovation*. Routledge; Sivaram, V., Cunliff, C., Hart, D., Friedmann, J., Sandalow, D. (2020). *Energizing America: A roadmap to launch a national energy innovation mission.*

34 Relative to the sector's added value contribution to national GDP.

35 OECD. (2019). Chapter 5. Innovation policy and the agricultural innovation system. In *Innovation, Productivity and Sustainability in Food and Agriculture: Main Findings from Country Reviews and Policy Lessons*.

36 See, for example, Asselin, Robert, Sean Speer, and Royce Mendes. 2020. "New North Star II: A Challenge-Driven Industrial Strategy." Public Policy Forum. https://ppforum.ca/wp-content/uploads/2020/04/NewNorthStarII-PPF-APRIL2020-EN.pdf.

37 Lipsey, R. G., & Carlaw, K. I. (2020). Industrial Policies: Common Not Rare. *Simon Fraser University*. 12. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3854149

38 The recent report by the Canadian Institute for Climate Choices, undertaken at the same time as our analysis, also assesses prospects for Canadian economy in a global transition to net-zero. There are many similarities to the strategic opportunities identified as well as some differences, as noted below. Any differences raise questions for discussion and suggest further analysis could be warranted. A common feature of both our analysis and that of the CICC is a review of technologies and sectors likely to thrive in the global context. Canadian Institute for Climate Choices. 2021. "Sink or Swim: Transforming Canada's Economy for a Global Low-Carbon Future." Ottawa, Canada. https://climatechoices.ca/reports/sink-or-swim/.

39 For more details, see Victor, D. G. and Allan, B. (2022). Deep Decarbonization from a Global Perspective: Finding Canada's Future in a Net-Zero World. Smart Prosperity Institute Discussion Paper.

40 Victor, D. G., Geels, F. W., & Sharpe, S. (2019). *Accelerating the Low Carbon Transition: The Case for Stronger, More Targeted and Coordinated International Action*. Brookings. https://www.brookings.edu/wp-content/uploads/2019/12/Coordinatedactionreport.pdf

41 Malhotra, A., & Schmidt, T. S. (2020). Accelerating Low-Carbon Innovation. *Joule*.

42 Nahm, J. (2021) Collaborative Advantage: Forging Green Industries in the New Global Economy. Oxford University Press; Nemet, G. F. (2019). How solar energy became cheap: A model for low-carbon innovation. Routledge.

43 Victor, D. G., Geels, F. W., & Sharpe, S. (2019). *Accelerating the Low Carbon Transition: The Case for Stronger, More Targeted and Coordinated International Action*. Brookings. https://www.brookings.edu/wp-content/uploads/2019/12/Coordinatedactionreport.pdf

44 Max Åhman, Lars J. Nilsson & Bengt Johansson (2017) Global climate policy and deep decarbonization of energy-intensive industries, Climate Policy, 17:5, 634-649, DOI: 10.1080/14693062.2016.1167009; Sivaram, V., Cunliff, C., Hart, D., Friedmann, J., Sandalow, D. (2020). Columbia University, & Center on Global Energy Policy. Energizing America: A roadmap to launch a national energy innovation mission.

45 For a more detailed analysis of the "Pull" and "Push" policies, with extra attention to "Grow" policies (for turning development and demonstration products into marketable ones) and "Strengthen" policies (to make the whole clean innovation system more effective), see Brownlee, Michele, Stewart Elgie, and William Scott. 2018. "Canada's next Edge: Why Clean Innovation Is Critical to Canada's Economy and How We Get It Right." Discussion Paper. Smart Prosperity Institute, https://institute.smartprosperity.ca/library/publications/canada-s-next-edge-why-clean-innovation-critical-canada-s-economy-and-how-we.

46 See for example, "Canada is playing catch-up in global frenzy for lithium, as China's grip on critical clean energy mineral tightens", Niall McGee, Globe and Mail, 2022-01-12, https://www.theglobeandmail.com/business/article-canada-is-playing-catch-up-in-global-frenzy-for-lithium-as-chinas-grip/

47 Our assessment framework overlaps with that of CICC's 2021 report, "Sink or Swim" as referenced above. Both approaches begin with a list of technologies and sectors expected to grow as the global economy transitions to a low-carbon and even net-zero future. Both approaches also examine demand and the prospects for Canadian advantage in innovation, including for example current research and business presence and expertise. While CICC analyzed recent investment flows into these areas, we undertook an expert consensus survey. This approach captures opinions of not only investors, but other stakeholders, with an explicit forward-looking perspective. The approaches should be seen as providing complementary information.

48 The Canadian Vehicle Manufacturing Association. Important Facts. https://www.cvma.ca/industry/facts/

49 Sharpe, B., Lutey, N., Smith, C., & Kim, C. (2020). *Power play: Canada's role in the Electric Vehicle Transition* (p. 52) [White Paper]. The International Council on Clean Transportation. https://theicct.org/sites/default/files/publications/Canada-Power-Play-ZEV-04012020.pdf

50 Nealer, R., Reichmuth, D., & Anair, D. (2015). *Cleaner Cars from Cradle to Grave*. Union of Concerned Scientists. https://www.ucsusa.org/sites/default/files/attach/2015/11/Cleaner-Cars-from-Cradle-to-Grave-full-report.pdf

51 International Organization of Motor Vehicle Manufacturers. (2019). *World Motor Vehicle Production* (2019 Production Statistics). https://www.oica.net/category/production-statistics/2019-statistics/

52 The Lion Electric Co. (2020). *Investor Presentation*. https://s27.q4cdn.com/902820926/files/doc_presentations/August-2021-IR-Presentation-(Website)-FINAL.pdf

53 Fisher, G. (2021, January 9). *If You Like EV And Tesla, Spend Some Time With Lion Electric*. Seeking Alpha. https://seekingalpha.com/article/4398032-you-like-ev-and-tesla-spend-time-lion-electric

54 Market Screener. (2021, April 20). *We are Charged Up about Electrovaya*. https://www.marketscreener.com/quote/stock/TORRENT-CAPITAL-LTD-49478156/news/We-are-Charged-Up-about-Electrovaya-EFL-TSX-33009643/

55 *Canadian Hydrogen and Fuel Cell Sector Profile* (p. 30). (2018). Canadian Hydrogen and Fuel Cell Association. http://www.chfca.ca/wp-content/uploads/2019/10/CHFC-Sector-Profile-2018-Final-Report.pdf

56 Loop Energy. (n.d.). *Market Applications*. Retrieved September 13, 2021, from https://loopenergy.com/market-applications/

57 Ballard Power Systems (n.d.). *Fuel Cell Power Products*. Retrieved September 13, 2021, from https://www.ballard.com/fuel-cell-solutions/fuel-cell-power-products

58 Sharpe, B., Lutey, N., Smith, C., & Kim, C. (2020). *Power play: Canada's role in the Electric Vehicle Transition* (p. 52) [White Paper]. The International Council on Clean Transportation. https://theicct.org/sites/default/files/publications/Canada-Power-Play-ZEV-04012020.pdf

59 The Observatory of Economic Complexity. (2021). *Canada Exports, Imports, and Trade Partners*. https://oec.world/en/profile/country/can

60 Victor, D. G., Geels, F. W., & Sharpe, S. (2019). *Accelerating the Low Carbon Transition: The Case for Stronger, More Targeted and Coordinated International Action*. Brookings. https://www.brookings.edu/wp-content/uploads/2019/12/Coordinatedactionreport.pdf

61 Alternative proteins can be derived from either agricultural commodities like wheat, soy or lentils i.e. plant-based, or can be cultivated from single-celled organisms through fermentation, or can be derived from cell culture by growing animal cells in an artificial growth medium

62 Pulse Canada. (2015, November). *Canada's $3 Billion Pulse Industry Celebrates Launch of the UN International Year of Pulses 2016*. *Newswire.Ca*. https://www.newswire.ca/news-releases/canadas-3-billion-pulse-industry-celebrates-launch-of-the-un-international-year-of-pulses-2016-544663882.html

63 Statistics Canada. (2020, June 29). *June preliminary estimates of principal field crop areas*. https://www150.statcan.gc.ca/n1/daily-quotidien/200629/t001c-eng.htm#fn02

64 Good Food Institute. (2021). *Alternative Protein Company Database*. https://gfi.org/resource/alternative-protein-company-database/

65 Good Food Institute. (2021). *Alternative Protein Company Database*. https://gfi.org/resource/alternative-protein-company-database/. Pure play firms are those pursuing only plant-based approaches.

66 (VP Corporate Affairs Greg Northey "Pulse Canada" Personal Communication 2021)

67 Laychuk, R. (2017). Massive pea-processing plant nears completion, opening new market for Manitoba growers. *CBC News*. https://www.cbc.ca/news/canada/manitoba/roquette-manitoba-portage-la-prairie-pea-processing-1.5892463

68 Good Food Institute. (2021). *Alternative Protein Company Database*. https://gfi.org/resource/alternative-protein-company-database/

69 Ryan, H. (2021). Halifax company first in Nova Scotia to harvest single-cell organisms. CBC. https://www.cbc.ca/news/canada/nova-scotia/halifax-company-first-in-nova-scotia-to-harvest-single-cell-organisms-1.5940247

70 (Dr. Lenore Newman "University of the Fraser Valley", Personal Communication, 2021)

71 (Dr. Lenore Newman "University of the Fraser Valley", Personal Communication, 2021)

72 ISED Canada. (2021, February 12). Canada's Protein Industries Supercluster. https://www.ic.gc.ca/eic/site/093.nsf/eng/00012.html

73 Ritchie, H. (2019). Half of the world's habitable land is used for agriculture. *Our World in Data*. https://ourworldindata.org/global-land-for-agriculture

74 Meticulous Market Research. (2020). *Alternative Protein Market is Expected to Grow at a CAGR of 9.5% to Reach $17.9 Billion by 2025- Meticulous Research®*. https://www.globenewswire.com/news-release/2020/02/03/1978845/0/en/Alternative-Protein-Market-is-Expected-to-Grow-at-a-CAGR-of-9-5-to-Reach-17-9-Billion-by-2025-Meticulous-Research.html

75 Good Food Institute. (2021). *Alternative Protein Company Database*. https://gfi.org/resource/alternative-protein-company-database/

76 (Dr. Lenore Newman “University of the Fraser Valley”, Personal Communication, 2021)

77 (Dr. Lenore Newman “University of the Fraser Valley”, Personal Communication, 2021)

78 Kadzere, C. T., Murphy, M. R., Silanikove, N., & Maltz, E. (2002). Heat stress in lactating dairy cows: A review. *Livestock Production Science*, 77(1), 59–91. https://doi.org/10.1016/S0301-6226(01)00330-X

79 Ballard, J. (2021, August 23). Drought in B.C. has caused a hay shortage—And that’s forcing ranchers to consider thinning herds. *CBC*. https://www.cbc.ca/news/canada/british-columbia/bc-drought-hay-shortage-farmers-cattle-1.6145551

80 (Dr. Lenore Newman “University of the Fraser Valley”, Personal Communication, 2021)

81 (VP Corporate Affairs Greg Northey “Pulse Canada” Personal Communication 2021)

82 (Dr. Lenore Newman “University of the Fraser Valley”, Personal Communication, 2021)

83 (Dr. Lenore Newman “University of the Fraser Valley”, Personal Communication, 2021)

84 Innovation, Science and Economic Development Canada. (2018). *Report of Canada’s Economic Strategy Tables: Agri-food*. https://www.ic.gc.ca/eic/site/098.nsf/eng/00022.html

85 Poore, J., & Nemecek, T. (2018). Reducing food’s environmental impacts through producers and consumers. *Science,* 360(6392), 987–992. https://doi.org/10.1126/science.aaq0216

86 Gan, Y., Liang, C., Chai, Q., Lemke, R. L., Campbell, C. A., & Zentner, R. P. (2014). Improving farming practices reduces the carbon footprint of spring wheat production. *Nature Communications*, 5(1), 5012. https://doi.org/10.1038/ncomms6012

87 Drever, C. R., Cook-Patton, S. C., Akhter, F., Badiou, P. H., Chmura, G. L., Davidson, S. J., Desjardins, R. L., Dyk, A., Fargione, J. E., Fellows, M., Filewod, B., Hessing-Lewis, M., Jayasundara, S., Keeton, W. S., Kroeger, T., Lark, T. J., Le, E., Leavitt, S.M., LeClerc, M.-E., … Kurz, W. A. (2021). Natural climate solutions for Canada. *Science Advances*, *7*(23), 6034. https://doi.org/10.1126/sciadv.abd6034; ECCC. (2019). *Canada’s Fourth Biennial Report on Climate Change. Government of Canada*. Gatineau, QC. https://www4.unfccc.int/sites/SubmissionsStaging/NationalReports/Documents/1687459_Canada-BR4-1-Canada%E2%80%99s%20Fourth%20Biennial%20Report%20on%20Climate%20Change%202019.pdf

88 IEA. (2020). *Aluminium*. Paris. https://www.iea.org/reports/aluminium

89 IEA. (2020). *Aluminium*. Paris. https://www.iea.org/reports/aluminium

90 Cole, W. J., & Frazier, A. (2019). Cost Projections for Utility-Scale Battery Storage (NREL/TP-6A20-73222, 1529218; p. NREL/TP-6A20-73222, 1529218). *National Renewable Energy Laboratory*. https://doi.org/10.2172/1529218

91 Energiapotior. (2021). How EnPot Works. https://www.energiapotior.com/how-enpot-works

92 Natural Resources Canada. (2021). *Aluminum Facts*. https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/aluminum-facts/2051

93 Elysis. (2021). *Rio Tinto and Alcoa announce world’s first carbon-free aluminum smelting process*. https://www.elysis.com/en/rio-tinto-and-alcoa-announce-worlds-first-carbon-free-aluminium-smelting-process

94 IEA. (2020). *Aluminium*. Paris. https://www.iea.org/reports/aluminium

95 Natural Resources Canada. (2021). *Aluminum Facts*. https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/aluminum-facts/2051

96 Patel, U. (2019). Aluminium vs plastic: Who’ll win the water bottle war? *Wood Mackenzie*. https://www.woodmac.com/news/feature/aluminium-vs-plastic-who-will-win-the-water-bottle-war/

97 Patel, U. (2019). Aluminium vs plastic: Who’ll win the water bottle war? *Wood Mackenzie*. https://www.woodmac.com/news/feature/aluminium-vs-plastic-who-will-win-the-water-bottle-war/

98 Patel, U. (2019). Aluminium vs plastic: Who’ll win the water bottle war? *Wood Mackenzie*. https://www.woodmac.com/news/feature/aluminium-vs-plastic-who-will-win-the-water-bottle-war/

99 IEA. (2020). *Aluminium*. Paris. https://www.iea.org/reports/aluminium

100 Government of Canada. (2020). *Indicator: Exports of forest products*. https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/state-canadas-forests-report/how-does-forest-sector-contribut/indicator-exports/16558

101 Stinson, G., & Freedman, B. (2001). *Potential for carbon sequestration in Canadian forests and agroecosystems. Mitigation and Adaptation Strategies for Global Change*, 6(1-23), 24. https://doi.org/10.1023/A:1011396115488

102 Drever, C. R., Cook-Patton, S. C., Akhter, F., Badiou, P. H., Chmura, G. L., Davidson, S. J., Desjardins, R. L., Dyk, A., Fargione, J. E., Fellows, M., Filewod, B., Hessing-Lewis, M., Jayasundara, S., Keeton, W. S., Kroeger, T., Lark, T. J., Le, E., Leavitt, S. M., LeClerc, M.-E., … Kurz, W. A. (2021). Natural climate solutions for Canada. *Science Advances*, *7*(23), 6034. https://doi.org/10.1126/sciadv.abd6034

103 Natural Resources Canada. (2020). *Indicator: Forest carbon emissions and removals*. https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/state-canadas-forests-report/how-does-disturbance-shape-canad/indicator-carbon-emissions-removals/16552

104 Natural Resources Canada. (2020). *Indicator: Forest carbon emissions and removals*. https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/state-canadas-forests-report/how-does-disturbance-shape-canad/indicator-carbon-emissions-removals/16552

105 Sustainable Lumber Co.. (2013). *Pine Beetles Kill Forests Builders Seek to Use the Wood*. https://www.sustainablelumberco.com/2013/01/pine-beetles-kill-forests-builders-seek-to-use-the-wood/

106 Carbon Leadership Forum. (2020, March 24). *The Embodied Carbon in Construction Calculator (EC3) Tool*. https://carbonleadershipforum.org/what-we-do/initiatives/ec3/

107 National Sciences and Engineering Research Council of Canada. (2018). *NSERC Strategic Network on Innovative Wood Productions and Building Systems*. https://www.nserc-crsng.gc.ca/Business-Entreprise/How-Comment/Networks-Reseaux/newbuilds-newbuilds_eng.asp

108 Koberstein, P., & Applegate, J. (2019, May 23). Tall and old or dense and young: Which kind of forest is better for the climate? *Mongabay*. https://news.mongabay.com/2019/05/tall-and-old-or-dense-and-young-which-kind-of-forest-is-better-for-the-climate/

109 Breneman, S., Timmers, M., Richardson, D. (2019). *Tall Wood Buildings in the 2021 IBC Up to 18 Stories of Mass Timber.* Wood Works – Wood Product Council. https://www.woodworks.org/wp-content/uploads/wood_solution_paper-TALL-WOOD.pdf

110 Anderson, R., Atkins, D., Beck, B., Dawson, E., & Gale, C. (2020). *State of the Industry North American Mass Timber The Beck Group*. 6.

111 Anderson, R., Dawson, E., & Muszynski, L. (2021). *International Mass Timber Report*. 50.

112 Anderson, R., Atkins, D., Beck, B., Dawson, E., & Gale, C. (2020). *State of the Industry North American Mass Timber The Beck Group*. 6.

113 Carbon Leadership Forum. (2020, March 24). *The Embodied Carbon in Construction Calculator (EC3) Tool*. https://carbonleadershipforum.org/what-we-do/initiatives/ec3/

114 The Standing Senate Committee on Energy, and the Environment and Natural Resources. (2018). *Decarbonizing Heavy Industry:* The Low-Carbon Transition of Canada's Emission-Intensive and Trade-Exposed Industries. *The Senate of Canada*. https://sencanada.ca/content/sen/committee/421/ENEV/reports/2018-03-23_EITE_FINAL_WEB_e.pdf

115 The Standing Senate Committee on Energy, and the Environment and Natural Resources. (2018). *Decarbonizing Heavy Industry:* The Low-Carbon Transition of Canada's Emission-Intensive and Trade-Exposed Industries. *The Senate of Canada*. https://sencanada.ca/content/sen/committee/421/ENEV/reports/2018-03-23_EITE_FINAL_WEB_e.pdf

116 Hassan, S. M. N. (2005). *Techno-Economic Study of CO_2 Capture Process for Cement Plants*. https://www.collectionscanada.gc.ca/obj/s4/f2/dsk3/OWTU/TC-OWTU-544.pdf

117 Barkley, Y. (n.d.). Salvage Logging after a Wildfire (UI Extension Forestry Information Series). Retrieved September 9, 2021. *University of Idaho*. https://www.uidaho.edu/-/media/UIdaho-Responsive/Files/Extension/topic/forestry/Salvage-logging-F11.pdf?la=en&hash=AE422322B8CA5AF3624C3126D7E0C3D0D7236629; Barkley, Y. (2015). After the Burn Assessing and Managing Your Forestland After a Wildfire. University of Idaho. https://www.fs.usda.gov/rmrs/documents-and-media/after-burn-assessing-and-managing-your-forestland-after-wildfire

118 Simmons, L. A., & Anderson, S. H. (2016). Effects of logging activities on selected soil physical and hydraulic properties for a claypan landscape. *Geoderma*, 269, 145–152. https://doi.org/10.1016/j.geoderma.2016.02.005

119 There is a similar opportunity structure in battery metals, plastics, synfuels, hydrogen, fertilizers, alternative proteins, and more.

120 University of Idaho. (2016). *Alternative Fuel Production and Distribution from Woody Biomass in the Inland Northwest: A Profit Analysis*. *University of Idaho*. https://www.uidaho.edu/-/media/UIdaho-Responsive/Files/cals/college/services/grant-project-development/alternative-fuel-production-distribution-from-woody-biomass.pdf?la=en&hash=304816CA90075F1A1FC1C4AC6341CB360FA95C8D

121 Barrette, J., Pare, D., Manka, F., Guindon, L., Bernier, P., & Titus, B. (2018). Forecasting the spatial distribution of logging residues across the Canadian managed forest. *Canadian Journal of Forest Research*, *48*(12). https://doi.org/10.1139/cjfr-2018-0080; Natural Resources Canada. (2020). *Indicator: Forest carbon emissions and removals*. https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/state-canadas-forests-report/how-does-disturbance-shape-canad/indicator-carbon-emissions-removals/16552; Statistics Canada. (2020). *Chart 3 Turbo fuel consumed, Canadian air carriers, Level I*. https://www150.statcan.gc.ca/n1/daily-quotidien/200730/cg-b003-eng.htm

122 Malins, C. (2011, November). IFPRI-MIRAGE 2011 Modelling of Indirect Land Use Change: Briefing on Report for the European Commission Directorate General for Trade. *The International Council on Clean Transportation*.

123 Malins, C. (2011, November). IFPRI-MIRAGE 2011 Modelling of Indirect Land Use Change: Briefing on Report for the European Commission Directorate General for Trade. *The International Council on Clean Transportation*.

124 Giuntoli, J. (2020). Forest Bioenergy and Canada 'Clean Fuel Standard': Potential carbon impacts. Report produced for the International Council on Clean Transportation.

125 Giuntoli, J. (2020). Forest Bioenergy and Canada 'Clean Fuel Standard': Potential carbon impacts. Report produced for the International Council on Clean Transportation.

126 Natural Resources Canada. (2020). *Indicator: Forest carbon emissions and removals*. https://www.nrcan.gc.ca/our-natural-resources/forests-forestry/state-canadas-forests-report/how-does-disturbance-shape-canad/indicator-carbon-emissions-removals/16552

127 Durufle, G., & Carbonneau, L. (2016). Forging a Cleaner and More Innovative Economy in Canada. Sustainable Development Technology Canada, *Cycle Capital Management*. 15,20.

128 Durufle, G., & Carbonneau, L. (2016). Forging a Cleaner and More Innovative Economy in Canada. Sustainable Development Technology Canada, *Cycle Capital Management*. 15,20.

129 Green Centre Canada. (2020). *Entrepreneurs*. https://greencentrecanada.com/working-with-us/entrepreneurs/

130 (Executive Director Dr.Andrew Pasternak 'Green Centre Canada' Personal Communication 2021)

131 (Executive Director Dr.Andrew Pasternak 'Green Centre Canada' Personal Communication 2021)

132 Le Feuvre, P. (2019, March 18). *Are aviation biofuels ready for take off?* https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off

133 IEA. (2021). *Net Zero by 2050—A Roadmap for the Global Energy Sector*. 57.

134 Energy Transitions Commission. (2018). *Mission Possible Reaching Net-Zero Carbon Emissions From Harder-To-Abate Sectors By Mid-Century*. https://www.energy-transitions.org/publications/mission-possible/

135 Energy Transitions Commission. (2020). *Mission Possible: Sectoral Focus Aviation*. https://www.energy-transitions.org/wp-content/uploads/2020/08/ETC-sectoral-focus-Aviation_final.pdf

136 International Civil Aviation Organization. (2020). *The World of Air Transport in 2019*. https://www.icao.int/annual-report-2019/Pages/the-world-of-air-transport-in-2019.aspx

137 gevo. (2019). *SUSTAINABLE AVIATION FUEL: Alcohol-to-Jet Synthetic Paraffinic Kerosene Is a Proven Pathway to Deliver a Bio-Based, Low-Carbon Option to Travelers. December 2019*. https://gevo.com/wp-content/uploads/2020/05/Gevo-Whitepaper-Sustainable-Aviation-Fuel.pdf

138 Research And Markets. (10/20). *Sustainable Aviation Fuel Market by Fuel Type (Biofuel, Hydrogen Fuel, Power to Liquid Fuel), Biofuel Manufacturing Technology, Biofuel Blending Capacity, Platform, Region—Forecast to 2030*.

139 Le Feuvre, P. (2019, March 18). *Are aviation biofuels ready for take off?* https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off

140 N. Sönnichsen. (2019). *Largest hydroelectric power generating countries worldwide in 2019*. https://www.statista.com/statistics/474799/global-hydropower-generation-by-major-country/; Natural Resources Canada (2020). *Hydrogen Strategy for Canada*. https://www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen%20Strategy%20for%20Canada%20Dec%2015%202200%20clean_low_accessible.pdf

141 Bloomberg New Energy Finance. (2020). *Hydrogen Economy Outlook Key Messages*. https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

142 Sachs, J. D. (2018a). Eurasia on the Rise America on the Sidelines. In *A New Foreign Policy* (pp. 62–64). Columbia University Press.

143 Radwanski, A. (2021, March 15). Canada to sign agreement with Germany on joint push to develop hydrogen market. *The Globe And Mail*. https://www.theglobeandmail.com/business/article-canada-to-sign-agreement-with-germany-on-joint-push-to-develop/

144 Bloomberg New Energy Finance. (2021). *1H 2021 Hydrogen Market Outlook: A Defining Year Ahead*.

145 eurostat. (2020). *Water Statistics*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Water_statistics#Water_abstraction; Fuel Cells and Hydrogen Joint Undertaking. (2019). *Hydrogen Roadmap Europe A Sustainable Pathway for the European Energy Transition*. https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf

146 Bloomberg New Energy Finance. (2020). *Hydrogen Economy Outlook Key Messages*. https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

147 ZEN and the art of Clean Energy Solutions, BET, & G&S Budd Consulting Ltd. (2020). *British Columbia Hydrogen Study*. https://www2.gov.bc.ca/assets/gov/government/ministries-organizations/zen-bcbn-hydrogen-study-final-v6.pdf

148 Nel. (2021, January 21). *Nel Capital Markets Day*; Thyssenkrupp. (2020, August 6). *Green hydrogen: Thyssenkrupp expands production capacities for water electrolysis to gigawatt scale*. https://www.thyssenkrupp.com/en/newsroom/press-releases/pressdetailpage/green-hydrogen--thyssenkrupp-expands-production-capacities-for-water-electrolysis-to-gigawatt-scale-82759

149 Bloomberg New Energy Finance. (2020). *Hydrogen Economy Outlook Key Messages*. https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

150 Janssen, D. (2020, October 13). Europe, China battle for global supremacy on electrolyser manufacturing. *EURACTIV.Com*. https://www.euractiv.com/section/energy/news/europe-china-battle-for-global-supremacy-on-electrolyser-manufacturing/; VentureRadar (2021). Top Electrolysis Companies. https://www.ventureradar.com/keyword/electrolysis?#

151 Det Norske Veritas group. (2021.). *Energy Transition Outlook 2021 Technology Progress Report*. https://eto.dnv.com/2021/technology-progress-report/about

152 Planetary Hydrogen. (2021). *Technology*. https://www.planetarytech.com/technology/

153 Bloomberg New Energy Finance. (2020). *Hydrogen Economy Outlook Key Messages*. https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

154 ZEN and the art of Clean Energy Solutions, BET, & G&S Budd Consulting Ltd. (2020). *British Columbia Hydrogen Study*. https://www2.gov.bc.ca/assets/gov/government/ministries-organizations/zen-bcbn-hydrogen-study-final-v6.pdf

155 ZEN and the art of Clean Energy Solutions, BET, & G&S Budd Consulting Ltd. (2020). *British Columbia Hydrogen Study*. https://www2.gov.bc.ca/assets/gov/government/ministries-organizations/zen-bcbn-hydrogen-study-final-v6.pdf

156 Charisius, C. (2021, March 15). Canada to Sign Agreement with Germany on Joint Push to Develop Hydrogen Market. *The Globe And Mail*. https://www.theglobeandmail.com/business/article-canada-to-sign-agreement-with-germany-on-joint-push-to-develop/

157 Bloomberg New Energy Finance. (2020). *Hydrogen Economy Outlook Key Messages*. https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

158 Bloomberg New Energy Finance. (2020). *Hydrogen Economy Outlook Key Messages*. https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

159 Bloomberg New Energy Finance. (2020). *Hydrogen Economy Outlook Key Messages*. https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

160 Bloomberg New Energy Finance. (2020). *Hydrogen Economy Outlook Key Messages*. https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

161 ECCC. (2019). Canada's Fourth Biennial Report on Climate Change. *Government of Canada*. Gatineau, QC. https://www4.unfccc.int/sites/SubmissionsStaging/NationalReports/Documents/1687459_Canada-BR4-1-Canada%E2%80%99s%20Fourth%20Biennial%20Report%20on%20Climate%20Change%202019.pdf

162 Talaie, A., Switzer, J.,Hastings-Simon, S.& Mellor, B. (2020). *The Carbontech Innovation System in Canada*. https://cmcghg.com/wp-content/uploads/2020/12/Carbontech-Innovation-System-online.pdf

163 Natural Resources Canada (2020). Hydrogen Strategy for Canada. https://www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen%20Strategy%20for%20Canada%20Dec%2015%202200%20clean_low_accessible.pdf

164 Natural Resources Canada (2020). Hydrogen Strategy for Canada. https://www.nrcan.gc.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen%20Strategy%20for%20Canada%20Dec%2015%202200%20clean_low_accessible.pdf

165 Whitecap Resources Inc (2020). *Weyburn Unit a Responsible Energy Story*. https://www.wcap.ca/sustainability/co2-sequestration

166 McGlade, C. (2019). *Can CO_2-EOR really provide carbon-negative oil?*. https://www.iea.org/commentaries/can-co2-eor-really-provide-carbon-negative-oil

167 Talaie, A., Switzer, J.,Hastings-Simon, S.& Mellor, B. (2020). *The Carbontech Innovation System in Canada*. https://cmcghg.com/wp-content/uploads/2020/12/Carbontech-Innovation-System-online.pdf

168 Kelly, A.,Sanguinetti, D., Mellor, B. & Shin, R. (2021). *Exporting CCUS Technology: An international business development strategy for Canadian carbon capture, utilization, and storage companies*. https://foresightcac.com/wp-content/uploads/2021/04/Exporting-CCUS-Technology_Report-1-1.pdf

169 Talaie, A., Switzer, J.,Hastings-Simon, S.& Mellor, B. (2020). *The Carbontech Innovation System in Canada*. https://cmcghg.com/wp-content/uploads/2020/12/Carbontech-Innovation-System-online.pdf

170 IEA. (2020). *Direct Air Capture*. https://www.iea.org/reports/direct-air-capture

171 Realmonte, G., Drouet, L., Gambhir, A., Glynn, J., Hawkes, A., Köberle, A. C., & Tavoni, M. (2019). An inter-model assessment of the role of direct air capture in deep mitigation pathways. *Nature communications*, *10*(1), 1-12. doi: 10.1038/s41467-019-10842-5

172 Global CCS Institute (2021). CO_2RE Database - Facilities Report. https://co2re.co/FacilityData

173 Markets & Markets (2021). *Carbon Capture, Utilization, and Storage Market*. https://www.marketsandmarkets.com/Market-Reports/carbon-capture-utilization-storage-market-151234843.html

174 Abdulla, A., Hanna, R., Schell, K. R., Babacan, O., & Victor, D. G. (2020). Explaining successful and failed investments in US carbon capture and storage using empirical and expert assessments. *Environmental Research Letters*, 16(1), 014036. https://doi.org/10.1088/1748-9326/abd19e

175 Jaccard, M. & Griffin, B. (2021). *A Zero-Emission Canadian Electricity System by 2035*. https://davidsuzuki.org/wp-content/uploads/2021/08/Jaccard-Griffin-Zero-emission-electricity-DSF-2021.pdf

176 Bataille, C. et al. (2015). *Pathways to Deep Decarbonization in Canada, SDSN - IDDRI*. https://www.iddri.org/sites/default/files/old/Publications/CAN_DDPP_report.pdf

177 Hund, K., La Porta, D., Fabregas, T., & Drexhage, J. (2020). *Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition*. World Bank. https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

178 The White House. (2021). *Building Resilient Supply Chains, Revitalizing American Manufacturing, And Fostering Broad-Based Growth* https://www.whitehouse.gov/wp-content/uploads/2021/06/100-day-supply-chain-review-report.pdf

179 (Senior Policy Analyst Nadim Kara 'NRCAN', Personal Communication, 2021)

180 International Carbon Action Partnership. (2021, August 13). *International Carbon Action Partnership Access ETS Profiles*. https://icapcarbonaction.com/en/

181 International Carbon Action Partnership. (2021, August 13). *International Carbon Action Partnership Access ETS Profiles*. https://icapcarbonaction.com/en/

182 Drever, C. R., Cook-Patton, S. C., Akhter, F., Badiou, P. H., Chmura, G. L., Davidson, S. J., Desjardins, R. L., Dyk, A., Fargione, J. E., Fellows, M., Filewod, B., Hessing-Lewis, M., Jayasundara, S., Keeton, W. S., Kroeger, T., Lark, T. J., Le, E., Leavitt, S. M., LeClerc, M.-E., … Kurz, W. A. (2021). Natural climate solutions for Canada. *Science Advances*, *7*(23), eabd6034. https://doi.org/10.1126/sciadv.abd6034

183 Liu, H. (2021). *I*n-depth Q&A: Will China's emissions trading scheme help tackle climate change?. *Carbon Tracker* https://www.carbonbrief.org/in-depth-qa-will-chinas-emissions-trading-scheme-help-tackle-climate-change; Tooze, A. (2021, August 6). Present at the Creation of a Climate Alliance—Or Climate Conflict. *Foreign Policy*.

184 Clean Growth: The UK Carbon Capture Usage and Storage deployment pathway—An Action Plan. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/759637/beis-ccus-action-plan.pdf

185 Wolfe, D. (2015). "Introduction to the Carleton Library Series Edition" of Richard G. Harris, *Trade, Industrial Policy, and International Competition, Second. McGill-Queen's University Press.* https://49thshelf.com/Books/T/Trade-Industrial-Policy-and-International-Competition-Second-Edition3.

186 Schrank, A., & Whitford, J. (2011). The anatomy of network failure. *Sociological Theory*, *29*(3), 151-177; Samford, S., & Breznitz, D. (2022). Mending the net: Public strategies for the remediation of network failures. *Social Forces*, *100*(3), 1333-1356.

187 We ignore for present purposes the legitimate questions concerning practical and legal obstacles to carbon border adjustments. Some discussion of these can be found in Cosbey, A., Bernstein, M. and Stiebert, S. (2021). "Enabling Climate Ambition: Border Carbon Adjustment in Canada and Abroad." International Institute for Sustainable Development. https://www.iisd.org/publications/enabling-climate-ambition-border-carbon-adjustment-canada and also Böhringer, Christoph, Carolyn Fischer, Knut Einar Rosendahl, and Thomas Fox Rutherford. 2022. "Potential Impacts and Challenges of Border Carbon Adjustments." *Nature Climate Change 12 (1): 22–29.* https://doi.org/10.1038/s41558-021-01250-z.

188 Helper, S., Krueger, T. (2015). Supply chains and equitable growth. https://equitablegrowth.org/report/supply-chains-and-equitable-growth/

189 More detail on the Push-Pull-Grow-Strengthen policy framework to support clean innovation can be found in Brownlee, M., Elgie, S., and Scott, W. (2018). "Canada's next Edge: Why Clean Innovation Is Critical to Canada's Economy and How We Get It Right." Discussion Paper. Smart Prosperity Institute, https://institute.smartprosperity.ca/library/publications/canada-s-next-edge-why-clean-innovation-critical-canada-s-economy-and-how-we.

190 Sabel, C. and Victor D.G. 2021. How to Fix the Climate. *Boston Review*. https://bostonreview.net/forum/charles-sabel-david-g-victor-how-fix-climate/

191 Evans, P. B. (1995). *Embedded autonomy*. Princeton University Press; Chang, H. J., Andreoni, A., and Kuan, M. L. (2013). International industrial policy experiences and the lessons for the UK. Future of Manufacturing Project: Evidence Paper 4; Rodrik, D. (2014). Green industrial policy. *Oxford Review of Economic Policy*, *30*(3), 469–491. https://doi.org/10.1093/oxrep/gru025

192 Hall, B. and Milne, R. (2019). Europe First: how Brussels is retooling industrial policy. The Financial Times. https://www.ft.com/content/140e560e-0ba0-11ea-bb52-34c8d9dc6d84

193 Golden, J. M. and Wiseman, H.J. (2015). The Fracking Revolution: Shale Gas as a Case Study in Innovation Policy. Emory Law Journal 64(4).

194 Wilt, J. (2018). A brief history of the public money propping up the Alberta oilsands. The Narwhal. https://thenarwhal.ca/brief-history-public-money-propping-alberta-oilsands/

195 Emission Reduction Alberta. (2020). *Partnership Intake Program*. https://eralberta.ca/funding-technology/partnership-intake-program/

196 Emission Reduction Alberta. (2020). *Partnership Intake Program*. https://eralberta.ca/funding-technology/partnership-intake-program/

197 Emission Reduction Alberta. (2020). *Partnership Intake Program*. https://eralberta.ca/funding-technology/partnership-intake-program/

Smart Prosperity Institute

The Transition Accelerator

PICS
PACIFIC INSTITUTE FOR CLIMATE SOLUTIONS

1 Stewart St. (3rd Floor)
Ottawa, ON K1N 6N5