DESIGNING A MARKETPLACE FRAMEWORK FOR FUTURE-FIT HYDROCARBONS

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Smart Prosperity Institute

energyfutureslab
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The Energy Futures Policy Collaborative is a new and exciting initiative developed by the Max Bell Foundation and the Energy Futures Lab to explore how Alberta and Canada can harness its existing hydrocarbon resources, assets, and expertise to build the clean economy of the future. Smart Prosperity Institute is a member of the Working Group, and is serving as a strategic advisor on the project.

About Energy Futures Lab

The Energy Futures Lab is an award-winning, multi-stakeholder initiative to accelerate the transition to the energy system that the future requires of us. Initiated in the Fall of 2013, the Energy Futures Lab is powered by The Natural Step Canada, in collaboration with a number of Convening Partners and Funding Partners. The EFL also involves dozens more organizations in an unprecedented series of innovative partnerships and collaborations.

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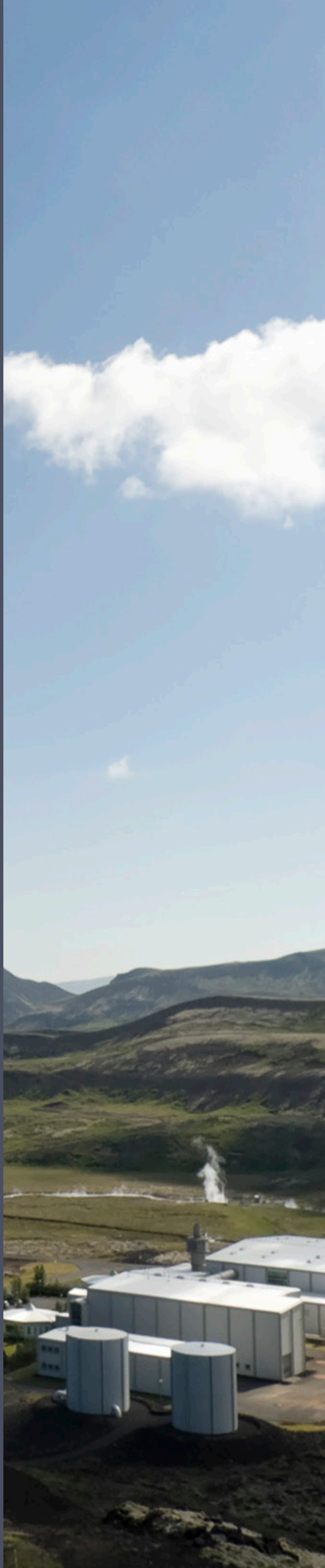
About Smart Prosperity Institute

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.



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Introduction

As the world shifts towards lower-carbon energy systems, Alberta faces the challenge of reducing its economic reliance on supplying hydrocarbons for combustion. Alberta has the opportunity to develop new industries which are compatible with climate change targets, but also take advantage of the assets which have developed around Alberta's hydrocarbon industry, including financial and technical expertise, intellectual property, and infrastructure. There is a diverse range of proposals for prospective future fit hydrocarbon (FFH) industries in Alberta, many of which are already being pursued by federal and provincial government actors.

This policy brief makes the case that federal and provincial governments need to act to encourage investment in FFH industries, and presents a framework for how they might do so. This marketplace framework is based on a rigorous, peer-reviewed Clean Innovation Framework developed by the Smart Prosperity Institute, which identifies how public policies can support the growth and adoption of clean technologies, processes, and business models at various stages of the innovation cycle.

The marketplace framework identifies four categories of policy that need to be present to encourage investment in FFH industries:

- Policies to **generate new ideas** (such as funding or fiscal support for research, development and demonstration)
- Policies to **generate demand** (such as carbon pricing and standards, public procurement, or public infrastructure investment)
- Policies to **drive firm growth** (such as de-risking private investment or offering investor incentives)
- Policies to **encourage a healthy innovation system** (such as strategic coordination or data-sharing initiatives)

The marketplace framework shares best practices for designing policies in each category and ensuring policies from different categories work together. To illustrate, it discusses specific policy levers that are available to federal and provincial governments to support investment in clean hydrogen, an example of a scalable FFH industry.

What are future-fit hydrocarbon industries?

This brief uses the term "FFH industries" to refer to a diverse group of economic diversification proposals for Alberta with two common features. The first is the potential to repurpose assets from Alberta's hydrocarbon cluster -- from hydrocarbon resources, to infrastructure, to workforce skills, to intellectual property. The second is its compatibility with societal objectives for the future, or "future fitness". In this brief, we define future fitness based on compatibility with a net-zero emissions future. Future fitness is determined by: a technology's or process' life cycle carbon intensity, its ability to reduce the carbon intensity of Alberta's economy and exports, and its ability to drive global decarbonization. There are many other important societal objectives that determine future fitness, but we focus on compatibility with climate change objectives recognizing that it is a necessary component of future fitness, even if it is not sufficient alone.

Examples of future-fit hydrocarbon industries

Clean hydrogen

Hydrogen is a versatile energy carrier with a wide range of potential uses, from industrial feedstock to transportation to heating to energy storage. Clean hydrogen, produced with no or low greenhouse gas emissions, has great potential to decarbonize the global economy. By 2050, hydrogen end use could reach $47 billion CAD per year domestically and $102.7 billion CAD per year including US and overseas markets[1].

Alberta may be well positioned to become a low-cost producer of clean hydrogen.[2] Currently, Alberta can produce cheap blue hydrogen through reforming of natural gas with carbon capture and storage or use (CCUS). Alberta has abundant, cheap natural gas, of which the oil industry is currently the largest consumer. It is also home to a nascent CCUS cluster, as discussed in the next section. Alberta's engineering expertise and renewable energy resources could also allow the province to produce green hydrogen with renewable electricity or hydrogen from biomass gasification. Green hydrogen is currently more expensive than blue hydrogen, but this may change as early as 2030[3].

Using hydrogen currently makes the most economic sense for geographically-concentrated clusters of users due to transportation and distribution costs. Alberta has the advantage of having a concentrated cluster of industries that already use hydrogen as an input, including ammonia fertilizer, bitumen conversion, and petroleum refining, as well as some hydrogen pipelines. With abundant renewable energy resources, Alberta could develop hydrogen use for long-term energy storage. Alberta may also be an appropriate environment for other hydrogen applications which are competing with electrified end-uses, such as long-distance heavy-duty freight transportation in cold climates.

Carbon Capture, Utilization and Storage (CCUS)

The removal of carbon from the atmosphere or from industrial facilities' emissions will likely be an important part of meeting climate change objectives[4]. The technologies to do this are maturing, but business models to drive widespread carbon capture and permanent storage, particularly as fossil fuel production and consumption decline, are still being worked out. Enhanced oil recovery has been the main commercial use for captured carbon so far; others include synthetic fuels, cement, and carbon fibre. However, these uses have not yet created large enough revenue streams to fund carbon capture without substantial government support.
Alberta has developed an early advantage in CCUS. In particular, the provincial and federal governments and hydrocarbon and petrochemical industries have funded the removal of carbon dioxide from industrial emissions and use of carbon for enhanced oil recovery. Alberta has developed sophisticated expertise and infrastructure in these areas, including the Alberta Carbon Trunk Line.
In contrast, atmospheric carbon capture has received little support in the province, although this may change with Canada's net-zero commitment. Alberta's geology is conducive to carbon storage, with many large aquifers near the surface. Many assets from Alberta's hydrocarbon cluster, from subsurface data and expertise to engineering expertise, could be repurposed towards a CCUS industry.

Geothermal power

Alberta has large geothermal resources with the potential to provide emissions-free power and heat to nearby communities and industrial facilities. Alberta's geothermal industry could repurpose many assets from the hydrocarbon cluster, including: subsurface data; expertise in drilling, subsurface thermodynamics and 3D mapping; and even active or inactive oil wells[5]. These complementarities are already being exploited: most geothermal ventures in Alberta have a prior connection to the oil and gas industry[6].

1 Layzell et al (2020a)
2 APERC (2018)
3 Bloomberg New Energy Finance (2021)
4 Babiker et al (2018)
5 Leitch et al (2019)
6 ibid

Lithium

Lithium ion batteries are currently a frontrunner in electric vehicle technology and lithium may be in short supply if current trajectories continue[7]. Lithium demand has been forecasted to grow 18% per year to 2030[8]. Alberta has a large, low-concentration lithium resource in subsurface brine[9] and several firms have developed techniques to extract it either from oil and gas operations' wastewater or from dedicated extraction of lithium-enriched brine[10]. A lithium industry in Alberta could repurpose many of the existing hydrocarbon cluster's assets. These include: subsurface data and expertise in drilling; subsurface thermodynamics; 3D mapping; and, moving large quantities of brine; active or inactive oil wells; roads, pipelines and well pads; industrial carbon capture facilities; and supporting industries such as environmental services.

Carbon fibre

Alberta Innovates has issued a Grand Challenge to commercialize the manufacture of carbon fibre from bitumen and bitumen-derived asphaltenes. The technologies and processes to do this at scale, at a competitive price, and with acceptably low life cycle emissions have not yet been developed. However, if these are realized, demand could reach 246,500 tons per year by 2030 according to a report commissioned by Alberta Innovates[11]. If these technologies were commercialized, a carbon fibre industry could repurpose Alberta's bitumen resources and substantial expertise in bitumen extraction and processing. Alternatively, carbon fibre could be made from captured carbon.

Why do we need a marketplace framework?

If firms in Alberta are to stay competitive in a decarbonizing world, they need to act quickly. But realizing any of the opportunities outlined above at the necessary scale and speed will also require government support, for two main reasons. First, there are market barriers to innovation in general, and clean innovation in particular, which only governments can correct. Second, many FFH industries rely on disruptive, mission-driven innovations, rather than incremental ones. For example, a cost-effective system for transporting large quantities of clean hydrogen will not emerge from incremental innovation.

This all means that FFH industries need public policies to encourage new ideas, bolster early demand, help companies grow, establish priorities, and facilitate knowledge-sharing. This section further explains why government support is needed, while the next section gives more detail on what governments can do.

Market failures

There are a suite of market failures that discourage innovation in FFH industries, even though there is demand for this innovation. If innovation in FFH industries is to meet demand, governments must address these barriers:

- **Knowledge spillovers**:In the early stages of research and development, when researchers discover something new, their findings and knowledge may, at least in part, 'spill over' to benefit other researchers, firms, or sectors. As a result, they may be unable to capture the full value of their discoveries. This well-documented market failure leads to an under provision of research and development. As a result, innovation takes place at a lower than optimal level.

- **Environmental externality**: Typically, the prospect of profits attracts investors and businesses to finance the commercialization of new ideas and inventions. In the case of innovation for improved environmental performance however, many of the benefits produced, such as lesser pollution and greenhouse gas emissions, have no market value because markets don't price most environmental costs and benefits. This results in little profit incentive to invest in or develop such solutions.

- **Information barriers**: FFH industries involve new technologies, processes, and business models, which investors and end users do not fully understand. This lack of understanding means they may hesitate to invest in these new technologies and struggle to assess their potential value.

7 Hund et al (2020)
8 Roskill (2020)
9 AER (2020)
10 Smith (2020)
11 Meisen (2017)

- **Reliance on policy**: Demand in FFH industries relies on government policies, such as carbon prices, which have a history of volatility. It is difficult to predict the future stringency of these policies, discouraging investment.

- **Capital intensiveness**: Many FFH industries require large capital investments in facilities, equipment, and infrastructure. Those which involve disruptive new technologies also tend to require long time horizons before investments pay off.

- **Policy non-alignment**: Policy non-alignment between provincial and federal governments creates uncertainty for investors in FFH industries. Climate change policy is the most important area of non-alignment, but these industries are also affected by other areas of policy which have conflicts with climate change policy, such as trade and financial policy.

- **Behavioural dynamics**: Several behavioural dynamics slow deployment and diffusion of FFH industry technologies even where they have positive economic returns. For example, landlords lack incentives to improve home heating efficiency when tenants pay the bill; people tend to over-discount future cost savings when making purchases; and people can be attached to old technologies even when they underperform.

- **Imperfect competition**: Many FFH technologies, processes, and business models face competition from incumbents with advantages such as market power, public subsidies, and preferential regulation.

Beyond "fixing" markets

While the conventional wisdom is that governments should focus on fixing market failures, there is evidence that they have a bigger role to play.

Looking forward, some FFH industries will require disruptive, rather than incremental, innovation if they are to scale. This is partially because mitigating climate change and developing a strong basis for economic activity in Alberta are both time sensitive. Even if we knew for certain that incremental innovation would eventually produce the technologies needed to mitigate climate change, this would not happen quickly enough. In addition, in many cases, disruptive innovation is needed to break lock-in to high carbon systems[12]. Private investors underinvest in disruptive innovation because of risks and uncertainty, since, as economist Dani Rodrik put it, "market prices cannot reveal the profitability of resource allocations that do not yet exist"[13].

In some cases, the best government response to a market failure may be to introduce another market imperfection[14]. This may be the case where a market failure cannot be corrected or where its correction will have negative side-effects. For example, knowledge spillovers are difficult to correct, even with strong intellectual property protections. Further, while knowledge spillovers discourage private investment in research and development, many of the innovations which have revolutionized energy systems, such as the steam engine, resulted from technologies being repurposed outside of their original use context. Rather than simply correcting knowledge spillovers, governments need to make strategic decisions about how to encourage research and development while also encouraging the diffusion and repurposing of new technologies.

Finally, governments have a role to play in identifying market failures. In reality, the size and magnitude of many market failures is not known by governments or private firms. Discovering and assessing market failures should be an ongoing, collaborative process between governments and industry[15].

Governments are well placed to lead disruptive innovation motivated by a public interest mission, for a few reasons. They are able to make riskier investments than the private sector. They also have the mandate to consider the public interest and to coordinate a multifaceted approach to advancing it. In Alberta, for example, the provincial government established the vision of exploiting the oil sands, took on the risk of financing research and development, and provided leadership and direction through the process, resulting in the development of steam-assisted gravity drainage[16].

12 Unruh (2000)
13 Rodrik (2008b)
14 Lipsey and Carlaw (2020)
15 ibid
16 Hastings-Simon (2019)

How can governments help?

Thoughtful government intervention to encourage investment in FFH industries is justified by the urgent need to address climate change and diversify Alberta's economy, the opportunities offered by FFH industries, and the barriers to private investment. But how can governments help?

Supporting FFH industries will be challenging because the best way to structure these industries is not yet clear. They will require new technologies, processes, and business models whose adoption is still accompanied by some risk. Some FFH industry proposals, such as making carbon fibre from bitumen, involve technologies which are still in development. Others, such as geothermal power, involve mature technologies which are still developing business models to support diffusion.

The example of clean hydrogen is illustrative of the fact that the precise opportunities associated with FFH industries are not yet clear. For example, we do not yet know which production technologies, export strategies, and end uses for clean hydrogen will deliver the best economic and environmental outcomes in Alberta, as detailed here:

Production technology: Producing "blue" hydrogen by reforming natural gas and capturing and storing the resulting carbon emissions is currently the cheapest, most mature technology for producing low-emissions hydrogen. Alberta also has a global advantage in blue hydrogen production. However, by 2030, "green" hydrogen from electrolysis with renewable power will likely be cheaper[17], will likely have a lower carbon intensity, and will not produce carbon which needs to be disposed of. Some studies suggest it will be cost competitive with blue hydrogen by 2030[18]. More nascent hydrogen production technologies, such as biomass gasification, also play an important role in the future in some projections[19]. Alberta could develop an advantage in green or biomass hydrogen, as it has abundant renewable energy and biomass resources as well as engineering expertise. Whether blue hydrogen can compete or coexist with other clean hydrogen sources will depend on several factors. Environmentally speaking, these include improvements in methane emissions control in upstream natural gas production, the carbon capture rate, and carbon storage and use technologies. Economically speaking, these include hydrogen trade and use patterns. Blue hydrogen can allow Alberta to deploy low-emissions hydrogen quickly in order to develop infrastructure and end uses, but it also has the potential to become economically and environmentally uncompetitive in the coming decades.

Export strategy: A viable FFH industry in Alberta will need to create export opportunities. When it comes to clean hydrogen, Alberta could export either hydrogen itself or the technologies that produce, transport, or use it (or both). It is still not clear how large the export market for hydrogen will be. Hydrogen can be transported inexpensively by pipeline, depending on volumes, distance, and blending. But its low energy density by volume means it must be compressed, liquified, or incorporated into a molecule such as ammonia before shipping by truck or boat. This significantly raises costs, depending on the technique used, distances, and mode of transport[20]. In addition, if international dynamics make supply chain and energy security a strategic priority for countries, some may pay extra to develop hydrogen locally. For countries like Japan and Korea, importing hydrogen will likely be significantly cheaper than local production, but these may be very competitive markets: countries around the world are developing hydrogen export strategies while many projections foresee limited international trade in hydrogen[21]. Overseas export markets will depend on developments in transportation and storage technologies, and all export markets will depend on the development of hydrogen end uses and of hydrogen production in other jurisdictions. Albertan hydrogen's ability to compete internationally will depend on its cost but also its carbon intensity. In this environment, it is not clear whether Alberta should focus its hydrogen export strategy on production, or follow the example of Germany and focus on exporting technologies, processes, and expertise for hydrogen production, transportation, and use[22].

End uses: Hydrogen has a broad range of potential end uses. In some uses, clean hydrogen can reduce emissions by replacing carbon-intensive fuels such as diesel or natural gas. In others, it can support activities which

17 IRENA (2020)
18 IHS Markit (2020) and Bloomberg New Energy Finance (2021)
19 Larson et al (2020)
20 IEA (2019)
21 BP (2020) and IEA (2020a)
22 Zen (2019)

reduce emissions - for example, by providing long-term storage for renewable power. For others still, it can reduce emissions by replacing carbon-intensive fuels but support activities that contribute to emissions - for example, by replacing grey hydrogen as a feedstock for bitumen upgrading or petroleum refining. The latter category presents a challenge for governments. On one hand, fuel switching for these activities can reduce emissions substantially. Further, the oil and gas industry has helped to develop hydrogen technologies and could be an important early market for clean hydrogen in Alberta. Similarly, the use of captured carbon for enhanced oil recovery (EOR) has driven research and market formation for carbon capture, transportation, and injection[23]. However, petroleum refining, bitumen upgrading, and EOR all support the continued extraction and combustion of fossil fuels, undermining climate objectives.

As the example of clean hydrogen illustrates, governments must perform a delicate balancing act when encouraging investment in FFH industries. On one hand, they should advance a variety of options, since success often comes from unexpected sources and supporting only one or two specific technologies is accompanied by a higher risk of failure. On the other hand, time and resources are limited, and governments should focus on the most promising pathways and quickly identify (and move on from) dead ends. While governments should not be in the business of picking winners, they need to be clear about what winning looks like.

Why a marketplace framework?

Governments have an important role to play in encouraging investment in FFH industries, but performing this role well requires careful policy design. The marketplace framework in this brief is a valuable guide for informing the design of these policies. Three characteristics make it particularly useful:

- **It looks at innovation through a systems lens.** Not all innovation consists of a linear progression through the stages of innovation, from research to diffusion. The framework recognizes the importance of facilitating learning between stages and provides guidance on how this can be done.
- **It treats innovation as a collaborative process between the public and private sector.** The framework provides guidance on where governments are well placed to act and where they should seek out private expertise and initiative.
- **It considers both technology and people.** The framework does not focus narrowly on advancing technological development. It also considers the social and economic factors that determine a technology's success.

23 Celia (2017)

This brief outlines the marketplace framework and illustrates how it could be used to encourage investment in FFH industries in Alberta. This marketplace framework is based on the Clean Innovation Framework, which was developed to inform how public policies can drive clean innovation. It identifies four types of government policies for most effectively unleashing industry initiatives for change: PUSH policies (to spur new ideas), PULL policies (to help create market demand for these solutions), GROW policies (to grow ideas into marketable products and services), and STRENGTHEN policies (to make the whole innovation system more effective and resilient).

PUSH policies focus on the early stages of innovation and generate ideas that carry through to later stages. They generally do two things. One, they incentivize private research initiatives, either through direct incentives (e.g., tax credits) or by helping firms capture the economic returns from that research (e.g., through intellectual property rights). Two, they supplement private research with public research through funding for government labs and universities.

PULL policies are particularly important in the commercialization phase of innovation. They generate market demand for innovations which might otherwise not appear profitable given that there is little market reward for solving problems (like pollution) that firms and households do not pay for in the first place (i.e., considered environmental externalities). PUSH and PULL policies work best when applied simultaneously. However, they are not sufficient. Two additional types of government support are required to completely encompass the innovation ecosystem.

GROW policies are the bridge between PUSH and PULL. They help take promising innovations from the R&D stage to the point where they are ready for market entry. They help entrepreneurs and firms secure financial and non-financial support required to turn their ideas into demonstration products and services and then scale up their solutions to meet market demand.

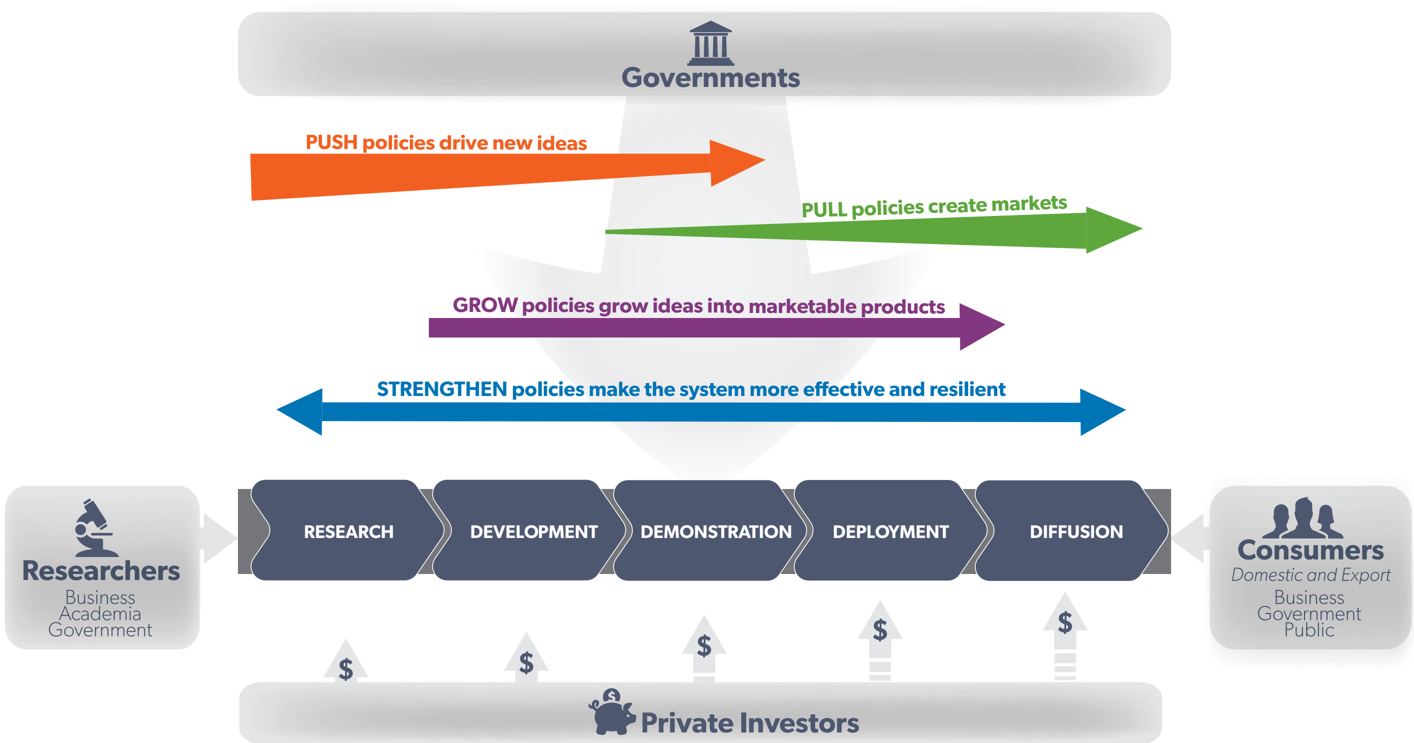

Figure 1: Smart Prosperity's Clean Innovation Framework

Finally, STRENGTHEN policies support the system as a whole. Government intervention to bolster this system includes: defining a clear vision and translating it into strategies, strengthening public institutions, building partnerships, investing in new skills, identifying and measuring key performance indicators and metrics, enriching the policy mix and ensuring accountability and continuity.

A marketplace framework for FFH in Alberta

PUSH

The FFH industries discussed in Section 2 all rely on new processes, technologies, and/or business models. Some industries, like geothermal energy, use mature technology but require new business models and processes to work in the Albertan context. Others, like carbon fibre, would depend on technological innovations that have yet to happen. Each FFH industry has different research, development and demonstration (RD&D) needs, but RD&D is critical in every case.

The case of clean hydrogen illustrates that a single FFH industry can have diverse RD&D needs. Overall, technology development remains the top priority for hydrogen fuel cell (HFC) organizations in Canada.[24] Some hydrogen technologies are already widely commercialized, such as HFC forklifts. Others are commercialized but require further research and development to be cost-competitive, such as passenger fuel cell vehicles. Other technologies are in the demonstration stage, such as heavy-duty fuel cell trucks. Others still require basic research, from the development of processes allowing hydrogen to replace coal and oil as a chemical feedstock, to improvement of the proportion of emissions captured when carbon capture is paired with steam methane reforming or autothermal reforming to make blue hydrogen. Many hydrogen technologies are at a stage where pilot projects are needed to assess how well they work in different applications and their ability to provide returns to investors. For example, pilot projects are needed to improve applications of hydrogen for electrical storage in Alberta. Finally, demonstration projects can educate investors about hydrogen technologies and how they might align with their interests.

FFH industries require large investments in RD&D, but these investments are unlikely to be made without government support. As discussed in Section 3, firms generally underinvest in RD&D. This is especially true for clean technologies, which are particularly susceptible to knowledge spillovers because they can often be applied beyond their sector of origin[25], and for basic research, which often does not produce intellectual property.

Clean hydrogen has seen a wave of private RD&D investment in Canada, but more is needed. In Alberta, investment is driven by the oil industry: less than 1% of RD&D spending by CHFCA members was spent in Canadian provinces other than BC, Quebec, and Ontario in 2017[26], while Canada's oil industry invested $52 billion in hydrogen in 2019 (although not necessarily clean)[27]. Alberta's oil industry is accumulating intellectual property related to blue hydrogen, such as the Scotford Shell refinery's proprietary carbon capture process for SMR. However, Canada is in the process of losing early leads in RD&D on both hydrogen and CCUS technologies[28].

How can governments help close the RD&D investment gap for FFH industries in Alberta? Three important roles stand out:

- Fill gaps in private investment
- Focus support strategically
- Connect research efforts

Fill gaps in private investment

Among OECD countries, Canada has strong public RD&D programs but weak private investment in RD&D - although Canadian governments have recently cut funding to universities and labs[29]. More can be done to leverage private investment in RD&D, particularly given the recent wave of corporate net zero commitments. In the case of clean hydrogen, while private RD&D investment continues, Canada is losing early leads in RD&D investment for both hydrogen fuel cell and CCUS technologies. Canada also has few demonstration and pilot projects considering its performance in hydrogen research, with some Canadian hydrogen firms recently choosing to conduct demonstration projects abroad[30].

24 CHFCA (2018)
25 Dechezleprêtre et al (2013)
26 CHFCA (2018)
27 Zen (2020)
28 Zen (2020) and CHFCA (2018)
29 SPI (2018)

Since the goal is for FFH technologies to eventually become commercially viable without direct government support, governments should encourage the private sector to lead RD&D where possible by using public RD&D investments to leverage private ones. There are also certain types of research which publicly supported research institutions are best placed to perform.

Support a role for public research institutions

Public research institutions are better able to pursue longer-term, public-interest research than industry. In the domain of clean energy, research by universities and government labs has played an important role in basic research, linking basic and applied research and overcoming barriers to commercialization[31]. In addition, while industry is better placed to research incremental improvements, public research institutions have had success coordinating or performing disruptive, mission-oriented energy research, as illustrated by the Government of Alberta's role in developing oil sands technologies through AOSTRA[32] or the US agency ARPA-E's role in developing hydrogen-to-fuel technologies[33].

Clean hydrogen has benefited enormously from public research from universities and government labs. Important federal labs have included Natural Resources Canada's Hydrogen Lab, the National Research Council's Vancouver lab focused on fuel cell and hydrogen technology, and CanmetENERGY's fuel cell and hydrogen program and lab in Devon, Alberta focused on CCUS technologies for the oil sands[34]. Provincial institutions such as HydroQuebec and BC Hydro are also doing important work.

The Government of Alberta's success in developing and diffusing knowledge on oil sands extraction technologies suggests that public research institutions can encourage investment in FFH industries by

- **Attracting and training research talent**, who may then transition to industry[35].
- **Maintaining their intellectual property while licensing it to private firms**, allowing governments to encourage the diffusion of knowledge[36].

Encourage private investment

Governments can support private RD&D investment through tax incentives, direct supports such as procurement and grants, or regulatory changes.

Tax incentives

Most public support for private RD&D in Canada is delivered through tax incentives[37]. The federal Scientific Research and Experimental Development program delivers much of this support, and is complemented by provincial tax credits in most provinces. Federal and provincial incentives tend to be general, rather than targeted towards clean technology RD&D. Investor tax credits can also be used to encourage investment at the development and demonstration stages.

Tax incentives tend to favour incumbent firms and industries with established revenue streams; and other tools are needed to support early-stage firms. In addition, more research is needed on SRED's additionality: a 2007 investigation found it resulted in a net economic gain[38], but in a more recent survey analysis conducted by SPI, clean technology firms raised concerns about SRED's additionality. SRED is also a poor fit with the needs of clean technology firms in that it excludes capital costs[39]. Governments may want to explore targeted clean technology tax credits, which could better align the distribution of RD&D support resources with policy objectives and address the unique characteristics of clean technologies.

30 Zen (2020) and CHFCA (2018)
31 Popp (2017) and Weyant (2011)
32 Hastings-Simon et al (2019)
33 Bonvillain (2018)
34 SPI (2018)
35 Hastings-Simon et al (2019)
36 Hester and Lawrence (2010)
37 OECD (2016)
38 Parsons and Phillips (2007)
39 SPI (2018)

Direct support

The federal Industrial Research Assistance Program (IRAP) is an important source of direct support for RD&D at small and medium enterprises[40]. In the case of clean hydrogen, 27% of R&D spending and 22% of demonstration spending by HFC organizations in Canada in 2017 was funded by governments[41]. Firms have received support from federal initiatives like the National Innovation Program for Hydrogen and Fuel Cell Technology and the former NSERC Hydrogen Canada Strategic Research Network. The Government of Alberta's direct support for private RD&D in FFH industries has included challenges and prizes such as Alberta Innovates' Carbon Fibre Grand Challenge and Emissions Reduction Alberta's Natural Gas Challenge. Direct government support for RD&D can be improved by finding ways to top up or sustain support over time to allow longer-term planning and attract investment.

Regulatory measures

Governments can also remove regulatory barriers to private RD&D. For example, regulations in Alberta currently limit utilities' ability to recover the cost of innovation for the purpose of decarbonization from ratepayers. In contrast, the BC Utilities Commission approved a $24.5-million ratepayer-funded Clean Growth Innovation Fund for FortisBC last year. Innovation by utilities is critical to the early diffusion of clean hydrogen, as utilities' activities cover several potential hydrogen applications and infrastructure types, including transportation and storage[42].

Focus support strategically

Governments should focus on those pathways and industries with the greatest potential to mitigate climate change and generate economic activity in Alberta. This is because resources are limited, but also because multiple objectives are dangerous for public innovation policy[43]. Governments will need to adjust their focus as FFH industries develop and more information becomes available about their carbon intensity and market opportunities.

Public RD&D support should be allocated according to performance-based criteria tied to broader strategic objectives. This will allow firms to plan ahead while allowing flexibility as the prospects of technologies shift. For example, in the case of clean hydrogen, governments should tie RD&D funding to criteria such as life cycle emissions intensity (including Scope 3 emissions) and diffusion and export potential. Governments can improve predictability by engaging experts to project performance milestones to indicate to government decision-makers and investors whether technologies are on track.

Criteria should be designed and applied through non-political, transparent, and predictable processes. Arms-length institutions do this best, but ministerial departments can also create these types of processes. This will look different for different types of PUSH policies: general support programs like IRAP and SRED should make highly predictable decisions, while higher-touch "mission-driven" programs should follow clear criteria while following expert judgement and vision. This is the case at ARPA-E, which also adds transparency and accountability by allowing applicants to respond to initial selection evaluations[44].

Connect RD&D efforts

Governments also have an important role to play in connecting RD&D efforts across sectors and coordinating them with other levels of government.

Many FFH industries rely on the simultaneous advancement of basic research, deployment and business models, and policy frameworks. To succeed, this effort requires improved communication between academia, industry, and government. In the case of clean hydrogen, governments encourage the creation of RD&D clusters where research expertise and hydrogen sources and applications coexist. Programs like Mitacs, which fund collaborative projects between industry, government and academia, should be expanded.

Governments should ensure that innovation needs and market opportunities inform research priorities, both by convening discussions and by consulting with experts and industry when planning PUSH policies. For example, governments should closely watch the success of early efforts to export hydrogen overseas, such as those by Pacific Hydrogen Canada and Renewable Hydrogen Manitoba, and use these to inform future support for RD&D on hydrogen storage, transportation and distribution.

40 ibid
41 CHFCA (2018)
42 Coyne et al (2018)
43 Lipsey and Carlaw (2020)
44 Bonvillain (2018)

Finally, governments should strengthen international research linkages. In the case of clean hydrogen, many countries are enacting similar hydrogen strategies to Canada's. There are important learning opportunities here. Canada is already part of several international research networks, including the International Partnership for Hydrogen in the Economy, Mission Innovation, the Clean Energy Ministerial Initiative, and the Hydrogen Ministerial Initiative.

PULL

Even promising technologies, processes and business models may not catch on without government support for demand, referred to as PULL policies. There are many reasons for this: market prices do not reflect FFH technologies' full environmental value; many FFH technologies require infrastructure which is not yet in place; and some FFH technologies can only be produced economically at large scales.

The case of clean hydrogen exemplifies the importance of PULL policies in attracting investment. Clean hydrogen's environmental advantage over grey hydrogen or fossil fuels is not fully reflected in prices, as carbon prices are lower than the social cost of carbon. Investment in hydrogen production is also limited by small, uncertain demand. Blue hydrogen production, for example, is capital-intensive and only economical at large scales; investment is sparse without a guarantee of large-scale, stable demand. And while many clean hydrogen applications are ready for market[45], demand for these applications is limited by a small supply of clean hydrogen, a lack of distribution infrastructure, and high prices. Access to markets was the second-biggest challenge cited by HFC firms in 2017, after a lack of funding[46].

Governments can stimulate demand through

- Environmental policies
- Tax incentives
- Removing regulatory barriers
- Procurement
- Infrastructure investment and planning

Environmental policies

Governments should ensure that the environmental benefits of FFH industries are communicated in prices. Well-designed environmental policies, such as carbon prices or clean fuel standards, can encourage investment in FFH industries by:

- **Raising the cost of carbon-intensive alternatives**. In the case of clean hydrogen, carbon pricing across Canada and BC's clean fuel standard have already stimulated investment. Carbon pricing helps clean hydrogen compete against carbon-intensive energy sources, from transportation to industrial feedstocks to heating. Low-carbon and clean fuel standards help clean hydrogen to compete against carbon-intensive fuels like gasoline and diesel. Other standards, like zero-emissions vehicle mandates and vehicle emissions standards, can also stimulate demand for clean hydrogen and its use technologies.

- **Creating stable revenue streams**. For example, clean hydrogen production and distribution projects could generate credits under Alberta's industrial carbon pricing scheme and the proposed federal Clean Fuel Standard[47]. Credit mechanisms under zero-emissions vehicle mandates and emissions standards could also provide revenue for clean hydrogen applications. However, creating new opportunities to generate credits has the potential to flood regulatory markets with supply and undermine emissions reduction targets if not accompanied by more stringent regulations. This is difficult to get right and even more difficult to adjust, so governments should also explore other approaches to guaranteeing revenue streams, such as procurement, which is discussed below.

Environmental policies can encourage investment in FFH industries if they are sufficiently stringent, flexible, and predictable:

Stringency. The stringency of an environmental policy determines how much it will raise the cost of carbon-intensive fuels or how lucrative credit sales will be for FFH industries. Stringency is a product of the level of a price

45 Zen (2020)
46 CHFCA (2018)
47 Layzell et al (2020b)

or standard, the breadth of coverage, and the activities deemed eligible for credits. In the case of clean hydrogen, the federal government has proposed to apply carbon intensity standards to hydrogen projects applying for federal support or to generate credits or reduce credit burdens for liquid fuels under the proposed federal Clean Fuel Standard. Because gaseous fuels are excluded from the Clean Fuel Standard, it does not create a general life cycle carbon intensity requirement for hydrogen. Governments should set standards at a level that aligns with their objectives, building in growing stringency over time. They should also continually revise the list of activities eligible to generate credits under standards, like the Clean Fuel Standard, to remove activities from the list when they become common practice.

A lack of stringency in one environmental policy can be made up by stringency in another, but some policies are more cost effective than others. In the case of clean hydrogen, the proposed federal Clean Fuel Standard does not apply to natural gas, meaning it will not help clean hydrogen compete with natural gas (which is currently one-fifth the price of hydrogen in heating applications)[48] or lower the life cycle carbon intensity of natural gas. This means that other policies will be needed to help hydrogen compete with natural gas, and upstream methane regulations become essential determinants of the future fitness of blue hydrogen.

Flexibility. Flexible environmental policies allow emissions reductions to be achieved in the most cost-effective way. In the case of clean hydrogen, governments can encourage demand by allowing flexibility in how emissions reduction requirements can be met and including the incorporation of clean hydrogen as a compliance option. When designing incentives for hydrogen projects - from credit-generating schemes to government support - governments should allow a broad range of hydrogen projects to qualify. However, governments may want to consider reserving a portion of incentives for desirable hydrogen projects that would not otherwise be competitive. For example, the federal government has proposed that a portion of government support be dedicated for renewably-generated hydrogen projects. This type of policy can help prevent lock-in to blue hydrogen as other production technologies develop and lower their costs. However, these carve-outs should be based on performance, rather than specific technologies, where possible.

Predictability. If environmental policies are to encourage investment, they must be predictable. For example, a carbon price that increases along a predictable schedule signals to investors that clean hydrogen will become more competitive over time. It can also inform manufacturers as to when they should begin producing hydrogen-ready appliances. To date, federal and provincial governments have often had conflicting objectives and levels of stringency, making carbon prices unpredictable. Remedying this through intergovernmental cooperation should be a priority for clean hydrogen development. Similarly, if revenue generated by selling credits is to form the basis for investment, it must be predictable. The revenue stream from credits can attract project finance, but not if the future value of credits is uncertain[49]. Tools for addressing this include setting a price floor for credits and setting clear criteria for how the list of credit-generating projects will be revised over time - in the case of clean hydrogen, these may include market penetration, carbon intensity, and the future fitness of end uses. Where governments reserve a portion of any support for renewably generated hydrogen, it should be clear how the size of the carve-out is set and how it will change in the future.

Incentives

While stringent environmental policies can encourage investment in FFH, they can also raise costs for companies. In addition, even with environmental policies, other market barriers make some early-stage FFH industries uneconomic. Incentives for the installation or use of clean technology can ease the burden on firms and encourage the diffusion of clean technology, which almost always leads to falling costs.

One way of delivering incentives is through the tax system. For example, the 2021 federal Budget proposed adding green hydrogen production equipment to the list of clean technologies which can be fully expensed in the year of purchase. It also proposed a corporate tax cut for manufacturers of clean technology and investment tax credits for carbon capture, use and storage. Notably, the use of captured carbon for enhanced oil recovery was excluded from the latter. At the provincial level, tax credits like BC's FCEV Fleet Incentive encourage use of hydrogen technologies. In the US, the Section 45Q tax credit for the use and storage of capture has made carbon capture economic for some industrial applications with

48 Zen (2020)
49 Berger and Barrow (2020)

highly concentrated emissions streams, although others, including hydrogen production, still require improved coordination and infrastructure to become profitable[50].

Incentives can also be delivered in ways other than through the tax system. For example, BC Hydro has begun offering discounted electricity to industrial customers with clean energy projects.

Remove regulatory barriers

Investment in clean technologies has been hampered by ambiguity or outright conflict in existing regulations. The novel technologies, processes and business models involved in FFH industries often have unclear regulatory statuses, deterring investors. For example, it is still unclear in Alberta whether regulated utilities can own energy storage and recover investments in it from ratepayers[51]. This is a barrier to investment in applications of clean hydrogen, among other things.

Federal and provincial governments need to cooperate with each other and with governments in other jurisdictions to clarify how FFH industries are defined and which safety and quality standards will apply. Expert working groups should be convened to determine codes, standards and regulations. Encouraging pilot and demonstration projects and improving the quality and accessibility of data collected from them is also important to ensuring high-quality codes and standards. So is communication and coordination with organizations setting codes and standards in other jurisdictions, which has the benefits of facilitating international trade and promoting the spread of best practices. In the case of clean hydrogen, Canada is participating in the establishment and harmonization of safety and carbon intensity codes and standards through venues like the Canada/US Regulatory Cooperation Council.

Governments will also need to remove regulatory conflicts which are preventing investment in FFH industries. In the case of clean hydrogen, the Canadian Hydrogen Installation Code needs to be updated to allow for new generation technologies. And federal and provincial regulations and codes and standards should be updated to allow hydrogen to be blended into natural gas networks[52]. Governments should lay the groundwork now for higher hydrogen blending concentrations in natural gas pipelines, and dedicated hydrogen pipelines, that may be realized in the future.

Updating and harmonizing codes and standards was one of the eight "pillars" of the federal hydrogen strategy.

Procurement

Governments can encourage investment in FFH industries through their substantial buying power. One way they can do this is by establishing internal incentives for clean procurement, for example, by applying an internal carbon price when assessing the life cycle costs of new assets.

Governments can also encourage investment in FFH industries by committing to procuring pre-commercial clean technologies. This can bring down the cost of technologies that are costly due to limited demand, such as hydrogen fuel cell trucks and buses. It can also help work out technical kinks and attract investment by signaling a company's credibility.

Where possible, governments should use flexible decision tools such as carbon prices. That said, it may be desirable to include other considerations, such as supporting early-stage local innovators and compatibility with broader industrial and climate change mitigation strategies, in decision-making. Governments should clearly communicate the criteria that are used to select technologies.

Infrastructure investment and planning

Some FFH industries will require a substantial buildout of public and private infrastructure. Clean hydrogen is particularly demanding when it comes to infrastructure. Transporting, distributing and storing hydrogen cheaply may require the conversion of gas pipelines to carry hydrogen or the construction of dedicated hydrogen pipelines. If FCEVs are to diffuse, a network of fuelling stations is needed. And if CCUS is used for hydrogen production, infrastructure will also be needed to transport and store captured carbon dioxide.

With regards to public infrastructure, governments and Crown corporations can invest in a few priority projects that fill gaps in Canada's infrastructure system and that advance strategic objectives for the future, such as competitiveness in a decarbonized world. In the case of clean hydrogen, pipelines for hydrogen or carbon dioxide could be built as public infrastructure and sold when the industry has matured[53]. Alternatively, governments could finance additional capacity in pipelines being built

50 Tarufelli et al (2021)
51 AUC (2021:130)
52 Zen (2020)
53 Haszeldine et al (2018) and Edwards and Celia (2018)

for private use, such as carbon pipelines used for EOR[54]. This could be cheaper than building separate public infrastructure as pipelines benefit from economies of scale. Governments can also integrate climate change and innovation considerations into infrastructure planning processes.

With regards to private infrastructure, governments can use a range of policies to de-risk investment and continue Canadian governments' tradition of co-investing in infrastructure which contributes to the public interest, benefits from economies of scale, and creates natural monopolies. Public-private partnerships can be used to distribute the risk of infrastructure investments between government and private-sector investors. Governments can also support private infrastructure investment directly through loans or grants, or indirectly through special tax structures and loan guarantees. Another option is for governments to expedite hydrogen or carbon dioxide pipelines by preemptively securing right-of-way permits for pipelines, as has been done in Wyoming[55]. The range of policies available to de-risk private investment in FFH industries is discussed in the next section, on GROW policies. In the case of clean hydrogen, de-risking infrastructure investment could be important to the construction of hydrogen storage: geological hydrogen storage requires a large up-front investment, but many firms in the hydrocarbon cluster have the storage space, skills, and equipment to lead these projects.

Whether infrastructure is publicly or privately owned, governments have an important role to play in identifying infrastructural gaps and coordinating infrastructure development to fill them. This is an area where federal-provincial cooperation is essential. In the case of clean hydrogen, supply and distribution infrastructure need to be built out simultaneously with the growth in demand. When developing an infrastructure strategy for clean hydrogen, governments should consider uncertainties around future production, export, and end uses, and prioritize flexible or repurpose-able infrastructure where possible. This includes planning infrastructure that can accommodate hydrogen from a variety of sources and ensuring that infrastructure is not built exclusively to serve demand centres whose future fitness is uncertain. Infrastructure planning and coordination will also be an important part of developing export markets for clean hydrogen. Since most public infrastructure spending is provincial or local rather than federal, this strategic planning needs to occur primarily at these levels. The federal government could make strategic planning and coordination a condition for funding[56].

When performing strategic planning, governments should also consider the life cycle environmental costs of infrastructure and capital spending. This could have important implications for FFH infrastructure planning. For example, in the case of clean hydrogen, this would allow comparison of the environmental cost of building new electric infrastructure with that of repurposing fossil infrastructure (e.g., pipelines and storage caverns)[57].

GROW

Canada performs well in the early stages of innovation, but innovative firms have trouble commercializing innovations and growing[58]. Even if governments create demand for FFH industries through PULL policies, firms with demonstrated technologies often need help growing to a point where they can supply this demand because of market barriers.

In the case of clean hydrogen, many technologies and processes have already been technically demonstrated and need financing to commercialize. These are currently too expensive for widespread diffusion, requiring scale to lower costs. Capital intensity and long payback periods also often deter investors. For example, roughly 80% of pipeline costs tend to be capital costs[59], and the payback period for investments in hydrogen or carbon pipelines depends on government policy, creating uncertainty. Temporary support can help hydrogen firms to grow.

Governments are well placed to help firms in FFH industries to transition from demonstration to commercialization. Governments can provide much-needed cash at stages when private investors are deterred by risk. Governments can also provide firms with networks and help firms attract investment and demand through partnerships that signal firms' legitimacy and quality[60].

54 Edwards and Celia (2018)
55 Edwards and Celia (2018)
56 SPI (2018)
57 Keast (2020)
58 SPI (2018)
59 Edwards and Celia (2018)
60 Doblinger and Anadon (2019)

Governments can encourage investment in growth and commercialization by:

- Complementing and leveraging private investment
    - Providing capital directly
    - Connecting firms with investors
    - De-risking investments
    - Offering investment incentives
    - Improving climate-related financial disclosure
- Developing risk-tolerant, expert, nimble, apolitical institutions and programs

Complement and leverage private investment

Since the ultimate goal of GROW policies is to create industries that can compete without government support, governments should take care not to compete with private investors. Rather, they should lean into their unique value as risk-tolerant, well-resourced institutions with public interest mandates.

Direct public investments in FFH industries should be temporary and should help smooth the transition to solely private support. Involving private investors in public investments lets governments tap into industry judgement as to which ventures are likely to thrive and equips firms with market knowledge and industry contacts which can help them to attract financing and customers later on.

Governments can encourage investment in growth and commercialization in several ways:

- **Provide capital directly.** Governments can do this through non-dilutive grants, project financing, or other instruments. For example, Sustainable Development Technology Canada provides project financing for pilots and demonstration projects. Wherever possible, direct financing should be used to catalyze private co-investment.

- **Connect firms with investors**. Governments can provide networking support, as done by SDTC, for example. Governments can also work to convene non-traditional investors to invest in capital intensive projects[61].

- **De-risk investment**. Governments can offer to help recoup unsuccessful investments, for example, by providing loan guarantees for commercial bank loans. They can also increase certainty around firms' future revenue, for example, by promising to purchase a set quantity of output[62] or designing PULL policies which allow FFH industries to generate and sell credits. In the case of clean hydrogen, experience in California has shown that credits created under a clean fuel standard can provide a basis for project finance for hydrogen fuelling stations and production infrastructure, but only if future credit revenues are reliable[63]. Creating a credit price floor can help, as previously discussed, but governments can also help by allowing activities to generate credits with complementary revenue streams (e.g., allowing capacity-based credits for infrastructure as well as fuel sale-based) and facilitating long-term credit sale agreements.

- **Offer investor incentives**. For example, investment in clean hydrogen could be encouraged through investment tax credits or by adding hydrogen to the list of technologies eligible for flow-through shares.

- **Improve climate-related financial disclosure**. Potential policies include mandating the use of reporting frameworks such as SASB and TCFD, supporting standardization of reporting, and developing reporting capacity in small firms.

Governments should coordinate GROW policies across stages of the development process and scales of government. Governments should also ensure that GROW institutions (like SDTC), PUSH institutions (like NSERC and NRC) and PULL institutions (like BDC and EDC) share strategic objectives. FFH industries would also benefit from overarching coordinating policies such as a requirement that governments consider both economic and environmental returns when planning public investments.

Design institutions and programs that allocate resources wisely

Well-designed GROW policies will support many failed ventures, but governments should ensure that bets fail for the right reasons. GROW policies perform badly when governments do not involve those with market knowledge

61 SPI (2018)
62 Rodrik (2008a)
63 Berger and Barrow (2020)

in the selection process; when public support is used to buy political favour; and when institutions are unable to recognize (and act on) failure early on[64]. The most successful public investment programs are risk-tolerant, nimble, expert, and apolitical.

Governments should take informed risks when supporting the growth of FFH technologies. Government support should be allocated based on technologies' potential to advance policy objectives and market potential. For example, Sustainable Development Technology Canada requires applicants to form a consortium with end users or other partners who can validate the technology's market potential. At ARPA-E, a successful American public program for growing disruptive clean energy technologies, program managers with industry experience select ventures with the potential to solve societal energy problems and achieve wide diffusion. The market potential of FFH industries should be considered under multiple scenarios in which domestic and global climate change objectives are met. For example, public investments in clean hydrogen technologies should be reserved for technologies with market potential across multiple climate change pathways.

Governments will need to balance the stringency of eligibility criteria for government support with the availability of applicants that meet those criteria. For example, federal clean innovation funding programs have struggled to attract project proposals from Alberta industry that meet their criteria. It may be necessary to adjust criteria and scope or deploy complementary PUSH and PULL policies to encourage desirable project proposals.

To deal with the uncertainty surrounding FFH industries, GROW policies need to be administered by nimble, apolitical institutions. Over the next decades, some FFH industries may fail, and those that thrive may do so in unexpected ways. This will depend on factors outside the provincial and federal governments' control, such as global scientific progress and policy decisions in other countries. To avoid locking in environmentally inferior pathways for political reasons, GROW policies should be designed to reallocate public resources as we learn more about the environmental and economic potential of different FFH industry pathways. Since firms need predictable funding to grow, adjustments in GROW policies should be decided by transparent, predetermined criteria. For example, funding for hydrogen production technologies could be periodically reviewed based on life cycle carbon emissions and price. Arms-length bodies like BDC or SDTC are best placed to do this, but ministerial funding programs can also create these conditions with expert advisory bodies and clear decision-making processes.

STRENGTHEN

Governments can also encourage investment in FFH industries by creating policies to STRENGTHEN the clean technology innovation system as a whole. Governments should design these policies according to the same overarching objectives recommended in this brief for PUSH, PULL, and GROW policies:

- Establish a strategic vision
- Design institutions that allocate resources wisely
- Facilitate knowledge exchange

Establish a strategic vision

Comprehensive, integrated strategic planning is needed to ensure that PUSH, PULL, and GROW policies are working together. History has shown that uncoordinated policy objectives can sink innovation and industrial policies[65]. Integrated strategic plans can help governments create a predictable investment environment despite the uncertainty surrounding FFH industries, by establishing objectives which can be translated into performance-based policies. Coordination between federal, provincial, municipal, and Indigenous governments will be essential here.

Specific plans for proposed FFH industries should be integrated with overarching plans for climate change, energy, and industrial policy. Overarching plans should consider models of potential pathways to meeting climate change objectives as well as contextual factors such as global trends towards lower-carbon energy systems, changing trade patterns with the US, and trends towards electrification and distributed electricity demand. They should also aim to identify necessary supporting policies such as workforce development and just transition policies.

In the case of clean hydrogen, an important question to be addressed in overarching plans regards CCUS. A CCUS strategy is needed which includes realistic estimates of its potential, its downsides, and how capacity should be allocated through the Canadian economy to achieve

64 Lipsey and Carlaw (2020)
65 Lipsey and Carlaw (2020)

climate change objectives. Given markets, storage potential, and the environmental footprint of carbon use and storage, to what extent should CCUS be reserved for "hard-to-abate" sectors or negative emissions? This should all be considered when developing a clean hydrogen strategy.

Overarching plans can be used to inform specific strategic plans for FFH industries. It may be helpful to establish technological milestones in these plans. For example, a strategic plan is needed for clean hydrogen which considers potential hydrogen producers, end uses, and how they might be connected. Technological milestones could include a date by which biomass gasification needs to be demonstrated at scale or carbon capture from steam methane reforming or autothermal reforming needs to capture 95% of emitted carbon.

Design institutions and programs that allocate resources wisely

Wise decisions by government institutions are determined by institutional design. Brendan Haley[66] proposed ten design principles for innovation institutions, which can inform governments seeking to encourage investment in FFH industries:

- Comprehensiveness
- Flexibility
- Autonomy from short-term political pressure
- Mission-orientation
- Embeddedness within policy networks
- Autonomy from private interests
- Competence
- Credibility
- Stability
- Accountability

A single institution can't embody all of these principles. To support FFH industries, governments will need a variety of institutions encouraging investment. Some should prioritize close industry consultation; others, a public-interest mission orientation. Some should prioritize predictability; others, nimbleness. For example, a high-touch, mission-driven, selective program like ARPA-E can complement a more predictable, general funding mechanism.

Facilitate knowledge exchange

Governments can foster connections and encourage information sharing in the clean innovation ecosystem. This can counter coordination problems and incomplete information, both of which hinder investment in FFH industries. In the case of clean hydrogen, development is hindered by the fact that potential producers, users, and transmitters are not fully aware of each others' needs and potential synergies. Governments can help fix this by convening and supporting hydrogen nodes and clusters. Governments should also support learning from the many countries around the world currently pursuing hydrogen development.

When industries are in their early stages, early trials and demonstrations offer invaluable learning. Governments should create policies to ensure this learning is widespread, for example, by providing resources and incentives for data collection, standardization, and sharing. In the case of clean hydrogen, better and more widely available data from pilot and demonstration projects will help the industry develop, encourage investors, and help governments design good, evidence-based policies. Governments should also work to encourage international data sharing.

66 Haley (2016)

Conclusion

Alberta has an opportunity to develop a range of future fit hydrocarbon industries which use assets from its hydrocarbon industry, but only with government support to encourage investment. To encourage investment in FFH industries, governments should avoid roles they're bad at, such as picking specific technologies or providing long-term financing. Governments should lean into their strengths, such as identifying and communicating societal priorities, providing temporary support when private support is unavailable, and facilitating knowledge exchange.

Governments' challenge will be balancing focus with agility. They do not have the resources to try a little bit of everything: rather, they must pick a few bets with good odds. On the other hand, clean energy technologies are changing quickly and governments should avoid premature lock-in to technologies that may prove to be too dirty, uneconomic, unscalable, or unpopular. In the case of clean hydrogen, there is significant uncertainty around which production technologies, end uses, and export strategies are the best choice for Alberta.

Governments can perform this balancing act by conducting integrated strategic planning, setting clear, predictable, performance-based standards and criteria, and developing nimble, apolitical, risk-tolerant, expert institutions to apply these criteria. In the case of clean hydrogen, governments should use a mix of general criteria and standards, such as a carbon price and a life cycle carbon intensity standard for government support, with strategically targeted support for hydrogen hubs and applications. While it is true that governments cannot pick specific winners among industries and technologies, they have a critical role in defining what winners look like.

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