A Review of Barriers to Full-Scale Deployment of Emissions-Reduction Technologies*

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Abstract

We review the regulatory, economic, financial and policy environment for cleantech in Alberta, focusing on the petroleum industry, and identify challenges and barriers faced by cleantech proponents. Three themes emerge from the discussion; first, in evaluating policies to support successful innovation in Alberta's and Canada's petroleum industry, we must clearly differentiate between start-up and scale-up. The incentives of an innovation proponent to accelerate its development and reach commercialization more quickly are well-understood but a *rush to the finish line* mentality can have unintended and detrimental consequences. Second, all parties need to recognize the importance and role of non-dilutive funding. Non-dilutive funding from government agencies can be leveraged as a signal to private financiers that a project has satisfied the due diligence exercises conducted by these agencies. Third, more analysis is needed on firm-level determinants of successful innovation rather than program-level determinants since firm-level supports can foster a more efficient allocation of resources between projects. Freedom to fail, and fail quickly, is at least as important here as freedom to succeed.

Keywords: Innovation, Emissions Reduction, Capital Investment, Commercialization, Industrial Policy, Barriers to Investment, Technology Development

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Policy Recommendations:

- Policymakers and those implementing policy should clearly distinguish between "start-up" and "scale-up" as projects in each stage require very different conditions for support. Innovation supports at the start-up phase should be focused on fostering innovation that has strong potential for effective commercialization whereas scale-up should rely on demonstrated strengths to obtain private sector support for growth.
- Granting agencies and governments should focus on clearly demonstrating and communicating their due-diligence around funding decisions, as this both justifies their spending and presents a signal of project quality (for funded projects) to private sector investors.
- More analysis is needed on firm-level vs project-level supports and the conditions leading to efficient funding allocations (i.e. which projects or firms require funding, vs those with limited commercial potential or those where government supports crowd out efficient private sector decisions).

Introduction and Focus

Part of the solution to reducing emissions in Alberta and Canada — and in the petroleum industry specifically — is innovative clean technologies. Proponents of these technologies, however, face barriers to full-scale deployment and commercialization, even with policy and financial support from government and government agencies. Given the challenge and scale required to reduce emissions in Alberta's petroleum industry[1], there is a need to better understand the transition in clean technology (cleantech) development projects from inception, through deployment and final commercialization. Effectively supporting innovation requires knowledge of (1) the factors critical to effective commercialization, and (2) how policy supports and hinders favorable outcomes in cleantech. We review the regulatory, economic, financial and policy environment for cleantech in Alberta, focusing on the petroleum industry, and identify challenges and barriers faced by cleantech proponents.

Throughout this analysis, we maintain a broad and intentionally vague definition of cleantech as any innovation that supports improved environmental outcomes (although we have a particular interest in projects that focus on reducing greenhouse gas emissions from the petroleum industry). Innovation is distinct from (albeit related to) the concept of creativity. Creativity is the imaginative conceptualization of a new technology or process, whereas innovation is the practical implementation of a new technology or process. Our focus is on projects as an innovation process — how ideas and projects are (or are not) developed and implemented for ultimate commercialization — rather than ideas as a creative output.

[1] Canadian 2018 emissions from oil and gas (upstream and downstream) were 193 Mt CO_2-equivalent, or 26% of Canada's total (ECCC 2020). Alberta's oil and gas emissions were 138.9 Mt, 51% of the province's total emissions, 72% of Canadian oil and gas emissions and 19% of total Canadian emissions.

In identifying critical factors for effective commercialization, we reviewed existing literature and investigated publicly available information for a sample of late-stage emissions-reduction technologies at various phases of deployment in Alberta's oil and gas sector.[2] We reviewed this sample of technologies in order to gain general insights about cleantech innovation, though our research is not a case study approach to barriers to cleantech. We describe common themes identified in academic literature on barriers to commercialization of innovations in cleantech in general and verified these themes through informal discussions with subject matter experts.

We identify three themes that can improve cleantech innovation and supporting policy in Alberta and Canada's petroleum industry:

> **Due-diligence and de-risking.** An unmeasured rush to faster-paced or expedited innovation processes is likely to be detrimental. Due diligence and de-risking is necessary for successful innovation; myopically pursuing an expedited process can lead to cut corners and exposes proponents to incompletely "proved" (and hence riskier) technologies in later stages of innovation.

> **Funding Sources.** All players in the cleantech innovation space must recognize the importance of non-dilutive funding. Government grants are often treated as "dumb money" by private investors; however, grants are generally accompanied by a significant amount of due diligence. Communicating this due diligence as a signal to investors should be a priority, both for projects deemed to have merit and for those that are not (positive and negative signals are both important in building investor confidence for investment in meritorious innovation). Further to this, innovation proponents (particularly those outside

[2] We summarise the six technologies in Table 1 in the appendix. Emissions Reduction Alberta staff recommended these specific technologies; all at one point were part of the funding portfolio of Emissions Reduction Alberta.

of existing incumbent firms) prefer non-dilutive funding at earlier stages as it allows them to maintain control over their projects. Moreover, due diligence works both ways. Proponents that control and manage spending responsibly can and should document this as a signal to later-stage financiers.

Innovation Processes. More thought is needed on the distinction between firm-level supports and project-level supports. Supporting innovation at the firm-level means the firm can be more flexible: pursuing potentially fruitful innovations and cancelling projects as soon as it becomes clear they will not be successful without forfeiting a source of financing. Funding agencies and policy makers should be aware of this critical difference in incentives between firm vs project supports.

Prior to discussing specific insights into the factors determining effective commercialization of cleantech in Alberta's petroleum industry, we review two critical pieces of context. First, defining "effective commercialization." Second, describing general features of innovation financing, as these decisions are key to projects' success in successive steps towards commercialization. We then turn to key factors affecting access to financing for Alberta's cleantech, followed by conclusions with a more detailed summary of the themes outlined above.

Defining Effective Commercialization

Not all innovation is good or desirable. Innovations that lead to negative returns on investment, fail to deliver sufficient environmental benefits, or reduce the market value of the underlying resources are not desirable. We define "effective commercialization" and "favorable outcomes" using the socio-economic concept of "efficiency." With this definition, an efficient commercialized innovation is a private sector development and deployment that delivers social benefits that are higher than the social costs incurred in the commercialization process (positive net social benefits).[3] Social benefits include both the return on investment to the private interests in the innovation program as well as any additional benefits (such as reduced environmental impacts) that accrue to the rest of society.[4] Social costs include both the costs borne by private interests in the innovation program as well as any costs borne by the rest of society. Benefits beyond those realized by private interests that accrue to society are "positive externalities," while costs beyond those incurred by private interests that are borne by society are "negative externalities."

Based on this definition, governments should not blindly encourage all innovation, but rather should attempt to support socio-economically efficient innovation projects and discourage socio-economically inefficient projects. This implies two distinct, but related, policy goals. The first is to help identify and promote financing for efficient projects while screening out inefficient projects. The second is to promote actions that can turn inefficient projects into efficient ones where possible.

Market economies provide less innovation than is optimal because of the public-good nature of knowledge (Bloom et al. 2016). That is, because an innovator cannot capture the entire value of an innovation, there will always be larger net social benefits than there are net private benefits. It is likely that this problem is worse in the petroleum industry (in the absence of any large negative externalities) because the additional presence of resource royalties further inflates the social benefit relative to the private benefit. Through the royalty formula, provincial governments receive a share of the value of any resource produced. Thus, if an innovation increases the value of the

[3] Innovation outcomes that are provided primarily through public government funding fall outside our definition of "commercialization" since the term, commonly defined, implies a private financial return on an investment.

[4] Who is included in society, called the reference group, determines the size and scope of social benefits and costs.

resource or contributes to an expansion in production, an added social benefit accrues to the public (through government collection of royalties).

Environmental benefits are an additional social benefit that accrues to the public through improvements to environmental outcomes (relative to a baseline). This benefit is important for motivating the potential use of public funds (subsidies) on cleantech in the petroleum industry. The existence of other policies is important here, particularly those related to emissions regulation (implicit costs) or pricing (explicit costs). The presence of emissions pricing helps to align the private and social benefits of an emissions-reducing innovation. We will return to this point below.

In the interests of a comprehensive definition of "effective commercialization" it is worth acknowledging that exporting intellectual property via something like a formal licensing agreement should be considered an effective commercial outcome (if it is accompanied by a positive social return). There are potentially significant private benefits from exporting or licensing intellectual property related to oil and gas cleantech innovations that are developed domestically and sold to operators in other jurisdictions. It follows that potential cleantech investors may be interested in supporting not just product development, but process development.[5]

Features of Innovation Financing

Absent persistent support from government funding, the ultimate determinant of success or failure of full-scale deployment of an innovation is the ability to access sufficient private capital to fund

[5] However, considering private and social benefits in the context of potential export or licensing requires a more nuanced approach. When a technology is developed and commercialized in Alberta or Canada, the bulk of private and social returns are likely to occur domestically. However, when a technology is exported and licensed, a large proportion of the social (non-private) benefits will likely accrue in other jurisdictions. This raises a broader question about the economic efficiency of government supports for cleantech. If we consider this in the context of cleantech subsidies or other financial support deriving from public sources there is an intuitive, albeit normative, argument that Alberta's public funds should not be supporting social returns in other jurisdictions (even if they are accompanied by private returns within Alberta). That said, to the extent that exporting Canadian cleantech reduces global emissions via its use in other countries, Canadians also benefit from lower global emissions.

commercial development. A project's net private benefit (the return to investment spending for a project) is critical in any discussion of commercialization. For cleantech innovation in the petroleum industry, as with any industry, financing is required throughout a project's lifespan in order to fund development and deployment.

Sandberg and Aarkikka-Stenroos (2014) show that, for small firms engaged in "radical innovation," difficulties in accessing financing were by far the firms' largest barrier. Similarly, studying carbon capture and storage innovations, Bui et al. (2019) find cost and revenue are the most critical elements for firms, noting specifically the need for innovators to show a positive return to progress within the context of investment risk. Examining renewable energy innovation, Seetharaman et al. (2019) also emphasize risk is an important barrier, discussing both the need for sufficient information regarding benefits and the need to reduce other uncertainties related to financial feasibility. Gegg et al. (2015) find much the same when reviewing the commercialization of aviation biofuels in Europe, suggesting that commercialization requires significant de-risking by demonstrating both profitability and reduced environmental impact.

These articles, and numerous others, all find the critical elements on the path to commercialization are (1) minimizing risk, and (2) demonstrating a sufficiently probable and positive return on investment to potential private financiers. Financing can come from many sources; a non-exhaustive list includes angel investors (friends and family), venture capital, private equity firms, institutional investors and lenders, joint venture partners, and public capital markets. Individual financiers have different preferences over the ventures in which they invest. This is most apparent in comparing debt financiers with equity financiers, but it is true of different agents within these two classes as well. It also applies to other sources of financing, whether they be joint venture partners, or those involved in a purely internal (to a firm) budgetary process that allocates funding to internal projects. One factor that is generally common in the preferences of all financiers, however, is the relationship between expected return and risk.

Ex ante, the return on investment for any project is unknown, or at least not known with certainty. However, in deciding where to allocate funds, financiers (implicitly or explicitly) assign an expected return and a perceived risk to a project. Consider a financier who makes several projections about the return on investment for a project, each based on different scenarios with different likelihoods. The expected return is a weighted average (mean) of these projected returns, while the perceived risk is analogous to the variance or standard deviation between them. Generally, the higher the perceived risk, the higher the expected return required to motivate a financier to finance a project.

Generally, as a project moves through the development phase, the return on investment becomes more certain. Early stages of development prove the technology at bench-scale. Field demonstrations and pilots improve the certainty of technology risk, start providing some certainty of commercial-scale viability, and potentially even alleviate some of the economic risk of a project. The ultimate goal of pre-commercialization activities is to prove that a technology works and to demonstrate to financiers that it is cost-effective and can generate a sufficiently positive return on investment with sufficient certainty.

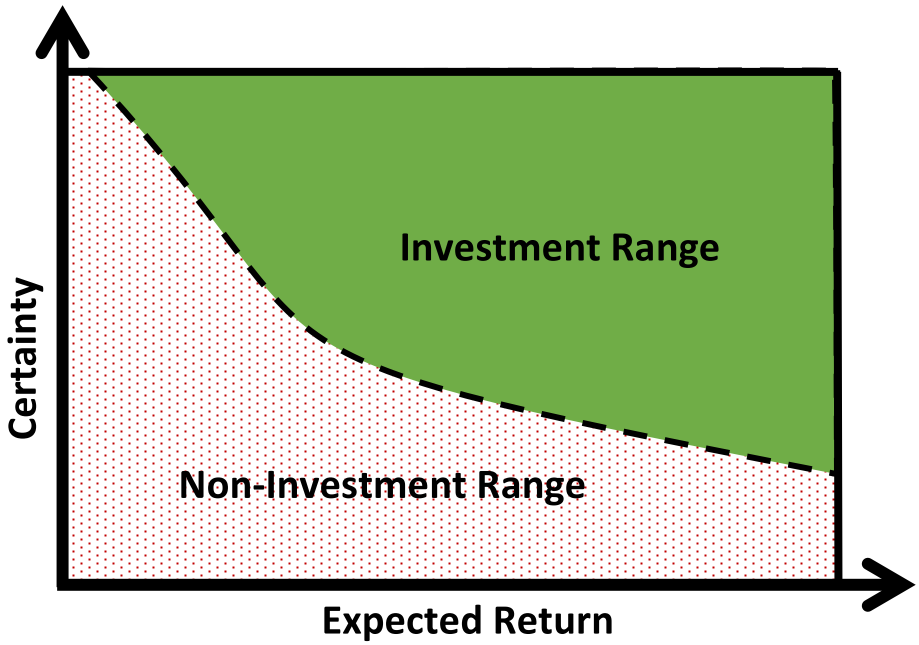
Meijer et al. (2019), reviewing the Dutch experience with sustainable energy innovations, find that banks impose higher interest rates and investors demand higher returns from sustainable energy proponents. This is due to higher perceived risks of investing in the sector. Identified risks are direct financial risks (inherently high in any pre-commercial venture), technological risks (will the technology scale at a reasonable cost), reputational risks (by definition, start-ups lack an established reputation), and legal risks (existing legislation may have an unforeseen impact on commercialization). Additionally, potential financiers also required proponents present more evidence of feasibility. That is, financiers required that proponents demonstrate de-risking in terms of technology (technical feasibility) and economics (positive profits, market exists).[6]

Key to this process is the change in ***perceived*** risk on the part of the financiers. If the actions of the project proponent do not clearly demonstrate increased certainty of a positive return, then their efforts in de-risking an innovation will be fruitless. It is important to distinguish between "inherent risk" (objective risk) and "perceived risk" (subjective risk). A project has an inherent risk that can be influenced by "de-risking" actions by the proponent. These actions will only attract financing if the proponent communicates the reduction in inherent risk to potential financiers and by extension becomes a reduction in perceived risk. Gegg et al. (2015), studying European aviation biofuels, find that more confidence from investors leads to more investment and by extension a faster uptake.

Figure 1 demonstrates a general relationship between certainty and expected return on investment for a financier. Each class of financier will have different preferences over risk and return, which in turn will imply a different shape and location for the demarcation between the green "Investment Range" and the red "Non-Investment Range." For all financiers, the dashed demarcation line will slope downward, indicating a tradeoff between the certainty and expected return of a potential investment.

[6] This process is often referred to as a "due diligence review."

Figure 1: Risk Reward Tradeoff for Investors



In addition to financiers' risk-reward preferences, their preferences relating to the size of an investment are also critical in understanding the innovation and commercialization process. Recall that risk is conceptually identical to the variance in projected returns under different scenarios. A financier's risk-reward preferences do not just apply to a specific project, but also in aggregate across their entire portfolio. When we consider risk in a portfolio, we are essentially talking about the weighted variance of the portfolio, with weights defined by the position (value) of each individual holding. Because of this, a financier with many small investments (such as venture capital fund) has a more diversified portfolio, and therefore faces lower aggregate risk, compared to a financier with a more concentrated portfolio (fewer, larger holdings).[7] Venture capital portfolios tend to have a large number of investments in order to increase the probability of positive outcome for the portfolio as a whole (Ghosh and Nanda 2010).

[7] The relationship between increased diversification and reductions in aggregate risk (variance) holds as long as the projected returns for each holding in the portfolio are not highly correlated with each other.

This has important implications for financing innovation projects, especially those in petroleum cleantech, since each stage of de-risking tends to require a significant increase in required capital. At early "proof of concept" stages (bench and lab tests, intended to demonstrate a viable technology) the capital requirements are relatively low, which lets financiers tolerate higher individual-project risk since they can effectively hedge individual projects against each other. As a project moves to later stages of de-risking (up to and including a commercial-scale demonstration plant), the capital requirements grow, which in turn generally reduces the potential financiers' tolerance for risk.

The amount of funding required to commercialize an innovation is generally beyond the scale that venture capital is willing to provide. As a result, venture capital tends to exit as a viable financing source before an innovation gets to the commercial stage. This creates a potential funding gap, the so-called "valley of death" (Ghosh and Nanda 2010). In the energy industry, financing gaps are especially acute between the piloting stage and the realization of first sales (Globe Capital 2019).

Therefore, the relationship between the rate at which an innovation is de-risked and the rate at which its capital requirements grow is a critical determinant of an innovation project's ability to raise financing on its journey toward commercialization. Furthermore, the innovation proponent must not only de-risk, but must also be able to demonstrate clearly to a potential financier that it has in fact de-risked sufficiently. If a financier cannot be convinced of the reduction in risk, then it will not adjust its behavior accordingly.

While the above discussion references venture capital and other outside financiers specifically, the same type of incentives exist for any project. Even an innovation project that is developed in-house, using budget allocations from a large producer, faces the same risk-reward concerns and the same tradeoffs. A firm engaging in internal innovation is likely to have a larger number of earlier stage projects, which it would cull in later stages, in order to focus on projects with lower risk-reward ratios. Later-stage innovation projects (those closer to commercialization) require more capital and therefore take up a larger share of any portfolio (internal or external) that finances them. The later the stage of the project, the lower risk it must be in order to secure or maintain continued financing or budget allocation.

This is the context through which we discuss factors that limit or promote effective commercialization of cleantech innovations in Alberta's petroleum industry.

Key Factors in Accessing Cleantech Financing in Alberta's Petroleum Industry

Through a review of ongoing cleantech innovation in Alberta's petroleum industry, we identify a core of nine related factors fundamental to accessing and maintaining innovation financing in the sector. We also note that there are hurdles commonly afflicting cleantech innovation that do not apply to Alberta's petroleum industry. We discuss each of these in turn.

Necessity of Pre-commercial Due-Diligence to De-risk

As we note above, pre-commercial de-risking is critical to innovation projects' maintaining continued financing. A core reason for this, not articulated above, is that the initial task of the innovation process is formation of intangible capital[8] (Bloom et al. 2019). Intangible capital has little or no perceived salvage value should the innovation project fail to commercialize, increasing the downside risk of the project relative to standard capital formation. In effect, a pre-commercial innovation project represents a negative cash flow with a perceived all-or-nothing outcome. Any

[8] Intangible capital is any capital asset that lacks physical substance. Examples of tangible capital assets include equipment and structures; an example of intangible capital is any piece of intellectual property (sometimes embodied by a held patent although this is not necessary).

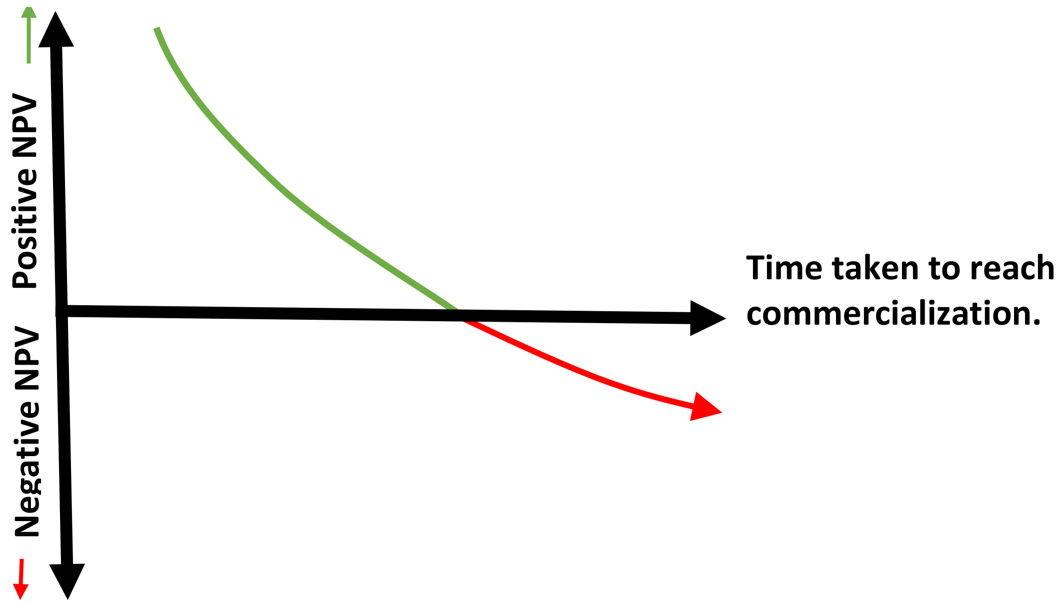
financing committed to the project represents a sunk cost, so if the innovation is not suitable for deployment or otherwise not economic, all of that value is lost.

Furthermore, even if the innovation proves to be commercial, the financiers' interest is to shorten or truncate the de-risking process. Not only do they want innovations de-risked, they want it done quickly. If commercialization takes too long, funding agencies and investors can become impatient and stop funding the innovation's progress. Gompers and Lerner (1999) document bias among venture capital funds towards projects that have three- to five-year returns, linked to the compensation structure for venture capital fund managers. Anecdotally, other institutional investors have a similar bias for shorter-term investments (seven or at the outside 10 years).

Outside of these investor-specific preferences, proponents' and financiers' incentives for expedited de-risking can be clearly illustrated by considering its effect on the discounted cash flow of an innovation project. Holding constant the total up-front cost to de-risk and the eventual value of commercialization, each delay in reaching commercialization reduces the net present value of the project because the financiers and proponent must wait longer for positive cash flows. *Figure 2* shows a stylized version of this relationship.

The resulting incentive is for early financiers to prefer that de-risking occur more quickly. This is not an issue if done properly; however, there is a potential problem if the drive to expedite de-risking compromises the de-risking process. It also raises a credibility issue in accessing future financing. If de-risking is expedited and is inadequate (or, more importantly, if there is a perception of insufficient de-risking), then an innovation project will be unable to access additional financing needed in later stages. The eventual outcome is that commercialization can take longer (or fail to happen altogether) because of early-stage rushing.

Figure 2: The Relationship between a Commercialization Timeline and the Net Present Value (NPV) for Pre-Commercial Finance



Asymmetric Information and Signaling Incentives for Small Start-ups

In de-risking for commercialization, an innovation proponent needs to establish that the technology works, that it is economical and can provide a return, and that it will be able to achieve sufficient market penetration to realize that return. This then needs to be clearly and credibly communicated to potential financiers. The proponent has better information than financiers (the information asymmetry). Credibility of the innovation proponent is the critical element here. If the proponent is credible, and if technology de-risking is well-documented and -articulated to investors, then it is possible to access later-stage financing.

Lindgren and Hallberg (2016) examine the "Black Pellet"[9] technology innovation, finding that the proponent lacked credibility due to its incomplete grasp of the full commercial potential of the innovation. This was a key factor in limiting access to later-stage financing. They note that this is

[9] The "Black Pellet" technology is a processed bioenergy product intended to act as a substitute for traditional hydrocarbons in energy storage/production.

less of a problem for larger firms, as they can leverage general knowledge and expertise to illustrate credibility for individual projects.

Similar to the incentive to move quickly (as discussed above), smaller firms also have an incentive to overvalue their innovations and by extension the firm itself. This incentive arises if initial innovation proponents, who control the firm, want to maintain a controlling interest. The result is that start-ups in search of capital may overvalue themselves in order to raise additional financing without giving up controlling interest. This represents a critical danger to commercialization since a start-up that overvalues itself will face a capital market unwilling to agree to the implied financing terms. The problem can then snowball, as the longer it takes a start-up to raise additional capital, the more that signals to potential financiers that the start-up is a poor investment. Eventually, the start-up can lose momentum and the market will "move on", labelling the innovation as a failure.

When attempting to attract equity financing, the need or desire to protect a firm's intellectual property also constitutes a potential barrier to funding. To motivate investors to provide financing, a firm must clearly communicate its efforts to de-risk, which likely implies sharing significant information about the nature of the developing innovation. However, this is at odds with the firm's interests in protecting its intellectual property (IP). The result is a necessity to balance secrecy and communication in order to establish de-risking efforts while sufficiently protecting valuable IP.

The "Chicken and Egg" Financing Problem

For a mature firm engaged in traditional (non-innovation-related) capital formation, the credibility problem is less acute; firms are able to leverage existing financing in order to access additional financing. Once a firm can demonstrate that it is able to access capital (regardless of the level of risk aversion inherent in the capital source), it can then use that financing as evidence of reduced risk when searching for additional financing.

In early stages of development, cleantech is generally deemed too risky to attract debt financing. As discussed above, this implies a reliance on venture capital for innovation start-ups and funding from general budget allocations for innovation within larger incumbent firms (Ghosh and Nanda 2010). Angel investors (family and friends or the proponents themselves) are also heavily relied on for initial financing.

Government grants often play a substantial role in fostering early growth in cleantech innovations; however, they come with an unintended consequence. Persistent use of government grants may signal to the market that the economics of a project are not strong.

Government grants by their nature do not require any repayment; as such, there is no guarantee for later-stage investors that the vetting process associated with these grants is informative about the market risk of the underlying innovation project.[10] Despite this, government grants are not "dumb money" and granting agencies generally have due diligence standards and make comprehensive assessments. In our review of the industry, however, it is clear that potential private sector financiers do not regard government funding as a strong signal of quality, likely because the terms of these grants do not explicitly align the incentives of the funding source with the project proponent. That is, there is no implied direct financial gain to the funding agency (government) associated with success of the project. Because of this, the ability of proponents to attract grants might not be regarded as a strong signal.[11] This is in contrast to conventional equity or debt

[10] Interest free loans (although not loan guarantees) are exceptions since the granting agency still requires payback of the principal. But even in the case of interest free loans there is no requirement that the project earn a positive return, only that it breaks even (nominally).

[11] The argument behind this assertion is well-established in signaling theory and derives from Spence (1978). The core issue is that if the government (the party issuing the grant) has no financial stake in the project's outcome,

financing, where there is an explicit financial return contingent on the commercial success of the proponent's innovation program.

Therefore, firms that rely heavily on government grants or angel investors may fall into a trap, wherein private financiers do not view existing funding as a signal of potential merit. This limits the ability of a proponent to leverage additional financing, giving rise to a chicken-and-egg problem where the only solution is to find a way to credibly communicate to debt or equity financiers that the innovation is sufficiently low-risk.

Some government granting agencies require that a proponent raise private sector financing in order to access matching funds through a grant program. This has the merit of encouraging proponents to search for private sector financing (in order to avoid the potential funding trap described above). However, this can constitute a different type of hurdle for innovation since a proponent's potential inability to access private sector financing early on can also bar it from accessing non-dilutive grant-based financing. Hence, another chicken-and-egg problem: a firm may be unable to access a grant program, because it cannot access private sector financing, but may be unable to access private sector financing because it lacks financing to sufficiently de-risk an innovation.

A potential solution to some of these issues would be for funding agencies to better communicate the due diligence activities surrounding their funding allocation decisions. This kind of communication would require carefully defined terms of reference, since there are likely liability and other legal issues if a government agency is viewed as providing investing advice. However, clearly communicating and expositing the process and outcome of funding agency due diligence

then the grant itself may be a weak or uninformative signal of the government's favorable assessment of the project. There is also substantial anecdotal evidence of governments' inability to "pick winners", which further dilutes the signaling value of government support.

could go a long way towards correcting the view of government funding as "dumb money". Further to this point, for this to be most effective the reporting needs to be consistent across funding applications. That is, disclosure of due diligence activities would be most effective if it happened across both successful and failed funding applications.

Business Competencies of Innovation Proponents

In the preceding text, we made multiple references to the need for clear communication by innovation proponents to investors. The market for capital is very broad and capital itself is very mobile; innovation proponents compete with a very broad range of potential investments in trying to attract capital. Effective communication is paramount to these efforts. Often the proponents that best understand an innovation have significant expertise in science and engineering, but limited expertise in economics and business.

Reviewing technology commercialization in the Dutch cleantech sector, Meijer et al. (2019) find that a subset of proponents lacked sufficient project management skills and had not clearly developed (let alone communicated) a strategy for the long-term commercialization process. Similarly, in a systematic meta-analysis of radical innovation projects, Sandberd and Aarkikka-Stenroos (2014) note the importance of innovation proponent competencies related to incubation, and acceleration and commercialization.

Simply put, successful commercialization requires that innovation proponents develop or acquire sufficient expertise in assessing and communicating the investment potential of their innovations. I.e., showing that the technology works (or will work, with reasonably certainty) at scale, and showing that it is economically viable (provides a private return on investment) and that there is a credible plan to access sufficient market share to deliver a return to investors. Related to this last point, the size of the market for an innovation and the ability of an innovator to achieve sufficient market penetration are large concerns in their own right.

Also notable here is that managerial competencies required of a cleantech innovation program vary significantly throughout the development process. Early on, scientific and engineering literacy and experience are critical. As the project grows, more managerial expertise is required. At the commercialization stage, financing and business development skills are required. As discussed, the type and source of financing is likely to vary throughout the program's development. This implies that one contributor to success may be the flexibility of program governance to ensure that specific skills are reflected in the program management team at the appropriate time in the development process.

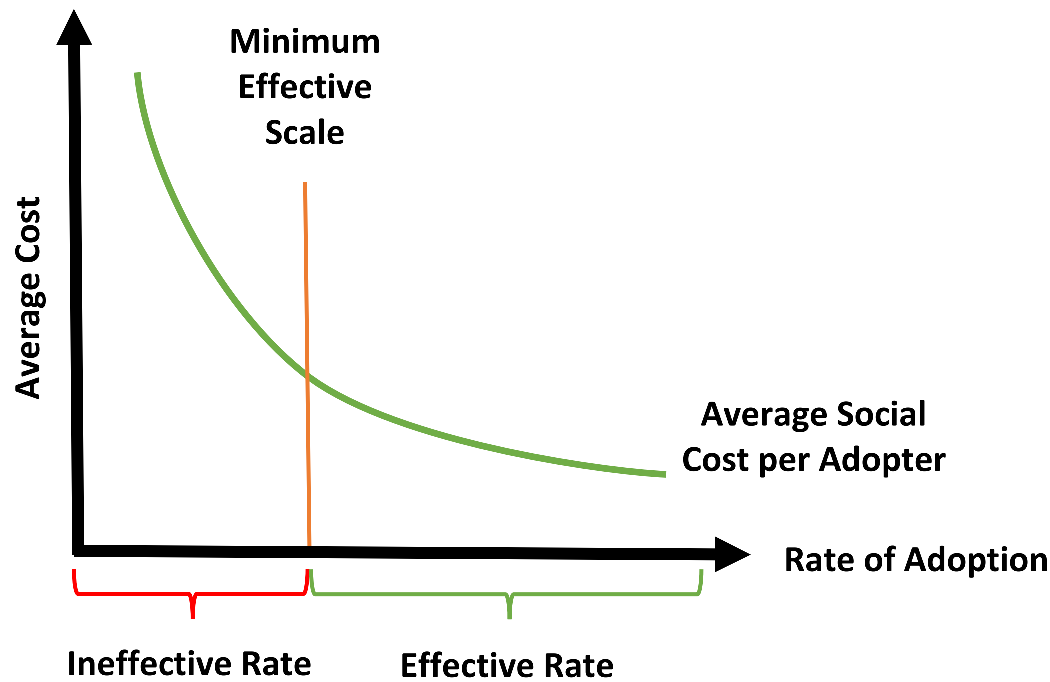
The Market for an Innovation: Greenfield versus Brownfield

The process of innovation requires a substantial up-front fixed cost in the form of negative cash flow (already discussed above) required in developing and de-risking the innovation. Once the innovation is "proven," the value of the innovation is as intellectual property, but that value is driven by how useful and *how extensively used* the innovation is. While there are significant capital costs to deployment, as incremental deployment occurs, the upfront cost can effectively be amortized over a larger and larger market share. That is, the average cost for the first deployment is high because it includes all the upfront development costs, but the average cost falls with every additional unit since the development costs are only incurred once.

In every case, there is a minimum effective scale for technology adoption, below which the average cost is too high (from a social standpoint) to justify the initial fixed costs associated with development (*Figure 3*). Adoption below the minimum efficient scale implies ineffective commercialization (in the sense we defined above), further implying that the project should have been abandoned earlier than the commercialization phase. Adoption above the minimum efficient scale implies effective commercialization and suggests that the project should be commercialized. Therefore, successful effective commercialization requires both a sufficiently large market and sufficient penetration of that market.[12]

In evaluating the market for cleantech in Alberta's petroleum sector, there are two paramount issues: (1) the nature of an innovation in supporting greenfield or brownfield deployment, and (2) market access for the sector as a whole (the much-discussed pipeline issue).

Figure 3: Ineffective vs Effective Rates of Innovation Adoption due to Economies of Scale



In the current environment, oil exports are constrained by pipeline capacity (all of Alberta's export pipelines currently operate at, or near, capacity), reducing incentives for significant production

[12] While this is a stylized representation of the economics of technology innovation, the concept represented here is widely if not universally applicable across industries. The core logic is that the cost of technology innovation (not including implementation) does not vary with overall adoption. This in turn implies economies of scale in adoption, regardless of the specific industry under consideration.

expansions. Greenfield development in the oil sands is less likely, as any greenfield investment would add significant production to a region that is already oversupplied. Absent a significant increase in takeaway capacity — either through policies to support crude-by-rail, or through additions of export pipeline capacity — brownfield investments are a more credible strategy and more likely buyers of cleantech. Commercial incentives and social benefits of cleantech do not just apply to expanded production (marginal output) they also apply to current production (inframarginal production). As such, market access concerns may limit incentives/opportunities at the margin but should not be an overwhelming concern for cleantech innovations in Alberta in general.

Without additional market access, innovations that can be implemented as brownfield investments will generally be less risky than those that can only be implemented as greenfield investments. Better still are innovations implementable in either brownfield or greenfield sites as these have the widest potential uptake. For innovations targeted at brownfield operations, whether the innovation is specific to mining or in-situ operations will also determine the potential market; of the province's 27 active oil sands projects, six are mining and 21 are in situ (Fellows et al. 2017).

Furthermore, the January 2021 rejection of the Keystone XL pipeline (actioned by U.S. President Joe Biden's decision to rescind the project's presidential permit) illustrates that domestic policy makers may have little control over market access. While policy choices related to market access are an important area of policy development, the interests of clean-tech innovation are likely much better served by policies over which domestic policy makers and proponents can exercise more control.

To illustrate the potential for effective commercialization and attract later-stage financing, proponents need to develop and communicate a plan to attain the required scale. It is not enough to show an economic technology and a large potential market. Proponents need to demonstrate a plan for accessing a sufficient portion of that market to generate a positive return on investment. This is a critical element in attracting financing and it requires a proponent to have expertise in business or economics and communication of the same. Such plans need to show either that an innovation can augment existing brownfield or planned greenfield capital investments in a way that is attractive to producers, or that the innovation can successfully supplant an existing technology with enough uptake by producers.

Technology "lock-in" is a concern here. It is entirely possible for an innovation to promote a higher return than existing technology and yet fail to be adopted. If firms adopt a lower-return technology first, when presented with an innovation that would carry a higher return, firms may fail to adopt it because they have already incurred a now-sunk cost implementing the lower-return technology. The bar for an innovation supplanting an established technology becomes much higher (in terms of the promised return on investment) compared to an innovation that augments established technologies. This strengthens the already acknowledged incentive to expedite the innovation process in order to get to a commercialization phase earlier, since this reduces the potential that an innovation is denied commercialization due to tech lock-in. All the same, when expediting innovation, an innovation proponent must still be diligent in de-risking and communicating de-risking to financers.

The Overall Investment Climate for Cleantech in Canada's Petroleum Industry

The macroeconomic climate and the state of the Alberta and Canadian petroleum industry affects investment in any type of innovation, including cleantech. Reduced profits for an oil and gas firm means reduced availability of net positive cash flow to fund cleantech innovations (George et al. 2016). When rationalizing investments in a period of declining profits, oil and gas firms focus on investments with stronger proven returns, which can have the consequence of deemphasizing cleantech opportunities in capital plans (George et al. 2016). Seetharaman et al. (2019) observe that both government and firm-level support for cleantech innovations decline in economic downturns: rather than government support acting as a substitute for declining private support, both end up being pro-cyclical.

In the wake of the 2014 global oil price fall and current pipeline capacity constraints in Alberta, as well as current and lingering effects from the COVID pandemic, firms may not have sufficient free cash flow to support cleantech innovations. Further, the provincial government may not be willing to sufficiently support cleantech innovations given its own reduced revenues.[13]

Expectations about prices in Alberta and outside markets may also play a significant role, depending on the nature of the innovation in question. Some innovations require a specific price differential to be economic. As an example, bitumen partial-upgrading technologies require some combination of (1) a bitumen to heavy oil crude differential and (2) a sufficiently high diluent price to be economical. As uncertainty about petroleum prices increases, or as the expected value of any critical differential falls, a cleantech innovation specific to the petroleum industry may become harder to finance and commercialize.

Emissions Policies, the Market for Carbon and Overall Impacts on Adoption Economics

From a potential adopter's perspective, cleantech innovation provides economic benefits and environmental benefits. For example, an innovation that reduces the steam-to-oil ratio for an in situ oil sands operation delivers an economic benefit in that less energy is needed to produce steam

[13] Public opposition to subsidies to oil and gas or fossil fuel companies (see, for example, Environmental Defence 2018) may also play a role here, though there is also general support for government support of clean tech investment (see, for example, Abacus Data, 2018). These opposing public views may influence government policy.

(per barrel of bitumen production) and an associated environmental benefit, since less natural gas is burned to deliver the reduced quantity of steam, which results in fewer greenhouse gas emissions. In the presence of explicit emissions pricing, that environmental benefit is also an economic benefit.

Innovation proponents need to articulate the economic benefits of an innovation separately from the environmental benefits. It is also important to be explicit about whether environmental benefits are the primary value of the innovation or simply incidental in the search for other direct economic benefits.[14] If an environmental benefit is the primary value proposition of the innovation, this will generally signal a vulnerability to policy-based risk. Consider a technology that reduces greenhouse gas emissions but delivers little or no other benefit. The future financial value of such an innovation is then very sensitive to any changes in emissions pricing or related regulations. Contrast this with an innovation that has a value proposition primarily based on cost reduction with an ancillary environmental benefit. The future financial viability of this second innovation is much less sensitive to regulatory, policy or legislative changes. Clearly identifying a gap in existing processes or in compliancy with existing or impending regulation or legislation can make a significant contribution to commercialization efforts, but it is not a necessary condition for commercialization.

Government policy, regulations and legislation have a predominant role in aligning economic and environmental incentives. More specifically, regulations and legislation can be used to turn an environmental benefit into an economic one either by subsidizing environmental benefits or by

[14] Partial upgrading technology is an example of this. Some of the technologies developed in this category will lead to overall emissions reductions (across the value chain). Yet such reductions are not the goal driving these innovations and are incidental rather than sought-for in the innovation process.

penalizing environmental damages. Economic benefits can flow from an innovation's environmental benefits, but these will be dependent on policy.

A potential adopter will generally only be interested in the economic benefits of an innovation. The exception is if the firm expects a positive reputational effect from involvement in or adoption of cleantech. Absent some regulation or legislation mandating or incentivizing the environmental benefit, there may be insufficient incentive for firms to adopt cleantech innovations based solely on improved environmental impacts. The most prominent example is provincial and federal implementation of emissions pricing, which provides a direct return per tonne of emissions reduced by an adopted innovation. This aligns (to a certain extent) the private economic benefits of a cleantech innovation with the innovation's environmental benefits (at least, those associated with emissions reductions).

However, as noted by Jones (2015), risks of significant policy changes translate directly into commercialization risks for cleantech innovation proponents. If the emissions price is not known with relative certainty, then there is increased variance (increased risk) in the expected return on a cleantech innovation.[15] As indicated above, an increase in risk is counterproductive to commercialization efforts.

Reputation and Investor Sentiment

Beyond the risk-reward context discussed in Section 3, investor sentiment towards the sector is also important in attracting innovation financing. Among investors looking for "green" sectors to invest in, Alberta's petroleum industry is not perceived as attractive given its reputation (deserved or not) as a "dirty" sector. "Green" investors, with a preference for projects with little or no

[15] This is true of all policy, but environmental policy risk is specific to cleantech.

environmental footprint, will look to other sectors. At an extreme level, efforts by the industry to reduce negative environmental consequences of production can actually drive these investors away. George et al. (2016) note that oil and gas companies attempting to communicate sustainability efforts to investors can face accusations of "green-washing": under-representing their environmental footprint or over-representing their efforts to mitigate that footprint. If investors perceive a firm is cynical (rather than earnest) in its actions, they may look elsewhere to invest.

This is a more acute issue for small start-up firms than it is for larger producers, as start-ups rely entirely on new financiers rather than incumbent investors. However, even for large firms, the general sentiment of investors still matters. Regardless of the actual risk and return on investment, if investors are uninterested in financing a specific firm because of an unrelated preference for clean sectors, then that firm will have more difficulty in raising and maintaining innovation financing.

It is worth mentioning here that these investor sentiments are representative of wider public sentiment as well, and this broader public preference can make it difficult for governments to provide public financing support for cleantech innovation in the oil and gas sector. It is reasonable to extend the conclusions by George et al. (2016) from investors to the voting public. The resulting assertion is that the portion of the public that is supportive of efforts to reduce emissions may be in opposition to any additional subsidies of the oil and gas sector (even if those subsidies deliver reduced emissions). As a corollary, the portion of the public supportive of the oil and gas industry may be disinterested in any subsidies provided to achieve climate ambitions.

The reputation of the innovation proponent or the type of innovation also matters. If the proponent or the type of innovation has a reputation for cost overruns, this can cause financiers to look elsewhere. A reputation for cost overruns can be very pernicious and hard to correct. There is also a "free rider" problem, as one proponent is potentially able to damage or ruin the reputation of all firms in a particular innovation space if they are dishonest (or just personally poorly informed) about their own development and deployment costs.

Finally, policy and political risk also matter for investor sentiment. Baker, Bloom and Davis (2016) show that policy uncertainty reduces investment and employment in policy-sensitive sectors; cleantech is arguably policy-sensitive. Political climate and associated policy decisions can therefore influence investment and investor decisions. To the extent that governments are perceived as "unfriendly" to FDI[16] or indifferent/unsupportive to cleantech innovation, this will dissuade investors and reduce options for cleantech firms, also reducing options for cleantech adopters.

The Regulatory Framework

Related closely to the need for pre-commercial diligence to de-risk is the onus on proponents to reduce risk associated with regulatory processes. Regulatory requirements for petroleum-sector projects differ significantly depending on the stage of project. Commercial (or "non-experimental") applications require more approvals, and face more scrutiny and longer review timelines. In Alberta, for example, application-processing timelines alone (not including potential interrogatories and public hearings) could range from 14 business days or less for an application for minor modifications to an oil sands project (brownfield application), to upwards of 1,900 business days for a new oil sands (greenfield) commercial scheme (AER 2019). As institutional investor bias leans towards projects achieving returns within 10 years, as discussed above, it is

[16] For example, Canada's requirements to review "significant investments" by non-Canadians under the *Investment Canada Act* are a deterrent to FDI. Canada's political relationships also matter; specifically, geopolitical tensions with China is correlated with lower Chinese investment in Canada (Snyder 2020).

critical for proponents to have an early and strong grasp of regulatory requirements and associated timeframes and factor this into their plans for deployment.

More broadly, regulations may act as a barrier to cleantech deployment in three additional ways. First, a lack of or ineffective regulations allowing for uptake of solutions by the target market may hinder demand for the innovation. Second, where an innovation is a new technology with no close comparators, the applicable regulatory framework may be unclear, adding time and uncertainty to the regulatory review process. Third, when the market for the technology is reliant on government policy or regulation, perceived risk of changes to the policy or regulation may hinder investment.

Lindgren and Hallberg (2016) identify regulatory risk as one of the four forms of risk to pre-commercial renewable technology that policymakers can reduce, defined as when a change in government priorities has an influence on the market. They argue policymakers can influence industry growth by encouraging rivalry among competitors or supporting new technologies with beneficial policies such as regulating substitutes for existing technologies. Distortionary fiscal and regulatory policies may also restrain the use of emissions-reduction technologies, as seen with conventional oil and gas R&D subsidies hindering uptake of clean energy technologies (Brown 2001; Polzin 2017).

Uncertainty about how regulations will be applied, or whether regulations may change also hinders investment. Polzin (2017) finds banks refrain from lending to clean energy ventures too heavily dependent on policies. In their assessment of critical barriers to alternative and renewable fuel and vehicle deployment, Burke et al. (2016) find that the top barrier to investment in biofuels was policy uncertainty, e.g., how long a policy may remain in effect. Policy uncertainty affected revenue predictability and profitability.

Of course, regulations may act as an enabler of cleantech deployment; for example, through creating a market for the technology or enabling government investment. However, government policy support may not keep pace with technical advancements, or the industry may not have reached the critical mass needed to trigger regulatory reform to accommodate its growth. Studying the commercialization of cleantech in the Netherlands, Meijer et al. (2019) find the relative newness of the sustainability sector posed barriers to government support and regulation of the sector.

Common Innovation Problems Absent from Alberta's Petroleum Industry

In our review of the existing literature on barriers to the commercialization of cleantech, we found three additional themes that seem common to a large proportion of cleantech innovation but do not afflict the Alberta petroleum industry. It is worth briefly commenting on these before we conclude.

First, Jones (2015) and others find that a lack of human capital can be a limiting factor in cleantech innovation, which generally requires skilled engineers and project managers. We find no evidence of this as a limiting factor in Alberta. This may be a consequence of the 2014 oil price crash, or because firms in the Alberta petroleum space have an established history of innovation beyond cleantech, both of which would lead to a stock of available human capital supporting a healthy innovation ecosystem. Regardless of the specific reason, the skills of Alberta's existing workforce translate well to cleantech innovation.

Second, Flamos et al. (2008) and Suzuki (2015) note that established consumer preferences for pre-existing products can limit proliferation of cleantech. However, this observation is driven by product consumers rather than technology consumers (which we refer to as "potential adopters"). In effect, products produced by the Alberta petroleum sector are unlikely to change dramatically (if at all) because of cleantech adoption. This consumer-side issue is inapplicable in our context.

Finally, for smaller economies searching for foreign financiers, inflation rate and exchange rate risk can be an issue (Jones 2015). Increased inflation (relative to expectations) can quickly reduce the real return on an investment for a given nominal return. Accordingly, exchange rate volatility makes repatriated returns on an investment more volatile (and by extension more risky) for foreign investors. Irrespective of its other implications, Canada's central bank has a recognized reputation for providing very stable and predictable levels of inflation. However, there is a tradeoff where stronger Canadian controls on inflation mean increased (Canada-US) exchange rate volatility (Globerman and Storer 2005). Yet, anecdotally, it seems that this exchange rate volatility has not translated into a serious concern for cleantech innovation. Nevertheless, this may require additional inquiry and attention.

Concluding Remarks

Given the range and diversity of factors we discuss above, it is difficult to synthesize a central thesis from our review. Instead, we focus on three themes that emerge from the discussion.

First, in evaluating policies to support successful innovation in Alberta and Canada's petroleum industry, we must clearly differentiate between start-up and scale-up. The need to sufficiently de-risk and develop innovations underlies much of the discussion above. The incentives of an innovation proponent to accelerate its development and reach commercialization more quickly are well understood. This *rush to the finish line*, however, can have unintended and detrimental consequences. Innovation supports at the start-up phase should be focused on fostering innovation that has strong potential for effective commercialization whereas scale-up should rely on demonstrated strengths to obtain private sector support for growth.

A considered and methodical approach to accelerating innovation, rather than following the impulse to cut corners and "expedite" certain aspects of the development process, ensures appropriate due-diligence and de-risking. Policy to accelerate innovation is best implemented by finding ways to support innovation and de-risking. While supporting innovation does not exclusively imply capital provision, in our analysis of this market it appears that access to capital is the most critical bottleneck. It is important to navigate the stages of innovation and the related capital finance process in a more considered and efficient fashion rather than focusing solely on simplifying or expediting that process.

Second, all parties need to recognize the importance and role of non-dilutive funding (specifically government grants). Funding agencies conduct methodical reviews and similar due diligence, which can be leveraged as a signal to private financiers who currently seem to consider government grants as *"dumb money"* that provides no signal of investment quality. There is scope for an increased communications role from those funding agencies, communicating their degree of diligence to potential later stage financiers. There is also an onus on proponents. All financing, particularly government grants, needs to be effectively managed and efficiently spent. Furthermore, these decisions and the overall quality of management of existing financing needs to be clearly communicated to potential financiers.

Finally, though the discussion above has used the context of innovation programs, going forward, more analysis is needed on firm-level determinants of successful innovation rather than program-level determinants. Compared to project-level financing, firm-level supports can foster a more efficient allocation of resources between projects. Under a project-level financing arrangement, financing does not continue after a projected is cancelled, so firms have an incentive to direct resources towards projects that can (or have already) secure initial financing rather than projects with the most merit. While there may be overlap between these two, this overlap is not complete and firms should constantly evaluate the potential merit of their innovation project profiles.

We also discussed the definition of effective commercialization with an implication that not all innovations should reach commercialization. Freedom to fail, and fail quickly, is at least as important here as freedom to succeed. The longer non-commercial innovations or those with negative net social benefit are allowed to develop, the more financing they divert from more productive uses. This is inefficient and ineffective.

When assessing policies and tools to support effective commercialization, firms, granting agencies and policymakers should consider policies that support the failure of innovation programs that should not reach commercialization. This conversation is best at a firm level, rather than a program level, since effectively managed firm-level financing provides both freedom to succeed and freedom to fail. Policies can support a firm failing to commercialize and innovation (where appropriate) but once a program fails there is, by definition, nothing left to support.

Appendix: Projects covered in the review

Table 1 - Innovation Projects Summary

Project	Proponent	Type of application	Potential Market	Technology details
CLEANSEAS™ Demonstration Project	Enlighten Innovations	Processing: Heavy oil and oil sands bitumen	Marine fuel distributors	DSU® is a sulphur-removal and upgrading technology that produces marine fuel from heavy oil feedstock. The technology "uses molten sodium to significantly reduce the levels of sulphur, metals, acid (TAN) and asphaltenes in heavy oil feedstocks, including oil sands bitumen" Field Upgrading (n.d.).
Creating Value from Waste (CVW™) Horizon Project	Titanium Corporation	Oil sands tailings management	Oil sands mine operators	CVW™ "remediates oil sands froth treatment tailings, recovering contained valuable minerals and hydrocarbons (bitumen, diluent)," resulting in significant GHG emissions avoidance and other air quality benefits (Government of Canada n.d.-a).
eMVAPEX (Enhanced Modified Vapour Extraction) Pilot, Phase 3	MEG Energy	Improved in situ extraction	Oil sands in situ operators	The technology "involves infill wells and the injection of a light hydrocarbon instead of steam after initial SAGD operation when bitumen recovery reaches between 20-30%" (Government of Canada n.d.-b).
Enhanced Solvent Extraction Incorporating Electromagnetic Heating	ESEIEH Consortium	Improved in situ extraction	Oil sands in situ operators	The ESEIEH™ technology preheats a bitumen reservoir with electromagnetic energy and uses "a light hydrocarbon solvent to mobilize and recover the bitumen" (Emissions Reduction Alberta n.d.-a).
In-Pit Extraction Process (IPEP) technology	Canadian Natural Resources Ltd.	Improved surface mining extraction	Oil sands mine operators	An alternative bitumen extraction method that involves a relocatable, modular extraction plant that processes ore and separates bitumen right in the mine pit.
N-Solv BEST Oil Sands Scale-Up Project	N-Solv Corporation	Improved in situ extraction	Oil sands in situ operators	Warm propane or butane is "injected as a vapor and condenses underground, washing the valuable compounds out of the bitumen" Emissions Reduction Alberta (n.d.-b).

Sources: Canadian Natural Resources Limited (2018); Emissions Reduction Alberta (2018, n.d.-a,-b); Field Upgrading (n.d.); Government of Canada (n.d.-a,-b).

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