Accelerating Clean Innovation in Canada's Energy and Natural Resource Sectors – The Role of Public Policy and Institutions

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Key Messages

- Promoting clean innovation is a growing policy priority given the need to promote greener growth in a way that builds on the natural resource and knowledge-based nature of Canada's economy. Government has an important role to play in fostering clean innovation: both to correct market and system failures, and to strategically leverage the efforts of private actors in this emerging area.

- The academic literature includes a variety of different perspectives on innovation, which offer distinct policy insights. A pipeline model counsels both supply-push policies like R&D spending and demand-pull policies like carbon taxes. Systems approaches add insights on the importance of sharing knowledge through networks, analyzing the structural environment that impedes innovations, and promoting a diversity of technological niches. Evolutionary economic geography adds a spatial perspective, which can be critical to policymakers concerned with issues of regional prosperity and competitiveness.

- Canada performs well compared to the rest of the world on general innovation drivers due to a high quality university system and entrepreneurial aspirations. It has also developed a cadre of smaller clean technology companies judged to have high innovative potential. Canada falls short in the commercialization and deployment of technologies and the creation of policies specifically targeted to the needs of clean technology sectors. These shortcomings appear to be leading to a truncation of Canada's clean technology sector.

- Clean innovation offers significant opportunities for Canada's energy and natural resource sectors, both to meet growing market demand for environmental performance and to generate innovative products and processes that could be valuable – both for them and other sectors – in the emerging low carbon global economy.

- A more targeted policy strategy that avoids the dangers of "picking" undesirable technology paths will require both strategic policy decisions by government, and more effective public institutions to ensure policies are effectively implemented, evaluated, and adjusted based on regional and sectoral requirements. Such approaches are often referred to as *diagnostic monitoring*, where governments support a portfolio of projects or experiments and continuously detect and correct errors in light of experience.

- Boosting clean innovation will require not only well-designed policies but also a suite of organisations to support innovation. This includes the creation of institutions focused on scaling up clean technology companies by offering financing and market supports, organizations focused on innovation experiments, and intermediary organizations making new connections between innovation actors.

- Future research priorities include: the collection of better data; ongoing analysis of Canada's potential clean innovation strengths; studying the design and mix of policies to boost clean innovation and remove impediments; and examining how the public sector can be designed to promote experimentation and to value critical, but less tangible, innovation activities.

Executive Summary

There is a growing interest in developing a more robust clean innovation framework in Canada. The federal and provincial governments have committed to increasing investment in this area, and the March 2016 First Ministers meeting struck a working group on "clean technology, innovation, and jobs".

This report undertakes a review of existing knowledge within Canada and internationally to answer three questions. First, how do we understand innovation and what are the analytical frameworks that guide innovation policy? Second, what is unique about the Canadian context and what are the country's strengths, weaknesses, and opportunities? This includes considering the role of Canada's natural resource sectors in clean innovation. Third, what policy actions can accelerate clean innovation and what types of policy structures should be created?

Innovation Perspectives

The report discusses three conceptual models and their different policy implications: the linear/pipeline model, systems approaches, and evolutionary economic geography perspectives. We consider the implications for "clean innovation", which are changes linked to reducing environmental impacts or improving environmental outcomes.

The linear or pipeline model views innovation as a series of sequential stages from basic research to commercial entry. Public policies can seek to provide a supply-push to innovation by promoting research, development and demonstration, which helps correct market failures associated with incomplete internalization of knowledge spillovers. Public policies can also seek to provide demand-pull for innovation by introducing policies such as carbon pricing or renewable energy standards. These policies help correct environmental externality market failures whereby environmental costs are not reflected in prices. The literature within this framework suggests both supply-push and demand-pull policies are needed. While demand-pull helps provide stimulus for market adoption, supply-push policies are needed to direct technological change trajectories, increase knowledge spillovers which could be substantial, and avoid premature lock-in within a given technology.

The systems of innovation perspective highlights the importance of interactions between different innovation actors such as users and producers. It views economic development as an evolutionary process driven by innovations that produce a diversity of new options/ developmental potentials and a structural environment that selects against these innovation options. This process of diversity generation and selection generates different innovation trajectories. These perspectives highlight *systems failures* that relate to problems with the direction created by innovation searches and structural impediments. Systems failures can include social networks that are too closed or disconnected and institutional failures related to financial, educational, and regulatory systems. Policies to alleviate systems failures often need to be tailored to innovation gaps or weaknesses in particular sectors and technological areas.

Evolutionary economic geography perspectives highlight innovation as a spatial process. Innovation is geographically rooted because specific places can have the right configuration of social, institutional, and political factors for a technology to evolve, or access to relevant knowledge inputs from the global environment because of cognitive, organizational, or social proximity. Evolutionary economic geography perspectives counsel policymakers to avoid regional lock-in within industries inconsistent with a decarbonized and sustainable economy, and also highlight the variety of horizontal linkages between old and new sectors that could promote new economic pathways.

It is widely accepted that government has an important role to play in advancing clean innovation – both to address underlying market and system failures, and to strategically intervene in ways that support and catalyze private efforts in this emerging area.

Canada's Clean Innovation Context

There are signs of a trajectory towards clean innovation in Canada. Environmental patents are growing faster than the average rate of patenting and employment in clean technology companies is growing faster than the rest of the economy. However, Canada's growth in clean technology development is failing to keep up with the global economy.

Comparisons with the rest of the world demonstrate that Canadians perform well in general innovation drivers due to a high quality university system and entrepreneurial aspirations. Canada has also developed clean technology companies judged to have high innovative potential. Despite Canada's high potential it performs poorly in actually commercializing or scaling-up and deploying clean technologies. This means Canada is not reaping environmental benefits from its research and inventions. The lack of scale-up and deployment is demonstrated by a clean technology industrial structure made up of smaller, older, and R&D intensive firms. A reason for the truncated state of Canada's clean technology industry could relate to the lack of policies specifically targeted towards the sector, in comparison with other countries. These issues resemble the general innovation policy discussion where experts are increasingly questioning the policy emphasis on non-targeted measures such as tax credits rather than sector specific interventions.

Clean innovation policy in Canada should include a significant focus on natural resources and energy, which are key parts of Canada's economy. Clean innovation is critical for this sector to meet the growing market demand for improved environmental performance while maintaining cost competitiveness, and to help Canada meet is global climate commitments. Moreover, since most innovation springs from areas of existing expertise and focus, Canada's strength in resources offers tremendous opportunity to develop innovations that boost that sector's own competitiveness – in a global economy with increasing emphasis on resource efficiency and clean performance – and also generate spin-off innovations that are valuable to other parts of the economy. Both Canadian and international literatures point towards the need to consider linkages between natural resource sectors and a greener economy. Some Canadian resource sectors are already moving in this direction. For instance, the forestry sector is exploring the creation of light-weight composites for automobiles and bio-plastics. Governments, working with private actors, might consider more actively searching out areas where natural resource sectors can advance and complement clean innovations, and where the clean technology sector can be linked more directly to support the sustainable growth of energy and natural resource industries across Canada.

Policies and Institutions

A sustainability transition will need to involve multiple producers and users as well as a diverse array of technologies and new social practices. This makes the policy model more complex than projects focusing on creating a single technological breakthrough, or with a single technology buyer. Policies to accelerate clean innovation in energy and natural resource sectors in particular will need to be targeted towards the specific problems encountered by certain sectors and technological areas within diverse regional contexts, while supporting a variety of technologies to guard against uncertainty.

A targeted policy strategy that avoids the dangers of following undesirable technology paths will be part of this process. While some studies have sought to identify Canadian clean innovation strengths, they have been one-off and inconsistent. Designing innovation policies and institutions using a diagnostic monitoring approach to continuously re-examine technological choices with new insights from on the ground experience could assist policymakers.

A clean innovation policy framework needs to be highly adaptive, tailored to sectoral and regional contexts, and comprehensive – supporting all innovation functions across the entire innovation pipeline. Research has identified key attributes of effective clean innovation policies, e.g. stringent, predictable and flexible. Of equal importance, policy design strategies should focus on the suite of *institutions* required to support innovation – the main focus of this paper.

Given the scale-up challenge Canada might consider creating an organization that would help finance developments beyond the demonstration stage and be tailored to clean technology needs and risk profiles. Governments can also promote the scale-up of companies and deployment of new technologies through public administration reforms that better support green public procurement and export promotion. While a focus on scale-up is crucial, a policy framework cannot neglect the need to continuously produce a variety of new technological and social options to support greener growth. The creation of technological diversity will ensure scale-up organizations have good options from which to choose. Canadian policymakers might therefore also consider creating an innovation agency tasked with promoting experiments linked to the anticipated Canadian demands in a low-carbon economy.

There is also a critical role for *intermediary organizations* whose primary function is to create new connections between innovation actors such as users and producers, experts and entrepreneurs in different sectors. These organizations can help explore different innovation pathways, and might be particularly important to exploring clean innovation opportunities involving natural resource sectors.

Key areas for future research include: producing better quality data to track clean innovation; supporting ongoing analyses of innovation strengths, opportunities, and gaps (including in resource sectors); examining the extent to which clean innovators use existing government programs, and how they can be improved; exploring the mix and design of policies best suited to advance clean innovation and remove impediments; examining institutional configurations in Canada's regionally diverse federation; and developing new public administration structures and practices capable of catalyzing critical innovation processes such as knowledge exchange, visioning, and experimentation (which must accept openness to failure).

Accelerating Clean Innovation in Canada's Energy and Natural Resource Sectors – The Role of Public Policy and Institutions

1. Context

There is a growing interest in developing a more robust clean innovation framework in Canada. At the International Climate Change Conference in Paris Prime Minister Trudeau (2015) committed to doubling investment in clean energy research, development and demonstration. This included investing in clean technology producers as well as the "use of clean technologies in our natural resource sectors". In addition, at the March 2016 First Ministers meeting the Prime Minister and Premiers struck a working group on "clean technology, innovation, and jobs". The 2016 federal budget also included significant funding for clean technology.

Clean innovation is required to address Canada's environmental challenges and grasp new opportunities in a greening global economy. For example, the clean technology market is growing rapidly and projected to exceed $2 trillion by 2020 (Smart Prosperity 2016, 2). While Canada's energy and natural resource sectors are a tremendous source of wealth, jobs, and exports, they can also create significant environmental impacts. These sectors face increasing market scrutiny of their sustainability performance, as well as growing market opportunities for environmentally innovative products, practices and technologies (Dobbs et al. 2011). Canada needs to reduce the environmental footprint left by natural resource exploitation and examine how resource sectors can influence Canada's transition to a sustainable economy – and secure economic opportunities from improved environmental performance.

To accelerate clean innovation, Canada requires an effective policy framework. This report contributes to the development of that framework by examining:

1) The definition of clean innovation and the analytical frameworks that guide innovation policy

2) Clean innovation in the Canadian context, including the country's strengths, weaknesses and unique challenges, such as the role of Canada's natural resource sectors in clean innovation.

3) The policy actions that can accelerate clean innovation and the kinds of public sector institutions needed to implement a comprehensive clean innovation policy agenda.

2. Implications

This report aims to provide insights to two main audiences: Canada's research community and policymakers. The synthesis of existing knowledge will help Canada's research community identify areas for policy relevant research contributions. For Canadian policymakers this report provides ideas on how to think about innovation policy in Canada, and the kinds of policy structures required to effectively implement a clean innovation policy agenda.

3. Approach

The purpose of this report is to synthesize existing knowledge. This synthesis is based on a review of academic and public policy literatures. The latter, so-called "grey" literature, are important materials to understand stakeholder perspectives, policy agendas, and the Canadian context. This literature can be a significant source of policy relevant insights. Publications to review were identified through keyword searches within databases as well as suggestions of relevant materials by experts in the field.

4. Results

The results of our findings are divided into three sections. The first outlines different perspectives on innovation and their respective policy implications. The second section provides a review of clean innovation in the Canadian context. The third section reviews policy models and places particular emphasis on the types of public sector institutions required to implement innovation policy.

4.1 Innovation Definitions and Perspectives

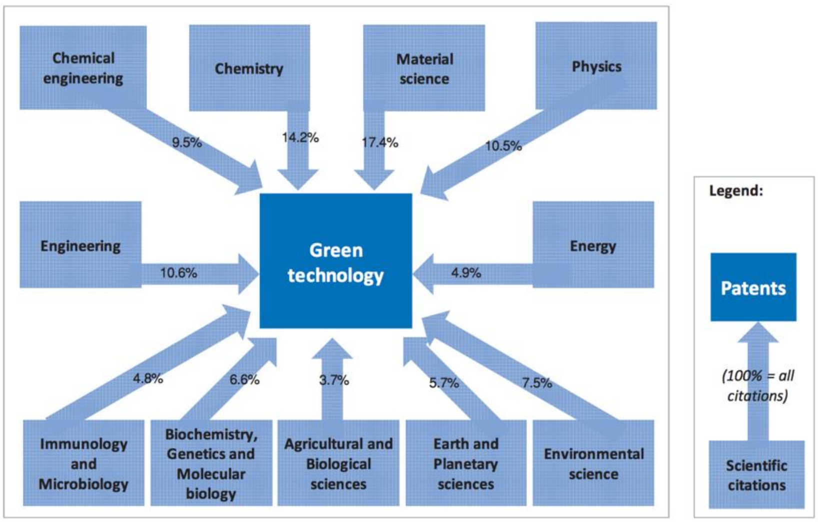
The OECD's Oslo Manual (2005) defines an innovation as "the implementation of a new or significantly improved product (good or service), a new marketing method, or a new organizational method in business practices, workplace organisation or external relations". Innovation must be differentiated from pure invention. While invention involves initial discovery or the occurrence of an idea, innovation refers to putting that idea into practice and diffusing it widely (Fagerberg 2005). The person or organization who puts ideas into practice is often labelled an "entrepreneur" (see Hébert and Link 1989).

Introducing a new idea or technology into society can require a blend of the different types of product, process, marketing, organizational, and relational changes noted in the Oslo Manual's definition. Innovation often occurs because existing things are configured in novel ways; indeed, the prominent innovation theorist Joseph Schumpeter (1934) defined innovation as "new combinations".

In this report we are interesting in *clean* innovation, which we will define as innovations specifically linked to reducing environmental impacts or improving environmental outcomes. Following from the multiple types of changes expressed in the above definition of innovation, we can find examples of green (or clean) technologies, products as well as clean business models (Hastings-Simon, Pinner, and Stuchtey 2014); environmental management systems, standards, and audits (Kollman and Prakash 2001); new partnerships such as more open knowledge exchange between firms (Radnejad and Vredenburg 2015), and efforts to highlight environmental performance through eco-labels and certifications (Auld et al. 2010; Boivie 2007).

Clean innovation is defined by the type of environmental *improvements* rather than the sector making the improvements. In actuality, clean innovations are linked to a wide variety of different sectors and scientific fields. Figure 1 shows the categories of scientific publications referred to by green technology patents from 2000-2007. As can be seen, green technological inventions do not solely stem from environmental science. Scientific fields as varied as material science, engineering, microbiology, energy, chemistry, and agricultural science produce relevant knowledge. Thus when we discuss clean innovation we need to consider that it encompasses multiple sectors and scientific fields, in contrast with innovation studies that might focus on one sector such as information and communications technology.

Figure 1 – The Patent-Science Link in Selected Green Technologies via 2000-2007 citations



Source: (OECD 2011, 56)

The emphasis on environmental improvements implied by clean innovation signifies a particular innovation direction. Dosi (1982) outlines how technological innovation follows distinct trajectories and paradigms. A technological trajectory sets a particular direction of technological advance with its own definition of the relevant problems to be solved and the types of desirable incremental technological improvements. Following Kuhn (1996), Dosi describes that a change in paradigm involves a discontinuity in trajectory, possibly created by new opportunities opened up by a scientific breakthrough or difficulties associated with existing economic paths. A paradigm change will reconceptualise the problems that need to be solved and how to go about solving them. Working within a paradigm means including and excluding different technological options. Economic historians have documented a series of "techno-economic paradigms" centered around particular core technologies such as railroads, electricity, and information and communication technologies (see Christopher Freeman and Louca 2001; Lipsey, Carlaw, and Bekar 2005).

As noted by Freeman (1992) the transition towards sustainability has the characteristics of a new techno-economic paradigm because it must establish a new economic direction, cutting across production and consumption, as well as all sectors of the economy. It might also require a reconceptualization of economic progress (see Osberg and Sharpe 2002; Hayden 2014; Victor

2008) and new forms of design and engineering (see McDonough and Braungart 2002; Hawken, Lovins, and Lovins 1999). Thus clean innovation is likely to disrupt existing economic trajectories more than incremental innovations occurring within existing economic paradigms (see Alkemade, Hekkert, and Negro 2011). Schumpeter (1942) describes "creative destruction" as a political and economic consequence of innovations. The term fits clean innovation because the innovation trajectory sought will *create* environmental improvements and *destroy* or eliminate harmful environmental practices and pollutants such as greenhouse gas emissions. The nature of the businesses that now use environmentally harmful practices is likely to change in an environmental techno-economic paradigm in the same way that the information and communication techno-economy paradigm has revolutionized a number of economic sectors.

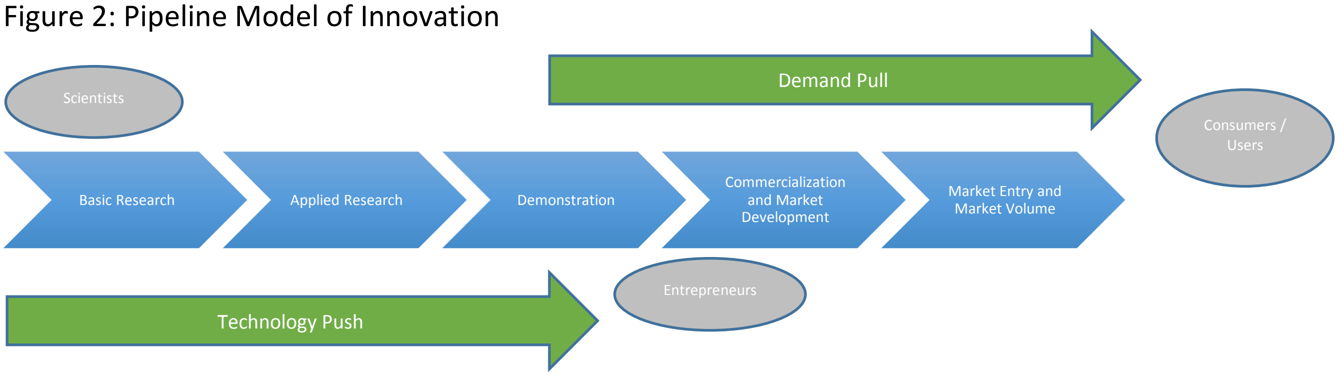
4.2 *Models of Innovation*

There are different conceptual models of how innovation works, which provide separate insights and policy implications. This section will review three perspectives: the linear or pipeline model of innovation and studies on innovation push and pull factors, the systems of innovation perspective, and studies in evolutionary economic geography.

4.2.1 *The Linear/Pipeline Model*

The linear or pipeline model of innovation portrays a new idea or technology undergoing a series of sequential stages starting with basic research and ending in commercial entry and market volume (figure 2).

Figure 2: Pipeline Model of Innovation



Vannevar Bush's (1945) post-war report to the US President titled *Science the Endless Frontier* is credited with creating the original version of this model. Bush proposed that federal funding focus on exploratory basic research and that this focus on the initial stage would deliver economic and social progress.[1] This became known as a supply-push perspective, since government action is focused on the early stages of the innovation pipeline. Schmookler (1966) contested the supply-push model, demonstrating through patent data and case studies that

[1] As noted by Bonvillian (2014), Bush himself did not necessarily subscribe to the linear model. During the war he implemented a highly "connected" model that managed technology at each stage of development to meet major technology challenges (e.g. radar and atomic weapons). Bush's *The Endless Frontier* was a political document, seeking to maintain support for research in expectation that science support would be discontinued after the war.

demand for products and services helped stimulate inventive activity. This perspective highlights demand-pull from the latter stages of the innovation pipeline.

Academics and policymakers have debated the importance of push versus pull factors. For instance, Mowery and Rosenberg (1979) wrote a comprehensive critique of the idea that market demands induce innovation, calling for a perspective that recognized interactions between demand and supply side influences and the innovation contexts of particular sectors. They noted that market-generated incentives are particularly weak in sectors without clear technical solutions, noting alternative energy and antipollution policies as examples.

In the environmental policy field the respective supply-push and demand-pull policies help grapple with two prominent market failures: knowledge spillovers and environmental externalities (Jaffe, Newell, and Stavins 2005). The first failure concerns positive knowledge spin-offs not captured by the investor, meaning private incentives will tend to result in underinvestment in R&D and innovation (see Arrow 1962). The recognition of this market failure justifies public funding of R&D and public investments to increase knowledge spillovers and to provide some supply-push along the innovation pipeline.

The second failure -- environmental externalities -- relates to the fact that markets do not price, or at least underprice, most types of environmental harm. The result is the absence of an adequate market-generated price signal to reward environmental improvements and discourage environmental degradation. Thus the demand-pull signal for environmental improvements is weak. This market failure justifies policies such as environmental taxation, and other initiatives to shape markets via regulations, renewable energy standards, consumer subsidies, etc.

Economic studies have examined the role of both push and pull factors on clean innovation, generally concluding that both are needed. Acemoglu et al (2012) create a growth model with environmental constraints where goods are produced using either “dirty” or “clean” inputs. They find that a sustainable growth path is possible with a combination of carbon taxes to control emissions and research subsidies to direct the path of technological development. Failing to provide research subsidies to direct technical change would result in excessively high carbon taxation, with distortionary implications to production and consumption. Popp (2006) developed a model emphasizing that only focusing on R&D would provide little additional incentive to adopt technologies. His model estimated that 95% of social welfare gains were produced by a carbon tax. Fischer (2008) develops a model emphasizing that R&D is only effective if coupled with emissions pricing. She suggests that technology policies should be viewed as a complement rather than substitute to demand-pull policies. Fischer and Newell (2008) evaluate the performance of policies to promote renewable energy. They find that a range of demand-pull policies achieves reductions at relatively lower costs than R&D subsidies, but that R&D subsidies are nonetheless part of an optimal policy portfolio.

While too much focus on R&D over policies such as carbon pricing might provide insufficient stimulus for technology adoption, authors emphasize that an overemphasis on demand-pull policies could result in lock-in or a premature convergence towards a dominant design with lower long-term performance (see Nemet 2009; Hoppmann et al. 2013). Patent citation analysis from Dechezleprêtre et al. (2014; 2016) suggests that low-carbon R&D produces high knowledge spillovers. The use of knowledge from low-carbon inventions by other sectors is similar to that found in "general purpose technology" (Lipsey, Carlaw, and Bekar 2005) sectors such as information and communication and biotechnology. This finding suggests there are significant benefits to increasing existing levels of clean R&D support.

We can also find insights on the effective design of demand-pull policies to promote innovation. Porter and van der Linde (1995) originally suggested that environmental regulations could improve business competitiveness. The "Porter Hypothesis" emphasizes the need for regulations to be flexible and open to new technological options. A review of the Porter hypothesis also notes how stringent regulations can be backed up by other policies to influence business strategy, as well as organizational and governance innovations (Ambec et al. 2013). Johnstone et al (2010) identify the key characteristics of policy design to incent clean innovation: stringency, flexibility, predictability, incidence, and depth.

To conclude this review of the pipeline or linear model of innovation policy, we can see a consensus that both supply-push and demand-pull policies are needed, and that the design of these policies matters. This perspective also lends itself to quantitative analyses of R&D inputs and market demand policies on innovation indicators such as patents and publications.

4.2.2 System Perspectives

Another innovation perspective comes from the systems of innovation literature. This perspective emphasizes the interactions that occur between different actors such as firms, universities, research labs, and technology users within a given structural environment (Nelson 1993; Lundvall 1992; Christopher Freeman 1987). Rather than a linear progression of a technology along different stages of development, systems thinkers emphasize the role of interactive learning across the boundaries created by the linear model. For instance, studies in technological history outline how users and producers interact and co-develop innovations and that lessons from demonstrations or market entry feed back towards defining problems for basic and applied science (Lundvall 1992; Chris Freeman and Soete 1997).

Systems perspectives are closely related to evolutionary economics which understand economies as constantly changing systems and actors within economies engaging in processes of search because they have imperfect information or "bounded rationality" (Simon 1965; Veblen 1898). Economic change is explained by exploring processes of diversity creation and selection (Nelson and Winter 1982; Bergh et al. 2007). Innovations increase diversity by introducing new ideas, technologies, and practices. The larger economic structure defined by market forces as well as non-market factors such as regulations, cultures, and physical geographies selects certain innovations and excludes others. Thus structures or *selection environments* enable certain technological paths and a particularly exclusionary structural environment and/or a lack of diversity creation could lead to economies becoming locked into an undesirable technological trajectory (Arthur 1989; Lipsey and Carlaw 1996; Grabher 1993). Building on systems evolution perspectives, Unruh (2000) sees climate change a problem of “carbon lock-in”.

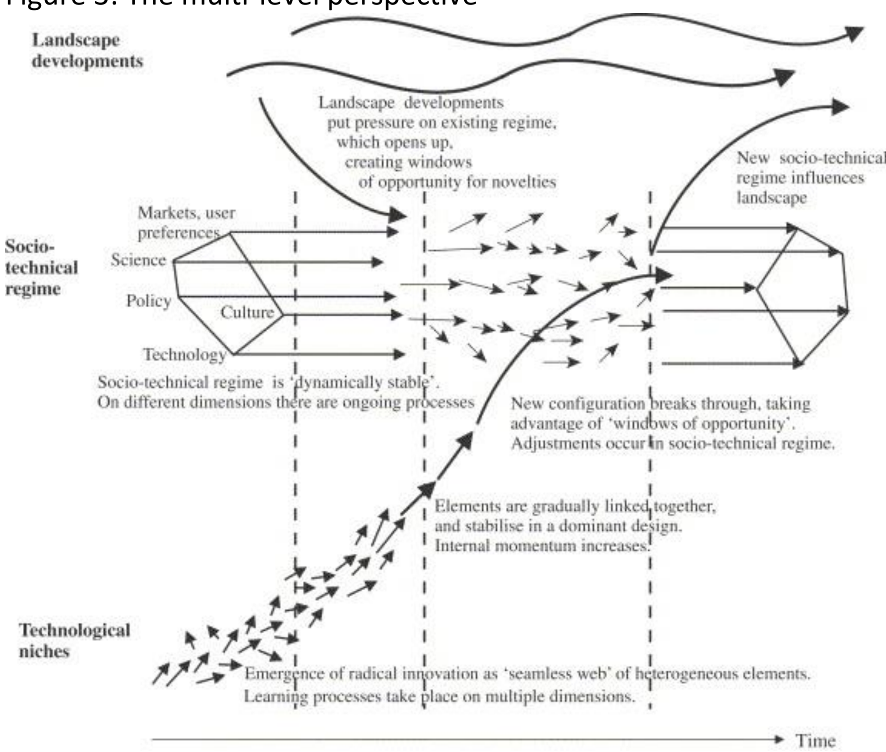
The systems perspective introduces the idea of *system failures* in addition to market failures. While market failures focus on problems that occur with the allocation of resources (i.e. incorrect pricing signals and R&D investment decisions), systems failures describe problems related to innovation searches and structural environments that influence innovation trajectories. This can include network failures created by either a lack of connections that facilitate knowledge sharing or a group closed to new ideas and adaptations. Systems problems also include hard institutional failures that occur when regulations or organizations, such as education and financial institutions, fail to complement innovation and softer institutional failures that occur when culture or habits create barriers, such as an unwillingness to share resources and information (see Carlsson and Jacobsson 1997). Systems failures can also include the role of infrastructures (e.g. electric vehicle charging infrastructure) or a lack of capabilities (Woolthuis, Lankhuizen, and Gilsing 2005).

There are two academic literature streams that have used systems perspectives to explore clean innovation and sustainability transitions: the multi-level perspective and technological innovation systems approaches. The multi-level perspective is an analytical framework constructed from a review of historic studies of social and technological change such as the transition from sailing boats to steamships (Frank W. Geels 2002), the transition from horse-drawn carriages to the automobile (Frank W. Geels 2005), and the breakthrough of rock and roll (Frank W. Geels 2007). It takes a socio-technical perspective, emphasizing that technology can only be understood in relation to the societal function it is trying to fulfill. Thus the transition of technology is intertwined with societal factors such as social needs, culture and symbolic meaning, and political power (see Bijker, Hughes, and Pinch 1987).

The multi-level perspective analyzes socio-technical transitions with reference to systems operating on three different levels: regime, niche, and landscape. The regime represents the dominant social and technological structure. It sets the trajectory of incremental innovations and can exclude innovations that do not fit within its configuration. The niche is a space protected from the *selection pressures* of the regime, where diverse technologies and social practices can develop with potential to change the regime. The landscape represents macroeconomic forces such as major wars, global recessions, and cultural values. Transitions can be described by referring to dynamics and interactions amongst these levels. A common pattern involves a landscape change disrupting the regime, which creates a window of opportunity for niche technologies to develop (figure 3). For example, in the transition from sailing ships to steamships, steamships originally developed in niche markets because of natural protection (inland waterways and a niche role in helping sailing ships navigate through ports), and government created protections (a subsidized system of mail steamers to improve communications within the British Empire). Major landscape changes occurred with the opening of the Suez Canal (where sailing ships could not pass), and political revolutions in 1848 and the Irish Potato Famine, which produced mass emigration pressures. The steamships took advantage of the distance advantage provided by the Suez Canal and the larger cargo sizes required for emigration. A new regime around the steamship emerged as ports were enlarged, a global coal production infrastructure was created, and shipyards made complementary changes. The sailing ships defended themselves through defensive technological improvements (more masts and sails, as well as larger cargo capacity), yet steamships eventually provided better price and performance (see Frank W. Geels 2002). Different regime-niche-landscape patterns have been used to describe low-carbon transitions (G. Verbong and Geels 2007; G. P. J. Verbong and Geels 2010; Hofman and Elzen 2010), including transition dynamics in Canada (Rosenbloom and Meadowcroft 2014; Haley 2014).

For policy, the multi-level perspective counsels creating protected spaces to facilitate socio-technical diversity within niches and working to strengthen these niches. This is an agenda known as strategic niche management (Kemp, Schot, and Hoogma 1998; Schot and Geels 2008). Similarly, *transitions management* considers how to manage both niches and regimes. It counsels developing long-term visions to prepare the regime for change and to guide a series of transitions experiments within niches to facilitate learning and to create public support (see Rotmans, Kemp, and Asselt 2001).

Figure 3: The multi-level perspective



From (F. W. Geels 2006)

Technological Innovation Systems is a complementary perspective (Markard and Truffer 2008). It examines different innovation processes or activities (called innovation functions) that are important to the successful development of a particular technology (see table 1). It thus has potential to provide policymakers with a go to list of factors to consider in technology promotion activities. The list of innovation functions can be used to identify important gaps and the structural factors that contribute to system strengths or weaknesses. Numerous studies have used this approach to analyze sustainable energy technologies such as biofuels, offshore wind, electric vehicles, and carbon capture and storage (Suurs and Hekkert 200910; Wieczorek et al. 2013; Haley 2015; Alphen et al. 2009). A synthesis of renewable energy studies found that key barriers include hard institutional failures related to policy inconsistencies and misalignment between sectors and government policies, market structures that promote large over decentralized energy technologies, and soft institutional failures related to the opposition to change from different interests (Negro, Alkemade, and Hekkert 2012). A key finding in this literature is that policy interventions need to be highly tailored to particular technologies, sectors, and geographies (Jacobsson and Bergek 2011).

Both the technological innovation systems and multi-level perspectives view clean innovation as part of a large-scale transition. They emphasize that innovation is a social as well as a technological process and that structural or systemic barriers need to be analyzed. This literature calls for a wide mix of policies. The policy approaches stemming from the multi-level perspective emphasize the role of preparing the regime for a change and promoting technological niches. The technological innovation systems approach lists a variety of processes that must all work in concert.

Table 1: Innovation Functions - A Useful List for Managing Technology Innovation

This is a list of key innovation processes or activities policymakers need to monitor and encourage - adapted from (Bergek et al. 2008; Hekkert et al. 2007)

Entrepreneurial Experimentation	New firms, incumbents, as well as public and social sector organizations need to experiment in order to upscale technologies, and find new opportunities.
Knowledge development	Research and development as well as learning by doing, learning by using new technologies
Knowledge exchange	Exchange of knowledge by interacting through social networks
Direction of the Search	Developing and signaling the intention to meet a clear development goal or mission, based on technological expectations, user demands, and societal needs.
Market Formation	Creation of markets from small niches to large-scale markets. Can include developing a variety of different user groups, discovering new applications for technologies, and expanding to export markets
Resource Mobilization	Financial, human, and physical resources act as important inputs to production and learning
Political Legitimacy	The presence of advocacy coalitions and developing public support is critical to counteract resistance to change from established interests

4.2.3 Evolutionary Economic Geography

Evolutionary economic geography is a literature closely related to the systems perspectives previously discussed. Economic geography emphasizes the importance of *proximity* to innovation processes (Coenen, Raven, and Verbong 2010). Learning and knowledge exchange can be both global, as well as highly localized (see Wolfe and Lucas 2005; Binz, Truffer, and Coenen 2014). Innovation processes are local because of the role of hard to replicate tacit knowledge (Gertler 2003), and the need for frequent interactions amongst innovation actors (Andersen and Lundvall 1988). Innovation is also geographically rooted because specific places have the right configuration of social, institutional, and political factors for a technology to evolve (Coenen, Benneworth, and Truffer 2012). Proximity however does not only relate to geographic closeness, but can also refer to cognitive, organizational, social, and institutional proximity with linkages that are more global in nature (Boschma 2005; Raven, Schot, and Berkhout 2012).

Evolutionary economic geographers describe how regions follow particular innovation trajectories and specialize in particular industries. As technological dynamics change and industries decline, a region can face problems of lock-in within old industries (Grabher 1993). To avoid this lock-in situation economic geographers have studied how regions change their development paths by building on existing capabilities stemming from previous industrial structures. Statistical studies have demonstrated that new industries that emerge at the regional level are *proximate* in terms of capabilities and technology to old industries (Neffke, Henning, and Boschma 2011; Boschma, Minondo, and Navarro 2013). This phenomenon is called “related variety” because it describes how diversity creation is nevertheless linked to similar industrial structures.

This pattern of “related variety” is particularly relevant to clean innovation. Consider for example how the Danish wind industry has linkages with the agricultural sector. Vestas, a global wind turbine manufacturer, was previously a manufacturer of milk-cooling technologies for the regional diary industry (Philip Cooke 2012). The Danes developed wind turbines in the same way as they constructed farming machinery. Agricultural institutions, such as co-operatives, also facilitated high levels of local ownership and knowledge exchange between wind users and manufacturers (see Garud and Karnøe 2003). Cooke (2009) reviewed the emergence of green clusters in California, Denmark, and Wales and found that they evolved out of other technological networks in areas such as agriculture, information technology, and bio-technology. He emphasizes the importance of horizontal linkages between sectors for eco-innovation, in contrast to the policy focus on vertical specialization found in policy agendas focused on industrial clusters (P. Cooke 2012). For Cooke, the concept of “transversality” involves the active search and realization of market opportunities through knowledge interactions across sector or cluster boundaries.

The policy implications of this perspective is that public policy and public institutions can actively facilitate linkages and knowledge exchange between different sectors to help regions transition towards cleaner technologies and industries. This involves analyzing the regionally specific innovation pathways that stem from inter-sectoral linkages (Haley 2016; Meadowcroft 2014) and the creation of intermediary organizations tasked with exploring innovation opportunities that individual firms or sectoral organizations might overlook (Asheim, Boschma, and Cooke 2011).

4.2.4 *Innovation Perspectives Conclusion*

Table 2 summarizes the three innovation perspectives discussed and their policy implications. Each perspective has its distinct strengths. The linear/pipeline model allows for quantitative analysis of different trade-offs, while the systems models emphasize the broad mix of policies required for a successful innovation strategy. Evolutionary economic geography highlights that innovations will face different opportunities and barriers in particular places, requiring an analysis of regional advantages and disadvantages when choosing which technological systems to examine and promote.

Table 2: Clean Innovation Perspectives

Innovation Model	Sustainability Problem	Type of Analysis	Climate Policy Implications
Linear/Pipeline Model	Market Failures	Trade-off / optimal policy mix between demand-pull and supply-push	Promote R&D Create demand-pull through smart regulations, carbon pricing
Systems Model	System Failures	Analyze evolution / transition Technology and sector specific studies of innovation processes and structural impediments	Create protected spaces for new technologies Promote diversity and experimentation Create long-term visions to guide policy Change structural factors (institutions, networks, infrastructures, capabilities)
Evolutionary Economic Geography	Regional Lock-in	Find regional strengths and assets, as well as global linkages Find linkages between different sectors to promote transition/resilience	Explore inter-industry interactions to target policy towards regionally-specific low-carbon pathways.

Each perspective emphasizes different policy actions, yet are complementary. For instance, the pipeline model counsels R&D spending and demand-pull policies like carbon taxes. The systems approaches support both of these policies because the former results in knowledge production and the latter helps guide innovation searches in a green direction. The systems perspective adds further insights such as the importance of sharing knowledge through networks, analyzing the structural environment that impedes innovations, and promoting a diversity of technological niches. Evolutionary economic geography adds a spatial perspective, which can be critical to policymakers concerned with issues of regional prosperity and competitiveness. The next section will explore clean innovation in Canada's context and return to policy implications of these different innovation perspectives.

4.3 Clean Innovation in the Canadian Context

While there are some general principles for designing policies to promote clean innovation (Johnstone, Hascic, and Kalamova 2010; Ambec et al. 2013; Lipsey and Carlaw 1998), studies of national innovation patterns have not found a one-size-fits all innovation policy. Since national contexts can differ substantially, a nation's innovation challenges and ideal policy response can also differ (see Nelson 1993; Hall and Soskice 2001). This section reviews Canada's innovation context. It examines Canada's clean innovation performance by analyzing indicators and making cross-country comparisons. It then draws lessons from Canada's general innovation policy discussion and the country's historic innovation patterns. Finally, this section will discuss the unique issues concerning the role of Canada's natural resource sectors in a low-carbon transition.

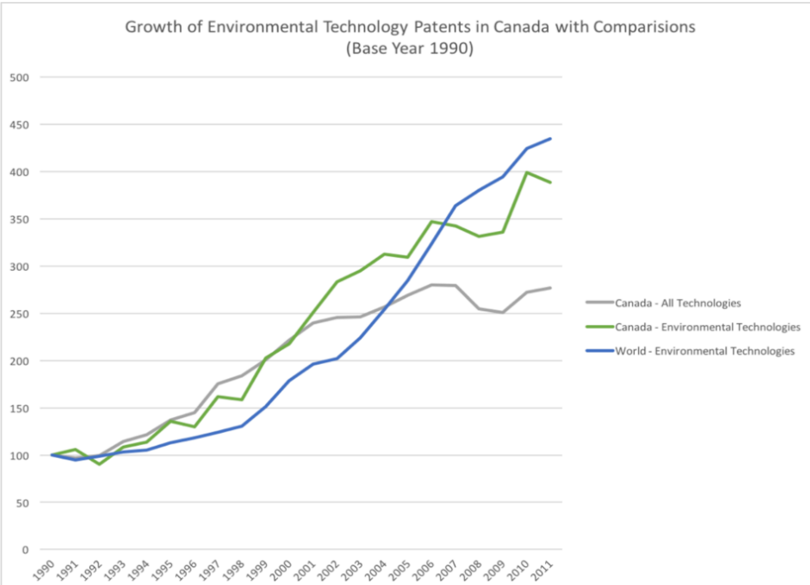
4.3.1 Canada's Clean Innovation Performance

Canadian inventions in environmentally related technologies are growing (figure 4). Environmentally related inventions grew at a rate similar to all inventions until the 2000s when environmental technologies overtook the growth rate of all technologies. This divergence suggests Canada began to move towards a clean innovation trajectory. However, in the late 2000s the growth of global environmental technology patents overtook Canada's growth rate, suggesting Canada might not be keeping pace with the global rate of environmental inventions. In 2011 Canada filed 1.6% of global environmental technology patents. Down from 2.2% in 2000 and 2.5% in 2005 (Figure 4). This put Canada in 7th place for environmentally related patents amongst OECD countries.

Patent indicators present a picture of clean invention growth within Canada that is nevertheless failing to keep pace with the rest of the world. This picture is also repeated in the environmental manufacturing sector. The Analytica Advisors (2015) Industry Report reveals that employment in Canada's clean technology sector is growing faster than the overall economy, and that the export of environmental goods is on par with sectors such as mineral products and wood.[2] However, Canada's share of the global manufactured environmental goods market has been steadily declining.

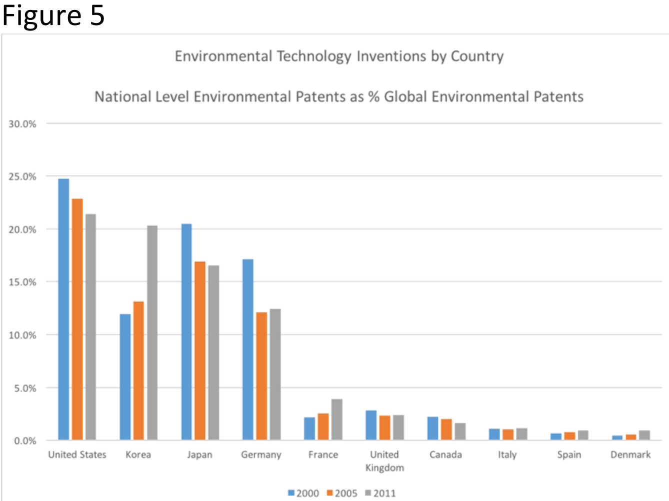
[2] Analytica Advisors compiles firm level data to create a picture of Canada's clean technology sector.

Figure 4



Source: Authors calculations from OECD.Stat[3]

Figure 5



Source: Authors calculations from OECD.Stat

The Global Cleantech Innovation Index produced by the World Wildlife Fund and the Cleantech Group (Parad et al. 2014) provides a picture of Canadian innovation strengths and weaknesses. This index is constructed from a variety of sources and includes scores in sub-categories of general innovation drivers, clean-tech specific innovation drivers, evidence of emerging

[3] Based on a patent family count of 1, meaning that patents are counted if they are registered with any patent office worldwide. Thus this indicator does not attempt to control for patent quality by restricting patent counts to those registered within several patent offices, in anticipation of global diffusion.

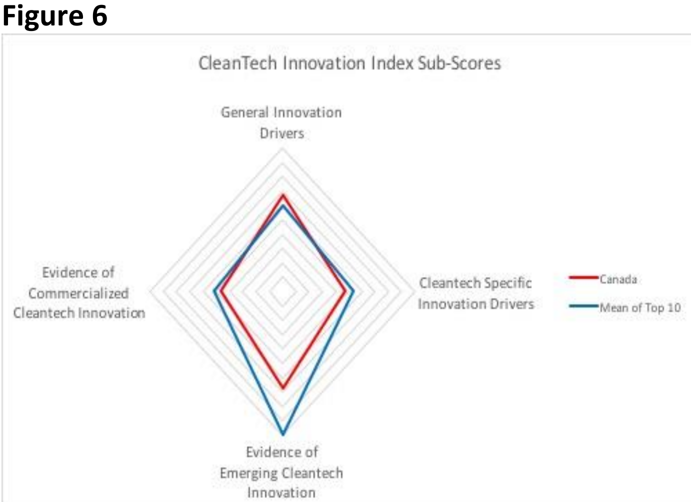
cleantech innovation, and evidence of commercialization. The general innovation drivers score is based on two other indices that capture innovation inputs such as highly ranked universities and strategic alliances, as well as an assessment of a nation's entrepreneurial culture (e.g. new businesses and entrepreneurship as career choice). The cleantech specific innovation drivers category assesses policies and economic structures specifically targeted towards clean innovation, such as government policies, infrastructure for renewable energy, and cleantech industry associations. Evidence of emerging cleantech innovation assesses early-stage or "start-up" progress by looking at indicators such as number of high impact companies, environmental patents, and early-stage investments. Evidence of commercialization assesses the potential to scale-up companies and technologies via indicators such as renewable energy consumption, renewable energy jobs, and number of publicly traded companies.

Table 3: Canada's Position in 2014 Global Cleantech Innovation Index

	Overall Index	General Innovation Drivers	Cleantech Specific Innovation Drivers	Evidence of Emerging Cleantech Innovation	Evidence of Commercialized Cleantech Innovation
Canada's Rank	7	3	18	10	14
Top 2 Countries	Israel / Finland	Sweden / Switzerland	Denmark / United States	Israel / Finland	Denmark / Brazil

(Parad et al. 2014)

Figure 6



(Parad et al. 2014)

Table 3 shows Canada's relative rank within the overall index and sub-categories amongst the 40 countries evaluated in the index, and figure 6 shows Canada's sub-category scores compared to the average of the top ten countries in the index. Canada is in 7th place in the overall index. It scores very well in the general innovation drivers category, performing above the average of the top ten countries (see table 3). This is because of the strength of Canadian universities and the Global Entrepreneurship Monitor's assessment of entrepreneurial culture.

Canada falls within the top ten countries within the "emerging" innovation category, however the leading countries in the index score well ahead of Canada. Countries with a strong "start-up" culture and policies (Israel, Finland, United States) lead. The emerging innovation category includes venture capital investments in renewable energy where Canada ranked third overall from 2011 to 2013 (Parad et al. 2014, 29). It also includes an indicator for "high-impact companies", assessed by listings in the Cleantech Group's top 100 companies. Companies are nominated by the public, analyzed, and finally judged by a panel of experts to have high innovative potential. Canada has nine companies on this list (the second highest country, but well behind the US's 57 firms). Examples of Canadian companies include General Fusion working to develop the holy grail of nuclear technologies; Ostara, a company that recovers phosphorous and nitrogen from water to re-use as fertilizer; and Encycle, which creates energy efficiency controls. This sub-index suggests Canada is producing companies with significant potential and satisfactory support during early stages of development.

Canada performs poorly compared to other countries in commercialization of clean technology innovations. This low index score is substantiated by Celine Bak's (2016) (Analytica Advisors) description of firm demographics. Of the 814 firms she analyzed, 780 had annual revenues less than $50 million. Furthermore, these small revenue levels cannot be explained by the prevalence of new start-ups that could be expected to eventually grow. On average, Canada's clean technology firms were founded 17 years ago (Bak 2016, 3). This cadre of smaller, older firms suggests Canada's clean technology sector is truncated and unable to develop companies of sufficient scale. A reason for Canada's poor commercialization performance can be explained by Canada's 18th place ranking in the "Specific Innovation Drivers" sub-index. This indicator represents direct government and private sector involvement in directing innovation systems towards a green paradigm. Denmark and the United States lead in this sub-category. A lack of scale-up financing, small home markets with limited support through public procurement, inadequate export promotion, an uncoordinated clean technology sector, and a lack of political leadership are some of the factors that studies have listed to explain why the Canadian clean technology sector is stalling (see Analytica Advisors 2015; Woynillowicz, Comette, and Whittingham 2013; Philip et al. 2012).

4.3.2 Lessons from General Innovation Policy Discussions

The overall pattern presented from the CleanTech Index sub-scores suggests Canada is a country with strong innovative capabilities, demonstrated by its high ranking in general innovation drivers and ability to create companies judged to have high innovative potential by both venture capitalists and technology experts. However, Canada is failing to scale-up its companies, leading to low levels of clean technology commercialization. Canada also ranks poorly compared to other countries in public policies specifically directed towards building the clean technology sector.

This pattern within the cleantech sector mimics patterns found in more general innovation policy discussions. While Canada has strong and internationally well-regarded academic research, Canada is a chronically weak business innovator. Canada ranks well in terms of scientific articles, cited paper, and newly registered corporations (i.e. “start-ups”), but poorly when it comes to private sector investment in research and development and the scale-up of Canadian companies (see Conference Board of Canada 2015). Furthermore, Canada’s support for research and development is largely indirect (through tax credits) rather than directly targeted towards specific firms or sectors (see Jenkins et al. 2011; Creutzberg 2011; Breznitz and Wolfe 2015).

The Council of Canadian Academies (2013) synthesis of the numerous studies on business strategy and innovation in Canada highlights that these problems have persisted over Canada’s history, and thus conclude that the roots of the problem are structural.[4] The Council (2013) describes a “low-innovation equilibrium” maintained because business and political leaders have seen little need to escape from it. Canadian businesses have specialized as upstream suppliers of commodities and cost-competitive manufacturing within production networks dominated by US firms. Innovations are acquired from elsewhere because this is easier and cheaper. Within this value chain specialization Canadian profits and job growth have remained healthy, and national economic growth has been supported by either a low dollar or commodity booms.[5] The Council stresses that dangers of remaining within this “low innovation equilibrium” by highlighting oncoming challenges that will require Canada to improve its productivity and to undergo economic transitions. These challenges include an ageing population creating the need for improved productivity to maintain standards of living, declining growth rates in the US and the rise of emerging economies such as China requiring Canada to find new export markets, major technological changes, and the destabilization of Canada’s resource exports due to environmental concerns and global economic volatility.

To change this situation, the Council (2013) calls for moving away from a linear towards a systems perspective of innovation. The linear perspective expects R&D and academic research inputs to deliver innovation performance, yet the problem in Canada is that firms are not demanding these types of research inputs because they are not following innovation-based strategies. The Council suggests some “small catastrophes”[6] are needed to disrupt business behaviours, and that policy should focus on analyzing the health of innovation ecosystems to identify bottlenecks as well as leverage points. This calls for targeted firm-level and sector-level policy approaches. As noted in another Council Report (Expert Panel on Business Innovation 2009, 11) analysis needs to be “informed by a deep understanding of the factors that influence

[4] There is a long tradition of discussing the reasons for Canada’s structural deficiency in creating domestic technologies and companies in Canadian Political Economy (see Innis 1930; Panitch 1981; Laxer 1989; Watkins 1997; Haley 2011; Smardon 2014).

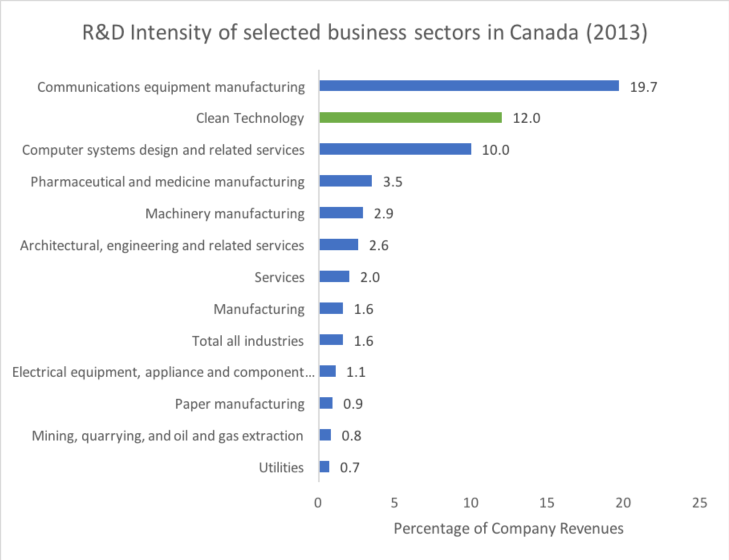
[5] Although the change from a low dollar environment supporting manufacturing exports to a high-dollar environment with the commodity boom has created uneven regional and sectoral effects, and potential long-term vulnerabilities (see Stanford 2008; Beine, Box, and Coulombe 2012; OECD 2012).

[6] This idea comes from Marquez (1972), former CEO of Northern Electric, which later became Nortel - one of Canada’s leading high-technology companies. He traces Nortel’s success back to the small “catastrophe” of losing privileged access to Bell Labs’ technology when AT&T’s monopoly was broken up.

business decision makers, sector by sector," requiring "forms of micro-analysis of the innovation process".

The clean technology sector does not suffer from some of the structural deficiencies found in the larger economy. Canada's clean technology sector invested an estimated 12% of industry revenues in R&D in 2013. This level of R&D intensity is higher than most sectors (see figure 7) and suggests that clean technology companies are following innovation-based business strategies. However, as seen in the Clean Technology Index, Canadian companies face challenges scaling up, which suggests there are problems within the larger innovation ecosystem that supports these firms. If Canadian clean technology businesses remain in their truncated state, there is a danger that they will abandon globally oriented growth strategies towards surviving in particular specializations, or they could be bought up by foreign-owned companies attracted by talent and the level of R&D intensity (see Analytica Advisors 2015). These developments would place clean technology companies within the "low-innovation equilibrium" lamented by the Council of Canadian Academies - characterized by high innovative capabilities, but without the ability to capture the value that comes from growing globally oriented companies.

Figure 7[7]



We must also note that the transition to a sustainable economy requires much more than building a competitive clean technology sector. Clean innovation is a broad concept that must consider how environmentally improving technologies and practices are created and adopted by all sectors of society. The transition towards a sustainability paradigm is a grand challenge. Articulating this grand challenge might help create the type of "small catastrophes" that could jostle Canada out of its low-innovation equilibrium.

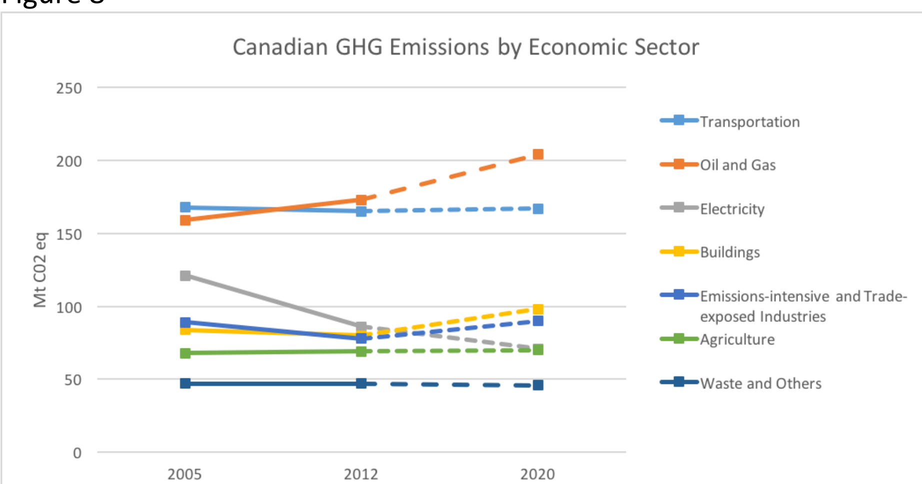
[7] Source Bak (2016, 4) for Clean Technology and Statistics Canada. Table 358-0211 - Business enterprise current intramural research and development expenditures as a percentage of performing research and development company revenues, by country of control and North American Industry Classification System (NAICS), annual (percentage), accessed March 29th, 2016. Based on Total Country of Control.

4.3.3 Clean Innovation and Canada's Natural Resource Sectors

The discussion above noted the importance of sector-specific innovation strategies. In the Canadian context the natural resource sectors are particularly important. These sectors play a major role in Canada's economy and have significant influence of the country's environmental performance. In 2014, natural resources contributed about 20% to Canada's GDP and made up 53% of Canada's exports. Natural resources play a significant role in certain regional economies, making up over 30% of GDP in Saskatchewan, Alberta, and Newfoundland and Labrador (Natural Resources Canada 2016).

Natural resource sectors do not fare well using standard innovation indicators, such as business investment in R&D and patents.[8] Certain resource sectors could also face disruptions due to changing global markets, new technologies, and social demands. A McKinsey Report (Dobbs et al. 2011) argued that resource scarcity, globalized commodity markets, and growing demand from emerging technologies has potential to introduce an era of volatile resource prices. They call for a revolution in resource productivity to deal with resource supply and environmental challenges – both by increasing the efficiency of end-use (e.g. efficient buildings and irrigation systems) and changing the way resources are extracted and converted.

Figure 8[9]



(Environment Canada 2014)

Canada's natural resource sectors also have a strong influence on Canada's environmental performance. Figure 8 shows that oil and gas emissions have been steadily increasing and are projected to drive the bulk of Canada's emissions growth by 2020.[10] This increase in Canada's oil and gas emissions parallels the increase in Canada's export of energy products. In addition to

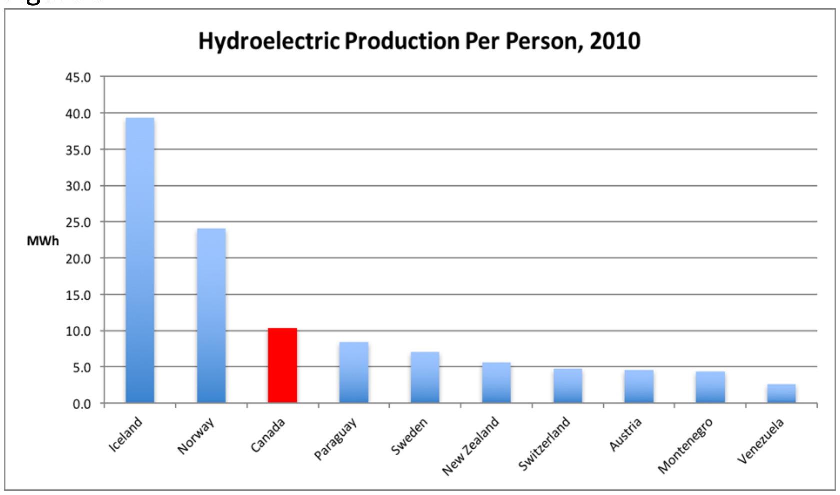
[8] The Council of Canadian Academies (2013) notes that while the oil and gas sector has low investments in R&D and a low share of patents, Canadian oil and gas patents are highly cited suggesting that Canadian innovations are useful.

[9] Excludes LULUCF - Land-use, Land-use changes, and forestry.

[10] These projections do not reflect Alberta's new carbon tax or cap on oil sands emissions.

being an exporter of GHG-intensive resources, Canada is also a significant user and producer of low-carbon natural resources. The demand for some resources such as bioenergy, forestry products, and clean electricity could increase in a sustainable and low-carbon economy. For instance, consider that Canada is amongst a handful of countries with a high share of hydroelectricity within its generation mix (about 60%). In terms of per capita annual hydroelectric production, Canada is the third highest (figure 9). The hydro resource could be a significant advantage, as a recent deep decarbonisation scenario for Canada foresees an almost emissions free electricity sector and significant electrification to help reduce emissions in transportation, building, and industrial sectors (Bataille et al. 2014).

Figure 9



(World Bank 2014 via www.gapminder.org)

Richard Hawkins (2012) provides a perspective on how to think about innovation in natural resource sectors. He suggests that indicators such as R&D intensity and patents help reveal innovation dynamics in sectors such as information and communications technology, but might fail to represent important process innovations or forms of social and organizational learning. He further notes that resource sectors have long supply chains, requiring them to purchase goods and services from other sectors to operate, as well as deep value chains, requiring them to undertake a number of activities to produce the products and to find value for these products in different markets. These are what Watkins (1963) called backward and forward linkages in his Staple Theory of Economic Growth to explain the evolution of the Canadian economy from its resource base. Hawkins (2012) suggests that exploring the systemic linkages between resource and other sectors could provide a “uniquely Canadian perspective” on innovation.

The transversality perspective within economic geography (P. Cooke 2012) also highlights the potentially transformative links between different industries, however it looks well beyond supply and value chains to find these links. Two prominent examples of transversality used by Cooke (2012) involve natural resource linkages. One relates to how wind turbine innovation in Denmark grew out of agricultural industry linkages (see above). The other concerns converting a pulp and paper mill in Sweden into a profitable biorefinery - producing cotton substitutes, biodiesel, and bioethanol. Canada's forest products industry is undergoing similar adaptations. For instance, there are potential opportunities for the forestry sector to create lighter-weight composites for automobiles, and to also produce bio-plastics for medical applications, and to use wood-based chemicals to remediate oil and mining tailings ponds (Forest Products Association of Canada 2016). Some of these initiatives were supported by the federal government's Forest Sector Innovation Program aimed at producing higher value forest products and processes, and a not-for-profit research institute co-funded by federal, provincial, and industry called FPInnovations.

Other linkages with resource sectors can be envisioned. Such as the use of Canada's consulting engineering capabilities to create large off-grid renewable energy projects for mines (Van Praet 2014), and the use of drilling and exploration activities stemming from the oil and gas sector to spur the development of enhanced geothermal technologies (see Gray, Majorowicz, and Unsworth 2012). Lovekin et al (2013) explored renewable energy opportunities in the oil and gas sector, citing overlaps in areas such as energy market insights and mega-project management, and finding niche markets such as the use of concentrated solar thermal energy for enhanced oil recovery and the use of off-grid systems in remote camps.

The lead author of this report explored linkages between Québec's hydroelectric sector and electric vehicle and wind energy technologies (Haley 2014; Haley 2015). Hydro-Québec and the wider regional innovation system played a role in the production of battery and motor technologies, the diffusion of electric vehicles, and the creation of software programs to manage the integration of variable renewables within power systems. A key lesson from these studies is that these linkages were not naturally fostered due to the physical presence of hydroelectricity. The organizational infrastructure created by the Hydro-Québec Research Institute and the cultural understandings stemming from the province's Quiet Revolution played a role in these innovation histories. This suggests policymakers need to look broadly within a given regional context to discover fruitful technological configurations from a natural resource base, and consider the organizational and institutional characteristics of innovation systems.

Canada's natural resource sectors present unique challenges and opportunities. Fossil fuel resource exports make a significant and growing contribution to GHG emissions, Canada's resource endowments could provide the inputs needed for a low-carbon transition, and strategic actions could turn Canada's resource endowments into platforms to spur low-carbon transitions. Managing clean innovation in Canada, given the importance of natural resources, suggests the need to envision future resource demands, and to think broadly about how natural resources interconnect with other sectors as well as the social and organizational dimensions of innovation.

4.4.Innovation Policies and Institutions

We have considered different innovation perspectives and their policy implications as well as problems and opportunities particular to the Canadian context. This section discusses in greater detail the type of policy approaches and policy structures that can be created to support clean innovation.

Section 4.2 discussed the various rationales for government actions to promote innovation. Most innovative activities ultimately come from private actors, such as entrepreneurs, investors, firms, and consumers. However, it is also well understood that governments must play a role. The market failures perspective highlights how clean innovation can be undersupplied by private actors. The systems perspectives highlights how economies can become locked into an unsustainable and high-carbon economic structure, and that policy actions need to work towards redirecting the path of economic change – often by shaping and creating new markets. Governments have played a significant role in many past technological innovations and major structural economic changes (see Perez 2002; Mazzucato 2013; Lipsey, Carlaw, and Bekar 2005). In Canada, the oil sands provide an example of government setting a mission and taking on the risks of technological development, including early manufacturing and commercialization, as well as changes to the regulatory environment (see Pratt 1976; Demerse and Woynillowicz 2014). However there are also many examples of government attempts to promote innovation going terribly wrong (Lipsey and Carlaw 1996; Lerner 2009). Policy approaches need to pursue the most effective ways to take action -- ones that see the public sector playing its role in catalyzing clean innovation in partnership with the private sector. This section will discuss different policy models, the issues with choosing innovation directions, and the types of public institutions Canada might need for an effective clean innovation policy.

4.4.1 Policy Models

A number of different innovation policy models exist. Analogies to the “Manhattan” or “Apollo” projects are used to express the need for urgency and a significant public policy effort. Clichés such as “government cannot pick winners” are also used - often to dismiss the public sector’s role in spurring technological innovation. What type of policy model is needed to tackle global warming and the sustainability challenge?

Figure 10 depicts the relationship between government, technology, and the users and producers of technologies. A “picking winners” model involves the government prioritizing a particular *technology* to *commercialize* (Nelson and Langlois 1983). The British-French project to build a supersonic jet (the Concorde) is an example. This is a very specific model that runs into problems because it lacks market feedback or guidance by scientific, technical or market experience. The finding that government has a poor track record in choosing specific technologies to commercialize does not mean governments remove themselves from activities that involve directing policy towards particular sectors or technological areas, inducing a change in technological trajectory, or coordinating private competition.[11]

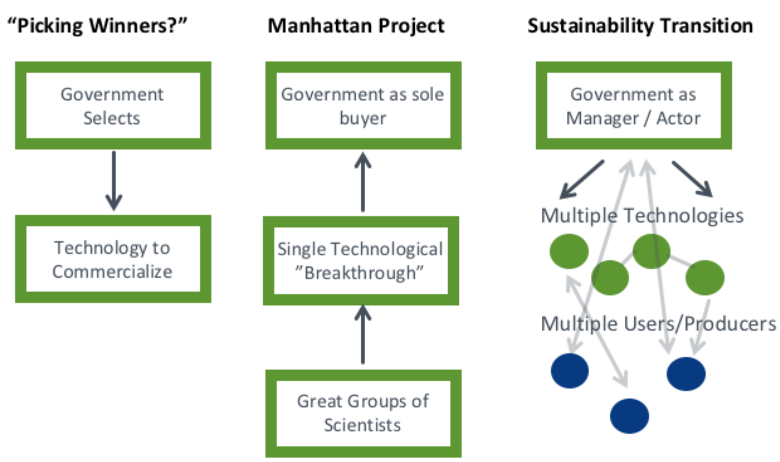
A Manhattan or Apollo project is another model and has been proposed to tackle energy and environmental problems (Hoffert et al. 1998; Amidon 2005; King et al. 2015). In this model a

[11] On the importance of government coordination to avoid collective action problems that arise in commercial competition see Chang (1994).

"great group" of scientists is gathered together to work on a particular technology problem and the government acts as the sole buyer. The demand from government helped shape the innovation trajectory, and the model is focused on producing a single technological breakthrough. This is a relatively straightforward policy model, which nonetheless concerns complicated technological problems requiring insights from numerous areas of science.

A sustainability transition requires a different model because of a different configuration between users and producers, technology, and government. Multiple technologies need to be deployed (rather than a single breakthrough), and these technologies will need to continue to evolve over decades. While the end goal is environmental improvements, the government cannot act as a single buyer; and since numerous technologies are needed it is not possible to rely on a small group of scientists or producers. A heterogeneous and large group of users and producers are involved (see D. C. Mowery, Nelson, and Martin 2010). Thus a sustainability transition will likely involve a network of different actors, numerous public policy organizations and require the use of multiple policy tools. Governments must oversee the numerous actors involved, become an entrepreneurial actor itself (Mazzucato 2013), and guide the evolution of a new innovation trajectory involving numerous sectors and technologies (see Rotmans, Kemp, and Asselt 2001). This could see governments playing a variety of different roles, including buyer, manager, as well as market creator and shaper through technology development activities.

Figure 10: Innovation Policy Models



While macro-level or so-called "technology neutral" policy approaches, like carbon pricing, are important, governments cannot restrict themselves to these approaches (Azar and Sandén 2011) because barriers to social and technological innovations will be quite unique to particular sectoral, technological, and regional contexts (see Jacobsson and Bergek 2011; Bergek et al. 2015). For example the type of environmental problems in the oil sands are quite unique (Council of Canadian Academies 2015), as are the possible innovation trajectories that might be spurred by exploring linkage opportunities with the oil and gas sector. Furthermore, what linkages can be most fruitfully exploited will be strongly influenced by the institutional context in the province of Alberta.

Governments will have to make some choices regarding the portfolio of sectors and technologies they will seek to promote. Supporting a diversity of technologies and initiatives can help guard against uncertainty and lock-in (see Lipsey and Carlaw 1996; Bergh et al. 2007). In the selection and management of projects, Kuznetsov and Sabel (2014) suggest a "diagnostic monitoring" procedure, which involves "systemic evaluation of a portfolio of projects or programmes to detect and correct errors as each project evolves in light of experience and new information". The key idea is that both the public and private sectors, working together, need to engage in a process of search, learning, and adaptation.

4.4.2 Choosing Innovation Directions

Choosing strategic sectors or innovation directions is a difficult task. In Canada, there have been some efforts to uncover potential areas of Canadian strength in a low-carbon economy. In 2012, the National Roundtable on Environment and Economy evaluated Canadian strengths in low-carbon goods and services through a combination of modelling and interviews. They found healthy export and production performance in hydro, nuclear, carbon capture and storage, and strong export performance in efficient industrial processes. Their overall assessment of low-carbon opportunities is that they are "significant, diverse, and regionally specific" (NRTEE 2012, 27). Regional players identified different areas of potential technology specialization such as marine renewables and off-grid energy in Atlantic Canada; transportation manufacturing, low-carbon forestry products, and applications of information technologies to energy efficiency in Québec; nuclear energy and vehicle manufacturing in Ontario; applying energy expertise to geothermal energy, carbon capture and storage, electrification, and waste heat recovery in Western Canada. Also in 2012, a report prepared for Natural Resources Canada (McKinsey & Co. 2012) evaluated technology areas based on global markets and Canadian competitive advantage. They suggested Canada had a clear advantage in unconventional oil and gas, uranium mining, and traditional hydro; that Canada could increase its competitiveness in next-generation automobiles, advanced trains and jets, and water; and that Canada could capture emerging markets in areas like solar photovoltaic, energy efficiency in buildings and industry, unconventional hydro, bioenergy, and waste to energy.

The analysis of particular clean technology sectors is difficult because of the lack of publicly available data. Clean technology production and consumption of environmental products do not fall within standard industry or product classification codes. The analysis of potential Canadian strengths or future technological trajectories has also been one-off and inconsistent, which does not enable a "diagnostic monitoring" procedure to iterate between analysis and experience. One thing that is clear from the studies above is that Canada's potential strengths in clean innovation are quite regionally distinct and diverse. The potential advantages stem from both Canada's natural resource endowments as well as knowledge based assets.

4.4.3 Public Sector Institutions

Thus far this review has highlighted a need to target policies towards the challenges faced by particular sectors, that Canada's innovation pathways are likely to be regionally distinct, that multiple actors will participate within networks, and that innovation policy requires an ongoing process of diagnostic monitoring. All of these findings point towards the critical question of the types of public sector institutions required to implement clean innovation policy.[12] A suite of well-designed, cross-cutting policies will provide an important foundation to boost clean innovation. These should reflect the key design principles identified by Johnstone et al, e.g. they should be stringent (push firms to develop new technologies and practices), predictable (set out a future policy path, to enable long term investment), and flexible (particularly price-based approaches).

Building on this general policy foundation, the policy instruments deployed at different times and places will depend to a large extent on specific innovation contexts. Thus it is important to look at more than just the ideal mix of policy instruments, and also think about developing public sector institutions capable of adapting strategies over time and working across different sectors and regions. This section will discuss the types of public sector institutions Canada might require and the roles they will fill based on the innovation perspectives discussed above.

Canada's primary national public sector institution to promote clean innovation is Sustainable Development Technology Canada (SDTC).[13] SDTC was created in 2001 as an arms-length foundation to provide funding for development and demonstration projects to help companies cross the "valley of death" stage between research and development and real-word demonstration as a critical step to market entry. In terms of the innovation functions listed in table 1, SDTC principally promotes entrepreneurial experimentation and knowledge development through learning by doing and learning by using. SDTC also plays a role in putting together consortia and promoting the clean technology sector. It created a virtual incubator program and programs to help companies find next-stage financing and access export markets. Thus it has branched into other stages of the innovation pipeline and in terms of innovation functions it has broadened its reach to promote financial resource mobilization, knowledge exchange, and the guidance of innovation searches in a clean direction. It is a national program, that also works with regional partners such as the MaRS Discovery District in Toronto and the Climate Change and Emissions Management Corporation in Alberta.

The review of Canada's innovation context in section 4.3 demonstrated that the scale-up of clean technologies is a major challenge. Scaling up clean technology requires activation of the "resource mobilization" innovation function; including access to human resources, new

[12] In this case "institutions" primarily refers to organizations, as well as the larger concept of how these organizations operate and interact with other governmental departments and with non-governmental organizations.

[13] Other institutions, like research granting councils, also play critical roles, though not targeted specifically at *clean* innovation.

infrastructures, as well as financial resources. Scale-up financing requires a level of investment higher that what is available (or mandated) from SDTC – which focuses on demonstration stages of development by supporting projects, and cannot provide equity or debt finance. However, the private sector (both equity and debt finance) still see most large scale investments in clean innovation as too risky or with payoffs too far in the future.[14] Some other clean technology investments are too small (e.g. $50M) to meet project finance thresholds for traditional investors (Bak 2016). It is increasingly recognized that there is inadequate private financing available to support clean technology sectors in Canada, particularly as they scale up, putting at risk the prior public investments in research, development or demonstration.

Mazzucatto and Penna (2014) have shown that state investment banks have been a major source of finance for climate change adaptation and mitigation projects. In other countries, existing institutions like Germany's KfW development bank opened up environment and climate protection funding areas. In 2012 the United Kingdom created a *Green Bank* to increase the deployment of some clean technologies. Connecticut, New York, and Rhode Island have also created Green Banks. These banks provide a number of financial services such as solar insurance, loan loss reserves, green bonds, and loan securitization. In Canada, the Business Development Bank and Export Development Canada are public institutions that provide financing services[15], however they have been criticized for having insufficient focus on clean technology and some have called for the creation of new institutions (e.g. a Green Investment Bank) at federal and provincial levels (Rand 2015; Broadbent Institute & Mowat Centre 2015).

Government policy can also promote scale-up by increasing access to domestic markets through public procurement. Numerous countries have used public procurement as an innovation tool, by either increasing demand directly and/or by seeking to solve a particular societal problem by committing to buying something new in the future and working with domestic companies to produce a new product or service (see Edquist et al. 2015). However attempts to promote green public procurement in Canada have run into inter-departmental barriers (Toner and Bregha 2009, 34). How to coordinate public procurement within Canada's public sector deserves new consideration, as well as the extent to which clean innovation is promoted through existing public procurement programs, such as the Build in Canada Innovation Program.[16]

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[14] One important element of this risk is that much of the demand for clean technology is driven by government policy, such as new environmental standards. Unlike most other types of innovations, environmental benefits are mainly an unpriced market 'externality', thus there is limited market demand for these innovations absent government demand or public pressure. This creates an element of *policy risk*, over and above the general risks surrounding innovation – and also explains while policy predictability is so important to help drive clean innovation (Johnstone, Hascic, and Kalamova 2010)

[15] Export Development Canada has partnered with SDTC to create an Export Market Access Program and the BDC Capital (a subsidiary of the Business Development Bank) offers "growth and transition" capital and it has an Industrial, Clean and Energy Technology Venture Fund.

[16] The BCIP is a program operated by Public Works and Government Services that procures and tests late stage innovative goods and services within the federal government. The federal government gives entrepreneurs feedback on their product's performance. The program provides an opportunity to validate the application of their product.

In addition to promoting scale-up through the domestic market, access to export markets is especially important in Canada's small economy and for Canada's energy and natural resource sectors. Export Development Canada (EDC) can provide loan guarantees and growth equity. SDTC created a partnership with EDC to make linkages between clean technology companies and potential international buyers. In addition, the Canada Trade Commission service has established a special stream for cleantech companies. However, a review of clean technology export policy supports did not find a comprehensive strategy at the federal level or significant activities at provincial levels outside of Ontario and Quebec (Comette, Kniewasser, and Lightburn 2015). Other nations have more sophisticated supports. For instance, the US Department of Commerce produces detailed market assessment tools for exporters. There are also opportunities to enhance insurance programs for exporters and to make links between Canada's international development funding and Canadian capabilities in areas like energy and water.

While scale-up is essential in Canada's clean innovation context, institutions to promote ongoing experimentation to produce new technological options should also be considered. Canada's score within the "emerging" category of the Global CleanTech Innovation Index was higher than average, but lower than the top ten performers. In addition, an evolutionary innovation framework suggests that there is a continuous need to promote a diversity of new innovations so institutions focused on scale-up have a number of options from which to select. As McDowall and Ekins state (2014) state, diversity is "fuel for the evolutionary process".

Canada currently has institutions such as start-up incubators and accelerators as well as the Industrial Research Assistance Program which provide support for start-ups and small and medium sized businesses as well as Centres of Excellence programs that seek to commercialize research out of universities. These policies are generally aimed at earlier innovation stages from the pipeline innovation perspective. However, a mission-oriented agency like the Advanced Research Projects Agency-Energy (ARPA-E) in the Unites States plays a different role. As explained by Bonvillian (2014), ARPA-E works "right-left" across the innovation pipeline by first envisioning society's need for energy innovations (the final commercial product or service) and then reaching back to challenge basic and applied research to meet these goals. This model combines both guidance of search and knowledge development innovation functions. It differs from the Canadian approach which either takes a linear view of innovation where R&D naturally produces insights that can be commercialized; or which seeks to have the private sector, rather than a societal mission, define research and innovation problems. The former model fails to promote the user-producer-researcher systemic linkages needed to direct innovation efforts and exchange knowledge, while the latter model fails to grapple with the lack of demand for innovation from Canada's business sector, as discussed by the Council of Canadian Academies (2013). Canada should consider if it needs an experimental innovation agency to help accelerate clean innovation, including for energy and natural resource sectors, and how it might be structured.

There is likely also an important role to be played within Canada's policy landscape by intermediary organizations that focus on making new connections between different innovation actors such as users and producers, entrepreneurs and funders, and experts within different sectors (Stewart and Hyysalo 2008; Howells 2006; Backhaus 2010).[17] These organizations can explore the innovative potential of connections between different sectors, articulate new expectations and visions, and build up new networks of actors (see Kivimaa 2014). Such work is required to build linkages between green technologies and Canada's natural resource sectors and to articulate potential regional innovation pathways. Cooke (2012) demonstrates that innovation agencies in Sweden (Vinnova) and Germany (Bayern Innovativ) explore innovation "white spaces" or innovation potentials that result from combinations within different sectors. This includes exploring the natural resource linkages previously discussed. Intermediary organizations can play a critical role in an innovation system by facilitating knowledge exchange and coordinating new sectors and political coalitions. Yet these organizations are also most likely to face challenges in a public administration paradigm focused on "management by results" (see Savoie 2015) because intermediaries might produce few measureable policy outputs on their own. Intermediary organizations also require a degree of neutrality from central government so they have the freedom to create new networks and explore potentially disruptive visions and alliances (Kivimaa 2014; Breznitz and Ornston 2013).

The policy model discussion above points towards the need to create multiple institutions rather than a super-ministry.[18] Ideally the public sector can create a system that fills gaps and provides comprehensive support for innovation, but also leaves room for institutional innovations. Overly centralized decision making can "suppress innovation and the development of new strategies" (Wilson, Post, and Srinivas 2007 quoted in; D. C. Mowery, Nelson, and Martin 2010). A "networked" state (Block 2008; O'Riain 2004) where multiple organizations exist, and sometimes overlap, opens up the possibility for novel combinations between elements of the public and private sectors and guards against group think and political capture. It is an organization of public administration that matches a sustainability transition policy model recognizing the need to involve multiple users and producers and to encourage the development of a variety of social and technological innovations. A networked structure with some decentralization of innovation activities to cities and regions might also fit Canada's federalist context, where sustainability challenges and clean innovation potentials are geographically distinct (see Haley 2016).

Coordination of a network of public organizations is critical. In Canada, SDTC has received praise for helping companies through the development and demonstration phase, yet SDTC has not been able to seamlessly hand-off most of its projects to other financing bodies (public or private) that can support scale-up, particularly for technologies with high capital costs. Intermediaries, experimental technology agencies, and green banks need to be politically neutral and open to risk, and are thus often arm's length from government. Yet, the discussion above also highlights the role of public procurement, which requires coordination across multiple entities of government; as well as export promotion which might leverage the

[17] The Industrial Research Assistance Program and Networks of Centres of Excellence, mentioned above, play this role to some extent.

[18] These more centralized innovation models can be found in the economic history of Japan (Johnson 1982) and Korea (Chang 1994; Amsden 1992).

government's diplomatic capabilities. In addition, government investment in infrastructure can be a critical enabler of innovation (e.g. in energy or transportation systems). Thus the creation of a number of arms lengths organizations cannot detract from the need to build up capacity within the civil service. Canada might consider creating a coordination institution, such as a sustainability transitions czar and/or a federal office tasked with supporting and coordinating multiple organizations at national, regional, and local levels.

Table 4 provides an overview of how the different institutions contribute to innovation functions and where they operate along the innovation pipeline. Combined, this institutional mix works across all innovation functions and stages of the innovation pipeline. Many of the institutions contribute to the "direction of search" innovation function because they specialize in clean innovation. In addition, not all organizations can neatly be segregated based on their role within the innovation pipeline or across functions. Some organization, such as intermediaries and experimental innovation agencies, play an important role by making connections across the innovation pipeline. Others aim to create positive feedbacks between different innovation functions. For instance, demonstration agencies spur entrepreneurial experimentation and knowledge development through learning by doing and learning by using. Intermediary organizations can build up political legitimacy by creating new networks of actors by envisioning possible futures through knowledge exchange and guidance of search activities such as strategic planning and foresight.

Table 4: Roles of Public Sector Institutions

Public Sector Institutions	System Coordinator					
	Experimental Innovation Agency (e.g. ARPA-E)	**Demonstration Agency (e.g. SDTC)**	**Intermediary Organizations**	**Public Procurement Organizations**	**Green Bank**	**Export Promotion Organizations**
Innovation Systems Functions Perspective						
Entrepreneurial Experimentation						
Knowledge Development						
Knowledge Exchange						
Direction of Search						
Market Formation						
Resource Mobilization						
Political Legitimacy						
Innovation Pipeline Perspective						
Basic Research						
Applied Research						
Demonstration						
Commercialization and Market Development						
Market Entry and Market Volume						

5. Areas for Further Research

There are numerous opportunities for further policy relevant research and for the creation of new research tools and infrastructures. What follows are some suggestions for further research that stem from this knowledge synthesis.

The creation of publicly available, clean innovation specific industry and product classification codes and other clean innovation relevant data would be a valuable tool for further research, and other purposes. Developing these indicators themselves is a challenge. Clean technology itself includes many sectors (e.g. smart grids, water, waste management) that might have little in common other than the ability to create environmental improvements. The definition of a clean technology firm might also be fluid as many different innovations can lead to environmental improvements. The adoption of environmentally friendly technologies should also be tracked. Adoption will also be a moving target as the best environmental products change as technology improves. Finding useful indicators for tracking Canada's sustainability transition will require major data collection efforts informed by relevant conceptualizations of what we seek to measure.

More research is required to explore Canadian strengths, opportunities, and gaps. This work should not be one-off, but part of an ongoing "diagnostic monitoring" process. It could be aided by research infrastructures that enable access to relevant data, the use of scenario models, data analytics, and data visualization, as well as expertise in facilitation, strategic planning, and interviewing techniques. Clean innovation opportunities can be discovered by exploring potential linkages between different sectors (especially natural resource sectors), as well as potential clean innovation pathways at municipal and regional levels. The list of innovation "functions" noted in this report can be used as a way to diagnose innovation system weaknesses and strengths.

The challenge of scaling-up clean technology companies and deploying existing technologies requires more work. We need a better understanding of the factors that prevent scale-up and the best way to implement potential solutions. For instance, what are the best practices for governments to promote green technologies through public procurement; what export strategies work best; where is government needed to fill finance gaps and leverage private investors; and how could a Canadian Green Investment Bank be designed and operated. A key question is whether clean innovators are being adequately supported by existing government programs and organizations, or if organizations with a stronger clean innovation mission are required.

We need to find an institutional configuration that fits Canada's regionally diverse and decentralized federation. Canada's decentralized state and regional diversity has been recognized as a significant challenge for state directed innovation (see Simeon 1979; Jenkin 1983; Atkinson and Coleman 1989), and political leaders have highlighted national unity as a factor that complicates the implementation of policies such as a carbon price (De Souza 2016).

However, Canada's regional diversity could be turned into a strength if it promotes a diversity of technologies and learning opportunities, which can be shared at national and international levels (see Haley 2016). What are the respective roles of federal, provincial, and municipal governments, as well as different regional actors in promoting clean innovation in Canada's context? How does this differ across regions with different natural resource industries and sectoral compositions? How can the federal government best add value to this mix?

There is also important research to be done on policy design, keeping in mind the above-noted five key elements of effective clean innovation policy. For example, how can Canada do better at creating policies regimes with predictable, increasing levels of stringency – which is critical to encourage long term investment. In what areas can price-based approaches be adopted (e.g. for water or pollution), and potentially stacked or combined for greater efficiencies? What other types of flexible regulatory approaches (beyond pricing) can better incent innovation? To what extent do existing regulatory rules unnecessarily hamper clean innovation; this may require a sector-by-sector analysis. And how can enforcement and compliance regimes – which tend to discourage risk-taking – be tailored to better support innovation?

The public administration challenges involved in monitoring and evaluating innovation also deserve consideration. How do governments enable public sector organizations to have an open attitude towards experimentation and risk? How do government leaders assess the functioning of intermediary organizations which might play critical roles within innovation systems, but produce few quantitative outputs?

There is also an overall need for more and better research into the effectiveness of existing clean innovation policies and institutions, both in Canada and abroad, to better enable learning from these experiences.

6. Knowledge Mobilization Plan

Sustainable Prosperity's knowledge mobilization efforts will be directed towards the academic and public policy communities. We will follow a two-stage approach to knowledge mobilization. The first stage will focus on communicating and disseminating the report, and the second stage will focus on using the report to develop a new research agenda focused on clean innovation.

With respect to the first stage, the report will be communicated and disseminated using a number of Sustainable Prosperity's communications tools and channels. First, the findings of the knowledge synthesis will be submitted to a journal such as *Canadian Public Policy*, *Renewable and Sustainable Energy Reviews*, or *Wiley Interdisciplinary Reviews: Energy and Environment*. Second, the report will be profiled prominently as part of a "Clean Innovation" communications campaign, which will include posting on the Sustainable Prosperity website, distribution through social media, blogs, newsletters, and presentations as well as media opportunities including op-eds and potential interviews. This will be done in conjunction with Sustainable Prosperity's Communications Team. Finally, the report will be distributed through Sustainable Prosperity's extensive networks, including its substantive Research Network, a growing Policy Network, and through the Smart Prosperity network – a new grouping of Canadian leaders from business, think tanks, labour, Indigenous Peoples, youth, and non-governmental organization communities.

Thus far, elements of this research have been presented to the *Economics and Environmental Policy Research Network Symposium*, and were discussed with senior leaders from the Government of Ontario. Further meetings with high-level decision makers will occur in the future.

The second stage of this work involves using the findings to develop new research projects, based on the opportunities and gaps identified. Sustainable Prosperity's Senior Research Associate will use this report as a discussion document for engagement with interested researchers and potential partners. She will work with the Research Director and Sustainable Prosperity's Research Network to develop specific research proposals in areas such as public procurement, regional innovation strategies, and institutional design.

References

Acemoglu, Daron, Philippe Aghion, Leonardo Bursztyn, and David Hemous. 2012. "The Environment and Directed Technical Change." *American Economic Review* 102 (1): 131–66.

Alkemade, Floortje, Marko P. Hekkert, and Simona O. Negro. 2011. "Transition Policy and Innovation Policy: Friends or Foes?" *Environmental Innovation and Societal Transitions* 1 (1): 125–129.

Alphen, Klaas van, Jochem van Ruijven, Sjur Kasa, Marko Hekkert, and Wim Turkenburg. 2009. "The Performance of the Norwegian Carbon Dioxide, Capture and Storage Innovation System." *Energy Policy* 37 (1): 43–55.

Ambec, Stefan, Mark A. Cohen, Stewart Elgie, and Paul Lanoie. 2013. "The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness?" *Review of Environmental Economics and Policy*, res016.

Amidon, Lt Col John M. 2005. "A 'Manhattan Project for Energy." *Joint Force Quarterly* 39: 68–77.

Amsden, Alice Hoffenberg. 1992. *Asia's next Giant: South Korea and Late Industrialization*. Oxford University Press.

Analytica Advisors. 2015. "2015 Canadian Clean Technology Industry Report (Synopsis)." Ottawa.

Andersen, Esben Sloth, and Bengt-Ake Lundvall. 1988. "Small National Systems of Innovation Facing Technological Revolutions: An Analytical Framework." In *Small Countries Facing the Technological Revolution*, edited by Christopher Freeman and Bengt-Ake Lundvall. London: Pinter.

Arrow, Kenneth. 1962. "Economic Welfare and the Allocation of Resources for Invention." In *The Rate and Direction of Inventive Activity: Economic and Social Factors*, 609–626. Princeton University Press. http://www.nber.org/chapters/c2144.pdf.

Arthur, W. Brian. 1989. "Competing Technologies, Increasing Returns, and Lock-In by Historical Events." *The Economic Journal* 99 (394): 116–31.

Asheim, Bjørn T., Ron Boschma, and Philip Cooke. 2011. "Constructing Regional Advantage: Platform Policies Based on Related Variety and Differentiated Knowledge Bases." *Regional Studies* 45 (7): 893–904. doi:10.1080/00343404.2010.543126.

Atkinson, Michael M., and William D. Coleman. 1989. *The State, Business, and Industrial Change in Canada*. Toronto: University of Toronto Press.

Auld, Graeme, Benjamin Cashore, Cristina Balboa, Laura Bozzi, and Stefan Renckens. 2010. "Can Technological Innovations Improve Private Regulation in the Global Economy?" *Business and Politics* 12 (3).

Azar, Christian, and Björn A. Sandén. 2011. "The Elusive Quest for Technology-Neutral Policies." *Environmental Innovation and Societal Transitions* 1 (1): 135–39.

Backhaus, Julia. 2010. "Intermediaries as Innovating Actors in the Transition to a Sustainable Energy System." *Central European Journal of Public Policy* 4 (1): 86–108.

Bak, Céline. 2016. "Growth Innovation and COP21: The Case for New Investment in Innovative Infrastructure." Policy Brief 73. CIGI.

Bataille, Chris, Jacqueline Chan, Dave Sawyer, and Richard Adamson. 2014. "Pathways to Deep Decarbonization - Interim 2014 Report (Canada)." Sustainable Development Solutions Network & Institute for Sustainable Development and International Relations.

Beine, Michel, Charles S. Box, and Serge Coulombe. 2012. "Does the Canadian Economy Suffer from Dutch Disease?" *Resource and Energy Economics* 34 (4): 468–92.
Bergek, Anna, Marko Hekkert, Staffan Jacobsson, Jochen Markard, Björn Sandén, and Bernhard Truffer. 2015. "Technological Innovation Systems in Contexts: Conceptualizing Contextual Structures and Interaction Dynamics." *Environmental Innovation and Societal Transitions* 16 (September): 51–64. doi:10.1016/j.eist.2015.07.003.
Bergek, Anna, Staffan Jacobsson, Bo Carlsson, Sven Lindmark, and Annika Rickne. 2008. "Analyzing the Functional Dynamics of Technological Innovation Systems: A Scheme of Analysis." *Research Policy* 37 (3): 407–29.
Bergh, Jeroen van den, Albert Faber, Annemarth M. Idenburg, and Frans H. Oosterhuis. 2007. *Evolutionary Economics and Environmental Policy*. Northampton: Edward Elgar.
Bijker, Wiebe E., Thomas Parke Hughes, and T. J. Pinch. 1987. *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. Cambridge: MIT Press.
Binz, Christian, Bernhard Truffer, and Lars Coenen. 2014. "Why Space Matters in Technological Innovation systems—Mapping Global Knowledge Dynamics of Membrane Bioreactor Technology." *Research Policy* 43 (1): 138–55. doi:10.1016/j.respol.2013.07.002.
Block, Fred. 2008. "Swimming Against the Current: The Rise of a Hidden Developmental State in the United States." *Politics & Society* 36 (2): 169–206. doi:10.1177/0032329208318731.
Boivie, Per Erik. 2007. *Global Standard: How Computer Displays Worldwide Got the TCO Logo*. Stockholm: Premiss.
Bonvillian, William B. 2014. "The New Model Innovation Agencies: An Overview." *Science and Public Policy* 41 (4): 425–37.
Boschma, Ron. 2005. "Proximity and Innovation: A Critical Assessment." *Regional Studies* 39 (1): 61–74.
Boschma, Ron, Asier Minondo, and Mikel Navarro. 2013. "The Emergence of New Industries at the Regional Level in S Pain: A Proximity Approach Based on Product Relatedness." *Economic Geography* 89 (1): 29–51.
Breznitz, Dan, and Darius Ornston. 2013. "The Revolutionary Power of Peripheral Agencies Explaining Radical Policy Innovation in Finland and Israel." *Comparative Political Studies* 46 (10): 1219–45.
Breznitz, Dan, and David Wolfe. 2015. "Canada's R&D Tax Breaks Can't Replace Strategic Innovation Policy." *The Globe and Mail*, September 13. http://www.theglobeandmail.com/news/national/canadas-rd-tax-breaks-cant-replace-strategic-innovation-policy/article26349428/.
Broadbent Institute & Mowat Centre. 2015. "Step Change - Federal Policy Toward a Low-Carbon Canada."
Bush, Vannevar. 1945. "Science: The Endless Frontier."
Carlsson, Bo, and Staffan Jacobsson. 1997. "In Search of Useful Public Policies — Key Lessons and Issues for Policy Makers." In *Technological Systems and Industrial Dynamics*, edited by Bo Carlsson, 299–315. Springer US.
CCA. 2013. "Paradox Lost: Explaining Canada's Research Strength and Innovation Weakness." Canadian Council of Academies.
Chang, Ha-Joon. 1994. *The Political Economy of Industrial Policy*. Macmillan.

Coenen, Lars, Paul Benneworth, and Bernhard Truffer. 2012. "Toward a Spatial Perspective on Sustainability Transitions." *Research Policy* 41 (6): 968–79.

Coenen, Lars, Rob Raven, and Geert Verbong. 2010. "Local Niche Experimentation in Energy Transitions: A Theoretical and Empirical Exploration of Proximity Advantages and Disadvantages." *Technology in Society* 32 (4): 295–302.

Comette, Penelope, Maximilian Kniewasser, and Patricia Lightburn. 2015. "Canada's Policy Support for Clean Technology Exports." Pembina Institute.

Conference Board of Canada. 2015. "How Canada Performs: Innovation." http://www.conferenceboard.ca/hcp/provincial/innovation.aspx.

Cooke, P. 2012. *Complex Adaptive Innovation Systems: Relatedness and Transversality in the Evolving Region*. London: Routledge.

Cooke, Philip. 2009. "Regional Innovation, Collective Entrepreneurship and Green Clusters." In *Entrepreneurship and Growth in Local, Regional and National Economies: Frontiers in European Entrepreneurship Research*, 17–48. Cheltenham: Edward Elgar.

———. 2012. "Transversality and Transition: Green Innovation and New Regional Path Creation." *European Planning Studies* 20 (5): 817–34.

Council of Canadian Academies. 2015. "Technological Prospects for Reducing the Environmental Footprint of Canadian Oil Sands." Council of Canadian Academies. http://www.scienceadvice.ca/en/assessments/completed/oil-sands.aspx.

Creutzberg, Tijs. 2011. "Canada's Innovation Underperformance: Whose Policy Problem Is It?" Mowat Centre.

De Souza, Mike. 2016. "Moving Too Fast on Climate Could Damage National Unity, Catherine McKenna Says." *National Observer*, April 1. http://www.nationalobserver.com/2016/04/01/news/moving-too-fast-climate-could-damage-national-unity-catherine-mckenna-says.

Dechezleprêtre, Antoine, Ralf Martin, and Samuela Bassi. 2016. "Climate Change Policy, Innovation and Growth." Grantham Research Institute & Global Green Growth Institute. http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2016/01/Dechezlepretre-et-al-policy-brief-Jan-2016.pdf.

Dechezleprêtre, Antoine, Ralf Martin, and Myra Mohnen. 2014. "Knowledge Spillovers from Low-Carbon Technologies: A Patent Citation Analysis." Grantham Institute on Climate Change and the Environment Working Paper 135.

Demerse, Clare, and Woynillowicz, Dan. 2014. "A New National Prize: Making Clean Energy the Next Oil Sands." *Policy*. http://policymagazine.ca/pdf/9/PolicyMagazineSeptember-October-14-DemerseWoynillowicz.pdf.

Dobbs, Richard, Jeremy Oppenheim, Fraser Thompson, Marcel Brinkman, and Marc Zornes. 2011. "Resource Revolution: Meeting the World's Energy, Materials, Food, and Water Needs." McKinsey Global Institute. http://www.mckinsey.com/insights/energy_resources_materials/resource_revolution.

Dosi, Giovanni. 1982. "Technological Paradigms and Technological Trajectories : A Suggested Interpretation of the Determinants and Directions of Technical Change." *Research Policy* 11 (3): 147–62.

Edquist, Charles, Nicholas S. Vonortas, Jon Mikel Zabala-Iturriagagoitia, and Jakob Edler. 2015. *Public Procurement for Innovation*. Cheltenham: Edward Elgar.

Environment Canada. 2014. "Canada's Emission Trends."

Expert Panel on Business Innovation. 2009. “Innovation and Business Strategy: Why Canada Falls Short.” Council of Canadian Academies. http://www.scienceadvice.ca.

Fagerberg, Jan. 2005. “Innovation: A Guide to the Literature.” In *The Oxford Handbook on Innovation*, edited by Jan Fagerberg, David C. Mowery, and Richard R. Nelson, 1–27. Oxford: Oxford University Press.

Fischer, Carolyn. 2008. “Emissions Pricing, Spillovers, and Public Investment in Environmentally Friendly Technologies.” *Energy Economics* 30 (2): 487–502. doi:10.1016/j.eneco.2007.06.001.

Fischer, Carolyn, and Richard G. Newell. 2008. “Environmental and Technology Policies for Climate Mitigation.” *Journal of Environmental Economics and Management* 55 (2): 142–162.

Forest Products Association of Canada. 2016. “Product Innovation.” http://www.fpac.ca/forest-industry-innovation/products/.

Freeman, Chris. 1992. “A Green Techno-Economic Paradigm for the World Economy?” In *The Economics of Hope*. London, New York: Pinter.

Freeman, Chris, and Luc Soete. 1997. *The Economics of Industrial Innovation, Third Edition*. Cambridge: MIT Press.

Freeman, Christopher. 1987. *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter.

Freeman, Christopher, and Francisco Louca. 2001. *As Time Goes by: From the Industrial Revolutions to the Information Revolution*. Oxford ; New York: Oxford University Press.

Garud, Raghu, and Peter Karnøe. 2003. “Bricolage versus Breakthrough: Distributed and Embedded Agency in Technology Entrepreneurship.” *Research Policy* 32 (2): 277–300.

Geels, F. W. 2006. “Major System Change through Stepwise Reconfiguration: A Multi-Level Analysis of the Transformation of American Factory Production (1850-1930).” *Technology in Society* 28 (4): 445–76.

Geels, Frank W. 2002. “Technological Transitions as Evolutionary Reconfiguration Processes: A Multi-Level Perspective and a Case-Study.” *Research Policy* 31 (8–9): 1257–74.

———. 2005. “The Dynamics of Transitions in Socio-Technical Systems: A Multi-Level Analysis of the Transition Pathway from Horse-Drawn Carriages to Automobiles (1860–1930).” *Technology Analysis & Strategic Management* 17 (4): 445–76.

———. 2007. “Analysing the Breakthrough of Rock ‘n’roll (1930–1970) Multi-Regime Interaction and Reconfiguration in the Multi-Level Perspective.” *Technological Forecasting and Social Change* 74 (8): 1411–1431.

Gertler, Meric S. 2003. “Tacit Knowledge and the Economic Geography of Context, or the Undefinable Tacitness of Being (There).” *Journal of Economic Geography* 3 (1): 75–99.

Grabher, Gernot. 1993. “The Weakness of Strong Ties: The Lock-in of Regional Development in the Ruhr Area.” In *The Embedded Firm*, edited by Gernot Grabher, 253–77. London: Routledge.

Gray, D. Allan, Jacek Majorowicz, and Martyn Unsworth. 2012. “Investigation of the Geothermal State of Sedimentary Basins Using Oil Industry Thermal Data: Case Study from Northern Alberta Exhibiting the Need to Systematically Remove Biased Data.” *Journal of Geophysics and Engineering* 9 (5): 534.

Haley, Brendan. 2011. “From Staples Trap to Carbon Trap: Canada’s Peculiar Form of Carbon Lock-In.” *Studies in Political Economy* 88: 97–132.

———. 2014. “Promoting Low-Carbon Transitions from a Two-World Regime: Hydro and Wind in Québec, Canada.” *Energy Policy* 73: 777–88.
———. 2015. “Low-Carbon Innovation from a Hydroelectric Base: The Case of Electric Vehicles in Québec.” *Environmental Innovation and Societal Transitions* 14: 5–25.
———. 2016. “A Green Entrepreneurial State as Solution to Climate Federalism.” Broadbent Institute. http://www.broadbentinstitute.ca/green_entrepreneurial_state.
Hall, Peter A., and David W. Soskice. 2001. *Varieties of Capitalism : The Institutional Foundations of Comparative Advantage*. Oxford [England] ; New York : Oxford University Press,.
Hastings-Simon, Sara, Dickon Pinner, and Martin Stuchtey. 2014. “Myths and Realities of Clean Technologies.” McKinsey & Company. http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/myths-and-realities-of-clean-technologies.
Hawken, Paul, Amory B. Lovins, and L. Hunter Lovins. 1999. *Natural Capitalism : Creating the next Industrial Revolution*. 1st ed. Boston : Little, Brown and Co.,.
Hawkins, Richard. 2012. “Looking at Innovation from a Uniquely Canadian Perspective.” Institute for Science, Society and Policy.
Hayden, Anders. 2014. *When Green Growth Is Not Enough: Climate Change, Ecological Modernization, and Sufficiency*. McGill-Queen’s Press-MQUP.
Hébert, Robert F., and Albert N. Link. 1989. “In Search of the Meaning of Entrepreneurship.” *Small Business Economics* 1 (1): 39–49.
Hekkert, M. P., R. A. A. Suurs, S. O. Negro, S. Kuhlmann, and R. E. H. M. Smits. 2007. “Functions of Innovation Systems: A New Approach for Analysing Technological Change.” *Technological Forecasting & Social Change* 74 (4): 413–32.
Hoffert, Martin I., Ken Caldeira, Atul K. Jain, Erik F. Haites, LD Danny Harvey, Seth D. Potter, Michael E. Schlesinger, et al. 1998. “Energy Implications of Future Stabilization of Atmospheric CO2 Content.” *Nature* 395 (6705): 881–884.
Hofman, Peter S., and Boelie Elzen. 2010. “Exploring System Innovation in the Electricity System through Sociotechnical Scenarios.” *Technology Analysis & Strategic Management* 22 (6): 653–70.
Hoppmann, Joern, Michael Peters, Malte Schneider, and Volker H. Hoffmann. 2013. “The Two Faces of Market support—How Deployment Policies Affect Technological Exploration and Exploitation in the Solar Photovoltaic Industry.” *Research Policy* 42 (4): 989–1003.
Howells, Jeremy. 2006. “Intermediation and the Role of Intermediaries in Innovation.” *Research Policy* 35 (5): 715–28. doi:10.1016/j.respol.2006.03.005.
Innis, Harold. 1930. *The Fur Trade in Canada*. 1962nded. Toronto: University of Toronto Press.
Jacobsson, Staffan, and Anna Bergek. 2011. “Innovation System Analyses and Sustainability Transitions: Contributions and Suggestions for Research.” *Environmental Innovation and Societal Transitions* 1: 41–57.
Jaffe, Adam B., Richard G. Newell, and Robert N. Stavins. 2005. “A Tale of Two Market Failures: Technology and Environmental Policy.” *Ecological Economics*, Technological Change and the EnvironmentTechnological Change, 54 (2–3): 164–74. doi:10.1016/j.ecolecon.2004.12.027.
Jenkin, Michael. 1983. *The Challenge of Diversity: Industrial Policy in the Canadian Federation*. Ottawa: Science Council of Canada.

Jenkins, Tom, Bev Dahlby, Arvind Gupta, Monique Leroux, David Naylor, and Nobina Robinson. 2011. “Innovation Canada: A Call to Action.” Government of Canada.

Johnson, Chalmers. 1982. *MITI and the Japanese Miracle: The Growth of Industrial Policy, 1925-1975*. Stanford, California: Stanford University Press.

Johnstone, Nick, Ivan Hascic, and Margarita Kalamova. 2010. “Environmental Policy Characteristics and Technological Innovation.” *Economia Politica*, no. 2/2010. doi:10.1428/32540.

Kemp, René, Johan Schot, and Remco Hoogma. 1998. “Regime Shifts to Sustainability through Processes of Niche Formation: The Approach of Strategic Niche Management.” *Technology Analysis & Strategic Management* 10 (2): 175–198.

King, David, John Browne, Richard Layard, Gus O’Donnell, Martin Rees, Nicholas Stern, and Adair Turner. 2015. “A Global Apollo Programme to Combat Climate Change.” *London School of Economics, London*. http://cep.lse.ac.uk/pubs/download/special/Global_Apollo_Programme_Report.pdf.

Kivimaa, Paula. 2014. “Government-Affiliated Intermediary Organisations as Actors in System-Level Transitions.” *Research Policy* 43 (8): 1370–80. doi:10.1016/j.respol.2014.02.007.

Kollman, Kelly, and Aseem Prakash. 2001. “Green by Choice? Cross-National Variations in Firms’ Responses to EMS-Based Environmental Regimes.” *World Politics* 53 (3): 399–430.

Kuhn, Thomas S. 1996. *The Structure of Scientific Revolutions*. 3rd ed. Chicago, IL : University of Chicago Press,.

Kuznetsov, Yevgeny, and Charles Sabel. 2014. “New Open Economy Industrial Policy: Making Choices without Picking Winners.” In *Making Innovation Policy Work: Learning from Experimentation*, edited by Mark. A. Dutz, Yevgeny Kuznetsov, Esperanza Lasagabaster, and Dirk Pilat. Organisation for Economic Co-operation and Development. https://www.wdronline.worldbank.org/handle/10986/11057.

Laxer, Gordon. 1989. *Open for Business : The Roots of Foreign Ownership in Canada*. Toronto: Oxford University Press.

Lerner, J. 2009. *Boulevard of Broken Dreams: Why Public Efforts to Boost Entrepreneurship and Venture Capital Have Failed--and What to Do About It.* Princeton University Press.

Lipsey, Richard, and Kenneth Carlaw. 1996. “A Structuralist View of Innovation Policy.” In *The Implications of Knowledge-Based Growth for Micro-Economic Policies*, edited by Peter Howitt. Calgary: University of Calgary Press.

———. 1998. “A Structuralist Assessment of Technology Policies - Taking Schumpeter Seriously on Policy.” Industry Canada Research Publication.

Lipsey, Richard, Kenneth Carlaw, and Clifford Bekar. 2005. *Economics Transformations: General Purpose Technologies and Long-Term Econoimc Growth*. Oxford University Press.

Lovekin, Dave, Jason Switzer, and Kelly Finigan. 2013. “Renewable Energy Opportunities in the Oil and Gas Sector.” Pembina Institute.

Lundvall, Bengt-Ake. 1992. *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London: Pinter Publishers.

Markard, J., and B. Truffer. 2008. “Technological Innovation Systems and the Multi-Level Perspective: Towards an Integrated Framework.” *Research Policy* 37 (4): 596–615.

Marquez, V. O. 1972. “Building an Innovative Organization: Wanted: Small Catastrophes.” *Business Quarterly* 37 (4): 40–47.

Mazzucato, Mariana. 2013. *The Entrepreneurial State : Debunking Public vs. Private Sector Myths*. London: Anthem Press.

Mazzucato, Mariana, and Caetano Penna C.R. 2014. "Beyond Market Failures. The Market Creating and Shaping Roles of State Investment Banks." Working Paper. University of Sussex, Science Policy Research Unit. http://marianamazzucato.com/wp-content/uploads/2014/12/2014-21_SWPS_Mazzucato-and-Penna.pdf.

McDonough, William, and Michael Braungart. 2002. *Cradle to Cradle : Remaking the Way We Make Things*. 1st ed. New York : North Point Press,.

McDowall, Will, and Paul Ekins. 2014. "Green Innovation: Industrial Policy for a Low-Carbon Future." Trades Union Congress.

McKinsey & Co. 2012. "Opportunities for Canadian Energy Technologies in Global Markets." Commissioned by Natural Resources Canada.

Meadowcroft, James. 2014. "Let's Get This Transition Moving!" In *Sustainable Prosperity Big Ideas Conference*. Ottawa.

Mowery, David C., Richard R. Nelson, and Ben R. Martin. 2010. "Technology Policy and Global Warming: Why New Policy Models Are Needed (or Why Putting New Wine in Old Bottles Won't Work)." *Research Policy* 39 (8): 1011–23.

Mowery, David, and Nathan Rosenberg. 1979. "The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies." *Research Policy* 8 (2): 102–53. doi:10.1016/0048-7333(79)90019-2.

Natural Resources Canada. 2016. "Key Facts and Figures on the Natural Resource Sector." http://www.nrcan.gc.ca/publications/key-facts/16013.

Neffke, Frank, Martin Henning, and Ron Boschma. 2011. "How Do Regions Diversify over Time? Industry Relatedness and the Development of New Growth Paths in Regions." *Economic Geography* 87 (3): 237–265.

Negro, Simona O., Floortje Alkemade, and Marko P. Hekkert. 2012. "Why Does Renewable Energy Diffuse so Slowly? A Review of Innovation System Problems." *Renewable and Sustainable Energy Reviews* 16 (6): 3836–46.

Nelson, Richard R. 1993. *National Innovation Systems : A Comparative Analysis*. New York : Oxford University Press.

Nelson, Richard R., and Richard N. Langlois. 1983. "Industrial Innovation Policy: Lessons from American History." *Science* 219 (4586): 814–818.

Nelson, Richard R., and Sidney G. Winter. 1982. *An Evolutionary Theory of Economic Change*. Cambridge: Belknap Press.

Nemet, Gregory F. 2009. "Demand-Pull, Technology-Push, and Government-Led Incentives for Non-Incremental Technical Change." *Research Policy* 38 (5): 700–709.

NRTEE. 2012. "Framing the Future: Embracing the Low-Carbon Economy." National Roundtable on the Environment and Economy.

OECD. 2005. "The Measurement of Scientific and Technological Activities: Proposed Guidelines for Collecting and Interpreting Technological Innovation Data: Oslo Manual." Organisation for Economic Co-operation and Development. http://www.oecd.org/science/inno/2367580.pdf.

———. 2011. *Towards Green Growth*. Organisation for Economic Co-operation and Development.

———. 2012. "OECD Economic Surveys: Canada." Paris: Organization for Economic Co-operation and Development.

O'Riain, Sean. 2004. *The Politics of High Tech Growth: Developmental Network States in the Global Economy*. 23. Cambridge University Press.
Osberg, Lars, and Andrew Sharpe. 2002. "An Index of Economic Well–Being for Selected OECD Countries." *Review of Income and Wealth* 48 (3): 291–316.
Panitch, Leo. 1981. "Dependency and Class in Canadian Political Economy." *Studies in Political Economy*, no. Autumn.
Parad, Michele, Stefan Henningsson, Tabaré A. Currás, and Richard Youngman. 2014. "The Global Cleantech Innovation Index 2014." World Wildlife Fund and CleanTech Group.
Perez, Carlota. 2002. *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*. Cheltenham, UK: Edward Elgar.
Philip, Ian, Jordan Isenberg, Jean-Frédéric Légaré-Tremblay, and Remzi Cej. 2012. "Launching Cleantech: Ensuring Canada's Place in the New Global Market." Action Canada.
Popp, David. 2006. "R&D Subsidies and Climate Policy: Is There a 'free Lunch'?" *Climatic Change* 77 (3–4): 311–341.
Porter, Michael E., and Claas van der Linde. 1995. "Toward a New Conception of the Environment-Competitiveness Relationship." *Journal of Economic Perspectives* 9 (4): 97–118.
Pratt, Larry. 1976. *The Tar Sands: Syncrude and the Politics of Oil*. Edmonton: Hurtig.
Radnejad, Amir Bahman, and Harrie Vredenburg. 2015. "Collaborative Competitors in a Fast–changing Technology Environment: Open Innovation in Environmental Technology Development in the Oil and Gas Industry." *International Journal of Entrepreneurship and Innovation Management* 19 (1–2): 77–98.
Rand, Tom. 2015. "An Arm's-Length Green Bank Would Accelerate Canada's Climate Transitions." *Globe and Mail*, December 7.
Raven, Rob, Johan Schot, and Frans Berkhout. 2012. "Space and Scale in Socio-Technical Transitions." *Environmental Innovation and Societal Transitions* 4: 63–78.
Rosenbloom, Daniel, and James Meadowcroft. 2014. "The Journey towards Decarbonization: Exploring Socio-Technical Transitions in the Electricity Sector in the Province of Ontario (1885–2013) and Potential Low-Carbon Pathways." *Energy Policy* 65: 670–679.
Rotmans, Jan, Rene Kemp, and Marjolein Van Asselt. 2001. "More Evolution than Revolution: Transition Management in Public Policy." *Foresight* 3: 15–31.
Savoie, Donald J. 2015. *What Is Government Good At?* McGill-Queen's University Press.
Schmookler, J. 1966. *Invention and Economic Growth*. Cambridge, MA: Harvard University Press.
Schot, Johan, and Frank W. Geels. 2008. "Strategic Niche Management and Sustainable Innovation Journeys: Theory, Findings, Research Agenda, and Policy." *Technology Analysis & Strategic Management* 20 (5): 537–54.
Schumpeter, Joseph A. 1934. *The Theory of Economic Development; an Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle*. Cambridge, Mass.: Harvard university press.
———. 1942. *Capitalism, Socialism and Democracy*. New York: Harper & Row.
Simeon, Richard. 1979. "Federalism and the Politics of a National Strategy." *The Politics of an Industrial Strategy - A Seminar*, March, 5–54.
Simon, Herbert Alexander. 1965. *Administrative Behavior*. Vol. 4. Cambridge Univ Press. http://journals.cambridge.org/production/action/cjoGetFulltext?fulltextid=5378404.

Smardon, Bruce. 2014. *Asleep at the Switch: The Political Economy of Federal Research and Development Policy Since 1960*. McGill-Queen's Press-MQUP.

Smart Prosperity. 2016. "New Thinking." http://www.smartprosperity.ca/sites/default/files/documents/spfullreport2016feb25a-final.pdf.

Stanford, Jim. 2008. "Staples, Deindustrialization, and Foreign Investment: Canada's Economic Journey Back to the Future." *Studies in Political Economy*, no. 82(December).

Stewart, James, and Sampsa Hyysalo. 2008. "Intermediaries, Users and Social Learning in Technological Innovation." *International Journal of Innovation Management* 12 (3): 295–325. doi:10.1142/S1363919608002035.

Suurs, Roald A. A., and Marko P. Hekkert. 200910. "Cumulative Causation in the Formation of a Technological Innovation System: The Case of Biofuels in the Netherlands." *Technological Forecasting & Social Change* 76 (8): 1003–20.

Toner, Glen, and Francois Bregha. 2009. "Institutionalizing Sustainable Development: The Role of Government Institutions." In *Innovation, Science and Environment*, edited by Glen Toner and James Meadowcroft. McGill-Queen's University Press.

Trudeau, Justin. 2015. "Prime Minister Announces Action on Clean Jobs and Energy." November 30. http://pm.gc.ca/eng/news/2015/11/30/prime-minister-announces-action-clean-jobs-and-energy.

Unruh, Gregory C. 2000. "Understanding Carbon Lock-In." *Energy Policy* 28 (12): 817–30.

Van Praet, Nicolas. 2014. "In Quebec, the Energy Future of the North Is Blowing in the Wind." *Financial Post*. http://business.financialpost.com/news/energy/in-quebec-the-energy-future-of-the-north-is-blowing-in-the-wind.

Veblen, Thorstein. 1898. "Why Is Economics Not an Evolutionary Science?" *The Quarterly Journal of Economics*, July, 373–97.

Verbong, G. P. J., and F. W. Geels. 2010. "Exploring Sustainability Transitions in the Electricity Sector with Socio-Technical Pathways." *Technological Forecasting and Social Change* 77 (8): 1214–21.

Verbong, Geert, and Frank Geels. 2007. "The Ongoing Energy Transition: Lessons from a Socio-Technical Multi-Level Analysis of the Dutch Electricity System (1960-2004)." *Energy Policy* 35 (2): 1025–37.

Victor, Peter A. 2008. *Managing Without Growth: Slower by Design, Not Disaster*. Cheltenham: Edward Elgar.

Watkins, Mel. 1963. "A Staple Theory of Economic Growth." *Canadian Journal of Economics and Political Science* 29: 141–58.

———. 1997. "Canadian Capitalism in Transition." In *Understanding Canada: Building on the New Canadian Political Economy*, edited by Wallace Clement, 19–42. McGill-Queen's University Press.

Wieczorek, Anna J., Simona O. Negro, Robert Harmsen, Gaston J. Heimeriks, Lin Luo, and Marko P. Hekkert. 2013. "A Review of the European Offshore Wind Innovation System." *Renewable and Sustainable Energy Reviews* 26 (October): 294–306. doi:10.1016/j.rser.2013.05.045.

Wilson, Paul, Sarah Post, and Smita Srinivas. 2007. "R&D Models: Lessons from Vaccine History." *Available at SSRN 1099495*. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1099495.

Wolfe, David A., and Matthew Lucas. 2005. *Global Networks and Local Linkages*. Montreal & Kingston: McGill-Queen's University Press.

Woolthuis, Rosalinde Klein, Maureen Lankhuizen, and Victor Gilsing. 2005. "A System Failure Framework for Innovation Policy Design." *Technovation* 25 (6): 609–19.

World Bank. 2014. *Electricity Production from Hydroelectric Sources (kWh)*. http://data.worldbank.org/indicator/EG.ELC.HYRO.KH.

Woynillowicz, Dan, Penelope Comette, and Ed Whittingham. 2013. "Competing in Clean Energy." Pembina Institute. http://www.pembina.org/reports/pembina-institute-competing-in-clean-energy.pdf.