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CLEAN TECHNOLOGY AND BUSINESS INNOVATION

Stewart Elgie
Smart Prosperity Institute
University of Ottawa

Geoff McCarney
Smart Prosperity Institute
University of Ottawa

William Scott
Smart Prosperity Institute

Michal Miedzinski
UCL - Institute for Sustainable Resources

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Smart Prosperity Institute

uOttawa
Institut de l'environnement
Institute of the Environment

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Abstract

As the world shifts to a low carbon economy, clean innovation represents a significant and growing market opportunity across Canada's economy. It is also critical to meeting our climate and environmental goals cost effectively. Yet it is well established in the literature that clean innovation poses unique challenges; it faces market failures and barriers beyond those encountered by innovation writ large – especially the failure of markets to pay for reductions in pollution and most environmental harm (they are an 'externality'). Clean innovation therefore requires both more and different types of government support, using a range of tools – including, in particular, public policies (pricing, regulations, and incentives) and targeted procurement programs that can 'pull' market demand. Without these kinds of strong policies to stimulate demand, other types of government investment and support programs for clean innovation will be much less effective.

The literature also highlights that, because clean innovation is a system, boosting it requires a broad mix of programs and policies. These should: be coherent, comprehensive, consistent and credible; signal sustained, ambitious direction that permeates across the system, and; help to disrupt technological lock-in and support a shift to cleaner technological pathways. This level of coordination requires effective institutions and processes that promote strategic alignment of programs and policies, to engage key actors and experts within, across, and beyond governments.

Since clean innovation is critical to meeting climate commitments, Canada is not indifferent to its direction and pace. Therefore the role of government in driving clean innovation should not be limited to correcting market failures (to 'level the playing field'), but should instead be oriented to actively 'tilt the playing field' in favour of cleaner outcomes – to overcome the existing 'lock-in' favouring carbon-intensive technologies (aided in many cases by prior public support). This type of 'mission-driven' approach to clean innovation implies a more active role for public investment, to share in financing the exceptional risks facing clean technologies (such as policy risk, high capital costs, and long scale-up periods), in order to catalyze private investment and direct it to higher risk, longer term opportunities. To this end, effective public support programs should facilitate experimentation, risk-taking, and failing (and learning) fast – traits that are often challenging for governments, and may require new types of public institutions, and evaluation and learning approaches.

Despite having many strengths, Canada's share of the global clean technology market is relatively small, and falling. The evidence (though limited) shows Canada's performance is strong in the early stages (RD&D) but falls off as innovations get closer to market. To improve our performance and seize the opportunity that accelerating clean innovation presents, government itself needs to be innovative: to take a more coordinated, nimble, risk-tolerant and proactive approach – in order to provide the support and direction needed to help Canadian businesses be among leaders in clean innovation globally.

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Introduction

The environmental and economic imperatives brought on by climate change and other environmental challenges have led to a growing interest by governments in accelerating clean innovation. In Canada, for example, the Pan Canadian Framework on Clean Growth and Climate Change, the 2017 federal budget, and a number of new and proposed government programs include a specific focus on accelerating clean innovation.

To help inform this program development, and ensure it is effective, this literature review seeks to answer the following questions:

- How is clean innovation different from innovation writ-large, in terms of the barriers it faces and the supports it needs?
- What types of government interventions are likely to be more successful in supporting clean innovation in Canada?

This paper contributes an overview of the academic, and some of the relevant grey/policy literature, specific to issues of government interventions and innovation program coordination needed to inform and support effective business innovation in clean tech – and to support business development and commercialisation of clean innovation more generally. The focus of this paper is public programming to support clean technology development and adoption by businesses. While specific discussion of the range of policy and regulatory approaches to support clean innovation is outside of the scope of this document, such approaches also have important implications for clean innovation programming, which will be addressed in this review.In order to appropriately frame the paper, some up front attention is required to introduce and define the concept of clean innovation. For the purposes of this paper, *clean technology* (or cleantech) refers to any product, process, or service designed with the primary purpose of remediating or preventing any type of environmental damage, *clean innovation* includes cleantech, but also expands the notion to include any new product, process, or service that improves environmental performance whose main purpose may or may not be environmental. Clean innovation is therefore relevant for the whole economy (including traditional resource sectors) rather than a technology-, product- or service-bound sector.

Appendix I overviews types of clean innovation that could fall under this definition. As will be discussed later, the type/categorization of clean innovation has strong implications for the interventions that should be considered by governments, as different innovations require different levels of programmatic support and different mixes of interventions. Importantly, more disruptive and emerging clean innovations, including system innovations (OECD, 2015a), require radically different kinds of public intervention and governance arrangements than programs prioritizing deployment of more mature clean technologies.

The Importance of Clean Innovation

There is a growing global recognition of the need to address the world's most pressing environmental challenges. In response to this, Canada, along with governments around the world, have signed on to the Paris Agreement and Sustainable Development Goals, as well as other major international agreements related to biodiversity loss, water security, and air quality. Canada has also recently taken a significant step with the Pan-Canadian Framework for Clean Growth and Climate Change (PCF) in 2016.

However, despite these commitments, the world is still expected to surpass the 2˚C temperature change target (UNFCCC, 2016), and Canada will be hard pressed to achieve its GHG reduction commitments, even with new policy commitments (First Ministers of Canada, 2017). To successfully achieve these targets will require advancing clean innovation throughout the economy, to shift to a more sustainable path and break from technological lock-in.

Further, accelerating clean innovation will be integral to bring down the costs of achieving these targets (Jaffe et al. 2005; Popp 2006). Countries and companies that excel at clean innovation and efficient resource use will be rewarded in global markets. For example, the global clean-tech market alone is projected to grow to up to C$2.5 trillion by the year 2022 – more than doubling its 2015 valuation (Bak, 2017). Similarly, estimates suggest that employment in the clean technology sector has grown at an average rate of over 10% since 2012, now employing more than 55,000 Canadians (Bak, 2017).

Market projections similarly point to growth in clean innovation opportunities outside the clean-tech sector. McKinsey estimates that resource-based sectors stand to benefit from a US$2.9 trillion investment in boosting resource efficiency and innovation worldwide by 2030. This environmental and economic imperative has been recognised by some of the world's most respected economic and business authorities as well as governments around the world (OECD 2011; McKinsey 2011; WEF 2015; G20 Leaders Declaration 2017).

Canada's Performance on Clean Innovation

Limited data availability and the complexity of the innovation system make quantifying Canada's clean innovation performance challenging -- however there are some general trends to note.[1] Evidence suggests that Canada performs well in the early stages of innovation and tends to fall off as innovations get closer to market, which highlights the importance of this review.

Canada has a strong reputation for research and ranks well in generating academic publications, particularly related to clean tech, with about 50% more publications than the US relative to size. However, Canada has had less success at turning publications into patents, with the US generating patents at over twice the comparable rate relative to size (Duruflé and Carbonneau, 2016). When we look at the conversion of patents into development, metrics show a similar pattern where Canada's clean innovation performance falls off as innovations move closer to market. While 3.4% of the world's environmentally-related patents were registered in Canada, only 1.6% of the world's clean innovations were actually developed here—suggesting a significant breakdown between Canada's ability to generate new clean innovation ideas and our ability to get them to market (OECD 2012).

Moreover, while the size of Canada's clean tech sector continues to grow, our share of the global clean-tech market has fallen by 12% since 2008, to a current 1.4% market share (Analytica Advisors, 2017), suggesting we are failing to keep pace with peer countries. Also, some evidence suggests Canadian firms are slow to adopt clean innovations. For example, a 2014 survey by Statistics Canada on the adoption of advanced technologies found that only 9.9% of Canadian firms reported the adoption of advanced green technologies - well behind our performance in the three other technology categories.

However, there remains a lot of potential for Canada to excel. The Cleantech Innovation Index -- which ranks countries based on where "entrepreneurial clean technology companies are *most likely to emerge* from over the next 10 years" -- saw Canada move up to #4 in 2017 from #7 in 2014 (WWF/Cleantech Group, 2017). This is largely due to Canada's improved score on indicators of 'emerging clean tech innovation', which reflects Canada's success in the early stages of innovation processes, and to new government policy and funding commitments.

[1] For example, recent reports by Analytica Advisors (2017), KPMG (2017), WWF/Cleantech Group (2016), MaRS Data Catalyst (2017), and SDTC/Cycle Capital (2016) provide insight into Canada's clean innovation performance.

Barriers and Drivers of Clean Innovation:

In order to effectively implement and coordinate programs to support clean innovation, it is necessary to understand different conceptualizations of innovation systems, and what they imply about the specific challenges of driving clean innovation. The conceptual framework developed in this section therefore informs thinking of the core challenges of clean innovation, and particularly: (i) how clean innovation fits within the broader business innovation context; (ii) why clean innovation (and business innovation in clean tech) is unique, and (iii) the specific challenges and barriers to be overcome.

Conceptualizing Innovation Systems: Identifying Key Issues & Barriers for Clean Innovation

While a range of innovation models are discussed in the literature (see Haley et al. 2016 for an initial review), a '*stages'* approach is often used to explain the general way innovation processes are discussed. This model conceptualizes innovation as a set of sequential stages, originating with research and development (R&D), and then passing through demonstration, deployment, and finally diffusion before exiting as commercialized products or services. Initial applications of this model emphasised the importance of public R&D financing to "PUSH" innovations through the system (Bush 1945), while later insights have demonstrated how demand for products and services can shape innovation, introducing the role of "PULL" (Schmookler 1966), and also highlighted how PUSH and PULL forces will interact differently based on sector-specific contexts (Mowery and Rosenberg 1979).

While these interactions are of vital importance, the general consensus across a range of literature is that for innovation writ-large, but especially to drive clean innovation, both PUSH and PULL policies and programs are needed (see Haley et al., 2016). The specific emphasis on clean innovation in this regard is due to a *double market failure* that prevents markets from providing clean innovation at what economists would argue to be the socially optimal level (Jaffe, Newell, and Stavins 2005). The 'double market failure' refers to the idea that clean innovation is not only affected by the standard *knowledge spillovers* that lead to under-investment in R&D for almost all innovation (Arrow 1962; Geroski 1995), it is also plagued by *environmental externalities* that lead to under-investment at later stages (commercialization, deployment, diffusion), since the benefits of clean innovation (less pollution, resource conservation) are typically under-priced or not priced at all in markets (Pigou 1920; Coase 1960; Raumol and Oates 1988; Rennings 2000). This is a *critical point*; although clean innovations provide important social benefits, they are ones that are normally undervalued, or not valued at all, by the marketplace. Thus government has an essential role to play in stimulating market demand for clean innovation – far more than for most other types of innovation.

Subsequent models developed a more sophisticated view of innovation as a *system* (as opposed to just a series of stages). These 'Systems' models recognize interactions and iterative learning between different actors in the innovation process (i.e. firms, universities, research labs) (Nelson and Winter 1985; Lundvall 1992), and point to the role of both consumers and producers in driving innovation, arguing that innovations don't necessarily traverse the pipeline in a one-directional linear way (Lundvall, 1992; Freeman and Soete 1997).

Scholars from evolutionary economic geography then overlay additional complexity by tying innovation models to the larger environment in which it takes place, contextualizing an *innovation ecosystem*. These 'Innovation Ecosystem' approaches are unique in acknowledging the role of larger economic structures, defined by market and non-market forces (including regulation, cultures, and geography), that create a selection environment tied to a particular place and time, which enables some innovations to succeed while others fail (Coenen et al. 2012).

While scholars emphasize the differences in these models, they are actually consistent. Innovation does typically proceed in stages, albeit with different pacing, twists and turns for different types. And system interactions and regional differences do make a real difference. Understanding the different forces and barriers that affect innovation is important to inform where and how government should intervene. In the case of clean innovation, those barriers are many. Iin addition to the double market failure, discussed above, many types of clean innovation face additional market barriers , including:

- incomplete information and technological risk (Scherer et al. 2000; Anderson & Newell 2004),
- network effects and infrastructure risk (Arrow 1962; Rosenberg 1982; Mulder et al. 2003; Nicholson 2003),
- lack of policy congruency (OECD 2003b; van den Bergh 2013; Sulzenko 2016),
- high capital costs and long scale up times (Ghosh & Nanda 2010; Rai et al. 2015),
- policy uncertainty (Freeman & Haveman 1972; Taylor 2008; Popp et al. 2009),
- behavioural gaps (Jaffe & Stavins 2004; Gillingham et al. 2009),
- perverse subsidies for environmentally harmful activities (OECD 2003a),
- deployment externalities (del Rio 2017), and
- imperfect competition (Whitley and van der Burg 2015; Kozuk & Johnstone 2017).

These barriers are outlined in more detail in Appendix II. The important point is that clean innovation typically faces more market failures and barriers than other types of innovation – particularly as it gets closer to market (Smart Prosperity Institute 2017).

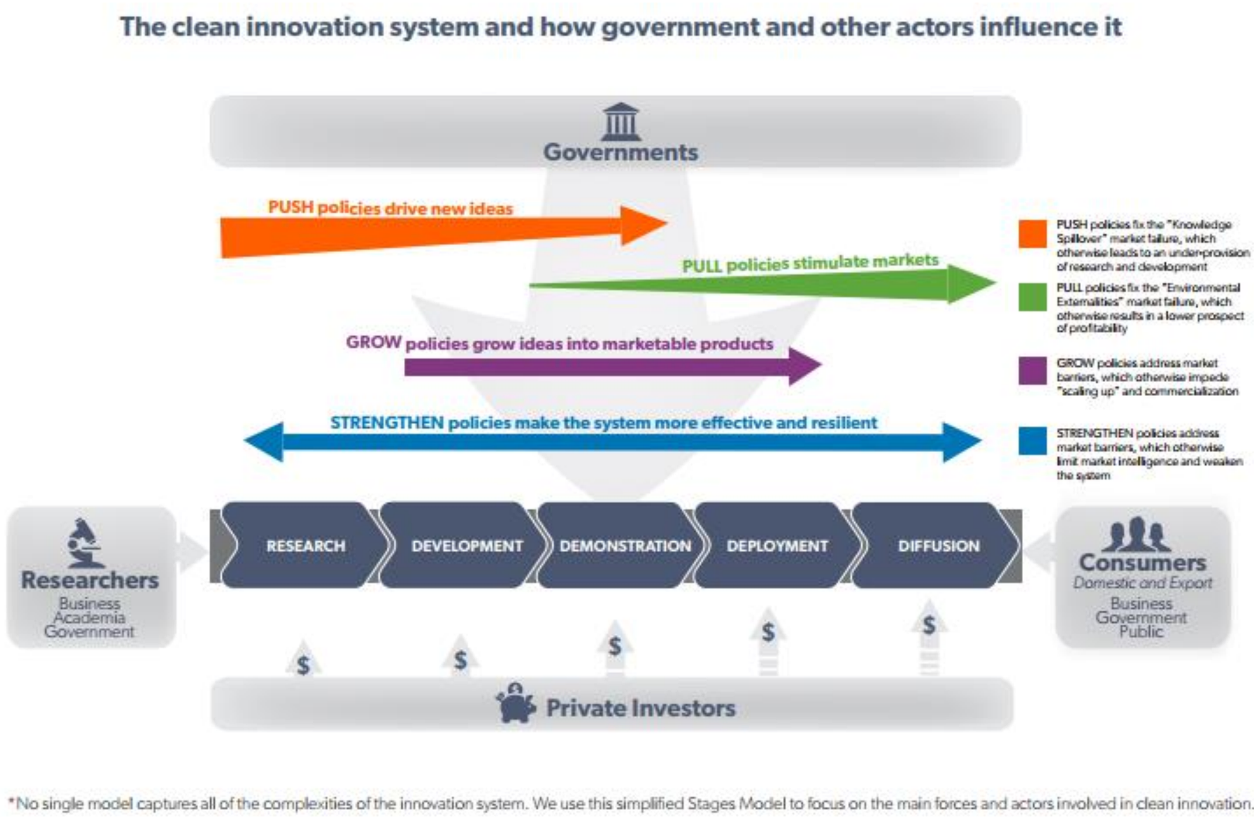


Figure 1: *This model – built up from the 'stages' model – incorporates elements from the 'systems' and 'evolutionary economic geography' models that add depth to acknowledge the complex interactions within the innovation ecosystem. This allows the organization of public policies based on the part of the ecosystem they target (Smart Prosperity Institute 2017).*

Figure 1 aims to illustrate the different forces involved in innovation (and clean innovation in particular), and the key market failures affecting each one. Understanding these forces and market barriers helps to highlight where clean innovation differs from business innovation more generally, and how business innovation programs can be tailored to most effectively support clean innovation and green growth – advancing both eceonomic and environmental objectives such as those in the Pan-Canadian Framework on Clean Growth and Climate Change.

In the figure, 'PUSH' policies (to drive new ideas), and 'PULL' policies (to stimulate markets and overcome environmental externalities) directly address the well documented market failures noted above. The figure also includes two other forces, 'GROW' and 'STRENGTHEN', which represent how public intervention can address the additional market and system barriers facing clean innovation. 'GROW' policies are those interventions meant to help firms scale new technologies, by supporting them to traverse the gap between demonstration and commercialisation (often called the 'valley of death') to build innovative, new marketable products or processes. 'STRENGTHEN' policies aim to improve the resiliency and effectiveness of the innovation system overall, by spurring connections among businesses (and other innovators), providing key supports (skills, data), and removing barriers to innovation (Smart Prosperity 2017).

Uniqueness of the Challenge to Drive Clean Business Innovation:

Policy and programmatic support for clean innovation must therefore overcome multiple market and system failures (Rennings 2000; Smith 2010; Kemp 2011). While some of these barriers apply to business innovation generally, clean innovation is unique in facing environmental externalities that significantly reduce market signals of potential profitability and lower market demand, as well as additional barriers that go beyond those affecting most other types of innovation (e.g. infrastructure risk, high capital costs / long scale-up, policy risk).

Clean innovation is therefore heavily reliant on environmental policies and regulations, most notably emissions pricing, regulations and standards, and public procurement, in order to internalize environmental externalities and provide signals to innovators of market profitability. The importance of these policies and their role in driving clean innovation cannot be overemphasized; public investment and other 'push' programs will be far less effective without strong, smart environmental policies and procurement creating the market 'pull' for clean innovation – analogous to pushing up a rope without pulling the end. While specific discussion of the range of policy and regulatory approaches to address these externalities is beyond scope of this document (though it merits further consideration and study), it does have important implications for clean innovation programming, and which we will address through the remainder of this review, including:

1. *The importance of enabling clean business innovation through mixes of programs that are aligned with policy direction:* Because much of the demand for clean innovation needs to be driven by government policies (including pollution pricing, regulations, standards) and public procurement, policy researchers are increasingly pointing to the importance of aligning the entire policy and program mix (including programmatic support, instruments and processes, and learning facilities), across the entire innovation system, with broad policy directions, strategies and targets for clean innovation and green growth (Fischer & Newell 2008; Flanagan et al. 2011; Marques & Fuinhas 2012; Rogge & Reichart 2016).

2. *Utilizing clean innovation programs to support disruptive technologies and overcome incumbent 'lock-in'*: Again, because market demand for clean innovation is reliant on government policies to address environmental externalities, shifts to future clean technological pathways are often policy-driven, dependent on societal preferences, and diverge considerably from business as usual technological trajectories. For example incumbent industries have the advantage of decades of public and private investment and infrastructure that supports their technology platforms, such as oil and gas pipeline systems, or electrical grid systems built around large, centralized generating facilities. Clean innovation that is disruptive, as opposed to incremental, therefore requires investors to bet on specific technologies on the basis of uncertain (and policy-reliant) assumptions about future returns. This uncertainty often means that government intervention is required to disrupt environmentally unsustainable technological pathways and break technological 'lock-in' (e.g. Kivimaa & Kern 2016; Turnheim & Geels 2012), while aligning innovation support programs and policies to encourage alternatives, often before they reach commercial viability (Altenburg & Pegels 2012; Weber & Rohracher 2012).

3. *Supporting commercialisation of clean tech through strategic public investments:* The unique characteristics of many clean innovations include high capital requirements, long development times, and competition in established commodity markets, which, in addition to the presence of the environmental externality, make acquiring (affordable) private capital challenging (Ghosh and Nanda 2010). This is particularly prevalent at the scale-up and commercialization stages, often referred to as the 'valley of death'. Given these challenges, it is argued that governments must move beyond targeted 'commercialisation' programs, and towards broader market creation efforts, through targeted use of public spending, including direct R&D support, financial programs, as well as clean public procurement, to help finance riskier clean innovations and create direction in innovation by

tilting the entire innovation system towards clean outcomes (Mazzucato 2017, Mazzucato & Semieniuk 2017, *forthcoming*)

4. *Designing program governance and evaluation processes that encourage experimentation:* Supporting commercialisation of clean innovations through broad alignment of program support and public investments (including public procurement) with policy direction on clean innovation and green growth will require new governance and evaluation processes designed to enable strategic public investments throughout the innovation chain. These processes must hold public investment programs accountable, but also encourage the public sector to help absorb the high degree of (often policy-related) uncertainty in clean innovation, while being robust to potentially higher failure rates for specific clean innovations, and encouraging experimentation (Haley 2016; Mazzucato 2017; Mazzucato & Semieniuk *forthcoming*).

The remainder of this report will dive deeper into these four implications for clean innovation programming, outlining the key research done in theses areas and highlighting some examples of best practices. While the existing research cited often tends to tends to focus on the roles of polcies and 'policy-mix' for driving clean innovation, the implications elicited are inherently linked to the design of clean innovation programs and thus merit consideration in this review.

1. Aligning Programs with Policy Direction to 'PULL' Clean Innovation

A core message from the literature is that, because innovation is a system, any single policy or program targeting clean tech is likely to be insufficient in supporting or driving clean business innovation. Given the barriers to clean innovation described above, and in particular the requirement to support market creation and 'PULL' demand for clean tech, accelerating clean innovation requires a mix of policies and programs, which must be broadly **consistent, comprehensive, and coherent** so as to support the **credibility** and dynamic predictability of policy direction on clean innovation and green growth.

Combinations of Policies & Programs for Clean Tech are More Effective than Single Instruments:

The overall lesson stemming from this review is that governments need to consider the *entire* policy and programmatic mix when designing, implementing, and evaluating both individual instruments and public interventions aimed at providing support for clean business innovation. In the case of clean innovation – due to its unique challenges, barriers, and multiple market failures – mixes of policy instruments and public programs are needed to simultaneously tackle different challenges, and these must be comprehensive, coherent, and mutually supportive across the innovation system (Rogge et al. 2017).

For example, it is well known that to help overcome the challenges of knowledge spillovers to innovation, governments around the world invest in R&D (particularly for basic research) using a variety of tools including: direct funding and subsidies for private R&D, indirect funding such as tax incentives for private R&D, regulatory supports such as IP, and other support for public research institutions and partnerships (including universities and government labs). The literature provides a compelling case for many of these interventions. Recent evidence, however, suggests that spillovers are potentially greater for clean technologies than for other types of innovation. A study by Dechezleprêtre et al. (2014) finds that, on average, the patenting rate for low-carbon technologies is about 50% greater than for high-carbon technologies, and generates larger economic benefits (as measured by increases in stock values). This has several implications. First, economic theory tells us that public support for private investment in innovation should scale with the magnitude of the knowledge spillovers produced, which strengthens the arguments for additional investment or programmatic support for clean innovation R&D activities (e.g. Goulder & Schneider 1999). Secondly, this may suggest increased benefits of more systemic instruments, such as ‘cluster support’ programs – as the extent of knowledge spillovers in a region has been shown to influence firms’ ability to develop clean innovations (see Hansen & Coenen 2015 for a review).

Yet even well designed R&D PUSH policies, with effective programmatic support, are not sufficient to incentivize adoption of clean technologies -- due to the presence of the environmental externality market failure (Fischer and Newell 2008). A range of research has shown that clean innovation R&D support programmes have to be complementary with (and cannot substitute for) environmental regulations that create the demand (PULL) to induce technological change. This general view is increasingly accepted by innovation researchers (Foxon and Pearson, 2008; Cunningham et al., 2013; Kivimaa and Kern, 2016; Rogge and Reichardt, 2016), political scientists (Howlett and Lejano, 2013; Howlett and Rayner, 2007; Kern et al., 2017) as well as by economists (Jaffe and Stavins, 1995, Jaffe et al., 2005; Popp, 2006, Fischer and Newell, 2008; Newell, 2010; Johnstone, Haščič and Popp, 2010, van den Bergh, 2013; del Rio, 2017; Costantini et al., 2017). Indeed, a study by Popp (2006) finds that while a policy mix of both R&D support and carbon pricing produces optimal results, carbon pricing alone can account for over 90% of the economic welfare benefits.

While it is widely recognized that market mechanisms such as emissions pricing are the most economically efficient policy to PULL market demand (e.g. Canada’s Ecofiscal Comission, 2015, Howard and Sylvan 2015), evidence for induced innovation from market mechanisms versus other approaches is more mixed, and suggests that policy or regulatory design characteristics including **stringency, flexibility, and dynamic predictability** (or policy certainty) may be the more important factors (Popp, 2003; Vollebergh, 2007; Fischer and Newell, 2008; Johnstone et al., 2010). For example, pollution pricing systems with low price (low stringency) and high volatility (low predictability) can be less effective than stringent and predictable regulations (Taylor 2012). While this discussion is specific to the policy literature, a broader literature on policy and program mix suggests that different interventions and public support programs may influence the perceived characteristics of clean innovation policies – by contributing to the overall ‘policy mix’. In this regard, additional characteristics of the overall policy and program suite, including consistency, comprehensiveness, coherence, and credibility, are highlighted in the literature for driving clean innovation (OECD, 2003b; Foxon and Pearson, 2008; Howlett and Rayner, 2007; Kern and Howlett, 2009; Rogge and Reichardt, 2016). In particular, Rogge and Reichardt (2016) argue that consideration of these characteristics is essential to optimize the effectiveness and efficiency of directing and accelerating technological change.

Success Factors of Support Programs for Clean Business Innovation:

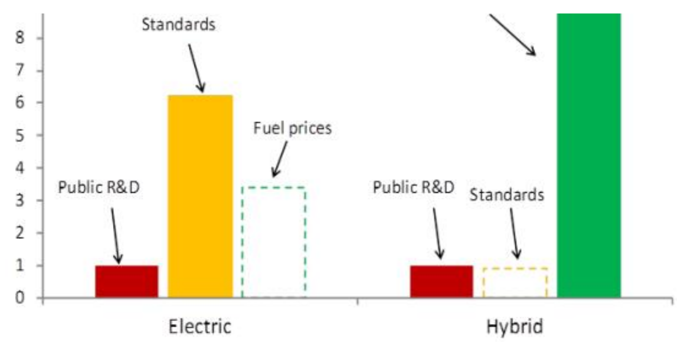
Effective coordination of policy and program characteristics is key to supporting ambitious clean innovation goals, such as Canada’s Paris Agreement commitments, or broad green growth policy directions, such as those laid out in the PCF. Characteristics specifically relevant to the policy and program mix supporting clean innovation are discussed in detail below, including how they may link to policy approaches consistent with the PCF:

Comprehensiveness:

While increased stringency of specific policies (i.e. how tightly they ‘bind’ decisions) is generally considered to increase innovation (Johnstone et al. 2010; Rogge et al 2011; Schmidt et al. 2012; Botta & Kozluk 2014), it is important to note that stringency of clean innovation support may also be considered in terms of the level of incentives provided by a whole policy and program mix (Botta & Kozluk 2014). The comprehensiveness of innovation program support can therefore support stringency by considering how broadly clean innovation incentives apply across an innovation system. The latter observation is particularly relevant in the case of clean innovation, where market-based policies, such as emissions pricing, are often sub-optimally applied (e.g. price too low to achieve goal, limited coverage) . In such cases the role of a comprehensive set of complementary environmental and clean innovation policies and programs may help to increase the stringency of the overall policy mix.

A comprehensive mix of policies and programs should be designed to apply sufficiently stringent instruments to different challenges and across different levels of technology maturity within an innovation system (Rogge and Reichardt 2016). Effective program design needs to be adapted to the maturity (or development stage) of the supported clean innovation area or sector (Altenburg & Pegels 2012). For example, Haščič and Johnstone (2011) show how different types of low-carbon vehicle technologies (hybrid vs electric) require different policy and program mixes (see Figure XX[2]).

Figure 1 Relative Effect of Technology Standards, Fuel Prices and Public R&D on Innovation i electric and Hybrid Vehicles



While market-based policy instruments tend to be more effective when technologies are relatively mature and more likely to attract private investment, these instruments should be complemented in a more comprehensive policy suite by programs focussed on less mature technology development. For example, such programs might foster a broader range of clean technologies and offer more direct market support (including direct R&D, public spending or procurement incentives, or learning and networking support) for technologies with high market potential, but which are further from the market and may benefit from the increased learning and economies of scale enabled by public intervention (Azar & Sandén 2011, Hogan 2014).

Similarly, the OECD (2015b) calls for comprehensive sequencing of public interventions to support system innovation, tailored across innovation stages. While support for emerging innovation niches may consist of a combination of foresight and networking activities combined with technology-neutral instruments, more specific support is called for at scale-up and commercialisation phases, when further development may require technology specific programs, including: funding, network development, demonstration programs, procurement, and/or technology platforms.

Credibility, Consistency & Coherence:

Because much of the demand for clean innovation needs to be driven by government policies or regulation (e.g. pollution pricing, standards, or procurement), it can be hard for investors to predict the pace, scale, or reliability of the future policy changes. More than other business innovation, therefore, investors in clean tech or clean innovation generally are subjected to higher levels of 'policy risk', or the risk of policy reversal, and therefore market loss (Freeman and Haveman 1972; Taylor 2008; Popp et al. 2009).

Different policy and program mixes have been shown to convey different impressions of dynamic predictability in policy support (e.g. Barradale 2008; Criscuolo & Menon 2014), and relate to a field of

[2] Note: For ease of interpretation, elasticities have been normalised such that the effect of R&D=1. Unfilled bars indicate no statitistical significance.

literature around ‘policy mix’ credibility. Rogge and Reichardt (2016) define credibility as “the extent to which the policy mix is believable and reliable, both overall and regarding its elements and processes”. They argue that credibility may be positively or negatively influenced by a range of factors, including the commitment from political leadership, consistency and coherence of the policy mix, introduction of formal targets into instruments, competences of public administration, or effective coordination between ministries and delegation of competencies to independent agencies for program support. This credibility can be strengthened by ensuring policy “stickiness” – the abilitiy of policies and programs to outlast short political cycles – this can be encouraged, for example, by setting default long term trajectories with planned review periods, or using arms-length (and apolitical) institutions to review progress and provide advice (see Section4) (Levin et al. 2012).

In this regard, numerous studies call for increased consistency and coherence of policies and programs for clean innovation (Foxon et al., 2004; Kemp and Rotmans, 2005; Foxon and Pearson, 2008; Reid and Miedzinski, 2008; Kemp, 2011; Rogge and Reichardt, 2016). The need to study consistency and coherency rests on the assumption that improved consistency of policy instruments and better coherence of innovation policies, programs, and public interventions may contribute to the effectiveness and credibility of innovation policies and programs. For example, Bödeker and Rogge (2014) suggest that the most relevant determinants of perceived policy credibility were the stability and temporal consistency of the policy mix, including the perceived commitment from political leadership, and followed by the consistency of the instrument mix and the support level of policy instruments. Uyarra et al. (2016), meanwhile, confirm that concerns about policy coherence can lead to questioning of policy credibility, and may negatively influence innovation activities by SMEs active in low-carbon innovation.

Rogge and Reichardt (2016) point to a lack of clarity and different definitions of consistency and coherence in the literature. They propose to distinguish between the two terms. Consistency is to capture how well the elements of a policy/program mix are aligned with each other, including consistency of the policy strategy (i.e. alignment of objectives across different relevant strategies and policies), instrument mix (i.e. positive, neutral or negative interactions between instruments), and consistency of the instrument mix with the policy strategy (i.e. the ability of the policy strategy and the instrument mix to work together in a unidirectional or mutually supportive fashion). The more consistent the policy and program mix, the more effective and efficient it becomes.

Coherence, meanwhile, can be achieved via structural, organisational and procedural mechanisms, including strategic planning (e.g. joint planning initiatives), coordinating structures (e.g. innovation councils) or communication networks, to ensure innovation instruments and programs are strategically aligned to existing policy objectives (Rogge & Reichart 2016). The OECD (2003b) differentiates between three types of policy coherence: horizontal, vertical and temporal. Horizontal coherence is to ensure that individual objectives and instruments developed by various entities are mutually reinforcing. Vertical coherence is about ensuring that the practices of agencies and autonomous bodies, as well as the approaches of sub-national levels of government, are mutually reinforcing with overall policy commitments. Temporal coherence ensures that policies continue to be effective over time and that longer-term commitments are not contradicted by short-term programs or decisions. Ensuring “dynamic efficiency” is another way of expressing this perspective. Examples of approaches to improve coherence include integration and coordination of public sector organizations to enhance information flows (e.g. the establishment new policy departments bringing together energy and climate in the UK and Denmark) (Rogge & Reichardt 2016).

While innovation researchers point out that perfect policy and program consistency and coherence may be impossible to achieve in reality (Carbone, 2008; Rogge and Reichardt, 2016), some approaches to improvement have been proposed. For example, Howlett and Rayner (2013) propose strategic policy/program patching as a realistic strategy for improving the consistency and coherence of policy and program mixes. 'Patching' refers to a gradual change of policies and programs that they liken to upgrading operating systems (Howlett and Rayner, 2013). Kern et al (2017) offer recent support for Howlett and Rayner's approach through a study of the UK and Finnish implementation of energy efficiency goals.

Case-Studies of Policy and Program Mixes to Support Clean Innovation:

While research so far indicates that there is no single blueprint for designing an effective instrument mix for clean innovation, qualitative case studies embracing the policy mix approach contribute empirical evidence on the role of specific policy and program characteristics.

For example, in their study on the German off-shore wind sector, Reichardt and Rogge (2016) analyse the innovation impact of the characteristics of the policy/program mix on companies. They find that the consistency and credibility of the mix have been very important incentives for clean innovation.

Uyarra et al. (2016) analyse UK policy for low-carbon innovation support with a focus on SMEs operating in the low-carbon and environmental sectors. They report concerns among companies that point out to an increasingly crowded landscape and limited coordination between multiple agencies. This confirms the importance of policy coherence and consistency, and the role of policy stability, communication and credibility in fostering innovation activities by SMEs.

Cantner et al. (2016) provide an analysis of how different instruments work together to influence renewable energy innovation in Germany. They find a combination of demand-pull, technology-push and strengthen (cluster support) instruments had a positive influence on both network size and collaboration to promote innovation, emphasizing the importance of a consistent policy mix.

In their analysis of public support for energy efficiency, Kern et al (2017) found that UK and Finland have increasingly complex mixes of goals and a variety of different instruments. This confirms the finding that, in order to meet EU targets, many EU member states introduce additional instruments into an already crowded space. In line with Howlett and Rayner (2007), they argue that strategic 'patching' may be a more promising approach for governments than the creation of completely new policy packages. Their analysis has identified ways in which such patching can be strategically used by policymakers in both countries to increase the chances of significant improvements in building energy efficiency. Finland has achieved coherence through patching by improving not only inter-departmental coordination but by also creating a dialogue between a range of stakeholders regarding policy and program design.

2. Enabling Disruptive Clean Technologies and Avoiding 'Lock-In'

While broadly consistent, comprehensive, and coherent clean innovation programs are required to support the credibility, stringency, and predictability of clean innovation policy directions, the role and impact of different instruments and programmatic supports will differ depending on the type of innovation, its level of disruptiveness, as well as the capacity of actors targeted by direct or indirect support (Bergek & Berggren 2014; Kemp & Pontoglio 2011). In particular, in the context of clean innovation, the significant transition required to meet current goals to decarbonize the economy by mid-century, as set out by the G7 in 2015 (G7 Leaders 2015), and in Canada's Paris Agreement goals (Government of Canada 2015), and the PCF (First Ministers of Canada 2016) has led many researchers to examine the issues for supporting clean business innovation from a 'transitions perspective' (e.g. see Markard et al. 2012), instead of the instrument/program design perspective taken above.

This *transitions* perspective to clean innovation support leads to a different set of insights into how innovation programs can enable clean business innovation, and in particular innovation in more disruptive clean technologies – which are discussed in more detail below. At a general level, this body of work: (1) explores historical transition episodes such as the shift from sail to steam ships in oceanic transport (Martínez Arranz 2017); (2) examines more recent and even unfolding transition experiences involving the diffusion of emerging innovations across a range of sectors (Papachristos et al. 2013); (3) synthesizes lessons for the governance of 'sustainability' transitions (Loorbach and Rotmans 2010); and, (4) deploys insights to complement modelling and planning approaches informing clean innovation policy and programs (Foxon et al. 2010; Geels et al. 2016a; McDowall, 2014; Rosenbloom, 2017; Turnheim et al. 2015).

The Challenges of Disruptive (Clean) Innovation, Transitions & Lock-In

Transitions can be understood as long-term processes of social and technological change involving the reorientation of one or more large-scale systems such as the provision of electricity or mobility (Geels 2004). These multi-decadal shifts not only involve the deployment of new technologies and systems but also the adoption of novel social practices, rules, and governance mechanisms. In this way, socio-technical system configurations are not simply technological but rather involve an array of interwoven social and material elements that together fulfil a function or provide a service. For example, consider how power plants and transmission infrastructure work in concert with regulations and markets as well as end-user technologies (buildings, appliances) and practices to provide electricity services.

The specific configurations of socio-technical systems – often referred to as a regime – are long-lived and resistant to change. Regimes display deeply embedded path dependent characteristics, which constrain choices in a fashion which tends to reproduce existing patterns (Berkhout 2002). Correspondingly, innovation typically follows an established trajectory and advancements are often incremental in nature (Dosi 1982). These established configurations tend to resist alternative (or disruptive) innovation trajectories due to distinct political and economic interests (e.g. of vested powers or incumbent firms), which benefit from current arrangements due to their embodied distributional consequences (Geels 2014; Meadowcroft 2009; Smith et al. 2005). In this way, the interests and frames of reference of key actors are at least as important as institutional and infrastructure rigidities in shaping development pathways (Stirling 2014).

Together, these factors can act to lock-in particular trajectories, and near-term commitments (e.g., investments in infrastructure) and can perpetuate established arrangements over the long-term. There are numerous examples of lock-in throughout the transition, innovation, and political-economy literatures. Klitkou et al. (2015), for instance, show how economies of scale, network externalities, and collective action barriers create lock-in for the existing fossil-fuel dependent road transportation system and prevent alternatives such as electric and hydrogen vehicles from gaining market share. Similarly, Unruh (2000) demonstrates that firms tend to focus preferentially on their core competencies and promote incremental improvements to existing technologies and practices rather than drive more disruptive innovation around alternatives, continually re-investing in assets that promote dominant technology trajectories. Still others focus on the role of power, revealing how deliberative processes tend to support outcomes that extend established (e.g. carbon-intensive) development paths (Stirling, 2015).

It is within this context that novel (disruptive) innovations that can shift development pathways (such as clean tech) need to emerge and compete. At the outset, new technologies and practices, including many clean innovations, typically appear inferior to incumbent technologies (Geels, 2002, 2005), may find it difficult to live up to initial assessments of their potential (Verbong et al., 2008), face considerable public acceptance issues (Fast et al., 2016), and often experience failures (Sovacool, 2009). Beyond these limitations, emerging innovations tend to be mismatched with existing configurations of infrastructure and other support systems, and imply disruptive technological, economic and behavioural adjustments (which are resisted) to enable their diffusion (Perez, 1983; Perez and Freeman, 1988). There is often also disagreement about the potential direction disruptive change should take (Foxon et al., 2013; Rosenbloom and Meadowcroft, 2014). Governments should recognize that their choices about how and where to intervene are not neutral: they will influence political-economic trajectories that have important impacts on the future character of society, such as the nature of work, and transportation, energy and urban systems.

The above-mentioned barriers represent fundamental challenges for clean innovation, as current GHG reduction targets imply disruptive socio-technical change on many fronts, e.g. transportation, energy, industrial and urban systems. While the market will play an important role in supporting low-carbon innovation, the role of government programs and interventions in driving sustainability transitions at the pace and scale needed to address climate change is well-established in the transition literature (Meadowcroft, 2016; Rotmans et al., 2001; Unruh, 2002). Indeed, a considerable body of historical work demonstrates that government intervention has often been at the forefront of socio-technical transitions and innovation (Martínez Arranz, 2017, Mazzucato 2017) – a point not always well understood in the broader debate.

Supporting Disruptive Clean Innovation & Preventing Lock-In

Accelerating green (or clean) transitions and removing barriers to disruptive clean innovation through policy is a central preoccupation of transition scholarship; this can include for example using protected market niches to enable disruptive technologies with long-term potential to develop and eventually compete in broader markets (e.g. Kemp et al. 1998; Jacobsson and Lauber, 2006; Smith and Raven, 2012).

However, the transitions scholarship has also suggested that government may play an important role through support programs that lay the groundwork for disruptive clean innovation to emerge, such as convening actors who hold a stake in potential transitions (e.g., electric vehicle and renewable energy manufacturers) to develop common problem definitions, establish coalitions supportive of more disruptive innovation, and mobilize transition agendas (Loorbach and Rotmans, 2010; Rotmans et al., 2001). For example, a public waste management agency in Belgium brought companies, community organizations, researchers, and government actors together to envision the socio-technical changes needed to develop a closed-loop waste system and begin to implement this vision, reframing waste management as the responsibility of a broader set of societal actors (Loorbach and Rotmans 2010). While the governance of these transition exercises can face challenges in bringing together diverse actors (Meadowcroft, 2009; Shove and Walker, 2007), the creation of protected spaces for experimentation and shaping transition agendas is an essential enabler of disruptive innovation that creates market opportunity for cleaner technologies.

Other aspects of this literature inform how programs can be designed to leverage different actors, such as emerging SMEs and/or larger incumbents, and their associated networks (e.g., manufacturers, industry associations, and researchers). For instance, despite often resisting disruptive low-carbon innovation (Geels, 2014), incumbent industries may also serve as important drivers of innovation if they adopt an interest in emerging technologies such as wind turbines and solar photovoltaics (Geels et al., 2016b; Geels and Schot, 2007). Innovation and business scholars corroborate these findings, suggesting that more disruptive innovations need not remain the purview only of new entrants but may also be pursued by incumbent firms – who may simultaneously exploit mature markets while investing in new opportunities (O'Reilly III and Tushman, 2004). Governments can encourage such incumbent interest – and thus break down structural resistance to disruptive change – through a variety of instruments (Berkhout, 2008), such as providing incentives for cleaner technologies (e.g. by pricing pollution) or by actively destabilizing longstanding social and technological systems (Turnheim and Geels, 2012, 2013) – e.g. by announcing a phase-out of coal power. These studies suggest that it is critical to remove institutional supports, embedded incentives, and even undermine the legitimacy of unsustainable arrangements (Geels and Verhees, 2011; Rosenbloom et al., 2016), and points to the important role of coalitions and coalition-building in empowering alternatives by legitimizing their use in public debates and decision-making forums (Avelino and Wittmayer, 2016; Raven et al., 2016). This might involve expanding participation among diverse and marginalized constituencies within deliberative institutions such as consultations, stakeholder commissions, and scenario exercises (Stirling, 2009).

A key concern in this literature therefore relates not only to improving the effectiveness of climate policies through policy and program interactions (such as those described in the previous section), but also to using public investments (e.g. in supporting new infrastructure), incentives (e.g. electric vehicle subsidies) and programs (such as networking and public engagement) to help accelerate the overarching pace of the low-carbon transition through (clean) innovation (Kern and Rogge, 2016).

3. Supporting Commercialisation of Clean Tech Through Strategic Public Investments

The double market failure and additional barriers outlined earlier impede the ability of firms to finance their innovations as they progress from R&D through commercialization to diffusion. These impediments are exacerbated by the nature of many clean innovations, which often require large capital investments over long time frames, and compete against established incumbents in price-taking commodity markets (Ghosh and Nanda 2010; Ault and Allmendinger 2016). For example, bio-fuels must compete with incumbent gas or diesel fuels that have extensive existing production and distribution networks and established customers; and solar power must compete with existing power generation systems (using coal, gas or nuclear) that have large generating stations (usually publicly funded), distribution networks geared to those technologies and often market access rules that favour them. These challenges are particularly acute at the scale-up and commercialization stages, where successive (and increasingly large) injections of capital are required to demonstrate commercial viability.

For supporting commercialisation of clean tech, the recent literature suggests that governments must apply the lessons above, and apply coherent, comprehensive, and consistent policies and programs to both address clean innovation market failures and overcome system barriers. However, it is also argued that governments must move beyond targeted 'commercialisation' programs, and towards broader market creation efforts, through strategic use of public spending, including direct R&D support, financial programs, as well as clean public procurement, to help finance riskier clean innovations and create direction (or mission-orientation) in innovation systems (Mazzucato 2017, Mazzucato & Semieniuk 2017, *forthcoming*).

Creating Direction towards Clean Innovation with Direct Public Investment

Mazzucato (2017) argues that public support for clean innovation is about creating direction in innovation (towards clean outcomes); accordingly, as a form of 'mission-oriented' program engagement, it cannot focus just on de-risking and levelling the playing field, but instead must *tilt the playing field* in the direction of desired goals or policy objectives. While this sort of 'mission-oriented' public intervention requires bold demand-side policies (like those in the PCF) to change consumption and investment behaviour, there is also a role for direct spending, R&D support programs, public investment banks, and public procurement to provide long-term, patient finance to high risk, capital intensive projects – crowding in future investment (Mazzucato 2017).

Importantly, this sort of mission-oriented innovation tends to be highly uncertain, have long lead times to develop new technologies, and require cumulative and collective action across a range of actors and innovators (Lazonick & Mazzucato 2017) – and this is especially the case for clean innovation. These qualities lead to underinvestment by private firms, therefore public investment and direct support can play a critical role in stimulating the additional investments needed to drive innovation at the desired pace and scale (Mazzucato 2017) – e.g. to meet climate goals. To be 'additional', these public investment and support programs must be willing to bear (or share) the exceptional risks and long lead times that private investors typically cannot; moreover, the heterogenous nature of clean innovation (multiple sectors, different stages of development) requires incentivizing or providing different forms of investment by a variety of public and private sources across the innovation chain (Mazzucato & Semieniuk 2017).

Therefore, providing effective support for the development and deployment of *clean* technologies typically requires public investment, spending and support programs that are not simply neutral (i.e. general innovation support), but ones deliberately designed to affect the nature, rate, and direction of innovation (O'Sullivan 2004; Mazzucato 2013, Mazzucato and Semieniuk 2017) – i.e. to tilt the playing field. It is also important to consider how government support is weighted across different sectors and innovation 'stages': where public investment is most needed, and how that choice affects the types of technologies advanced. For example, if the goal is to spur the development of new, potentially breakthough technologies, that suggests public support for high risk early financing; whereas support targeted at the venture capital stage will help to carry promising existing technologies from proof of concept to commercial scale (Arrow 1962, Auerswald & Branscomb 2003). Both are stages where public support is needed, but they will advance different types of technologies at different timelines, with different implications for meeting climate (and other) goals.

In a recent study of global renewable energy financial flows, more than two thirds of total renewable energy finance was found to support the downstream phases of innovation -- deployment and diffusion of market-ready technologies (Mazzucato, 2017). It needs to be recognized that such downstream support creates direction in innovation – favouring market-ready technologies over emertging ones – and not all sources are equal (Mazzucato & Semieniuk *forthcoming*). Davies et al. (2014) and Haldane (2016), provide evidence that in recent years private capital markets have retreated from long-term investments, focussing more on short-term returns, which will skew both the rate and direction of the innovation they support toward lower-risk, incremental innovations (Mazzucato and Semieniuk 2017). For clean tech especially, it has been observed that the most capital intensive, high risk innovations are particularly reliant on public funding (Mazzucato & Semieniuk *forthcoming*) and require both supply side (R&D) and demand side (deployment and diffusion) support to enable riskier innovations to move through commercialization and to market (Climate Policy Initiative 2013). Public investment is therefore needed to play a critical role in supporting more disruptive, clean innovation pathways across the innovation chain (Mazzucato & Semieniuk *forthcoming).*

Finally, public investment programs for clean innovation need to recognize that directing innovation in new, clean directions will require a collaborative and collective effort across many sectors, and across different actors (including SMEs, incumbents, and public agencies) (Mazzucato 2017). For example, a low-carbon energy transition will require collaboration between SMEs with novel technologies in energy generation and storage, large energy incumbents with established networks and knowledge, and public utilities and distribution networks. Public support and direct investment programs for clean innovation therefore need to enable bottom-up experimentation and learning across sectors (Rodrik 2004), provide long-term finance to enable trial and error (Janeway 2012), and engage throughout the innovation chain to encourage spillovers across sectors (including low tech sectors) (Foray et al. 2012), while creating and shaping markets with downstream investment (Mazzucato 2017).

Enabling Clean Innovation through Directed Public Procurement

While focussed generally on public investment and direct support programs, the discussion above also highlights a role for public procurement in supporting clean innovation programs. As the nation's largest purchaser, green public procurement strategies can be important to align with other market creation strategies – not just to lower government's environmental footprint, but also to direct innovation towards clean techologies, and support their development, demonstration and commercialization. Building on the discussion above, there is also a role for public procurement to play in ensuring consistency and coherence of government support for clean innovation, and to signal credibility and consistent direction to innovators and investors of the market potential for 'clean' technologies. Indeed, there is a growing recognition that procurement can be used as a tool to achieve policy priorities and drive innovation, in addition to government and public needs (Edler and Georghiou, 2007, Block & Keller 2011, UNEP 2017).

Public procurement represents a significant expenditure: on average 13% of GDP in OECD countries (OECD, 2015c). Aligning this large market with government clean innovation priorities can create a strong market-pull incentive for firms to supply clean technologies, and to direct innovation investments towards riskier outcomes and new, clean technology pathways (Edler and Georghiou 2007; Edquist and Zabala-Iturriagagoitia 2012, OECD, 2015b). Additionally, public procurement can help address systemic barriers to clean innovation from information asymmetries by articulating unmet needs and enabling interaction between users and potential suppliers (Uyarra et al., 2014). The commercial reputation of clean innovations and innovators may also be enhanced by government procurement contracts (Uyarra and Flanagan, 2010) -- and government contracts have also been shown to catalyse diffusion throughout the private market (Simcoe and Toffel, 2014).

Aligning procurement with clean innovation involves integrating insights from two interrelated though distinct bodies of literature: one on using procurement as a general tool for innovation generally, and one on green (or clean) public procurement more specifically (Rainville, 2016). The empirical evidence draws largely from research on public procurement for innovation, however it is important to note that *clean* public procurement will involve somewhat different instruments, implementation strategies and structures, and evaluation criteria – and may require its own specific targets -- as it needs to overcome the lack of market reward for most environmental innovations (i.e. the environmental externality market failure) (IISD 2012). Without such specific strategies and targets, clean innovations may get short shrift in overall procurement for innovation programs.

While the popularity of procurement for innovation has grown, and attention has shifted towards the potential for clean public procurement to shape markets and drive demand, implementation has lagged behind policy rhetoric and monitoring and evaluation has been insufficient – with many programs still in early stages (Uyarra 2017). While evidence for the effect of public procurement on innovation is therefore still fragmented and merits further investigation (Georghiou et al. 2014; Dutz and Pilat, 2014), there are a few notable examples:

Aschoff and Sofka (2009) conducted a comparative assessment of more than 1100 innovating German firms to look at how public procurement performs relative to other innovation policy interventions. Results indicated public procurement had strong positive effects on innovation, more so than regulations and public R&D funding -- with only knowledge spillovers showing equally strong effects.

Georghiou et al. (2014) conducted a survey of 800 UK firms and found that 67% of innovating firms indicated bidding for or delivering contracts to public sector clients has had some impact on their innovation activity, while 51.4% of suppliers in the sample that carried out R&D in the last three years admitted to having increased their R&D expenses as a result of delivering or bidding for public sector contracts.

A recent study by Guerzoni and Taiteri (2015) used a quasi-experimental design with data from over 5000 European firms to investigate the effect of R&D subsidies, R&D tax credits, and public procurement on innovation behaviour. The study found public procurement to have a robust effect on innovative behaviour and private R&D spending. Preliminary results also show reinforcing/interaction effects between procurement and other public policies and programs for innovation, and suggest procurement could reinforce potential positive effects from instruments designed to drive technology-PUSH.

The US Small Business Innovation Research Program (SBIR) is a widely lauded program targets the first step on the procurement ladder, and has been replicated by several countries (OECD 2010). The program mandates government agencies to target small businesses with R&D contracts to develop prototypes based on public sector (or societal) needs and thus gives the government an opportunity to test innovations. A recent study by Howell (2017) shows that firms winning SBIR support from government are significantly more likely to patent new innovations, attract financing, and become revenue positive.

These studies are encouraging, and research has identified a variety of pubic instruments that can be used to encourage innovation through procurement programs (see Georghiou et al. 2014 for a proposed taxonomy) as well as tools to drive clean public procurement, including life-cycle costing, internal carbon pricing, and low carbon government performance targets (OECD, 2015b). However, barriers to effective implementation of clean public procurement have also been identified – especially ones that limit the coordination of procurement with other (clean) innovation policies and programmes, such as: insufficient skills, decentralised processes, principal-agent problems, and competing objectives across public agencies (see Uyarra et al. 2014; OECD, 2014).

4. Designing Program Governance and Evaluation Processes to Encourage Experimentation in Clean Innovation

The preceding discussion highlights that public investment and direct support for clean innovation must be coherent and consistent across the innovation chain, while also enabling bottom-up experimentation and learning to generate spill-overs across sectors. In addition, public spending programs need to help 'tilt' the entire innovation system, by providing long-term, high-risk public investment to create and shape markets for 'clean', while enabling trial and error and directing the rate and type (risk-level) of innovation activity. These observations have strong implications for the kinds of governance processes and institutions needed to coordinate and administer the range of public investments (direct R&D support, procurement, and networking activities), needed to drive clean innovation. Moreover, they suggest that new types of evaluation processes and indicators may be needed to enable public and private risk sharing and experimentation across sectors and technology pathways.

Institutional Frameworks to Enable Experimentation in Innovation:

Researchers have begun to point to the importance of experimentation in scaling up clean innovations (Luederitz et al., 2016), particularly as understanding has increased that the specific form and possibilities that constitute new clean innovation pathways are often deeply tied to particular places and times

(Coenen et al., 2012), meaning that some innovations will inevitably fail (Schot and Geels, 2008). To overcome this challenge, it is argued that a multiplicity of discrete experiments should be fostered across contexts and sectors (e.g. from housing to agriculture), and that innovation policy should enable experimentation with options “beyond the narrow boundaries set by incumbents” (Schot and Steinmueller 2016).

Mounting international efforts to proliferate and draw lessons from innovation or clean transition experiments (both failed and successful) are accumulating in the literature (e.g. Pitkänen et al. 2016, Kivimaa et al. 2017, Sengers et al. 2016), and include studies looking at the benefits of supporting learning-by-doing, or doing-by-learning approaches (Loorbach and Rotmans 2010). However, in order to be transformative and not end up as isolated single experiments, experimentation should be embedded in broader approaches to clean innovation policies and programs, and be given a dedicated space in broader organisational and institutional frameworks (Chataway et al., 2017).

Public institutions to support clean innovation can therefore perform important roles throughout the innovation process to coordinate support and enable experimentation across different clean technology programs. This requires institutions to be capable of identifying and utilizing different strategies depending on the unique regional, sectoral, and technological context in which they work, while guarding against potential issues such as mission-drift, capture by political or incumbent interests, or coordination failures.

While evidence on the most effective public institution configurations is mixed; countries like Japan and South Korea have had success with powerful agencies leading industrial development missions (Johnson 1982; Chang 1994), while the US has found success with a more decentralized structure or “networked” state of labs, agencies, and initiatives at various levels of government (Block, 2008). While there is little consensus, some studies suggest that while a centralized agency can promote growth in mature industries, they are at risk of capture from the existing regime, whereas a decentralized configuration with arms-length institutions operating on the periphery may be more conducive to disruptive clean innovation (e.g. Breznitz and Ornston, 2013). As an example of the pitfalls to be avoided, the Netherlands’ Energy Transition Project aimed to manage the transition to a more sustainable regime for the energy sector through a centralized approach within the Ministry of Economic Affairs, but Ken and Smith (2009) suggest that dominance of the established business community in guiding the process led to capture of the process and outsized influence in favour of incumbent interests. (This has potential implications for the design of federal superclusters or economic sectors strategies.) These insights warn that streamlining initiatives might inadvertently close off innovative government-entrepreneur alliances, and that careful thought should be given to where to locate initiatives within government to enable them to experiment and play an innovative role.

A particularly notable example of effectively navigating some of these tensions may be the US Advanced Research Projects Agency – Energy (ARPA-e). Modelled on defence focussed DARPA, ARPA-e is an arm’s-length mission-driven organization that promotes experimentation in energy innovation. The agency uses an “island-bridge” model to balance *political autonomy* and *accountability*, by operating “as an island” to allow the *flexibility* to experiment, with a direct “bridge” to the government through the Secretary of Energy who is *accountable* for performance and charged with keeping energy innovation issues high on the agenda (Haley 2016).

Haley (2016) has examined the design features of different public institutions for clean innovation (such as ARPA-e) across a range of countries and examples, and developed a list of ten design principles that can be applied to institutions across the clean innovation spectrum. These principles are listed in Appendix III.

Measurement and Evaluation Processes in Clean Innovation:

In addition to considering the design of public institutions that manage investment and support for clean innovation, the understanding that public investment is needed to direct innovation to riskier portfolios, and that *clean* innovation investments in particular are highly uncertain, means that public investors must be willing to accept a fairly level of uncertainty and risk in supporting clean innovation (Mazzucato 2017). Evaluation processes for public investment may therefore need to be reconsidered, and new metrics developed that allow for an (inevitable) degree of failure, and lower short-term financial returns, while appropriately weighting environmental outcomes, in order to balance higher levels of risk and longer return timelines from public investments in clean innovation (Mazzucato & Wray 2015, Mazzucato 2017).

Measuring clean innovation outcomes from support programs is particularly challenging as metrics must capture both the environmental and economic effects of innovation. Despite various studies and research projects implemented in recent years, the availability of data and robust approaches to measuring clean innovation generally still poses several issues, and compounds the difficulty in measuring program outcomes. Based on the experience of recent projects investigating the measurement of clean innovation, the major conceptual and operational challenges include:

- Developing metrics capable of capturing trade-offs between economic and environmental outcomes;
- Improving the data aggregation methods, and taking into account rebound effects and other undesired effects;
- Clarifying different analytical levels and scope of clean innovation analyses, notably in relation to the meso level (e.g. value chains, functional areas); and
- Improving the operational approaches linking clean innovation metrics to other key indicators, most notably to those measuring economic growth and sustainable development.

Given these challenges, some authors have tried to articulate principles for selecting appropriate indicators for clean innovation (e.g. see Kemp 2011), while others, such as Miedzinski et al (2013), have pointed to the need to ensure stakeholders have an appropriate understanding of the range of short and long term effects of clean innovation policies, including: outputs (the products or processes that directly result from innovation); outcomes (the short- to medium-term effects of innovation outputs, e.g. on environmental or economic performance); and impacts (the long-term effects of an innovation program, such as reduced energy demand). However, it has also been observed that the more 'upstream' policy instrument is, or the further it is removed from its final application (e.g. R&D support vs. downstream deployment funding), the more difficult it is to anticipate its environmental impacts and attribute outcomes (Miedzinski et al 2013).

There is thus a need to continue to improve the robustness of measurement and evaluation approaches by refining available metrics and generating new data – and, some argue, to consider innovative new metrics and appraisal criteria that reflect the transformative ambition of public support programs for clean innovation (Weber and Rohracher, 2012; Schot and Steinmueller, 2016). For example, for public interventions meant to enable commercialization of clean technology, and particularly for downstream investments, some researchers are suggesting that governments should apply the portfolio strategies of venture capitalists to structure investments across different levels of risk – so that lower risk investments might help offset higher risk ones (Mazzucato 2017). Matching downstream spending with new public risk-return models could provide for improved measures of performance in public investment, while increasing accountability (Mazzucato & Wray 2015), and could be implemented through return-generating mechansims such as retaining equity or royalites, or using income-contingent loans (Mazzucato 2013).

Notable initiatives focused on clean innovation measurement

The European Commission funded several projects dedicated to developing clean/eco-innovation metrics. For example, the Measuring Eco-Innovation (MEI) project (Kemp and Pearson, 2007) focused on innovation in companies and collected information on real products. The ECODRIVE project (CML et al., 2008) meanwhile, approached clean innovation from the perspective of efficiency analysis, and suggested analysing clean innovation on three levels: (i) micro (product or service, company); (ii) meso (sector, supply chain, region, product-service system); and (iii) macro (country, economic blocks, global).

Since 2010, the Eco-Innovation Observatory (EIO) has worked to followed up on these two projects by performing broad data collection and establishing the knowledge platform for measuring clean/eco-innovation. The EIO has brought together a number of indicators from various data sources and organised them in a specifically designed online database[3], while also developing a new tool to monitor clean/eco-innovation performance across the EU member states: called the Eco-Innovation Scoreboard (EIS)[4]. The scoreboard was developed to complement innovation metrics already established at the EC, notably the Innovation Scoreboard, by introducing an environmental dimension to the metrics, including the notion of resource efficiency. EIS is published on EUROSTAT.

The ASEIC (Asia-Europe SMEs Eco-Innovation Center)[5] has separately developed the *ASEM Eco-Innovation Index (ASEI)* that measures the status and level of clean/eco-innovation of ASEM member countries, with a broader scope by including the 28 Member States of the EU, Norway, Switzerland and 21 Asian countries.

More recently, the Inno4SD project (Arundel et al., 2017) proposed collecting three types of indicators, environmental (including indicators for natural assets), clean innovation, and policy indicators. A fourth category is to collect indicators for socio-economic well-being to create flexibility in how sustainability goals are met and to ensure that any trade-offs in reaching sustainability are balanced by equivalent improvements in the quality of life.

These initiatives also need to be considered alongside ongoing initiatives in Canada, including Statistics Canada's Survey of Environmental Goods and Services (SEGS) – which was recently expanded to include a broader range of environmental services – and Statistics Canada's new 'satellite account' pilot project for clean technology.

Conclusion

Clean innovation is important. As the world shifts to a low carbon economy, clean innovation represents a significant and growing market opportunity for many parts of Canada's economy. It is also critical to meeting our climate and environmental goals cost effectively. Despite having many strengths, Canada's share of the global clean technology maket is relatively small, and falling. The evidence (though limited) shows Canada performance is strong in the early stages (R,D & D) but falls off as innovations get closer to market.

Clean innovation poses unique challenges. It faces additional market failures and barriers, and therefore requires both more and different types of government support compared to innovation writ large. In particular, because of the "environmental externalities" failure, public policies (pricing, regulations, incentives) and procurement must play a critical role in driving market demand for clean innovation. While

[3] See http://database.eco-innovation.eu

[4] See https://ec.europa.eu/environment/ecoap/scoreboard_en

[5] ASEIC is an international platform with the aim to promote cooperation between Europe and Asia in creating and enhancing eco-innovation in small and medium sized enterprises. See http://www.aseic.org/center/asei/result/result_2015.do

the role of policies, and how their design can promote clean innovation, is beyond the scope of this study, it warrants further consideration. Without strong 'pull' policies to stimulate demand, other types of government investment and support programs ('push' and 'grow') for clean innovation will be much less effective.

Clean innovation is a system. Therefore, boosting clean innovation by Canadian businesses requires a broad *mix* of programs and policies that is coherent, comprehensive, consistent and credible – to signal broad, sustained ambitious direction across the innovation system. This requires, among other things, institutions and processes that promote strategic alignment and coordination of programs and policies -- to engage key actors and experts within, across, and beyond governments.

Clean innovation involves disruption. Accelerating clean innovation requires active support throughout the system, designed to help break "lock-in" of high carbon technologies, overcome incumbents' intertia, and promote the transition to cleaner technology pathways. This kind of disruptive ambition should inform the design of programs and polcies (like those in the Pan-Canadian Framework), and be built into cross-cutting initiatives, such as superclusters and sector growth strategies.

Clean innovation is mission-driven. It is critical to meeting our climate commitments, so Canada is not indifferent to the direction and pace of clean innovation. Therefore, the role of governments is not just to fix market failures and level the playing field, but to actively 'tilt the playing field' in the direction of clean innovation – as governments have done for other types of mission-driven innovation. This includes an active role for public investment, both at the early stages (to develop new breakthrough technologies) and later stages (to promote commercialization and deployment). By sharing in the exceptional financing risks facing most clean technologies – particularly those with high capital costs and long scale-up periods – governments can catalyze private investment and direct it to higher-risk, longer term clean innovation outcomes.

Clean innovation is risky. Providing effective public support requires experimentation, risk-taking, failing and learning (fast) – traits that are often challenging for governments. It requires trying new types of public programs and institutions, novel approaches to risk-sharing, and unique (but challenging) evaluation and learning processes. And it requires government itself to be innovative: to take a more coordinated, nimble, risk-tolerant and proactive approach, in order to provide the support and direction needed to help Canadian businesses be among the global leaders in clean innovation.

Appendix I: Types of Clean Innovation

Box 1. Typology of clean innovation

Product innovation

- Novel products, components or materials with a reduced lifecycle-wide environmental impact and capacity to substitute existing alternatives (e.g. material- and energy-efficiency, durability, reparability, re-usability, recyclability, biodegradability)

Service innovation

- B2B: Provision of services aimed at improving internal processes of other businesses (e.g. waste management, water and waste water management, environmental consulting, eco-design, production optimisation)
- B2C: Provision of services that are less resource intensive and reduce emissions of products (e.g. extended warranties and repair services)

Process innovation

- Pollution control and pollution treatment technologies:
  - Pollution control technologies
  - Cleaning technologies that treat pollution released into the environment
  - Noise and vibration control
  - Environmental monitoring technologies
- Waste prevention and waste management:
  - Waste management processes and equipment
  - Integration of secondary materials in the production
- Resource efficient processes:
  - Material, energy and water efficient production processes
  - Renewable energy uses in manufacturing

Organizational innovation

- Environmental management and auditing systems
- Introduction of Total Quality Management to the organization
- Introduction of Extended Producer's Responsibility solutions

Source: Miedzinski et al (2017), based on Kemp and Pearson (2008); Huppes et al. (2008); Reid and Miedzinski (2008)

Appendix II : Market Barriers Impeding Clean Innovation

Barrier	Where it Occurs	Description
Incomplete information and technology risk (Scherer et al., 2000; Anderson and Newell, 2004)	Can impact any stage, but is most substantial at the demonstration to diffusion stages	Because clean technology is a rapidly emerging area where many of the technologies remain new and unproven, investors see additional risk in the sector. Many lenders (especially traditional ones) are unfamiliar with the profile of the clean technology sector and have a poor understanding of the potential markets and future returns from clean technology investments, even when the technologies have been proven. End users may also be hesitant to adopt new technologies, particularly as first users. For cleantech companies, having made a Canadian sale can show international markets that they have operational expertise and a proven product.
Capital intensity (Ghosh and Nanda, 2010; Rai et al., 2015)	Demonstration deployment phases	Many clean technologies require costly plants and equipment, as well as longer time frames for testing and scaling up before they can get to market and realize a return on investment – making the cost of capital more of a driver of overall cost. This combination of high capital needs and longer return periods can make financing a bigger challenge than in other sectors, such as information technology.
Network effects and infrastructure risk (Arrow, 1962; Rosenberg, 1982; Mulder et al., 2003; Nicholson, 2003)	All stages	Some innovations increase in quality and value (or decrease in cost) the more they are adopted. This is commonly known as a network effect or learning-by-doing, in which large scale deployments are required in order to prove the technology and lower costs. For many clean technologies, successful deployment depends on changes to existing public infrastructure platforms (transmission lines and smart grids, high speed rail systems, vehicle fuel station networks). Financing innovations is inherently risky because the path to growth and profitability depends on large-scale government investment in new forms of infrastructure – which investors cannot predict. Further, once infrastructure investments are made, it can pose as a barrier to future innovation in the form of technological lock-in.
Lack of policy congruency (OECD, 2003b; van den Bergh, 2013; Sulzenko, 2016)	A lack of policy congruency can impact the entire system	Clean innovation is dependent on many policies – including those that target different technologies, stages of readiness, economic sectors, and/or types of companies. Further, different policy regimes – from trade policy and IP frameworks to skill and immigration policies to financial regulations – all impact clean technology companies. If these oppose one another or are not well aligned, they risk creating a barrier for clean innovation. The same is true when different levels of government share jurisdiction but are not aligned, or of international regimes (which may lead to emissions leakage).
Behavioral gaps (Jaffe and Stavins, 2004; Gillingham et al. 2009)	Deployment and diffusion stages	In clean technology adoption, incentives between the technology adopter and end user may misalign. Principle-agent problems and split incentives – in which one person can make choices on behalf of another, such as is the case where building owners may be responsible for the choice of home heating technology, but the tenant is responsible for paying bills – can slow widespread adoption of investments that have positive returns and that would have otherwise occurred. Similarly, difficulties in energy efficiency valuation, uncertainty in outcomes, (over) discounting of the future and other behavioural gaps are possible. This is particularly relevant at the adoption stages for technologies like energy efficiency and water conservation solutions, where solutions are often cost-effective with short payback periods and yet have not penetrated the market as would be expected.

Policy uncertainty (Freeman and Haveman, 1972; Taylor, 2008; Popp et al., 2009)	All stages	Unlike other technologies, much of the demand for clean technologies is driven by government policies (pollution pricing, regulations, public procurement). The Paris Climate Accord, for example, is likely to spawn a raft of domestic policies that will create growing global demand for low-carbon technologies. However, it is very hard for investors to predict the pace and scale of these future policy changes (unlike other types of market risks), which tends to chill investment in these technologies.
Imperfect competition (Whitley and van der Burg, 2015; Kozuk and Johnstone, 2017)	Particularly diffusion	Imperfect competition is known to exist in key sectors – such as the electricity sector – and can lead to disadvantage against new entrants. This can be exacerbated when there is an uneven playing field due to the presence of subsides for conventional alternatives (which ties in to the point about technological lock-in noted under infrastructure risk). Additionally, vintage differentiated regulations often included as 'grandfather' clauses in regulations that favour incumbents.

Appendix III: Design Principles for Public Institutions to Support Clean Innovation

1. **Comprehensiveness**: Understanding clean innovation as a complex system is necessary to ensure objectives are aligned and unintended consequences are avoided (Bergek et al. 2008; Hekkert et al. 2011).
2. **Flexibility:** Innovation is a dynamic and uncertain process that requires institutions to be flexible to scale-up successes, quickly discontinue non-performing projects, and adjust to new evidence as it becomes available. Using arm's length bodies can help. While government can be risk-averse and hesitant to close down poor performers, arm's length bodies can be more flexible
3. **Autonomy from short-term political pressure:** Institutions need room to experiment; failures will occur and institutions need to be risk tolerant and not susceptible to short-term political agendas in pursuing a long-term goal like clean innovation (Savoie, 2015). For this reason, public institutions need to emphasize policy "stickiness", which not only protects specific policies—but the broader innovation strategy as a whole.
4. **Mission-orientation:** Clarity of mission and policy objectives targeted toward specific transformational change for the public good need to be maintained to avoid capture by private interest and to prevent continuation of projects for their ancillary benefits when they fail to attain their primary objectives (Lipsey and Karlaw, 1996).
5. **Embeddedness within policy networks:** Consistent and sustained linkages with the private sector are needed to ensure effective two-way flow of information to facilitate mutual learning and build trust and reciprocity to develop the most effective and complementary policies (Evans, 1995).
6. **Autonomy from private interests** – Any action (or non-action) by government can result in favouring some industries over others, yet public institutions need to be embedded with the private sector to understand the demands of the market. Effective institutions must act in the public interest without being captured by special interests; to avoid this, institutions should house sufficient *competence,* remain *mission-oriented,* and be held *accountable* through transparent evaluation (Evans, 1995).
7. **Competence:** Public institutions need to have sufficient in-house expertise to maintain their own vision and independence from private interests and earn trust within the sector.
8. **Credibility:** The public institution must have the ability to do what it says it will and act predictably in order for the private sector to have the confidence to invest without fear of sudden policy change (Schmitz et al. 2013).
9. **Stability**: Similarly, clean innovation requires a long-term commitment that must transcend political cycles and changing winds, and provide predictability for business to invest in innovations (Khanberg and Joshi 2012; Narayanamurti et al. 2009; Foray, Mowery, and Nelson 2012).
10. **Accountability:** Public institutions require a high degree of transparency, which includes a need for high-quality data and evaluation processes that are open to the public to ensure accountability, support iterative learning, and maintain legitimacy e (Arnold 2004). Ensuring a high-level political leader is accountable for the performance of the institution as well as its champion in government can help ensure innovation issues remain high on the political agenda (Rodrik, 2007).

Source: Haley (2016).

References

Abramovsky, L., Harrison, R. and Simpson, H. (2007) University Research and the Location fo Business R&D, *Economic Journal 117*:114-141.

Altenburg, T. and Pegels, A. (2012) Sustainability-oriented innovation systems – managing the green transformation, *Innovation and Development*, 2(1):5-22.

Analytica Advisors (2017) The 2017 Canadian Clean Technology Industry Report, *Analytica Advisors.*

Anderson, S.T. and Newell, R.G. (2004) Information programs for technology adoption: The case of energy efficiency audits, *Resource and Energy Economics, 26*(1):27-50.

Arrow, K. J. (1962) The economic implications of learning by doing, *Review of Economic Studies 29*:155-173.

Arnold, E. (2004) Evaluating research and innovation policy: a systems world needs systems evaluations, *Research Evaluation 13*(1):3-17.

Arundel, Anthony, et al. (2017) Measuring eco-innovation, green growth and the green economy, *Deliverable 2.4; Inno4SD*.

Aschhoff B., W. Sofka (2009) Innovation on demand – Can public procurement drive market success of innovations?, *Research Policy* 38:1235–1247.

Auerswald , P. E. and L. M. Branscomb (2003) Valleys of Death and Darwinian Seas: Financing the Invention of Innovation Transition in the United States, *Journal of Technology Transfer 28*(3–4):227–39.

Ault, T. and Allmendinger, T. (2016) Benchmarking the Canadian Cleantech Ecosystem, *Cleantech Group.*

Avelino, F., Wittmayer, J.M. (2016) Shifting Power Relations in Sustainability Transitions: A Multi-actor Perspective, *Journal of Environmental Policy and Planning 18:*628–649. doi:10.1080/1523908X.2015.1112259

Azar, C. and Sandén, B.A. (2011) The elusive quest for technology-neutral policies, *Environmental Innovation and Societal Transitions 1*:135-39.

Barradale, M.J. (2008). Impact of Policy Uncertainty on Renewable Energy Investment: Wind Power and PTC. US Association for Energy Economics, Working Paper 08-003. *Mimeo.*

Baumol, W. and Oates, W.E. (1988), Theory of Environmental Policy, *Cambridge University Press*.

Bergek, A. and Berggren, C. (2014) The impact of environmental policy instruments on innovation: A review of energy and automotive industry studies, *Ecological Economics 106*:112-23.

Bergek, A., Jacobsson, S., Carlsson, B, .Lindmark, S. and Rickne, A. (2008) Analyzing the Functional Dynamics of Technological Innovation Systems: A Scheme of Analysis, *Research Policy* 37 (3): 407–29.

Berkhout, F. (2002) Technological regimes, path dependency and the environment, *Global Environmental Change 12*:1–4.

Berkhout, F. (2008) Innovation theory and socio-technical transitions. *Edward Elgar*, Cheltenham, UK.

Block, F. (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.

Block, F., & Keller, M. (2011) State of innovation: The U.S. government's role in technology development, *Paradigm Publishers*, Boulder, CO.

Bloom, N., Griffith, R. and Van Reenen, J. (2002) Do R&D tax credits work? Evidence from an international panel of countries 1979-97, *Journal of Public Economics* 85: 1-31.

Bödeker, P. and Rogge, K. (2014) The Impact of the Policy Mix for Renewable Power Generation on Invention: a Patent Analysis for Germany', *15th ISS Conference of the International Schumpeter Society*, Jena

Botta, E. and Kozluk, T. (2014) Measuring Environmental Policy Stringency in OECD Countries: A Composite Index Approach, *OECD Economics Department Working Papers*, 1177.

Breznitz, D. and Ornston, D. (2013) The Revolutionary Power of Peripheral Agencies: Explaining Radical Policy Innovation in Finland and Israel, *Comparative Political Studies 46*(10):1219-1245

Bush, V. (1945) Science: The Endless Frontier, National Science Foundation.

Canada's Ecofiscal Commission (2015) The Way Forward: A Practical Approach to Reducing Canada's Greenhouse Gas Emissions.

Cantner, U. et al. (2016) Inventor networks in renewable energies: The influence of the policy mix in Germany, *Research Policy*, 45(6):1165-84.

Carbone, M. (2008) Mission Impossible: the European Union and Policy Coherence for Development, *Journal of European Integration 30*(3):323-42.
Chang, H. (1994) The Political Economy of Industrial Policy, *Macmillan*.
Chataway, J. et al. (2017) Developing and enacting transformative innovation policy. A comparative study, *8th International Sustainability Conference*, 18-21 June 2017, Gothenburg, Sweden
CML, PSI, and CSM (2008) *A framework for measuring eco-innovation: typology of indicators based on causal chains, Final report*, (ECO-DRIVE project, FP6-2005-SSP-5-A).
Coase, R (1960), The Problem of Social Cost, Journal of Law and Economics, 3, 1-44.
Coenen, L., Benneworth, P., and Truffer, B. (2012) Toward a spatial perspective on sustainability transitions, *Research Policy 41:*968–979. doi:10.1016/j.respol.2012.02.014
Costantini, V., Crespi, F., and Palma, A. (2017) Characterizing the policy mix and its impact on eco-innovation: A patent analysis of energy-efficient technologies, *Research Policy 46* (4):799-819.
Criscuolo, C., and Menon, C. (2014). Environmental Policies and Risk Finance in the Green Sector: Cross-Country Evidence. *OECD Science, Technology and Industry Working Papers 2014/01*. OECD Publishing, Paris.
Cunningham, Paul, et al. (2013) Innovation policy mix and instrument interaction: a review, *Nesta Working Paper 13/20*.
Czarnitzki, D. and Fier, A. (2002) Do Innovation Subsidies Crowd Out Private Investment? Evidence from the German Services Sector, *Centre for European Economic Research Discussion Paper No. 02-04.*
Czarnitzki, D. and Lopes-Bento, C. (2014) Innovation Subsidies: Does the Funding Source Matter for Innovation Intensity and Performance? Empirical Evidence from Germany, *Industry and Innovation 21*:380-409.
Dechezlepretre, A., Martin, R., and Mohen, M. (2014) Knowledge spillovers from clean and dirty technologies: A patent citation analysis, *Grantham Research Institute on Climate Change and the Environment Working Paper No. 135.*
del Rio, P. (2017) Why does the combination of the European Union Emissions Trading Scheme and a renewable energy target makes economic sense, *Renewable and Sustainable Energy Reviews 74*:824-34.
Department for Environment, Food, and Rural Affairs (DEFRA) (2006) Procuring the future – Sustainable Procurement National Action Plan: recommendations from the Sustainable Procurement Task Force.
Dobbs, R., Oppenheim, J., Thompson, F., Brinkman, M., and Zornes, M. (2011) Resource Revolution: Meeting the world's energy, materials, food, and water needs, *McKinsey & Company, November 2011.*
Dosi, G. (1982) Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change, *Research Policy 11*:147–162.
Duruflé, G. and Carbonneau, L. (2016) Forging a Cleaner and More Innovative Economy in Canada, *Cycle Capital Management and Sustainable Technology Development Canada (SDTC).*
Dutz M.A., D. Pilat (2014) Fostering innovation for green growth: learning from policy experimentation *Chapter 7 in: Making Innovation Policy Work, OECD Publishing, Paris.*
Edler, J. and Georghiou, L. (2007) Public procurement and innovation – resurrecting the demand side, *Research Poli*cy 36(7):949–963.
Edquist, C. and Zabal-Iturriagagoitia, J. M. (2012) Public Procurement for Innovation as mission-oriented innovation policy, *Research Policy 41*:1757-1769.

Engel, D., Rothgang, M> and Eckl, V. (2016) Systemic aspects of R&D policy subsidies for R&D collaborations and their effects on private R&D, *Industry and Innovation 23*(2):206-222.
Environment and Climate Change Canada (2017) Canadian environmental sustainability indicators: progress towards Canada's greenhouse gas emissions reduction target, *Government of Canada,* Ottawa.
Evans, P. (1995) Embedded Autonomy: States and industrial transformation, *Princeton University Press.*
Fast, S., Mabee, W., Baxter, J., Christidis, T., Driver, L., Hill, S., McMurtry, J.J., and Tomkow, M. (2016) Lessons learned from Ontario wind energy disputes, *Nature Energy 1*. doi:10.1038/nenergy.2015.28
First Ministers of Canada (2016) Pan-Canadian Framework on Clean Growth and Climate Change
Fischer, C. and Newell, R. (2008) Environmental and technology policies for climate mitigation, *Journal of Environmental Economics and Management 55*(2):142–162.
First Ministers of Canada (2016) Pan-Canadian Framework on Clean Growth and Climate Change.
Flanagan, K., Uyarra, E. and Laranja, M. (2011) Reconceptualising the 'policy mix' for innovation, *Research Policy 40*(5):702-13.

Freeman, A.M. and Haveman, R.H. (1972) Clean rhetoric and dirty water, *Public Interest 28*:58-65.
Freeman, C. (1987) Technology Policy and Economic Performance: Lessons from Japan, *Pinter*, London, UK.
Freeman, C. and Soete, L. (1997) The Economics of Industrial Innovation, Third Edition, *MIT Press*, Cambridge MA.
Foray, D., Mowery, D.C., and Nelson, R.R. (2012) Public R&D and Social Challenges: What lessons from mission R&D programs? The need for a new generation of policy instruments to respond to the grand challenges, *Research Policy,* 41(10):1697-702.
Foxon, Tim, et al. (2004) Innovation systems and policy-making processes for the transition to sustainability, *Governance for Industrial Transformation. Berlin: Environmental Policy Research Centre*, 96-112.
Foxon, T.J., Hammond, G.P., Pearson, P.J.G. (2010) Developing transition pathways for a low carbon electricity system in the UK, *Technological Forecasting and Societal Change 77*:1203–1213. doi:10.1016/j.techfore.2010.04.002
Foxon, T. and Pearson, P. (2008) Overcoming barriers to innovation and diffusion of cleaner technologies: some features of a sustainable innovation policy regime, *Journal of Cleaner Production 16*(1S1):148-61.
Foxon, T.J., Pearson, P.J.G., Arapostathis, S., Carlsson-Hyslop, A., and Thornton, J. (2013) Branching points for transition pathways: assessing responses of actors to challenges on pathways to a low carbon future, *Energy Policy 52:*146–158. doi:10.1016/j.enpol.2012.04.030
G7 Leaders (2015) Leaders' Declaration G7 Summit, June 6, 2015.
G20 Leaders (2017) G20 Leaders Declaration: Shaping an interconnected world, *G20 Germany 2017, Hamburg.*
Geels, F.W. 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, *Research Policy 31*:1257–1274.
Geels, F.W. (2004) From sectoral systems of innovation to socio-technical systems, *Research Policy 33:* 897–920. doi:10.1016/j.respol.2004.01.015
Geels, F.W. (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 and Strategic Managment 17*:445–476.
Geels, F.W. (2014) Regime resistance against low-carbon transitions: Introducing politics and power into the multi-level perspective, *Theory Culture and Society 31*:21–40. doi:10.1177/0263276414531627
Geels, F.W., Berkhout, F., van Vuuren, D.P. (2016a) Bridging analytical approaches for low-carbon transitions, *Nature Climate Change 6*:576–583. doi:10.1038/nclimate298
Geels, F.W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., Neukirch, M., and Wassermann, S., (2016b) The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014), *Research Policy 45*:896–913. doi:10.1016/j.respol.2016.01.015
Geels, F.W. and Schot, J. (2007) Typology of sociotechnical transition pathways, *Research Policy 36*:399–417. doi:10.1016/j.respol.2007.01.003
Georghiou, L., Edler, J., Uyarra, E., and Yeow, J. (2014) Policy instruments for public procurement of innovation: choice design and assessment, *Technological Forecasting and Social Change, 86*:1-12. https://doi.org/10.1016/j.techfore.2013.09.018
Gillingham, K., Newell, R.G., and Palmer, K. (2009) Energy efficiency economics and policy, *Annual Review of Resource Economics 1*:597-620.
Ghosh, S. and Nanda, R. (2010) Venture Capital Investment in the Clean Energy Sector, *Harvard Business School Working Paper 11-020.*
Geels, F.W., Verhees, B. (2011) Cultural legitimacy and framing struggles in innovation journeys: A cultural-performative perspective and a case study of Dutch nuclear energy (1945–1986), *Technological Forecasting and Societal Change 78:*910–930. doi:10.1016/j.techfore.2010.12.004
Goulder, L. H. and Schneider, S. H. (1999) Induced technological change and the attractiveness of CO2 abatement policies, *Resource and Energy Economics 21*(30)211-253.
Government of Canada (2015) Canada's INDC Submuission to the UNFCCC.
Guellec, D. and Van Pottelsberghe de la Potterie, B. (2003) The impact of public R&D expenditure on business R&D, *Economics of Innovation and New Technology 12*: 225- 243.
Guerzoni, M. and Raiteri, E. (2014) Demand-side vs. supply-side technology policies: Hidden treatment and new empirical evidence on the policy mix, *Research Policy, 44*(3):726-747. https://doi.org/10.1016/j.respol.2014.10.009

Haley, B., 2011. From staples trap to carbon trap: Canada's peculiar form of carbon Lock-in, *Studies in Political Economy 88*:97–132. doi:10.1080/19187033.2011.11675011
Haley, B. (2016) Getting the Institutions Right: Designing the Public Sector to Promote Clean Innovation, *Canadian Public Policy*
Hekkert, M., Negro, S., Heimeriks, G., and Harmsen, R. (2011) Technological Innovation System Analysis, Utrecht University
Hogan, W.W. (2014) Clean Energy Technologies: Learning by Doing and Learning by Waiting, *John F. Kennedy School of Government, Harvard University.*
Howard, P. and Sylvan, D. (2015) Expert Consensus on the Economics of Climate Change, *Institute for Policy Integrity, New York University.*
Howell, S.T. (2017) Financing Innovation: Evidence from R&D Grants, *The American Economic Review* 107*(4):1136-1164.*
Howlett, M. and Rayner J. (2007) Design Principles for Policy Mixes: Cohesion and Coherence in New Governance Arrangements, *Policy and Society 26*(4):1-18.
Howlett, M. and Rayner J. (2013) Patching vs Packaging in Policy Formulation: Assessing Policy Portfolio Design, *Politics and Governance 1*(2):170-82.
Howlett, M. and Lejano, R.P. (2013) Tales from the crypt: The rise and fall (and rebirth?) of policy design, *Administration & Society 45*(3):357-81.
IISD (2012) Procurement, Innovation and Green Growth, *International Institute for Sustainable Development.*
Jacobsson, S., Lauber, V. (2006) The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology, *Energy Policy 34*:256–276. doi:10.1016/j.enpol.2004.08.029
Jaffe, A. B. (1989) Real Effects of Academic Research, *American Economic Review 79*(5):957-970.
Jaffe, A.B., Newell, R.G. and Stavins, R.N. (2005) A tale of two markets failures: Technology and environmental policy, *Ecological Economics 54*:164-174.
Jaffe, A.B. and Stavins, R.N. (1994) The energy paradox and the diffusion of conservation technology, *Resource and Energy Economics 16*:91-122.
Janeway, W. (2012) Doing Capitalism in the innovation econom*y*, *Cambridge University Press*: Cambridge
Johnson, C. (1982) MITI and the Japanese Miracle: The Growth of Industrial Policy, 1925-1975, *Stanford University Press,* Stanford, California.
Johnstone, N., Hascic, I., and Popp, D. (2010) Renewable energy policies and technological innovation: Evidence based on patent counts, *Environmental and Resource Economics 45* (1):133–155.
Kemp, R. (2011) Ten themes for eco-innovation policies in Europe, *SAPIENS 4*(2).
Kemp, R. and Pearson, P. (2007) Final report MEI project about measuring eco-innovation, *MEI-Measuring eco-innovation project*.
Kemp, R. and Pontoglio, S. (2011) The innovation effects of environmental policy instruments — A typical case of the blind men and the elephant, *Ecological Economics*, 72 28-36.
Kemp, R. and Rotmans, J. (2005) The management of the co-evolution of technical, environmental and social systems, *Towards environmental innovation systems*, 33-55.
Kemp, R., Schot, J. and Hoogma, R. (1998) Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management, *Technology Analysis & Strategic Management 10*(2):175-98.
Kern, F., Kivimaa, P., and Martiskainen, M. (2017) Policy packaging or policy patching? The development of complex energy efficiency policy mixes, *Energy Research & Social Science 23*:11-25.
Kern, F. and Howlett M. (2009) Implementing transition management as policy reforms: a case study of the Dutch energy sector, *Policy Science 42*(4):391-408.
Kern, F., and Rogge, K.S. (2016) The pace of governed energy transitions: Agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? *Energy Research and Social Science 22*:13–17. doi:10.1016/j.erss.2016.08.016
Kern, F. and Smith, A. (2008) Restructuring Energy Systems for Sustainability? Energy Transition Policy in the Netherlands, *Energy Policy 36* (11):4093-4103
Khanberg, T., and R. Joshi, R. (2012) Smarter and Stronger: Taking Charge of Canada's Energy Technology Future, *Mowat Centre,* School of Public Policy and Governance, University of Toronto.
Klitkou, A., Bolwig, S., Hansen, T., and Wessberg, N. (2015) The role of lock-in mechanisms in transition processes: The case of energy for road transport, *Envirionmental Innovation and Societal Transitions 16*:22-37.

Kozuk, T. and Johnstone, N. (2017) Vintage Differentiated Regulations and Plant Survival: Evidence from Coal-Fired Power Plants in the OECD, *OECD ENV/EPOC/WPIEEP(2017)1.*

Kivimaa, P., Hildén, M., Huitema, D., Jordan, A., and Newig, J. (2017) Experiments in climate governance – A systematic review of research on energy and built environment transitions, *Journal of Cleaner Production*. doi:10.1016/j.jclepro.2017.01.027

Kivimaa, P. and Kern, F. (2016) Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions, *Research Policy 45:*205–217. doi:10.1016/j.respol.2015.09.008

Lasagabaster and Pilat (2014), *Making Innovation Policy Work – Learning from Experimentation*, OECD and the World Bank

Lipsey, R. and Carlaw, K. (1996) A Structuralist Assessment of Innovation Policy, *The Implications of Knowledge-Based Growth for Micro-Economic Policies, University of Calgary Press*

Lundvall (1992) National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, London: Pinter Publishers.

Loorbach, D. and Rotmans, J. (2010) The practice of transition management: Examples and lessons from four distinct cases, *Futures 42*, 237–246. doi:10.1016/j.futures.2009.11.009.

Luederitz, C., Schäpke, N., Wiek, A., Lang, D.J., Bergmann, M., Bos, J.J., Burch, S., Davies, A., Evans, J., König, A., Farrelly, M.A., Forrest, N., Frantzeskaki, N., Gibson, R.B., Kay, B., Loorbach, D., McCormick, K., Parodi, O., Rauschmayer, F., Schneidewind, U., Stauffacher, M., Stelzer, F., Trencher, G., Venjakob, J., Vergragt, P.J., von Wehrden, H., and Westley, F.R. (2016) Learning through evaluation – A tentative evaluative scheme for sustainability transition experiments, *Journal of Cleaner Production*. doi:10.1016/j.jclepro.2016.09.005

Markard, J., Raven, R., Truffer, B. (2012) Sustainability transitions: An emerging field of research and its prospects, *Research Policy 41*, 955–967. doi:10.1016/j.respol.2012.02.013

Marques, A.C. and Fuinhas, J.A. (2012) Are public policies towards renewables successful? Evidence from European countries, *Renewable Energy*, 44 109-18.

Martínez Arranz, A., (2017) Lessons from the past for sustainability transitions? A meta-analysis of socio-technical studies, *Global Environmental Change 44*, 125–143. doi:10.1016/j.gloenvcha.2017.03.007

Mazzucato, M. and Penna, C. C. R. (2014) Beyond Market Failures: State Investment Banks and the 'Mission-oriented' Finance for Innovation', *SPRU Working Paper Series, 2014–21*.

Mazzucato, M. (2016) The Green Entrepreneurial State, Science Policy Research Unit, Working paper 2015-28.

Mazzucato (2017) Mission-Oriented Innovation Policy: Challenges and Opportunities, *UCL Institute for Innovation and Public Purpose Working Paper (2017-1).*

Mazzucato, M. and Semieniuk, G. (forthcoming) Public Financing of Innovation: From market fixing to mission oriented market shaping.

McDowall, W. (2014) Exploring possible transition pathways for hydrogen energy: A hybrid approach using socio-technical scenarios and energy system modelling, *Futures 63*, 1–14. doi:10.1016/j.futures.2014.07.004

Meadowcroft, J. (2009) What about the politics? Sustainable development, transition management, and long term energy transitions, *Policy Science 42:*323–340. doi:10.1007/s11077-009-9097-z

Meadowcroft, J. (2016) Let's Get This Transition Moving!, *Canadian Public Policy 42:*S10–S17. doi:10.3138/cpp.2015-028

Miedzinski, M. et al. (2013) A short guide to assessing environmental impacts of research and innovation policy, *DG Research and Innovation*, *European Commission*.

Mowery, D. and Rosenberg, N. (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.

Mulder, P., de Groot, H.L.F.,and Hofkes, M.W. (2003) Explaining slow diffusion of energy-saving technologies; a vintage model with returns to diversity and learning-by-using, *Resource and Energy Economics 25*(1):105-126.

Narayanamurti, V., Anadon, L.D. and Sagar, A. (2009) Transforming Energy Innovation, *Issues in Science and Technology*, 26(1):57–64.

Nelson (1993) National Innovation Systems: A Comparative Analysis, Oxford University Press

Nelson, R. R. and Winter, S. G. (1985) An Evolutionary Theory of Economic Change, *Harvard University Press,* Cambridge MA.

Newell, R. G. (2010) The role of markets and policies in delivering innovation for climate change mitigation, *Oxford Review of Economic Policy*, 26 (2), 253-69.

Nicholson, P.J. (2003) The Growth Story: Canada's Long-run Economic Performance and Prospects, *International Productivity Monitor, Centre for Living Standards,* 7:3-23.
OECD (2003a) Environmentally Harmful Subsidies: Policy Issues and Challenges, *OECD Publishing.*
OECD (2003b) Policy coherence*, 27th Session on the Public Management Committee*, (GOV/PUMA(2003)4, OECD, Paris).
OECD (2010) Public procurement programmes for small firms – SBIR-type programmes, *OECD Innovation Policy Platform.*
OECD (2011) Fostering Innovation for Green Growth, *OECD Green Growth Studies.*
OECD (2014) Intelligent Demand: Policy Rationale, Design and Potential Benefits, *OECD Science, Technology, and Industry Policy Papers No. 13.*
OECD (2015a) System innovation: Synthesis report, *OECD Publishing, Paris*.
OECD (2015b) The Role of Public procurement in Low-carbon Innovation, *Background paper for the 33rd Round Table on Sustainable Development, 12-13 April 2016, OECD Headquarters, Paris.* *https://www.oecd.org/sd-roundtable/papersandpublications/The%20Role%20of%20Public%20Procurement%20in%20Low-carbon%20Innovation.pdf*
OECD (2015c) *Government at a glance 2015,* OECD Publishing, Paris. http://www.oecd-ilibrary.org/governance/government-at-a-glance-2015_gov_glance-2015-en
O'Reilly III, C.A., Tushman, M.L., (2004) The Ambidextrous Organization, *Harvard Business Review 82:* 74–81.
Papachristos, G., Sofianos, A., and Adamides, E. (2013) System interactions in socio-technical transitions: Extending the multi-level perspective, *Environmental Innovation and Societal Transitions 7:*53–69. doi:10.1016/j.eist.2013.03.002
Perez, C. (1983) Structural change and assimilation of new technologies in the economic and social systems, *Futures 15*:357–375. doi:10.1016/0016-3287(83)90050-2
Perez, C., and Freeman, C. (1988) Structural crises of adjustment, business cycles and investment behaviour, in: Technical Change and Economic Theory, Francis Printer, London.
Pigou, A.C. (1920), The Economics of Welfare, Macmillan.
Pitkänen, K., Antikainen, R., Droste, N., Loiseau, E., Saikku, L., Aissani, L., Hansjürgens, B., Kuikman, P.J., Leskinen, P., and Thomsen, M. (2016) What can be learned from practical cases of green economy? –studies from five European countries, *Journal of Cleaner Production 139*:666–676. doi:10.1016/j.jclepro.2016.08.07
Popp, D. (2003) Pollution control innovations and the clean air act of 1990, *Journal of Policy Analysis and Management 22:*641–660.
Popp, D. (2006) R&D Subsidies and Climate Policy: Is there a "free lunch"?, *Climatic Change 77*(3-4):311-341.
Popp, D., Newell, R.G., and Jaffe, A.B. (2009) Where Does Energy R&D come from? Examining Crowding Out from Environmentally-Friendly R&D, *NBER Working paper #15423.*
Rai, V., Funkhouser, E., Udwin, T., and Livingston, D. (2015) Venture Capital in Clean Energy Innovation Finance: Insights from the US Market during 2005-2014, *Social Science Research Network*.
Rainville, A. (2016) Standards in green public procurement – A framework to enhance innovation, *Journal of Cleaner Production,* 18 October 2016. https://doi.org/10.1016/j.jclepro.2016.10.088
Raven, R., Kern, F., Verhees, B., and Smith, A. (2016) Niche construction and empowerment through socio-political work. A meta-analysis of six low-carbon technology cases, *Environmental Innovation and Societal Transitions 18:*164–180. doi:10.1016/j.eist.2015.02.002
Reid, A. and M Miedzinski, M. (2008) Eco-innovation: Final Report for Sectoral Innovation Watch, *SYSTEMIC project*.
Rennings, K. (2000) Redefining innovation--eco-innovation research and the contribution from ecological economics', *Ecological Economics*, *32*(2):319-32.
Rodrik, D. (2004) Industrial Policy for the Twenty-First Century, *John F. Kennedy School of Government Working Paper Series, rwp04-047*.
Rodrik, D. (2007) Industrial Policy for the Twenty-First Century, in *One Economics – Many Recipes: Globalization, Institutions, and Economic Growth,* 99-152, Princeton University Press, NJ.
Rogge, K.S., Schneider, M. and Volker H. and Hoffmann, V.H. (2011) The innovation impact of the EU Emission Trading System — Findings of company case studies in the German power sector, *Ecological Economics 70*(3):513-23.
Rogge, K.S. and Reichardt, K. (2016) Policy mixes for sustainability transitions: An extended concept and framework for analysis, *Research Policy 45*(8):1620-35.

Rogge, K.S., Kern, F., and Howlett, M. (2017) Conceptual and empirical advances in analysing policy mixes for energy transitions, *Energy Research and Social Science*, in press, available online 24 October.
Rosenberg, N. (1982) Inside the Black Box: Technology and Economics, *Cambridge University Press,* Cambridge, UK.
Rosenbloom, D. (2017) Pathways: An emerging concept for the theory and governance of low-carbon transitions, *Global Environmental Change 43:*37–50. doi:10.1016/j.gloenvcha.2016.12.011
Rosenbloom, D., Berton, H., and Meadowcroft, J. (2016) Framing the sun: A discursive approach to understanding multi-dimensional interactions within socio-technical transitions through the case of solar electricity in Ontario, *Canada Research Policy 45:*1275–1290. doi:10.1016/j.respol.2016.03.01
Rotmans, J., Kemp, R., and Van Asselt, M. (2001) More evolution than revolution: transition management in public policy, *Foresight 3*:15–31.
Savoie, D. (2015) What is Government Good At?, *McGill-Queen's University Press*.
Scherer, F., Harhoff, D. and Kukies, J (2000) Uncertainty and the size of rewards from technological innovation, *Journal of Evolutionary Economics 10*:175-200.
Schmidt, T.S., et al. (2012) The effects of climate policy on the rate and direction of innovation: A survey of the EU ETS and the electricity sector, *Environmental Innovation and Societal Transitions 2:*23-48
Schmitz, H., Johnson, O., and Altenburg, T. (2013) Rent Management: The Heart of Green Industrial Policy, *University of Sussex Institute of Development Studies Working Paper No 418,* . http://dx.doi.org/10.1111/j.2040-0209.2013.00418.x.
Schmookler, J. (1966) Invention and Economic Growth, *Harvard University Press*, Cambridge, MA.
Schot, J., Geels, F.W. (2008) Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy, *Technology Analysis and Strategic Management 20*:537–554. doi:10.1080/0953732080229265
Schot, J. and Steinmueller, E. (2016) Framing Innovation Policy for Transformative Change: Innovation Policy 3.0, *SPRU Science Policy Research Unit, University of Sussex: Brighton, UK*,
Schwaub, K. (2016) The Fourth Industrial Revolution: what is means, how to respond, *Foreign Affairs.*
Sengers, F., Wieczorek, A.J., and Raven, R. (2016) Experimenting for sustainability transitions: A systematic literature review, *Technological Forecasting and Social Change*. doi:10.1016/j.techfore.2016.08.031
Shove, E., and Walker, G. (2007) CAUTION! Transitions ahead: politics, practice, and sustainable transition management, *Environmental Planning 39*:763–770. doi:10.1068/a39310
Simcoe, T. and Toffel, M. W. (2014) Government green procurement spillovers: Evidence from municipal building policies in California, *Journal of Environmental Economics and Management, 63*(3):411-434. https://doi.org/10.1016/j.jeem.2014.09.001
Smart Prosperity Institute (2017) Accelerating Clean Innovation in Canada, *Smart Prosperity Institute.*
Smith, Keith (2010) Innovation as a Systemic Phenomenon: Rethinking the Role of Policy, *Enterprise and Innovation Management Studies 1*:73-102.
Smith, A., and Raven, R. (2012) What is protective space? Reconsidering niches in transitions to sustainability, *Research Policy 41:*1025–1036. doi:10.1016/j.respol.2011.12.012
Smith, A., Stirling, A., and Berkhout, F. (2005) The governance of sustainable socio-technical transitions. *Research Policy 34*, 1491–1510. doi:10.1016/j.respol.2005.07.005
Sovacool, B.K. (2009). Rejecting renewables: The socio-technical impediments to renewable electricity in the United States, *Energy Policy 37:*4500–4513. doi:10.1016/j.enpol.2009.05.073
Statistics Canada (2014) Survey of Advanced Technology, *The Daily,* 11 December 2015.
Stirling, A., (2014). Transforming power: Social science and the politics of energy choices, *Energy Research and Social Science 1:*83–95. doi:10.1016/j.erss.2014.02.001
Stirling, A. (2015) Emancipating transformations: From controlling "the transition" to culturing plural radical progress, *in: Scoones, I., Leach, M., Newell, P. (Eds.), The Politics of Green Transformations, Routledge, New York,* pp. 54–67.
Taylor, M.R. (2008) Cap-and-trade Programs and Innovation for Climate Safety, *University of California Berkeley Working Paper.*
Taylor, M. R. (2012) Innovation under cap-and-trade programs, *Proceedings of the National Academy of Sciences of the United States of America,* 109(13)4804-9.
Treasury Board of Canada (2017) Horizontal Innovation & Clean Technology Review.

Turnheim, B. and Geels, F.W. (2012) Regime destabilisation as the flipside of energy transitions: Lessons from the history of the British coal industry (1913–1997), *Energy Policy 50:*35–49. doi:10.1016/j.enpol.2012.04.060
Turnheim, B., Geels, F.W. (2013) The destabilisation of existing regimes: Confronting a multi-dimensional framework with a case study of the British coal industry (1913–1967), *Research Policy 42*, 1749–1767. doi:10.1016/j.respol.2013.04.009
Turnheim, B., Berkhout, F., Geels, F.W., Hof, A., McMeekin, A., Nykvist, B., and van Vuuren, D.P., (2015) Evaluating sustainability transitions pathways: Bridging analytical approaches to address governance challenges, *Global Environmental Change 35*, 239–253. doi:10.1016/j.gloenvcha.2015.08.010
UNEP (2017) Global Review of Sustainable Public Procurement, *United Nations Environment Programme.*
United Nations (2015) Transforming our World: The 2030 Agenda for Sustainable Development.
United Nations Framework Convention on Climate Change (UNFCCC) (2016) Aggregate effect of the intended nationally determined contributions: an update, *Conference of Parties Twenty-second session.*
Unruh, G.C. (2000) Understanding carbon lock-in. *Energy Policy 28*:817–830.
Unruh, G.C. (2002) Escaping carbon lock-in, *Energy Policy 30*:317–325.
Uyarra, E. (2016) The impact of public procurement of innovation, in Edler, J. and Gok, A., *Handbook of Innovation Policy Impact, EU-SPRI Forum on Science, Technology and Innovation Policy series,* Edward Elgar Publishing
Uyarra, E., Edler, J., Garcia-Estevez, J., Georghiou, L., and Yeow, J. (2014) Barriers to innovation through public procurement: A supplier perspective, *Technovation*, 34:631-645.
Uyarra, E., Shapira, P. and Harding, A. (2016) Low carbon innovation and enterprise growth in the UK: Challenges of a place-blind policy mix, *Technological Forecasting and Social Change*, 103 264-72.
Uyarra, E. and Flanagan, K. (2010) Understanding the Innovation Impacts of Public Procurement, *European Planning Studies 18*(1):123-143.
Van den Bergh (2012) Effective climate-energy solutions, escape routes and peak oil, *Energy Policy 46*:530-536.
van den Bergh, Jeroen C.J.M. (2013) Environmental and climate innovation: Limitations, policies and prices, *Technological Forecasting and Social Change* 80(1):11-23.
Verbong, G., Geels, F.W., and Raven, R. (2008) Multi-niche analysis of dynamics and policies in Dutch renewable energy innovation journeys (1970–2006): hype-cycles, closed networks and technology-focused learning, *Technology Analysis and Strategic Management 20:*555–573. doi:10.1080/09537320802292719
Vollebergh, H. (2007) Differential Impact of Environmental Policy Instruments on Technological Change: A Review of the Empirical Literature, *Tinbergen Institute Discussion Paper TI 2007-042/3*.
Weber, K. Matthias and Harald Rohracher (2012) Legitimizing research, technology and innovation policies for transformative change, *Research Policy*, 41(6):1037-47.
Whitley, S. and van der Burg, L. (2015) Fossil Fuel Subsidy Reform: From Rhetoric to Reality, *The New Climate Economy and Overseas Development Institute Working Paper.*
Williams, J. (2016) Can low carbon city experiments transform the development regime?, *Futures 77*:80–96. doi:10.1016/j.futures.2016.02.003
WWF/Cleantech Group (2017) The Global Cleantech Innovation Index 2017.

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