Smart Prosperity Institute

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ACCELERATING CLEAN INNOVATION IN CANADA

Written by:
Stewart Elgie and
Michelle Brownlee

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

Key Messages

- The global demand for clean innovation – new technologies, products and practices that improve environmental performance – is rapidly growing. Accelerating the pace of clean innovation in Canada is not only an important tool for meeting climate and environmental goals, it also represents a critical economic opportunity across all Canadian sectors.
- Canada's cleantech sector can tap into a fast-growing global market that is expected to be worth as much as C$2.5 trillion by 2020. Resource and manufacturing sectors can also gain market advantage through clean innovation. For example, McKinsey estimates that improvements in energy and resource efficiency will represent a C$3.8 trillion economic opportunity by 2030.
- Canada performs comparatively well in the early stages of clean innovation, such as R&D. But our performance drops off increasingly as potential clean innovation moves towards commercialization and market deployment – where the majority of jobs and wealth are created. Canada's share of the global cleantech market has fallen from 2.0% to 1.3% since 2005 – a 41% decline.
- Entrepreneurs, researchers and investors generate clean innovation. But government has also played a key role in the development of almost every major new technology of the past century, from smart phones to the oil sands.
- Government action is needed to address the "knowledge spillover" market failure that results in an under-supply of new inventions generally. *Clean* innovation faces an additional market failure in the form of "environmental externalities" – because market prices do not reflect environmental harm, there is little economic reward for most pollution-reducing innovations.

- This double market failure, plus other barriers, means that government involvement is particularly important to catalyze clean innovation. But it must be done wisely, through targeted measures that reduce market uncertainty and unleash private initiative and investment to carry new technologies through to market.
- Innovation is a *system*, which includes research, development, and ultimately commercial deployment and diffusion. This Policy Brief identifies four policy areas that must be used in combination to accelerate clean innovation in Canada: (1) PUSH policies that drive new ideas, (2) PULL policies that stimulate markets, (3) GROW policies that help ideas develop into marketable products, and (4) STRENGTHEN policies that make the system more effective and resilient.
- Canadian governments at all levels recently have begun to make real progress in building this policy architecture. For example, the Pan-Canadian Framework on Clean Growth and Climate Change, signed in December by First Ministers, and the latest federal budget set out a series of new policies, programs and investments aimed at boosting low-carbon innovation. The challenge now is to turn these commitments into action, while continuing to flesh out other key parts of the clean innovation policy framework. This will require a sustained commitment over a number of years, and close coordination between all governments, the private sector, and civil society.

"Combined with a strong entrepreneurial ecosystem, we have a maturing cleantech sector with a healthy number of market-ready companies poised to compete globally and deliver strong export revenues in large overseas markets."

– Advisory Council on Economic Growth, February 2017[2]

THE ISSUE

The world is facing unprecedented and growing environmental challenges. At the same time, the pace of technological change to address those challenges is accelerating, offering both environmental solutions and economic opportunities.

Canada has joined other governments from around the world in committing to address these challenges. The Paris Agreement (2015) marks an unprecedented global commitment by governments to tackle climate change. It joins other pivotal agreements related to biodiversity loss, water security, and air quality, among others.

These global commitments reflect a new economic imperative. Nations and businesses are seeking new ways of generating economic growth that put less strain on the planet. Achieving this means accelerating clean innovation – that is, new technologies, products and business practices that improve environmental performance.

Accelerating clean innovation across all sectors of the economy represents a two-pronged opportunity for Canada. It can help meet environmental commitments as well as secure competitive economic advantages that grow the economy and create jobs.

When it comes to climate change, the Pan-Canadian Framework on Clean Growth and Climate Change indicates that existing climate mitigation measures combined with those announced in the Framework will reduce Canada's projected 2030 emissions from 742 Megatonnes (Mt) to 567 Mt, leaving a gap of 44 Mt to be obtained through other measures if Canada is to achieve its target of 523 Mt.[1] Accelerating clean innovation will be critical for closing this gap, reducing emissions reduction costs, and achieving climate objectives.

But equally important, accelerating clean innovation across all sectors of the economy also sets Canada up for being a leader in an increasingly lucrative global market for resource-efficient, low-pollution, and particularly low-carbon technologies.

This Policy Brief defines the clean innovation opportunity for Canada and begins to evaluate Canada's current performance, explore the different drivers and stages of the clean innovation system, and explain the role for targeted government interventions to catalyze clean innovation across all sectors of the economy.

Perhaps most importantly, this Policy Brief aims to provide a framework within which governments and stakeholders can understand the many and interrelated drivers of a vibrant clean innovation system. This is important – there has been lots written on individual elements of the clean innovation system and Canada's performance in it – but to effectively choose where to intervene and spend scarce government resources requires an understanding of the system as a whole, including where its strengths are as well as its weaknesses.

Smart Prosperity Institute's findings are informed by over two years of work on clean innovation, including a conference, two workshops, in-depth studies, and over 40 interviews with a broad cross-section of Canadian and international experts in clean innovation. This Brief forms the beginning of a broader work program on clean innovation. Future Smart Prosperity Institute work will explore in more depth the particular challenges and policy implications for different parts of Canada's clean innovation system, based on the model presented in this Policy Brief.

CLEAN INNOVATION: A GLOBAL ECONOMIC OPPORTUNITY

According to some of the world's most respected economic and business authorities, countries and companies that excel at clean innovation and efficient resource use will be increasingly rewarded in global markets.[3] These rewards are borne out by market projections for different economic sectors.

The value of the global cleantech market alone is projected to double in size by 2020, growing to C$2.5 trillion[4] (bigger than Canada's annual GDP). This growth represents an opportunity for Canada's cleantech sector, which currently owns 1.3% of global market share.[5]

Market projections point to growth in clean innovation leading to opportunities across the economy. For example, 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.[6] For Canada's oil & gas sector this could bolster a market for carbon-capture-and-storage (CCS) technologies, where Canada has world-leading expertise having pioneered two of the world's 15 currently operating large-scale CCS projects.[7] And, for Canada's forestry industry, which has already cut water pollution by 70% and air pollution by 52% from 2005-2015,[8] it could ramp up new opportunities in wood pellet manufacturing for bioenergy, for example. Cleantech also represents an opportunity for other

Box 1

Growing Environmental Challenges Need Innovative Solutions

With global temperatures set to rise beyond the 2°C target even with current national commitments, **climate change** may be the most urgent environmental pressure, but it is not the only one. **Water scarcity** currently affects more than 40% of the world's population, including every single continent. **Urban air pollution** is on the rise globally, with more than 80% of the world's city-dwellers living with air quality that exceeds the World Health Organization's limits. **Biodiversity declines** have reached historic levels. According to WWF's 2016 Living Planet Report "the number of mammals, birds, reptiles, amphibians and fish across the globe is, on average, less than half the size it was 40 years ago," driven by a number of causes including habitat loss and fragmentation.

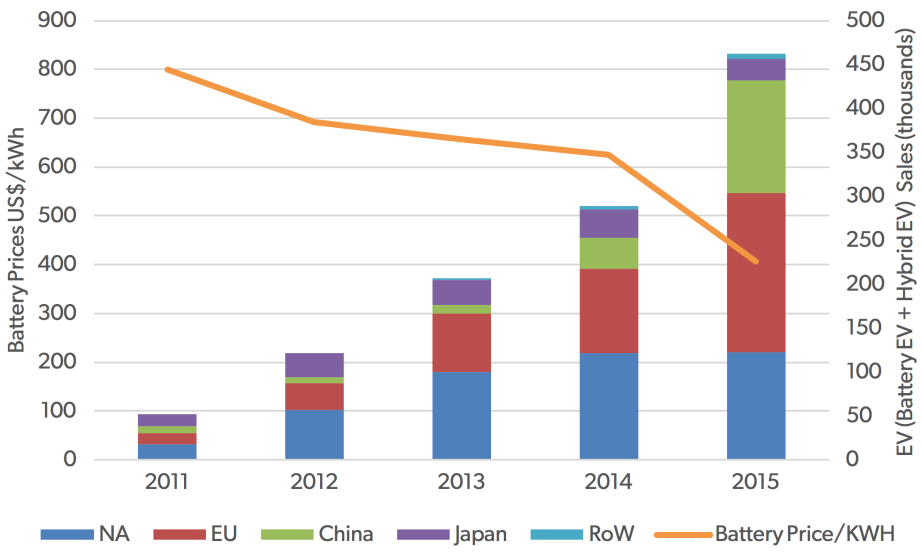
These findings are informed by over two years of work on clean innovation, including a conference, two workshops, in-depth studies, and over 40 interviews with Canadian and international experts.

Canadian sectors, such as mining. Some estimates see demand for rare earth elements – which many clean technologies depend on – rising by as much as 2,600% by 2025.[9]

Meanwhile, an estimated US$90 trillion is also projected to be invested worldwide by 2030 in new infrastructure for urban, energy and resource systems to lay the foundation for a global clean economy.[10] By showing leadership in building clean infrastructure at home, Canada can give its domestic firms the advanced skills and experience to tap into this massive global economic opportunity.

This growing global economic opportunity for clean innovation is more than an abstract prediction. The market trends are already visible. Take the electric vehicle (EV) market, for example. Breakthrough innovations are making EVs more affordable and more accessible. From 2011-2015, EV sales increased by more than 7.5 times while estimates suggest that sales will hit 41 million vehicles by 2040.[11] This would represent 35% of all new vehicle sales. This rapid growth is driven by process improvements that have seen EV battery costs fall by nearly half over the same period.

Figure 1. Total Electric Vehicle (EV) Sales and Battery Prices



Source: Bloomberg New Energy Finance (2016)[12]

The solar power industry shows a similar trajectory. Globally, solar installations have risen by 58% per year on average since 2010.[13] This growth has been spurred by solar innovations that have steadily lowered technology costs—the cost of photovoltaics (PVs) has dropped on average 10% per year since 1980, a trend that experts predict will continue.[14] According to Bloomberg New Energy Finance, solar is expected to be the lowest-cost electricity generation technology in most countries by 2030.[15]

Box 2

The Cleantech Market Boom

US$80 billion: Estimated size of the energy-efficient vehicle market by 2020

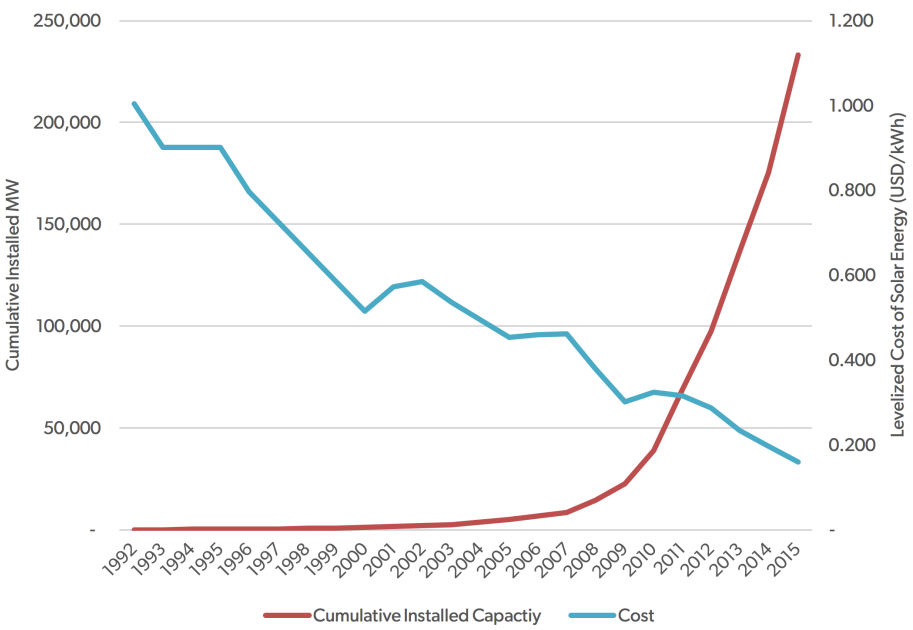
US$83 billion: Estimated value of the renewable chemical market by 2018

US$55.4 billion: Estimated global market for water treatment technologies by 2020

US$221 billion: Estimated global investment in energy efficiency in 2015

30%: Estimated growth in the market for smart homes and buildings by 2020

Figure 2. Solar Power Installations and Costs



Source: Data courtesy of the Pembina Institute (2016)[16]

Electric vehicles and solar power are only two examples of global clean innovation trends. Advances in energy storage technology, methane emissions mitigation, bio-plastics, renewable chemicals, bio-fuels, and water treatment technologies, among others, all represent burgeoning markets with large forecasted growth for the years ahead.

The overall pace of clean innovation is accelerating. Patents for innovations in clean technologies—like wind, solar, and carbon capture and storage—are outpacing technology patents in almost all other sectors.[17] Six out of the World Economic Forum's 10 emerging technologies are related to addressing climate change and other environmental challenges.[18]

These new frontiers are not isolated to the cleantech sector. The clean innovation opportunity applies across all parts of the economy. It is giving rise to new industries, while at the same time rewarding traditional industries such as resource development, manufacturing and agriculture for making existing products more efficiently and creating altogether new products.

Clean innovation can help the environment while producing the next generation of jobs. The Canadian cleantech sector, for instance, has seen continual job growth since tracking began in 2011 – with an average annual growth rate of 12.7% from 2011-2014 – and alone currently accounts for 55,600 jobs.[19] The job creation opportunities could be even greater in other sectors. For example, McKinsey estimates that innovation in Canada's energy sector could add up to 60,000 new jobs per year by 2020, while contributing up to C$9 billion/year in incremental GDP.[20]

Box 3

Clean Innovation Defined

Clean innovation includes new technologies, products, and business practices that improve environmental performance. Clean innovation can be advanced in all sectors of the economy, from traditional resource sectors, to manufacturing, to services.

Clean technology - or cleantech - is the sector of the economy focused exclusively on developing next-generation green innovations such as renewable energy systems, biochemicals, or emission-free vehicles.

Box 4

Types of Innovation

'Innovation' is a broad term that encompasses many different kinds of innovation – both technological and behavioural – such as:

Disruptive innovation fundamentally changes how we do things (like the internet), and even creates opportunities to do new things never before imagined. It can include new technologies, new business models, new market opportunities or new value propositions for existing technologies.

Technological innovations replace the tools of the past with the tools of the future, for example, of the shift from incandescent to fluorescent and then to LED lighting. The end product is the same: light. But the new technologies used to create those valued products have a very different environmental impact and open the door for efficiencies, cost-savings, and new economic opportunities.

Systemic innovation is about new forms of interaction between diverse players in the economy and new ways of deriving and providing value. Ride-sharing apps, for example, are using smart phone technology to significantly transform, and potentially shrink the footprint of, transportation while creating a new business model and opportunity.

Incremental innovation refers to improvements in existing technologies or processes that increase efficiency and lower environmental impact. The advent of more fuel-efficient cars and energy smart appliances are key examples.

Is Canada Meeting its Clean Innovation Potential?

Canada has all of the ingredients needed to become a leading supplier of clean innovation, meeting both our environmental commitments and the global economic opportunity. According to Dominic Barton, Global Managing Partner of McKinsey & Company and Chair of Canada's Advisory Council on Economic Growth, "Canada has an unparalleled mix of resources to deal with the implication of these global trends. We are a leader in natural resources and energy production. We have a skilled labour force… We have a strong financial system that helped us survive the financial crisis remarkably well. Canada has never been in a better position to be a global leader."[21]

So how is Canada doing when it comes to the development, deployment and adoption of clean innovation? Available evidence suggests a mixed record, with stronger performance in the earlier stages (such as research) and weaker performance in the later stages (like commercialization).

However, measuring clean innovation is not simple. There is no single established global benchmark, available metrics sometimes present conflicting information, and there are recurring data and analytical gaps. But there are some valuable sources of data and metrics.

Canada's performance on innovation in general

Reviewing Canada's general innovation performance is an important place to start. Current research outlining broader trends suggests that Canada is not meeting its potential. A landmark study from 2011, *Innovation in Canada – A Call to Action*[22] (widely known as the Jenkins report), put forth significant evidence that, while Canada has substantial public research muscle, it has failed to translate this strength into marketable application.* The report pointed to challenges such as low business enterprise research and development investment (BERD) and an unnecessarily complex innovation funding system. The report offered a number of recommendations, some of which were implemented in the subsequent five years[23] (and more in the recent federal budget). However, Canada's overall innovation performance remains underwhelming, a point underscored by the first report from the Advisory Council on Economic Growth in October 2016.[24]

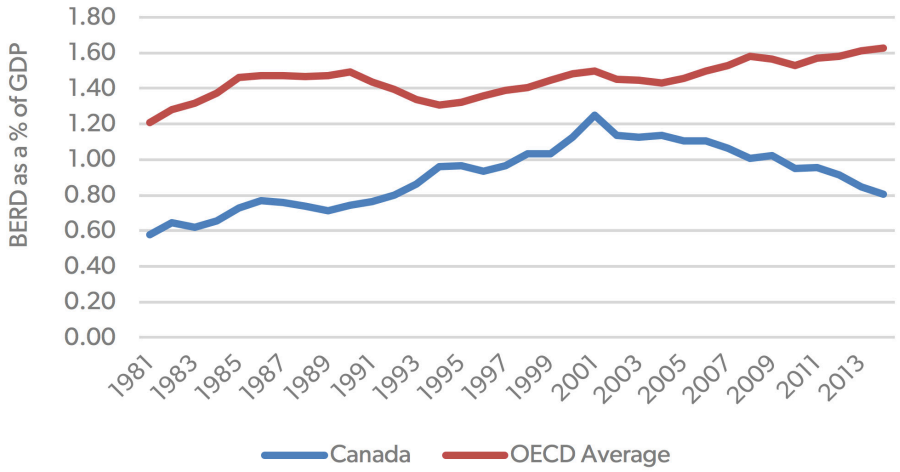
Also, in 2015, the Conference Board of Canada compared Canada's general innovation performance with peer countries and gave Canada a grade of C, ranking it 9th out of 15 comparators.[25,**] The research finds that while Canada's innovation performance has improved slightly in the past few years thanks to strengthened venture capital (an indicator of entrepreneurial ambition), Canada has seen declines in already low BERD, slow growth in patents, and declining public research and development (R&D) expenditure.

Finally, the World Economic Forum similarly ranked Canada "lukewarm" on its Global Competitiveness Index—putting Canada 15th overall (or just above average for an advanced economy) and ranking it significantly lower on specific metrics, including capacity for innovation, company spending on R&D, and government procurement of advanced technology products.[26]

* The innovation discussion was continued in 2013 with *Paradox Lost: Explaining Canada's Research Strength and Innovation Weakness*, which told a similar story of Canada's failure to capitalize on early research strength.

** Similarly, Internationally, the World Intellectual Property Organization in conjunction with Cornell and INSEAD have published the Global Innovation Index, this year the index ranks Canada at 15 among 128 countries.

Figure 3. Business Enterprise R&D Spending



Source: OECD (2015)[27]

According to the Conference Board of Canada, this trend persists across sectors: "[w]ith few exceptions, Canadian businesses across sectors have lower BERD intensity than their OECD peers."[28] BERD is important not only for its contribution to innovation, but because it reflects business's commitment to innovation.

The causes and solutions to Canada's innovation inertia are not all clear. As the Conference Board and others like the Council of Canadian Academies have pointed out, the story seems to be one largely of business being sluggish on innovation and, in particular, poor results when it comes to commercialization. As the Council of Canadian Academies notes, Canadian businesses, on the whole, have been only as "innovative as they have needed to be" and no more.[29]

Canada's clean innovation performance

Clean innovation can be even more challenging to measure than general innovation. However, a combination of broad and specific metrics can provide important insight into Canada's clean innovation performance.

The Global Cleantech Innovation Index, published by World Wildlife Fund and the Cleantech Group in 2014, examines a series of factors that drive innovation in general and clean innovation in particular.[30] Out of 40 countries, Israel, Finland, USA, Sweden, and Denmark ranked as top performers, well ahead of the rest of the pack. Canada ranked fairly well in the overall index, performing best in the area of general innovation inputs. On clean innovation specifically, Canada ranked 10th at the early stages, 15th at the later stages, and 17th for clean innovation drivers overall, placing it near the back of the pack among the most developed nations. Uncertain government policies, lack of funding, and low cleantech company revenues drive these lower rankings. Similar findings emerged from Smart Prosperity Institute's interviews with over 40 clean innovation experts and practitioners: Canada does fairly well at R&D, but poorly at the commercialization and deployment of clean innovation – which are the stages where most wealth and jobs are created.

Box 5

The Importance of BERD

Business Enterprise R&D (BERD) represents the level of firm investment in the early stages of innovation, measuring the quantity - but not the quality - of investment. Canada's BERD expenditure has steadily declined since 2001, while spending by peer countries has steadily grown.

These insights may help to explain why Canada's share of the global cleantech market has fallen by 41% since 2005, to a 1.3% market share. According to Analytica Advisors, Canada's clean technology firms had estimated revenues of C$11.63 billion in 2014, almost unchanged from 2013. On the positive side, Analytic Advisors' research finds that clean technology firms do very well at securing exports (over half of their sales), generating employment (55,600 jobs) and investing an impressive 10% of their revenue in research.[31]

Looking at the different stages of clean innovation, a number of metrics provide additional insight into Canada's performance.

Starting with early stage research, publications and patents are important metrics. Canada consistently ranks well in generating academic publications, including in earth and environmental sciences.* Canada's academic publications related to clean technology, proportionally, are about 1.5 times higher than those of the US.[32] When looking at how publications are converted into patents, however, the reverse is true. Overall, there are 2.3 times as many academic clean technology patents per capita in the US than in Canada. Looking at industrial clean technology patents, Canadian patents are roughly on par with US patents relative to the size of their economies. However, a 2016 report by Cycle Capital and Sustainable Development Technology Canada (SDTC) finds that, in most sectors, the majority of the top 15 patent assignees (i.e., owners) are non-Canadian multinationals. In a nutshell, Americans convert clean technology research into patents more successfully than Canadians do.[33]

Looking at the translation 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.[34]

In terms of growing Canadian clean technologies, venture capital investment is a telling metric. The Cleantech Group's 2016 study found Canada ranks second only to the US in dollars of venture investment relative to GDP.[35] The study by Cycle Capital and SDTC finds that, over the period 2010-2016, "relative to the size of the economies, the number of VC rounds in Canada is comparable to that in the US (9.8%), but round size is about half (56%) so that the total amount invested is about half as well (5.5%)."[36] Both the Cleantech Group study and the SDTC and Cycle Capital study found that the Canada-US gap in round size is wider in later stage financing. This suggests that Canada is falling short when it comes to financing the scale up and commercialization of clean technology firms.

The evidence also suggests that Canadian businesses lag in adopting clean technologies. For example, Statistics Canada surveyed firms on their adoption of four different kinds of advanced technologies, and found that clean technology adoption was by far the lowest. While a large portion of Canadian firms adopted advanced technologies in the areas of logistics (43.3%), design and fabrication (38.4%), and business intelligence (29.2%), only 9.9% adopted clean technologies (air, energy, water or waste).[37] Our interviews suggested that this low adoption rate could be due in part to the relatively low prices of energy, water and waste disposal in Canada.

Canada is falling short when it comes to financing the scale up and commercialization of clean technology firms.

* This finding of strength in early research is consistent with the preliminary data analysis of The Expert Panel on the State of Science and Technology and Industrial Research and Development in Canada, which shows that in earth and environmental sciences, Canada outperforms the G7 average (though with a slight recent decline). Source: Council of Canadian Academies (2016) Preliminary Data Update on Canadian Research Performance and International Reputation.

While these numbers do not provide cross-national comparisons, there is anecdotal evidence pointing in the same direction. For example, in 2015, electric vehicles represented only 0.4% of new car sales in Canada, behind the 0.7% market share in the US,[38] and far behind the world leader, Norway, where EVs represented 22% of all new car sales.[39] Similarly, Canada lags behind most peer countries in solar and wind power generation (as a percentage of all power), although some provinces such as Ontario are closing this gap, and others already have significant clean energy resources in hydroelectricity.[40]

So, as the global clean innovation race heats up, how is Canada doing in relation to major competitors? Not well enough. The available evidence – strongly supported by the findings of the interviews undertaken in our clean innovation research – shows that Canada is strong in the early stages (R&D), slows down in the middle (turning ideas into companies and growing those companies), and stumbles towards the finish line (commercialization and deployment). We have the foundational strengths and skills to succeed, but are not making the most of them.

The clean innovation opportunity will not wait. As the world rapidly embraces low-carbon and other resource-efficient, low-pollution solutions, Canada cannot afford to fall behind. To seize this growing global economic opportunity, and meet our climate and environmental commitments, Canada must move swiftly to boost clean innovation performance.

Canada's governments have begun to rise to this challenge, including with the recent Federal Budget and the Pan-Canadian Framework on Clean Growth and Climate Change, as discussed later in this Brief. But first it is worthwhile to provide an overview of how clean innovation happens, what drives it, and where and why government intervention may be needed.

The available evidence shows that Canada is strong in the early stages of clean innovation, slows down in the middle, and stumbles towards the finish line. We have the foundational strengths and skills to succeed, but are not making the most of them.

SEIZING THE CLEAN INNOVATION OPPORTUNITY

A Model for Understanding Clean Innovation

Accelerating clean innovation requires identifying the right places for government intervention and designing smart policies, which in turn requires an understanding of how clean innovation happens. What drives and guides the search for new ideas and inventions? How do these inventions get developed into commercially viable products? And where is government help most needed to remove barriers and create incentives to foster clean innovation?

Innovation is complex – a product of many different forces. A number of different models help explain the theory of how innovation works. Three of the most commonly cited ones are described below. These are models for general innovation, which can then be adapted for a clean innovation context.

Innovation is a complex system with a number of interacting forces. Two of those include a 'push' force, whereby new ideas and inventions are generated through R&D, and a 'pull' force, whereby societies and markets determine which of those inventions have value.

The Stages or "Pipeline" Model

Dating back to 1945, the linear or "pipeline" model of innovation is the foundation for much of the language and structure we find used in innovation discussions today.[41] It conceives of the process of innovation as a pipeline, with new ideas and technologies fed into one end and commercially marketable innovations coming out the other end. It identifies sequential stages for innovation: (1) research and development (R&D), to (2) demonstration, to (3) deployment, and ultimately to (4) diffusion to the market. While there are variations of the Pipeline Model that use different labels for each phase, or break these phases down differently, they all share the same basic principle – innovation as a mainly linear, sequential process.

The Systems Model

The Systems Model differs from the linear model in that it emphasizes the interactions between various actors in the economic system – for example the relationships between firms, universities and polytechnics, research labs, and technology users. This perspective emphasizes the role of interactive learning across the stages described by the linear model.[42] Users and producers interact and co-develop innovations, taking lessons from demonstrations or market entry and feeding them back towards defining problems for basic research and applied science. The Systems Model acknowledges that information flows in different directions and that technologies can develop through pathways that are not necessarily linear.

The Evolutionary Economic Geography Model[43]

This model builds on both the Stages and the Systems models, but focuses on regional interactions as determinants for technological pathways. Economies tend to evolve differently in different regions, due to particular strengths (such as resources, skills, access to markets, etc.) or historical factors, and this has implications for potential innovation pathways. This theory adds a spatial and contextual perspective, grounding innovation in real places in real time, which can be critical to policymakers concerned with issues of regional prosperity and competitiveness.

While these models accentuate different aspects of innovation, they are compatible. It is possible to see them as three layers, each layer adding depth and complexity to the one beneath it. The Stages Model sets out the basic stages of innovation. The Systems Model adds the complexity of the real-world interactions that take place between these stages and actors. And the Evolutionary Economic Geography Model adds the further dimension of space and context, showing how various stages differ by region, by sector, or by technology. [For a more in-depth discussion of innovation models, see Haley and Elgie, 2016.[44]]

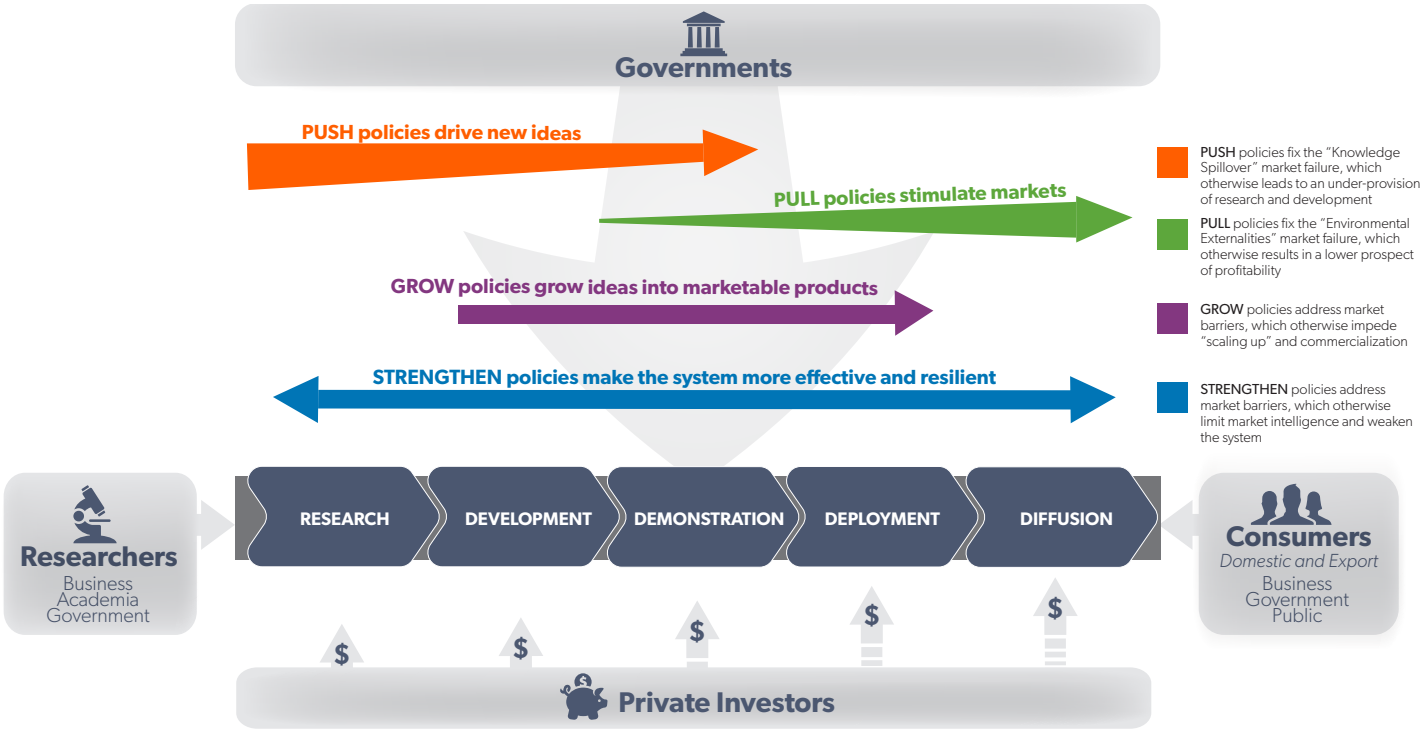
To show how clean innovation happens, we begin with a model that is similar to the Stages Model (see Figure 4). This model shows the main stages or components of clean innovation as well as the underlying forces and key actors involved.

Central to the model is the notion that innovation involves two major forces: a *push* force, whereby new ideas and inventions are generated through R&D (public and private), and a *pull* force, whereby societies and markets determine which of those inventions have value, and whereby the successful inventions secure investment, initial commercialization and use, and eventually broader diffusion to both domestic and export markets.

Most innovations go through the stages identified in the Stages Model, though not always in the same sequence and sometimes with varying emphasis on different stages. Some technologies, for example nuclear fusion, require a bigger than usual push on basic research; others, such as bio-based chemicals, need a major investment to support demonstration and scale up; while others, such as advanced thermostats or car sharing systems, face a more critical challenge in deployment and diffusion.

Figure 4 also shows the key actors involved in clean innovation. Academic researchers are involved mainly in the early stages. Consumers – both Canadian and foreign – enter at the final stages. Firms and entrepreneurs are active throughout, from private research to technology development to ultimate commercialization and deployment. Traditionally, Government has been seen as playing a larger role in the earlier stages, particularly by funding R&D (to correct "knowledge spillovers", explained below); then, as technologies are developed and move closer to market, Private Investors take over and play a larger role. This is one important way in which clean innovation is different from general innovation: it faces additional barriers such as "environmental externalities". Because of this important difference, governments must play a more active role in stimulating the *pull* force. This will be discussed further below.

Figure 4. The clean innovation system and how government and other actors influence it



*No single model captures all of the complexities of the innovation system. We use this simplified Stages Model to focus on the main forces and actors involved in clean innovation.

For the sake of simplifying the model, the arrows in this Clean Innovation Model point in one direction. But in reality the information flows can be multi-directional and there are interactions and feedback loops among all these actors and stages in the clean innovation process. Similarly, while not shown in this figure, the complete system fits within a real-world context that can vary by region and jurisdiction as well as for different types of technologies. Functions like knowledge creation and diffusion, entrepreneurial experimentation, infrastructure support, and resource mobilization are critical considerations within this model, as is the importance of having accurate clean innovation data at all stages and for all sectors, along with vibrant knowledge clusters, incubators and exchanges.

Market Failures and Market Barriers to Clean Innovation

Understanding the particularities of the clean innovation system – including where it is working well and where it is falling short – is critical for directing government interventions to the right places and to design them for maximum effectiveness. Using the above Clean Innovation Model, it is possible to break clean innovation into stages in order to identify where there are market failures and other barriers that impede the development, deployment and adoption of clean innovation. Some of these market failures and barriers apply to innovation in general, while others are unique to clean innovation in particular.

Knowledge Spillover Market Failure

Looking at the earliest stages of research and development, clean innovation is not unlike other forms of innovation. In these early stages, when researchers discover something new, their findings and the new knowledge they create are generally available to anyone. This means at least part of their findings "spill over" to benefit other researchers, firms or sectors. In other words, innovators are not always able to capture the full value of their discoveries. This **knowledge spillover market failure** is well documented and leads to an under-provision of research and development.[45,46] As a result, innovation – which stands to benefit everyone – occurs at lower than optimal levels. This is true for all kinds of innovation, although there is evidence to suggest that clean innovation suffers from even greater spillovers.[47]

Governments frequently intervene to address this market failure. As part of Smart Prosperity Institute's clean innovation work program, future research will look specifically at PUSH policies, which are those that stimulate and support the generation of new ideas, for instance through post-secondary research funding, investment in government labs, and incentives for private research.

Environmental Externality Market Failure

Once past the R&D stage, new ideas and inventions typically depend on market demand and the prospect of profit to pull them through to commercialization. New medicines, faster-growing wheat, smarter smart phones – these inventions succeed because customers are willing to pay more for them, or because they lower production costs. This clear prospect of profit is what attracts investors and businesses to finance their commercialization and deployment, getting the inventions through the final stages of the innovation system.

The difference for clean innovation is that the benefits produced – cleaner air and water, lower greenhouse gas emissions, or less waste – are ones that normally have little or no market value, because markets fail to put a price on environmental harm. As a result, there is generally little incentive to invest in or develop such products. The end result is that too few clean innovations are produced and that the market fails to

The public policy challenge for clean innovation is to address both the knowledge spillover market failure and the environmental externality market failure concurrently.

deliver the environmental solutions that society needs. This is the **environmental externality market failure**, and it is a distinct and fundamental challenge faced by most types of clean innovation.*

To correct this market failure, there is a greater role for governments to introduce PULL policies, which help stimulate market demand for clean innovation – for example tax credits for technology adoption, pollution pricing, smart environmental regulations, or targeted procurement policies. Future work in our clean innovation work program will look specifically at such PULL policies.

Together, the knowledge spillover failure and environmental externality failure are referred to as a **double market failure**, making clean innovation distinct from innovation more generally. This creates the public policy challenge: to address both the knowledge spillover market failure and the environmental externality market failure concurrently.

Market Barriers

In addition to the double market failure that impedes clean innovation, there are a number of additional market barriers that create risk and uncertainty and that discourage private investment. Some of these market barriers are summarized below.

Table 1. Market Barriers Impeding Clean Innovation

Barrier	Where it Occurs	Description
Technology risk and barriers of information	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, the financial community sees extra investment 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. 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	Demonstration and 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. This combination of high capital needs and longer return periods can make financing a bigger challenge than in other sectors, such as information technology.[48]
Infrastructure risk	Across the entire system	For many clean technologies, successful deployment depends on changes to existing public infrastructure platforms (renewable energy and smart grids, high speed trains and rail systems, clean water technology and sewage plants). Financing these technologies is inherently risky because the path to growth and profitability depends on large-scale government investment in new forms of infrastructure – which private investors cannot predict.
Lack of policy congruency and dependence on multiple policy regimes	A lack of policy congruency can impact the entire system	Clean innovation is dependent on many policies, including those that target different stages of technology readiness, different economic sectors, different technologies and/or different types of companies. Further, different policy regimes – from trade policy 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.

* Some clean innovations do create benefits that have a market reward. For example, energy saving devices reduce energy costs. But even those cost savings still do not reflect all of the product's benefits, such as reducing air pollution or greenhouse gases, which are normally unpriced.

	Trade and competitiveness policies impact deployment and diffusion Intellectual Property (IP) policies impact early phases (R&D)	In particular, two policy regimes of note include trade policy and IP policy. Improved competition policies – including those around taxation, immigration, trade, and small and medium-sized enterprise (SME) support – have been cited as a means of supporting innovation.[49] Policies to support increased trade exposure can present the opportunity for firms to exploit increased economies of scale and spur innovation through stiffer product market competition and more rapid diffusion of best practices to domestic producers.[50] IP rights and copyright law can also either support or deter innovation. These policy regimes are particularly relevant for clean innovation, where the economic opportunity is largely driven by export markets, and where the spillover effects are larger than for most forms of innovation (which will be discussed further in the research under this work program).
Split incentives	Deployment and diffusion stages	In clean technology adoption, incentives between the technology adopter and end user may misalign. Principle-agent problems, in which one person can make choices on behalf of another – such as where a building owner is responsible for the choice of home heating technology, but the tenant is responsible for paying bills – can slow widespread adoption of investments that would have positive returns. This is particularly relevant at the adoption stage for technologies like energy efficiency and water conservation, where solutions are often cost effective with short payback periods and yet have not penetrated the market as would be expected.
Policy uncertainty	Across the entire system	Unlike other technologies, much of the demand for clean technologies is driven by government policies (pollution pricing, regulations, public procurement).[51] 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.

A Role for Well-designed Public Policy: Push, Pull and more

While most innovations are ultimately developed by private actors, governments have an important role to play in removing barriers and providing incentives that catalyze private innovation. In fact, most of the major commercial technologies developed over the past century have involved significant government support[52] – such as the smart phone,[53] and the technologies that unlocked Canada's oil sands.[24] Government's role is particularly important in the area of clean innovation, for reasons explained above.

Most of the major commercial technologies developed over the past century have involved significant government support.

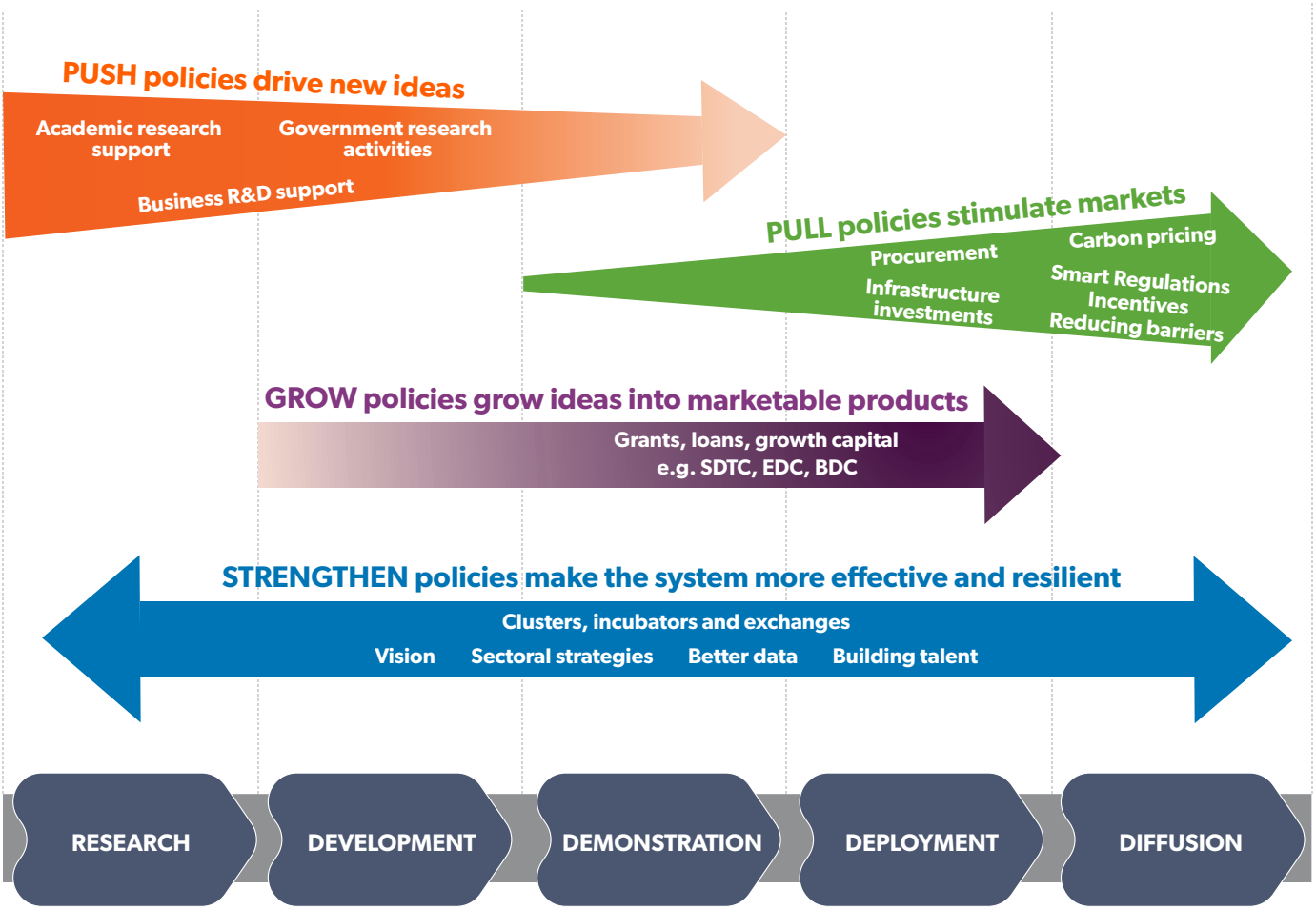
The need for government to help clean innovation markets work to their full potential has profound implications for the clean innovation system. It means that entrepreneurs, investors, and researchers rely on governments' actions to help create the demand for their products and services. If there is uncertainty around a government's environmental policy agenda – what policies it will put in place, how those policies will evolve, how resilient they are to political change – that will translate directly into market uncertainty. This policy risk leads to under-investment in clean innovation, and it is a problem only government can solve.

The key for governments is to intervene in smart ways that target market failures and other barriers, and to do the things that private actors cannot do, with the ultimate aim of creating well-functioning markets for clean innovation. Doing this requires linking government interventions to the different stages of the clean innovation system, and to the underlying barriers and needs at those stages.

Figure 5 shows how this can be done. It maps potential public policy actions against the stages of clean innovation, grouping them into 4 categories: PUSH (policies that drive new ideas), PULL (policies that help stimulate market demand), GROW (policies that grow ideas into marketable products), and STRENGTHEN (policies that cut

across the clean innovation system, making it more effective and resilient). This is only a partial and high level list, but it serves to illustrate how public interventions can be tailored to the different needs at different stages of the clean innovation system.

Figure 5. Examples of policy interventions, applied to the stages of the clean innovation system



Starting on the left hand side of the model, this is where the knowledge spillover market failure occurs and where the role for government is well understood. As Popp has stated, "long-term benefits, spillovers, and uncertain R&D returns all suggest a role for public R&D support, either through direct financing or targeted policy incentives."[55]

A variety of **PUSH policies** can be used to address this market failure. Generally, these policies seek to do one of two things. Some seek to incentivize private research initiatives, either through direct incentives (e.g. tax credits) or by helping firms capture the economic returns from that research (e.g. through IP rights), while others focus on supplementing private research with public research through funding for government labs and universities.[56] While these types of PUSH policies focus on the early stages of innovation, they generate ideas that carry through to later stages.

The far right-hand side of Figures 4 and 5 is where **PULL policies** have an important role in rectifying the second market failure – the environmental externality, which is a particular problem for *clean* innovation.

It is widely accepted that market prices do not reflect the full costs of pollution and environmental harm. What is less well understood is that this market failure results in too little investment in clean innovation. Because firms and households to not pay the real costs of pollution, there is little market reward for developing innovations to reduce pollution. Government action is necessary to fix this failure, so markets can work as they should.

Pricing pollution is one of the most effective and cost-effective PULL policies governments can put in place to address environmental externalities. This can take the form of explicit pricing, such as a carbon tax or an emissions trading system (as Canadian jurisdictions are increasingly adopting). Or it can take the form of an implicit price on polluting activities, such as through regulations or standards (for example, car efficiency standards make it more expensive to drive a high-polluting vehicle). In a market where pollution bears a price, clean innovation—which reduces pollution—assumes real economic value.

However, pricing and smart environmental policies are not the only tools governments can use to pull clean innovations through to market. For example, as the largest purchaser in the country, government procurement policies can be a powerful market driver, as well as a safe space to try new clean innovations.

Such PULL policies can have an impact on all stages of innovation, but are particularly important at the later stages: deployment and diffusion. Moreover, there is mounting evidence that PUSH and PULL policies work best in combination.[57] For example, one study found that government support for emissions control R&D is only effective if there is at least moderate environmental (i.e. PULL) policy in place to encourage the adoption of the resulting technology.[58]

An Ecosystem of Policies

PUSH and PULL policies are essential, but not sufficient. The interviews undertaken for this research project underscored this point. Without exception, every interviewee mentioned other important types of government intervention needed to build a vibrant clean innovation ecosystem. These other policies can be thought of in two groups: GROW and STRENGTHEN.

GROW policies are important for helping promising inventions move from the R&D stage to the point where they are ready for large scale market entry. This can be a long and difficult journey – one that is often called the "valley of death" for innovation. For manufactured products, it typically involves an initial demonstration stage (or "proof of concept") and then scaling up through a series of larger and larger facilities.

Navigating these stages – and financing them – can be a challenge for any kind of innovation, but particularly for *clean* innovation. As the Advisory Council on Economic Growth recently stated, "the (cleantech) industry has unique barriers to scale: it is capital intensive and includes systemic adoption constraints."[59] It is not unusual for a clean technology venture (in bio-chemicals, energy storage, water treatment, etc.) to require ten or more years and hundreds of millions of dollars of investment in order to reach commercial viability.[60]

Further, the fact that cleantech is a relatively new sector, and faces the additional barriers discussed above (such as dependence on public infrastructure systems), adds to the uncertainty and risk for investors. This combination of higher risk profiles and longer scale-up timeframes chills private investment in many emerging clean technologies, particularly capital-intensive ones.

Box 6

Smart government support can catalyze private investment

Like government, private investors have a critical role in all stages of clean innovation from early research all the way through to broad adoption and diffusion. As innovations move beyond the R&D stage, and government intervention transitions from *pushing* research to *pulling* demand, there is an increasing need for private investment to take on a larger role. This is a sensible place for private investors to exert their influence, given that the closer the technology gets to market, the less risky it becomes, and the greater the odds of good returns.

The aim of government policy and funding is to *draw in* private investment as technologies develop. Over time, as strong public policies (like rising pollution prices) help create a growing market for clean innovation, the private sector will naturally take on a larger role in commercializing and adopting clean innovation, allowing governments to scale back their efforts.

PUSH and PULL policies are essential, but not sufficient. They must be complemented by GROW and STRENGTHEN policies.

It also explains why most clean innovations worldwide depend on a mix of public and private funds to reach market.[61] A number of studies have found that targeted public investment—such as grants, loans, and access to growth capital—is a necessary complement to overcome market barriers and enable clean innovations to scale up.[62] For capital intensive firms, helping them to access project-based funds (e.g. through loan guarantees) is particularly important. However, government's role here should be limited and transitional – aimed at de-risking investment in early stage clean innovation in order to draw in private investors who will then play a larger and larger role in developing the technology and carrying it though to market. These public investment decisions are normally best made through arm's-length bodies (such as SDTC or Business Development Canada (BDC)) that combine private financial expertise with public mission.[63]

Similarly, STRENGTHEN policies – those that support the ecosystem as a whole – magnify the impact of all other policies. Those interviewed for this research indicated a number of important roles for government to strengthen the overall clean innovation ecosystem's health. Their comments fall into five main themes: skills, data/information, connections, accountability and vision/strategy.

For instance, in the Pan-Canadian Framework on Clean Growth and Climate Change, federal and provincial governments noted that "there is inadequate data on Canada's clean technology capacity and potential" and better information would "inform future government decision making, to improve knowledge in the private sector and stakeholder community, and to foster innovation."[64] Similarly, Harvard competitiveness guru Michael Porter has argued that *clusters* – geographic concentrations of interconnected companies and institutions in a particular field – increase companies' productivity and drive innovation,[65] which has been shown to hold true in real-world analysis.[66]

All four of these policy areas – PUSH, PULL, GROW, and STRENGTHEN – will be explored more deeply by Smart Prosperity Institute in its clean innovation research program over the coming months.

Canada's Recent Clean Innovation Policy Progress

Canadian governments have made substantial progress in recent months in building the policy architecture that will boost clean innovation. This has happened through a series of new policies, programs and commitments at the federal, provincial and municipal levels. While this Policy Brief will not delve into that progress (that will be done in forthcoming research by Smart Prosperity Institute), two particularly important recent initiatives are worth highlighting here.

Last December, the Prime Minister and most Premiers signed the **Pan-Canadian Framework on Clean Growth and Climate Change**.[67] This landmark national accord sets out a range of federal and provincial policy commitments designed to move Canada towards meeting its Paris climate targets and help stimulate low-carbon innovation. These include a national floor price on carbon (building on existing provincial regimes) and commitments to ambitious standards for low-carbon energy, vehicles and transportation, buildings, industrial production and government operations. All of these, if well designed, will serve as important PULL policies that stimulate market demand for clean innovation across the Canadian economy.

"By taking a focused approach to leveraging our cleantech assets, Canada could spark collaboration between industry and government, reward early adopters and outcomes, and attract the private capital necessary to implement projects at scale."

– Advisory Council on Economic Growth, 2017*

* Advisory Council on Economic Growth (2017) Unlocking Innovation to Drive and Scale Growth. *February 6 2017.*

The recent 2017 **federal budget** builds on this framework by making a major investment in all stages of clean innovation.[68] Broken down by policy area, they are:

- PUSH: More than $400 million in new funding over 4 years targeted primarily at supporting R&D on clean energy, transport and other clean technologies, with a particular focus on Canada's resource sectors.
- PULL: Support for development of the ambitious low-carbon regulations and programs set out in the Pan-Canadian Framework on Clean Growth and Climate Change ($650 million over 5 years). This includes funds to help meet the federal commitment to reduce its own GHG emissions by 40% by 2030 (making it a major buyer of clean energy, vehicles and building technologies), plus a new procurement program targeting innovative new technologies ($50 million). In addition, the budget fleshes out the Fall 2016 commitment to invest $21.9 billion over 11 years in green infrastructure, such as advanced buildings, energy and transportations systems.
- GROW: $1.4 billion over 3 years in financing to invest in the scale up and commercialization of clean technology firms, to be administered by BDC and Export Development Canada (EDC), with a particular focus on capital intensive technologies. Plus an additional $400 million over 5 years for SDTC to support innovative clean technologies at the demonstration stage.
- STRENGTHEN: In addition to a broad skills agenda, the budget includes $950 million in funding for superclusters in key sectors (including cleantech and clean resources) and $14.5 million for a Clean Technology Data Strategy. It also creates Innovation Canada, a new federal body (which will contain a Clean Growth Hub ($12 million)) that will oversee sector tables in six key growth sectors, including clean technology and clean resources.

Smart Prosperity Institute will have more to say about these and other government initiatives in upcoming analysis. But the important point is that Canada has begun to make real progress in building and strengthening its foundation of policies and programs to accelerate clean innovation.

These new commitments are important, but they are just a start. The challenge ahead is to turn them into action by designing new policies and programs, implementing them, and then evaluating and adapting them. In addition, there is still more to be done to flesh out Canada's clean innovation policy framework, for example to tackle other emerging clean innovation challenges, such as water, waste, and biodiversity (the current commitments apply mainly to carbon).

All of this will require close coordination between all levels of government, the private sector, researchers and civil society, so that all the key actors are pulling together in the same direction. And it will require sustained effort and leadership over a decade or more, to seed these changes and allow them to grow into a stronger, cleaner, more innovative economy – one that builds on Canada's strengths and positions us to prosper in a changing, 21st-century global economy.

"As the world increasingly seeks out more sustainable and renewable sources of energy, and new technologies to improve the quality of air and water, Canadian companies can lead the way. Our clean technology companies are well-positioned to compete and win in this large and growing global market"

– Budget 2017, Government of Canada, page 95

IMPLICATIONS FOR POLICY MAKERS

From climate change, to water scarcity, to biodiversity loss—the world is facing a new imperative for clean, low-pollution, resource-efficient economic growth. All sectors of the Canadian economy have an opportunity to build on our unique strengths to provide these solutions to the world. Doing so will require a new vision and framework for aggressively adopting the best clean technologies the world has to offer while simultaneously getting Made-in-Canada clean innovations to scale and to market.

- Accelerating clean innovation across all sectors of our economy offers tremendous economic opportunities. Clean innovations lower costs. They meet an increasing market demand for environmental solutions that will only surge in value in the years ahead. And they both open and strengthen global market avenues for Canadian firms in every economic sector. While it is impossible to fully predict the business horizons that will come with solving the world's most pressing environmental challenges, policymakers should not underestimate the role clean innovation will play as a major global economic driver in the years ahead.
- Canada – its governments, firms and other institutions – must continue with recent efforts and go even further if we want to keep pace with global leaders in the clean innovation race. The double market failure facing clean innovation – and in particular the environmental externality market failure – calls for government to play a more extensive role than it does for innovation generally. What is needed is not just one policy, but a suite of coordinated measures that address different needs in different parts of the clean innovation ecosystem.
- While public policy has an important role to play in all stages of clean innovation, there is now a particular need in Canada for GROW policies to help finance the commercialization and scale up of promising new technologies (especially capital intensive ones), and PULL policies to stimulate market demand through pollution pricing, smart regulations and government procurement.
- It is especially important – and challenging – for governments to provide as much *predictability* as possible about the future trajectory of these policies (e.g. by setting a ramp-up schedule for carbon pricing), if they want to draw in private investors who are making decisions with time horizons of 5-10 years or more. If governments can do this, over time there will be a decreasing need for government to provide *financial* support at later stages (commercialization, scale up), as predictable policies send a strong signal of steady, growing market demand for clean innovations, thus de-risking private sector investment.

By providing as much *policy predictability* as possible government can help send a signal of steady, growing market demand for clean innovation, thus de-risking private investment.

- Ultimately, the job of governments is to help position our economies for long-term success. Governments can invest more patiently than most other investors; they can dilute risk to make investments more attractive to private capital; and they can design policies to "crowd in" private investment so that Canada's scale of effort matches our scale of ambition. At the same time, only governments can provide policy certainty and create the market conditions that will unleash clean innovation. This argues for governments setting a bold vision for Canada's clean innovation performance, matching that vision with policy ambition, and approaching risk differently.
- Governments at all levels across Canada have begun to take significant steps in this direction. The key now is to build on this momentum by turning commitments into effective policies and programs, and filling in remaining parts of the policy Framework – for example, moving beyond carbon to target other clean innovation opportunities in areas such as water, waste and biodiversity.

Capturing the environmental and economic potential of clean innovation requires a strong, healthy, and integrated system of research, education, and finance all functioning together. It also requires well-designed environmental standards and incentives. Flexible policy tools, like pollution pricing and smart regulations, as well as a predictable policy path, help create the certainty needed to unleash investment, invention and entrepreneurship across Canada. This also requires uniting diverse players and bringing ideas, market application, and financing together. Most of all, achieving this future will require smart, far-sighted, and sustained government actions that enable private initiative to flourish.

Accelerating clean innovation in Canada will require smart, far-sighted, and sustained government actions that enable private initiative to flourish.

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Boxes

Box 1. Growing Environmental Challenges need Innovative Solutions

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Box 4. Types of Innovation

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Cover image
Courtesy of Veriform, a small metal fabricator in Cambridge, Ontario, that cut its GHGs by 70% and saved $1.42M over 10 years through clean innovation.

Smart Prosperity Institute

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