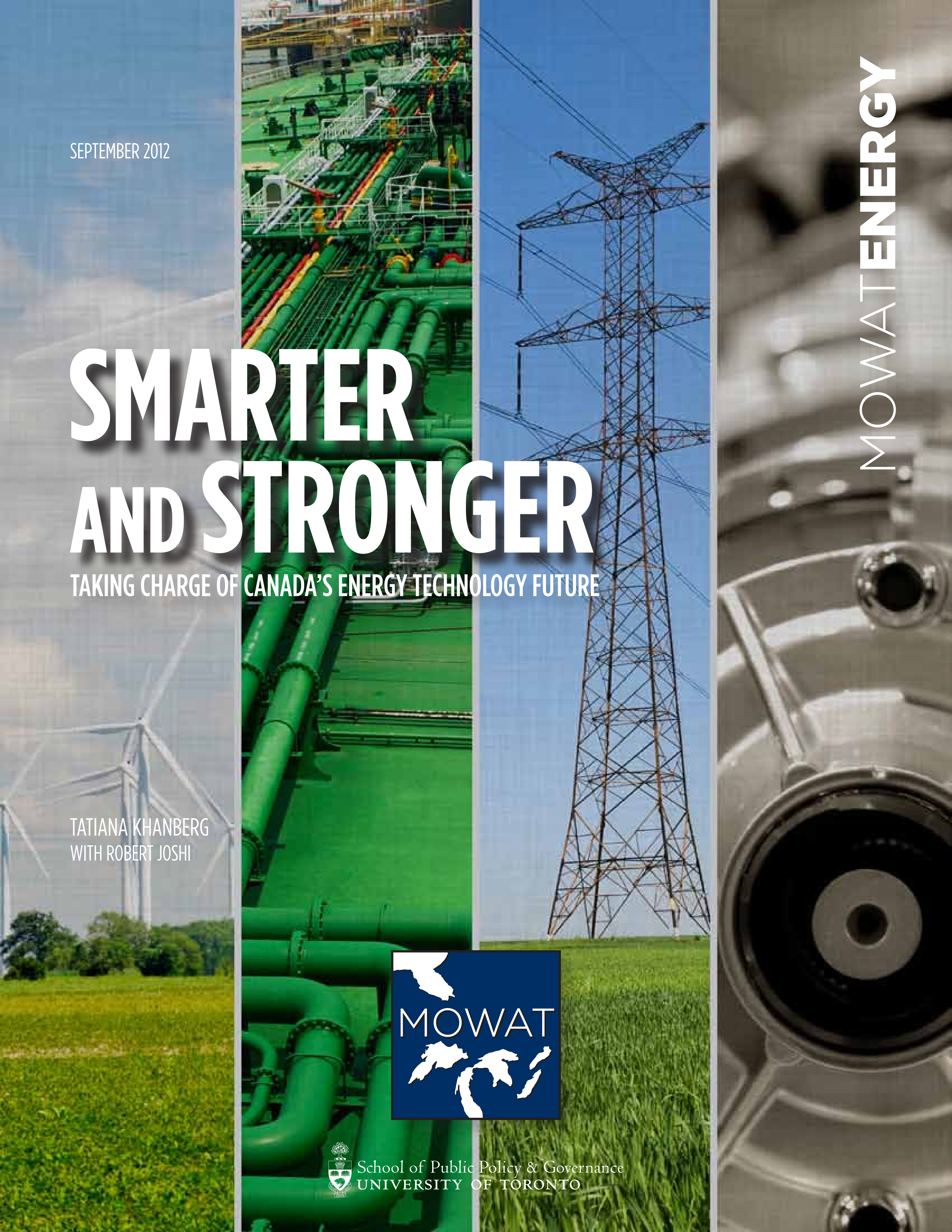

MOWAT**ENERGY**

SEPTEMBER 2012

SMARTER AND STRONGER

TAKING CHARGE OF CANADA'S ENERGY TECHNOLOGY FUTURE

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Ontario's voice on public policy

ABOUT THE MOWAT CENTRE

The Mowat Centre is an independent public policy research centre located at the School of Public Policy & Governance at the University of Toronto.

The Mowat Centre is Ontario's non-partisan, evidence-based voice on public policy. It undertakes collaborative applied policy research, proposes innovative research-driven recommendations, and engages in public dialogue on Canada's most important national issues.

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EXECUTIVE SUMMARY

Canada aspires to become a global energy superpower. However, the transition from resource-driven prosperity to a modern energy superpower is not simple. This transition requires strategic policy informed by economic, political, social, and environmental goals that are national and based on cross-regional consensus. It starts with defining what being an energy superpower means for Canada, what we are trying to achieve, and why this would be good for Canadians.

To become an energy superpower, Canada needs to be a global leader in energy technologies, a leader that offers the world not only access to raw energy resources, but also provides the technology for the efficient development and use of energy across the entire energy system, the tools to reduce related environmental damage, and, eventually, the breakthrough technologies that will allow a transition to new sources of low-carbon energy.

Energy technology should be the national energy priority. Becoming an energy technology leader should be a concrete policy commitment from both orders of government. That commitment should span the whole energy system, from supply to end-use.

Canada's current approach to energy technology investments is piecemeal and fragmented. With some exceptions (which are highlighted in this report), governments rely on a mix of short-term and overlapping boutique energy research and development (ER&D) programs. These have a mediocre track record when assessed on the basis of measurable outputs, such as Canada's (poor) performance in developing new energy technologies.

A national energy strategy, with a sustained and comprehensive national approach to ER&D as its foundation, is a precondition for energy superpower status. Development of a national energy strategy is of course a challenge, given provincial ownership of natural resources and a lack of alignment of regional interests on many energy issues.

But energy technology could be the basis for a wider intergovernmental consensus because, unlike physical resources, expertise in energy technologies is much more broadly distributed across the country. A province like Ontario could benefit from a national commitment to energy technology investments due to its abundance of human, financial, and knowledge capital. These assets can translate into attractive opportunities to export and develop ER&D services and new energy-using technologies—both across Canada and to the world.

Canada's natural resources represent an enormous opportunity to diversify our exports and become more active in the multi-billion dollar global energy technology market. Canada risks missing out on the opportunity of becoming a leader if it fails to invest.

The current suite of ER&D policies and programs is not designed to meet the needs of an emerging energy superpower. This report charts the path forward from our current approach to one where Canada builds on its natural endowments in order to meet political, economic, social, and environmental objectives domestically and abroad. Our quest for energy superpower status must strive to maximize benefits for Canadians, providing opportunities to regions across the country.

This is a moment for policymakers to act, given renewed interest in a pan-Canadian energy strategy, nascent federal and provincial efforts to reform their R&D policies, and a growing recognition that Canadian policymakers must identify and invest in those energy areas where there is a broad national consensus rather than interprovincial division.

WHAT WE DID

In the preparation of this report we completed two distinct research components, which informed our conclusions and policy recommendations.

The first component included a detailed review of literature and available evidence to establish: whether investing public funds into ER&D is a good idea; what policy mechanisms are available for delivering support; how ER&D policies have evolved and the lessons from previous practices; examples of effective policy delivery mechanisms; and, finally, what is the current state of Canada's and Ontario's policy frameworks for supporting energy technology innovation.

The second component of our research was a consultation with experts in the field and key stakeholders in Canada's energy technology space. We conducted detailed interviews with a wide cross-section of experts in order to hear their feedback on the current federal and provincial (Ontario) ER&D support frameworks, and what can be done to improve their effectiveness.

WHAT WE LEARNED

The two research components lead to the same conclusion: Canada needs to make improvements to its current policy framework in order to advance ER&D and improve competitiveness in energy technologies.

This report finds that direct-push policies—that is, directly funding ER&D projects within established priority areas—are the most effective tool for accelerating energy technology development, and that Canada's current policy mix is severely underutilizing this approach. The present Canadian energy technology policy portfolio, heavily biased toward indirect-push and direct-pull policies (see pages 22-23), is not suitable for achieving significant improvements in ER&D outputs.

This report concludes that Canadian policies around energy technology need to be improved, and we examine four successful examples of policy delivery:

- Finland's national innovation system (NIS), which effectively turned the country into one of the world's R&D leaders;
- the U.S. Department of Energy (DOE), that is a successful model of federal ER&D support l;
- the Alberta Oil Sands Technology Research Authority (AOSTRA), that was a strategic provincial energy technology agent that unlocked the oil sands;
- and the former U.S. Gas Research Institute (GRI), a collaborative industry-lead delivery model.

The key conclusion from this report is that Canada's and Ontario's current policy frameworks for supporting energy technology development are not delivering the desired results. Canada's performance in energy technology innovation is unremarkable, despite energy superpower aspirations, while Ontario's commitment to renewable energy is not generating sufficient improvement in commercializing new technologies. In order to achieve a measurable improvement, ER&D policies need a comprehensive overhaul. We recommend the following reforms to begin Canada's transformation from laggard to leader in the global energy technology market:

THE FEDERAL GOVERNMENT SHOULD:

1. Create a pan-Canadian energy policy, with energy technology as its centerpiece.

2. Merge the current suite of energy-related programs run through various departments into a federal Department of Energy.

   i. Move the federal Canmet labs into the new DOE and conduct a review of their roles and responsibilities, ensuring that their mandate fits into the new comprehensive ER&D strategy.

   ii. The new DOE should report annually on investments in energy technology, with a view toward continuity, sustained investments, and measurable long-term impacts.

3. Consolidate ad hoc federal programs and reroute funding from expiring programs to the new structure.

   i. Re-fund Sustainable Development Technology Canada (SDTC) and consider expanding its mandate.

FOR THE ONTARIO GOVERNMENT, THIS MEANS THAT:

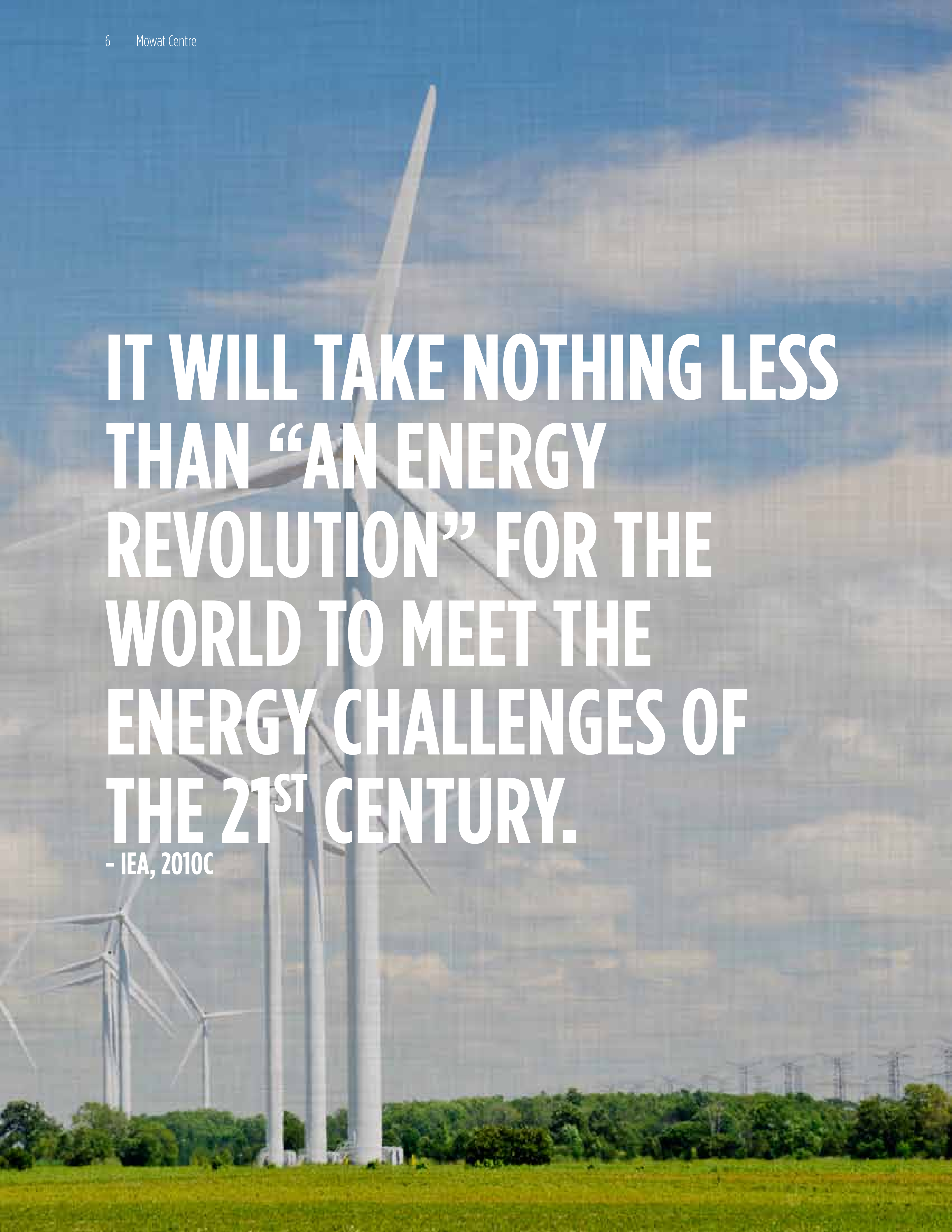
1. **The Ontario Ministry of Energy (MOE) should adopt a whole-of-energy-system approach in order to move away from its disproportionate focus on electricity, and make ER&D a foundational pillar in provincial energy policy.**

2. **The reformed MOE should consolidate ad hoc provincial programs and reroute support from deployment programs to direct ER&D funding.**

3. **The MOE should direct the Ontario Energy Board to develop a rate-recovery mechanism for collaborative industry research.**

IT IS IMPERATIVE THAT BOTH GOVERNMENTS ALSO:

1. **Set long-term federal and provincial ER&D intensity targets consistent with pan-Canadian energy goals.**



IT WILL TAKE NOTHING LESS THAN "AN ENERGY REVOLUTION" FOR THE WORLD TO MEET THE ENERGY CHALLENGES OF THE 21ST CENTURY.

– IEA, 2010C

INTRODUCTION

THE SCALE OF THE PROBLEM

World demand for energy will continue to rise in the foreseeable future, largely driven by the developing world (IEA, 2011). This creates multi-billion dollar opportunities for energy resources and new energy technologies.

Significant environmental challenges, from climate change to water use and air quality, result from growing energy use, which in turn multiplies the opportunities for new low-carbon energy technologies to supplement conventional energy sources and reduce the environmental impact of their production and use.

With the help of sizeable government subsidies, alternative energy sources are becoming more accessible. Nonetheless, alternative energy sources remain largely cost-inferior to conventional fuels, requiring breakthrough technological improvements to compete. This means that there are significant opportunities for jurisdictions that develop the next generation of energy technologies.

New energy technologies range from incremental solutions that improve the effectiveness of the present energy mix (e.g., end-use efficiency-enhancing innovations) to revolutionary solutions, such as breakthrough technologies that can lead to the desired shift away from carbon-intensive fuels to non-emitting alternatives (e.g., renewable sources). Both incremental and revolutionary innovations are necessary if nations are to meet stated greenhouse gas (GHG) reduction targets and stabilize the rate of climate change.

This requires immense increases in energy research and development (ER&D) funding levels, both public and private. Based on the current GHG stabilization targets, "public [E]R&D expenditures should increase considerably over the peak levels of 1980s for at least 3 decades" (Bosetti et al., 2009, p. 133).

At the same time, Canada continues to assert its role as "an emerging energy superpower."[1] However, becoming an energy superpower requires more than just taking things out of the ground and selling them around the world. What Canada really has are "the raw ingredients to become an energy superpower" (Kimber and Gibbins, 2011, p. 2); what is missing is energy technology.

The story is similar in Ontario, where the government tries to assert a leading position in clean

DEFINING ENERGY R&D (ER&D)

It is important to clarify that we use the terms R&D and ER&D in their broadest sense, referring to the entire cycle of technology development—from basic research through to commercialization.

ER&D "encompasses both basic and applied research, technology development and demonstration associated with each phase of the energy life cycle, including production (e.g., mining, drilling), energy conversion and power generation (e.g., nuclear fission and fusion, fossil and renewable energy systems, bioenergy, hydrogen production), transmission, distribution, energy storage, end use and energy efficiency, and carbon management" (Runci and Dooley, 2004, p. 443).

1. "As I have told audiences around the world, Canada is an emerging energy superpower. But, as you all well know, the only way we are going to stay competitive in the global energy market of the future, is if we are also a clean energy superpower. We must develop new, clean sources of energy, and we must develop technologies that make cleaner use of conventional energy." –Prime Minister Stephen Harper (2009)

energy technologies but has yet to make a comprehensive commitment through sustained ER&D investments that can result in such leadership for the province.

The current Canadian approach fails to recognize the bigger gains that stem from developing new energy technologies, rather than just manufacturing someone else's. Weak performance in developing new energy technologies means lost market opportunities, strategic disadvantages within the rapidly changing global economy, and higher costs of mitigating climate change. Energy is a large system that extends beyond resources into distribution and end-use, as do the energy technology opportunities that constitute a multi-billion dollar global market that will continue to grow for the foreseeable future.

Why should Ontario care about ER&D if it does not have any significant energy resources? The question contains the answer. Ontario has a vested economic interest in improving its energy technologies to reduce the cost of energy imports and minimize the economy's exposure to volatile energy prices. Key energy technology leaders, such as Japan and California, came to this conclusion decades ago.

> **WHY SHOULD ONTARIO CARE ABOUT ER&D IF IT DOES NOT HAVE ANY SIGNIFICANT ENERGY RESOURCES? THE QUESTION CONTAINS THE ANSWER. ONTARIO HAS A VESTED ECONOMIC INTEREST IN IMPROVING ITS ENERGY TECHNOLOGIES TO REDUCE THE COST OF ENERGY IMPORTS AND MINIMIZE THE ECONOMIC IMPACT OF ENERGY PRICES.**

The benefits of energy technology leadership would begin with a much-needed economic diversification from just resources and manufacturing to also creating technologies for resources and manufacturing. These benefits are as relevant to Ontario as to other provinces, regardless of energy resource endowments. Over time, ER&D itself—that is, the service of developing energy technologies—could be exported as Canada's leading ER&D regions become global leaders in solving difficult technical problems. The powerhouses for these sorts of benefits are most likely to be the existing clusters of leading R&D universities, colleges, and industries.

WHAT DOES POLICY HAVE TO DO WITH IT?

Governments support R&D to correct market failures that cause the private sector to underinvest in it. In the energy sector, these failures are particularly marked, resulting in distinctively low levels of private ER&D.

The recent Expert Panel review of federal support for research and development, *Innovation Canada, a Call to Action,* highlighted the urgent need to fix Canada's R&D machinery and made recommendations for how to do so. One key piece of advice was the need for strategic focus: "beyond programs of broad application, there is a complementary role for programs tailored to the needs of specific sectors that the government identifies as being of strategic importance" (Independent Panel on Federal Support to Research and Development, 2011, p. 4-2).

The energy sector is a key strategic sector. It is already a substantial part of the Canadian economy, contributing nearly 7% to our GDP, and constituting 23% of our exports (NEB, 2011). But our record on energy technology does not reflect this.

In Ontario the energy sector is roughly 2% of the economy, and the province spends over $90 million dollars every day on just the major energy commodities (electricity, oil, and natural gas).[2] Ontario imports the majority of its energy inputs, mainly fossil fuels and uranium.

The provincial government embarked on the mission of becoming a leader in new renewable energy technologies and introduced aggressive subsidies to accelerate the deployment of renewable power. However, Ontario has not matched this with sufficient policy measures to drive ER&D into new energy technologies. This means that much like Canada as a whole, Ontario is not capturing the lucrative opportunity of value-driven technology development.

Market forces do not always work for the development of technologies that provide the highest benefit to the public. Government can carefully fill this gap.

Technology policy through direct support of ER&D, the most effective way to fill the gap, is politically controversial and difficult to do. However, energy is too crucial a sector for Canada, problems such as climate change are too important, and the public benefits from developing new energy technologies are too large "to abandon policy efforts

2. Note: This estimate does not include spending on refining and distribution infrastructure, so the end-use cost is much higher.

Source: Author's estimate based on source data from Statistics Canada Energy Data; Hydro One Annual Report, 2010; Ontario Energy Board Historical Natural Gas Rates; National Energy Board Crude Oil Prices.

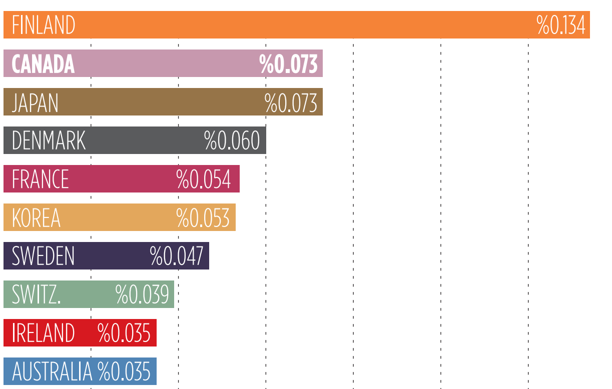
because they are hard. Everyone agrees that there are many ways in which public education is flawed, but it is not widely suggested that, as a consequence, the government should simply get out of the business of education" (Jaffe et al., 2004, p. 62).

THE SCALE OF THE PROBLEM

The good news is that Canada remains one of the top ER&D funders in the world. It is tied with Japan in second place among the International Energy Agency (IEA) peers by ER&D investment intensity (ER&D spending as a share of GDP), after Finland (see Figure 1).[3]

The bad news is, first, that this funding is largely short term. Second, it is thinly spread among countless uncoordinated programs that lack useful performance measures and are disconnected from outcomes.

FIGURE 1 TOP ER&D FUNDERS BY INTENSITY (ER&D/GDP) IN THE IEA

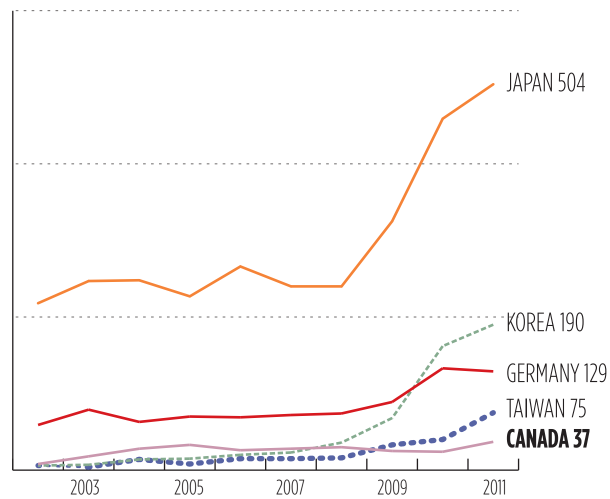


Source: IEA, 2011.
Sample: Top ten IEA ER&D funders with GDP per capita PPP above 20,000 international dollars (IMF 2010). This excludes Hungary, which otherwise would have been number two.

Canada's poor ER&D performance can be seen in 'clean energy' technologies innovation output (Figure 2). The Clean Energy Patent Growth Index (CEPGI), published quarterly by the by the Heslin Rothenberg Farley & Mesiti P.C. Cleantech Group, measures all clean energy patents[4] registered in the U.S. patent office since 2002. Despite significant investments by federal and provincial governments to support innovation in clean energy, Canada is in fifth place by measure of its clean energy inventions, after Taiwan.

Canada's share of all clean energy patents granted in the U.S. since 2002 is only 2%, compared to Korea's 5%, Germany's 7%, and Japan's 26% (which is the second highest after the U.S. itself, with 49%) (Heslin Rothenberg Rarley & Mesiti P.C., 2012). This is a clear signal of an ER&D policy failure given Canada's geographic and cultural proximity to the US—a strong advantage over other cited countries.

FIGURE 2 CLEAN ENERGY PATENTS FOR TOP COUNTRIES REGISTERED IN THE U.S. 2002 - 2011



Source: Heslin Rothenberg Farley & Mesiti P.C., Clean Patent Growth Index, 2012

Weak performance is even more evident when comparing the number of patents relative to population[5] for 2011 (see Figure 3). Canada is sixth, with 1.09 patents per million people. This is less than a quarter of Japan's and Korea's rates, just over one-third of U.S. and Taiwan rates, and about two-thirds of Germany's.

Canada's exports in new clean energy technologies tell a similar story. The Conference Board of Canada's report, *Global Climate-Friendly Trade*, showed that the value of Canada's exports in this area has been flat or declining, despite a significant expansion in the global market, which signals that "Canadian companies not only failed to seize new

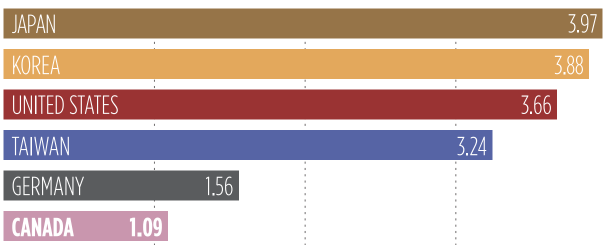
3. In the previous year, Canada was third—behind Japan. However, in light of the recent slight increase in Canada's government investment (+0.007%), coupled with a decrease in Japan's spending (-0.005%), Canada has moved to second place. Over the long run however, while Canada's funding followed a boom-and-bust cycle, Japan kept its funding relatively stable for decades.

4. The index includes patents related to: "solar, wind, hybrid/electric vehicles, fuel cells, hydroelectric, tidal/wave, geothermal, biomass/biofuels, and other clean renewable energy" (Heslin Rothenberg Rarley & Mesiti P.C., 2012).

5. Patenting intensity, or the number of patents per population, is a standard indicator used to measure industrial innovation output (Committee on the State of Science & Technology in Canada, 2006).

opportunities to sell climate-friendly technologies in export markets but also lost existing opportunities." Between 2002 and 2008, "when adjusted for inflation, Canada's trade in climate-friendly technologies actually declined by 2 per cent annually on average" (CBOC, 2010a, p. 12). For example, Figure 4 demonstrates Canada's trade balance in wind turbines—with a net deficit of over $800 million, and net exports only in the low-tech components. When it comes to Canada's 'natural advantage' in resource-based industries, the story isn't much different, and "patenting intensity lags behind the US" (Committee on the State of Science & Technology in Canada, 2006).

FIGURE 3 2011 CLEAN ENERGY PATENTS PER CAPITA, U.S. PATENT OFFICE



Source: OECD, 2011; Heslin Rothenberg Farley & Mesiti P.C., Clean Patent Growth Index, 2012; CIA World Factbook, 2012

These mediocre results are not surprising given an uncoordinated and inefficient energy technology policy. With some exceptions, Canada and Ontario rely on a mixture of short-term and overlapping boutique ER&D programs. The recent federal Panel on R&D also noted that "the combination of small size and sheer number" of federal R&D supporting programs is a major challenge for ensuring their intended outcomes of spurring business innovation, and "this challenge is exacerbated by the large additional number of business innovation support programs delivered by provincial governments." (Independent Panel on Federal Support to Research and Development, 2011, p. 3-12)

Canada's federal arrangement further exacerbates the situation by adding a provincial web of related but disconnected programming to the parade of initiatives. This creates a certain "factor 10 dilution" effect, where "nothing is connected or connectable, and the best we often achieve is that everybody gets really good at doing a part of not very much" (Hawkins, 2009, p. 78).

If Canada and Ontario are indeed serious about their pledge to address energy and environmental challenges there will have to be a pronounced, sustainable change in ER&D policy. A conclusion that has already appeared in The National Advisory Panel's report on Sustainable Energy Science and Technology: "... only a new, knowledge-intensive approach to energy innovation will help us to compete in supplying a rapidly increasing global demand for more efficient, environmentally responsible energy technologies, assuring maximum benefits to Canadians over the long term." (National Advisory Panel on Sustainable Energy Science and Technology, 2006, p. 21)

So, how do we get more new energy technology? The current suite of government programs, largely focused on aggressive deployment measures, does little for energy technology improvement if complementary ER&D funding is missing. ER&D requires direct funding. If Canada wants to compete in this lucrative market for new energy technologies it will have to commit to a deliberate, long-term, and well-financed energy technology strategy, built on accountable and stable institutions, established with a long view of continuous progress.

THE SOLUTION

In order for Canada to become an energy technology leader and an energy superpower, a clear pan-Canadian energy technology policy is needed. This means that the provincial governments and the federal government would set and follow through on long-term ER&D targets, and deliver effective funding through stable institutions. Effective funding means following strategic priorities set by long-term policy and organized in a diversified portfolio that cuts across the energy system and stages of investment (see Figure 5).

FIGURE 4 CANADA WIND TURBINES TRADE BALANCE

Canada is a **net importer** of high-tech parts:

gears & speed changers	$82M (exports) - $911M (imports)
clutches & universal joints	$77M (exports) - $81M (imports)

Canada is a **net exporter** of low-tech parts:

towers & masts	$147M (exports) - $74M (imports)
Net trade balance	**- $833.8M**

Source: Research undertaken by the Conference Board of Canada for the National Round Table on the Environment and the Economy, 2011

The energy technology development process has many important components. Among others, these include research infrastructure, education, and human capital. However, in order to operate, these components require two main things: funding and strategic policy. Each is individually necessary but alone not sufficient; only if both elements are present will Canada be able to steer its energy technology performance forward.

This report unpacks these two components—money and policy—and outlines what they mean in terms of actionable policy recommendations, which are set out in the concluding Section 8. These recommendations provide guidance on how to increase the effectiveness of Canada's ER&D investments and ensure the greatest benefit to Canadians.

First, Canada needs a national energy policy and a federal department of energy in order to consolidate the current convoluted mix of ER&D-related programs into a single department.

Second, it is necessary that Canada and Ontario set and commit to a measurable ER&D target—a level of gross ER&D investment in the economy, or combined private and public spending, as a share of the GDP—in order to ensure a stable policy environment for progress to occur.

Third, the Ontario Ministry of Energy should adopt a whole-of-energy-system approach to reflect the weight of non-electricity sources and uses in Ontario's economy and make ER&D a priority.

It is important to recognize that the transition from technology follower to technology leader will not happen overnight. It requires a long-term commitment of both resources and political will. The current fiscal pressures make it a challenge. However, both federal and provincial governments could find substantial savings that would help to fund the new governance framework, simply through transitioning from a series of short-term programs to consolidated long-term agencies. Consolidation can bridge the current period of fiscal austerity with longer-term ER&D targets.

FIGURE 5 MANAGING ENERGY TECHNOLOGY INVESTMENTS

A BALANCED ENERGY TECHNOLOGY PORTFOLIO INCLUDES:

A. varied investments in different technologies, based on established priorities

B. balanced investments across all stages of the technology development process to ensure energy innovation continuity

C. a balanced policy and delivery mechanisms portfolio to ensure there are no gaps in the energy innovation system

(for further discussion see Anadon, et. al. Transforming the U.S. Energy Innovation, 2011)

IN ORDER FOR CANADA TO BECOME AN ENERGY TECHNOLOGY LEADER AND AN ENERGY SUPERPOWER, A CLEAR PAN-CANADIAN ENERGY TECHNOLOGY POLICY IS NEEDED.

THE CASE FOR INVESTING PUBLIC FUNDS

THE RATIONALE FOR DEVOTING SCARCE PUBLIC RESOURCES TO ENERGY TECHNOLOGY DEVELOPMENT: THE TECHNOLOGY DEVELOPMENT CYCLE, ASSOCIATED MARKET FAILURES, AND THE CASE FOR FOCUSING ON ENERGY

In order to justify investing public funds into ER&D we need to understand the technology development cycle, why investing public money into that cycle is justified, and why energy technologies in particular should get special attention.

UNDERSTANDING THE TECHNOLOGY CYCLE AND WHY ER&D MATTERS

While the innovation process has many steps, one element enables the entire process. This factor is technology R&D, a necessary driver of technological innovation.

Importantly, "it should go almost without saying ... that we understand energy technology to mean not only hardware but also the software, practices, and knowledge related to its effective use" (Gallagher et al., 2006, p. 194).

Innovation can include anything from improving the office furniture layout to changing human resources practices, to implementing a 'lean' management strategy. All those actions can improve productivity, reduce waste, and improve the *proportional* breakdown between inputs and outputs. However, these are marginal changes, the benefits of which are finite—limited to the size of the margin between inputs and outputs. Technology is the component of innovation that can exponentially change the outcomes.

Technological breakthroughs, from the steam engine through to the transistor, the laser, and the internet, were revolutionary in taking society away from diminishing returns by increasing the size of the margin between inputs and outputs and opening up new avenues for growth. Between breakthroughs there are also equally important incremental technological changes whereby these revolutionary inventions continue to be improved, and to compete with each other, creating even more value. To continue improving our way of life we need to carry on creating value, and to create more value we need new technology. The broader innovation ecosystem can enhance this outcome, but new technology is the prime mover. It is "the force that could offset diminishing returns" by increasing "return on investments in physical and human capital" (Nelson and Romer, 1996, p. 13).

> **"ENERGY TECHNOLOGY REFERS TO THE MEANS OF LOCATING, ASSESSING, HARVESTING, TRANSPORTING, PROCESSING, AND TRANSFORMING THE PRIMARY ENERGY FORMS FOUND IN NATURE...TO YIELD EITHER DIRECT ENERGY SERVICES...OR SECONDARY FORMS, MORE CONVENIENT FOR HUMAN USE..."**
>
> - (GALLAGHER, ET. AL., 2006, P. 194)

Energy technology is a special case within the broader technology innovation narrative because it is the key to solving major pressing energy and climate challenges of the day, and the pace of its development must be accelerated to meet these challenges. The goal of accelerating the world's transition to carbon-neutral energy requires unprecedented policy action because when left to normal forces of the market the process of energy transition is very slow and can stretch over centuries. Because fossil fuels continue to have vast cost and performance advantages over low-carbon technologies, they dominate in the global energy market and the only way to change this is by making the low-carbon technologies more technologically competitive (Wilson and Gruber, 2011). Historically, performance advantages, like versatility, convenience, safety, or relative cleanliness, have been key drivers of major energy shifts, even if these came with a higher price. When it comes to low-carbon technologies, there are, for the most part, no such obvious performance advantages that could justify paying extra for them under the current policy environment (Wilson and Gruber, 2011, p. 178).

In other words, the technological distance that low-carbon technologies need to cover in order to become feasible substitutes for the current carbon-intensive fuels is still huge, and without a robust energy technology policy the distance will not be covered in time to make an impact on climate change. For a detailed discussion see: Galiana et. al, 2012.

THE TECHNOLOGY CYCLE

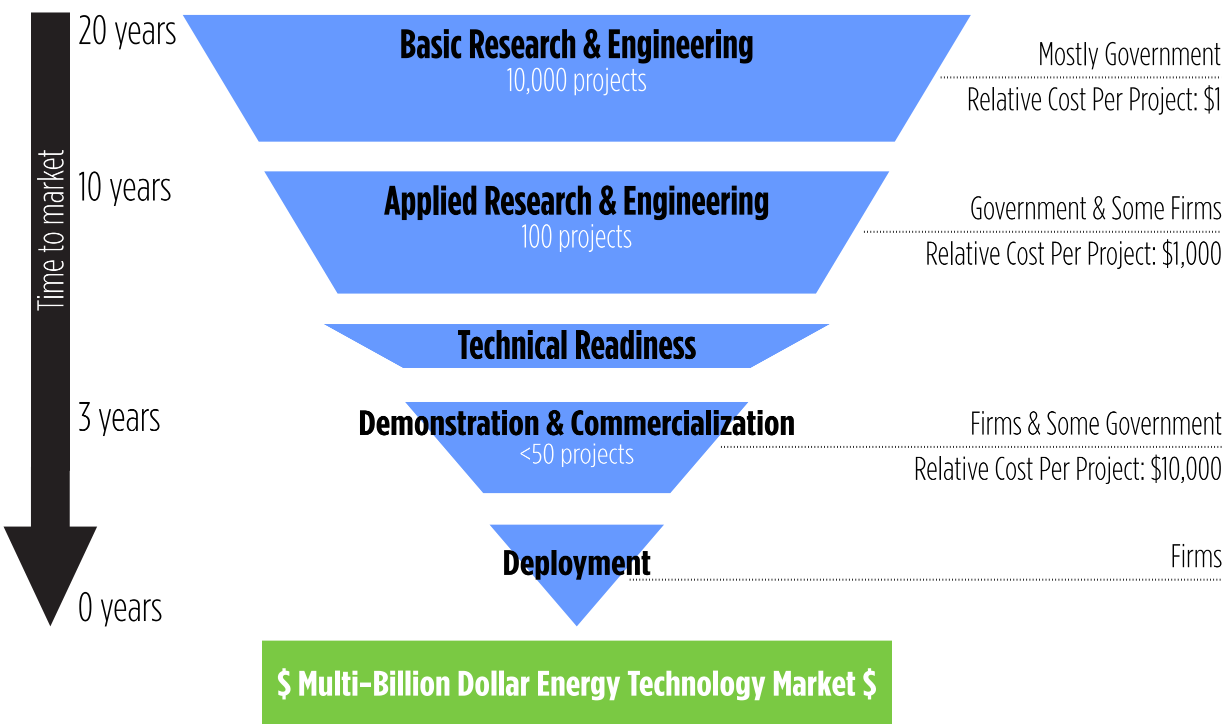
To design effective ER&D policy, it is essential for policymakers to understand the complexity and length of the full technology cycle. Any new technology is based on some basic scientific concept, and the process of its development into a new energy technology is long and complex. It can take decades for a technology to reach the stage when it is ready for market use. Hence, to be effective, a technology policy must be backed by a stable long-term commitment that corresponds with technology's long cycle.

Figure 6 is an illustrative model of the technology cycle, which demonstrates how the order of magnitude changes for the number of projects and their cost progressions as they move through the technology funnel.[6] It should be noted that, in reality, technology paths are not necessarily linear.

Basic ER&D is undertaken predominantly in post-secondary institutions. At this stage, the probability of project success is highly uncertain; the cost per project is relatively low; and there are thousands of such projects. Basic research projects are, on average, at least 20 years away from market. In the oil and gas sector, for example, the average lead time for a new technology from concept to market is roughly 16 years (National Petroleum Council working paper, 2007). Although individual projects are relatively inexpensive to fund, basic research requires a significant overall public commitment.

There is almost no incentive for the private sector to fund basic research because the risk is too high while the generated knowledge is largely inappropriable. Therefore, the funding of basic research is almost entirely public. Some large industry players may participate, but these investments are a relatively minor share of the total.

FIGURE 6 THE TECHNOLOGY CYCLE



Note: The number of projects and associated cost figures are illustrative not—actual—to demonstrate relative scale.

6. The diagram and stage descriptions were primarily adapted from Bernard and Santini's 1989 article; for additional reading see Gallagher et al. (2006) and Oil and Gas Technology Development Subgroup of the National Petroleum Council Committee on Global Oil and Gas (2007).

Applied ER&D, where the science concept moves into development through applied research and engineering, is a crucial mid-point in the technology cycle. Roughly one in 100 projects will make it to this stage, with the cost per project being 1,000 times higher than at the basic stage. The technology is much closer to commercialization, about three to ten years to market, and the technology risk is, therefore, reduced.

At this stage, public funding is critical for the continued development of a promising technology. It is a filter, moving a potentially promising technology through the funnel by reducing the technology risk and increasing the prospect of success from possible to highly probable. It is sometimes referred to as 'proof of concept.'

AN APPRECIATION OF THE WHOLE TECHNOLOGY CYCLE AND AN UNDERSTANDING OF FAILURE AS A LEARNING PROCESS, RATHER THAN AS A DYSFUNCTION IN THE CHAIN OF TECHNOLOGICAL INNOVATION, ARE ESSENTIAL FOR AN EFFECTIVE ER&D STRATEGY.

The private sector invests into this stage, but only if there is a highly probable prospect of profit and minimal technological risk. Normally, it is believed that "the criteria for most industrial R&D investment are typically a three-year horizon to commercialization, a probability of success exceeding 90%, and a sufficient return on investment" (Bernard and Santini, 1989, p. 557). Because many energy technologies do not meet these criteria, government usually funds a significant amount of applied ER&D.

In addition, some publicly beneficial energy technologies can have minimal to no profit potential. This is especially the case when technologies are meant for something that is a pure public good, like the environment. Such technologies require significant government funding as there may be no business case for the private sector to invest in their development.

Demonstration & Commercialization is the last stage before a technology enters the market. A large-scale real-life prototype is built to test its feasibility and prepare for commercial operation. This is the most expensive stage in the process with a relative cost 10,000 times higher than at the basic stage, and only a few projects remain. While there is significant private-sector involvement at this stage, even the most promising technologies may often require public support to be pushed through the funnel.[7]

In many energy technologies, this is still a very costly and risky stage. New energy options, such as biorefineries and electric vehicles, include trying out multiple new technologies combined with older ones in ways that have not been seen before, lengthening the lead times and stretching costs. For example, in the oil and gas sector an energy technology "is not considered developed until it has gone from the initial theoretical formulation, through the commercial testing phase—where the rule of thumb is fifteen to twenty commercial tests (site specific) for every single technology—to the final acceptance and usage" (Hester and Lawrence, 2010, p. 24).

The high cost of capital and long, uncertain timelines—it often takes several years just to construct a commercial-scale demonstration—minimize the market incentive for private-sector investment. Correcting this market failure may require the government to share the risk by co-investing.

Deployment is the final stage in the cycle. The stream of future cash flow begins and the risk is reduced to that of market uncertainty as to whether the market will adopt the technology and pay enough to more than cover the earlier ER&D investments. This is predominantly a private-sector stage.

UNPREDICTABILITY AND FAILURE

Failed projects are part of the technology cycle, and far more common than successful projects. But the distinction is awkward because both failures and successes are important to growing the body of knowledge. New knowledge adds to the capacity to innovate and researchers today stand on the shoulders of their predecessors—the technology innovation process is continuous (Jones and Williams, 2000).

Throughout times of substantial uncertainty and during the long timelines, technology ER&D requires a significant amount of money from investors willing to accept many more failures than successes and willing to see the benefit of others discovering completely unexpected uses for the technologies they have invested in.

An appreciation of the whole technology cycle

7. Note that at this stage the market can still fail to adopt projects that have significant public benefits. This can be due to the spillover effects—private investors not being able to capture all the gains from the technology in which they invested because the benefits spread to the public at large—something that is discussed in the following section.

and an understanding of failure as a learning process, rather than as a dysfunction in the chain of technological innovation, are essential for an effective ER&D strategy. These are the basic tenets that need to be engrained in the foundation of any well-functioning R&D policy.

WHY SPEND PUBLIC MONEY?

Why should governments invest public money in this vital but unpredictable process? There are two reasons: the environment and the economy.

PUBLIC INTEREST TECHNOLOGIES

Public interest technologies provide valuable public benefits, such as health, safety, and a cleaner environment. The market often does not provide private investors with incentives to invest in the development of these technologies, particularly when health, safety, and environmental regulations do not provide clear price signals (Blumstein and Wiel, 1998; De Martino Jannuzzi, 2003). For example, the environment is a public good, and R&D meant to solve problems like climate change generates broad public benefits, especially in the absence of a carbon price for markets to act on. Public funds are a way to bridge the gap between public interest and private incentives (Gallagher et al., 2006).

When it comes to the development of technologies with the highest public benefit, a double market failure is at play—the difficulty of privately capturing all the benefits of ER&D and the difficulty of internalizing the cost of pollution. This means that the market will provide many fewer of these technologies than is socially desirable. "Pollution creates a negative externality, and so the invisible hand allows too much of it, [while] technology creates a positive externality,[8] and so the invisible hand produces too little of it" (Jaffe et al., 2005, p.173).

ECONOMIC BENEFITS MARKETS CANNOT CAPTURE

Technological innovation produces positive externalities, known as spillovers, which are the main reason why, in general, governments fund R&D activities.

Assuming that markets alone will invest the optimal amount of ER&D dollars does not account for the fact that private actors underinvest in R&D because they usually cannot capture all the benefits from the inventions they fund. These benefits are called spillovers.

Spillovers represent "the benefits of knowledge to firms, industries, or regions not responsible for the original investment in the creation of this knowledge" (Fischer et al., 2008, p 2). The spillover effect means that the benefits from ER&D to the public at large exceed the private benefit, thus minimizing the incentive for a private agent to invest. Knowledge has public good qualities, which makes it almost impossible to fully appropriate for a private firm. In the realm of private industry, we often observe how the scientific or technological discoveries made by one firm become quickly applied in the production of another, transforming production

WHAT IS A PUBLIC GOOD?

These are goods or services which provide benefits to the society at large. The benefits they provide cannot be appropriated by a single individual. "As nobody can be excluded from using them, public goods cannot be provided for private profit" (Oxford Dictionary of Economics).

ENERGY TECHNOLOGY AND CLIMATE CHANGE

A whole suite of new GHG-reducing energy technologies is necessary to slow the rate of climate change and avoid severe environmental consequences. It is often assumed that environmental policy that puts a cost on pollution will produce sufficient incentive for firms to invent new technologies that pollute less. However, because technology itself is not free, a firm will only innovate if the cost of polluting is greater than the cost of technology—an outcome very difficult to achieve politically. Given the political reality, it is highly unlikely that governments will ever be able to implement an environmental policy assertive enough to reflect the dynamic nature of climate change costs. This makes a policy directly supporting technology development not only desirable, but also necessary to enable Canada to meet its environmental obligations (Jaffe et al., 2004, 2005).

8. "Externality is an economically significant effect of an activity, the consequences of which are borne (at least in part) by a party or parties other than the party who controls the externality-producing activity" (Jaffe et al., 2004, p. 37).

processes across firms and industries (e.g., smart phone technology) (Nelson and Romer, 1996; Kafouros and Buckley, 2008).

In some rare cases, market distortions that induce over-investment in R&D can occur, and patent races in the information technology industry are one example of this distortion (see Jones and Williams, 2000; Kafourous and Buckley, 2008 for further discussion).[9] However, over-investment in R&D is usually rare, and the private sector normally under-invests in R&D.

PUBLIC BENEFITS

The spillover effect causes divergence between the social rate of return (the total return to society, including spillovers) and the private rate of return (the benefit captured by the original investor) (Parsons and Phillips, 2007). The market invests based on the private rate of return, but the public benefits most from investments based on the social rate of return; and the gap between these rates can be quite large (see Giriliches, 1992; Jones and Williams, 2000).

TABLE 1 ESTIMATES OF THE SOCIAL RATES OF RETURN TO R&D INVESTMENT

Canada	SOCIAL RATES OF RETURN ON R&D
Griffith, Redding & Van Reenen, 2004 | **1974-90**	70
Park, 2004 | **1980-95**	160
Mohnen & Lepine, 1991 | **1975-83**	86
U.S.	
Park, 2004 | **1980-95 (country)**	57
Luintel & Khan, 2004 | **1965-99 (country)**	175
Bernstein, 1996 | **1964-86 (industry)**	80
Wolf & Nadiri, 1993 | **1947-77 (industry)**	47
Bernstein & Nadiri, 1991 | **1957-86 (industry)**	37
Bernstein & Nadiri, 1988 | **1958-81 (industry)**	28
Giriliches & Lichtenberg, 1984 | **1959-78 (industry)**	61
Scherer, 1982 | **1964-78 (industry)**	88
G7	
Park, 2004 | **1980-95**	66
Griffith, Redding & Van Reenen, 2004 | **1974-90**	69
Luintel & Khan, 2004 | **1965-99**	123
Van Pottelsberghe & Lichtenberg, 2001 | **1971-90**	68
Xu & Wang, 1999 | **1983-90**	70
Coe & Helpman, 1995 | **1971-90**	122

Source: Parsons and Phillips (2007). Parsons and Phillips summarized evidence from a number of studies and the social rates of return from these studies are in the table. They found that the median R&D spillover rate in Canada was 56%, within a range of 9–138%.

> **IN SPITE OF ALL THESE [MEASUREMENT] DIFFICULTIES, THERE HAS BEEN A SIGNIFICANT NUMBER OF REASONABLY WELL DONE STUDIES ALL POINTING IN THE SAME DIRECTION: R&D SPILLOVERS ARE PRESENT, THEIR MAGNITUDE MAY BE QUITE LARGE, AND SOCIAL RATES OF RETURN REMAIN SIGNIFICANTLY ABOVE PRIVATE RATES.**
>
> - GIRILLICHES, 1992, P. 543

Although measuring the exact social rates of return to R&D is difficult, there is a substantial body of research comprised of decades of in-depth studies providing authoritative estimates. The main conclusion—that public returns to R&D are very high—has not changed from the early inquiries in the 70s to the literature today.[10]

Table 1 summarizes the results of previous studies of Canadian, U.S., and G7 social rates of return to R&D. Canadian results show social rates of return to R&D between 70 and 160 per cent. U.S. numbers, including both country-wide and industry-specific studies, range between 28 and 175 per cent, and the G7 rates are also very high, ranging from 66 to 123 per cent.

These very high returns support the case for investing public funds in technology R&D in order to bridge the gap between private and social return and to capture the full benefit of R&D investments.

Spillovers also exist on an international level. One study found that "in 1990 the average 'own' rate of return from investment in R&D in the G7 countries was 123%, and the worldwide rate of return was 155%" (Expert Panel on Business Innovation, 2009).

Other research on spillovers provides insight into the nature and scope of these spillover benefits and points to their particular characteristics. First, location matters. Second, individuals matter; much of the geographic spillover relates to the patent process, which is, in turn, connected to individuals.

9. The second distortion that may be considered as a case of over-investment in R&D is "creative destruction" whereby a new product eliminates its predecessor without significantly improving the net social return (Jones and Williams, 2000).

10. For detailed discussion and review of returns to R&D, see: Girilliches, 1992; Jaffe et al., 1993; Jones and Williams, 1998; Jones and Williams, 2000; Fischer et. al., 2009; Hall et al., 2010.

People change employers and start new firms and take with them knowledge and techniques that are not captured by the original investor.[11]

LOCATION

Research suggests that geographic distance has a significant impact on spillovers—the shorter the distance the bigger the spillover (Fischer et al., 2008).

In their study of this phenomenon, Jaffe et al. (1993) found that patents that refer to other patents are up to three times more likely to come from the same geographical area, and up to six times more likely to come from the same metropolitan area.

Mansfield's study (1995) of industry-funded university R&D showed that firms seem to care about distance in applied research and are more likely to finance a university that is within a 100-mile radius and less likely to do so for universities more than 1,000 miles away. However, for basic research, the distance did not figure prominently in the financing choice, while the quality of the faculty did.

It is important to note that this evidence does not justify policies promoting 'clusters'. It suggests that the uptake of R&D funding will be unevenly distributed in a given region or country, and that this is normal. Distributing funds to oppose this outcome and provide a more equal regional balance can, therefore, reduce the public benefit of R&D spending.

> While it is easy, after the fact, to identify successful clusters and to analyze what led to their success, public policies designed to create a cluster from whole cloth have yet to demonstrate much success … The development of a cluster is an organic process that typically depends on the fortuitous confluence of factors that self-reinforce, often in unpredictable ways (Expert Panel on Business Innovation, 2009).[12]

So, an existing cluster of research-intensive higher education institutions is likely to capture more basic and applied research funding, an outcome which should not be deliberately opposed if the goal is to maximize the public benefits of R&D.

PEOPLE

Knowledge spillovers have important implications for the labour market. Increased concentration of highly skilled workers in a particular region also facilitates greater diffusion of knowledge and contributes to the spillover effect. This has many causes, from simple social network interaction between the creators and carriers of knowledge, to changing jobs and transferring one's skill set from a previous firm to the next. Though workers may change employers several times over their career, they are less likely to relocate to a new region. There are also those who are referred to as "mobile inventors," including consultants and academic scientists, who can provide services to different companies on a contractual basis (Breschi and Lissoni, 2009).[13]

This evidence points to the importance of continuity in R&D funding, necessary to attract and retain skilled people who will help generate public benefits in a given region.

> When research produces potentially large social benefits but is so prone to the spillover problem that firms will not view it as profitable, there is an analytical basis for performing that research in the public sector or through direct private research contracts (Jaffe et al., 2004, p. 56).

WHY LOOK AT ENERGY?

The case for public spending on R&D is clear, but why give special attention to energy technologies?

First, energy R&D can address the double market failure associated with public interest technologies (the environment) and with R&D spillovers (the economy). To recap, when it comes to developing new energy technologies, a double market failure is at work: the disincentives to invest in ER&D induced by knowledge spillovers are reinforced by the ability to free-ride on environmental costs.

There is a strong link between ER&D and public interest. Mitigating climate change and improving local air quality are largely about producing and consuming energy—how it is done and what kinds of energy are used.

ER&D is also directly connected with the economy. The importance of the energy sector in the

11. Industry structure and firm size also appear to have an effect on the rate and direction of spillovers, but this discussion is outside of the scope of this report. For further reading see Kafouros and Buckley, 2008.

12. For further discussion see Martin and Sunley, 2003; Caniels and Romijn, 2005.

13. Whereas knowledge spillovers are positive labour externalities, negative labour spillovers may occur in the event of erratic commitments to technology funding. Abrupt funding decreases result in 'wasting' labour capital in the short term, and losing it over the long-run.

PUBLIC INTEREST ER&D EXAMPLE

Research on residential heating and cooling ducts, conducted in the U.S. in the 90s, showed that residential ducts lost 30% of energy through leaks, costing homeowners several billion dollars a year. Published results created commercial opportunities to prevent this problem in new construction and to market new technologies for sealing ducts in existing homes (Blumstein and Wiel, 1998).

Canadian economy, and opportunities created by growing global demand for new energy technologies, mean that ER&D provides significant business opportunities. Public funding of ER&D creates leverage for growing the private sector's share of ER&D investments—key determinant of industrial competitiveness. A Harvard Kennedy School report, *Transforming U.S. Energy Innovation*, found that "government, academia, and the national labs play a major role in shaping private sector energy innovation decisions ... and government grants and contracts are the next most important driver of innovation after costs" (Anadon et al., 2011, p. 33).

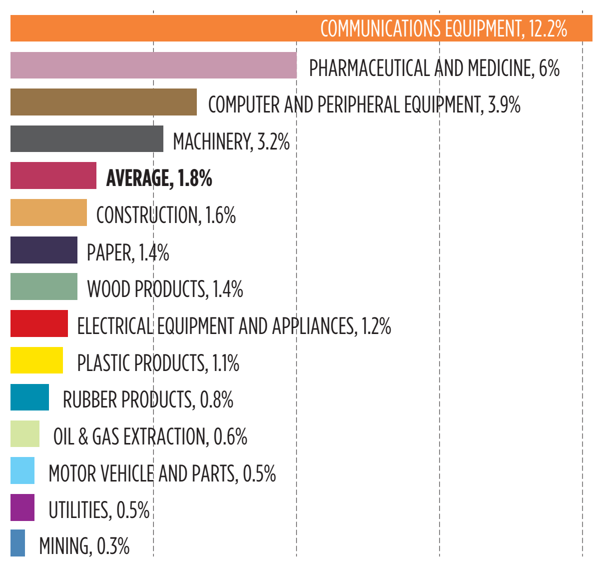
Canadian policymakers seem to be recognizing these opportunities.[14] Energy-related innovation is a stated priority of both federal and provincial governments across Canada. For example, two of the four stated national research priorities are the "environment", and "natural resources and energy" (Government of Canada, 2007).

Current policy is defining a major role for energy technology in meeting public goals, whether it is to unlock natural resources, to reduce the economy's environmental footprint, or to reduce exposure to volatile commodity prices. The reason for this is clear: without major breakthroughs in energy technologies, key policy aspirations, such as reducing greenhouse gas (GHG) emissions and expansive resource development, cannot be achieved.

The other reason for public ER&D support is the structure and history of the energy sector, which is prone to significantly under-invest in R&D. Because the level of privately financed ER&D is considerably below average, there are major public benefits to be gained, whether through generalized R&D spillovers, as discussed in the previous section, or through better environmental outcomes that markets currently do not value (e.g., reduced GHG levels).

Too little R&D in the ICT sector seems unlikely, given that many firms invest substantial portions of their revenue into R&D; that ICT R&D often delivers new profits within a few years, not decades; and that being innovative is necessary for survival—product and service differentiation is essential to compete with rivals. In the energy sector, however, most firms are in a distinct business universe. Here, the product is a homogenous commodity, the infrastructure is shared, the utility profits are regulated, and the services provided are practically indistinguishable to consumers (e.g., electricity service cannot be differentiated). So, the energy sector has little market incentive to invest in R&D, and so it is known for its "chronic underinvestment in [R&D]" (WBCSD, 2010, p. 14). There are large public benefits—for example, cleaner air, reduced climate change—that are not priced by markets, further increasing the public benefit to be gained from investing in ER&D as it fills a noted market failure.[15]

FIGURE 7 CANADA INDUSTRIAL R&D INTENSITIES (R&D SPENDING RELATIVE TO REVENUES)



Source: Statistics Canada Intramural Research and Development Expenditures as a percentage of revenues

Data for Utilities and Wood Products* is just for the R&D performed by Canadian-owned firms, while other indicators are of total R&D perfromed by both Canadian and Foreigh-owned firms

Canada needs a national energy technology strategy to capture the added benefits of its large resources and to become globally competitive in advanced energy technologies. This strategy will

14. In its national science and technology strategy document, the federal government noted that "Canada has the potential to be a leader in the rapidly emerging business of environmental technology" (Government of Canada, 2007, p. 27).

15. For further discussion of energy industry's limited research tradition, see, for example: Morgan and Tierney, 1998; Margolis and Kammen, 1999.

benefit all of Canada's regions, by pooling national knowledge resources and creating new opportunities for the provinces to become knowledge-intensive energy technology developers, irrespective of their own resource endowments.

ER&D POLICY DESIGN PRINCIPLES

There is very strong evidence in support of publicly funding ER&D. Furthermore, this evidence, combined with the nature of energy technology, points to design principles that should formulate successful ER&D policy—continuous, cross-cutting, and maximizing the public benefit.

DESIGN PRINCIPLES

The nature of the technology cycle and R&D spillovers provide evidence as to why public money should be invested in ER&D. But, how should we make the most of scarce funding? We identified three foundational principles that must shape public ER&D policy.

Continuity in ER&D policy is essential because of the long timelines and preponderance of failures over successes in the technology cycle. Significant labour-based spillovers reinforce the notion of how important continuity is for building and retaining expertise. Large swings in public funding reduce the likelihood and magnitude of public benefits by leaving important ER&D paths unexplored and limiting the ability to attract and retain the people who help generate public benefits and high social returns.

Cross-cutting in ER&D policy should capture the varied and uncertain nature of the technology cycle, where final market technologies represent a very small share of the total research projects. This means that policy should cut across technology paths—covering the whole technology development cycle and multiple applications—as well as cutting across the energy system, from supply to infrastructure and end-use. Because R&D in one area can often lead to breakthroughs in others, it is essential that policy not impede collaboration across fields of research, enterprises, or regions.

Since funding is scarce, it is impossible to pursue every ER&D path, and prioritization is necessary. "The outcome of innovation is uncertain, and, as a result, managing risks requires spreading bets across a range of projects while expecting failures. At the same time, given that budgets are constrained, and that bets that are too small are unlikely to yield results, not everything can be supported" (Anadon et al., 2011, p. 48).

The best way to deliver on this principle is by adopting a portfolio approach in delivering ER&D policy, which, much like a sound financial portfolio, will balance the risk-and-return profile of its investments with the aim of achieving the greatest net return. Clear and measurable targets in each priority area will determine the portfolio composition.

Maximizing public benefits must be the goal of every public ER&D policy. This includes supporting not just the total level of ER&D, but importantly also supporting avenues of development that will not be provided by the private sector, such as public interest projects for health, safety, the environment, and energy security.

The next section will connect principles to practice by discussing specific energy technology policy instruments, and how policy can deliver on these principles.

CANADA NEEDS A NATIONAL ENERGY TECHNOLOGY STRATEGY TO CAPTURE THE ADDED BENEFITS OF ITS LARGE RESOURCES AND TO BECOME GLOBALLY COMPETITIVE IN ADVANCED ENERGY TECHNOLOGIES.

THIS STRATEGY WILL BENEFIT ALL OF CANADA'S REGIONS IRRESPECTIVE OF THEIR OWN RESOURCE ENDOWMENTS.

THE POLICY TOOLKIT

POLICY LEVERS FOR INCENTING ENERGY TECHNOLOGY ACTIVITY: LESSONS FOR CHOOSING AN OPTIMAL OUTCOME-ORIENTED POLICY MIX

How can public policy most effectively apply the ER&D design principles and deliver on energy technology goals?

There are two broad ways to characterize ER&D policies: by where the policy is aimed—to *pull* new technologies into the market or to *push* them in; and by how the policy is delivered—being directly or indirectly applied to ER&D. An understanding of how the different combinations of these two policy approaches work will clarify how to design effective ER&D policy.

POLICY AIM

DEMAND-PULL VS. SUPPLY-PUSH

Demand-Pull measures are premised on the concept that increasing market demand for new energy technologies, such as in times of high energy prices, will pull in new technologies, as investors respond to the market signals. It is believed that if there is a growing market for a certain technology or innovation, it will drive greater R&D to the given technology path. The chance of higher profits will act as the incentive for investors and innovators. Government policies aiming to create a larger market can vary in scope and scale, from imposing standards and environmental regulation to creating markets through subsidies (WBCSD, 2010).

Supply-Push measures are based on the concept that the technology development process is unpredictable and long, and therefore often cannot be treated as a mere reaction to the market. This is particularly relevant in energy technologies where the technology turnover can be longer than a decade—too long to respond to market signals in time. In this logic, advances in scientific and technical knowledge determine the direction and pace of technology turnover (Peters et al., 2011a, 2012).[16] Policies to push technology forward include higher-education funding, R&D tax credits, direct funding of the development of a particular technology, government laboratories, and research institutes.

Both policy types are important and there is general consensus on their complementarity.

POLICY DELIVERY:

DIRECT VS. INDIRECT SUPPORT

Governments can deliver ER&D policy through direct support, such as grants or the funding of research facilities, or through indirect measures, such as R&D tax credits. One of the core distinctions is that "direct R&D grants/subsidies can target specific projects with high potential social returns while tax credits reduce the marginal cost of R&D spending and allow private firms to choose which projects to fund" (OECD, 2010, p. 2).

While Canada's indirect R&D tax credits are technology-agnostic and industry- and region-neutral, direct measures can be targeted to specific projects that are considered to have high social returns. "In general, tax credits are used mostly to encourage short-term applied research, while direct subsidies are directed more to long-term research" (OECD, 2010, p. 2).

Similarly, both delivery methods can be effective in achieving their distinct goals and correcting particular types of market failure, and the choice of which one to use should be based on the desired outcome.

The matrix on the following page summarizes the possible combinations of policy aims and delivery methods (see Figure 8).

16. In this view, the supply of available knowledge is related to the success of a new technology—the greater the base of knowledge available, the greater the likelihood of success (Popp, 2004; WBCSD, 2010).

FIGURE 8 ER&D POLICY OPTIONS MATRIX

ENERGY R&D POLICY TYPES		DELIVERY	
		INDIRECT	DIRECT
AIM	DEMAND-PULL	**Indirect-Pull** Example: carbon tax	**Direct-Pull** Example: electric vehicle rebate
	TECHNOLOGY-PUSH	**Indirect-Push** Example: R&D tax credit	**Direct-Push** Example: funding federal labs

APPLYING THE TOOLS

How can these tools be applied to formulate an effective ER&D policy portfolio and deliver on the goal of accelerating technology innovation?

'Pull' measures can play an important role in accelerating the uptake and refinement of new commercial technologies. Nonetheless, aggressive ***direct-pull policies***, such as Ontario's feed-in-tariff, may not be the optimal measure to incent domestic invention because of significant international spillovers they create—the growing domestic market also creates incentives in other jurisdictions. In Germany for example, the introduction of the feed-in-tariff for solar installations in 2000 resulted in rapid market growth, yet not in a better competitive position for technology development: "As a result [of the subsidy], newly installed capacity in Germany represented over half of world market in 2009. In global comparison, however, the German PV industry did not gain a higher share of patents" (Peters et al., 2012, p. 4). At the same time, domestic demand-pull policies in countries like Germany and Spain fuelled innovation in foreign countries, such as China and Taiwan.

Anecdotal evidence suggests that "the evolution of a rapidly growing market may actually have created a disincentive for the development of non-incremental technology improvements" (Nemet, 2009, p. 705). This can also have an effect of 'locking' a technology that is currently commercially available (e.g., crystalline silicon PV), even if it is technologically inferior to newer but pre-commercial technologies.[17] Aggressive demand-pull policies create a period of rapid and volatile growth in a given incentivized industry (e.g., solar panels). This makes rapid production scale-up and associated cost reduction (through expanding manufacturing) the main competitive goals for the industry, diverting resources away from R&D and technological improvements (Peters et al., 2011). In practice, direct-pull policies can produce results contradictory to long-term policy goals when rewarding "deployment of market-ready technologies is at the expense of developing technologies with greater transformative potential" (Wilson and Gruber, 2011, p. 170).

Therefore, if the goal of long-term energy technology policy is to develop a diversified portfolio of technologies and to impact the entire technology development process, it cannot be achieved by demand-pull measures alone. 'Push' measures are necessary in a successful ER&D policy portfolio because they provide the most leverage for non-incremental energy technology innovation, the greatest impact on increasing ER&D investments, as well as the highest potential public-benefit return on investment.

Direct-push policies provide the most leverage on energy technology outcomes because they allow the greatest ability for implementing the foundational principles of public benefit, cross-cutting, and continuity. By definition, supply-push concentrates more on 'upstream' (pre-commercial) R&D, where social spillovers are greatest (see, for example, Nelson and Romer, 1996), which allows focus on projects with greatest social return potential. Conversely, **indirect-push** policies are not the right tool to create a sector-specific R&D policy because they provide minimal leverage or specific impact on energy technology in particular.

Indirect-pull, another major aim/delivery combination, can be an effective catalyst for new energy technologies—when applied broadly enough, such as through a comprehensive carbon tax. However, much like the indirect-push policy, it does not necessarily target the projects with highest social returns. While "[i]n principle, governments could announce a time path for future environmental policies that might induce the appropriate level of R&D investment in anticipation of future emissions policy, ... there are many reasons both practical and theoretical why such advanced policy commitments are unlikely to be forthcoming, and why they may not represent credible commitments if announced" (Jaffe et al., 2005, p. 169). Note that if tech-

17. A study that examined historical patenting trends in wind turbines (Nemet, 2009), showed that: "The periods of strong demand-pull do not coincide with the periods in which the most important patents were developed ... The peak in filing of variable patents occurred when there was almost no market for the technology ..." (Nemet, 2009, p. 704).

nology policy is used as a substitute, not a complement, to environmental policy, it will prove highly expensive (Jaffe et al., 2005).

Just as technology is the prime-mover within the innovation system, direct ER&D funding is the key to getting more new energy technologies, and the most important instrument for delivering ER&D policy.

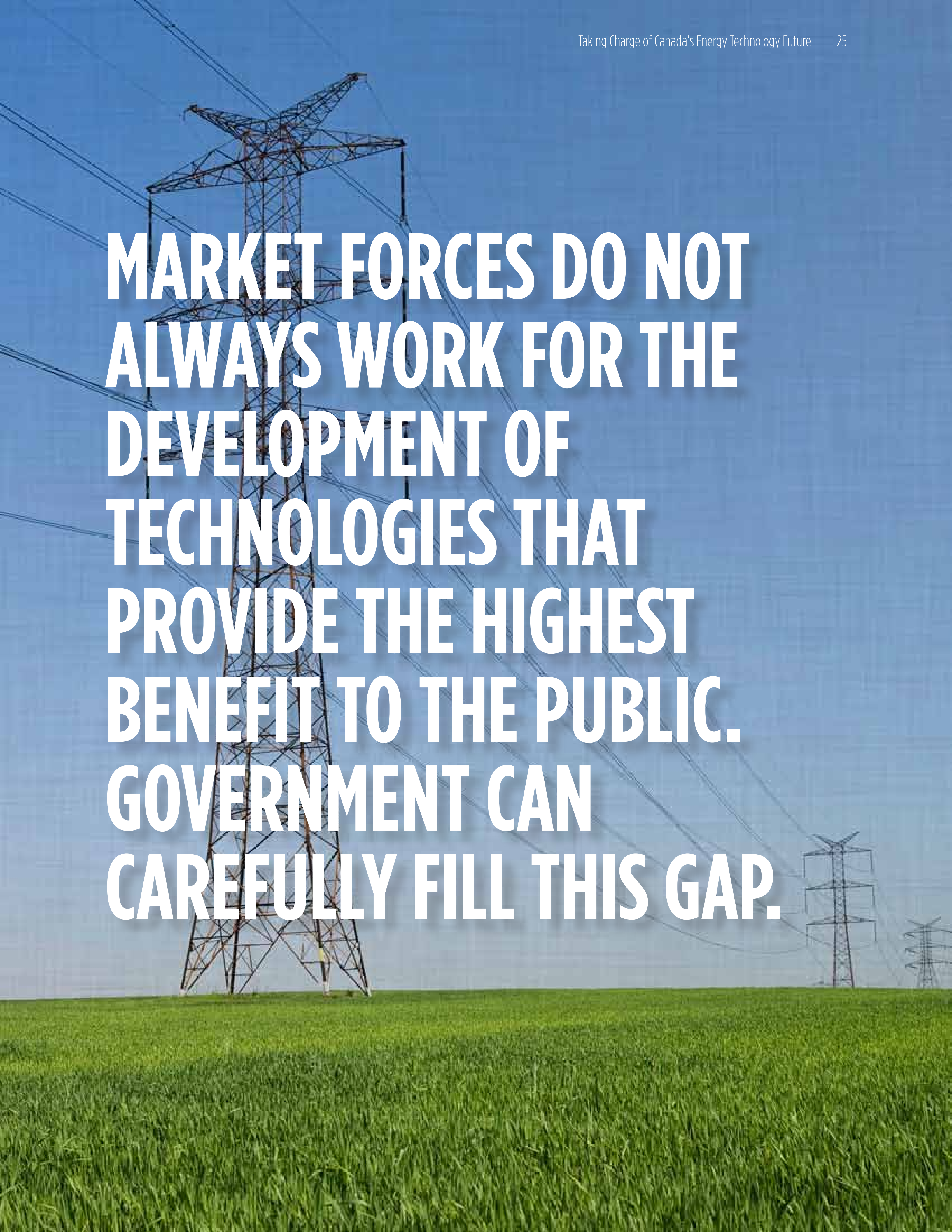
CONCLUSION

One option for allocating scarce public funds is to "treat investments in technology-push and demand-pull policies like a portfolio of financial assets," allocating assets based on a risk return profile (Peters et al., 2011, p. 28). A deliberate ER&D policy will be most effective when the policy portfolio is optimized to the desired outcomes.

The current Canadian policy portfolio tends to over-use direct-pull and indirect-push measures—Ontario's feed-in-tariff and federal R&D tax credits—while undermining the necessary direct-push mechanisms.

While modest pull incentives or renewable standards and technology-agnostic R&D tax credits can be parts of a complete ER&D policy, substantially more attention should be given to direct-push measures. The evidence shows that there are large public gains to be made and that the core policy lever to maximize these gains is direct-push funding.

The next section reviews past international and Canadian experiences in ER&D policymaking to find out if direct-push ER&D policy has been implemented before, in what context, and whether it worked.



MARKET FORCES DO NOT ALWAYS WORK FOR THE DEVELOPMENT OF TECHNOLOGIES THAT PROVIDE THE HIGHEST BENEFIT TO THE PUBLIC. GOVERNMENT CAN CAREFULLY FILL THIS GAP.

ER&D FUNDING IN RETROSPECT

ENERGY TECHNOLOGY POLICY SINCE THE 1970s: IMPORTANT LESSONS FOR REFORMING CURRENT APPROACHES

THE 70s ENERGY SHOWDOWN

What can we learn from the history of public spending on ER&D?

The notion of expecting energy technology to handle global energy challenges is anything but new. The benefit of four decades of ER&D policy hindsight is the key to getting it right this time.

History shows that the practice of 'picking winners' can be successful in some cases. But history also shows that maintaining ER&D as a priority is difficult with the waxing and waning of political preferences. It is also evident that policy and institutional design are critical to predetermining ER&D outcomes.

The 1970s story is foundational to energy policy in general and ER&D in particular. Oil supply shocks of the 1970s are recognized to have been "among the strongest drivers of energy R&D efforts in industrialized countries. Between 1973 and 1981, government investments in energy R&D rose to their highest levels, as new programs and institutions formed in response to oil supply interruptions initiated by the OPEC" (Runci and Dooley, 2004, p. 445).

In 1973, the first major global energy crisis alerted the world to a new energy reality of price instability and the possibility of foreign supply shocks. The crisis initiated a wave of energy policy actions around the world. Many key energy governance institutions, both national and international, were created in this wave of crisis management. The International Energy Agency (IEA) was established, and energy became a top priority across the Western world. The G7 committed to "continue to cooperate in order to reduce ... dependence on imported energy through conservation and the development of alternative sources" (G7, 1975) after its first meeting in 1975.

For national governments, the energy crisis sparked a major wave of policy activity focusing, for the first time, on comprehensively managing energy challenges (mainly through conservation and diversification away from oil). This marked the first boom cycle in comprehensive ER&D funding.

In the **United States**, the response was the Nixon doctrine, Project Independence. As the name suggests, the goal was to make the U.S. energy-independent by 1980. This was to be accomplished mainly through increasing domestic production, while dramatically reducing demand and establishing a comprehensive ER&D program.

Energy conservation was recognized as "a national necessity," and Nixon highlighted "the need for the development of a national energy ethic directed equally toward conserving the energy we now use and exploring ways to limit future energy demands" (Morton, 1973, p. 71).

> **FOR NATIONAL GOVERNMENTS, THE ENERGY CRISIS SPARKED A MAJOR WAVE OF POLICY ACTIVITY FOCUSING, FOR THE FIRST TIME, ON COMPREHENSIVELY MANAGING ENERGY CHALLENGES, MAINLY THROUGH CONSERVATION AND DIVERSIFICATION AWAY FROM OIL.**

The Office of Energy Conservation was established, under the umbrella of the Department of Commerce, to coordinate scattered existing federal programs. Later, the Ford Administration followed through with establishing the Energy Research and Development Administration (ERDA), with a proposed budget of $10 billion ($52.3 billion in current USD) over 5 years (Morton, 1973; Wilson Quarterly, 1981). In 1977, the Carter Administration and Congress acted to further consolidate federal energy policy, ER&D, and nuclear defense functions and created a Cabinet-level U.S. Department of Energy (DOE)—effectively combining "50 different agencies, departments, and bureaus in the federal gov-

EPRI (ELECTRIC POWER RESEARCH INSTITUTE) and GRI (GAS RESEARCH INSTITUTE)[18] were two important offspring of the new ER&D culture in the United States. EPRI, established in 1973, and GRI, in 1976, were the energy utilities' industry responses to the widespread demand for new technology solutions to energy challenges. They were industry non-profit collaborative research organizations of electricity and gas utilities, respectively (Star, 1983).[19]

ernment" (Priddy, 2008, p. 3).[20]

Other industrialized countries also undertook robust action on energy governance.

The **European Community** created two consecutive joint ER&D programs, 1975–79 and 1979–83. These programs aimed to stimulate and coordinate contract research, with the European Commission bearing up to 50% of the costs. Priority areas included energy conservation, the production and use of hydrogen, solar energy, geothermal energy, and energy systems analysis (McMullan and Strub, 1985).

In addition, national European governments created their own programs: the **Netherlands** set up an Energy Research Council; the **UK** created its Department of Energy, the Energy Technology Support Unit, and the Advisory Council on Energy Conservation; **France**, **Germany**, and **Japan** also created sizeable ER&D organizations (Surrey and Walker, 1975; McMullan and Strub, 1985; Lootsma et al., 1986).

Canada, like its peers, took action in response to the oil shocks, making energy self-sufficiency a new policy aim. But the Canadian approach to ER&D policy was markedly different from those of the countries mentioned above. Instead of a centralized ER&D governing body, the Canadian government opted for a decentralized approach, forming the Interdepartmental Panel on Energy R&D (IPERD). There was no Canadian equivalent of the DOE. "Because of the many departments involved in energy, Canada rejected the notion of a centralized agency like ERDA and adopted a lighter structure" (Gingras and Rivard, 1988, p. 36).

IPERD acted as a central policy and planning committee. It coordinated the federal ER&D program and recommended resource allocation among different parts of the energy system, in collaboration with the provinces and the IEA. The government provided IPERD with an annual budget, which was then distributed based on federally-set energy policy priorities.

Implementation was left to the discretion of ministries and agencies involved. The key organizations involved in ER&D through IPERD were: the Ministry of Energy, Mines and Resources; Atomic Energy Canada Ltd (AECL); and the National Research Council (NRC). IPERD also included representation from many other federal departments, including: Transportation, Public Works, Agriculture, Fisheries and Oceans, and Defence (Gingras and Rivard, 1988).

The key weakness of such a decentralized approach, with no clear lines of authority, was the resulting duplication of responsibility for the energy file across various government entities. The issue was further complicated by Canada's constitutional division of powers, which made the emergence of a central coordinating body challenging. The result was numerous federal and provincial agencies legislating and implementing in the same area, such as conservation or research. A 1982 paper, 'Consumer Energy Conservation Policy in Canada,' identified "four major obstacles to energy conservation policy formulation and implementation ...: federal-provincial relations, intra-departmental organization, inter-departmental overlap, and lack of government-industry cooperation" (McDougall and Mank, 1982, p. 219). Three decades later, Canada's energy governance faces very similar issues.

A historical analysis of IPERD's activity shows three periods of the boom-bust cycle in Canada's public ER&D funding. The initial period during 1975–80, when funding was on the rise; the peak in 1981–84, after the creation of the National Energy Program; and the subsequent decline, which saw a rapid drop in the IPERD budget (Gingras and Rivard, 1988).[21] In Canadian current dollars, the

18. The GRI will be examined in greater detail in the next section of the report . It serves as an example of institutional design for delivering collaborative industry R&D.

19. EPRI was not formed as a response to the OPEC crisis. The organization's roots are more directly linked to the massive 1966 blackout, which put the industry under threat of government-mandated research and induced it to opt for a voluntary organization instead (Morgan and Tierney, 1998).

20. DOE was a consolidation of the former ERDA, Federal Energy Administration, Federal Energy Regulatory Commission, the Economic Regulatory Administration, the automotive research and development sections of the Environmental Protection Agency, Solar Research and Development from the National Science Foundation, and Fossil Energy and Development from the Department of the Interior's Office of Coal Research, as well as several power administrations.

21. Most of this decline was in areas like renewables and conservation, while the oil sands and heavy oil budgets were not cut in IPERD during the examined period of decline—1984 – 86 (Gingrais and Rivard, 1988).

ENERGY EFFICIENCY—A NEW DIMENSION

One of the most notable developments of this era was the establishment of energy conservation as a key energy policy priority. The pay-off was quickly visible in energy savings (Penner, 1979).

One example is the public investment into advanced refrigerator and freezer compressors, electronic ballasts for fluorescent lamps and low-emissivity glass, where $12 billon of total DOE and private investment has generated cumulative savings of over $30 billion (Newell, 2011).

funding for these three periods would be roughly equal to: $90.5 million in 1981; $332.8 million in 1984, and roughly $153 million in 1986 (Gingras and Rivard, 1988; Bank of Canada Inflation Calculator). Today, the total annual budget for the contemporary IPERD, the Panel for Energy Research and Development (PERD), is held constant at $55 million annually (IEA, 2010a).

The legacy of a decentralized hands-off approach carried forward into the present. Unlike the US, which institutionalized a serious approach to energy policy and ER&D, Canada never followed that route. Although major drops in ER&D financing from the early 1980s peak occurred in most industrialized nations, through the 1990s and into the 2000s, in Canada this was further exacerbated by the lack of centralized responsibility and expertise to guide a balanced energy technology policy.

One notable exception in Canada's generally weak ER&D policy track record was a provincial success story—the Alberta Oil Sands Technology Research Authority (AOSTRA). Established at arm's length in 1974 and lasting for nearly two decades, independent AOSTRA became instrumental in a major breakthrough in oil recovery technology, the steam-assisted gravitational drainage (SAGD). For a provincial project, it had an impressive scale of funding provided largely by the province,[22] with an initial provincial budget endowment of $100 million over 5 years, equivalent to roughly $489 million today (Hester and Lawrence, 2010; Bank of Canada Inflation Calculator).[23] Below in Section 5 we look at this case in more detail for policy and institutional design lessons.

THE 90s—SPIRALING DOWN

Despite a policy momentum triggered by the energy crises, public commitment to energy technology did not last in the 1990s; the discomfort of the crises was quickly forgotten as low oil prices and excess supply "alleviated the sense of urgency that had helped previously to spur high R&D investment levels" (Runci, 2005, p. 2). As a result, global ER&D went through a period of rapid decline, with drastic funding reductions across the IEA (except Japan and Switzerland) (Runci, 2005).[24]

The fading of pressing "perceptions of vulnerability" was also accompanied by a wave of structural changes in IEA countries' energy industries, usually referred to as liberalization, deregulation or privatization. The transfer of utility control from public to private hands has in effect translated into "an implicit transfer of R&D responsibility from public to private sector" (Runci, 2005, p. 2), without adequate policy consideration about overcoming the market's failure to provide incentives for sufficient ER&D investment.

In a regulated environment, with vertically integrated structures, utilities were able (and often required) to reinvest a portion of their revenues into collaborative ER&D efforts to benefit the industry and the public at large (public interest R&D) (Sterlacchini, 2012; Sanyal and Cohen, 2009). However in a price competitive setting with a greater number of players, ER&D investments were being drastically reduced in an effort to save on extra costs.

This negative effect on ER&D funding does not negate the purpose of deregulation as a means for increasing sector management efficiency. But it does highlight an unintended consequence—the further reduction of an already low ER&D rate.

After governments scaled down ER&D investment in the late 80s, many technologically feasible long-term projects disappeared from the scene, creating a major delay in technology development. In the private sector, ER&D investments were "typically a three-year horizon to commercialization, a probability of success exceeding 90 per cent, and a sufficient return on investment" (Bernard and Santini, 1989. p. 557). This is in direct opposition to

22. Federal funds were not substantive, relative to the provincial contribution.

23. Over its lifetime, AOSTRA spent $448M, equivalent to roughly $1.1 billion today (Hester and Lawrence, 2010; Bank of Canada Inflation Calculator).

24. At the time, over 90% of industrialized world's public sector ER&D was performed by nine countries: Canada, France, Germany, Italy, Japan, the Netherlands, Switzerland, the UK, and the US, and in all of these countries, except Japan and Switzerland, public sector R&D expenditures fell significantly (Dooley, 1998).

the long timelines required for energy technology development.

LESSONS FROM HISTORY

The policy history of the past 40 years is in direct contradiction to the principle of continuity. Historical trends demonstrate a disturbing boom-and-bust cycle in ER&D funding. The first boom reached its peak within just a decade, and the following bust lasted twice as long. Contrasted with the energy technology cycle, which lasts on average 20 years, policy failure becomes apparent.

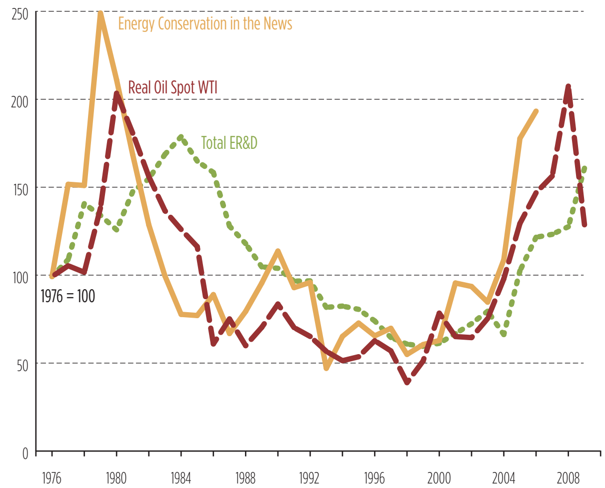
During the bust years, ER&D in both the public and private sectors in many of the top ER&D performing nations shifted toward "very near-term projects, implying that very little long-term, high-risk (and therefore presumably) high-reward energy R&D [was] being carried out" (Dooley, 1998, p. 549). This meant a general move away from strategic ER&D funding for future energy supply options (Dooley, 1998). That shift violated both the principle of cross-cutting energy R&D and the principle of public-benefit maximization.

But there is another lesson to be learnt from past experience. Serious commitment to a public goal can translate into real successes and institutions that effectively deliver ER&D over multiple decades. This has been the case with the U.S. DOE, the U.S. GRI, and Alberta's AOSTRA. Long-lived approaches are the key to overcoming the wasteful inefficiencies of the boom-and-bust cycle ER&D funding approach and ensuring continued delivery of results.

The current decade is the first to see increasing ER&D funding levels since the bust years, though these are still below the peak level years of the last boom. The prolonged trough that came out of governments' waning attention to ER&D led to slowed progress for energy technologies and many lost opportunities.

Figure 9 shows that ER&D spending is correlated with the price of oil. The news index illustrates the number of times the words "energy conservation" appeared in the Financial Times, and demonstrates that it has only been prominent when prices rose, and dropped as suddenly as the energy crisis receded. This lesson from history poses a serious challenge to delivering on the first design principle for ER&D: ***continuity***.

FIGURE 9 HISTORICAL INDEX: TOTAL CANADA ER&D SPEND, "ENERGY CONSERVATION" IN THE NEWS AND OIL SPOT-PRICE



Source: author's compilation using Financial Times Digital Archive; IEA ER&D budgets (1976–2009); St. Louis Federal Reserve Inflation Calculator

Prior to restructuring, large U.S. utilities were funding ER&D projects in a major way. In addition to applied research, the utilities spent significant portions of their research budgets on public-interest environmental research projects. After restructuring, large projects with potential externalities were replaced by small and targeted ones. For Southern California Edison, such R&D spending dropped from $11 million to $160,000, or by 98%, as a result of privatization (Sanyal and Cohen, 2009).

THE UTILITIES' STORY

In the United States, the drop in ER&D investment by the utilities became pronounced with the passage of the Energy Policy Act of 1992 that allowed states to begin privatization processes. While federal funding for ER&D through the DOE declined by 10% in real terms between 1985 and 1994, private-sector funding declined more than 42% in real terms over the same period (Dooley, 1998). ER&D expenditures by U.S. electric utilities dropped by roughly 74%, from 1993 to 2000 (Sanyal and Cohen, 2009). The same trend occurred in other privatizing jurisdictions around the world (see, for example, Sterlacchini, 2012).

Aside from the drop in utility ER&D funding levels, the remaining balance shifted from long-term, higher-risk projects to very short-term ones, both in the U.S. and across other industrialized countries. For example, UK utilities' typical sponsored ER&D projects had lifetimes of 5–7 years prior to deregulation, and under 3 years after. The little R&D that remained was less cross-cutting.

The Gas Research Institute (GRI), ceased to exist soon after deregulation. The Institute was slowly dissolved by its members in response to the changing competitive structure of the market. Gas industry players were no longer prepared to commit a set amount to collaborative ER&D when price competition was about to become a major factor. GRI merged with another gas research organization to form the current Gas Technology Institute, an applied research service organization for the industry. It does not function as a broader public ER&D body, as did the GRI (Paulson, 1998; American Gas, 1999; Schimmoller, 2000).

Similarly, in the UK over one-third of electric utilities completely pulled out of the 3-year collaborative ER&D programs in the EA Technologies (a British equivalent of EPRI) (Dooley, 1998).

This development, in turn, had a ripple effect on the research budgets of electric and other utility equipment-manufacturers (EMs). "Faced with such a chaotic market for their goods and a lack of cost-sharing for R&D, EMs appear unwilling to bear the full cost and full risk of developing new energy supply technology systems and are therefore curtailing their own R&D investments" (Dooley, 1998, p. 553).

HOW TO DELIVER RESULTS

FOUR CASES OF SUCCESS IN DELIVERING POSITIVE TECHNOLOGY RESULTS: LESSONS FOR EFFECTIVE INSTITUTIONAL DESIGN

THE BIG SPILLOVER

HOW TO DO DIRECT ER&D FUNDING

Perhaps the most important lesson from history is: not to take good policy momentum for granted, hoping that it will continue to propel itself forward indefinitely. Recent increases in ER&D may be at risk, due to the need for governments to restrain spending. The conditions are in place for another ER&D bust.

History shows that direct ER&D funding was cut not for lack of effectiveness or value for money. Rather, direct ER&D funding was cut mostly due to unrelated political trends, changing perceptions, and shifting priorities.

To use historical examples to learn how to deliver ER&D, the first question we should be asking ourselves is: Was it worth it? If the answer is "yes," then ER&D policy is less about something completely new, and more about doing what we already know is a good idea.

As it turns out, publicly funded long-term programs did succeed in providing substantial benefits.

Most of today's mainstream renewable energy technologies were developed in the previous ER&D boom (notably, modern wind turbines and solar modules). Some of the key breakthroughs in energy technology generated by publicly sponsored research included: distributed generation technology (combustion turbines, fuel cells, and photovoltaics); integrated gasification combined cycle; renewable technologies (wind, geothermal, biofuel); and the creation of demand side management (DSM) programs (Morgan and Tierney, 1998). Arguably, with renewed interest in these technologies, we are picking up today where our predecessors left off 30 years ago.

In this section we look at four examples covering international, regional, and industry-led public-funding mechanisms: Finland's national innovation system (NIS), the U.S. Department of Energy (DOE), the former Alberta Oil Sands Technology Research Authority (AOSTRA), and the former Gas Research Institute (GRI). Each case study represents a distinct method of delivering public energy technology policy. All show measurable success and provide further lessons for how to design and implement ER&D policy. But all share one key lesson: when ER&D funding is sustained for the long-run and delivered consistently with the core principles outlined above (see p. 21), the benefits of public ER&D can be huge.

FINLAND

NATIONAL INNOVATION SYSTEM (NIS)

Finland's rapid transition from a stagnating resource economy, driven mostly by the export of processed forest products, into a sophisticated high-technology leader makes it a valuable example. "A peculiarity of the Finnish case is in the atypical pattern of industrial renewal from essentially natural-resources-based industries toward machinery, engineering, electronics, and ICT" (Andersson, 2010, p. 12).

Today, "70 per cent of business sector R&D is dedicated to high-tech," the highest share in the EU (Andersson, 2010, p. 18). Finland is a top performer in patenting activity, and has the fifth highest ratio of triadic patent families[25] in the OECD—63 per million of population, nearly four times the Canadian number of 17 (OECD, 2012).[26]

25. Refers to patents registered simultaneously in Japan, the US, and the EU.

26. Canada is in 17th place in triadic patent families per million of population (OECD, 2012).

FROM PULP AND PAPER TO MOBILE PHONES

In the 1980s when the Finnish government first started discussing the need to transform the country into a knowledge economy, Nokia was a large diversified corporation with "strong roots in pulp and paper production" (Oinas, 2005, p. 1230). Finland's economy was hit hard in the 1990s by a combination of factors, including the collapse of its major export market (the USSR), escalating debt, and a major banking-sector crisis, pushing it into deep recession. Already by 1999, Finland was ahead of many peers with "strong export positions in mobile phones, base stations and switches," and Europe's largest manufacturer of PCs (Lyytinen and Goodman, 1999, p. 13).

Finland's success was not a lucky coincidence, but the result of decades of deliberate policy choices and prudent planning. Finnish technology policy success became visible only gradually—in 1990, Finland still had a trade deficit in high-tech products, with technology imports being almost double the exports. But over the decade, Finland became a net exporter of high-technology and "overtook Sweden, the U.S., and the EU average in the ratio of high-tech exports to high-tech imports." (Ali-Yrkko and Hermans, 2002, p. 24)

The Finnish National Innovation System (NIS) is a case study full of prudent technology-policy lessons, particularly for its institutional and policy design. Finland is in first place among ER&D funders in the IEA, as measured by intensity of funding, with nearly double that of Canada's per unit of GDP—0.134% vs. 0.073% (IEA, 2011).

Most notably, Finland has been continuously increasing its public funding of R&D for several decades. But in relative terms, the government share of total R&D support has been dropping as a result of a more rapid growth of the business share. Today, the Finnish private sector funds some two-thirds of the gross national R&D expenditures (GERD) (Andersson, 2010).

The Finnish government demonstrated a remarkable ability to carry through with its R&D mission across electoral cycles. Its national technology policy demonstrates all three foundational principles: it seeks to maximize public benefit, with a commitment to continuity, and cuts across areas and stages of R&D.

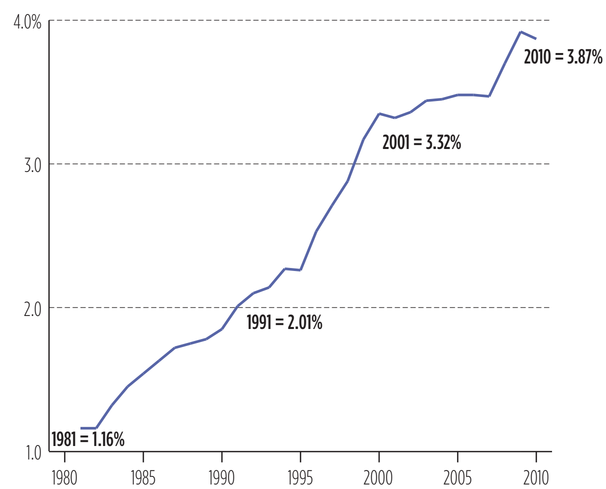
This sustained case of public-policy commitment seems almost anomalous. For instance, public funding for R&D in Finland "rose at a time when virtually all other public expenditures were cut in the midst of a recession" (Andersson, 2010, p. 17).

HOW IT WORKS

Finland channels its public R&D funds through a single centralized NIS. What is known today as the Finnish NIS was largely created in the 1960s and 70s, when the Finnish government began tackling the problem of low R&D levels, particularly in the private sector. The government's goal was to transition the economy from a resource-based one to a knowledge-based one.

In the 1970s, Finland chose to put policy emphasis on "technical research, technical faculties, research institutes and firms" (Oinas, 2005, p. 1235). Hence, the core suite of science and technology organizations was mainly created in the mid-1970s, and they and their tasks have largely remained intact (Oinas, 2005).

FIGURE 10 EVOLUTION OF FINLAND'S R&D INTENSITY - TOTAL R&D PER UNIT OF GDP



Source: OECD, 2011

Institutional design clearly reflects these technology policy goals, delivering them through a focused R&D portfolio. Although the highest level of authority lies with the parliament, its decisions are limited to general direction-setting and are largely guided by the advice of the Science and Technology Council. Most importantly, particular funding choices are made by two key expert R&D funding agencies,[27] the Academy of Finland and the Nation-

27. Note that Finland does not use R&D tax credits for delivering its public funding. Direct methods of delivering public R&D support are used.

INSIDE THE NIS

1. High-level policy delivery is facilitated by the Science and Technology Council. The Council acts as a high-level advisory and coordinating body, bringing together high-level representatives from government, industry, academia, and labour-market organizations. Responsible for the strategic development and coordination of science and technology (S&T) policy, and NIS as a whole, the Council has been credited with ensuring policy continuity through government transitions. One of its core functions is to conduct a comprehensive review of the system and its effectiveness every three years, and this review in turn serves as the main guide for policy direction.

Ministries—There are only two key ministries responsible for technology policy: the Ministry of Industry and Trade and the Ministry of Education. They distribute budget allocations among appropriate agencies.

2. R&D funding agencies set research priorities and make specific funding decisions.

The first, Academy of Finland, funds basic research through competitive grants and is a central agency for science administration under the Ministry of Education. The second, National Technology Agency of Finland (TEKES), funds collaborative R&D on a competitive basis, acting as the link between basic research and industry through selective project funding.

Technology focus areas are aligned with strategic priorities in the national strategy.

Having only two players in this space is a major advantage. "Cooperation between them is very tight and joint programs are common" (Andersson, 2010, p. 39). There is also an independent fund that provides venture capital for high-tech business, SITRA (Finnish National Fund for R&D).

3. R&D-performing agencies include universities, polytechnics, and government research institutes.

One key performer is the Technical Research Centre of Finland (VTT), a state-owned agency and "the biggest polytechnic applied research organization in Northern Europe. It constitutes 6 relatively independent research institutes, with a strong central organizational function" (Andersson, 2010, p. 4).

al Technology Agency of Finland (TEKES). Specific funding decisions, therefore, are isolated from parliamentary politics (Andersson, 2010).

The main attribute of the Finnish system is its relative simplicity, characterized by a clear centralized structure with defined roles and responsibilities for every agent. This example demonstrates that success can be achieved with a relatively small number of players with clear roles.

Finland's continued commitment to R&D policy driven by the goal of growing the nation's R&D intensity translated into remarkable success, illustrated by Figure 10. In just two decades, Finland was able to triple its R&D intensity, from a mediocre 1.16% in 1981 to the second highest in the world (after Israel), 3.87%, in 2010 (OECD database, 2011).

UNITED STATES

DEPARTMENT OF ENERGY (DOE)

The U.S. manages its energy technology policy federally, through a centralized Department of Energy (DOE). One of the DOE's core mandates is its "leadership role in transforming the energy economy through investments in research, development of new technologies, and deployment of innovative approaches" (US Department of Energy, p. 1). It is the largest science-based department in the U.S. (measured by level of funding).

There have been failures, most notably the infamous Synthetic Fuels Corporation (SFC) in the 1980s, and Solyndra in 2011. Nevertheless, the overall benefit of DOE R&D activity has been large, significantly exceeding its costs, as has been demonstrated by the U.S. National Research Council's Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy (Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, 2001).[28]

The Committee found that programs "yielded significant benefits (economic, environmental, and national-security-related), important technological options for potential application in a different (but possible) economic, political, and/or environmental setting, and important additions to the stock of engineering and scientific knowledge in a number of fields" (Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, 2001, p. 5).

28. The independent committee was tasked to review the work of two of the DOE's offices over their 20 years of existence (1978–2000) in order to evaluate program effectiveness by comparing generated benefits to funding costs.

Even though the Committee used a conservative assessment, assuming that public funding could do no more than bring technologies to market five years faster than otherwise, the net economic benefits over 22 years were $30 billion for energy efficiency and $11 billion for fossil fuels, on investments of $7 billion and $4.5 billion, respectively (1999 USD) (Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, 2001).[29]

The DOE has partially failed on the principle of **continuity**, having followed the boom-and-bust cycle in ER&D funding. Nonetheless, the sheer scale of its remaining activity, even in the years of lowest funding still provides a substantial level of continuity. Overall, DOE investments in ER&D were a success, with sizeable net public benefits.[30] This is another piece of evidence for the unusually large spillovers that can be captured from public ER&D funding.

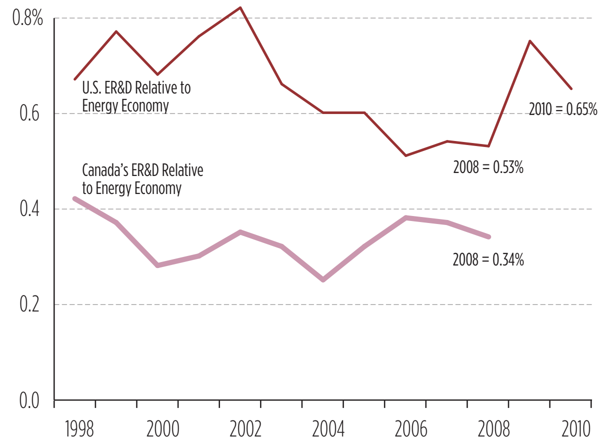
HOW IT WORKS

The U.S. centralized federal approach to ER&D is, by design, fundamentally different from the current Canadian model. One of the key differences is the fact that the U.S. has a comprehensive federal energy policy, the goals of which inform the corresponding ER&D policy. In Canada there is no unified energy policy at the federal level, which makes creating a coherent approach to ER&D more difficult.

The National Research Council (NRC) Committee report argues that it was only in the 1990s that the DOE finally reached a balance and began adopting a portfolio approach to deliver its ER&D funding (Committee on Benefits of DOE R&D on Energy Efficiency and Fossil Energy, 2001). A necessary feature of this approach is the recognition that "energy policy must serve multiple goals and that research produces failures as well as successes" (US Department of Energy, 2011, p. 10).

The U.S. continues to be a world leader in high technology and innovation. In absolute terms, it funds the most ER&D in the world, over USD $4.7 billion in 2010 (IEA, 2011).[31] This is a much smaller intensity than Canada's on a per GDP basis, however the sheer scale of American investment makes it a key player in energy technologies and a leader in several areas, from fossil fuels to renewables and nuclear. Also, as seen in Figure 11, Canadian ER&D investments are actually lower than in the U.S., compared relative to the size of each country's energy economies.

FIGURE 11 CANADA'S ER&D INVESTMENTS RELATIVE TO THE SIZE OF ENERGY ECONOMY



Source: Author's calculation using data from Statistics Canada, IEA, and U.S. Bureau of Economic Analysis
Note: Canadian data is not available for 2009 and 2010, but it is likely that in light of the recent Canadian ER&D level increase, Canada's intensity gap with the U.S. has narrowed.

Given past success and continued commitments, it is worth noting where the DOE's policy is going. The portfolio approach appears to remain the backbone of the DOE's ER&D management. In recognition of the need to substantially increase the pace of technology development, the DOE intends to make its research "more goal-oriented and multidisciplinary; ... to better couple basic and applied work; and ... [to] encourage academia-laboratory-industry partnerships" (US Department of Energy, 2011, p. 16). To accomplish this, the DOE developed a portfolio of new research programs, including Energy Frontier Research Centres (EFRCs),[32] Energy Innovation Hubs,[33] and the Advanced Re-

29. It is likely that fossil energy benefits are significantly lower due to the SFC scandal.

30. This may be at odds with reader impressions from media coverage of specific failures.

31. The majority of that funding (USD$3.3 billion in 2012) is distributed through direct investments (Congressional Budget Office, 2012).

32. **EFRCs** are designed to address fundamental research needs for transformational energy technologies. These "integrated, multi-investigator Centers will conduct fundamental research focusing on one or more of several 'grand challenges' and use-inspired 'basic research needs' recently identified in major strategic planning efforts by the scientific community." See http://science.energy.gov/bes/efrc/.

33. **The Hubs** are designed to bring together multidisciplinary teams of "top researchers from academia, industry, and the government laboratories with expertise that spans multiple scientific and engineering disciplines under the leadership of a dynamic scientist-manager. These teams orchestrate an integrated, multidisciplinary-systems approach to overcoming critical technological barriers to transformative advances in energy technology." See http://energy.gov/articles/what-are-energy-innovation-hubs.

Steam-Assisted Gravitational Drainage (SAGD)

AOSTRA was instrumental in bringing the world a revolutionary oil sands technology: SAGD. The process has advantages over earlier technologies, including an up to 45% higher bitumen-recovery rate, significantly lower natural gas and water usage, and less damage to the environment than the incumbent cyclic steam stimulator (CSS) (Humphries, 2008).

In 1982, AOSTRA and the Gulf Canada Resources company completed "an in-depth feasibility study and engineering design for a shaft and tunnel field pilot" (Hester and Lawrence, 2010, p. 25). The prototype was needed to demonstrate combined horizontal drilling and steam technology, which could provide the necessary breakthrough for in-situ recovery. However, the 1980s crash in oil prices resulted in Gulf's withdrawal from the project before construction could begin. Remarkably, AOSTRA decided to proceed on its own, with industry acting only as advisors.

In 1984, AOSTRA announced the construction of the Underground Testing Facility (UTF), with an initial projected cost of $42 million and a real cost of $84 million. In 1987, the UTF was completed and open for testing and, in 1993, AOSTRA announced being "on the verge of a commercial breakthrough with SAGD" (Hester and Lawrence, 2010, p. 25).

This is not the entire timeline of the technology however. The fundamental concept of SAGD technology was first discovered by Dr. Roger Butler in 1969 (Lowey, 2006). Furthermore, after the successful demonstration in the 1990s, full-scale deployment is still in its early stages today due to the length of industry lead times. The SAGD technology cycle exceeded forty years.

search Projects Agency-Energy (ARPA-E).[34] All three are meant to do "mission-oriented" work and to foster high-risk, high-return technology development projects with strong transformational potential, which makes these programs particularly notable from a **public-benefit maximization** perspective.

ALBERTA OIL SANDS TECHNOLOGY RESEARCH AGENCY (AOSTRA)

The AOSTRA is a predecessor of the present-day Alberta Innovates. AOSTRA was one of the largest provincial ER&D programs in Canada. It generated some 116 patents and patent applications and invention disclosures from nearly 200 projects over its lifetime. The organization is often credited with 'unlocking' the oil sands resources in the province (Hester and Lawrence, 2010).

In the 1970s, Alberta's government made a decision to develop the province's unconventional oil reserves. The venture was highly risky and expensive at the time, requiring decades of R&D, millions in investment, and a high degree of political risk.

When the commitment was made, there was no commercial technology to extract the majority (80%) of 'potentially' valuable oil sands resources, and the technological challenges standing in the way were vast. After two decades of the Alberta government staying the course, AOSTRA delivered by developing a breakthrough in-situ technology and unlocking billions of barrels of oil sands.

Over its two-decade existence, AOSTRA also worked on other related technologies, such as upgrading. It made multiple contributions to industry knowledge, which continue to provide a foundation for research in the field (Heidrick and Godin, 2006; Hester and Lawrence, 2010).

HOW IT WORKED

AOSTRA received most of its funding from the provincial heritage fund established by Premier Lougheed in the 1970s. Its main assets were the high level of expertise and the ability to manage research projects, which were selected based on a carefully designed request for proposal process (Heidrick and Godin, 2006).

AOSTRA did not perform ER&D itself, but instead contracted it out based on specific techno-

34. **ARPA-E** focuses exclusively on funding the potentially transformative energy technologies that fall outside of the scope of regular DOE research programs. "ARPA-E focuses exclusively on high risk, high payoff concepts – technologies promising genuine transformation in the ways we generate, store and utilize energy." See http://arpa-e.energy.gov/About/Mission.aspx. .

logical expertise criteria. One of its key tenets was to engage industry, working as a public-private partnership. The total funding for its projects over its lifetime was, on average, split 53-47 between industry and AOSTRA (Heidrick and Godin, 2006; Hester and Lawrence, 2010).

The most prominent features in the organization's success were its continuity and acceptance of failure as an inherent part of ER&D progress. Policymakers in Alberta were conscious of the long-term nature of this technology project and clearly understood that "widespread commercial applications would be unlikely for two-three decades" (Hester and Lawrence, 2010, p. 21). Even after ten years in operation, when "the only full-scale commercial oil sands operations remained surface mines" and AOSTRA's "goal of delivering a commercially viable in-situ technology [still] remained elusive," the program continued its work in fulfilling the mandate (Hester and Lawrence, 2010, p. 25). Today, it is clear that AOSTRA is a success story when measured against the goal of unlocking unconventional oil through technological innovation.

Although AOSTRA was instrumental in the oil sands breakthrough, it should be noted that the research in the sector dated back to the 1920s. AOSTRA's success cannot be viewed in isolation from this prior work, which was conducted mostly by the Alberta Research Council. AOSTRA continued to build on what had been started decades earlier (author's interviews).

GAS RESEARCH INSTITUTE (GRI)

The GRI was a collaborative not-for-profit industry research organization formed by the gas industry in the U.S. for the purpose of advancing public-benefit industry research. GRI is widely recognized as an example of industry-led public ER&D success for the vast contributions it made to energy technologies over its lifetime. It played a key role in transforming natural gas from what in the 1970s was believed to be "the fuel of the past" into a "fuel of the future" by dramatically changing its cost structure through technological improvements (Burnett et al., 1993).

The GRI produced 643 patent listings in the U.S. According to its internal assessment, it generated a net economic benefit in the range of USD$55 billion to USD$132 billion (1994 net present value), based on net savings from GRI technologies. This does not include a broader public-benefit estimate, associated with positive spillovers. The estimated average rate of return on GRI's R&D investment was between 200% and 500%, with a 6.8:1 benefit to cost ratio (Burnett et al., 1993).

Industry restructuring had a major effect on the feasibility of the institute, and the GRI was slowly dissolved by its members in response to the changing competitive structure of the market. Gas industry players were no longer prepared to commit a set amount of funds to collaborative R&D when price competition was about to become a major factor. GRI had to merge with another research organization to form the present day GTI (Gas Technology Institute), an applied research service organization (Paulson, 1998; American Gas, 1999; Oil & Gas Journal, 2001).

HOW IT WORKED

The key distinction between this model and the ones described above is that the GRI was an entirely industry-led organization that received its funding from the public, through a regulated cost-recovery mechanism called volumetric surcharge.

The GRI's members represented all segments of the industry, including producers, pipelines, and local distribution firms. The funds for its activities were provided through a small gas surcharge charged to the interstate pipelines' ratepayers.

Like AOSTRA, the GRI did not perform research internally—it managed it. Its primary role was to review proposals and select the research agenda. The Institute is credited with many breakthroughs, including major contributions to shale gas technology, major improvements in resource identification, and gas-recovery technologies (Burnett et al., 1993).

Institutional design and a governance structure that incorporated all three foundational principles contributed to the effectiveness of the GRI model in delivering high-quality public-interest ER&D. In addition to the industry-led board of directors, the governance structure included four board-level advisory bodies, representing non-industry stakeholders and experts at-large, alongside technical industry experts. A core mandate of the Advisory Council (non-industry stakeholders) was to ensure that the GRI research portfolio was representative of public interest.

Like AOSTRA, expertise was the GRI's core asset, which was backed by a unique project selection system, project assessment methodology (PAM). PAM was a detailed evaluation method for R&D portfolio design, which quantified project criteria based on the priorities determined by the organization's management in consultation with stakeholders (Burnett et al., 1993). As a result, the GRI seems to have achieved a rather well-balanced and cross-cutting R&D portfolio mix (within its predetermined narrow mandate), covering both upstream (supply) and downstream (demand) technologies, while being involved in all stages of R&D (with a greater focus on applied projects, as is naturally the case with industry organizations).

GENERAL LESSONS

The main lesson from these four institutional profiles is that when ER&D policy is implemented through **continuity** of support, a **cross-cutting** portfolio approach and with explicit, measurable **public-benefit maximizing** goals, it generates net benefits that significantly exceed costs. ER&D is likely to produce especially large public-benefit gains when it addresses the double market failures that affect technological development and the environment.

Continuity is necessary to handle a basic trait of technology development: there are more failures than successes.

Consistent political support is one way to achieve continuity: directly through political agenda consistency, as in the case of Alberta; or indirectly through institutionalization, as in the U.S. DOE. AOSTRA's continuity was more easily brokered with the same political party in government over its lifetime.

In the U.S. the importance of energy policy, and the recognition of ER&D as its key component, was entrenched in the permanent institutional makeup of the DOE. In Finland, long-term R&D targets were locked in within the permanent structure of the NIS and consistently supported by successive governments. Institutional continuity is critical for building expertise and balancing consistent implementation methods with learning from failures.

US ER&D, while strongly affected by political change, maintains a minimum multi-billion-dollar funding level as part of a commitment to the importance of energy policy. This ensures basic continuity in the U.S. ER&D sphere.

In Finland, ER&D as part of the broader R&D policy, benefits from long-standing government commitment to achieving clear national targets. These measurable targets at the top level seem to be driving continued commitment.

The GRI provides an example of how to fund ER&D with a mechanism that is 'biased' toward continuity, but not impervious to political trends. Funding linked to regulatory frameworks can provide a level of separation from politics, while still benefiting from the accountability required by utility regulators.

Cross-cutting the technology cycle and the energy system is necessary to manage the unpredictability of the technology development process whereby a breakthrough can come from unexpected directions. This principle needs to be explicit in an institution's mandate. This is usually achieved by adopting a portfolio approach to ER&D.

FIGURE 12 PRINCIPLES UNPACKED

PRINCIPLE	COMPONENTS
CONTINUITY	Political
	Institutional
	Funding mechanism
CROSS-CUTTING	Energy Technologies
	Technology Cycle
	Scale
PUBLIC BENEFITS	Net Public Benefits
	Verifiable

AOSTRA, despite being narrowly focused on a single natural resource, funded a portfolio of different possible in-situ technology paths, and looked to the necessary research stages across the technology cycle. The GRI also achieved a broad portfolio of its ER&D segment, across both axes (technology type and R&D stage), by using its unique selection system (PAM). The U.S. DOE uses its sheer scale to fund ER&D across both the technology cycle and energy system.

Delivering optimal cross-cutting results also means being open to many types of collaboration, which can be as unpredictable as technology development itself. Delivering cross-cutting ER&D could mean collaboration across borders, with other funding institutions, as well as with industry and higher education. All four examples were successful in managing stakeholders: Finland through institutional design and direct stakeholder engagement;

DOE through contracting practices; AOSTRA through industry collaboration and contracting; and the GRI through management representation and contracting.

Finally, scale is also a basic requirement for achieving cross-cutting ER&D portfolio. Minimum funding scale should be proportionate to the delivery agent's mandate and its corresponding portfolio size.

The GRI and AOSTRA were of appropriate scale to deliver on their relatively focused mandates at USD $321 million (in peak year 1995) (American Gas Foundation, 2007) and roughly CAD $155 million (in peak year 1985) (Heidrick and Godin, 2006), in today's dollars. Broader responsibility, such as that of the U.S. DOE, requires much greater funding scale. The U.S. government minimum ER&D budget in 1997 was roughly USD $2.8 billion in today's dollars (IEA, 2011; Federal Reserve Bank of Minneapolis Inflation Calculator).[35]

Importantly, totaling the budgets of multiple funding delivery agents does not equal minimum scale—it is essential that accountability for each ER&D funding mandate rests with a single entity, not dispersed among countless agents.

Public benefits are the foundational reason to use the public's money for ER&D. Therefore, public benefits should be explicitly pursued.

The GRI, an industry collaboration, achieved this principle through making public benefits an explicit criterion in funding decisions and through regulatory oversight. As for the NIS, the DOE, and AOSTRA, as public institutions, they all have been subject to performance reporting and evaluations of various kinds: Finland has a regular institutionalized review process of the NIS and its components; DOE has detailed activity reporting available for independent reviews and it recently implemented a new quadrennial review process; AOSTRA submitted annual reports to the legislature through the Minister of Energy.

As dictated by the nature of the technology cycle, ER&D failure is far more common than success. Failure needs to be measured and evaluated, both to contribute to the body of knowledge and to allow for program optimization. The ability to measure outcomes of any public ER&D program is critical for ensuring that the foundational principle of maximizing public benefit is continuously met. This means that transparent data and project follow-up are necessary to maximize public benefit.

Centralized organizational structures with clear roles, responsibilities, and accountability were a common element in all featured cases. This is an important component for delivering on all three principles: clear lines of accountability are necessary, which in turn require clear delineation of roles and responsibilities, and centralized management capacity to ensure cross-cutting delivery and design. Small, independent, short-term programs are unlikely to deliver maximum public benefit.

Note that a centralized structure would be effective only if all three principles are simultaneously observed. Otherwise it could be problematic because larger programs are also more difficult to eliminate than smaller ones if they are ineffective, making reporting and evaluation all the more important.

Historical evidence further supports a strong case for the importance of public policy in energy technology, while cautioning against the tendency to follow political and economic cycles. There are both economic and societal reasons for publicly funding ER&D, especially in areas of high public interest. This review of past experiences and institutional profiles has identified the qualities inherent in well-designed policies and approaches to support effective ER&D. Now, we have to put this in the context of Canada's ER&D policy reality.

35. Note that this minimum was in the peak bust years for the U.S. ER&D. In the peak boom year—1979—it was $9.8 billion, today's U.S. dollars.

THE CURRENT STATE OF CANADA'S ER&D

WHY CURRENT ENERGY TECHNOLOGY POLICIES IN CANADA AND ONTARIO ARE ILL SUITED TO SUPPORT THEIR ASPIRATIONS OF GLOBAL ENERGY TECHNOLOGY LEADERSHIP

In its Science and Technology Strategy, *Mobilizing Science and Technology to Canada's Advantage*, the federal government identified "environmental science and technologies" and "natural resources and energy" as two of its four strategic R&D priorities "that are in the national interest from social and economic perspective" (Government of Canada, 2007 p. 13). Canada's current system of ER&D support is not designed to deliver on these priorities.

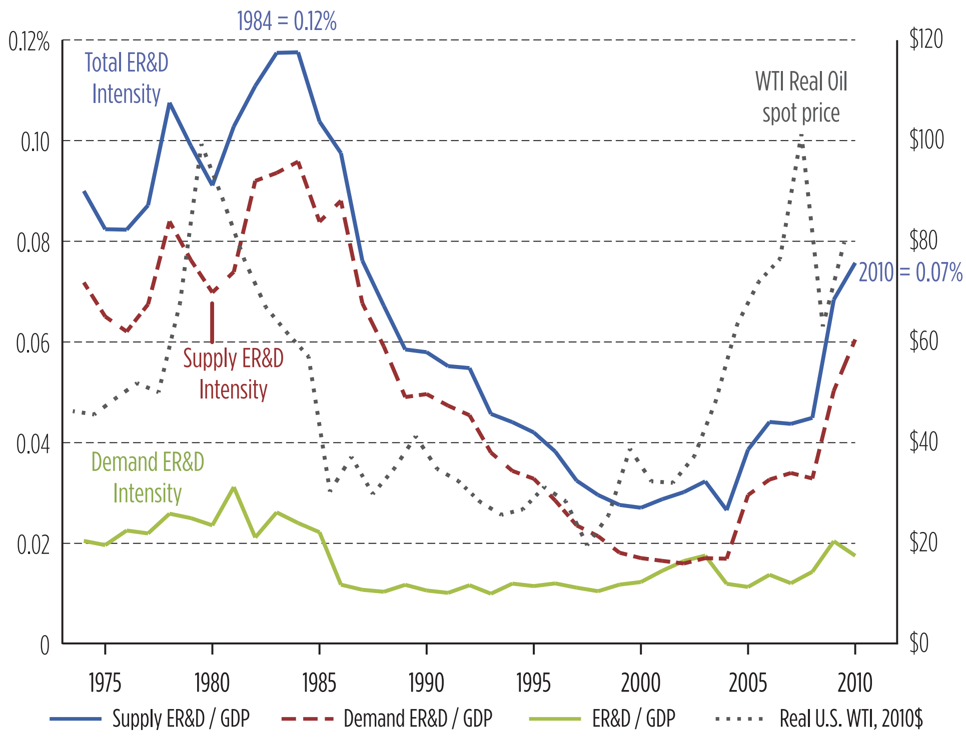
Canada's ER&D policy is not continuous, cross-cutting, or public-benefit maximizing. As a result, current ER&D funding is not being effectively used to strengthen Canada's energy innovation performance. In other words, the convoluted ER&D governance framework prevents Canadians from getting the full value from their ER&D dollars.

The recent ER&D funding increases, which followed the protracted 1990s bust period, are highly exposed to discontinuity. The short-term, decentralized, and unsystematic nature of their delivery heightens the risk of another bust.

Although high relative to peers, the present level of Canada's public ER&D funding is still below the peak of the 1980s: in 2010 Canada spent $1.18 billion on ER&D, or 0.07% of GDP, compared to 0.12% of GDP in 1984 (IEA ER&D Data, 2011). At the same time, energy challenges are exponentially greater today than they were 30 years ago. Figure 13 shows the historical boom-and-bust ER&D cycles, and the lack of an ER&D portfolio (left), compared to crude-oil prices (right).

The trends illustrated in Figure 13 are very telling of the two systemic weaknesses in Canada's approach to public ER&D funding. First, ER&D funding's boom-and-bust cycle is closely correlated with the price of oil. Given the long energy-technology lead times and the sensitivity of ER&D effectiveness to abrupt divestment of funds, this is not a sustainable model. The lack of pre-

FIGURE 13 CANADA'S ER&D FUNDING: BOOM AND BUST



Source: The author's disaggregation of IEA, 2010 ER&D budgets (IEA, 2011); WTI crude oil spot price index (Federal Reserve Bank of St. Louis).

dictability of funding commitments and a haphazard policy framework translate into highly inefficient use of funds, both public and private. As fiscal pressures grow globally, there is little reassurance that the current upswing will not follow the same boom-and-bust pattern as the previous one; another bust in the near future is likely.

Second, the data show that funding is disproportionally concentrated in supply-side technologies. This downplays the crucial consumer-side of the energy system, with demand-side ER&D representing well below one-third of the total funding.

These weaknesses are evidence of the lack of a portfolio approach to ER&D and failure to use the **cross-cutting principle**. A comprehensive energy-technology research portfolio should cut across the energy system, meaning that demand-side technologies are no less critical than supply-side ones.

The above has significant implications for Ontario being a jurisdiction that is heavily end-use oriented and that has the largest energy-consumer base in Canada. There are large demand-side global market opportunities that Ontario in particular is well situated to exploit, given its own domestic need for providing energy consumers with better energy technologies.

The Parade of Canadian R&D Programs

Several studies of Canada's R&D, innovation, and ER&D policy frameworks have identified the same problem—the landscape of R&D support is too cluttered. In general, there is a parade of federal R&D programs, which are often too small to matter, lacking performance measures or clear outcome objectives, and often operating in the same space without coordination.

The expert Panel on Federal Support to R&D reported that there were more than 100 programs and institutes delivering federal support to business innovation in 2010–11. Two-thirds of the funding under review was delivered through the Scientific Research and Experimental Development (SRED) program, and roughly one-third was split between 59 direct programs (the Panel reviewed 60 programs worth $5.14 billion in total).

> With respect to measuring outcomes, the Panel concluded that: "... many programs include outcome objectives at the scale of the entire economy—for example, productivity growth or the overall prosperity of Canadians. Such ultimate impacts of individual programs are effectively impossible to measure, since the specific contribution of the program in question can rarely be isolated from the myriad factors that affect all macroeconomic outcomes" (Panel on Federal Support to Research and Development, 2011, p. 5–2).

Tijs Creutzberg in Canada's Innovation Underperformance (2011), reported that Canada amalgamated a messy myriad of innovation policies and programs.

> "Over the years both federal and provincial governments have developed, in a largely uncoordinated manner, a broad mix of policies administered through an equally broad range of departments and agencies targeting directly or indirectly, one of the many facets of the innovation process. These departments and agencies range from those with direct mandates for innovation, such as Industry Canada and the Ontario Ministry of Research and Innovation, to those with no obvious responsibilities for innovation, such as the federal Public Works and Government Services ...." (Creutzberg, 2011, p. 4).

The National Advisory Panel on Sustainable Energy Science and Technology concluded that there is a plethora of ER&D programs and agencies, which is a key challenge for the effectiveness of energy technology funding.

> There are "too many funding pots from too many organizations ... [and] ... some energy technology areas have numerous federal actors involved, with no clear lead group or department ... Provinces also have research and funding programs in various technology areas that often work independently of federal programs[36] ..." (Advisory Panel, 2006, p. 26).

36. One example cited by the Panel was the federal government's Hydrogen and Fuel Cell Coordinating Committee that involves "over 30 groups within the federal government that participate in some capacity in the development of hydrogen fuel cells" (National Advisory Panel on Sustainable Energy Science and Technology, 2006, p. 26).

FEDERAL ER&D POLICY

Lacking a centralized department of energy, a federal energy policy, or an explicit energy technology policy, Canada runs many of its federal ER&D programs through the general suite of public R&D support initiatives. This makes the recent federal R&D Panel Review, *Innovation Canada: A Call to Action* (2011), broadly applicable to ER&D.

The Panel focused on the programs directly related to business expenditure on R&D (BERD). It reviewed 60 federal programs—delivered by 17 federal entities—that represent most, but not all, federally supported business and commercially oriented R&D initiatives. Surprisingly, the Panel Review was "the first exercise of its kind," and as the Panel noted, "an essential step toward conceptualizing the diversity of federal business R&D programs as overall portfolio of support" (R&D Panel, 2011, p. 3–2)." There is similarly a critical need to conceptualize ER&D programs as a comprehensive portfolio.

Below is a snapshot of the current federal energy innovation support framework. Note that this snapshot does not cover all initiatives, partly because the landscape is too wide, and partly because finding specifics on Canada's ER&D programs has been a challenge.[37]

The structure of federal energy technology policy governance has not evolved significantly since its inception in the 1970s. The former IPERD, now PERD (Panel for Energy Research and Development), continues to distribute funding across many government agencies and departments, which in turn allocate it according to their respective mandates. Instead of ten members, today's PERD has 13 (IEA, 2010a).[38]

There is a lack of comprehensive reporting and transparency as to how these funds are allocated, with what purpose, and under what performance standard. Public benefits cannot be effectively measured and cross-cutting scope cannot be ensured.

The following **five key mechanisms for federal ER&D**, as summarized by the IEA (2010a), comprise Canada's ER&D apparatus:

1. ER&D-dedicated programs (NRCan's energy research labs, funded by PERD to augment their base budgets);
2. Federal laboratories that perform R&D in other fields, such as environmental protection (National Research Council), but include an ER&D component, which is augmented by PERD;
3. programs that cover a number of fields and can include ER&D, such as university grants through the Natural Sciences and Engineering Research Council (NSERC);
4. R&D tax credits, which represent the largest component of federal support for all R&D, including energy;
5. climate change initiatives that often incorporate ER&D, including through federally funded organizations outside government.

Only the first one of these five mechanisms has an explicit focus on energy, representing a small amount of the total funding.[39] The bulk of federal funding is distributed through ad-hoc programs, with the exception of nuclear R&D and Sustainable Development Technology Canada (SDTC) fund.

The NRCan's **Canmet labs** perform the most federal ER&D. According to the advisory panel on energy S&T:

> federal labs are required to perform a wide array of important and potentially conflicting functions—including standard setting; conducting in-house, early-stage research and contract work for industry; running S&T funding programs; and providing policy advice to government, all in a very constrained funding environment. This broad set of responsibilities appears to have been acquired piecemeal over time, and the labs have not had the opportunity to develop a coherent framework for clearly defining their objectives, roles and key (Advisory Panel, 2006, p. 35).

It does not appear that there has ever been a comprehensive external review of the labs system.

37. We were not the first to note a data barrier: "During the preparation of this report, we were struck by how difficult it was to obtain high-quality, detailed data on energy technology initiatives, funding and outcomes from the federal government and from provinces and industry" (Advisory Panel, 2006, p. 29).

38. Natural Resources, National Research Council (NRC), Transport Canada, Fisheries and Oceans, Agriculture and Agri-Food Canada, Public Works and Government Services Canada, Health Canada, Environment Canada, Canada Mortgage and Housing Corporation, National Defence, Industry Canada, Atomic Energy of Canada Ltd (AECL), and Indian Affairs and Northern Development.

39. Data for the exact Canmet budget figures could not be found.

TRENDS IN CANADA'S OVERALL R&D COMPARED TO PEERS

Canadian Council of the Academies conducted a detailed review of Canada's (under)performance in business R&D (Expert Panel on Business Innovation, 2009), and highlighted some general trends:

- Business Expenditure on R&D (BERD) has been steadily declining in Canada, as a share of GDP over the last decade, from 1.30% in 2001 to 1.03% in 2007 (just over half of the U.S. level).
- Higher Education R&D (HERD) intensity has been rapidly increasing in Canada since the 1990s. Because of its reliance on HERD, Canada is an outlier in the OECD. Universities also perform a greater share of business-funded R&D than is normally the case elsewhere—8% in Canada versus 5% in the US.
- Canada is also an outlier in light of the significant decline in the share and intensity of R&D that is performed by government (GOVERD) since the 1980s. "By 2007, Canada's GOVERD intensity had fallen to 0.17%, and ranked 13th in the peer group (of 20)." U.S. is fifth in the group, with GOVERD intensity of 0.37% (Expert Panel on Business Innovation, 2009, p. 58).

The **Panel for Energy Research and Development (PERD)** is the only permanent long-term federal ER&D funding mechanism. Its funding is spread among the full spectrum of energy research stakeholders, including universities, collaborations with the private sector, consortia, and collaborations with the provinces (IEA, 2010a).

PERD has an annual budget allocation of $55 million. Funding for the panel "has remained constant over the years but is declining in real terms as new programmes have been added such as Generation IV nuclear and plug-in hybrids" (IEA, 2010a, p. 241). It also dropped significantly in absolute terms since the 80s—budget allocations for the former IPERD peaked at $332 million (in today's dollars) in 1984, six times what they are today.

Sustainable Development Technology Canada (SDTC) is a noteworthy exception in the federal ER&D framework, in terms of both its longevity and its high degree of effectiveness as measured by outcomes. The organization has a clear mandate to develop the most promising pre-commercial clean technologies, an independent governance structure, and operates arms-length from the government. National scope is a strong advantage giving it a unique perspective and awareness of diverse regional capabilities and existing projects, thereby avoiding duplication. The program is widely applauded by stakeholders and it is further discussed in the next section.

SDTC was established in 2001, with $590 million for the core SD Tech Fund and, later, an additional $500 million in the Next Generation Biofuels Fund (SDTC). Some further funding has been provided, but not consistent with continuous operations at the current scale. The 2012 federal budget did not provide any additional funding to SDTC.

National Research Council (NRC) is responsible for non-NRCan federal labs, many of which perform some ER&D. It is an arms-length federal organization tasked with promoting national science and technology, as well as providing general support for R&D and innovation. Although it was initially meant to deal with basic science, its mandate expanded over the decades to include everything from basic research to 'cluster' initiatives and the Industrial Research Assistance Program (IRAP). As noted by the R&D Panel report, "the sheer diversity of these activities raises the question of what is the most appropriate mission of the NRC. It is also unclear what the primary performance metrics of NRC institutes are" (Panel on Federal Support to Research and Development, 2011, p. 7–7).[40]

THE KEY IMPLICATION HERE IS THAT, IN ORDER TO SIGNIFICANTLY IMPROVE CANADA'S POSITION IN ENERGY TECHNOLOGIES, IT WILL NOT BE SUFFICIENT TO SIMPLY RAISE ER&D FUNDING LEVELS. IT IS NECESSARY TO FIX THE DELIVERY MECHANISMS OR RETHINK THE SYSTEM ALTOGETHER.

Stand-alone funds are the largest component in the federal direct-ER&D framework. These are usually short-term and created on a one-time basis. Two recent funds include the ecoENERGY Technology Initiative (ecoETI) and the Clean Energy Fund (CEF). EcoETI received $230 million in funding over five years; the program expired in 2011

40. In total, NRC runs 27 different institutes and programs, with a number of them related to energy. However, it is not clear how these are linked to the overall ER&D system.

and was replaced by ecoEnergy Innovation Initiative with $97 million in funding. The CEF received $850 million for five years (IEA, 2010a; CBOC, 2012). It is not clear why these two programs operate as separate funds, even though they appear to have very similar mandates supporting ER&D.

Generally, at the federal level, energy is narrowly viewed through the lens of natural resources, making it difficult to adopt a cross-cutting approach to energy technology. This lens is naturally biased toward the supply side of the energy system, reinforcing the notion of being a resource-rich nation, but inherently tipping the balance away from demand-side consumer and infrastructure technologies. Furthermore, to the extent that the rest of energy technology policy is scattered across numerous departments, lacking a single point of accountability, the current approach is inherently predisposed to inefficiencies and management challenges.

On balance, while there are a few good programs in the federal ER&D framework, such as the SDTC, the system as a whole is convoluted and inefficient. It lacks continuity and a transparent framework with which to measure cross-cutting scope, and public benefits.

The key implication here is that, in order to significantly improve Canada's position in energy technologies, it will not be sufficient to simply raise ER&D funding levels. It is necessary to fix the delivery mechanisms or rethink the system altogether.

ONTARIO

Ontario possesses the key attributes needed to become an energy technology leader. But the province's current approach to energy policy, an approach dominated by focusing on electricity supply and supplemented with scattered technology development funds, reinforces the federal supply bias and inefficiencies. The heavy focus on electricity supply can be seen in Ontario's Long Term Energy Plan's investments breakdown, Figure 14.

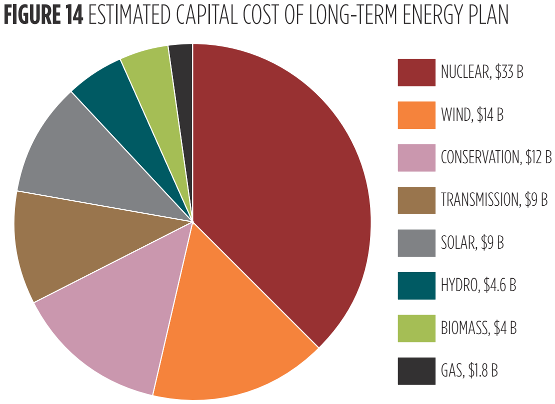
Some of Ontario's energy technology predispositions include:

- top R&D per capita province;
- critical mass of top universities and colleges;
- large industrial base;
- a strategic hub in North American energy trade;
- significant refining capacity;
- home to Canada's nuclear industry;
- large domestic market for end-use energy technology (most populous province);
- established access to the largest global market south of the border;
- access to a large pool of capital and finance expertise.

Similar to the federal government, Ontario favours delivering its R&D funding through standalone short-term-limited funds. Presently, Ontario has a number of innovation programs that, together with the existing high-quality knowledge infrastructure, are fostering technology activities in the province. Examples of such programs include: the Ontario Centres of Excellence (OCE)—directed at the commercialization of new technologies; the Innovation Demonstration Fund (IDF) with $50 million over four years—focused on supporting demonstrations of emergent technologies (similar to SDTC) and run by the Ministry of Economic Development and Innovation;[41] and the Ontario Emerging Technologies Fund (OETF) with $250 million over five years—a direct co-investment fund oriented to support promising Ontario venture companies (Ministry of Economic Development and Innovation, 2011).

With the exception of one centre of excellence devoted to energy, none of these are explicitly energy-focused. Put simply, the pie of ER&D support in Ontario is small, and is further sliced into many

FIGURE 14 ESTIMATED CAPITAL COST OF LONG-TERM ENERGY PLAN



Source: Government of Ontario Long-Term Energy Plan, 2010.

41. Unlike the SDTC, which is an independent, expertise-driven body, the IDF is located within a government ministry, which is a major disadvantage.

small servings.[42] Another exception is Ontario Power Generation, a public utility whose R&D spending was large, at $127 million in 2010 (OPG, 2011).[43]

The bulk of financial commitments to energy technology support is through a feed-in-tariff for renewable electricity supply. However, as has been previously discussed, this type of direct demand-pull policy, dollar for dollar, will deliver little technology development relative to direct R&D funding. As the Conference Board of Canada noted in one of its reports on climate technology, in the provinces "many of the programs examined place emphasis on applying existing technologies to improve energy efficiency or support energy conservation," as opposed to new technology development (CBOC, 2010a, p. 23).

SIMPLY RAISING ER&D FUNDING LEVELS WILL NOT ACHIEVE SIGNIFICANT IMPROVEMENT IN ENERGY TECHNOLOGY INNOVATION PERFORMANCE, UNLESS IT IS PRECEDED BY A COMPREHENSIVE REFORM OF DELIVERY MECHANISMS AND ER&D GOVERNANCE FRAMEWORKS.

The Ontario government touts its intention to become a leader in exporting clean energy technologies, portraying these technologies as one of the province's strengths. However, its current policy framework is not designed to support this aim.[44] To achieve the goal, the province has to rethink its suite of policies and commit to a sustained energy-technology program.

In the present Canadian ER&D framework, the bulk of ER&D support is provided by the federal government, while the provinces play only a marginal role. In total, the provinces collectively spend "roughly 20% of federal government investment and only a very small fraction of provincial revenues from energy-related sectors" (National Advisory Panel on Sustainable Energy Science and Technology, 2006, p. 18).[45]

However, the provincial governments should be contributing more to Canada's ER&D, for two reasons. First, the responsibility for energy lies mainly with the provincial governments, who are the owners and managers of their resources and energy systems. Second, the provinces stand to gain substantially from the net benefits generated by energy technology innovation. This has been noted by the National Advisory Panel on Sustainable Energy Science and Technology:

> Provinces own Canada's energy resources and are therefore beneficiaries of successful energy innovation. Consequently, we challenge the provinces to more than double their relatively small current investment in energy R&D over the next 10 years (National Advisory Panel on Sustainable Energy Science and Technology, 2006, p. 17).

The implication for the federal government—that of the need for systemic changes for effective reform—is also true for the provinces. Simply raising ER&D funding levels will not achieve significant improvement in energy technology innovation performance, unless it is preceded by a comprehensive reform of delivery mechanisms and ER&D governance frameworks. In addition, if Ontario or other provinces choose to become important players in Canada's energy technology future, the provincial governments will need to increase their ER&D funding commitments to contribute a larger share to the total. To achieve the levels of ER&D necessary to enhance Canada's global competitiveness in energy technologies while accommodating diverse provincial priorities, Canada's provincial and federal governments need to make concrete policy and money commitments.

42. In its Clean Tech sector asset map, the MaRS Discovery District identified some 35 different 'components' in Ontario's clean technology innovation network, providing innovation support to the sector (MaRS, 2010).

43. However, it is not clear what portion of this funding is devoted to research of new technologies.

44. "The government will also continue to diversify Ontario's exports. It will focus its export promotion efforts on the key strengths of Ontario's economy, including the clean energy technology sector" (Government of Ontario, Budget 2012, p. 36).

45. This estimate was provided by the Panel in 2006, and we were unable to produce an updated estimate due to a data barrier—present reporting does not include sufficiently substantial detail to enable such a calculation. However, based on other research and observations, it is unlikely that there has been a substantial change in the proportional provincial contribution to ER&D.

CONSULTING THE EXPERTS

FEEDBACK AND CORE THEMES FROM THE FIELD

With a strong case for public spending on ER&D, and examples of success, is there more to do than just replicate past examples of effective ER&D policy?

As part of the research, we consulted with experts in the fields of energy and ER&D policy, and key stakeholders from private and public spheres. A broad range of expert opinions were collected, including perspectives from Ontario, Alberta, the US, federal and provincial governments, academia, as well as from third-party experts from banking and finance.

There were two objectives behind this exercise. First, we wanted to find out what experts (with the exception of U.S. experts) think about the present state of ER&D institutions and programs in Canada and Ontario. We asked people to give their feedback and tell us what works and what doesn't. Second, we wanted to know their opinions on what can be done to improve the system.

Throughout this process, we heard valuable advice from a range of perspectives. We applied this information to our analysis, and the resulting conclusions are in the final recommendations at the end of this report.

Although interviewees came from highly diverse backgrounds, there was remarkable consensus on several key themes. There was also a clear awareness of Canada's and Ontario's challenges in the sphere of energy technology, and a broad understanding of the necessary steps for overcoming these challenges and improving the current situation. This tells us that there is a solid foundation for moving forward and, based on what we heard, it is possible to shape a consensus-based energy technology policy with widespread tangible buy-in from stakeholders.

Below is our characterization of the key themes from the consultation.

WE ARE PUNCHING BELOW OUR WEIGHT ON ENERGY TECHNOLOGY

ONTARIO AND CANADA AS GLOBAL LEADERS IN ENERGY TECHNOLOGY

Both Ontario and Canada need to step up their energy technology game. Although there are some segments where Canada developed a certain degree of global advantage (e.g., unconventional oil), on balance Canada's energy technology position is characterized by worrying underperformance and failure to capture its full potential. The foundation for global leadership already exists in Canada, thanks to its unique combination of energy resource wealth, high quality of human capital, and strong science performance. However, the mechanisms to pull these components together effectively in order to propel the energy technology engine forward are absent.

At the highest level, I'd say, Ontario needs to have a deliberate vision that it will be positioned among the top quartile of the developed nations, improve its ranking in its energy technology expenditures.

- Shahrzad Rahbar, President, DBT Solutions

We've proven that Canada can play in this space at advanced levels, if we choose to. If you want to play seriously in the energy R&D space, we must do so at a high level, not as just another player. So we'd need to carve it carefully vis-à-vis what we do and don't do. Here a policy would be helpful to steer the thinking.

- John R. McDougall, President, National Research Council of Canada

CANADA AS AN ENERGY SUPERPOWER

There was a general consensus that an abundance of resources alone is not sufficient for Canada to become an energy superpower. It is necessary for Canada to excel in developing new energy technologies to advance in maximizing the value of our resources and our competitiveness in global ER&D and new energy solutions.

The PM has talked about being an energy superpower, but without the technology, without being a technology leader, we are certainly not going to achieve the goal of being a superpower ... If the goal is to be a leader, to be one of the top countries in developing technology, then that would add value to the resources that we already have.

- Eddy Isaacs, CEO, Alberta Innovates - Energy and Environment Solutions

Lacking a Common Vision and Purpose in ER&D

If Canada is to become a "sustainable environmentally sound energy superpower", someone, or some group, has to create the vision and secure the national will.

- Clem Bowman, Founding Chair, Alberta Oil Sands Technology and Research Authority (AOSTRA)

CENTRALIZED DECISION-MAKING

Many experts discussed the need for a more centralized approach to ER&D governance. The present landscape of public ER&D programs was described as fragmented and confusing. There is significant duplication between provincial and federal programs, various departments, ministries, and agencies that often act in the same areas.

Effective and strategic alignment of what our overall energy and technology goals are, as a province and country, benefits Canada's economic prosperity. I would suggest that instead of pockets of information, dollars, and initiatives all running off and doing their own thing, we need a more concrete strategy around it all.

- Paul Cheliak, Director, Sustainable Growth, Canadian Gas Association

DELIBERATE ENERGY TECHNOLOGY POLICY THROUGH A FOCUSED ENERGY STRATEGY

There was a strong consensus around the general dissatisfaction with the status quo of both Ontario's and Canada's approaches to energy technology support.[46] Almost unanimously, experts emphasized that energy technology policy should be a priority for both Canada and Ontario, and that it must be comprehensive, deliberate, and driven by a long-term strategy. A majority called for a broader pan-Canadian energy policy to frame energy technology.[47]

The current suite of policies does not position Canada and Ontario for global leadership in energy technologies. Many experts felt that absent an energy policy, positioning Canada and Ontario for global leadership will be highly challenging. Some even felt it was an impossible task.

An energy policy is needed to provide long-term strategic guidance, and be based on a shared understanding of where Canada wants to be two or three decades from now. In addition, a long-term energy policy would send a strong signal to industry stakeholders about governments' commitment to stable, continuous energy and technology plans. Many stakeholders believe that the lack of a pan-Canadian energy policy results in major uncertainties about future policy directions, which is debilitating to their ability to manage ER&D and make investment decisions.

A deliberate policy needs to be national, and it needs to have some real muscle behind it.

- Malcolm Metcalfe, Founder and Chief Technology Officer, Enbala Power

Not having an energy technology policy ... is almost as absurd as not having an energy policy, period.

- Nicolas Morgan, Co-Founder and VP Business Development, Morgan Solar Inc.

Without a sound, articulated, and clear energy policy, I think that a technology policy will fail ... if you want industry participation, they need to understand that there is a long-term vision and commitment from the country or the province.

- Arunas Pleckaitis, Vice President, Regulatory, Public & Government Affairs, Enbridge Gas Distribution

46. About a third of the experts thought that an energy technology policy per se is non-existent, and the rest felt that there is one, but it either functions poorly with mixed performance and effectiveness, or is not working at all. A more detailed overview will be provided below.

47. Our interview script did not have a question about an energy policy, and these comments were unsolicited.

Canada's highly province-centric ER&D approach is often seen as an impediment to its performance in energy technology innovation. Several experts mentioned that there is excessive regionalization of public ER&D support, leading to duplication of efforts and significant inefficiencies. This creates major obstacles to Canada's ER&D progress. For example, public ER&D support rules across provinces can act as barriers for new ventures' ability to expand interprovincially—the receipt of funding for new technology in one province can result in refusal of support by another province, even if it is for an entirely new industrial application.

A pan-Canadian energy technology policy portfolio was frequently mentioned as an effective way to overcome this challenge. It would allow the provinces to collaborate instead of competing and to pool provincial resources together, avoiding duplication. Furthermore, this would allow appropriate focus on pockets of expertise and a much stronger ER&D capacity for Canada as a whole through interprovincial collaboration.

Much of the energy R&D in Canada is not well coordinated with many diverse programs ... [The] failure of Canada to commercialize its excellent basic research accomplishments has really not improved since the Lamontagne Senate reports of the 1970s identified this problem.

- Clem Bowman, Founding Chair, Alberta Oil Sands Technology and Research Authority (AOSTRA)

I think leadership can come from many sources ... ultimately it's the federal government that needs to make sure that they manage any potential conflicts that may arise between provinces ... There is really a need for Government of Canada leadership in this case.

- Eddy Isaacs, CEO, Alberta Innovates - Energy and Environment Solutions

How to Implement ER&D Policy

PICKING WINNERS

The policy debate on picking winners in publicly supported ER&D has been running for decades. The divergence in opinion on whether governments should be in the business of selecting technology winners resurfaced in our interviews. The issue is very important for ER&D policy, and views were polarized and strong. A large portion of interviewees argued that technologies must be chosen solely by markets and that governments should never be involved in this process. Others stressed that governments should in fact be selecting winners, when it is appropriate and if public money is involved.

These opposing views can be reconciled because they are often focused on somewhat different issues. Those who were avidly against picking winners were opposed to government officials picking technology paths, not setting high-level goals in general areas of strategic interest. Those supportive of picking winners were speaking of "mission-oriented research," such as extracting unconventional oil or improving smart grid technology, led primarily by experts, not the government itself. That does not imply writing technology paths into policy; it implies a policy that is prioritized at a high-level with substantial room for expert organizations to drive its delivery. Selecting winners by defining priorities is not only appropriate; it is necessary for governments to do because of funding constraints, but doing so by choosing one particular technology over another is both wasteful and dangerous because it may lead to an inferior technology lock-in.

There needs to be a much higher degree of care put into not picking the winners or deciding which technologies are going to be incentivized ... If you want solar energy, incentivize solar energy, but as soon as you start getting into the technical details of crystalline silicon you've excluded anything that isn't crystalline silicon.

- Nicolas Morgan, Co-Founder and VP Business Development, Morgan Solar Inc.

I firmly believe that government should be in the business of selecting winners across the innovation chain, but only up to commercial-scale demonstration ... Governments should not be in the business of commercializing technology.

- Eddy Isaacs, CEO, Alberta Innovates - Energy and Environment Solutions

ALIGNING POLICY GOALS WITH IMPLEMENTATION, AND BUILDING A POLICY PORTFOLIO FOR ENERGY TECHNOLOGY

A portfolio approach has been described by many experts as the most effective way to manage public energy technology policy and ER&D investments as it allows alignment of investment decisions with the policy goals. Once policy goals are set, and priority areas for ER&D are determined, they serve as guidelines for designing a diversified technology investment portfolio that would help meet said goals. Due to the high risk that is associated with ER&D investments, a diversified portfolio of technologies (for example, by stage of readiness, level of risk, and priority technology area) hedges the risk.

An effective policy portfolio cuts across both the type of technology and the overall technology cycle. It includes instruments addressing every stage of ER&D, from basic research to, in some cases, commercialization. This is a way to ensure that gaps in the technology cycle are eliminated or minimal.

The goals should be aligning the technologies with the policy ... so you really need a portfolio approach to your technology policy that starts with the technologies matching to strategic energy goals of the country or organization.

- Melanie Kenderdine, Executive Director, MIT Energy Initiative

Often when you invest in RD&D, you have to look at your top performers ... there is investment in quite a broad suite of things and a number of them will pay off. It is often hard to determine from the start which one will pay off, but at the end of the day a number of them will ... so in programs like this we can always pick off the top five which will always pay for the program multiple times over.

- Marc D'Iorio, Director General, Energy Sector, Office of Energy Research and Development, Natural Resources Canada

PROGRAM DELIVERY AND ACCOUNTABILITY

Most respondents favoured arms-length organizations for managing ER&D. Keeping publicly funded ER&D programs at arms-length from the government ensures greater independence from the budget cycle and cushions the program from volatile political and economic swings. This also allows greater operational flexibility, in terms of building expertise, working with clients, time constraints, and being separated from the burdens of government bureaucracy.

Arms-length delivery is also beneficial for accountability and performance measurement purposes. Measurable outcomes were stressed as key in designing and delivering an effective ER&D policy. This applies to both high-level policy with general targets and to implementation with more specific outcomes.

Transparent evaluation of effectiveness is necessary for keeping publicly funded ER&D programs relevant and efficient. Having dozens of short-lived programs scattered across multiple federal departments and provincial ministries makes this task difficult, if not impossible.

Similarly, government departments and ministries are policy experts, not technology experts. The lack of technical expertise in ER&D policy-shaping and implementing bodies has been highlighted as a challenge by many stakeholders.

Energy is a highly technical field, and in order to design and deliver effective programs for energy technology innovation, it is necessary to accumulate sector expertise and technical understanding. SDTC is a notable exception in the current suite of programs as it is built on expertise and thus able to 'speak the same language' with its clients. However, many other government programs lack this ability, making it very difficult for technology developers to communicate with public financiers.

If you have generalist investors, and very generalist public programs, you are only going to get very generalist technologies that promise a lot and look very shiny, but don't solve the problems.

- Anonymous

BUILDING CAPACITY, DEVELOPING EXPERTISE, AND GROWING CRITICAL MASS

Currently, ER&D funding is being spread too thin to satisfy everyone equally. A technology development policy should instead aim to stimulate pockets of expertise with the highest potential for advancement; otherwise it will be wasteful and fail to produce noticeable results. Many experts stressed that public ER&D funding should be distributed strategically, based on the highest potential and expertise.

The quality and diligence of management across the whole innovation process is also very important to ensure we get out of things early that are clearly busts and concentrate resources on the things that are working out. That's not easily done because the tendency in implementing policy is to try to make everybody happy by *sprinkling a little bit of pixie dust on everyone. But you don't build critical mass or real capability that way.*

- John R. McDougall, President, National Research Council of Canada

In my opinion, we have enough. But there is no focus on getting the best out of it. I believe that if it is done well, and governed by outcomes, you will get much better results ... but we normally have a certain amount of money which is spread around across too many activities.

- Hassan Hamza, Director General, Natural Resources Canada, CanmetENERGY Devon

MANAGING ENERGY AS A SYSTEM

There is a need for policy to adopt a whole-of-energy-system approach; instead, the current state is silo-based with too much focus on individual fuels or sectors at the expense of others. This is particularly relevant for Ontario, which focuses almost entirely on electricity supply in its energy policy, while paying much less attention to the rest (the majority) of its energy mix, including end-use and fossil fuels.

Many interviewees stressed that the Ontario Ministry of Energy in its present form is disproportionately preoccupied with electricity and needs to adopt a whole-of-energy-system approach. This has major implications for the design of an effective energy technology policy and choosing the right priorities for public support of ER&D.

So energy or an energy R&D policy has to look at total energy, not just one piece. Ontario's is an electricity policy, not an energy policy. The real problem is that there is no clear focus on what everyone is trying to achieve.

- Malcolm Metcalfe, Founder and Chief Technology Officer, Enbala Power

UNDERSTANDING BUSINESS INVESTMENT IN R&D/ER&D (BERD)

The need to understand the clearly distinct perspectives of government and business when it comes to investing into ER&D came out clearly from the consultations, strongly supporting our research findings.

Businesses and governments have different incentive structures when they invest in ER&D (or R&D in general). Private-sector investment is driven by profit expectations. As a result, the business sector invests primarily at the end of the technology cycle.

Public-sector investment can address both short- and long-time horizons, as it is motivated by the goal of maximizing public benefit rather than immediate profit. The government therefore is the stakeholder that can ensure that the entire ER&D technology cycle is functioning by focusing more on research that is further upstream and higher risk than the private sector is willing to take.

Unfortunately, this principle does not always clearly translate into policy design. In Canada, governments tend to put more emphasis on leveraging private funding than on maximizing public benefit. The reality, however, is that at earlier stages in the technology cycle it might only be possible to include the private sector as observers because this stage is too risky for businesses to come in as participants. This should not preclude the government from funding strategically important ER&D.

If the public sector believes that there is an overriding public good to be had from funding some body of energy R&D, in my opinion, that should be the overriding criteria. [In such cases] I would de-emphasize my concern about whether the private sector is going to co-fund it, because the willingness of the private sector to cost-share something is not a valid proxy for whether there is a pressing and important public good.

In the US, and probably in Canada too, we don't force the people that maintain the readiness of our nuclear weapons to put in a cost-share, or people that are working on the cure for the H1N1 virus—there is an undisputed accepted public good.

- James Dooley, Senior Staff Scientist, Joint Global Change Research Institute at the Pacific Northwest National Laboratory

Capital will naturally lean toward areas closest to commercialization ... our firm, for example, only invests in, or underwrites, technologies that are at commercialization.

- Sasha Jacob, President & CEO, Jacob Securities Inc.

The match requirements for programs like ARPA [Advanced Research Projects Agency, a U.S. program] could be problematic, especially for universities. ARPA-E [Advanced Research Projects Agency-Energy] was designed to identify and support technologies with the greatest potential for energy transformation, which may *or may not come with the capacity for meeting DOE match requirements.*

- Melanie Kenderdine, Executive Director, MIT Energy Initiative

THE ROLE OF UTILITIES

Experts mentioned numerous times that the absence of energy utilities from the ER&D landscape is problematic, because they have an important role to play in the development and, particularly, the deployment of new energy technologies.

Energy utilities are strategically positioned very close to the end-user, which gives them a significant advantage in understanding the end-use consumer segment of the energy system. They are also bearers of very 'patient capital,' which can be effectively leveraged to finance a portion of ER&D. However, utilities are also generally risk-averse, so this needs to be incorporated in the planning of ER&D strategy as utilities are probably not the likely candidates for generating breakthrough or disruptive innovation.

One area that I think we have done a disservice to energy technology commercialization is on the utilities side. There was a time when public and private utilities were much more active in facilitating the commercialization of new energy technologies. They were seen as critical and logical catalysts for energy technology transformations given their public mandate to serve the customer, their scale and low cost of capital, and the transparent policy and prudency oversight provided by their regulators. But things have changed as a result of cost-cutting efforts and a false premise that utilities don't need to be involved in new technology introductions as this role can be more effectively served by others. As a result, energy system planning and technology commercialization is significantly underfunded and exceedingly fragmented.

- Arunas Pleckaitis, Vice President, Regulatory, Public & Government Affairs, Enbridge Gas Distribution

THE NUCLEAR QUESTION

Canada's future role in nuclear energy technology is a key deliberate decision that should be made jointly by the federal government and Ontario. Ontario is home to the industry and much of the nuclear R&D infrastructure, so it has a vested interest in what happens on Canada's nuclear technology front.

The issue of Canada's nuclear technology is hard to ignore when discussing energy technology policy. There is a sense that there may have been policy failures in the management of Canada's nuclear technology development. However, it is beyond the scope of this report to explore this complex subject. What is clear at this time, however, is that Canada should make an explicit decision about whether it wants to hold a strong nuclear technology position globally or leave that field altogether. This decision would have an impact on the overall ER&D portfolio composition because, if pursued, it will take up a significant amount of the funding resources.

I think there was a big failure in the nuclear sector ... There wasn't an integrated approach between the federal government and the province of Ontario in supporting the next generation of CANDU technologies, and launching the technology within Canada and within Ontario to then demonstrate it to the world, thereby allowing an opportunity for international sales. It is difficult to have any international sales if this country itself can't adopt the technology. Having the federal government partnering with OPG [Ontario Power Generation] to develop the next-phase CANDU technology and supporting the replacement of Darlington would have been a great opportunity.

Now, we've potentially wasted the many decades of work that the AECL has done, and OPG is still going to have to procure technology for their nuclear reactors, which they are probably going to end up purchasing from foreign companies.

- Sasha Jacob, President & CEO, Jacob Securities Inc.

THINGS THAT ALREADY WORK WELL

The **SDTC** and **IRAP** have been singled out as programs that work very well, have the necessary expertise, and are making a positive contribution to progress in developing Canada's energy technology innovations. The SDTC, in particular, was commended virtually by every respondent as an excellent program for its expertise, oversight, and effectiveness of outcomes.

Provincially, several experts mentioned Ontario's Centres of Excellence and the MaRS Centre as useful programs. However, there were also some critiques of OCE's overly regional focus and constrained funding.

OCE is an excellent program; it's a very poorly funded program ... but it tends to have too much of a regional focus that isn't necessary. A national version I think could be extremely effective.

- Nicolas Morgan, Co-Founder and VP Business Development, Morgan Solar Inc.

SDTC may be the single best reason why we have a $9 billion clean-tech market in Canada.

- Tom Rand, Senior Advisor, Cleantech and Physical Science Venture Group, MaRS

Canada, overall, and Ontario, in particular, have long been known for excellent universities and high-quality basic research. This was largely echoed in the interviews, and the strength of Canada's higher-education was commended, but Canada relies too heavily on the higher-education sector for performing R&D.

Government laboratories are seen as an important and necessary component of ER&D policy. A majority of respondents mentioned that the Canmet labs are generally good mechanisms, however they are presently an underutilized resource and could be improved.

I think that we can do a lot better, and I am also not convinced that we have done justice to our federal labs ... whether it's NRC or the Canmet labs ... We would want the research to be at arm's length from the political system.

- Eddy Isaacs, CEO, Alberta Innovates - Energy and Environment Solutions

Complementary Policies for ER&D

The focus of the report is on the issue of public investments in ER&D, and this was reflected in the questionnaire. Nonetheless, we also asked experts to comment on business investment in ER&D and how governments could improve the conditions for growing BERD in energy. Some of the key points that were made are:

Price signals are important for pulling in private investment. A comprehensive carbon price, for example, would incent investments into low-carbon technologies.

Strategic government procurement is a tool that governments can use more effectively to stimulate the adoption of energy technology innovations. It is important to note that, if chosen, this measure should be used with the highest degree of care because it is the type of 'picking winners' that can lead to unfavorable technology lock-in.

Equal treatment for foreign investment, especially in the venture capital markets, is needed to grow the pool of available private capital for financing new energy technology projects. The present regulatory regime often discourages foreign investors from participating in the Canadian venture markets, which are in significant need of capital.

Bankability and project finance are critical to the success of new technology ventures. Policy options to improve bankability include:

- extending the flow through shares[48] mechanism for cleantech finance
- extending publicly supported technology credit-financing
- encouraging more consortia and public-private partnership (PPP) organizations
- leveling the playing field for foreign investment
- finding ways to encourage institutional investors to pursue venture markets.

Tax credits are often favoured by industry because of their general-application criteria and technology neutrality. The generous Canadian SRED tax credit proved a contentious mechanism, eliciting many strong opinions among respondents. Supporters highlighted the stability of the program over the long run. It is perhaps the only program that companies can count on over the longer term since it is run through the tax system and is less vulnerable to political fluctuations than most other R&D supports.[49] Detractors, on the other hand, pointed to research indicating that the SRED expenditure was not producing sufficient payoff given the level of investment.

48. Flow through shares (FTS) are a financial mechanism designed to help the resource and mineral extraction sectors raise capital for their projects. It allows new resource companies to pass on their tax credits to investors when they purchase FTS. The investor then will be able to apply the value of the FTS as a credit against their taxes.

49. For a more detailed review of the SRED program, see the Jenkins Panel on R&D Report (Independent Panel on Federal Support to Research and Development, 2011).

CONCLUSION

The clearest message from the interview process is that a national energy strategy, with an energy technology policy as its centerpiece, is essential. This policy should have a comprehensive whole-of-energy-system approach and an effectively diversified ER&D portfolio to cut across the energy system and technology cycle.

I think that governments should attach a great deal of importance to energy technology and show that it is an important thing to focus on. We need to develop strong leaders that are not risk-averse. In this business you need to have a portfolio of risks that you are willing to take.

- Eddy Isaacs, CEO, Alberta Innovates - Energy and Environment Solutions

POLICY RECOMMENDATIONS

HOW FEDERAL AND PROVINCIAL ENERGY TECHNOLOGY POLICY IS TO BE REFORMED TO GET BETTER BANG FOR THE PUBLIC BUCK AND ENSURE MEASURABLE RESULTS

The final step is to chart the path from where we are now to where we want to be—Canada's future as a technologically savvy energy superpower and Ontario's as one of its knowledge-intensive energy technology leaders.

Given the divergent energy perspectives of Canada's governments, the importance of energy technology may be the only item upon which they all agree. ER&D expertise is more evenly distributed across the country than are physical resources. Energy technology can therefore become a unifying element in the broader energy debate, necessary for Canada to start down the path of building a comprehensive energy strategy, so long as the federal focus is relevant to all provinces, regardless of resource endowments.[50]

THE PROBLEM STATEMENT

The current Canadian approach to energy policy fails to capture important economic and environmental benefits associated with pursuing leadership in energy technology innovation. The main global energy-related challenge—climate change—can only be addressed through significant advances in energy technologies. Major technological breakthroughs are needed to make the transition to low-carbon energy a reality. As an aspiring energy superpower, Canada should be aggressively working toward becoming a key player in solving global environmental challenges associated with the production and use of energy through expertise in energy technology.

Instead, the present Canadian policy framework for supporting energy technology innovation is largely complacent and highly inefficient. Canada currently has too many temporary, *ad hoc*, and often overlapping programs, with little measurement and evaluation of net public benefits. Moreover, despite this abundance of programs, Canada also suffers from incomplete coverage of the broader energy innovation system. Under this arrangement, Canadians are not getting the best value out of their ER&D dollars.

Canada's current ER&D support system is broken into too many pieces and therefore lacks the critical mass that is necessary to create a noticeable impact on the state of energy technology innovation. As a result, Canada is 'punching below its weight' in energy technology development, and is missing out on the benefits of providing leading ER&D services and new energy technologies to domestic and global consumers.

Recent increases in Canada's federal ER&D support are laudable. But the governance problem persists, preventing these funds from being delivered in accordance with the core principles of continuity, cross-cutting, and public-benefits-maximization. It is not necessarily the case that more funding is needed in the short term, but that the funding should be used more effectively. The same cannot be said for the provincial level, where the share of ER&D funding is disproportionately low.

The analysis presented throughout the report unpacked the two critical components necessary for changing Canada's energy technology trajectory to one of success—policy and money. This analysis results in specific recommendations on how to get there. The following actions are recommended in order to make Canada's energy technology policy effective at leveraging ER&D and supporting Canada on the path to becoming an energy technology leader.

50. For example, Ontario has achieved a certain advantage in water technologies (expert interviews), and this expertise could be applied to the environmental challenge of tailings water treatment in Alberta, creating a win-win situation for both provinces—and for Canada.

RECOMMENDATIONS FOR THE FEDERAL GOVERNMENT

1.Create a pan-Canadian energy policy with energy technology as its centerpiece

The absence of a pan-Canadian energy policy impedes the ability to effectively manage ER&D, which leads to Canada's below-par performance in energy technologies, thereby preventing it from becoming an energy technology leader.

The federal government should assume a strong leadership role and build interprovincial consensus to develop a pan-Canadian energy policy. If the federal government approaches the issue in a way that encourages ER&D across the energy system and technology cycle, thereby accommodating provincial differences, energy technology can serve as the centerpiece of interprovincial energy-policy consensus. There will be value in such policy for all provinces, regardless of resource endowments.

2. Merge the current suite of energy-related programs run through various departments into a federal Department of Energy

Currently, federal energy responsibility is dispersed among many agencies, with NRCan being the primary manager of the federal energy file. However, energy is one of many portfolios for NRCan, and the department's mandate is focused on the broad category of natural resources. This naturally creates a problem because energy is a comprehensive system, from supply to infrastructure and end-use, and it cannot be managed effectively by an organization focused on natural resources.

To transition from the current state to an effective federal ER&D policy based on a larger vision for energy technology leadership, the federal government should consolidate energy policy functions, including the responsibility for the ER&D portfolio, out of the plethora of federal agencies and into a single Department of Energy. This is not a novel concept, and we do not have to look far to see where this has been successfully done. The U.S. government completed this task in the 1970s when it consolidated some 50 government agencies into a single federal department of energy in order to "get energy planning under one roof" (Wilson Quarterly, 1981, p. 84).

2a. Move the federal Canmet labs into the new DOE and conduct a review of their roles and responsibilities, ensuring that their mandate fits into the new comprehensive ER&D strategy

The federal Canmet laboratories are an important but currently underutilized resource. The Canadian national energy lab system needs to be reformed by making the labs more independent of departmental bureaucracy and more connected within the broader energy technology innovation system.

3. Consolidate ad hoc federal programs and reroute funding from expiring programs to the new structure

Within this new framework, the federal government will be able to better utilize its energy laboratories; continue funding effective mechanisms, such as SDTC; and work together with the provinces to promote a pan-Canadian effort to achieve energy technology goals. This will help maximize public benefits for Canadians by pushing the most promising new energy technologies through the technology cycle into the marketplace.

Building critical mass will require a reduction in number and increase in scale of programs that the federal government uses for delivering ER&D support. A critical mass means fewer, larger, and long-lived programs that can acquire leading expertise in effective ER&D funding delivery, while delivering a cross-cutting portfolio of energy technologies. It will also improve the ability to measure results and track progress to ensure net public benefits. Finally, a smaller suite of larger-scale programs with clear statements of public benefit has greater potential for continuity. The process of consolidation should be based on increasing the leverage of the existing top performing programs, starting with SDTC.

3a. Re-Fund SDTC and consider expanding its mandate

SDTC is a highly successful model and should be maintained over the long-term as an important vehicle for commercializing breakthrough technologies. The SDTC mandate could be expanded to pursue demonstration projects that have exceptionally high public-benefit potential, but also a higher risk factor, thereby deterring the industry from investing at the same scale.

RECOMMENDATIONS FOR THE GOVERNMENT OF ONTARIO

1. The Ontario Ministry of Energy should adopt a whole-of-energy-system approach to move away from a disproportionate focus on electricity, and make ER&D a foundational pillar in provincial energy policy

Ontario already has a Ministry of Energy, but there are two barriers to implementing effective ER&D policy. First, Ontario energy policy attention is heavily biased toward electricity supply. Although electricity accounts for only about 20% of Ontario's total energy use (Joshi, 2012), most of the Ministry's attention is devoted to this single energy source. A much more comprehensive approach to energy policy is needed in Ontario in order to implement an effective ER&D policy that can make a positive impact on energy technology development in the province.

2. Consolidate ad hoc provincial programs and reroute support from deployment programs to direct ER&D funding

Ontario's approach to supporting energy technology is heavily reliant on direct-pull measures—the feed-in tariff—that also happen to be focused on electricity supply (see Figure 14). A more balanced approach, with a focus on direct-push ER&D funding, is needed to build an effective ER&D portfolio for Ontario and leverage energy technology development. For example, some of the planned renewables deployment investment could be redirected to cross-cutting ER&D, which could result in the same or lower electricity rates and significantly higher net public benefits. This new approach would assign appropriate weight to Ontario's priorities, such as end-use energy technologies, through sustained direct funding mechanisms.

3. Direct the OEB to develop a rate-recovery mechanism for collaborative industry research

Currently, the utilities are largely absent from Ontario's ER&D landscape, thus creating a large gap in the energy technology cycle. Utilities' ER&D efforts are needed to complement broader energy technology policy. Utilities should be given an opportunity to play a larger role within Ontario's ER&D through a collaborative model, such as the former GRI, subject to regulatory oversight and an explicit public-benefit requirement.

This would involve an industry proposal, or an OEB request for such a proposal, to establish a collaborative industry research institute to conduct ER&D. The mandate of proposed research organization(s) would have to be approved by the OEB separately, ensuring accountability and a focus on maximizing public benefits. The GRI model of performance measurements can be used as a starting point.

RECOMMENDATION FOR BOTH GOVERNMENTS

1. Set long-term federal and provincial ER&D intensity targets consistent with pan-Canadian energy goals

Keeping the new policy on track for continuous improvement is essential to enable Canada to achieve its energy technology goals. Both federal and provincial governments require long-term ER&D intensity targets to which they will commit.

The provinces are owners of their energy resources as well as the distribution infrastructure for end-use. Investments in ER&D that are aligned with provincial priorities and areas of expertise can generate substantial economic spillovers at the regional level, resulting in high net public benefits, so provincial governments should be increasing their ER&D investments. Currently, the federal government is the main funder of ER&D, while the provincial contribution is disproportionately low.

In order to avoid another bust and loss of public benefits, in the short-term the ER&D intensity targets can be set to maintain the current level of funding. In the current federal and provincial policy frameworks, dominated by short-term funds and small programs, this commitment will be difficult to sustain. As programs come to their end it will be tempting for governments to use the money elsewhere, especially in weak economic times.

In the medium-term, ER&D targets should be set to match the intensity (ER&D as a share of GDP) of the 1970s boom, but this time the transition to higher energy-technology spending can be more gradual, built on long-term institutional arrangements, and have greater provincial commitment.

CONCLUSION

A COMPREHENSIVE REFORM

In order to transform Canada's approach to energy technology in a substantial way, the above recommendations should be viewed as a package. Taken together, these recommendations ensure that the three foundational principles of sound energy technology policy are implemented within the broader Canadian energy policy framework—Table 2 matches the principles to these recommendations.

Marginal fixes to existing programs will be insufficient if Canada truly wishes to fulfill its ambition to be an energy superpower. Increased direct-push ER&D support will be key, so long as it is situated within a broad policy portfolio.

Canada has been complacent with its own energy wealth. Our natural resources have been significant contributors to our national prosperity. But being an energy superpower—and being able to capture more benefits from growing world energy markets—means more than just figuring out how to boost resource export revenues. It means taking advantage of existing opportunities in technology to meet the challenges of the 21st century and expanding Canada's energy leadership to knowledge-intensive components and ER&D services. It means becoming a global leader in a lucrative and rapidly growing market for new energy solutions, which includes, but is not limited to, our natural resources.

The current energy and ER&D policy suite is not designed for meeting the needs of an emerging energy superpower. This report has mapped out a path forward that, if followed, could see Canada play a more important role as a global energy superpower and knowledge-intensive energy technology leader. MC

TABLE 2 CHECKING RECOMMENDATIONS AGAINST CORE PRINCIPLES OF EFFECTIVE ENERGY TECHNOLOGY POLICY

	CONTINUOUS			CROSS-CUTTING			MAXIMIZE PUBLIC BENEFITS	
	Political	Institutional	Funding	Energy Technologies	Technology Cycle	Scale	Net Public Benefit	Verifiable
1. Pan-Canadian energy policy with energy technology as its centrepiece	✓					✓		
2. Federal Department of Energy		✓		✓	✓	✓		
3. Consolidate ad hoc federal programs, and re-route funding from expiring programs		✓				✓	✓	✓
4. Set long-term federal and provincial ER&D intensity target	✓		✓			✓		
5. Ontario Ministry of Energy should adopt a whole-of-energy system approach with ER&D as a foundational pillar	✓	✓		✓				
6. Consolidate Provincial ER&D delivery and re-direct support to direct ER&D funding		✓			✓	✓	✓	✓
7. OEB to develop a rate-recovery mechanism for collaborative industry research			✓	✓			✓	✓

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