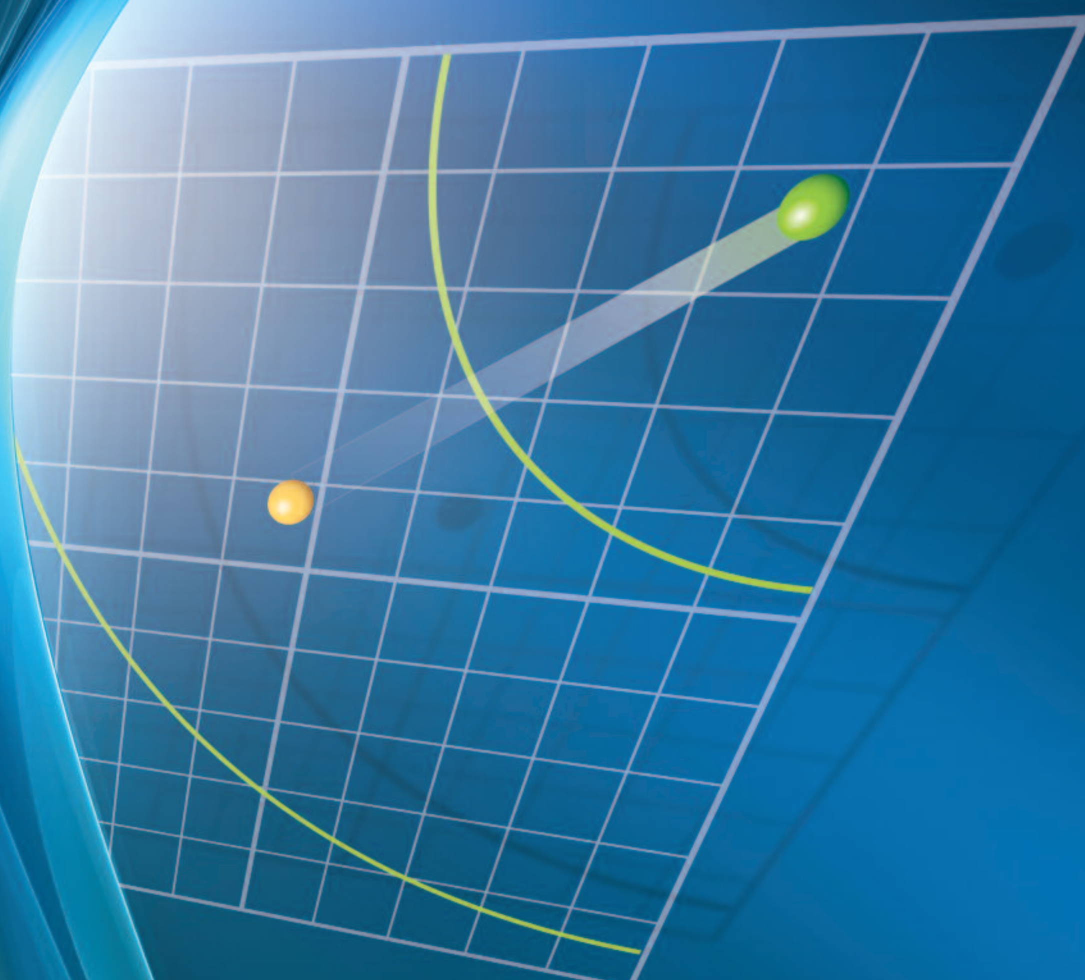
CANADA:
Winning as a Sustainable Energy Superpower

VOLUME I



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Canadian Academy of Engineering

Prepared by the CAE Energy Pathways Task Force
Edited by Richard J. Marceau and Clement W. Bowman

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THE BOWMAN CENTRE FOR TECHNOLOGY COMMERCIALIZATION

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THE CANADIAN ACADEMY OF ENGINEERING
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P. Kim Sturgess

Preface

Prime Minister Stephen Harper at the G8 Summit in St. Petersburg, Russia in 2006 called Canada "an emerging energy superpower"—a theme that has resonated in the media since then. But also resonating in the media are portrayals of Canada as a source of dirty oil and a laggard in global negotiations on climate change. Can the vision of Canada as a sustainable energy superpower—meaning a country that uses energy wealth wisely to maximize its economic, environmental and social prosperity and its global influence—be realized in a positive and sustainable way in the decades ahead? Can we be truly recognized as a good steward of our environment?

Meeting environmental and prosperity demands at the same time is a greater technological challenge than humanity has ever faced. It represents a powerful definition of the purpose of a sustainable energy superpower. Canada is one of the few nations that have the physical resources and the science and technology to become such a superpower.

Canada distinguished itself in the past by its ability to create and implement public-private collaborations that have built visionary physical infrastructure projects in transportation, communications and energy. These collaborations have created the country we know and have provided the wealth that has enabled Canada to establish world-leading social infrastructure projects related to health care, education, culture and human rights. This is the time for major new physical infrastructure projects that will shape Canada in the twenty-first century and help strengthen its social assets.

In this book, a team of energy industry experts describe possible pathways for Canada to become the first sustainable energy superpower. It is a book about new ideas for public-private collaboration on visionary projects on such a scale that they would require the next forty years to come to fruition. We examine individual components of the energy industry, which have stand-alone potential, but realize that the potential synergies among these components must be effectively leveraged to create a fully integrated energy system, the foundation of a sustainable energy superpower. It is time for Canada to think big.

The Canadian Academy of Engineering has been a long-time sponsor and supporter of this foundational work and we are proud to present these findings to our fellow Canadians.

P. Kim Sturgess, P.Eng., FCAE
President, Canadian Academy of Engineering

Executive Summary

Leadership is needed from the private and the public sector to define the goals, set the trajectory and initiate the projects.

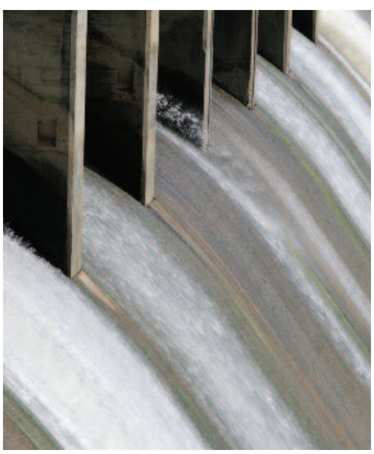
Big Projects and the Sustainable Energy Superpower Vision

Historically, the unequal distribution of the world's carbon-based energy resources has been a driver of human conflict[1]. Though there is increasing awareness of the need to transition to non-carbon energy resources, the quest for additional energy resources—in particular carbon-based resources—continues to shape national aspirations and tensions the world over. As the world begins its slow transition to non-carbon energy resources, Canada is in a position to serve both carbon- and non-carbon-based energy resource needs in an environmentally responsible manner, which might not be the case elsewhere.

The Canada we know has been created by big projects in transportation, communications and energy, initiated by visionaries who overcame enormous obstacles. Canada's "Big Project Innovation Strategy" has time and again provided the direction and challenges for Canadian industry to design, build and operate ambitious, strategic infrastructure. This strategy has subsequently benefited the country for decades and, in so doing, has provided numerous Canadian enterprises with a fertile ground for developing new opportunities and establishing themselves in their critical starting years.

New big projects can continue this tradition with emphasis on sustainable development and on a higher level of upgrading of our energy resources into value-added products. Canada now needs leadership from both the private and the public sector to define the goals, to set the trajectory and to initiate the projects that will lead to a sustainable energy superpower future. In this book, we urge Canada to take action in specified areas, recognizing that these actions will require dedicated private and public sector partnerships of the type that characterized previous big projects that have defined the nation.

Hydroelectric power can be more than doubled – a major pathway to lower greenhouse gas emissions.



Hydroelectric Power

Canada should proceed with major hydroelectric projects in five priority regions to capture part of the country's untapped hydroelectric and tidal power, estimated to be twice that now in service, and in so doing significantly reduce greenhouse gas (GHG) emissions.

The time for a national electrical power grid has come.

Interconnecting Canada

Canada should connect existing provincial electricity grids through a new high-capacity transmission system. This would enable significant reductions in Canada's carbon footprint by incorporating distant hydroelectric and tidal low-GHG electric power stations to replace aging coal-fired and other thermal power generating stations, when retired, and meet new demand. The business case for variable renewable energy ventures (wind, bioenergy, solar, tidal, wave) would also be improved.

Nuclear Energy

Applying nuclear-generated heat (rather than burning fossil fuel) for bitumen recovery and upgrading from Alberta's oil sands would strengthen Canada as a sustainable energy superpower by conserving natural gas, improving the carbon emissions profile of the oil sands, and facilitating oil sands industry growth. If Canada led the push to apply nuclear technology to a variety of

Nuclear-generated heat for the oil sands will reduce greenhouse gas emissions.

process-heat applications, this would give its resource industries a technical and economic edge, and add a new branch of nuclear expertise to its existing cluster of technological strengths, which already includes electricity supply, medical diagnosis and treatment, food safety and irradiation, uranium mining and exploration, and materials science.

Oil Sands

Production from the oil sands is poised to triple within the next two decades. New plants should be built to upgrade the bitumen from the oil sands to fuels and chemical products, thus capturing more than $60 billion per year in value-added products and commensurate jobs inside Canada. Current plans would see more than 50% of the bitumen upgraded outside Canada. The enormous assets of the oil sands have been one of the foundations for Canada's energy superpower vision, and Alberta must continue its environmental advances to achieve that goal. Alberta and Ontario should work together to develop and apply new environmentally-advanced upgrading technologies, and optimize the use of available labour and facilities at both the Alberta Industrial Heartland and the Sarnia-Lambton Refining and Petrochemical Complex.

Upgrading bitumen from the oil sands will be a century-long wealth generator.

Natural Gas and Liquefied Natural Gas (LNG)

The exports of natural gas to the U.S. may decline by 50% over the next few decades, with the U.S. becoming a net pipeline exporter of natural gas by 2025 . This puts pressure on Canada to seek markets outside of North America. British Columbia is developing a "big project" opportunity for liquefied natural gas (LNG), with the first commercial LNG export facility scheduled to open in Kitimat in 2015, and with three facilities in operation by 2020. Several other countries will be competing for Asian LNG markets. Canada needs to have a national strategy to realize the potential of natural gas and LNG, building on these BC projects.

Coal gasification can produce electrical power and high-value chemical and pharmaceutical products.

Coal

Coal is the world's most abundant and widely distributed fossil fuel. Canada has more energy in its coal than oil and gas combined. Coal gasification has the unique ability to produce electrical power, hydrogen and high-value chemical and pharmaceutical products. Gasification also has the ability to handle diverse feedstocks, to capture, store, utilize (i.e., for other value-added processes) or sequester carbon dioxide, and to capture sulphur and trace metals. Global coal use will increase dramatically over the next century, and coal gasification demonstration projects should be undertaken based on Canada's low rank coals, utilizing the latest international technology developments and meeting rigourous environmental targets.

Bioenergy is ready for a serious launch and needs a coordinated industry network.

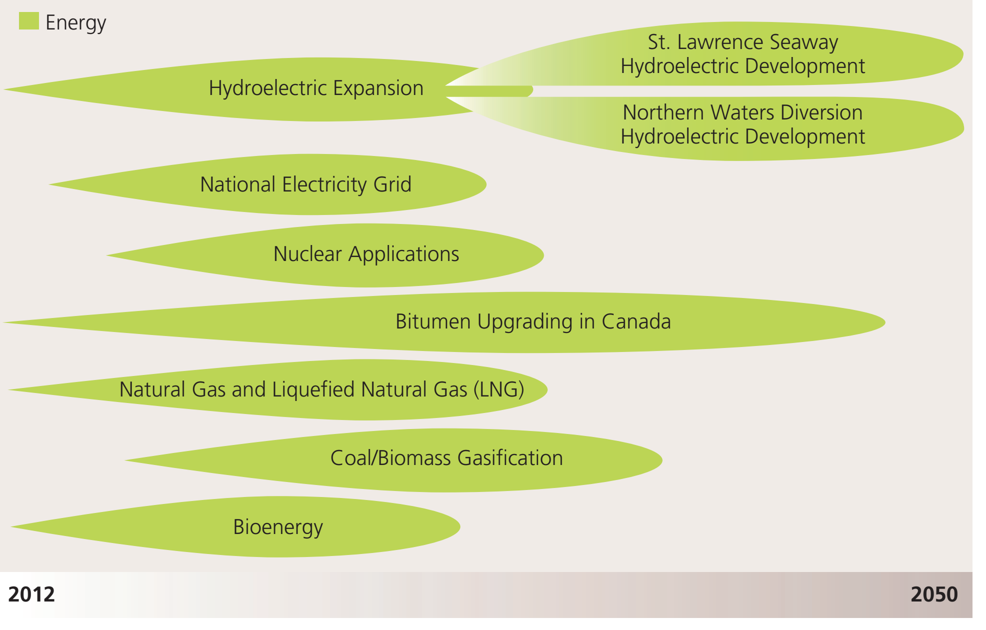
Bioenergy

Biomass resources in Canada are enormous and under-utilized. Canada has approximately 450 million hectares of forest lands, approximately 10% of the world's forests, and 67.5 million hectares of agricultural lands. Canada should undertake one or more bio-refinery demonstration projects to produce bioenergy, bio-chemicals and other bio-products from feedstocks harvested sustainably from these resources. This will require collaborative effort by the diverse Canadian bio-processing communities.

Our Energy Future

Canada should pursue opportunities for new big energy projects, supported by private/public sector consensus and collaboration, which would put the country on the pathway to become a sustainable and environmentally-sound energy superpower[2]. This would generate the wealth needed to enhance Canada's world-leading array of social programs. It would also promote healthy northern communities. There will be opportunities for managing these big projects as an energy system beyond the interest of individual companies acting alone, and requiring a new vision of Canada's energy future and the pathway forward. Canada should prioritize the "big project" opportunity areas identified in this book and proceed immediately with those of highest economic and social impact.

These new "big project" opportunities will stimulate Canada's economy over the next forty years.



I Setting the Stage

History of Big Projects

Canada has undertaken numerous significant, large-scale projects over the last 150 years, mainly in the areas of transportation, communications and energy, with twelve such projects shown in the following chart. In Chapter 1 of Volume II, we describe the events that drove these particular projects and the champions who created the vision and inspired the commitment to action.

Figure 1
Canada's Big Projects
1812 to 2012

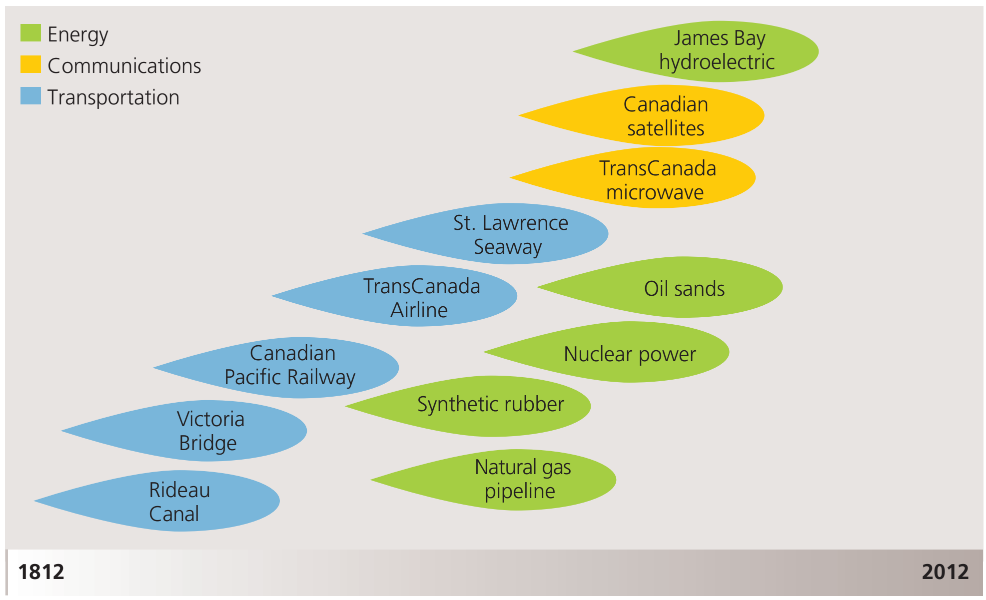


Figure 2
Drivers for Physical Infrastructure Projects

Physical Infrastructure	Principal Drivers
Rideau Canal	National security
Victoria Bridge	Movement of goods/people
Canadian Pacific Railway	Making a country
TransCanada Airline	East-west connectivity
Synthetic rubber	A war effort imperative
St. Lawrence Seaway	Seaway access to central Canada
Natural gas pipeline	Moving resources across Canada
Nuclear power	Electricity generation potential
TransCanada microwave	East-west connectivity
Canadian satellites	Control of Canada's air waves
Oil sands	Five visionaries
James Bay hydroelectric	Expanding electrical economy

What were the drivers for these twelve projects? It was rarely economics, and certainly not the short-term economics used by business to screen and select from an array of business opportunities. The projects that involved the movement of people or goods and those that involved communications had poor economic justification drivers. This was also true for the five energy projects.

The implementation of these projects changed the economics for all future projects and for the nation as a whole—in other words, they changed the business and social landscape of Canada from that time forth. They also nurtured the emergence of Canadian entrepreneurship and innovation to express itself in strategically-directed areas convergent with long-range government vision and leadership.

What is the right business model for prospective new big projects for Canada? If Canada is to become a sustainable and environmentally-sound energy superpower, what are the necessary big projects that will provide the infrastructure for opening up new industrial pathways, and provide the compelling economic drivers for new companies, new products and new processes to build a very different twenty-first century Canada? What does it take for visionaries to overcome the objections of the status quo and the risk-averse environment that seems to block and delay major new initiatives? These are the questions that we attempt to answer by considering the past "big projects" described in this book and the role of their visionaries. It is evident that Canada's "Big Project Innovation Strategy" has contributed significantly to the wealth and quality of life that characterizes Canadian society.

Our Vision as a Sustainable Energy Superpower

Canadians as discoverers, inventors and innovators have given the world insulin, standard time, and the telephone, to name only a few. Canadians as institution-builders and peacekeepers have contributed to providing the modern world a sense of stability. Within Canada, our opportunities have been shaped by the successful initiation and completion of ambitious projects such as a railway from the Atlantic to the Pacific, the St. Lawrence Seaway, major hydroelectric projects, and many others characterized by a high degree of public and private collaboration.

As Canada enters the twenty-first century, it remains blessed with an abundant array of energy resources. There will be opportunities for managing these big projects as an energy system which will go beyond the interest of individual companies acting alone, and require a new vision of Canada's energy future. By acting on this vision, Canada would be a country which sells higher value-added energy products and technology to the world, using the proceeds to durably strengthen its economy and influence, and be an exemplar of the stewardship required of all types of energy resources. It would also have a substantive influence on other nations to follow its lead. Canada's wealth of energy would serve to enhance its prosperity and international effectiveness, reduce energy poverty elsewhere, and reduce its carbon footprint. What is needed is a vision of becoming such a sustainable energy superpower, and later in this book, we lay out the elements of what Canada must do to achieve that vision.

There are challenges to be overcome. Among the challenges is geography; the locations where energy is generated can be far away from where it is needed. Another is Canada's political system which presents two challenges: the division of responsibilities between the federal and provincial governments, and the regulatory complexity that has evolved, create barriers to both energy development and value-added manufacturing, as has been recognized by the Chemical Industrial Association of Canada[3] and the Energy Policy Institute of Canada[4] amongst others.

Technology can provide answers to the challenges of energy efficiency and of conservation of Canada's natural resources. The technical answers must be part of a complete systems approach. However, technology is only part of the solution. Canada's path forward must take advantage of the three C's: consultation, compromise and consensus. To these must be added conviction, commitment and finally, action.

At the 2006 G8 Summit in St. Petersburg, Russia, Prime Minister Stephen Harper presented a vision of Canada as an emerging energy superpower, noting the importance of the Alberta oil sands in that goal. Two years later, Russian President Dmitri Medvedev invited Clement Bowman to St. Petersburg to present the status of the Alberta Oil Sands Project[5]. This was further evidence of the international recognition, and expectations, of Canada's huge energy endowments. The vision of Canada as a sustainable energy superpower is discussed further in Chapter 2 of Volume II.

Figure 3
International Recognition of Alberta Oil Sands

Canada, the world is watching.

Canada's Energy Assets and Capabilities

Canada is extremely fortunate to be endowed with significant non-renewable and renewable energy resources which must be exploited sustainably. Canada also has tremendous energy capabilities due to its effective energy corridors and highly trained work force which can develop and implement the next generation clean energy technologies required to drive an economically and environmentally-sustainable energy sector.

Figure 4
Canadian Energy Assets and Principal Products

Non-Renewable Energy
- Conventional Oil
- Oil Sands
- Bituminous Carbonates
- Conventional Gas
- Non-conventional Gas
  - Tight Gas
  - Coal Bed Methane
  - Gas Hydrates
- Coal
- Uranium

Canada's Energy Corridors

Petroleum Products
Fuels, Chemicals

Hydrogen
Production, Transportation, Use

Electrical Infrastructure
Generation, Transmission, Distribution, Storage

Carbon Dioxide
Capture, Transportation, Storage and Use

Renewable Energy
- Biomass
- Geothermal
- Hydro
- Solar
- Wind
- Tidal/Wave

Nuclear
- CANDU Power Reactor

All of Canada's energy resources should be considered together to form an integrated energy system which maximizes the benefits and wealth for the country, and adaptively takes advantage of future opportunities. Co-products and feedstocks can be shared between companies in energy corridors for the production of chemicals, fuels and electricity. Two examples of this are the Alberta Industrial Heartland and the Sarnia-Lambton Petrochemical and Refining Complex. These corridors have extensive, highly integrated chemical refining, oil upgrading and energy generation infrastructure and capabilities. Similarly, these regions are well serviced with pipelines, industrial land, water, electrical grids and manufacturing expertise. To optimize environmental responsibility and economic prosperity, Canada must now view its energy assets as a unified system. Canada's energy assets and capabilities are discussed further in Chapter 3 of Volume II.

Environment and Prosperity

Canada's options:
- **Superstore?**
- **Self-sufficient?**
- **Sustainable energy superpower?**

Environmental responsibility and economic prosperity are presently in tension. However, we now know that they are invariably interdependent in that achieving one without the other is no longer an option for the future of humanity. The perception that the economic and environmental costs of sustainable energy are too great must be challenged, and Canada is uniquely positioned to resolve this tension, and become a sustainable energy superpower.

Canada has three options:

1. Harvest its energy resources and ship them unrefined into global markets with minimum influence on those markets (an energy superstore).
2. Recover and produce refined energy products for its own use (becoming self-sufficient and environmentally benign).
3. Ship refined energy and petrochemical products into global markets as a sustainable energy superpower, with a major influence on those markets.

The following four areas provide a solid foundation on which to proceed with option 3, thereby achieving high GDP growth and high quality jobs:

1. **Greenhouse gases:** Canada's record in GHG emissions is not well understood. Canada's electrical industry has a significant advantage in its release of greenhouse gases: 34 megatonnes/exajoule from electricity generation compared to the U.S. at 162 megatonnes/exajoule[6]. When the processing of fossil fuels is added to the picture, Canada still has an advantage on an intensity basis. Significant efforts are presently underway for reducing carbon emissions and there is significant interest in developing processes for transforming greenhouse gases into value-added products.
2. **Private/public sector collaboration:** Canadian companies and governments have a solid track record in working together on key initiatives, backed by a consensus and a vision, and sharing long-term financial risks. Some projects will not have immediate payback but will have long-term value since they will enable other pathways, and attain other environmental and economic objectives. Following examples such as the Alberta Oil Sands Technology and Research Authority (AOSTRA), the Canadian Academy of Engineering has recommended that a cross-sectoral, public-private management entity be established and funded to provide the technology and associated business framework for the necessary investments.

3. **International opportunities:** A global energy superpower, with enhanced prosperity, will have increased international opportunities for improving the condition of those now living in energy poverty.
4. **Canada's competitive advantage:** Canada's energy system has unique advantages related to its multiplicity of energy resources and the ability through big projects to combine energy sources and products into an integrated system. This will achieve production efficiencies, value-added products and higher environmental standards. Canada benefits from its independent monitoring and regulatory agencies.

II The Electrical Enabler

Hydroelectricity

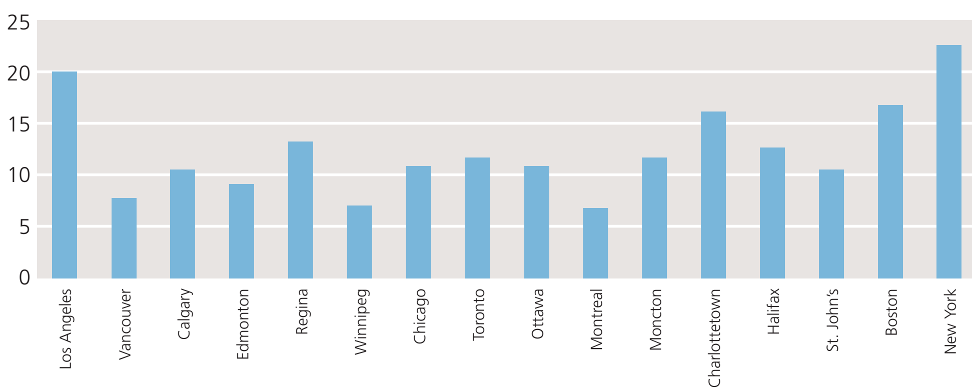
Hydroelectric development in Canada began in 1881 and continued unabated until the 1990s. Canada now has 73,000 MW of hydroelectric power in service, and another 163,000 MW could be developed for a total capacity of 236,000 MW. Currently, there are more transmission links between provincial networks and the United States than between the provinces of Canada. A prerequisite for moving ahead with major new hydroelectric projects is the establishment of a Canada-wide high-capacity transmission network, with three objectives:

1. Link new hydroelectric projects to areas of consumption.
2. Interconnect existing provincial networks.
3. Replace aging thermal power plants to reduce Canada's GHG footprint.

Low electric power rates lead to a stronger value-added manufacturing sector.

The high variability in the price of electricity across Canada, as shown in the accompanying chart, could be improved with enhanced interprovincial connections. Clearly, jurisdictions where hydroelectric power generation is prevalent tend to have lower electricity rates. Lower rates have demonstrably led to significant increases in value-added manufacturing.

Figure 5
Comparative Electricity Prices – Cents/kWh



Progress in the efficient use of electricity during the period 1990-2010 has reduced the pace of development of new hydropower, but given the scale of untapped hydroelectric potential, and the slower pace of the nuclear and wind industries, it is quite possible that Canada is at the dawn of a new rush for this "white gold". Environmental issues received extensive attention in projects initiated during the 1970s. Best practices for safeguarding the environment while harnessing the hydroelectric potential of new hydraulic sites, are now extensive in the form of preferred interventions, development measures, audits, corrective works, analyses, and procedures for safeguarding the environment while harnessing the hydroelectric potential of new hydraulic sites.

The following sites are particularly promising for near-term development and are discussed in Chapter 4 of Volume II:

Lower Churchill: Development of Labrador's Lower Churchill area would result in 4,000 MW of hydroelectric power.

Tidal Energy: Canada has significant tidal energy power and can be a global leader in its development. The tides of the Bay of Fundy present a particularly attractive "renewable" opportunity. As transmission systems migrate further north, the tides of Ungava Bay should also be considered.

St. Lawrence River-Great Lakes Basin and "Northern Waters": The St. Lawrence River and Great Lakes basin would greatly benefit from a flood-control infrastructure which would transform this entire basin into a waterfall of some ten reservoirs, and offer 1,000 MW of additional hydroelectric potential. A necessary companion project to maintain river levels involves intercepting the Bell and Waswanipi Rivers in the Matagami area of Northern Quebec, diverting water from these rivers into the nearby Ottawa River watershed by pumping it a height of 53 m, then exploiting the 300 m head of the Ottawa River as it flows into the St. Lawrence River. This project would maintain the level of the St. Lawrence River, generate 3,000 MW of additional hydroelectric power, and supply drinking water to a population of 150 million people.

James Bay: The southern portion of the La Grande complex is already connected to the Hydro-Quebec network. The completion of the northern portion of the La Grande Complex in the Great Whale (Grande Baleine) River region would offer 5,000 MW of additional hydroelectric potential.

Western Half of Canada: The Western Half of Canada presents a theoretical potential of 91,000 MW. This massive hydraulic potential poses a major difficulty in that the key watersheds, including those of the Mackenzie, Churchill and Thelon Rivers, cover several or all of the Prairie Provinces. A first step would involve a joint feasibility study by the five jurisdictions involved, to build on previous studies and investigations. Even so, Manitoba's Nelson and Burntwood Rivers offer a potential of nearly 5,000 MW, and the Site C hydroelectric generating station on the Peace River in northeast British Columbia represents more than 1,000 MW.

Figure 6
Western Half of Canada – Remaining Hydroelectric Potential (MW)

Alberta	11,775
British Columbia	33,137
Manitoba	8,785
Northwest Territories	11,524
Nunavut	4,307
Saskatchewan	3,995
Yukon	17,664
Total:	**91,187**

The interconnection of existing provincial grids through new high-capacity transmission corridors would be a major step to reducing Canada's carbon footprint.

Interconnecting Canada

Canada's electricity networks were historically designed and built on a province by province basis, with limited emphasis on provincial interconnections. Most provinces are close to being self-sufficient in electricity. Canada exports 4% of the electricity it generates to the U.S. In 2007, over 70% of the electricity that Canada produced was from low-GHG-emitting capacity, mainly hydro and nuclear. Of the remaining high-GHG-emitting capacity, 65% of this is over thirty years old. The interconnection of existing provincial grids through new high-capacity transmission corridors would enable significant reductions in Canada's carbon footprint by incorporating distant hydroelectric and tidal low-GHG electric power to displace high-GHG-emitting fossil fuel generating stations. Additionally, this would improve the business case for intermittent renewables such as wind and solar, assist in the management of regional peak loads, release stranded power, reduce power costs in some markets, enhance energy storage capability and provide strategic security advantages through a high-capacity transmission backbone. This is discussed further in Chapter 5 of Volume II.

Figure 7
Potential High-Capacity Continental Grid

Developing a cluster of distant hydroelectric and tidal power stations in several provinces, connected among themselves and simultaneously interconnected across all provincial grids, offers a convincing economic and environmental strategy for interconnecting Canada's electric power networks. A 735 kV transmission scenario, illustrated in Figure 7, shows that economic, long distance, high power transmission and compensation technologies are available today for interconnecting networks on a continental scale. Construction and equipment costs can be staggered to ensure a timely return on investment from the moment individual generating station units are commissioned. The system control technologies required for ensuring real-time adequacy, security, reliability, generation pricing and economic dispatching across multiple systems and time zones on a continental scale, may need enhancement. Even so, such a project is economically sound while addressing the pressing need of reducing Canada's GHG production. The main obstacle remains the political will to commit to such an objective, and to craft a workable financial architecture which spreads both risk and return on investment among all stakeholders.

III Nuclear Energy

New reactor designs and technology advances will resolve public concerns by being extremely safe and proliferation-resistant, and having low nuclear waste.

In its first fifty years, Canadian nuclear power technology development has been dominated by a few publicly owned companies and a single reactor technology. In recent years the industry's landscape has changed, with a number of new, or newly private players, and with new reactor technologies emerging. Maximizing the future benefits to Canada from opportunities in the nuclear industry may well depend on growing synergies among a set of applied technology clusters (e.g., energy supply, medical diagnosis/treatment, food safety/sterilization, uranium mining, materials science) and the science and technology networks that support them.

As shown in Chapter 6 of Volume II, the largest of these clusters—energy supply—offers nuclear power as a source of heat, not only for the production of electricity but for a variety of industrial processes, thereby contributing to the reduction of GHG emissions. In this regard, a particular opportunity is that of applying nuclear technology to in situ bitumen recovery from Alberta's oil sands, a process that currently uses fossil fuel. This would strengthen Canada's position as a sustainable energy superpower by contributing to reduce the carbon footprint of the oil sands industry, thereby facilitating further growth of that industry. It would also add a new branch of nuclear expertise to Canada's cluster of strengths. Given the diversity of new reactor designs available, a significant and ongoing multi-stakeholder effort would be needed to explore these opportunities on a technical level and narrow down the range of options.

The application of nuclear process heat to oil sands bitumen recovery processes would ultimately require a technology development initiative of the type and scope that made the oil sands an economically viable resource some decades ago. The Petroleum Technology Alliance of Canada (PTAC) has undertaken three screening studies which represent a start to this process. Such a process requires visionaries, public-private collaboration, and a significant investment in identifying feasible technologies and increasing the degree of certainty around their economics. Public policies that put a price on carbon emissions could make a substantial contribution to accelerating this and many other energy technology investments.

Figure 8
Four Reactor CANDU Darlington Plant, Ontario Power Generation

IV Fossil Fuels and Biomass

Alberta Oil Sands

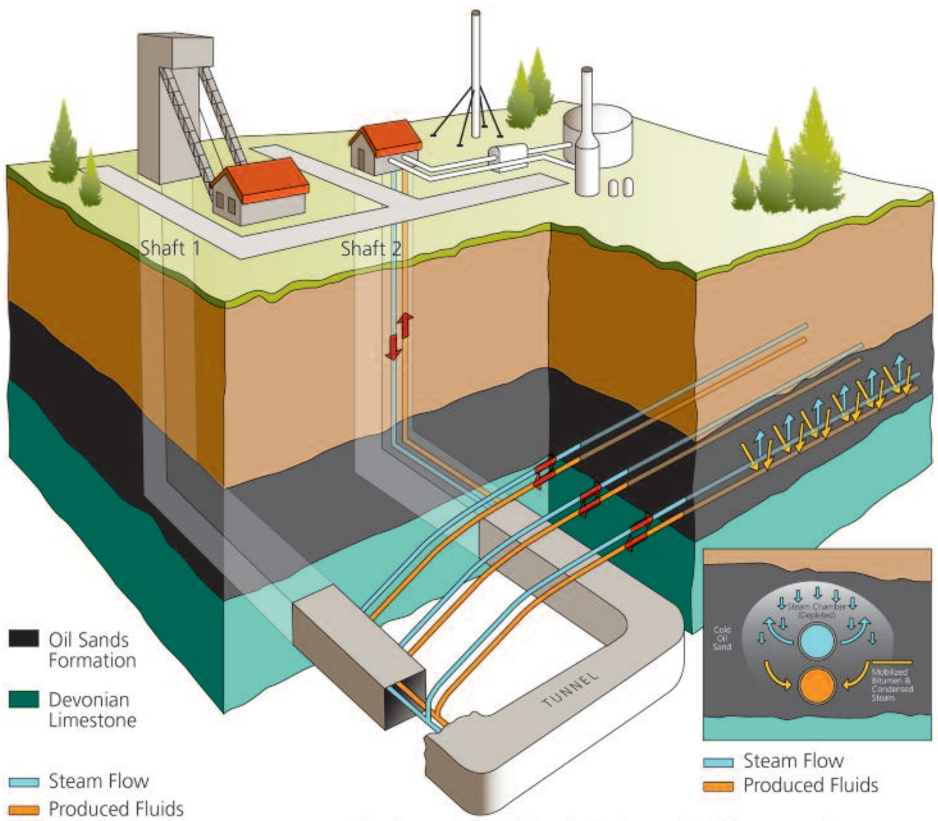
Though a transition to low-carbon energy resources has begun the world over, high-carbon energy resources are expected to be required for some decades. There is a significant opportunity to supply – and employ – such resources in the most environmentally responsible manner possible. The Alberta oil sands contain at least 1.6 trillion barrels of bitumen, of which 300 billion barrels are expected to be recoverable—larger than the oil reserves in Saudi Arabia. The oil sands have faced major challenges over the past 80 years; five visionaries stand out as heroic figures who faced and overcame technical, political and economic hurdles at critical periods.

Every dollar invested in the oil sands creates $6 worth of economic activity in Alberta and $3 of economic activity elsewhere.

The huge economic impact of oil sands development on Canada is documented in Chapter 7 of Volume II. Every dollar invested in the oil sands creates $6 worth of economic activity in Alberta and $3 of economic activity elsewhere. The capital expenditures on oil sands projects, since commercial development started, are close to $120 billion and in recent years, new investment has averaged about $15 billion per year. However, the economic impact of oil sands development represents more than an investment in new projects. A further $90 billion has been spent to operate and maintain the plants and this creates a supply chain of parts and assembly operations that ripple through the economy, at a value of more than $10 billion per year in current years. Over the next 25 years, capital investment is projected to be $218 billion.

The oil sands are facing new challenges related to the environment. The industry has made progress in reducing its environmental impact, with significant reductions in freshwater use, and in dramatically reducing the time to restore disturbed lands close to original conditions.

Figure 9
Demonstration of the Steam-Assisted Gravity Drainage Process



The Steam-Assisted Gravity Drainage (SAGD) process demonstrates the effectiveness of gravity forces in contacting and draining an oil sands reservoir.

For the 80-90% of the oil sands that is too deeply buried to be surface-mined, the Steam-Assisted Gravity Drainage (SAGD) process enables bitumen to be recovered with minimal disturbance of the land. The horizontal wells used in the original demonstration of the SAGD process were drilled from a shaft and tunnel, as shown in Figure 9. Although horizontal wells drilled from the surface have been used in subsequent commercialization, the shaft and tunnel approach is believed by one of the original developers to be the preferred approach[7]. Even with SAGD, however, bitumen extraction as it is currently accomplished burns large quantities of fossil fuels. While this leads to criticism of the oil sands as being too intensive in the production of GHGs, it also creates an opportunity to apply non-fossil heat sources, such as nuclear. This would conserve fossil fuels such as natural gas for future consumption, reduce carbon emissions, and possibly facilitate the scale-up of oil sands activity.

Still, industry is falling behind in capturing the full value of the resource. By 2019, 50% of the bitumen will be upgraded outside Canada, and limited progress has been made in the development of technologies to produce high-value products, based on the unique properties of the resource. Unless new capacity is built in Canada to upgrade bitumen to value-added fuels and chemical products, the country will forfeit $60 billion per year in economic activity by the end of this decade. Canada's future prosperity is strongly dependent on reversing this trajectory.

Natural Gas and Liquefied Natural Gas (LNG)

Over the next 20 years, global demand for natural gas in electricity generation, heating and transportation is expected to rise dramatically. Natural gas is the world's cleanest-burning fossil fuel and has a key role to play in reducing GHG emissions in Canada as well as abroad (i.e., emitting up to 60% less CO_2 than coal when used for electricity generation). Estimates of Canada's natural gas resources vary from the National Energy Board's 664 trillion cubic feet (TCF) (including "tight gas", coal bed methane, shale gas, and gas from frontier regions), to 3,915 TCF from the Canadian Society for Unconventional Resources for "total gas in place". An additional source of natural gas exists in the form of methane hydrates below permafrost and in sub-sea sediments. Estimates of Canadian natural gas volumes in hydrate form range from 1,540 to 28,500 TCF. In Canada, hydrate deposits found in Arctic gas formations in conjunction with free gas are likely to be developed first. Hydrate deposits are already in production in Russia. The process includes producing the free gas and depressuring the reservoirs so that the hydrate will dissociate. The natural gas resources of Canada are discussed further in Chapter 3 of Volume II.

While energy experts look upon the 21st century as the "Gas Age", Canada will have significant competition in export markets. The United States Energy Information Agency's latest "Energy Outlook" report[8] states: *"Over the projection period, cumulative net pipeline imports of natural gas from Canada and Mexico in the AEO2012 Reference Case are less than 50% of those projected in the AEO2011 Reference Case, with the United States becoming a net pipeline exporter of natural gas in 2025".* This increases the need for Canada to diversify its energy markets.

The market outlook for natural gas is heavily dependent on its price, which currently is about 60% of the comparable price of oil on an energy basis in North America. Current natural gas prices hover between $3 and $4 per MCF, less than half what they historically should be[9]. However, if natural gas prices go higher than $10/MCF, then coal becomes much more attractive for either gasification or power generation. China and Japan are both pursuing new supply – China to fuel its massive modernization, and Japan to diversify its fuel supply. With demand growing quickly, prices in Asia are also up to four times higher than they are in North America. There will also be competition in the liquefied natural gas (LNG) market from the U.S., Australia, Africa and Qatar.

British Columbia is developing a "big project" opportunity in LNG, with the first commercial export facility scheduled to open in Kitimat in 2015 (Figure 10). The Province has committed to work with investors to have three facilities in operation by 2020, assuming all environmental and permitting applications are granted. For this "big project" opportunity to materialize, numerous challenges have yet to be overcome, including securing private sector capital investments for new infrastructure, maintaining sustainable production, and ensuring the development of post-secondary skills for this growing industrial sector. To realize the potential of natural gas and LNG, Canada needs to have an appropriate policy framework, building on the "big projects" presently underway.

Figure 10
Schematic of the Kitimat LNG facility, in British Columbia

Courtesy of Apache Canada Ltd., ref: LNG – A Strategy for BC's Newest Industry

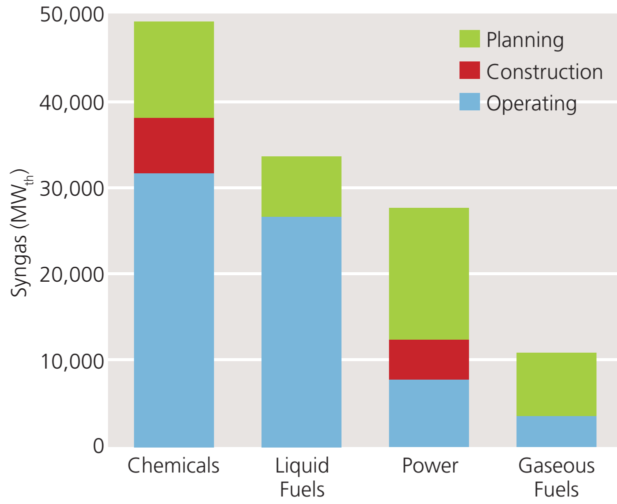
Gasification of coal, an alternative to direct combustion, will produce electricity, heat, hydrogen and a chain of chemical products, with lower environmental impact.

Coal and Biomass Gasification

Coal is the world's most abundant and widely distributed fossil fuel. It is also the most economical energy resource in many countries. Although Canada is a mid-size coal producer in the world, the coal mining sector plays an important role in the Canadian economy as a provider of about 10% of the country's primary energy. Canada is a net exporter of coal, and holds 8.7 billion tonnes of in-place coal resources, which will provide more than 100 years of production at current production rates. In addition, about 2 trillion tonnes of ultimate in-place coal resources have been identified in Canada.

Gasification, a proven and commercial technology, is likely the most promising alternative conversion technique from the environmental perspective compared to the direct combustion of coal. Gasification is a versatile way to convert coal simultaneously into electricity, heat, hydrogen, and other synthetic gases. Chemicals from the coal gasification process can be used as building blocks to manufacture a wide range of consumer products. Integrated gasification systems, which process both coal and biomass, could be ideal for a country like Canada, where both resources are economically and readily available. This is discussed further in Chapter 8 of Volume II.

Figure 11
Gasification Product Distribution



There are approximately 150 gasification plants operating worldwide which use coal as their major feedstock. There are no commercial coal gasification plants operating in Canada. However, the Swan Hills In Situ Coal Gasification (ISCG) being developed in Alberta will be the first of its kind in North America, integrating ISCG technology with carbon capture and storage to create a clean low-carbon syngas that will fuel a new 300 MW combined cycle power generation facility[10].

Chemicals represent approximately 45% of total gasification products followed by liquid transportation fuels of about 38%. Electrical power and gaseous fuels are also important products of gasification. It is important to capitalize on the learning and latest developments at these commercial gasification plants by collaborating with international firms to develop next generation gasification technologies. Increased conversion efficiency, ability to handle diverse feedstocks, carbon capture and storage, capturing sulphur and trace metals from the exhaust stream, improved economics, and overall environmental performance are expected features of next generation gasification technology. To become an energy superpower, Canada could be mastering the efficient utilization of coal resources in a clean and environmentally-responsible manner. A coal gasification demonstration project should be undertaken based on Canada's low rank coals, utilizing the latest international technology developments and meeting rigourous environmental targets.

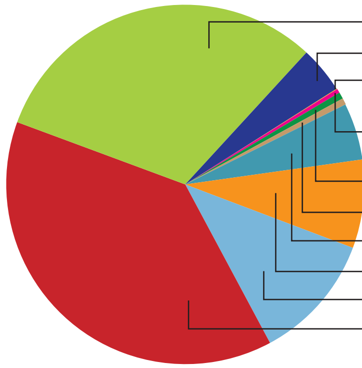
Bioenergy

Approximately 10% of the world's forests (or 450 million hectares) is found in Canada, and total agricultural land represents an additional 67.5 million hectares. The Canadian forestry industry currently has an overcapacity of approximately 12 million tonnes of lumber due to the recent downturn in the U.S. housing sector.

Additionally, approximately 4.75 million dry tonnes of wood residues are available annually from the Canadian forestry industry. Finally, the Mountain Pine Beetle infestation of British Columbia has caused massive damage to trees affecting nearly 10 million hectares of forests and resulting in approximately 385 million tonnes of additional biomass available for harvesting over the next decade.

Canadian farms produce over 100 million tonnes of grains, beans and hays annually. It is estimated that over 30 million tonnes of agricultural residuals such as cereal straws and corn stover can be sustainability harvested for energy applications. There could also be approximately 15 million dry

Figure 12
Provincial Farm Land Distribution (million hectares)



tonnes of biomass from municipal solid waste streams. The City of Edmonton is constructing a gasification plant to use municipal solid waste as a feedstock to produce ethanol, expected to start-up in 2013[11].

Canada should build one or more bio-refineries to demonstrate the production of bioenergy, bio-chemicals and other bio-products from diverse biomass feedstocks, leading to the emergence of a bio-economy in Canada. Integrated development options include the conversion of pulp and paper mills into bio-refineries and product diversification for sugar-based and cellulosic ethanol plants. The challenges of the bioenergy sector include technology improvements, meeting increasingly stringent environmental regulations, and the scarcity of funding to scale-up technologies. The challenge with bioenergy is the incorporation of sustainability principles in every segment of the chain. Business incubation support from the government and sustainability guidelines are of critical importance at present to properly develop the bioenergy sector in Canada. This is discussed further in Chapter 9 of Volume II.

Canada has been most productive when a big project is underway.

V Imagining Our Energy Future

Canada has a history of challenges related to technology commercialization. In the 1970s, Senator Maurice Lamontagne chaired a Special Senate Committee which proposed "A Science Policy for Canada" to address Canada's inability to cross the commercialization chasm, and to provide recommendations to solve this dilemma[12]. Forty years later, the Canadian commercialization challenge remains. It is the contention of the authors that Canada's nation-building "Big Projects Strategy" is the innovation strategy that has solved this dilemma in the past, and which can resolve it again in the future.

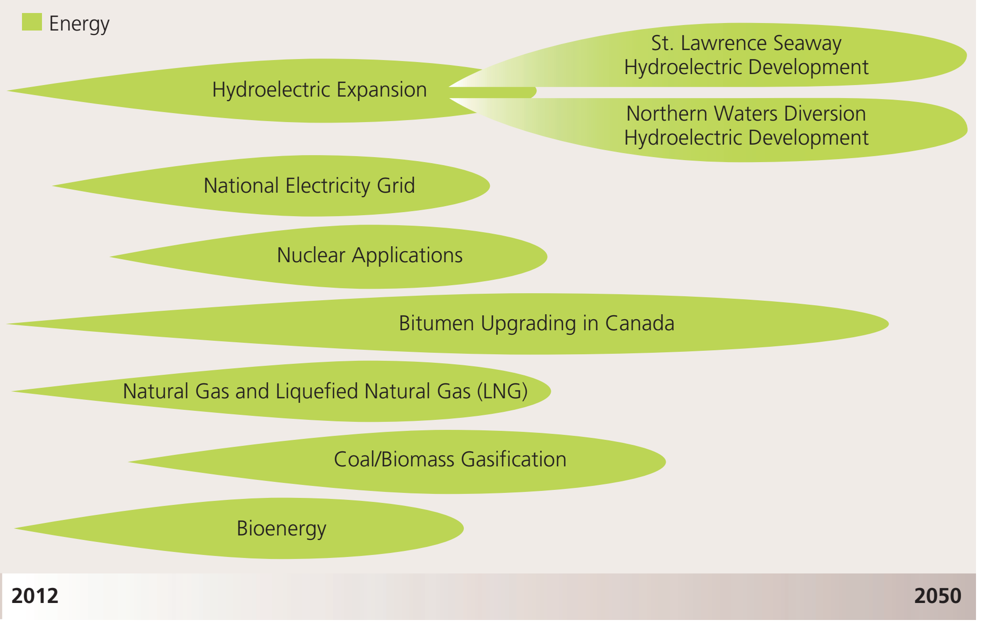
Canada's Innovation Strategy—Big Projects

Canada has massive natural energy resources that, if developed sustainably, in combination with exporting value-added products, could provide energy and wealth for thousands of years. Canada has a sound banking system and is admired by other countries for its strong economy. It has a highly skilled workforce, and Canadian colleges and universities have the capacity to graduate the valuable human capital required to develop and implement new energy-related technologies and processes. However, without the focus and scale provided by a big project, Canada will be challenged to commercialize the technologies and reap the benefits. Big national projects provide Canadian inventors, innovators and entrepreneurs with the leadership, direction and focus required to make a particular national vision a reality, and to raise their performance to another level.

Recommendation

Nine big projects have been identified in this book as "candidate big projects" for Canada to undertake over the next decades, as shown in Figure 13. These recommended projects will maximize the value of Canadian energy assets and propel Canada to the status of a sustainable energy superpower. These big projects will also provide the focus, drive and economic ecosystem required to bridge the innovation gap. Once these projects are underway, the benefits will result in sustained and significant job creation over the next forty years, and continuing prosperity for Canadians long into the future by providing a springboard for future initiatives.

Figure 13
Canada's Next Big Projects: 2012 to 2050



Measuring Progress

If these big projects are successfully implemented, can the progress made by Canada toward the sustainable energy superpower vision be measured? The Canadian Academy of Engineering's Energy Pathways Task Force took on this challenge and estimated the progress that Canada has made with respect to the criteria shown in Figure 14 as a result of past energy accomplishments, and what might be achieved if the big projects described above were undertaken[13]. The analysis used ProGrid methodology[14].

Figure 14
Criteria for Assessing Canada's Energy Superpower Status

Resources	Connectors	Impact
Non-Renewable	Generation Capacity	Meeting Demand
Renewable	Transport/Transmission	Economic Impact
Nuclear	Energy System	Quality of Life

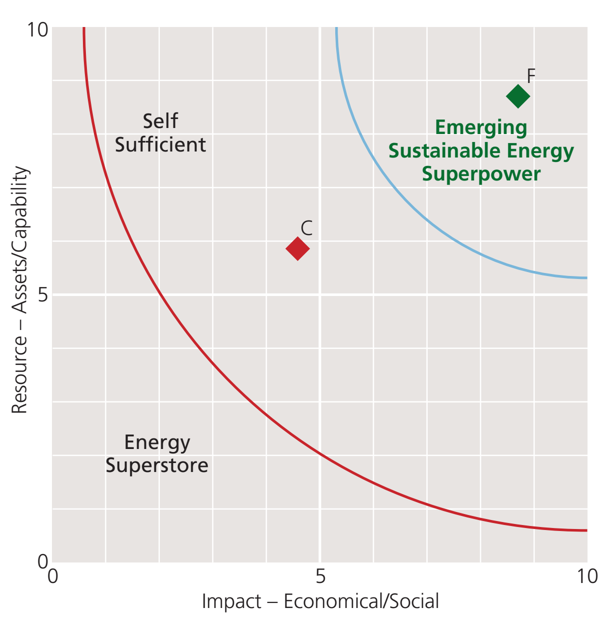
Canada's current position, shown as point "C" in Figure 15, is calculated based on the progress made in the economic development of fossil fuels, renewable energy sources (in particular hydroelectric and tidal power), and nuclear power (and related technologies). It reflects Canada's relative low and decreasing GHG emissions when measured on an intensity basis. Canada has made progress because of past big projects, and is now faced with the following three options:

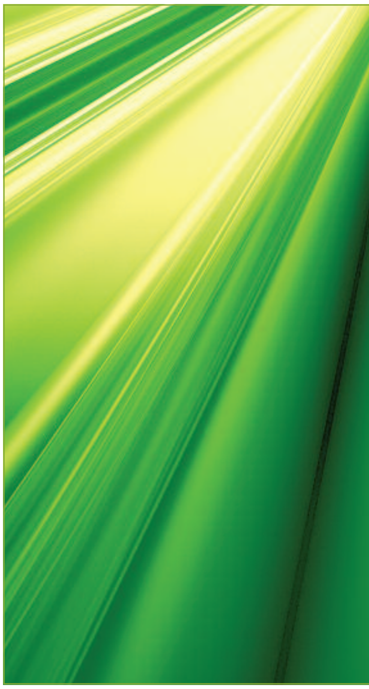
1. Sell its raw energy resources (bitumen, uranium, etc.) into international markets, acting as an energy superstore as it has in the past with many of its natural resources;
2. Upgrade its energy assets sustainably to meet its own needs for fuels and chemical products, essentially becoming self-sufficient; and
3. Offer sustainable, value-added products to the world as a sustainable energy superpower.

Canada's potential future state "F" is the estimate of its position if Canada can complete the big projects described in this book and follow the trajectory to a sustainable energy superpower.

This near-term future is discussed further in Chapter 10 of Volume II. We have also projected further into Canada's energy future on the following page.

Figure 15
Canada's Energy Superpower Trajectory – Current and Future States





Imagining Deeper into Our Energy Future

The big projects described in this book are those that Canada can implement over the next forty years as a pathway to becoming a sustainable energy superpower. However, energy innovation will not stop with these projects. For example, a highly efficient and integrated future Canadian energy system would likely include the aggressive expansion of other renewable energy sources such as wind, small hydro, solar, river current, tidal, ocean wave, geothermal, and district energy systems for reducing its carbon footprint. An integrated energy system would also facilitate the production of hydrogen from electrolytic and thermochemical processes, strengthening the place of hydrogen as a combustion fuel of choice. This would open the future to the concept of hydricity where only two dominant energy currencies serve the world's energy needs: electricity and hydrogen. Carbon dioxide could transition from being an unwanted combustion waste product to an essential feedstock in new, value-added processes and products. Nuclear generating farms located in isolated, northern regions could be accessed by means of the national grid, serving base-load, and storing energy in hydroelectric power station reservoirs or in the form of hydrogen where appropriate.

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